The 26th International Conference and Exhibition on Electricity Distribution

Europe's Leading International Conference & Exhibition on Power Distribution

Special Report

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SPECIAL REPORT

Session 1
Network Components

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Introduction

Session 1 deals with all aspects related to the components used in the electricity distribution networks:

- Cables and overhead lines,
- primary and secondary substations
- transformers
- switchgear plus their control
- protection and monitoring systems
- new active power electronics devices
- …

Session 1 covers topics related to the life cycle optimization of assets from design through installation, operation and maintenance, monitoring and diagnosis, to end of life management, including new techniques such as Big Data and Artificial Intelligence. The session also covers environmental aspects including eco-design and life cycle analysis, standardization, ergonomics and safety for both the operating staff and the public. It aims at providing an overview of the state-of-the-art in component design and proposals for future components: It includes the ones needed for smartgrids, e-mobility, smartcities and microgrids, as well as components for more resilient networks in the context of climate change anticipation. This session is an opportunity for DSOs and manufacturers to share their objectives.

136 papers have been selected for the Session 1 – Network Components – of CIRED 2021. They have been organized in four blocks, which are the same for both this special report and the Main Session.

The structure retained for these blocks is as follows:

Block 1 “Asset management and condition assessment of Network Components – Cables, lines and associated components” (25 papers):
- Testing & Monitoring
- Artificial Intelligence & Big data
- Health index, diagnostic and failures detection

Block 2 “Asset management and condition assessment of Network Components – Substations, switchgear and transformers” (39 papers):
- Upgrade to smart, and sensors integration
- Data for asset management
- Dynamic rating, adaptation to DER integration
- Use cases of diagnostic, maintenance, and retrofit

Block 3 “Innovation in Network Components – Cables, lines and new types of components” (27 papers):
- Materials & Models
- Metering & monitoring systems
- Systems for safety & security
- Components for protection & stabilization

Block 4 “Innovation in Network Components – Substations, switchgear and transformers” (45 papers):
- Greener components
- Smart substations
- Innovative network components
- Methods and tools for component design

6 papers per block have been selected for oral presentation in the main session (MS), and 6 other papers have been chosen for presentation in the Research and Innovation Forum (RIF) which details results of the research activity in the field of network components.

All other articles will be presented in the Interactive Poster Session (PS).

In addition to the Main, RIF and Poster Sessions, three Round Table (RT) discussions will take place within Session 1:

RT1 “DC network” (joint RT with Session 5),
RT2 “Secondary substation for the future”,
RT4 “Green Network Solutions”.

Block 1: “Asset management and condition assessment of Network Components – Cables, lines and associated components”

The 25 papers of this block are divided in 3 subblocks:
- Testing & Monitoring
- Artificial Intelligence & Big data
- Health index, diagnostic and failures detection

Sub block 1: Testing & Monitoring (5 papers)
The key role of testing and monitoring is to support decision making of DSOs regarding the ability of existing assets to transmit the required amount of power. The paper 439 is showing that the use of VLF, DAC or slope voltages give similar PD results (see Fig 4 of paper 439) and measured PD are not correlated to dielectric losses. Indeed, the dielectric losses depend mainly on humidity and thermal degradation.

\[ \text{Fig. 4 of paper 439: Detected PD defects separated by component and measuring method} \]

The alarm system of London underground distribution system based of continuous PD monitoring presented in the paper 747 shows that, with a good enough signal to noise ratio, combinations of PD presence and severity can be a reliable way to anticipate defects in MV grids for maintenance, pre-fault and life assessment.

The testing of MV collection cables in windfarms (110) and their thermal monitoring (1118) under severe weather conditions are key to increase the mix of renewable energy in actual grids.

The LV part of the distribution system is submitted to daily modifications, as presented in paper 249, and a phase angle measurement can prevent from incorrect installations of meters with consequently false measurement of consumed energy.

Sub block 2: Artificial Intelligence & Big data (9 papers)

Prerequisite for deep learning tools are the availability of large amount of measurement as well as load and environmental data. Such tools have been applied to PD analysis in some underground networks, resulting in a diagnostic prediction accuracy of up to 98% within few milliseconds for internal, corona and surface discharges activities (842, 942), allowing DSOs to use PD for real time monitoring.

The ability of the full PD measurement chain to adapt in real time to assess and reduce the noise is a major improvement in the use of PD for monitoring (108).

Using a more general approach thousands of signals are collected in the frame of the Forsight project in UK (paper 837) to create a priority map for the maintenance crews (see Fig. 5 of paper 837).

\[ \text{Fig. 5 of paper 837: Impedance contoured plan (D=distance in m, P= phase impedance in milliOhms). Locations highlighted} \]

The overhead distribution network offers opportunities to test predictive or automatic recognition approaches based on data analysis as a lot of operational and environmental data are easily accessible. Combining operational data with failures modes of poles, the approaches used in the paper 464 allow adjusting the maintenance operations by up to 40% for certain types of poles. With the
deployment of network components recognition, developers are faced to low resolution recordings due to bad conditions or disturbance. In paper 702 the performances of low-light graphic recognition algorithm are assessed. To reduce the complexity, paper 1046 proposes to create families of assets with similar characteristics and failure mode to predict the probability of failures in the future. Paper 587 gives a quantification of the reduction of time to action resulting from digitalization and risk-based prediction tools (see Fig. 6 of paper 587).

![Fig. 6 of paper 587: Economic efficiency results achieved with the systematic implementation of artificial intelligence methods by the utility](image)

Sub block 3: Health index, diagnostic and failures detection (11 papers)

The principle of Health Index is based on a continuous crossing of data based on failure or degradation measurement with characteristics and condition monitoring of asset. In the paper 788, the methods have been applied to PILC cable showing through destructive analysis of cable samples continuous sign of degradation. In the case of XLPE cable the signs of ageing are less evident and can only be assessed by nondestructive methods like in the paper 780 with the comparison of PD and dielectric losses over a large population and over the years (see below fig 6 of paper 780).

![Fig. 6 of paper 780: The dashboard with basic numerical and graphic information of a health index mapping- example of SOLAR system in Poland](image)

The development of asset management tools based on health index often suffers from missing data, but paper 934 recommends that it should not prevent from deploying such tool that increases the added value of new available information or model all along the grid life. An original approach is presented in the paper 738: authors investigate synergies between long term risk assessment (based on incident statistics of MV lines) and short-term approaches related to storms using the same AI risk predictive tool.

In case of external aggression due to anchor (917) in the case of submarine cables or exceptional weather (430), we are often in the situation of high impact and low probability events. Several strategies can be deployed: either to increase assets resiliency when the root causes are easily identified, like for OHL in paper 430 and 738 or to focus on bringing back as fast as possible the equipment in operation, like in paper 917 on submarine cable with predefined repair scenarios triggered by the identification of failure modes just after the incident.

Joints have been always identified as the weakest point of the cable system. The paper 165 shows a root causes analysis of seasonal joint failure linked to weather or load. In the papers 246, 415 and 500 the importance of joint preparation related to respectively the insulation system, the aluminum conductor splicing and the screen connection are highlighted.

The deployment of more intermittent energy has also an impact on the ageing of joints: paper 250 shows the effect of repeated sudden increase of power that can lead to failure.
<table>
<thead>
<tr>
<th>Paper No.</th>
<th>Title</th>
<th>MS a.m.</th>
<th>MS p.m.</th>
<th>RIF</th>
<th>PS</th>
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<tr>
<td>108</td>
<td>Machine Learning Based Evaluation of Dynamic Events in Medium Voltage Grid Components</td>
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<tr>
<td>110</td>
<td>Testing of Off-Shore Array Cables According IEC 63026 under Critical Weather Conditions</td>
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<td>165</td>
<td>Extreme weather conditions effects on MV underground cable joints failures</td>
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<td>246</td>
<td>Impact of “wrong” MV cables accessories assembly on its performances: an experimental study</td>
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<td>249</td>
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<td>250</td>
<td>Impact of energy intermittence on cables and their accessories reliability</td>
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<td>415</td>
<td>A Reliability Enhancement Study of MV Aluminum Cable Connections Regarding Connection Criteria and Processes</td>
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<td>430</td>
<td>Root Cause Analysis of overhead distribution network failures due to heavy snowfall- a Case Study Gilan, Iran, Feb. 2019</td>
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<td>439</td>
<td>Comparison of on-site partial discharge measurements using VLF-, DAC- and Slope-voltage forms and dissipation factor measurements on service-aged medium voltage cables</td>
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<td>500</td>
<td>Medium voltage cable screen connection behaviour</td>
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<td>587</td>
<td>Using artificial intelligence to prevent distribution networks accidents.</td>
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<td>592</td>
<td>Power feeding equipment for the condition monitoring of insulators for overhead VHV power lines</td>
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<tr>
<td>702</td>
<td>Improving Power Distribution Facilities Detection in Low-Light Images with Deep Learning</td>
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<tr>
<td>738</td>
<td>Analyzing overhead MV network fault risk with AI</td>
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<td>747</td>
<td>Partial Discharge alert system at London Underground</td>
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<td>780</td>
<td>The SORAL project - management of the MV cable network based on the Health Index of the individual cable line, obtained from diagnostic measurements</td>
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<td>788</td>
<td>Experience of Underground Cable Failures in a UK Distribution Network</td>
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<td>837</td>
<td>Foresight - LV Network Visibility and Fault Recognition</td>
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<td>842</td>
<td>A Study on Diagnosis of Partial Discharge of Underground Cables Using Deep Learning Diagnostic Model</td>
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<td>917</td>
<td>115kV Composite Submarine cable failure investigation and analysis of cable quality</td>
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<tr>
<td>934</td>
<td>Digital tool to compute health index for underground medium voltage cables</td>
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<td>942</td>
<td>Efficient feature extraction for machine-learning-based PD classification in medium voltage cables</td>
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<td>1046</td>
<td>Data-driven methodology to predict distribution lines fault location</td>
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<td>1118</td>
<td>Thermal analysis and debottlenecking of HVAC export cables for offshore windfarms</td>
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Block 2: “Asset management and condition assessment of Substations Components”

The block 2 “Asset management and condition assessment of Substations Components”, as a continuation of the previous CIRED, follows fundamental trends: The first one is the development of more advanced monitoring solutions for components in service, the definition of precise health indicators to improve predictive maintenance, and finally data management methods, with the introduction of self-learning techniques (AI) in order to extract the relevant information and correlations. The purpose of all this is to achieve a better optimization of Capex and Opex for the DSO.

In parallel, the distribution networks face a second challenge with the integration of distributed and fluctuating energy sources, as well as new types of loads such as EV charging. Many papers deal with the adaptation of the network components to this evolving situation, especially with their "dynamic rating" capabilities. In this block, are also included many on-site maintenance or retrofitting stories, and also laboratory tests which allow to identify the degradation modes of real components, and the associated physical ageing laws.

The 39 papers of this block are divided in 4 sub blocks:

- Upgrade to smart, and sensors integration
- Data for asset management
- Dynamic rating, adaptation to DER
- Use cases of diagnostic, maintenance, and retrofit.

Sub block 1: Upgrade to smart, and sensors integration (10 papers).

Four papers of this sub block deal with transformers condition monitoring. Real-time indicators are often directly derived from current/voltage measurements (papers 338, 526), but alternative solutions exist (458, 843).

Paper 338 proposes a method to detect faults in a distribution transformer by studying the circulating current in delta winding. Even with only a one-turn winding short circuited, the shape and magnitude of the circulating current present a clear change. This default is not detectable by the load currents measurement.

In paper 526, two real-time degradation indicators are continuously calculated thanks to three phase and neutral current measurements on earthing transformers.

Fig. 2 of paper 526: Easy-to-install split-core current transformers on a grounding transformer.

In a first part, paper 458 proposes a real-time algorithm to monitor accurately the network fundamental frequency, its harmonics content, and finally the power quality indexes, which is of primary importance in the context of DER. In a second part, these variables are used as inputs, for a parametric thermal model for distribution transformer. Premature ageing of the transformer is detected by any deviation between the measured and calculated oil temperatures. The model parameters need to be updated regularly via periodical measurement campaigns, for example during maintenance operations.

Paper 843 describes non-electrical health indicators for power transformers. The focus is set on factors affecting their lifespan, on which operator and maintainers can react efficiently (as air-coolers clogging, breather efficiency, oil moisture, and on-load tap changer performance). The long-term objective is to estimate a unique health index for all the transformers in the fleet, that could be used to trigger maintenance operations.
Three papers of the sub block concern partial discharge (PD) which is a localized non-disruptive discharge, indicating the insulation health status of the electrical assets.

The goal of paper 505 is to compare different typologies of PD sensors (TEV, HFCT, ultrasonic, capacitive) applied for the online monitoring of an MV GIS. Their optimal configuration and position are determined in the switchgear and its associated cables. PD signals from different artificial defects sources are used for this experimental study.

This methodology is also applied in paper 652, that presents a convenient handheld measurement device to be connected to the voltage presence indicator during service operation. It gives to the operator important information about eventual partial discharge activity in the switchgear.

Paper 833 introduces a distributed PD monitoring architecture, based on the capacitive detection method and wireless communication. To ease the system commissioning, generic PD signal propagation models are created and experimentally validated for each constitutive component. The models are used as the building blocks allowing a broader understanding of PD propagation in an entire switchboard.

Switchgear thermal monitoring, using low cost camera is discussed in paper 675, with the challenge to find an automatic real-time algorithm to analyze the thermograms. After a comprehensive review of the existing algorithms, the authors show that a relatively simple PixelCount method is efficient enough to extract the relevant information from the low-resolution images, and to distinguish faulty and healthy cases with a simple threshold.

The two last papers introduce the global “smartization” of existing substations. Paper 567 promotes the use of an integrated “all-in-one” system including control, monitoring and communication to simplify the installation complexity and limit the associated risks: less wiring, factory assembly and testing, simpler and transposable calibration of the sensors.
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**Fig. 4 of paper 567:** Simplicity of a standardized cabling

**Paper 588** is a comprehensive review of a substation monitoring architecture. It starts from the list of parameters to monitor, their respective assessment criteria. Then possible IoT sensors, data communication and treatment levels (edge or cloud) are proposed. It is expected that the predictive models will be obtained with an iterative process: over time, the devices will generate more and more data which can be used to improve the initial models and make failure predictions.

<table>
<thead>
<tr>
<th>Type of analysis of each assessment criteria</th>
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<tr>
<td>Sub block 2: Data for asset management (12 papers)</td>
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<tr>
<td>This sub block covers all the challenges related to data for asset management, at different stages and with various complexity levels:</td>
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<td>- Data collection</td>
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<td>- Statistics and correlations</td>
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<td>- Determination of variables of interest (for example: health index, probability of failure, Matrix of Risk, …)</td>
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<tr>
<td>- Self-learning algorithms, AI</td>
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<td>- Data security,</td>
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<tr>
<td>- Data models and digital twins for a full digital representation of the network components.</td>
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</table>

Two papers relate experiences of data mining as a source for representing pre-fault indications. In paper 42, operating times of a disconnector fleet are extracted from a SCADA system. In paper 362, events from medium voltage protection relays have been collected during 28 months whereas faults in the network have been registered in parallel. The two papers show the complexity to analyze the data and to find proper fault prediction models. Results are often biased by external factors (as communication transfer time for the first one) and statistical and visualization methods are not efficient with a limited dataset.

**Table 1 of paper 588:** Type of analysis of each assessment criteria

**Fig. 8 of paper 362:** Recorded fault pre-indication pattern from the protection relay

**Paper 38** presents an evaluation methodology developed to rank the replacement of instrument transformers. “Condition Indicators” (i.e. Health Index) are determined and combined with a “priority indicator” reflecting the operating priority of the transformer station. Thus, a global Matrix of Risk is built.
The same approach is followed at a larger scale in the project “Analytics 4 Assets - A4A” described in paper 382. The methodology is derived from the CNAIM (Common Network Asset Indices Methodology) established by UK DNOs, which defines “Health Index (HI)” iteratively calculated with usage and environmental factors. In the A4A project, a special attention has been paid to the determination of 15-days ahead “Probability of Failure (PoF)”, with additional data. Possible models are benchmarked in the paper 957, for distribution transformers. The A4A dashboards are now used for the DSO investment and maintenance planning.

![Fig. 3 of paper 382: CNAIM Methodology Main Blocks](image)

Fig. 3 of paper 382: CNAIM Methodology Main Blocks

Four papers (344, 442, 904, and 1149) relate the use of Artificial Intelligence (AI) to treat the data and establish predictive models.

In paper 344, past dataset that could explain slow opening times of circuit breakers are extracted and analyzed thanks to the SAS software platform (as for example: last opening time of the circuit breaker; elapsed since the last corrective maintenance, command type, year of entry into operation…). A predictive model is established using the SAS Miner module. A significant part of the paper explains the methodology used for the algorithm training.

Paper 442 is focused on AI for image diagnosis to assess the rust status of steel tank of pole transformers. The recognition accuracy reaches the value of 77.3%.

![Fig. 3 of paper 442: Rust rank by multi-label classification model](image)

Fig. 3 of paper 442: Rust rank by multi-label classification model

DataPoste, a mobile application performing image recognition with deep learning is presented in paper 904. It allows to automatically identify the equipment brand name and model reference from a captured picture. The Explainable Artificial Intelligence (XAI) method is used to provide more transparency and avoid “black box effect”, thus providing higher rate of trust and acceptance from the end-users.

In paper 1149, an advanced vibration monitoring method can detect early symptoms of degradation of the operating mechanism of a circuit breaker. Machine learning models allow to identify abnormal conditions vs. the healthy breaker state.

The last three articles of this sub block assess the use of digital twins data models, to contribute to the management of all the assets for the DSO.

Paper 547 is a topical review on the challenge to deploy digital twins of HV equipment. The main types of twins and their usage are explained, and the requirements applying to the data and the data processes are derived.
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**Fig. 3 of paper 547:** Digital twins across the lifecycle of a given asset

Paper 266 discusses the needed standardized data models, based on the findings of two working groups: the French “GIMELEC ontology WG” and the IEC TC17 AHG7.

**Fig. 4 of paper 57:** Mechanically opened fuse notch after current cycles

Paper 57 relates the development of a new HV fuse providing a significant improvement regarding the withstand to the cyclic current. A comprehensive study explains that the melting-elements progressively develop a grain-growth and become more sensitive against mechanical forces caused by thermal - expansion and contraction, in case of current cycles.

**Fig. 1 of paper 266:** Main current data models for HV equipment

Paper 538 follows the methodology issued from the IEC TC57, to review all the applications needed in order to have a proper inventory of traditional and digital assets

**Sub block 3: Dynamic rating, adaptation to DER (8 papers)**

The rise of renewable and decentralized power generation, as well as new electricity usages (for example electric vehicles) induces wider cyclic load in the distribution network. With dynamic rating, a high current can be allowed for a short period without exceeding the maximum design temperatures of the transformer/switchgear.

Paper 57 relates the development of a new HV fuse providing a significant improvement regarding the withstand to the cyclic current. A comprehensive study explains that the melting-elements progressively develop a grain-growth and become more sensitive against mechanical forces caused by thermal - expansion and contraction, in case of current cycles.

Papers 260 and 261 report several case studies of optimal selection of transformer to be used with cyclic load application. Technical solutions are also proposed to improve the thermal withstand of the transformer insulation system.

Adaptive numerical thermal models are often used to estimate the overload possibilities of an existing component. The formulation is often issued from the relevant product standard. Papers 425, 427, 603 and 1058 report such studies applied to switchgear and transformers. However, paper 302 includes a more advanced physical model based on the heat balance equation. In all cases, the models are not fully predictive, and their parameters need to be adjusted, thanks to preliminary test campaigns on the equipment.
Sub block 4: Use cases of diagnostic, tests, maintenance, and retrofit (9 papers):

Four papers relate diagnostic, and maintenance operations on power transformers. Hot-oil spray and circulating methods are used to remove water contamination in paper 315. The behavior of refurbished transformers with natural ester replacing oil is analyzed in paper 1116, and electric properties of aged ester are characterized in paper 664.

Paper 146 presents a test facility to reproduce transformer ageing. The originality of this device is a “thermal image box” allowing to insert insulating papers samples in the transformer circulating oil, in realistic operating conditions. Oil and paper samples are submitted to a permanent stress with a load rate between 130 % and 150 % of the transformer maximum nominal capability. In the end, the experimental results are compared to the aging model proposed by the IEC 60076-7.

Retrofitting consists in replacing switchgear components to upgrade, renew, or provide more functionalities. Paper 928 reports a massive modernization of a primary switchgear installation, with the “retrofill” of circuit breakers (all-in-one solution combining a new CB, a new frame and new interfaces), as well as a remote racking solution to improve the safety of operators.

Paper 849 studies the replacement of SF6 by an eco-friendly gas in an existing outdoor circuit breaker (using vacuum interrupters as arc quenching chamber). Crucial modifications are required to adapt the design, showing the complexity of such operation.

Internal arc withstand can be improved in substation buildings made of concrete or bricks. Paper 117 report overpressure calculations, and structural simulation results of such buildings during an internal arc event. A simple and affordable pressure relief hatch is proposed to solve the overpressure problems.
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Fig. 2 of paper 117: Plastic deformation of brick substation during an internal arc event

In paper 235, a wrong positioning of cable in a hydropower plant leads to a thermal failure due to the proximity effect. Thanks to thermal and magnetic field simulation, a better phase arrangement is identified.

Fig. 12 of paper 235: magnetic field distribution in two cables arrangement: the case b) is more favorable to limit heating.

In paper 323, an ageing test protocol and simple indicators are proposed to predict the behavior of lead-acid batteries. The degradation modes are discussed.

Table 2: Papers of Block 2 assigned to the Session

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<tr>
<th>Paper No.</th>
<th>Title</th>
<th>MS a.m.</th>
<th>MS p.m.</th>
<th>RIF</th>
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<td>38:</td>
<td>Integrating different predictive determinations for the Condition</td>
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<td></td>
<td>Assessment of a HV instrument transformer fleet</td>
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<td>42:</td>
<td>Study of Maneuvre Time of Distributed MV Disconnectors</td>
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<td>57:</td>
<td>HV Fuses with Improved Cyclic Stability ICS</td>
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<td>117:</td>
<td>Upgrading internal arc resistance of existing substations</td>
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<td>146:</td>
<td>Accelerated ageing test of MV/LV distribution transformers: Results</td>
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<td></td>
<td>and discussion</td>
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<td>235:</td>
<td>Proximity Effect in High Current Conductors – A Case Study</td>
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<td>260:</td>
<td>Overloadable distribution transformers for flexible loading in</td>
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<td>future distribution networks</td>
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<td>261:</td>
<td>Optimization of transformers for solar or battery storage</td>
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<td>installations based on a cyclic loading pattern</td>
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<td>266:</td>
<td>A standardized knowledge model for high-voltage equipment</td>
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<td>catalogue data contributes to simplify the life of end users and</td>
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<td>315:</td>
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<td>Oil Spraying</td>
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<td>320:</td>
<td>Data-driven Transient Temperature Rise Prediction Model for Medium-</td>
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<td>Predicting valve regulated lead-acid battery sensitivity to ageing</td>
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<td>Practical verification of medium voltage switchgear thermal loadability based on the IEC62271 thermal model</td>
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<td>Image diagnosis using artificial intelligence for pole transformers</td>
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<td>Harmonic analysis and distribution transformer monitoring</td>
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<td>Online MV PD monitoring system: improvements on the automatic assessment of the insulation systems</td>
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<td>Advantages of Integral Remote Access Management in Smart Secondary Substations in terms of costs, reliability and personnel (e.g. COVID-19)</td>
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<td>A comprehensive approach to the predictive maintenance of Secondary Distribution Substations: devices and methods</td>
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<td>603</td>
<td>Temperature rise simulation model of RMU with switch-fuse combinations for future load profiles</td>
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<td>Switchgear Sensorization for Flexible and Efficient Asset Management</td>
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<td>664</td>
<td>Analysis of Dissipation Factor Tan δ of Natural Ester with Temperature Normalization</td>
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<td>675</td>
<td>Automatic analysis of thermograms - challenge in thermal monitoring of switchgears using infrared cameras</td>
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<td>Innovative distributed architecture for continuous PD monitoring in MV substations</td>
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<td>Online monitoring of power transformers to improve their operating and maintenance model</td>
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<td>Retrofit of Outdoor Medium Voltage Circuit Breaker with Eco-Friendly Gas to replace SF6</td>
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<td>928</td>
<td>Installed base Safety upgrade at power generation station</td>
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<td>Analytics 4 Assets – The Advanced Asset Management Project applied to Power Transformers</td>
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<td>1058</td>
<td>Thermal response time of the LV fuse gear in secondary substations and cable distribution cabinets</td>
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<td>1116</td>
<td>Refurbishment of distribution transformers with benefits in the exchange of mineral oil by natural ester insulating liquid</td>
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<td>1149</td>
<td>Vibration Monitoring for Medium-Voltage Circuit Breaker Drives Using Artificial Intelligence</td>
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Block 3: “Innovation in Network Components – Cables, lines and new types of components”

The 27 papers of this block are divided in 3 sub-blocks:
- Materials & Models
- Metering & monitoring systems
- Systems for safety & security
- Components for protection & stabilization

Sub block 1: Materials & Models (7 papers)
The preservation of dielectric performance along the years for cable system is the fundamental hypothesis for energy distribution and transmission on existing and future networks. Innovation in this domain should propose new candidate materials with improved properties (paper 356) but also give solutions to extend lifetime or lower environmental impacts of existing assets, like oil filled cable (paper 113).

Fig. 5 of paper 356: Prototype cable using water-blocking sub-sheath layer

When exposed to abrasion or corrosion, overhead cables can show premature damage if an adequate protection has not been developed. And these developments require to reproduce complex phenomena. Stating some gaps in existing standards, the paper 597 presents a new abrasion bench to properly test cable and align all the actors to improve the products quality. In the paper 860 a simplified model allows to set up accelerate ageing test and to develop new hardware. When the rating model of cable is associated to geophysical soil mapping and real time load, one can reach a very useful real time rating tool (209). To have a first reliable cable rating with concrete duct banks, a simplified model with an equivalent resistivity of soil has been developed (553).

Sub block 2: Metering & monitoring system (6 papers)

The MV smart meters can generate different types of data depending on the request coming from the central control system and vendors’ product specificities. The paper 550 presents the development of a protocol adapted to the diversity of equipment to check the proper data collection from the smart meters and the execution of request to the smart meters.

New generations of passive voltage and current transformers integrated in the accessories (fig. below) are presented in paper 1034 and 744, compliant with standards for metering and protection functions and allowing integrated architectures, easy to install and easy to connect to any existing IEDs.

Fig. 1 of paper 1034 (left) and fig. 1 of paper 744 (right): Example of Low Power Voltage Transformer 24kV (green), Voltage Transformer 24kV DIN size (brown) and new type C Bushing (red)

The papers 485 and 753 propose new configurations of metering system on MV grids with recommendation on the measurement chain (signal cable, IEDs). Improvement of existing standards to use passive low power instrument transformers are discussed. The challenge of thermal monitoring of grids is the access to the cable or accessories core temperature without endangering the dielectric properties. The paper 1007 gives a solution coming as close as possible to the conductor by embedding the temperature sensors inside a type C bushing.

Sub block 3: Systems for safety & security (7 papers)
The underground networks are presenting many dangers and unauthorized access is a source of outages and accidents. An automated hatch is presented in the paper 517 to secure and monitor access to manholes.
Household PV panels connected to the grid can create a situation where the grounding of the cable at the transformer side is not enough to insure safe works conditions. A short circuit ring has been developed (paper 1056) to be installed on the consumers side of the LV cable in the trench prior to cut the cable and prevents power inrush coming from the PV panels (fig 7).

Fig. 8 of paper 1056: Screwing contact of short circuit ring through core insulation to secure operation on LV grid with PV installations

The densification of urban area and the presence of electrical networks make it difficult to reinforce grounding when needed, both for existing and new installations. The paper 671 proposes a set of methods to monitor visually and electrically the soil condition during drilling and to find reliable spots to install grounding rods.

The paper 1097 presents a new type of cable path marker based on magneto-mechanical resonance with a typical lifetime of 50 years. Safety measures on grids must be extended to animals and the paper 1124 is presenting a feedback over the past 17 years of the solutions experimented on overhead lines to prevent accidents with birds.

Sub block 4: Components for protection & stabilization (7 papers)

A grid extension may lead to an increase of fault current beyond the limit of installed equipment. The paper 537 proposes a technology of permanent magnet bias fault current limiter that allows to reduce drastically the insertion impedance and the losses compared to equivalent 20 MVA@11 kV class current limiting reactors.

MVDC links are used to support locally MVAC grid, and such links require also to be protected against overcurrent. Paper 124 presents an adaptative hysteresis control to prevent upper current from being exceeded. Going deeper in the combination of AC and DC networks, the paper 1141 describes the architecture of a multiport active bridge converter where local renewable generation can be converted and distributed to AC and/or DC grids depending on the demand, creating a flexible bi-directional power sharing node between AC, DC and generation sources.

Fig. 4 of paper 1141: cluster of MAB converters in a smart grid with renewable generation, storage devices, AC loads and DC loads

Power Electronic devices (PED) based on SiC are used in the paper 943 to realize a soft meshing of two LV or MV grids allowing power flow with a galvanized separation and higher penetration of low carbon technologies. The paper 100 presents an optimized remote-controlled switch to reconfigure dynamically LV grids according to the active loads and power sources distribution in the grids, like EVs’ charging stations and intermittent renewable generation. To democratize a digital version of protection relays, paper 955 describes a low-cost overcurrent relay based on three off-the-shelf components. Tests show compliance with existing standards.

In the case of battery storage integration to support local implantation of EVs, the paper 155 proposes an algorithm based on AI to choose the optimum sizing of the battery storage system.
### Table 3: Papers of Block 3 assigned to the Session

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<tr>
<th>Paper No.</th>
<th>Title</th>
<th>MS a.m.</th>
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<td>100:</td>
<td>Tapered link box switch for meshing low voltage distribution networks</td>
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<td>113:</td>
<td>Self-healing Dielectric Fluids for Fluid Filled Cables</td>
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<td>124:</td>
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<td>209:</td>
<td>An approach towards real-time cable ratings for underground medium voltage cables</td>
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<td>356:</td>
<td>Self-repair, water blocking materials for sub-sea power cables</td>
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<td>485:</td>
<td>Revenue Metering based on Low-power Passive Instrument Transformers complying with IEC 61869-10 and IEC 61869-11 Standards including Legislative View on Legal Metrology</td>
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<td>517:</td>
<td>Automated Hatch for the Underground Distribution Grid with Access Control</td>
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<td>537:</td>
<td>Practical verification of a low-loss 11kV distribution grid Fault Current Limiter – the pmFCL</td>
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<td>550:</td>
<td>Testing solution for field data concentrators – Multi channel integration</td>
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<td>553:</td>
<td>Sensitivity analysis of cable trench modelling with concrete pipe block and several material layers for the ampacity 150kV cables</td>
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<td>597:</td>
<td>Ingenious abrasive-strength tests ensure EDP Distribuição Low Voltage overhead line insulated cables resilience</td>
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<td>671:</td>
<td>Guided hole excavating device for ground rod construction of power cable and the method for electric ground safety</td>
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<td>Cable connection bushing type C according to EN 50181 with Rogowski coil current sensor and capacitive voltage sensor according to IEC 61869-10 and IEC 61869-11</td>
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<td>Hardware of Aerial Distribution Networks, for Use on the Seashore, Corrosion Resistant, Corona Discharges and Leakage Current</td>
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<td>Development of Power Electronic Devices to provide dynamic power sharing on 400V and 11kV distribution networks</td>
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<td>Low-cost overcurrent protection relay based on a standard microcontroller</td>
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<td>1033:</td>
<td>Distribution Network Modernization in TNB with the Application of Line Lightning Protection Device onto the 33kV Overhead Lines with High Soil Resistivity in Tenaga Nasional Berhad – Reimagined TNB Towards Grid of the Future</td>
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<td>INTEGRATED LPVT’s IN EACH FUNCTIONAL UNIT FOR SIMPLER PROTECTION AND CONTROL</td>
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<td>New advancements in electronic marking technology for underground asset</td>
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<td>Best practices and new opportunities for biodiversity protection facing power lines impacts</td>
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<td>1141:</td>
<td>Multi-port active-bridge converters: energy exchange blocks for smart grids</td>
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Block 4: “Innovation in Substations Components”

The block 4 “Innovation in Substations Components” of the CIRED 2021 highlights two major themes: First, the development of greener network components, especially with the SF6 free topic, but without forgetting other technologies as bio-based insulation for transformers, energy efficiency, etc. The second major theme is the increase of embedded intelligence in the substation, or “smartisation”: more sensors, more autonomy, more communication, and more remote control. This CIRED conference allows to compare the visions of end-users, as DSO, and manufacturers in several papers. Finally, innovations in traditional network components such as circuit breakers and transformers are also present: for example, circuit breakers with an enhanced capacitive switching performance, transformers with a better resistance to voltage transients, just to name a few. And of course, the development of simulation tools and test methods to improve the design process and the optimization level of the network components.

The 45 papers of this block are divided in 4 sub blocks:

- Greener components
- Smart substations
- Innovative network components
- Methods and tools for component design

Sub block 1: Greener components (16 papers)

The search for solutions to replace SF6 in MV GIS has been a major environmental topic of CIRED session 1 for numerous years (the last event being a round table organized in 2019 in Madrid). First SF6-free switchgear have been, or are about to be launched on the market by several manufacturers. The debate is still open between different technological options for medium voltage, and the 2021 session is a good opportunity to combine the requirements of end users (for example paper 873) and the different proposals of manufacturers.

Paper 435 reminds the high complexity to assess the different alternatives with a holistic approach, as some criteria can lead to contradictory effects. The authors also underline the lack of regulatory framework, and accepted standards.

Two main families of technological solutions emerge, with the objective to keep the dimension of the current equipment:

- Solutions based on the use of air (or of its natural constituents with different mixing ratio) as insulating medium. This yields to an increase of the operating pressure, to retrieve the same electric strength than SF6. This can be technically mastered in MV GIS by the right tank design and testing approach (paper 847), and counter-balanced using solid insulating materials to reinforce the insulation system (paper 88).

Fig. 4 of paper 847: FEM simulation of the mechanical tension in an air pressurized welded vessel

- Solutions based on mixtures of gases including one fluorinated compound associated to a carrier gas, as nitrogen or CO2. This makes it possible to retrieve insulation properties comparable to those of SF6, and therefore to keep all the advantages of a similar filling pressure (as for example a lower risk of
leakage). A comparative discussion concerning the filling pressure is proposed in paper 208. The toxicological assessment of the new F-gas mixtures and their decomposition by-products is required to evaluate the risks in case of accidental exposure. Paper 268 estimates the potential risks similar to those exhibited with an SF6-filled equipment.

Innovative load-break switches, or current interruption technologies, are developed to be compatible with the new gaseous insulation technologies. Paper 614 presents a pilot project with a puffer-based load-break switch based on arc interruption in gas. Paper 683 details the fundamentals physical processes on the arc interruption processes in new F-gases mixtures. Another approach is highlighted in papers 527 and 706. They both report the development and field test of load-break switch concepts with vacuum interrupter (VI) in auxiliary-path, avoiding arcing phenomena in the gas.

Fig. 1 of paper 527: Schematic diagram of a three-position load-break switch, with vacuum interrupter (3) in auxiliary-path.

Regarding transformers, a clear environmental benefit is also offered by the use of eco-friendly natural ester as an insulation fluid. Characterization of the electrical and thermal properties of new insulations fluids are presented in papers 183 and 262.

Two life cycle assessment (LCA) studies are presented. In paper 381 green GIS and transformers for offshore wind turbine application are assessed. Paper 674 presents the evaluation applied to a GIS and compares different estimation methods. To get a global picture of the “environmentally conscious design of MV switchgear”, a complete overview on the standardization framework is discussed in paper 265.

The last “green component” of this sub block is called GEM (for “Mobile Energy Generator”) and is presented in paper 890. It intends to replace classic diesel generators during outages and maintenance on MV grids, avoiding polluted gas exhaust as well as noise. A specific attention has been paid to the electrical protections, during usages both in islanded and grid-connected modes of the device.

Fig.6 of paper 890: “GEM” generator on a truck

Sub block 2: Smart substations (8 papers)

Smart substations need to meet the challenge of maintaining power quality and reliability, while supporting the integration of DER and new energy uses.

Starting with articles giving a broad vision, paper 622 discusses a prioritized list of requirements
and associated technical challenges from a DSO perspective. All the items are ranked using evaluation criteria, grades, and weights. This work can be seen as the preparation of a R&D roadmap.

Paper 617 introduces an integrated approach, with the project “NEXTSTEP”, considering concept of the smart substation as a whole. Advanced monitoring and control systems, but also eco design of the power equipment and of its housing are shown.

Paper 325 defines the functions of the Remote Terminal Unit (RTU), for control and monitoring of the substation, through a new dedicated French technical specification ST 64-S-63.

Paper 706, already mentioned in the “green component” sub block, presents the digital architecture of an RMU, including cybersecurity.

Papers 467 and 810 both focus on the control of the LV network side with OLTC (On-Line Tap Changer) transformer coupled to advanced LV network monitoring and real time algorithms. This is seen as a cost-effective solution to improve the capacity of the LV network, and to answer the simultaneous growth of DER (as micro photovoltaic sources) and the development of EV charging infrastructure.

Paper 471 proposes an architecture for an automated LV feeder including fast auto-reclosing and fine tunable coordination and selectivity features. It combines a vacuum circuit breaker, a fuse link for the highest short circuit levels, a disconnector and an earthing switch. An advanced IED allows to perform supervision, control, and protection tasks.
Sub block 3: Innovative network components (12 papers)

The third sub block consists of papers presenting innovative designs or functions for substations components.

Seven papers deal with vacuum breaking technology, six concern power transformers, of which two solid state transformer (SST) technology. The last paper presents an innovative self-powered ultra-fast earthing switch to mitigate the harmful consequences of an internal arc event.

Paper 189 presents the technical requirements, seen from a DSO, concerning primary 24kV switchgear equipped with vacuum circuit breakers. Different aspects are discussed: reduced dimension, internal arc withstand, ..., one of them is the mitigation of all the overvoltage risks inherent to the use of the vacuum technology.

As an answer, paper 755 investigates the influence of axial magnetic fields on different contact material compositions for vacuum interrupters, to reduce the chopping current level. These abrupt current variations generate high overvoltage in case of inductive load switching, and possibly irreversible insulation damages.

A series of articles from the same switchgear manufacturer present a novel vacuum circuit breaker, for repetitive capacitive breaking operations. Several innovations are considered. An improved vacuum interrupter design and contact material allow to reduce prestrike during closing (paper 679). Digitally controlled servomotor drives synchronize each individual pole operations with the network voltage waveform (paper 763), to reduce inrush current.

Fig. 3 of paper 763: Close Function, Synchronized and simultaneous modes.

A control unit (ACU), which is included in a scalable smart architecture (paper 767), guarantees the switching stability in all operating and environmental conditions thanks to sensors and self-adaptive features.

This circuit breaker demonstrates an increased lifespan (up to 5 times vs. standard breakers) for repetitive capacitive load switching operations, which are more and more frequent to ensure power quality on the electrical networks. An adapted version of the circuit breaker technology is used in paper 784 in an experimental DC set-up, where the poles of vacuum breaker are put in series.

Paper 646 presents the design of a modular 72,5 kV recloser, to be used in transmission networks. It combines vacuum technology, solid insulation with epoxy overmolding and magnetic actuation of the poles.

Fig. 3 of paper 471: Complete automated Low Voltage Board

To conclude this sub block, the last paper 509 presents a configurable MV test infrastructure representing a real network and integrating most of the communications technologies. It is used to validate the new “smart” technologies before their introduction on a real grid.
Paper 746 proposes a new method to detect, trigger and power an internal arc short-circuiting protection device by means of several solar cells placed inside the switchgear. There is no need of any auxiliary power. The system can activate the mitigation device within less than 3ms (for a 2.1kA arc fault current) and remains insensible to other light sources (as flash, sunlight, lamps).

First in the group of papers dealing with innovative transformers, paper 980 presents the design of a novel dry type transformer, resilient to transient voltage stresses generated by VCB operation. The concept is based on the shifting of natural transformer series resonance frequencies above the range of the expected reignition frequencies of VCBs (10 kHz – 90 kHz), to reduce the probability of interaction. Novel designs are verified by a series of tests replicating switching surges and transients typical for VCB operation.

<table>
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<tr>
<th>Parameter</th>
<th>change</th>
<th>effect on $f_{res}$</th>
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<tr>
<td>Number of turns</td>
<td>decrease</td>
<td>increase</td>
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<tr>
<td>Winding diameter</td>
<td>decrease</td>
<td>increase</td>
</tr>
<tr>
<td>Number of cooling ducts</td>
<td>decrease</td>
<td>increase</td>
</tr>
<tr>
<td>Width of cooling ducts</td>
<td>decrease</td>
<td>increase</td>
</tr>
<tr>
<td>Wire insulation</td>
<td>increase</td>
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</table>

Table 1 of paper 980: Impact of design parameters on the transformer resonance frequency

Papers 62 and 642 present dry-type transformers design where the insulation has been improved thanks to the use of solid insulation materials. In paper 62, a Solid Insulation Distribution Transformer (SIDT) for underground networks is presented. The insulation consists in Nomex paper and epoxy, and the enclosure is made of thermoplastic resin with a thermally conductive filler to dissipate the heat.

In paper 642 the design of a compact transformer with a 3D wound core layout, and VPI based insulation system (for Vacuum Pressure Impregnated) is shown.
In both articles, the technical advantages, the design methodology, as well as the validation tests are presented, including fire resistance, thermal cycles and shock, electrical tests... An overload capacity study is also shown in paper 642.

Last two papers in the transformer group concern the SST technology (Solid State Transformer).

Paper 365 highlights the technical-economical perspectives to use SST in a distribution network. On one hand, SST can support the energy transition though extra-functionality vs. CTT (conventional transformer with tap changer)
- An easier voltage regulation
- A DC connection point for storage
- Filter capabilities for harmonic mitigation
- ...

On the other hand, SST cannot yet compete financially with a conventional transformer because of its high initial cost and relatively shorter life span. However, depending on the future energy scenarios (and the needed functionalities) and taking into account the decrease of power electronics cost, the authors conclude that the total system cost of an SST may be comparable to CTT in the future.

Paper 476 analyses the impact of standardized dielectric tests defined in IEC 60073-3 on SST (focusing on the IVW & IVPD and AV tests). Passing these tests yields to an over dimensioning of the power electronics (more stacks needed) and accordingly has an impact on the final cost of the transformer. A second part deals with the impact of high frequencies on the insulation ageing in an SST: the coils and the overmolding of Litz wires are concerned on the MV side.

Sub block 4: Methods and tools for component design (9 papers)
The last sub block groups papers dealing with various design tools for the development of substations components.

Three papers discuss dimensioning methods of transformers.

Paper 43 proposes a new sizing criterion for neutral earthing transformers, which is based on a limited earth fault duration (up to maximum 10 s) as per applicable IEEE and IEC standards. However, the sizing based on a continuous earth fault is still valid for medium voltage systems having their neutral point grounded through high resistance, or systems with long tripping time in case of earth fault.

In paper 115, the reluctance network analysis is used to evaluate the magnetic flux density distribution in a hybrid core transformer consisting of amorphous and grain-oriented silicon steel cores. The results are compared with the traditional FEM approach. It is demonstrated that the hybrid core allows to increase the capacity and to reduce the standby power vs. non-hybrid transformer technologies, thus providing a substantial energy saving.

Fig. 1 of paper 115: Overall view and cross-section of the hybrid core of a 30 MVA three-phase prototyped hybrid core transformer. Paper 768 aims to improve the modelling of saturation effects of power transformers, and
their behavior during temporary overvoltage near the system frequency. The phenomena are highly non-linear and generate distorted secondary voltage and high primary side currents. Two methods of parameter identification and polynomial regression are proposed. Results are compared with experiments using a standard configuration and two overvoltage levels (1.14 and 1.3 p.u., the transformer initially being in a steady state).

Two papers of this sub block concern the modeling of internal arc faults in switchgear.

Unlike commonly used analytical or simplified CFD (computational fluid dynamics) internal arc models, which require multiple fit parameters, paper 97 integrates a full self-consistent arc physics representation, which allows to calculate the arc voltage, pressure, and arc displacement in the switchgear. Simulation and test results are compared.

The work presented in paper 512 also combines experimentation and CFD simulation for internal arc. Its purpose is to improve the prediction of cotton indicators burning, for different heat flux and exposure durations, which is the most prominent failure mode during internal arc testing.

Paper 865 discuss the cooling properties of pure air at different filling pressure, when used as a dielectric medium instead of SF6. The impact on the design can be evaluated using thermal network method (TMM) or CFD methods. The authors estimate that 3.25 bar of pure air provides a cooling performance equivalent to 1.3 bar of SF6 (absolute pressure).

Paper 145 is an experimental investigation of the role of eddy currents in the arc grids (also called arc “chutes” or “splitters”), on the arc motion in an LV circuit breaker.
Iron grid when the arc touches to the grid

The permanent reconfiguration of complex and interconnected grids will require an increase of mechanical endurance for all the switches and circuit breakers present on the network. Paper 525 propose a complete simulation workflow, to predict circuit breaker mechanical endurance. This approach combines several steps, starting from a global dynamic model and ending with a local fatigue analysis in the critical area only.

Fig. 4 of paper 525: Flowchart of novel workflow for endurance prediction of circuit breaker parts

Table 4: Papers of Block 4 assigned to the Session

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<th>Paper No.</th>
<th>Title</th>
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<td>Optimization of earthing transformer sizing in medium voltage networks</td>
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<td>62:</td>
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<td>Internal arc root movement and burn-through prediction by simulation using first principle</td>
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<td>115:</td>
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<td>Arc drive due to the eddy current in iron arc extinction grid and interrupting performance</td>
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<td>A new sustainable, readily biodegradable and high performance insulating liquid for power transformers.</td>
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<td>Evaluation of Sustainable SF6 Alternative Gas Mixtures Used in Electric Power Equipment</td>
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<td>325:</td>
<td>Enedis requirements for Secondary substations monitoring and control</td>
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<td>Feasibility of implementing MV/LV Solid state transformers in the Dutch electricity grids – from economic perspective</td>
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<td>Novel workflow for Prediction of Circuit Breaker Parts Endurance</td>
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<td>Influence of the Contact Material used in Vacuum Interrupters on the Chopping Behavior of Switching Arcs</td>
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<td>Smart Circuit Breaker: a unique and optimized solution for different applications</td>
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<td>Implementation and parameterization of transformers with saturation effects for the simulation of transmissions of temporary overvoltages</td>
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<td>Smart Secondary Substation as the source of the flexibility services</td>
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<td>Pressure vessels for voltage levels ≥ 24 kV for SF6-free medium voltage GIS</td>
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<td>Thermal management of MV GIS filled with pure air</td>
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<td>Utilities concerns about alternative to SF6</td>
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<td>890</td>
<td>A carbon free mobile supply solution combining Energy Storage System and local production, for planned and unplanned outages</td>
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<td>Novel distribution transformer design for data center applications resilient to transient voltage stresses generated by VCB operation</td>
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Session 1

Network Components

Block 1: Asset management and condition assessment of Network Components – Cables, lines and associated components

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¹TU Dresden, Institute for Acoustics and Speech Communication, Germany. ²Technische Universität Dresden, Germany. ³HIGHVOLT Prüftechnik Dresden GmbH, Germany. ⁴Brandenburg University of Technology Cottbus-Senftenberg, Germany

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¹Politecnico di Milano, Italy. ²UNARETI S.p.A, Italy. ³Università La Sapienza, Italy

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Aryan Salmanpour1, Nima Ebrahimi Noorali2, Mahyar Gholizadeh3, Milad Biazar Ghadikolaei1, Gholamali Rakhshani Mehr3
1Gilan Power Distribution Company, Islamic Republic of Iran. 2Tavanir Company, Islamic Republic of Iran. 3Tavanir, Islamic Republic of Iran

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Niklas Tichelkamp1, Thorsten Reske1, Nikolai Hopfer1, Markus Zdrallek1, Jürgen Herzer2, Janis Albert3, Oliver Strempel4
1University of Wuppertal, Germany. 2SWK Stadtwerke Kaiserslautern Versorgungs-AG, Germany. 3ENERVIE Vernetzt GmbH, Germany. 4Energienetze Offenbach GmBH, Germany

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1Kansai Transmission and Distribution Inc., Japan. 2K4 Digital Co., Ltd., Japan

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Klaus-Dieter Haim1, Yuyuan Xia2, Volker Brade3, Kai-Uwe Bentkowski4
1University of Applied Sciences Zittau/Görlitz, Germany. 2University of Applied Sciences Zittau/Görßlitz, Cocos (Keeling) Islands. 3University of Applied Sciences Zittau/Görlitz, Gibraltar. 4Behr Bircher Cellpack BBC Radeberg GmbH, Germany

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1LIBPhys-University of Coimbra, Portugal. 2Eneida.IO, Portugal

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Jaein Kim, Junbum Park, SungHo Park, Sung-Min Kim, Yehseul Park, Gi-Ryang Jeon, JooYoung Moon, Sangho Jeong
Korea Electric Power Corporation, Republic of Korea
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Anne de Moliner, Ilyes Kabbourim
Enedis, France

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Carlo Gemme¹, Kai Hencken², Ian Rosevear³, Andrew Pallett³
¹ABB, Italy. ²ABB, Switzerland. ³London Underground Limited, United Kingdom

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Slawomir Noske¹, Krzysztof Kolodziejczyk², Rogier Jongen³
¹ENERGA-OPERATOR SA, Poland. ²Globema Sp. z o.o., Poland. ³Onsite hv solutions ag, Switzerland

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Stelios Christou, Raed Ayoob, Andrew Wooldridge, Joe Stubbs, Ben Hickman
RINA Tech UK, United Kingdom

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David Roberts¹, Rebecca Kelly², Mark Marshall², Mike Lees¹, Chris Lowsley¹
¹EA Technology, United Kingdom. ²Northern Powergrid, United Kingdom

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Jihoon Lee, Mijeong Jun, Huisung Yan, Geonwoo Lee
KEPCO KDN, Republic of Korea

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¹Saudi Aramco, Saudi Arabia. ²RINA Tech UK Ltd, United Kingdom

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Ruben Costa¹, Ricardo J Santos¹, António R Neves¹, João Milheiro¹, Bruno Rodrigues¹, Carlos Santos¹, Pedro Alves¹, Vitor Manita¹, Jorge Mendes²
¹E-REDES, Portugal. ²Accenture, Portugal

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Christian Backe¹, Muhammad Shafiq², Haresh Kumar²
¹DFKI RIC, Germany. ²University of Vaasa, Finland
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¹INESC TEC, Portugal. ²FEUP, Portugal

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Syed Hamza H. Kazmi¹,², Rogvi Østerø¹, Thomas H Olesen¹, Troels S Sørensen¹, Joachim Holbøll²
¹Ørsted Offshore Wind A/S, Denmark. ²Technical University of Denmark, Denmark

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¹Uppsala University, Sweden. ²Vattenfall Distribution, Sweden. ³Swedish University of Agricultural Sciences, Sweden. ⁴Vattenfall R&D, Sweden

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¹Enexis Netbeheer, Netherlands. ²Engie Laborelec, Belgium

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¹EDF Lab les Renardières, France. ²Enedis Direction Technique, France

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¹DuPont, Poland. ²KYTE Powertech, Ireland
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1KYTE Powertech, Ireland. 2DuPont, Poland

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1Schneider Electric, France. 2RTE, France. 3EDF R&D, France. 4Université de Genève/CUI, Switzerland. 5GE Renewable Energy, France. 6Gimelec, France. 7Enedis, France

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SPECIAL REPORT

Session 2

Power Quality and Electromagnetic Compatibility

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Introduction

The scope of Session 2 has been defined by the Session Advisory Group and the Technical Committee as power quality (PQ) including the general concept of electromagnetic compatibility (EMC) as well as related safety problems in electricity distribution systems.

Special focus is put on the impact of new technologies on voltage quality (voltage level, flicker, unbalance and distortion). This session will also look into PQ system monitoring and mitigation methods, electromagnetic compatibility, electromagnetic interferences as well as electric and magnetic fields issues. Finally, this session discusses PQ related activities in standardization and regulation.

The aim of this special report is to present a summary of the present concerns in PQ and EMC, based on all selected papers of Session 2 (99 papers). The report is divided in the following four blocks:

Block 1: Magnetic fields, grounding, safety and immunity
Block 2: Power quality issues of new technologies
Block 3: Power quality measurement, analysis and mitigation methods
Block 4: Standardization, system monitoring, handling big data and regulatory issues

An unambiguous allocation of the papers is not always possible and topical overlapping may appear to some extent between the blocks.

Three Round Tables are organised within Session 2:

RT15: Impact of Renewable Energy Systems (RES) and Storage on Power Quality
This round table will give an overview concerning nowadays challenges in solving PQ related issues due to the massive integration of renewables and storage systems.

RT17: Emission Limits and Assessment of Disturbing Customer Installations
The calculation of emission limits for customer installations and techniques to evaluate the compliance of a customer installation with given limits are in the focus of this round table. Their importance and practical applicability are discussed from different viewpoints.

RT19: The Future of Flicker
The aim of this round table is to discuss possible options how to deal with flicker in the future. They might include new methods for flicker measurement, relaxed limits as well as abandoning “flicker” and replacement by “rapid voltage changes”.

The Research and Innovation Forum is dedicated to the impact of instrument transformers on the accuracy of distortion measurements with main focus on MV systems.

Block 1: “Magnetic fields, grounding, safety and immunity”

Magnetic Fields
In this year’s conference, three papers were addressing magnetic field issues.

The authors of [B1-0238(IT)] the mitigation of the magnetic field generated by current limiting reactors is analysed with 3D-FEM-simulations. The MF levels in the vicinity of these elements can be high enough to overcome the limits to protect both workers and the public from exposure. Different magnetic shielding configurations are analysed. From the results it can be concluded that the use of three-layered shields composed by Al+FEGO+Al can provide good results. In the optimum configuration, shielding plates are installed at the surrounding walls and partly on the floor. A shielding factor higher than 10 is achieved above 0.5 m height, while a lower efficiency is observed in the lower area.
The use of an innovative magnetic field source for the practical testing of low-frequency magnetic shielding is presented in [B1-0736(IT)]. The proposed source is composed of three coils for the generation of rotational magnetic fields in space. The supply system is based on a signal generator that controls a power amplifier. This allows to generate an arbitrary waveform or to control the frequency of sinusoidal currents. The supporting structure of the coil system is printed with a 3D-printer. With the designed setup, a field intensity of 35 µT is achieved in a distance of 20 cm of the source. The source has been applied successfully during the test procedure of a sample plate for determining the shielding factor.

Field mitigation by use of a passive loop is analysed by the authors of [B1-1057(EG)]. The goal is to reduce the field of overhead lines. A setup with a passive loop below a medium voltage line with flat conductor configuration was chosen. The passive loop with an aluminium/steel-conductor with 150/25 mm² cross section is installed in half the height of the overhead line. Simulation show that the field is reduced by almost 90 %. However, there is no information in the paper, at which location this reduction is achieved.

Grounding systems and safety
The design, analysis and optimisation of grounding systems and earthing impedance is presented in several research papers.

Special short circuit tests that were performed by the authors of [B1-0258(DE)] in a medium voltage grid revealed significantly lower earthing resistance compared with standard measurement methods. It can be assumed that the current injection method shows higher values due to divergent current distribution models compared to the real earth fault. The fall-of potential method shows even larger deviations. Based on the consideration that the elements of the lattice network, representing the earthing system, are to be regarded as ohmic-inductive impedances and that today’s measuring devices operate at frequencies above 50 Hz, one explanation could be found. Furthermore, there are hardly any empirical values for reduction factors available, describing the fault current distribution. This is especially valid for inhomogeneous grids with different cable types. For the verification of the results for the reduction factor as well as for the investigation of the earthing impedance measurements for different earthing conditions, further tests with real earth faults should be carried out in the future.
The problem of reduction factor respectively the of supplementary return paths for the ground return current is also addressed in [B1-0371(UK)]. It has been confirmed that if a supplementary metallic return path is present between the substations undergoing a fault, a reduction of the ground return current may be applied, having a significant effect upon the calculated earth potential rise. However, it strongly depends on the cable type. For plastic cables, it can be seen that with a higher soil resistivity or a smaller cable length, the ground return current would decrease. With regards to older hessian served lead-sheathed cables, the ground return current is largely related to the soil resistivity. As soil resistivity increases, the ground return current is smallest for longer cable lengths. To a lesser extent, the ground return current also depends upon the size of the cable sheath. No clear worst-case assumption can be applied for a lead sheath cable connection; therefore it is recommended that a more detailed study is conducted to calculate the ground return current in these cases.

Measurements of positive- and zero-sequence impedance in LV networks were performed by the authors of [B1-0884(DE)] by switching a load resistance and evaluating voltage and current changes. Nine LV grids were selected, covering TT and TN-C-S networks as well as a good mixture of rural, village and suburban class networks. The results for the positive-sequence impedance match the expected values, derived from typical cable parameters, with some deviations that could be explained. However, for the zero-sequence impedance the situation is different. Even accurate calculations considering the earth current depth showed larger deviations from measurement results regarding the reactance.

For substations with high fault levels it can be very demanding to design adequate earthing systems, if only traditional techniques are used. Additionally, small footprint area, which limits the earthing grid area, high resistivity soils, and poor reduction factor may ultimately lead to almost unfeasible and expensive earthing system designs, comprising dozens of long vertical electrodes. To overcome those problems, a novel design is introduced in paper [B1-0838(PT)]. The new design is based on the installation of an electro-welded steel mesh reinforced pavement, connected to the earthing grid, and the use of plastic insulated fences with a known breakdown voltage (approximately 4 kV). The touch voltages in the areas with the steel mesh are extremely low, as can be seen in Fig. B1-4. Regarding the switching station fence, the expected maximum touch voltage is 3500 V at the corners, still 700 V lower than the lowest breakdown measured voltage, thus, the safety of people is guaranteed in this solution. Compared with traditional design, a significant reduction of costs is achieved.
Decentralized earth fault compensation coils (EFCC) in resonantly grounded medium-voltage networks are becoming increasingly popular. Their installation places several demands on the earthing system with regard to equipment and personal safety. In [B1-0969(AT)] the authors analyse two MV grids, representative for an urban and a rural area. The effective earthing impedance and thus the earth potential rise is mainly determined by the (global) earthing systems. Another issue is the current distribution during an earth fault. Especially the cable shields of cables connecting ring main units with EFCC are affected.

In the Brazilian distribution grids, primary consumers or loads may be connected between the MV phases and the neutral conductor. In these situations, the neutral used in the MV is the same for the LV loads, called a common neutral conductor. Breakage of the common neutral and its consequences – overvoltage, undervoltage, voltage imbalance - is analysed in [B1-0197(BR)]. The phenomena strongly depend on the type of distribution transformer, grounding resistance and load. Simulation of a representative distribution grid were performed. Overvoltage as a consequence of neutral MV breakage only occurs in very poor grounding and imbalance conditions. In the LV system, phase-to-neutral overvoltage up to 2 pu were observed.

Safety and Immunity
Residual current devices (RCD) are important for ensuring personal safety and protecting from electric shock in case of insulation failures. Reliable tripping as well as avoidance of undesired malfunction is essential. The authors of [B1-0060(SE)] studied the impact of quasi-dc (0 - 4 Hz) and supraharmomics on the tripping characteristics of different types of RCDs with the aim to identify fail-to-trip and false tripping conditions. There is a clear gap in standardization regarding the frequency components included in test signals. Presence of supraharmomics might cause that higher 50 Hz currents are needed for the RCDs to trip. Fail-to-trip situations have been identified for residual currents with frequencies other than 50 Hz. AC-type RCDs should be avoided in cases of half wave pulsating residual currents with and without superimposed distortion since they failed to trip.

In the modern grid different types of voltage disturbances in the power supply are expected due to the integration of renewable energy sources and electric vehicles. These voltage disturbances affect the luminaires lifetime and may lead to light flicker and failures of LED lamps. In [B1-0026(SE)] a literature review on LED life assessment by accelerated test methods is done. LED driver circuits are responsible for about 60 % of failures. Cost-effective solid-state driver circuits or driverless topologies capable of handling adverse stress conditions need to be developed. Appropriate accelerated tests with stochastic input such as fast voltage fluctuation due to EV charging, undervoltage and overvoltage due to EV and PV interactions etc. need to be developed for LED lifetime estimation.
Potential scope of discussion
There are still a lot of uncertainties in the field of grounding system engineering. Simplified assumptions about the soil characteristics are used, which might lead to expensive earthing designs to guarantee safety. In addition, the impact of global earthing systems has to be further investigated.

Table 1: Overview of papers in Block 1

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<thead>
<tr>
<th>Paper (No. and Title)</th>
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<th>RIF</th>
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<td>0026 LED Life Assessment by Accelerated Test Methods – a Review</td>
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<td>0060 Impact of Supraharmonics and Quasi-DC on the Operation of Residual Current Devices</td>
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<td>0197 Overvoltage Analysis in Low Voltage Consumers Caused by Neutral Conductor Opening in the Power Distribution Grid</td>
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<td>0238 3D Shielding Modelling and Design of Three Phase Current Limiting Reactances</td>
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<td>0258 Interpretation of Reduction Factor and Earthing Impedance According to EN 50522 Through Earth Fault Tests in a Medium-Voltage Grid with Low-Impedance Neutral Earthing</td>
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<td>0371 Effect of a Supplementary Return Path on Ground Return Current</td>
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<td>0632 Earth Resistivity Tomography for Earthing System Design</td>
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<td>0736 A Proposal for Performance Evaluation of Low Frequency Shielding Efficiency</td>
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<td>0838 Application of a Novel Cost-Effective Earthing Design Solution for Switching Stations with High Short-Circuit Power, Using an Integrated Methodology</td>
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<td>0884 Determination of Positive- and Zero-Sequence Components of Line Sections in Low-Voltage Networks Using Impedance Measurements</td>
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<td>0969 Decentralized Earth Fault Compensation in MV-Grids – Challenges and Solutions</td>
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<td>1057 Passive Loop Mathematical Model as a Reduction Method for Overhead Line Magnetic Field</td>
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I: interactive poster presentation
Block 2: “Power quality issues of new technologies”

Photovoltaic

In paper [B2–0013(SE)] the peak load balancing of PV by integration of EV with respect to its challenges like multiple converter interactions leading to grid instability issues, voltage distortion and variations, resonances etc. are discussed. Especially the parallel operation of multiple converters and the impact on stability in a low voltage DC system integrating EV, PV and a grid connected rectifier are investigated in a theoretical way from the rectifier perspective. The system stability was investigated with parallel operation of multiple converters and their control systems. The most critical component that can ensure stability is identified as the substation rectifier DC-link capacitance since it will enhance damping of a low frequency enabled stable operation. From simulations, it was identified that the voltage mode control operation is more robust compared to the current mode control in the studied interconnected system.

Paper [B2–0285(EG)] studies the characteristics of low order harmonics emission from 18 installed small-scale PV (SSPV) systems with different capacities and different inverters type. According to the Egyptian grid code for small-scale PV, the PV system output should have low current distortion levels to ensure that no adverse effects are caused to other equipment connected to the utility system. The results of the survey of harmonic emission level from these small scale solar inverters are presented. It is concluded that the total harmonic distortion of the current almost exceeded the maximum permissible limit of 5% due to active power injected by the PV inverters, which varies due to different conditions. Concerning suprathermonic emission in the range 2 kHz – 9 kHz, the dominant harmonic current was found at 2.7 kHz.

A methodology to regulate power factor in installations with solar self-consumption is discussed in [B2–0891(FR)]. Photovoltaic energy is a strongly emerging technology and excellent as sustainable energy source. Despite all benefits, PV installations may lead to power factor degradation. To avoid this degradation, an algorithm-based solution for PV inverters is presented. The purpose of the presented method is to define in real-time the optimal set points of the photovoltaic system to avoid excess reactive power charges, but also to maximize the active power input from the photovoltaic inverters, so that the end user can get the maximum from its local energy production system. The proposed method is purely based on analytics and do not require loop control systems. It allows to fix the power factor at the point of common coupling with high accuracy while maximizing the active power and injecting a minimum of reactive energy. It can be concluded that the proposed approach is cost-effective and does not require the installation of additional equipment for power factor correction but economic benefits should be evaluated case by case.

Wind

It is common knowledge that wind-power installations influence the waveform distortion in the surrounding network. Details and the challenges to avoid waveform distortion however are less well known. The contribution [B2–0028(SE)] summarizes the results from four consecutive projects with respect to the waveform distortion in and around wind-power installations. It is highlighted that high levels may
occur due to a number of reasons, since harmonics and wind-power installations are a complicated issue and it is still not possible to predict when and where high levels will occur. However, it can be concluded that harmonics are not a major issue with wind-power installations. High levels of harmonic currents or voltages occur rarely and there is no need for strict requirements on each individual installation. A building up of general knowledge on this subject and monitoring levels and trends are of major importance, since modelling challenges and simulation are at this moment no obvious solution.

Paper [B2–0184(SE)] verifies the fault-ride-through of wind turbines using two distinct characterization approaches to obtain synthetic dip profiles based on real measurements. The first approach is based on the CIGRE checklist, while the other approach considers only magnitude and duration as characteristics of the voltage dip. The aim of this comparison is based on the fact that most of the fault ride through studies do not consider the latter in their evaluation. The verification is done in a Swedish wind park on double-fed-induction-generator (DFIG) turbines. The result of this study shows that by considering the detailed characteristics of the voltage dip a lower difference in the dynamic behaviour compared to the simplified synthetic profile is obtained, since the simplified synthetic profile shows overestimation as well as underestimation of the dynamic behaviour during all the stages of the voltage dip.

Monte Carlo simulations and is validated by measurements from a single wind turbine. Using a single probabilistic harmonic generator and commercial software package for power system analysis, this paper proposes appropriate modelling ranges and distributions of the equivalent model parameters and then validates the equivalent model of the wind farm based on field measurements at the PCC bus. It is concluded that the simulation results using the developed model reflect a good estimation of the available field measurements. This equivalent model is therefore deemed to be suitable for the first level approximation of harmonic propagation and the identification of potential harmonic issues in power electronics rich networks.

**Battery storage**

Paper [B2–0263(UK)] analysis the possibilities for mitigating the voltage unbalance in rural low voltage networks using single-phase BESS inverters. Therefore single-phase load demands are modelled using real consumption data on 1-minute-basis, while voltage unbalance is quantified corresponding the IEC 61000-2-2 standard. The BESS units are modelled in detail including the main electrical components and the control system. It is assumed that the BESS inverters can deliver both active and reactive power in order to limit the unbalance in the network with respect to overload conditions. The used distribution network model is based on a German rural network and consists of 24 customers connected via cables and overhead lines to the distribution transformer. Unbalance is quantified as negative–sequence to positive-sequence voltage ratio. A 24-hour simulation is carried out to identify the hour with the highest voltage unbalance levels and subsequently a sensitivity analysis is carried out to investigate the impact of installing the BESS at different locations in the distribution system. The results of this analysis show that single-phase BESS units can effectively mitigate voltage unbalance in residential distribution networks.

[B2–0389(UK)] develops and validates an equivalent model of a wind farm for probabilistic harmonic propagation and mitigation studies in power electronics rich transmission or distribution networks. The used methodology is based on both probabilistic distributions and
Electric vehicles

Paper [B2–0202(EG)] illustrates both harmonic voltage and current distortion caused by electric bus fast battery charger while maintaining the standard limit of the IEC 61000-3-12. As it is shown, the measurements carried out at the PCC comply with the limits of IEEE 519-2014 standard. Next to that, also the frequency range of the currents from 2 kHz up to 9 kHz is analysed. The charger measurements at the PCC showed compliance of the total harmonic voltage distortion with the IEEE 519-2014 standard, even so the total current demand distortion for the eight chargers and cumulative percentage P0.99 were within the standard limits. Current analysis confirmed the typical 5th and 7th order harmonic, however the 7th was the dominant one. Analysing the impact of higher frequency components a maximum was found at frequency of 2.1 kHz but also a component at 5.1 kHz was observed.

The impact of fast-charging of electric buses on the power quality based on field measurement in the Netherlands is discussed in [B2–0252(NL)]. A pilot study has been performed in a major city of the Netherlands, where every day many fast and slow charging of electric buses takes place in the same bus depot, which can be considered as point of common connection. Since EV chargers are basically power electronic converters they are sources of both harmonics and suprapharmonics. Power quality analysis is performed in PCC and various PQ measurement results are summarized and discussed. Concerning low frequency disturbances such as harmonics, voltage variations and flicker, all parameters are within the limits of the EN50160. In addition, suprapharmonics who can create problems at specific frequencies especially in case of end users consumers gave no significant impact.

In paper [B2–0473(FR)] the results of a study carried out for a depot with a capacity of 200 electric buses are compared in terms of different electric distribution architectures and the equipment making up these infrastructures. An overview of centralized and distributed solutions both in DC and AC were analysed. Out of the detailed analysis of the bus depot it is concluded that a centralized architecture distributing DC voltage, using 12-pulse rectifiers gives the best compromise on both the technical and economic criteria. However, this topology has the limitation that it does not allow V2G operation, which requires active frontends based on IGBT rectifiers. The AC distribution is nowadays probably still the easiest solution to install, however, it is shown that it is the least attractive solution in terms of energy consumption and of capital expenditure costs, as it requires the purchase and installment of several cables of large sections.

The increasing number of battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs) in the low-voltage grid must be considered in future simulations and new grid designs. For this purpose, measurements of load profile curves of EVs are performed in order to analyse the influence on voltage quality characteristics such as unbalance, rapid voltage changes, flicker and harmonics. Paper [B2–0503(GE)] describes and discusses load profile curves of 13 electric vehicles of different brand and associated PQ parameters. For the majority of the EVs, a very shortened constant voltage phase of a few minutes (from max. power to zero) is measured. For two charging cycles the maximum unbalance limit due to VDE AR-N 4100 is exceeded. The effects of the EVs on voltage quality vary significantly between the different vehicle types.
In paper [B2–0835(GE)] the challenges for the distribution network operators due to the increasing penetration of battery electric vehicles on PQ issues in public low voltage networks is discussed. It is shown that the changes in boundary conditions for network planning in LV networks is affected. The high coincidence of charging of multiple vehicles, mostly in the evening, can create unusual high demand situations, especially due to the fact that many EVs are single-phase connected. As a result, an increasing voltage unbalance in the network is observed. Next to that, the power electronic based rectifiers of EVs can emit both significant harmonics and supaharmonics. Two comprehensive field studies, namely a distributed charging infrastructure with eight BEVs and a central charging infrastructure with 45 BEVs were carried out in two different public low voltage networks in Germany. It is concluded that voltage unbalance limit of customer installations should not be independent of the short circuit power at the connection point in order to improve the utilization of hosting capacity, while low order harmonic and interharmonic currents are observed.

A survey of harmonic and supraharmonic emission of fast charging stations for electric vehicles in China and Germany is presented in [B2–1151(CN)]. Due to the massive integration of EVs there is the need for charging stations. Especially, in case of fast charging stations, DC chargers are used but not that much is known yet about their emission characteristic. The measurement results of 20 different chargers obtained from both China as well as in Germany are summarized and findings are discussed with focus on harmonic and supraharmonic emission up to 50 kHz. The analysis of the harmonic emission was limited to those time intervals where the highest charging currents occurred. It can be concluded that for power ratings up to 50 kW German chargers tend to have higher emission at odd harmonic orders than the Chinese chargers, while 5th and 7th harmonic current are the predominant harmonics in both countries.

LED lighting systems

The deviation from linear summation law for large number of homogeneous LED lamps is analysed in paper [B2–0072(SE)], where high energy LED lamps are studies with the aim to quantify the deviation of a linear increase from both harmonic deviation factor and aggregation exponent perspective in the frequency range up to 2 kHz. Therefore, measurements are performed in an installation with lamps of the same brand and type. After warming up, both current and voltage waveforms are recorded for each measurement and the harmonic spectra are obtained using DFT in Matlab, where each individual harmonic order is obtained as a function of number of lamps. It is experimentally shown that for large number of homogeneous LED lamps aggregation can lead to both underestimation and overestimation of aggregated harmonic emissions. This is valid for all harmonic orders. Since the lamps are not exactly the same, the differences between individual lamps generally increase with harmonic order. In general, however for same
LED lamps the linear summation law will give reasonable results.

Increased harmonic emission challenges nowadays equipment function especially in case of LED lamps, e.g. by causing undesired light intensity variation. Paper [B2–0461(SE)] studies this phenomenon deeper by analysing the harmonic impacts on LED drivers. Therefore, experimental studies are carried out where instantaneous light intensity, average light intensity, DC-link voltage and modulation depth, are investigated for different harmonic magnitudes, phase angle and harmonic orders. For testing of LED drive circuits, 1 %, 3 %, 5 % and 7 % individual voltage harmonics from 5th to 11th are applied. Results show that the existence of harmonics results in deviations in the light intensity depending on the phase angle and harmonic magnitude. This indicates that the sudden changes in harmonics can lead to variation in the average light intensity. If this variation is in the range of human visibility sensation, it results in temporary light flicker.

LED lamps with a power rating greater than 5 W need to fulfil the requirements as described in e.g. IEC 61000-3-2, EN 62612 and IEC 61000-4-13. Standardized test conditions can deviate from real environments and real grid conditions and a distorted grid voltage can significantly change the magnitude of the harmonics being injected by non-linear loads. The paper [B2-0077(SE)] discusses, how the term aging process in LED lamps affects the harmonic emission and how voltage distortion can affect the aging process. A total of 1080 LED lamps are being subjected to six different voltage profiles, going from undistorted grid over background distortion and voltage variations during 6500 hours while their performance in terms of current quality has being monitored. Even if the groups consist of identical lamps, there is a difference in the harmonic profile between the different setups, which is most pronounced for the higher order harmonics. It can be concluded that long-term aging seems to have a decreasing effect on the harmonic emission from LED lamps. However, the background voltage profile is seen to have an impact on the current harmonic emission, which is well known. The LEDs directly fed from the grid showed the largest decrease in current THD.

Further aspects

Paper [B2–0048(SE)] discusses interharmonics under fundamental frequency variations due to sustainable, new technologies. Different interharmonic patterns are observed in a number of sustainable energy sources and loads with respect to the signal processing of interharmonics of non-stationary signals. They are evaluated especially from the viewpoint, if these are real or just created by signal processing error and consequently misinterpreted as interharmonics. Case studies are performed on a wind farm, a PV inverter and a single-phase AC EV charger. Short time Fourier transform algorithm, desynchronized processing techniques and sliding-window ESPRIT are applied to the signals. From the specific case study of wind farm, it is shown that the jumps in phase angle are caused by transitions between reactive and active power and consequently are a transient phenomenon. Such events are manifested in signal processing as broad fundamental frequency deviations and subsequent interharmonics that are a product of the signal processing. As a conclusion, it is important to observe the time domain waveforms and not blindly trust the frequency domain.

In contribution [B2–0132(EG)] two fault-ride-through protection schemes for mitigating the effect of voltage to ground fault on a grid-connected double fed induction generator (DFIG) coupled to a wind turbine are examined by combining both the profiles of the stator and rotor voltages and currents and the dc link voltage and current. By relating this to the electrical torque and rotor speed, both sub and super synchronous speed are compared in order to have a better performance of the DFIG operation during unsymmetrical voltage to ground faults. It is shown, that the STATCOM
connected to the DFIG stator, while a three phase external impedance is connected to the rotor circuit result in high ripples at super-synchronous operation range. Other protection schemes, such as the DVR and the UPFC are suggested to improve the machine performance at super-synchronous speed.

![Stator voltage and current with STATCOM and three-phase RL impedance only during faults](image)

Fig. B2-9: Stator voltage and current with STATCOM and three-phase RL impedance only during faults [B2–0132(EG)]

An assessment of frequency-dependent component impedance for harmonic stability is discussed in [B2-0181(GE)] based on experimental investigations gathered out by laboratory tests using commercial single-phase inverters. It is shown, that analytical aggregation of multiple inverters at a centralized connection point is only is possible, if the individual impedances of all inverters are known and there is no mutual interaction. In the context of future standardization, type and amplitude of excitation voltages over a wide frequency range should be considered.

Paper [B2–0305(GE)] analyses the harmonic characteristics of a microgrid, which is composed of a single PV inverter, a battery charger and a number of household devices both from the type linear and non-linear. The aim of this study was to analyse different load scenarios under both interconnected and islanded operation from voltage and current harmonic distortion perspective. With the comparison between the islanded mode and interconnected operation, a detailed analysis of impact of power share between multiple power electronic generation sources is analyzed with the aim to provide a holistic perspective towards EMC coordination and standardization for islanded microgrids. It is concluded that the voltage distortion is higher in islanded operation mode than in interconnected mode due to the higher network harmonic impedance of the microgrid. Depending on the amount of non-linear loads and installed power, harmonic distortion might exceed the IEC compatibility levels.

![Voltage harmonics for load scenarios measured in interconnected (ICM) and island (ISM) mode](image)

Fig. B2-10: Voltage harmonics for load scenarios measured in interconnected (ICM) and island (ISM) mode [B2–0305(GE)]

A bang-bang controller for enhanced islanded microgrid frequency stability is discussed in paper [B2 – 0379(AT)]. In contrast to distribution grids, islanded microgrids have a low inertia, especially in case of a high penetration of power electronics. Consequently, conventional frequency control has to be improved. A novel control method, including load step pre-announcement (LSP) and bang-bang (BB) controller is used to reach this goal, since frequency disturbance caused by them does not create an instability issue. A simulated islanded microgrid consisting of a conventional generator, PV infeed and a lumped load is used as a study case. The simulation results illustrate that the dynamic frequency behaviour is significantly improved using the proposed control method with optimal settings of pre-set and total time for both 25% and 50% share of PV. The performance of the proposed controllers strongly depends on pre-set and optimal time settings.

Contribution [B2–0479(SE)] discusses the future impacts on grid from both energy flow and power quality perspective based on the growing need for data centres and their power consumption. Since a data centre can consume up to 1 MW, insight on their impact in terms of power quality on the grid, especially with respect to the increased use of renewable energy sources such as wind and PV, is needed. In this paper, six sets of measurements from high voltage over medium voltage to low voltage were obtained in Sweden. Based on the analysed data, no energy deficiency has been observed in the area. However, as data centres will grow in the future and power production from renewable energy
sources will increase, data centres will become more sensitive to changes in both harmonic emissions and power variations. The impact of data centres on the magnitude of aggregated harmonics at MV can lead to both a reduction or an increase in harmonic content. On its turn, higher current distortion can lead to increase in energy losses in the system, albeit the losses are rather low when compared to the power transfer losses in transmission and distribution.

The development of test methods for the investigation of the stability of inverters in low voltage grids with relation to reactive control is presented in [B2–0487(GE)] by experimental investigation of the behaviour of three inverters. The evaluation of the influence of grid impedance and the steepness of the Q(U)-relation on the control stability is investigated by analysing the difference of RMS values and the mean value of the voltage. Since the effect of the reactive power on the voltage in the network increases with increasing inductivity, an increased distance between connection point and transformer can lead to instabilities in the system. The investigated criteria show that an increased slope of the Q(U)-relation in combination with a decreased R/X-ratio may lead to problems with power quality.

Paper [B2–545(PT)] assesses the power quality of emergency generator units. Hence emergency generators and mobile power are usually not used for normal grid operating conditions, power quality related issues should still be met in order to provide optimal supply quality to the customer. Next to that, the distribution network operator must always comply with the EN 50160 standard. An analysis of different types of emergency generators and mobile power plants operated by E-REDES were assessed with respect to the compliance of the power quality standards corresponding with the NP EN 50160. Due to the short operating duration, it was not possible to fully conclude, if the supply voltage is in accordance to the NP EN 50160 standard. Although, it was possible to have an image of the overall quality of service provided by this type of assets. It was concluded that the monitored emergency generators voltage characteristic values where within the NP EN 50160 limits, even in cases where load variations were most pronounced. The overall performance of these assets was very good.

Paper [B2–0886(CZ)] is focused on the advanced design of responsive demand control into heat accumulation for energy management for prosumers. The approach is implemented in installations with a small-scale power generating unit in order to provide real equilibrium between electricity generation and consumption. Current and novel power flow control strategies are compared with regards to both power quality issues and energy measurements with standard meters. Finally, the total cost of installation are compared with respect to different topologies of power converters. From experimental results, it is shown that even though the performance might be improved using different topologies, universal devices cannot provide sufficient switching frequency and thus the cost of corrective and/or mitigating devices is still high. Specialized solutions providing sufficient switching frequency are worth to be developed in order to reduce the relative cost of compatible solutions.

Paper [B2–1106(UK)] describes techniques that have been used to pinpoint the root cause of tripping, overheating and harmonic distortion linked to solar arrays and to prevent recurrence. The techniques presented include both power quality measurements, residual & stray current measurements and earthing tests since most inverters will exhibit some degree of natural ‘leakage’. This tends to be related to the DC leakage of the system transferred across to the AC side, where standard 30mA RCDs (residual current devices) may experience nuisance tripping, particularly in wet weather. This issue is not only seen in domestic solar installations, but also in large solar arrays mainly due to leakage to earth through cabling and from PV panels to earth. A number of techniques which have been used to good effect to identify the sources of problems on solar and other generation sites are evaluated.

Fig. B2-11: Typical PV system showing current flow paths [B2–1106(UK)]
Potential scope of discussion
Upcoming integration of storage systems will or can reduce PQ problems in the grid, especially related to mitigation of unbalance and overvoltages caused by renewable energy sources. However, due to the upcoming grid flexibility with the aim to increase local hosting capacity, unbalance, flicker and both low and higher frequency disturbances (supraharmonics) in the grid may increase. In combination with the upcoming integration of EVs, the distribution networks will be massively affected, much more than nowadays by PV inverters. It is recommended to analyse and monitor charging stations from both stationary batteries and EVs in order to obtain sufficient information for a reliable assessment of their impact on both hosting capacity and power quality related issues.

In contrast to former CIRED conferences, the interest for the impact of wind turbines is rather low and shifted mainly to the study of massive integration of LEDs and the upcoming challenges of the integration of EVs in terms of their impact on power quality. However, renewable energy power plants still may have a significant impact on power system operation, such as voltage variations, unbalance and flicker effects. In addition, intensified monitoring and publication of results is recommended.

As mentioned before, LED technology is massively increasing in modern electricity distribution networks both in residential installations and public lighting. Due to their technology, power electronic converters are needed to control these types of lamps, creating various harmonics profiles and causing negative impacts on electrical equipment in electricity distribution networks. Future evaluations of the massive integration of this type of loads and their interaction with both linear and nonlinear loads and sources need to be monitored and followed up.
Table 2: Overview of papers in Block 2

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<th>Paper (No. and Title)</th>
<th>MS</th>
<th>RIF</th>
<th>PS</th>
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<tr>
<td>0013 Design and stability of a low voltage DC system integrating EV with PV</td>
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<td>0028 Harmonics and wind-power installations – findings and recommendations</td>
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<td>0048 Interharmonics under fundamental frequency variations</td>
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<td>0072 Deviation from linear summation law for large number of homogeneous LED lamps</td>
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<td>0077 Power quality during aging of LED lamps</td>
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<td>0132 Simple Scheme to Mitigate The Effect of Unsymmetrical Voltage Sag on Double Fed Induction Generator</td>
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<tr>
<td>0181 Experimental measurements of frequency-dependent component impedances for harmonic stability assessment</td>
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<td>0184 Comparative Analysis between a Measured Voltage Dip and its Equivalent Synthetic Dip on the Dynamic Behavior of a Wind Turbine</td>
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<td>0202 Harmonic Distortion Caused by Electric Bus Battery Charger in Alexandria Distribution System</td>
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<td>0252 Determining the impacts of fast-charging of electric buses on the power quality based on field measurement</td>
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<td>0263 Mitigation of voltage unbalance in rural low voltage networks using single-phase BESS inverters</td>
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<td>0285 Survey of Harmonic Emission Level from Solar Inverters</td>
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<td>0305 Waveform distortion characteristics of an islanded microgrid with residential loads</td>
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<td>0379 Optimizing load step pre-announcement and bang-bang controller for enhanced islanded microgrid frequency stability</td>
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<td>0389 Validation of the Equivalent Model of Wind Farm for Probabilistic Harmonic Propagation Studies</td>
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<td>0461 Interferences in LED lamps due to Harmonic Distortion</td>
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<td>0473 How to choose the best electric network for a large electric buses depot</td>
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<td>0479 Future impacts on grid: energy flow and power quality</td>
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<tr>
<td>0487 Development of test methods for the investigation of the stability of inverters in low voltage grids</td>
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<td>0503 Measurement of the voltage quality and load profiles of electric vehicles</td>
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<td>0545 Impact of high penetration of battery electric vehicles on power quality in public low voltage networks</td>
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<tr>
<td>0835 Impact of high penetration of battery electric vehicles on power quality in public low voltage networks</td>
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<td>0886 Advanced Design of Responsive Demand Control into Heat Accumulation for Energy Management of Prosumers</td>
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<td>0891 Methodology to regulate power factor in installations with solar self-consumption.</td>
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<td>1106 Advanced techniques for troubleshooting solar arrays and generator connections</td>
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<tr>
<td>1151 Survey of harmonic and supraharmonic emission of fast charging stations for electric vehicles in China and Germany</td>
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I: interactive poster presentation
Block 3: “Power quality measurement, analysis and mitigation methods”

This block contains papers dealing with simulation-based and/or measurement-based studies dedicated to different power quality phenomena and disturbance cases. It further covers methods and devices to mitigate network disturbances. Finally, papers discussing different aspects of instrumentation and measurement are allocated to this block.

The dominating share of papers is dedicated to medium and low voltage networks. Several papers address also high voltage networks, which underlines the fact that power quality is a system issue not only limited to a certain voltage level or the distribution network.

55% of the papers deal with simulation of harmonics (frequencies below 2 kHz) and supraharmonics (frequencies above 2 kHz), which are also referred to as higher frequency distortion. The number of papers addressing each frequency range are almost balanced. Many of those papers studying the impact of frequency-dependent impedance on interaction and propagation of distortion. Only about 11% of the papers are dedicated to other power quality phenomena, namely flicker and sags, presenting a good diversity between simulation-based and measurement-based papers. Another 17% of the papers are dedicated to mitigation devices and control techniques for those devices as well as one mitigation case study. The remaining 17% of papers are almost exclusively related to the impact of the frequency-dependent transfer characteristic of instrument transformers on the accuracy of distortion measurements. As this subject seems to attract particular attention in the community, it has been decided to dedicate the RIF (research & innovation forum) exclusively to this topic.

Compared to the conference two years ago, distortion and related topics like resonances and network impedance remain important in this year’s conference. Particular the number of papers addressing the frequency range 2-150 kHz has increased significantly. On the other hand, the interest in other power quality phenomena including voltage sags is not as high as at conferences before. Topics related to power quality measurement instrumentation itself almost disappeared for this year’s conference. Contrary, the accurate measurement of distortion below and above 2 kHz in MV distribution networks obtained much more attention compared to former conferences.

Harmonics and interharmonics

Nine papers in Block 3 are dedicated to different aspects related to harmonics. Beside one dedicated interference case study and two papers about measurement surveys, all other papers are focused on modelling and simulation. Most of these papers look in particular on harmonic impedance, which forms the link between harmonic currents and voltages.

[B3-0748(PT)] investigates an incident, where an HV system has been tripped by an EHV/HV transformer due to elevated 5th harmonic. At the time of tripping, a second power transformer was energized in parallel, while restoring normal grid operation after reconfiguration for commissioning works. Based on an EMTP simulation it was found that a sympathetic inrush of first (tripped) transformer caused by the inrush of the second transformer resulted in a high harmonic distortion in the zero-sequence voltage component on the HV side, which in turn excited an existing zero-sequence resonance between the transformer and the extensive underground cable network. A reconfiguration of the HV network is proposed to shift the resonance between two harmonics, which can decrease the disturbance levels significantly. Furthermore, the settings of more than 6000 earth-fault protection relays has been checked to ensure that only current fundamental is used as tripping criterion.

[B3-0351(SP)] is one of two papers dealing with measurement surveys in LV networks. Odd harmonic currents up to 25th order has been measured in 15 different homes for almost one year. Besides a statistic of the homes itself in terms of size, number of inhabitants and additional information about the penetration of homes in Spain with electric appliances, the paper presents a comprehensive statistical analysis of 3rd, 5th, 7th and 9th harmonic in terms of magnitude and phase angle. Magnitude cannot be modelled by simple normal distribution, but requires more complex representation, e.g. by mixture distribution. While 3rd and 5th harmonic current clearly show a prevailing direction, the phase angle of 7th and
9th harmonic become increasingly random and wider spread. Finally, the volatility in terms of minute-to-minute transition has been analysed. Results show a dominating share of transitions being for all harmonic orders below 1% in magnitude and 5° in phase angle.

Fig. B3-1: Boxplot for harmonic current magnitudes at different measured sites [B3-0351(SP)]

[B3-0137(SE)] reports results of a measurement survey performed at the terminals of three homes, an office building and a university campus to characterize the unbalance in harmonic voltages and currents. All analyses are performed in sequence components and a definition of balanced and unbalanced THD is introduced for further discussion. The results confirm that considerable unbalance exists for all harmonic orders, as for each harmonic next to the prevailing sequence component (balanced component) also the non-prevailing sequences (unbalanced components) do exist with non-negligible magnitudes. However, the balanced components do usually dominate. An important observation is that for triplen harmonics the ratio between unbalanced and balanced components is usually higher than for the non-triplen ones. This is valuable input, i.e. for further discussions about calculating current emission limits for LV installations.

Fig. B3-2: Comparison of simplified method with the full analysis for Vores Elnet grid [B3-0440(DK)]

[B3-0135(SE)] applies the transfer function method as tool to evaluate the harmonic emission of a wind park. In particular, the method is used to analyse the interaction between different turbines as well as between turbines and the grid. For this purpose four different combinations of considering MV cables and LV customers have been considered (I: no cables/no LV cust.; II: no cables/LV cust. of single feeder; III: with cables/LV cust. of single feeder; IV: with cables/LV cust. of whole MV network). A three-turbine wind park of 2 MW is used for illustrating the application of the methodology. MV cables and other LV customers do not significantly affect interaction between turbines. In addition, they have no significant impact on the voltage distortion at turbine terminals for frequencies below the first resonance. However, at higher frequencies they can affect the overall transfer impedance characteristic significantly in terms of magnitudes and resonances.

[B3-0440(DK)] proposes a method to estimate the harmonic network impedance in HV networks as basis for calculating emission limits. It is a trade-off between the very simplified extrapolated impedance based on short-circuit power and a full system study for the determination of the worst-case impedance locus. It still requires a network model, but does not consider any possible switching states in the upstream network anymore. Based on the impedance scan of the simplified network and a reasonable margin introduced by a floating maximum based on a frequency width of 200 Hz, the harmonic impedance is calculated. The method is illustrated using three radial networks as example. The authors identify applicability to meshed networks as future scope.
[B3-0152(SE)] presents a stochastic aggregate representation of downstream LV networks to study harmonic impedance characteristic in MV networks taking uncertainties due to varying impedance characteristics of downstream networks into account. The methodology is applied to two Swedish MV networks to study the frequency-dependent impedance characteristic in the MV network. The results show that in the MV networks the first resonance appears at rather low frequencies (in one of the networks even below 50 Hz) and the variance of magnitude can vary in large ranges, while at frequencies higher than the first resonance the variation is much smaller. The authors emphasize that customer impedance model itself is a particular uncertainty, which requires further attention.

[B3-0462(DE)] studies the network harmonic impedance and the aggregated customer-side equivalent impedance at the LV busbar in LV networks depending on different realistic combinations of common household appliances. Three different scenarios in terms of time of the day (I: low demand, II: average demand, III: high demand) and in terms of evolution stage (A: past, B: present, C: future) are distinguished considering both an urban and a rural LV network. The results confirm that the particular customer configuration has a significant impact on the network harmonic impedance in LV networks. Furthermore, the increasing share of modern power electronic equipment increases the probability of resonance with a tendency to lower frequency of first resonance.

[B3-0248(JP)] develops a methodology to include grid-connected inverters in frequency domain simulations for harmonic studies. The inverter is split into the filter part and control part, which both will influence the harmonic impedance and consequently the propagation of harmonics. While the filter-part can directly be added to the system admittance matrix, respective formulations are provided on how the control is included. The proposed methodology is finally applied to study the impedance characteristics in a one-inverter and a two-inverters scenario as well as the disturbance levels resulting from the emission spectrum of an additionally connected 6-pulse-rectifier. As expected, the impedance characteristics differs significantly between the scenarios and due to the introduction of additional resonances, an amplification of harmonics is observed compared to the reference scenario without inverters.

[B3-0566(DE)] is also focused on modelling of individual devices, but from the perspective of including the model in real-time simulations (hardware-in-the-loop systems). The presented method is based on the identification of the coupled Norton equivalent (CNE) and follows a Black Box approach. This has the advantage that the method can be applied to any equipment without detailed knowledge about circuits and control. The harmonic current response of the model is updated in real time depending on the
applied supply voltage. This is only possible for (Black-Box) frequency domain models, as (White-Box) time domain models would require too long simulation times. The method is validated in a lab environment consisting of a programmable amplifier as source, a network impedance and a hardware-in-the-loop simulator simulating a radial fan as device under test.

**Supraharmonics (2 kHz – 500 kHz)**

This sub-block includes seven papers dealing with different aspects in the frequency range from 2 kHz mainly to 150 kHz, but also up to 500 kHz. The frequency range between 150 kHz and 500 kHz includes the FCC band, which attracts increasing attention to be used for power line communication (PLC) applications. While three papers are focused on modelling aspects in LV networks, three papers study the particular interaction between converters and grid as well as between converters. This is complemented by one paper analysing the propagation of supraharmonics in MV networks.

[B3-0101(BE)] introduces a methodology for efficient (analytical) modelling of supraharmonic propagation in LV networks. It represents each element of the network by three chain matrices representing positive-, negative- and zero-sequence. Modell implementation for LV cable, MV/LV transformer and upstream MV grid as well as for single- and three-phase disturbance sources are explained in detail. The analytical (equation-based) implementation is much faster than any time domain simulation based on White-Box models. The application of the proposed methodology is illustrated by an example where a disturbance source (three-phase and single-phase) is connected at the end of a long cable. The results show that both damping and amplification of emission is possible in upstream propagation and that a significant difference exists between three-phase and single-phase sources.

[B3-0469(FR)] presents a new, simplified method to obtain the transfer function in the frequency range from 9 kHz to 500 kHz between any two nodes in a network using the voltage ratios between the nodes. The comparison with two other approaches (circuit-based and ABCD-matrix-based) for a single cable shows a good match between simulations and measurements. The new method provides a simple way, e.g. to characterize the transmission channel for PLC communication applications, which is important in case of solving transmission issues.

[B3-0343(BE)] focuses specifically on the modelling of LV multi-conductor cables in the frequency range 2 kHz to 500 kHz. Three different techniques, namely four-terminal sensing, time-domain reflectometry and impedance measurements are used to identify the parameters of a four-conductor transmission line. The authors show, how the techniques complement each other in determining the model parameter values, which can simplify the transmission line model identification considerably. The methodology is demonstrated for two different types of cables and two different lengths. The results match well with the expectations.

[B3-0073(SE)] presents the study of supraharmonic currents in an installation consisting of two emission sources, namely multiple LED lamps (42-52 kHz) and a PV inverter (16 kHz), as well as different neighbouring devices (e.g. heat pump, water cooker) without supraharmonic emission. The neighbouring devices as well as the MV/LV transformer are connected via cables, for which the lengths were varied. Measurements have been carried out over longer time intervals in
order to study the impact of different grid conditions to the supraharmonic currents. The results confirm that impedance configuration significantly determines the propagation characteristic. In presence of a weaker grid, less supraharmonic current flows to the network. The supraharmonic current to neighbouring devices also tends to decrease if the electrical distance between them increases.

![Characterization of SH variations](image)

[B3-0112(SE)] studies the interaction of multiple converters focused on both AC and DC data centre applications with main focus on the beating effect, which is caused by slight difference between the switching frequencies of multiple converters. The paper simulates a “two source” environment with switching frequencies being 20 kHz and 20.01 kHz. Beating is clearly observed both in AC and DC application. One major outcome of the simulations is that the electrical distance between the two sources has a significant impact on the beating amplitude, which decreases exponentially with increasing length of cable between the converters, but converges to a constant value.

[B3-0723(JP)] models the impact of grid-connected inverters on the voltage disturbance levels in the MV network considering the frequency range 3 - 10 kHz. In case the switching frequency is close to the series resonance frequency of the system (about 6.2 kHz in the example), a significant amplification of voltages is observed. In a two-inverter configuration, the authors observe also the beating effect as studied in the previous paper. As the simulations have been performed without any further loads connected, the amplification is expected to be lower in real-world scenarios. The voltage magnitude at the emission frequency is not doubling from one-inverter to two-inverter scenario, which results from the different impedance conditions seen by one inverter between the two scenarios. This also confirms the findings of other papers that particular in the frequency range 2-150 kHz impedance configuration has a significant impact on the propagation of emission, even in the MV network.

[B3-0023(SE)] studies the propagation of supraharmonics in MV networks. Driving point impedances at different nodes and transfer impedances between nodes are analysed based on the detailed implementation of an existing 11 kV distribution network with eight feeders in MATLAB/Simulink. LV networks are included by a series circuit of models for the MV/LV distribution transformer and a lumped model of the LV customers. The impedance characteristic shows many narrow peaks in the supraharmonic range and differs significantly between feeders. Skin effect of MV lines has a significant impact on the magnitude of these resonance peaks. The impact of LV customers on the MV network is limited to the lower frequency range of up to 5 kHz. Finally the number of MV feeders itself has a significant impact on number of resonances and impedance magnitudes.

![MV Test Network Frequency Scan at Node 101](image)
Other power quality phenomena

Only three papers study power quality phenomena other than distortion. While one paper deals with flicker, two papers study voltage dips, one paper from system perspective and one paper from customer/load perspective.

[B3-0290(AT)] uses a realistic large-scale MV distribution network model and develops respective flicker emission models of upstream HV network and connected customers in order to simulate the flicker levels in the MV network. The authors introduce different customer groups (e.g. household, agriculture, photovoltaics) and quantify their flicker emission by a flicker emission coefficient. A probabilistic simulation is performed to obtain the time characteristic of flicker levels at particular nodes in the MV network for a month. Simulations and measurements show a good match, proving that large-scale simulation of flicker levels is possible. The authors note that the parametrization of emission sources is still improvable.

[B3-0232(CN)] introduces a new index to evaluate the sag severity in a system individual for different regions. Therefore, all sag events of the system are divided into different clusters in terms of duration. For each cluster, the median of residual voltage is calculated. The region-specific index is obtained by calculating the average of all distances of sags in the considered region being lower than the respective (system) median line. The index aims to help utilities to evaluate the sag severity not only for a whole system, but also individually for different regions in the system, which might have different requirements in terms of sag performance. The application is demonstrated by using about one year sag data from a large Chinese city divided into 10 regions.

[B3-0961(US)] highlights the fact that not every voltage sag will affect customer operation. Consequently, it is important to distinguish between disruptive and nuisance events in terms of more focused/prioritized filtering and reporting of alarms. The authors propose to analyse the time characteristic of RMS voltage together with the time characteristic of active power, both calculated cycle by cycle and updated each half cycle. In case a load loss is detected, the event is identified as possibly disruptive. This way an automatic classification of sags is possible with regard to its impact on customers and manual tagging is not required anymore. Results can easily be visualized by colours in the voltage magnitude vs. duration plot.

Mitigation

This sub-block contains five papers. Besides a mitigation case study for flicker, the suitability of passive filters for harmonic mitigation is discussed. Three papers deal with improved control techniques for FACTS devices.

[B3-0287(EG)] analyses the flicker levels generated by a stainless steel factory with an electric arc furnace of 72 MW, which is connected via two lines from a 69 kV substation. Even with mitigation equipment installed at the steel plant, customers connected to the supplying substation suffered from flicker interferences. The authors carried out measurements in order to evaluate the flicker propagation and to recommend suitable
additional mitigation. It has been found that the grid code requirements are significantly exceeded with long-term flicker severity being about 1.0 at the substation in two- and single-line operation (limit: 0.6). At the connection point of the steel factory, long-term flicker severity levels amount 3.1 and 4.2 respectively. The utility finally decided to accept the violations at the connection point of the factory, but separated all other customers.

The authors of [B3-1037(BR)] study the feasibility of passive harmonic filters under the aspect of the increased cost reduction of active filters using an industrial pulp and paper plant as example. A simulation has been developed to study the efficiency of the designed passive filter. Together with Dy transformers to connect to the MV system, the distortion in the industrial plant can be reduced significantly with just one filter tuned to the 11th harmonic from THD values in the voltage of up to 9.7 % to values not exceeding 0.9 %. In any case the authors emphasizes that detailed simulations shall always accompany the filter design.

In [B3-0309(EG)], a decoupled stationary reference frame PLL (phase locked loop) is proposed to make the sag/swell detection in a dynamic voltage restorer (DVR) more robust in presence of unbalances in the supply voltage. The theoretical background is provided and the difference to the simpler PLL without separate (decoupled) evaluation of positive and negative sequence is described. Time-domain simulations show that the simpler PLL under unbalanced voltage conditions results in a constant fluctuating error in the fundamental frequency estimation, which does not appear for the proposed decoupled PLL. [B3-0422(EG)] proposes an enhanced and more robust control scheme for a static var compensator (SVC) as used in wind energy conversion systems. A more sophisticated model reference adaptive PI controller (MRAPI) replaces the traditionally used PI controller. Controller parameters are obtained by applying a Teacher learning based optimization algorithm. A simulation-based case study of a 22 kV wind park with three turbines shows the better performance of the new controller for sudden change in wind speed and load.

[B3-0139(EG)] deals with the improvement of the traditional used PI controller for a unified power flow controller (UPFC), which is used for improving power flow and voltage levels in a network. The authors introduce a fuzzy logic controller (FLC), whose parameters are optimized using harmony search algorithm. The improved performance is demonstrated using a Simulink implementation of the IEEE 15 bus system including a 1-MVA-UPFC. The presented results suggest that a further slight improvement is achieved with the proposed controller in terms of voltage profile, power flow and losses in the test system.

Measurement aspects
This sub-block contains five papers, where one paper deals with measurement accuracy of power quality instruments. Four papers study the frequency dependent transfer characteristics of MV voltage transformers and discuss different invasive and non-invasive methods for its identification. [B3-0945(DE)] provides in its first part a detailed description of a software package, developed by the authors, to perform harmonic load flow simulations. A comparison between the developed package and two commercial network calculation packages is provided. Significant differences have been observed in the results of one commercial package. In the second part, the authors investigate the impact of different parameters of a measurement instrument, like resolution of A/D-converter or sampling rate on the accuracy of harmonic measurements using the respective IEC standard implementation by a Monte-Carlo-simulation. The choice of the window function for the Fourier transform has been found to have the most significant impact.
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Fig. B3-11: Result of the correlation analysis for a PQI with variation of the whole state space for all parameters [B3-0945(DE)]

[B3-0765(IT)] introduces the European project IT4PQ, which runs in the framework of EMPIR (European Metrology Programme for Innovation and Research). One of the objectives is the study of the behaviour of the frequency response of voltage instrument transformers (VT) and current instrument transformers (CT) for MV application in order to support the activities in IEC TC38 to include respective requirements in future standards. Power quality parameters that can be influenced by instrument transformers are summarized and reference setups for the laboratory measurements are described. External influence parameters on the frequency response are identified and it has been shown that electric fields can have a significant impact on the measurement accuracy of low power voltage instrument transformers.

[B3-0369(GB)] studies the frequency response of five MV VTs in the laboratory under different secondary burden conditions. It has been found that in the considered frequency range up to 5 kHz significant resonances can exist, which cause ratio errors of up to 80 % and phase angle shifts up to 85° at certain frequencies. The authors emphasize that for characterizing a VT for possible calibration of harmonic measurements, it is essential to reproduce the in-situ burden at the final location as best as possible.

The authors of [B3-0230(AT)] use a standard testing device for Sweep Frequency Response Analysis (SFRA) to determine the frequency response of MV and HV VTs. The device has been modified in terms of its input impedance in order to achieve a good comparability with reference measurements. The main advantage of the device is its small size and weight, which enables frequency response measurements almost anywhere in the field. The device has been used to measure the frequency response of 47 MV and HV VTs. The results for the MV VTs are shown in Fig. B3-12 in terms of the relative application bandwidth for different acceptable ratio errors. The application bandwidth defines the maximum frequency up to which a harmonic voltage can be measured with a ratio error less than or equal to the specified one.

Fig. B3-12: Application bandwidth of medium voltage VTs determined with 1 MΩ SFRA [B3-0230(AT)]

While the measurement methods described in the former papers required the individual VT with primary and secondary side not connected in order to apply a generated frequency sweep, the authors of [B3-0216(DE)] developed an in-situ applicable method to identify the frequency response of MV VTs solely by connecting a standard PQ instrument with switchable burden. Ambient temperature can significantly impact the frequency response characteristic of a MV VT (e.g. it can shift the resonance by several hundreds of Hz) and has to be taken into account in case of a calibration. Therefore the authors propose a continuous monitoring technique, which in a first stage identifies the temperature-dependent frequency response of the VT in order to train an artificial neural network. This is implemented into a power quality instrument and enables a reliable real-time compensation of MV VT ratio errors.
Potential scope of discussion
Similar to the conference two years ago the accurate determination of frequency-dependent impedance remains a big challenge both for the frequency range below 2 kHz (harmonics) but especially for the frequency range above 2 kHz (supraharmonics). The accurate representation of customers at LV level covering the large diversity of appliances as well as the largely varying usage behaviour requires probabilistic modelling approaches, which still need significant further research.

The increasing importance of the frequency range above 2 kHz is also reflected in a significantly increased number of papers compared to the conference two years ago. While some reliable knowledge exists for the LV network up to 150 kHz, the need for studying the propagation towards the MV network as well as the extension to 500 kHz including the FCC band has started just now.

Nowadays, harmonic emission limits for larger customer installations are usually calculated by assuming balanced conditions. Recent research has shown that such assumptions do not hold true and particularly in LV networks triplen harmonics do not exclusively form zero-sequence systems. How these new findings affect the derivation of emission limits in the planning stage as well as the measurement-based determination of the customer emission in the operation stage has to be intensively discussed.

Another important aspect in power quality evaluation is the need for critical review, if established indices properly reflect existing and newly upcoming interference mechanisms. Furthermore, the link between disturbance levels and real impact on customer equipment and how to identify it, must gain higher importance in the future.

In terms of measuring power quality, in particular distortion, the accuracy of the whole measurement chain, which in most cases also includes external sensors has to be taken into account. Especially “traditional” instrument transformers have been designed for high accuracy at power frequency only and can exhibit high measurement errors for harmonics or supraharmonics. Beside the application bandwidth, which is commonly used to describe their suitability for distortion measurements, calibration procedures that take the continuously changing impact of external factors (e.g. temperature) into account need further attention in the future.
Table 3: Overview of papers in Block 3

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<td>23 Propagation of suprarahmonics in a medium-voltage network</td>
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<td>73 Assessment of grid impedance impact on suprarahmonics propagation</td>
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<td>101 Efficient method to study the propagation of suprarahmonics on the LV grid</td>
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<td>through symmetrical components and chain matrices</td>
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<tr>
<td>112 High frequency interaction of power electronics converters in AC and DC</td>
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<td>powered data centers</td>
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<tr>
<td>135 Application of transfer function method in a wind park for harmonic study</td>
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<tr>
<td>137 Comparing harmonic unbalance at multiple locations to characterize the unbalance</td>
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I: interactive poster presentation
Block 4: “Standardization, system monitoring, handling big data and regulatory issues”

Power quality standardization has to keep up with trends in distribution systems. Trends like the use of non-linear household appliances and the integration of non-linear renewable generation and charging units have been building up over the past years and need to be thoroughly analysed and understood. The aggregation of PQ phenomena of a large number of new appliances and interaction with already existing appliances connected to the distribution grid lead to a complex situation. In some cases, it will be important to respond appropriately before a tripping point is reached. Large-scale monitoring systems or campaigns are important in order to know the situation in the distribution grid and to recognize trends early. Applying machine learning and visualisation techniques is needed to analyse large amounts of data and to discern changes. Standardisation has to keep up and be amended in a timely manner.

New developments in standardization

New developments in standardization have the goal to maintain and enable efficient operation of the electric grid with adherence to the required quality. For this year’s conference we received ten papers dealing with new developments in this field.

[B4-0065(DE)] presents the results of a D-A-CH-CZ survey on MV grid characteristics for the improvement of emission limit-allocation for large customer installations. Regarding power quality, the grid is optimally utilised if the disturbance levels meet but not exceed the compatibility levels in the low voltage grid. The actual harmonic and unbalance levels in medium and low voltage grids are often lower than the planning or compatibility levels. A maximum hosting capacity is introduced to ensure that the global contribution is not exceeded. This capacity corresponds to the power of all expected customer installations in the grid including also future connections. The maximum hosting capacity presently assumes that all customer installations are directly connected to the MV grid. The aim of this paper is to verify the assumptions behind the equation to calculate emission limits. The authors performed a survey related to the characteristics of typical MV grids and the distribution of directly and indirectly connected customer installations. Fig. B4-1 shows the ratio between the maximum power of customer installations and the agreed power. Using existing equations, the emission limits differ by a factor of four, which means that in case only LV customers are connected to an MV grid the global contribution is utilized by about 25%. The results of the survey show, that in many cases the dominating share of customers is connected to the downstream LV grids. This suggests adapting the share of compatibility levels between LV and MV grids for the calculation of emission limits. However, the level of adaption has to take further factors, like the total hosting capacity utilization or the power utilization, into account.

Fig. B4-1: Histogram of the ratio between maximum observed power and agreed power [B4-0065(DE)]

[B4-0274(CZ)] focuses on the proposed changes in the design of the current IEC flicker meter (FM) which are mainly related to the calculation of the flicker severity index $P_{st}$. The difference between a new flicker meter implementation and the existing one is identified through measurements in laboratory and field and through experiments. The field measurements were performed at different locations in public low voltage networks. The results are that the proposed FM tends to provide smaller $P_{st}$ values than the current one and the proposed metric is less affected by peaks and rapid changes. Experiments were conducted with people in order to evaluate, which of the two FMs can better predict the properties of human vision and flicker perception. Depending on the waveform and frequency modulations, the current or proposed FM, or neither of them, is more favourable. In some cases, no clear conclusion is possible and one experiment suggests that neither of the
two FMs is able to predict the outcome correctly. As there are still uncertainties with some configurations of the measurements, the authors suggest further research. A round table discussion (RT 19) is organised to address the future of flicker.

The authors of [B4-0727(SE)] describe first steps towards a standardized hosting capacity method. This method can help assessing where and when network strengthening is needed. The hosting capacity is limited by phenomena like overvoltages, thermal overloads, incorrect protection operation, increase in unbalance, or excessive levels of voltage or current distortion. When multiple phenomena are considered, the hosting capacity is the lowest of the values found for the different phenomena. A standardised hosting capacity must fulfil consensus, stability, transparency, harmonisation, and interoperability requirements. Moreover, standardization enables benchmarking across network operators, countries, regions, and design methods. For stochastic methods, some standard models for handling the different uncertainties are required and especially for non-typical situations, certain approaches to aggregation, parameter selection and handling of distribution of uncertainties need to be modified.

In [B4-0772(DE)], new guidelines to determine the harmonic emission of an operating customer installation based on field measurements are proposed. The proposed framework consists of two stages, the first one analysing the current harmonics, while the second analyses the voltage harmonic contribution. Resulting from the framework are two flowcharts. In a first flow chart, the current emissions are assessed. If the currents are within a set limit, the installation complies with the emission limits. If they are well above the limits, the installation does not comply with the limits. If they surpass the limits slightly (up to factor 2), the voltage contribution assessment flowchart is used and if the limits are not surpassed, the installation is deemed to comply with the emission limits. Based on this procedure, several sites have been analysed. It showed that the assessment of harmonic currents alone could result in a number of cases in a non-compliance decision, which is not justified if the harmonic voltage contribution is evaluated. The proposed framework can therefore improve the reliability of the compliance assessment. For further analyses, due to the inherent variation of emissions, a continuous monitoring of harmonic emissions is suggested. Additionally, the need of additional input data, particularly the supply-side harmonic impedance, has been identified.

A new definition of interharmonic is presented in [B4-0841(CZ)]. The new subgroups are better able to tackle the main problem caused by interharmonics, the light flicker produced by modern lamp technologies, which cannot be assessed by the IEC flicker meter. Past implementations of subgroups are mostly subgroups based between two harmonics. As it has been determined in this paper however, the sensitivity to flicker around even harmonics is considerably lower than around odd harmonics. This means that subgroups should be centred around odd and even harmonics and therefore allow for more relaxed limits around even harmonics. In a numerical case study, the robustness of the new metric versus the desynchronization of the window used for the DFT with respect to the system fundamental frequency and versus the inaccuracy allowed by the requirements of the voltage measurement chain has been presented.

In [B4-0852(US)] presents ongoing and recently finished power quality standards and technical reports by the working groups sponsored by the Power Quality subcommittee of the IEEE Power & Energy Society. In this paper, the seven working groups operating within the Subcommittee Power Quality of the IEEE PES T&S Committee are examined in detail and their ongoing as well as shortly finished projects are presented. The working groups are divided in the following directions: Working Groups on harmonics, voltage quality, monitoring electric
power quality, power quality solutions, voltage imbalance, economic evaluation of voltage sags and on power quality data analysis.

Two different methods used in two different locations are compared to determine limits of the harmonic emissions from grid users. The methods discussed in [B4-0932(US)] include the limits prescribed by IEEE 519 used in the United States and the limits imposed by the IEC standard used in the D-A-CH-CZ region. As the IEC method has a more systematic approach in comparison to the approach of the IEEE method, the paper focuses on the necessary adaptations to the IEC method to factor for the differences in power grids between both regions. Comparing the results for the harmonic limits from both methods shows that the limits set by the adapted IEC method are tighter than those set by the IEEE method for the lower harmonic orders as well as the triplen odd harmonic orders. As for the higher harmonics, the IEEE method shows limits that are more restrictive. It is then concluded that the IEEE method lacks of a formal structure, which can result in potential voltage harmonic limit violations. The IEEE method also does not consider zero-sequence harmonics, which is especially important in the US power grid since it is mostly solidly grounded. The IEC derived method can be adapted for use in American power grids, which delivers less optimistic but more realistic limits, and the IEC method enables grid operators to optimize the utilization of the network’s harmonic hosting capacity.

In [B4-1031(IR)], a new correction factor for IEC 60364-5-52 standard in cable calculations under harmonic conditions is presented. The effects of a high number of nonlinear loads connected to the distribution grid are analysed. The results show that a total harmonic distortion current of 57% and a total harmonic distortion voltage of 8.5% are appearing in this case. Not only are those values above the Iranian standard, but they also lead to higher neutral currents than phase currents. Given that normally the neutral current cross-sections are smaller than the phase current cross-sections, this poses a problem to the distribution grid. This means that in case of high harmonic distortion, there is the need for a correction factor to account for the increasing phase and neutral currents. Upon inspection of the IEC 60364-5-52 standard, it has been found, that the factor included in the IEC standard has a non-monotonic behaviour. The proposed adaptations to the IEC standard propose to determine a monotonic correction factor.  

The third edition of the Austrian-Czech-Swiss-German technical rule described in [B4-1009(DE)] applies to customer installations connected to low, medium, and high voltage networks. It is a guideline for the calculation of emission limits, covering voltage changes, flicker, unbalance, harmonics, interharmonics, supraharmoinics, commutation notches and mains signalling. Commonly used mitigation measures for these phenomena are described as well. Further, it describes the basic principles of allocation methods and the general assessment methodology. The equations to calculate emission limits and the individualized assessment procedures for each disturbance phenomenon are provided. The last part contains a set of examples that illustrate the application of the assessment procedures and emission limit calculations. Although there are many improvements in the third edition, there are still open issues like the topic of supraharmoinics, the network-wide harmonic propagation or the sometimes-observed miscorrelation between the higher flicker levels and respective complaints that require a better understanding.
The authors of [B4-1150(CH)] describe the pre-normalization of grid impedance measurements in the power line communication frequency band. Power line frequency and time dependent grid impedance (FTdGI) influences the propagation of the power line communication (PLC) signals and influences the communication with smart meters. Currently, the precise measurement of the power line impedance is ill-defined and only possible with a few instruments. A large number of existing standards were compared with the results of measuring campaigns realised on sites in Europe. For all specified standard impedances, a higher value for the frequency dependent grid impedance (FDGI) was found compared to most of the cases when measuring the low voltage distribution grid in European locations. The defined standard reference impedance should be representative of average frequency behaviour of low voltage AC grid in Europe. Moreover, it should contain the dynamic range of impedance with stronger variations of phase and magnitude. Four grid impedance analysers with different characteristics were evaluated within the project. Two measurement modes, unenergized and energized 230 V / 50 Hz, were compared in the laboratories. All the results are compared with those obtained by METAS using an unenergized calibrated LCR meter. The correlation between the results with different equipment is good for the unenergized mode. For the energized mode, there are two ways of feeding the static reference impedance. It is possible to use an electric grid simulator or directly use the electric grid. The connection of the impedance analysers to the protective earth or to the neutral conductor and the use of a grid simulator can affect the measurement results significantly. Therefore, the measuring conditions are important to quantify the comparison. Fig. B4-4 shows the results of the energized measurements. For this purpose, the standard reference impedance defined in the Z-NET project is used. The results show that the magnitude at resonance differs only slightly from the unenergized measurements. A static impedance reference was specified based on available results. This reference can be used for the evaluation or the calibration of grid impedance analysers.

![Fig. B4-4: Results of the comparative energized measurements of the Z-NET Static Impedance Reference [B4-1150(CH)]](image)

**Large scale PQ monitoring systems and campaigns**

For this CIRED ten papers present findings related to large scale monitoring systems and campaigns, which have been built or undertaken in order to capture the different parameters of power quality in the respective distribution grid and to identify and understand trends and disturbances.

In [B4-0049(SE)], Short-Time Fourier Transform (STFT) is used to analyse the spectrum of real transients from a LV network. At first, several configurations for the STFT are tested and applied to different waveform lengths. Secondly, the transients from some random devices, an induction stove as well as from a PV panel have been analysed. It has been found that the transients from the random devices, the STFT has either a higher energy spectrum for frequencies below 3kHz or lower energy spectrum spread along the frequency domain. When analysing the transients originating from the induction stove, transients in the frequency range between 2.1 and 4.8 kHz with power frequencies over -20dB/Hz have been measured. In the case of the PV panel (Fig. B4-5), frequencies between 0.1 Hz and 0.2 Hz have more than double the power during the transient, while a second range from 1.375 kHz to 1.875 kHz sees power frequencies within -11.73 dB/Hz and -19.01 dB/Hz. A third range between 16.07 kHz and 16.52 kHz has power frequency values between -18 and -19 dB/Hz.
A new approach for estimating a safe hosting capacity in terms of harmonic distortion is proposed in [B4-0076(SE)]. This approach is based on standard limits for harmonic voltages and currents. Using the highest allowable currents for each harmonic with an impact factor $k=0.1$, while assuming no cancellation or aggregation, permits to establish a conservative and therefore lower bound on allowable harmonic devices at different positions in a grid. Using existing grid impedance values from almost 60'000 LV customers in Sweden, the safe hosting capacity for each harmonic has been determined. Fig. B4-6 shows the 5th percentile, 10th percentile, and the median. The lowest values were found for triple and even harmonics with a minimum for the 6th harmonic with a median value of 0.62, which then determines the total harmonic capacity for a LV customer. This being a very conservative method, using more realistic values of $k=0.9$ and an aggregation exponent of $a=1.4$, $6^{th}$ harmonic values of factor 18 higher are found. This method therefore allows for a lower bound estimation of safe integration of new loads, the determination of critical harmonics for certain grids as well as adaptations for more realistic values for safe harmonic hosting capacities.

Results of harmonic voltage measurements at multiple locations in a low voltage network are presented in [B4-0080(SE)]. In a first step, it is shown that the existing voltage levels from characteristic harmonics for the measured locations are well below the standard limits. In a second step, correlation matrices are calculated for different harmonics at the same location, different harmonics at different locations and correlation matrices for specific harmonics in different locations. This paper concludes that there is a strong correlation in low order harmonics up to the 13th order excluding triple order harmonics for the locations connected to the same LV network. The fact, that these low order harmonics can be found in several locations in the same grid, means that those harmonic levels originate at LV grid level or higher and that local loads only have limited impact on those harmonic levels. As an overview, Fig. B4-7 shows the correlations for locations in the same LV grid (1-5), as well as correlations to locations further away (6-9).
Fig. B4-7: Correlation coefficients for Harmonics 2 to 13 between all measured locations [B4-0080(SE)]

Paper [B4-0370(GB)] analyses power quality data from 33kV distribution networks gathered during 2020. The network power quality will be affected through the growing number of low carbon technologies (LCT) like solar PV sites and electric vehicle charging points. Two areas with different penetrations of LCTs were chosen for the analysis. Power quality monitors were installed at every available substation within the analysed 33kV networks. The measurements show that the sites in the areas with a higher LCT penetration see a greater variation in multiple harmonic orders. Other PQ measures are short- and long-term flicker, voltage total harmonic distortion and voltage unbalance. Similar to the results for the voltage harmonics, the magnitudes of the other PQ measurements vary between the different areas and across the sites within an area. Measurements of the 16th voltage harmonic at four different sites in the area with high LCT penetration show there can be substantial variations in aggregated PQ values in the long term. The results are shown in Fig.B4-8. Although the sites show similar trends in terms of when values rise and fall, the magnitudes are consistently higher at the solar PV sites. In addition, the range of variations for all voltage harmonic orders at sites that are solar PV farms is higher compared to sites without solar PV farms.

Fig. B4-8: Weekly 95th percentile aggregates of the 16th voltage harmonic at four sites with high LCT penetration [B4-0370(GB)]

Paper [B4-0372(GB)] deals with the development of an integrated platform for power quality monitoring. With an integrated PQ data collection and analysis platform, valuable resources for the manual analysis of PQ data are freed up and time is saved. There are several requirements for such a platform like vendor-agnostic, integration of several PQ analysis features, ease of use, integration with other systems and cybersecurity. The authors decided to use an already existing monitoring platform and then add the required PQ analysis features. The main features of the platform are the acquisition and processing of data from various PQ monitors, summarising PQ data and system status, visualising PQ data over time, browsing through events, viewing event recordings and producing PQ assessment and compliance reports. The developed platform features automated PQ data retrieval, processing, visualisation, notification and reporting as well as monitoring fleet management. However, the platform continues to be developed and new features like machine learning applications may be included.

In [B4-0438(DE)], the feasibility of selected measurement methods in the frequency range 2-150 kHz for long-term field measurements is studied. Measurements in public low voltage locations have been performed using two different methods namely the CISPR 16-1-1 method and the method specified in the standard IEC 61000-4-7. The disturbances measured are coming from a PV inverter and from EV chargers. Distinct disturbances form the PV inverter could be identified at 16 kHz and its second harmonic at 32 kHz. The EV chargers have disturbances at 10 kHz from the
switching frequency of the on-board charger, as well as at 18 kHz and 36 kHz from the switching frequency of the fast charger and its second harmonic. In both cases, the highest disturbance levels during the measurement period are well below the compatibility levels. It has been shown that the $Q_{\text{P max}}$ values from the CISPR method exceed the values in the consecutive RMS aggregation of the IEC method. However, the CISPR method provides lower values than the IEC method for the 99th and 100th percentiles of the consecutive maximum values. This shows that while the CISPR method is suitable for the assessment against compatibility levels, it tends to overestimate the impact of disturbances on additional thermal stress and it tends to underestimate the possible malfunction rate of connected electronic equipment. On the other hand, the IEC method is reflective of interference mechanisms but has limited application for the assessment of disturbance levels against compatibility levels. However, using the IEC method, the 99th and 100th percentiles of the maximum aggregated values are reliable at giving conservative estimates of the $Q_{\text{P max}}$ values.

The automatic identification of correlations in large amounts of power quality data from long-term measurement campaigns is described in [B4-0576(DE)]. To analyse large amounts of data from PQ monitoring in an efficient way, automatic data mining methods are required. In this paper, an automatic algorithm for identifying correlations in the trend between different PQ parameters and measurement sites is introduced. Correlation can be used as a measure of similarity between multiple time series of PQ parameters. Shorter time intervals or a transformation combined with averaging can lead to better results. For the analysis, voltage and current measurements from 21 different sites with a duration of up to 3 years were taken. The PQ parameters monitored include voltage parameters like voltage RMS, voltage unbalance, total harmonic voltage distortion, harmonic voltages and current parameters like fundamental currents and harmonic currents. The long-term measurement analyses show that the most common correlation between PQ parameters is between total harmonic voltage distortion and the 5th harmonic voltage. Future research will cover the analysis of time varying correlations and the application of correlation analysis on time series itself.

The authors of [B4-0950(ES)] use PQ data mainly to assess compliance with limits. The measurements are taken from an open power quality database where measurements from two different PQ monitors show data from different sites around the world. In this paper, only harmonic voltage data from Europe are considered and especially higher odd harmonic orders and even harmonics. From the study of long, medium and short-term PQ characteristics, information about trends, seasonal effects or deviations from "typical" values can be obtained. Yearly emission of higher-order odd voltage harmonics for four different cities is analysed. The results are visualized as boxplots that show the various harmonic amplitudes (Fig. B4-9 (a)) or as 50, 95, and 99 percentiles over the year, which represent the values from higher-order odd voltage harmonics (Fig. B4-9 (b)). Seasonal variations of electricity usage or the connection/disconnection of devices during certain times are potential reasons for these variations. The plots show an weekly pattern in the behaviour how people use electricity and for most orders and sites, the magnitude is reduced during the weekend.

![Fig. B4-9: (a): Boxplot of higher-order odd voltage harmonics at four sites, (b): 50, 95, 99 percentiles of higher-order odd voltage harmonics at four sites [B4-0950(ES)]](image)

Paper [B4-1051(FL)] deals with power quality data management and data analysis. As available data from distribution networks are plenty and diverse, complex automated preprocessing, integration, and analyses are needed. Right now, international standards for PQ management practices and technical specifications of the monitoring systems are missing. The authors state that PQ management should be an integral part of distribution network design, operation and maintenance. Right now, the standard series IEC TS 63222 is being developed which defines
use cases for PQ management and provides guidance for PQ monitoring systems. Open and common data formats, standardized communication protocols and flexible databases would all be beneficial for a better data management. Distribution management system (DMS) and supervisory control and data acquisition (SCADA) are two available systems for PQ data management in distribution networks, which have methods for data collection, transfer and storing and have some standards. The analysis method feasible in practice for PQ management in modern distribution networks remains to be determined. The analysis tools should be able to handle increasing quantities of data of various sources and types. Moreover, they should enable financial benefits of PQ management and consider the emerging PQ issues like interharmonics and voltage variations.

[B4-1132(DE)] describes site indices for high frequency harmonics for long term power quality monitoring. A common approach for reducing the data without losing its properties are site indices. Including the measurement of supraharmomics in the range from 2-150 kHz in long term monitoring systems drastically increases the amount of data. Consequently, new forms of data aggregation are necessary to retain information of the measurements in a highly compressed way. This paper presents a new approach for the aggregation of supraharmomics. The objective is to calculate indices, which are easy to interpret and visualize, and to compress the measurements. A first step to reduce the data size is by calculating and aggregating the measurements locally on the device and only sending the results to the monitoring server. For further aggregation, the lowest reserve of a specific parameter is used to represent the PQI of the site. In this study, the limits given in the IEC 61000-2-2 standard were utilized. With the resulting site indices, a straightforward visualization, interpretation, and comparison of the supraharmomics is possible and harmonics exceeding the prescribed limits are easily identifiable.

Visualization and machine learning for PQ big data

As monitoring and measurement systems are very sophisticated today, large amounts of data will easily be produced and have to be analysed in an efficient way. Manual analysis of all data will generally be no option. Consequently, machine learning and visualization of results using effective algorithms are of great interest. Five papers presenting different strategies have been submitted for this CIRED.

In [B4-0030(SE)], the visualisation of results from unsupervised deep learning is discussed. The generated graphs with daily, weekly and seasonal variations in harmonic voltages allow the interpretation of the results without having to understand the mathematical details of the method. The goal of the deep learning approach is the power system data analysis without pre-defined features and the extraction of the harmonic patterns. The presented method results in three plots. They show the two most dominant patterns, the patterns' spread and the results relevance. PQ data sets are from a continuous PQ measurement in a Northern Swedish distribution system. The PQ monitors are installed at MV (10 kV) and LV (0.4 kV). The measurement data consist of 10-min values for harmonics 2 through 50. The 3rd, 5th, 7th, and 9th harmonics are analysed in detail. In Table 4, the correlations between the patterns for each harmonic are listed. The low correlation of pattern spread for H3 points out, that it does not spread from one voltage level to another. For H5 and H7 it is different. Both show a high correlation between the patterns and between the voltage levels. It confirms that these harmonics have the same source and that they propagate through MV/LV transformers. The results show that inferences related to the daily variations, seasonality, origin, and propagation of harmonics could be obtained simply by the visualization of the DL results. The correlations between the patterns were used to confirm the inferences given by the visualisation.

Table 4: Correlation between the patterns for each harmonic [B4-0030(SE)]

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<th>Correlation (%)</th>
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<th>H7</th>
<th>H9</th>
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<td>93</td>
<td>92</td>
<td>74</td>
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<td>Pattern 1 and 2 in 10 kV</td>
<td>78</td>
<td>94</td>
<td>91</td>
<td>42</td>
</tr>
<tr>
<td>Pattern 1 in 0.4 kV and 10 kV</td>
<td>-51</td>
<td>97</td>
<td>93</td>
<td>-72</td>
</tr>
<tr>
<td>Pattern 2 in 0.4 kV and 10 kV</td>
<td>-67</td>
<td>08</td>
<td>96</td>
<td>-35</td>
</tr>
<tr>
<td>Spread in 0.4 kV and 10 kV</td>
<td>12</td>
<td>96</td>
<td>78</td>
<td>-68</td>
</tr>
</tbody>
</table>

[B4-0071(SE)] discusses graphical methods for presenting harmonic variations for different timescales and categorizes them in a
systematic way. In addition, it discusses various methods for presenting harmonic variation and extracting knowledge from big data. The question is how to extract knowledge about harmonics’ behaviour in an efficient way. Due to the time varying characteristics of current and voltage harmonics, the time scales of a few cycles up to a year cannot be neglected. The graphical display methods are classified based on the application of each method and the time scope. Harmonics can be expressed in time or frequency domain. For the aggregation and investigation of harmonic impact on equipment, the time domain can be more useful. The presented graphical methods are a spectrogram, a space phasor model, daily patterns, a time-series colour-plot, a correlation matrix, box plots, histograms, polar plots, and machine learning tools to extract patterns.

The authors of [B4-0160(SE)] provide a graphical tool to handle two different data inputs, namely individual interharmonics components in time-series and broadband spectra. Spectrograms allow an easy interpretation of interharmonics as they show the evolution of a spectrum with time. However, the graphical analysis is only suitable for a short period. For a long-term measurement, the use of an automatic tool is required. For a beneficial application, the method should be able to accurately estimate the frequency and the magnitude of the interharmonics or get characteristics of the broadband spectrum if such is present. This paper focuses on the application of deep learning to find patterns of interharmonics. The output of the DL method for time-series are main patterns of variations in PQ data. In this study, the DL method was applied to measurements of the aggregated values of the interharmonic currents between 50 Hz and 100 Hz over one year. Fig.B4-10 (a) shows the results provided by the DL method for interharmonics’ currents. The distribution of the three clusters over one year is shown in Fig.B4-10 (b). The colours represent how the daily distortion was classified. The lowest distortion days and duration of interharmonic currents (pattern 3) are predominant in winter. To get the data for spectrograms, one sample of 10-second duration was extracted every 10 minutes for 24 hours. This leads to 144 spectrograms per day. Fig. B4-11 shows the cluster distribution over one day as well as the solar elevation angle. Cluster 1 appears mostly around sunrise and sunset but sometimes in the middle of the day. Cluster 2 does not present interharmonic components and appears when there is no sunlight. Cluster 3 presents mixed frequency components and appears during the PV production. The results of this study show that DL methods can be used in time-series measurements to find daily-patterns for individual interharmonics. Moreover, the method provides a solution to handle patterns of interharmonics in a range of frequency instead of an individual component.

[B4-0575(FR)] deals with the harmonic risk estimation for LV networks by machine learning. Enedis, the main French distribution system operator (DSO), aims at obtaining a mapping of the harmonic risks for all its LV networks that considers various power electronics development scenarios in order to assess their impact. Such estimation is complex, as it requires extensive disturbance modelling for various grid situations. Thus, the authors decided to use machine-learning techniques for a more efficient computation. The output quantities provided by the model must be an image of the harmonic risk of the estimated networks. The considered output quantity is the maximal total harmonic distortion KPI for each network. The same database and dataset were used to train the machine-learning model with five different algorithms. After a first evaluation of the initial training algorithms, several parameters were adjusted to optimize the algorithms. In a last step the tuned machine-learning model was integrated into the risk estimation tool The finished tool allows any
DSO to select one or more LV networks, configure some model input quantities and run a harmonic risk estimation. However, the first results need to be consolidated because the new power electronics equipment model that was used is only based on assumptions and does not take measurements or harmonic dispersion into account.

In [B4-0871(FR)] machine-learning techniques are employed to predict the harmonic currents originating from most widespread power electronic devices and compared with time domain (TD) models. To achieve this goal, firstly a measurement-based time domain model needs to be built. It is determined by measuring the emitted harmonic currents following harmonic voltages as input, whose amplitudes and phases vary randomly. This model is then rebuilt in MATLAB Simulink to have a digital representation of the observed element. The influence of the network on the observed element is added to the model. As machine learning techniques, artificial neural network, support vector regression and decision tree regression machine learning models have been applied. Using a condensed set of measurements from input to the model in Simulink and its output is then used for the training of the three machine learning models. The output from the trained models show very similar current behaviour compared to the measured currents. The advantage of using machine learning models is that once the model is trained, it does not need additional tuning of the parameters whenever the supply conditions evolve, whereas the TD approach needs additional tuning and simulation when conditions change.

**PQ regulation, disturbances and customer issues**

In this sub block, seven papers discuss the issues related to disturbances and customer issues as well as regulation. Three papers from Brazil examine the issue of regulation of damage claims and the view of distribution system operators and possible measures at customer sites.

The goal of the paper [B4-0085(EG)] is to mitigate inter-area oscillations due to different disturbances using a battery energy storage system (BESS) with a fuzzy-based control system. For this goal, a model with two different areas with a significant generation/load mismatch between both areas, coupled with a long transmission line, is used. In a first study, one of the two generators from one area increased its output by 0.05 p.u. for a duration of 0.2 s. When no BESS was used, this resulted in an oscillation in both active and reactive power transfer through the line, which increased cycle by cycle and consequently, the system became unstable. When BESS where used in both areas, the oscillations could be counteracted and the system remained stable. In a second study, the effect of switching one cable connecting both areas on the stability of the system was examined. In this case, around 3 s after the disconnection of the cable, the system loses its synchronicity (Fig. B4-14). As in the first study, employing a BESS in both areas could alleviate the loss of synchronicity by injecting power following the fuzzy logic control. As a conclusion, it seems that BESS systems have a great importance in reducing the adverse impacts of inter-area power oscillations on the transmitted power quality and lowering the blackout vulnerability.
[B4-0090(SE)] analyses the risk of server outages. As server equipment is supplied by DC current from power supplies, they are sensitive to voltage dips in the AC system as that translates in dips in the DC system as well. Therefore, voltage dips caused by faults in the internal power supply system of the data centre are analysed. As benchmark for possible outage, the voltage-tolerance guideline of the Information Technology Industry Council has been used. A server layout with an internal power supply system (IPSS) has been modelled as subject of the analysis. A 10m single-phase cable connected to the load bus is determined to be the most sensible section of the IPSS. Depending on the location of the fault in the cable, the voltage drop might be large enough to affect the neighbouring buses and provoke further server equipment to be lost. Depending on the cable length of one server cluster to the uninterrupted power supply unit, the critical fault length in the 10m cable is longer or shorter and therefore the risk of affecting neighbouring server racks can be higher or lower. When including the failure rates of the cable in question, the failure rate of parts of the server cluster can be calculated for several layouts. It has been determined that in the studied system, a maximum of 33.33% of the servers could fail due to a fault in one of the 10m cables.

The Brazilian regulations assign damage compensations of consumer appliances to the power companies. Therefore, the power companies have sought to assess possible impacts of events that occurred in the power grid and the resulting voltage disturbances. In the paper [B4-0191(BR)], the different types of occurrences in the Brazilian supply grid that cause disturbances in voltage were analysed. Types of disturbances in supply voltage that may cause damages to the equipment are short- or long-duration overvoltages, switching transients, atmospheric surges and voltage imbalances. The main factors determining the overvoltages are the magnitude, duration, susceptibility, grounding condition and existing protection of the equipment. Measures to reduce the occurrence of damages can be implemented in the supply system or in the installations of customers. Either the measures could reduce the susceptibility of consumers' equipment to supply side faults or they could reduce the probability that internal problems from one consumer affect other consumers. Knowing the place and cause of a problem allows the company to adopt preventive measures towards future problems and therefore helps improving continuity indicators. Usually, there is no information on the causes of temporary faults in the distribution grid. Obtaining reliable information is a task that requires long-duration research work.

Paper [B4-0192(BR)] discusses best practices to reduce damage claims related to power appliances. Disturbances in the distribution grid may lead to damages of equipment and therefore to claims for compensation. However, it does not seem reasonable for utilities to bear all the burden of compensation for damaged equipment. In many cases, the damage could have been prevented if there were stricter requirements to manufacturers regarding the installation of protectors against overvoltages. In various countries, the installation of protection against transient overvoltages has been made compulsory. Where it is not compulsory, the utilities started to offer surge protection device (SPD) installation services. Both, the regulations and the services lead to a clear reduction in the number of cases of burning equipment. In the case of Brazil, there are standards specifying which protections are adequate for cases of overvoltages, lack of voltage, undervoltage and overcurrents.
However, most Brazilian utilities only recommend that their consumers install SPD's and most consumers ignore this recommendation. This paper proposes two ways for improving the protection against transient overvoltages. The utilities could install SPD compulsory in new consumers' inputs and establish a deadline for existing consumers to adapt to the new requirements or they could start to offer SPD installation services. Furthermore, insurance companies should establish by contract compulsory installation of SPDs.

[B4-0193(BR)] focuses on the influence of distributed photovoltaic generation on the supply voltages and on the claims for compensation for electric damages. For this study, several typical distribution grids were defined and implemented in MATLAB to simulate the impacts of distributed PV generation. In total, a sequence of 14 simulations was conducted. The maximum solar panel power was either 3.5 kW or 7.0 kW at two different common coupling points (CCP) between utility and consumer and the solar generation amplitude varied in steps with a first step at the initial instant and a second step at instant 2 s or only a single step at instant 2 s. Fig. B4-16 (a) shows the results in case of an increase and (b) shows the results in case of a decrease in solar irradiation. The red curves correspond to the impact on CCP1 and the black curves correspond to CCP2. In all situations, the values of the voltages in the CCPs never exceeded the established operation limits. Furthermore, the voltage settling times were short, generally in the order of 0.5 s. The results of the simulations show that the solar generation input or output is not expected to cause conditions that lead to damaged equipment and consequently to claims for compensation.

[B4-0689(DE)] is about the influence of area-structural characteristics on reliability of supply. So far, in quality regulation in Germany only the area-structural characteristic of load-density has been considered. A hyperbolic relationship between the unavailability index ASIDI (MV) or SAIDI (LV) and the load density (LD) has proven to be meaningful:

\[ \text{ASIDI}_\text{Ref}(LD) \text{ or } \text{SAIDI}_\text{Ref}(LD) = a \cdot \frac{1}{LD_c} + b. \]

The question arises, if alternative parameters or a combination of several regional structural features could provide stronger explanations. Publicly available high-resolution data are used to map the supply task and the geographical structure. The networks are generated using an algorithm in the form of standard operating resources depending on the supply task. In each case, complete distribution grids are developed that are able to fulfil the given supply task. Stochastic investigations can be carried out based on these grids. Planning principles can be used to map an endogenous specification of a network operator for network design and equipment. All investigations were carried out for ASIDI and for ASIFI parameters.
Area-structural characteristics like load density, connection density, average individual load size over all connections, and generation power density were examined individually to estimate their contribution to differences in supply reliability. Additionally, the industrial or commercial load share as percentage of the total annual peak load was considered. Table 5 shows the parameters of the regression function (ASIDI) and the statistical test results. The regression analysis shows that load density and connection density are the structural characteristics with the highest explanatory contributions. In addition to classical area-structural characteristics, parameters for describing the inhomogeneity of the supply task appear to be useful. To describe this inhomogeneity in the area of low load density, multiple regression is required. The starting point in each case is the load density combined with other characteristics. The contribution of load density for both reliability parameters ASIDI and ASIFI is confirmed for the MV level, if only one characteristic is considered. However, the multiple regression of classical area structural characteristics shows no clear statistical significance for the addition of a parameter to the load density.

Table 5: Parameters of the regression function (ASIDI) and statistical test results (classical area-structural characteristics) [B4-0689(DE)]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
</tr>
</thead>
<tbody>
<tr>
<td>load density</td>
<td>125.6</td>
<td>5.3</td>
<td>0.56</td>
<td>0.60</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>connection density</td>
<td>14.9</td>
<td>3.7</td>
<td>0.54</td>
<td>0.53</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>avg. individual load size</td>
<td>1032</td>
<td>3.0</td>
<td>1.12</td>
<td>0.53</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>generation power density</td>
<td>25.7</td>
<td>0</td>
<td>0.14</td>
<td>0.08</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>industrial + commercial load share</td>
<td>20.5</td>
<td>5.24</td>
<td>-0.88</td>
<td>0.48</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

The effect of one free disconnection/connection service offered to MV customers to the power grid's outages and inadequate voltage quality parameters are presented and discussed in [B4-0907(PT)]. The reason for this decision is the fact that a relevant percentage of incidents in the MV power grid originate on MV customers’ electrical facilities. The main Portuguese DSO has implemented this measure in 2014 and the subsequent evolution of disconnections/connections, the incidents on MV customer installations and their impact on the SAIDI indicator are presented. The results show that the DSO saw a threefold increase in maintenances in customer installations from 2016 to 2020. In the same timeframe, the number of incidents on customer secondary substations decreased by 18%, while their SAIDI contribution decreased by 0.83 minutes. This paper concludes that the incentive created to increase the maintenance rate of MV customers was a success in terms of increase of periodic preventive maintenances. Consequently, the number of incidents as well as the SAIDI contribution was reduced. By looking at the cost of the presented measure being on average 200 k€ per year, it is determined that one free disconnection/connection measure offered to MV customers is a very cost-effective measure compared to the cost of measures for a similar reduction in SAIDI.

Potential scope of discussion

Changes in the distribution system are getting faster and faster. With the net zero goals and the green energy pact, these developments will even intensify in the following years. This means also that power quality which is taken for granted in many places will become a hot topic with sensitive apparatus and systems on the one hand and a new mix of emissions on the other hand.

Distribution system operators should therefore monitor power quality constantly in order to identify trends in disturbances and take measures early before a tripping point is reached where large investments need to be undertaken. This applies even more to efforts in standardization and regulation, which also need to anticipate these changes. The goal will always be to enable coordination of emission and compatibility levels for an efficient operation of the distribution grid.
Table 6: Overview of papers in Block 4

<table>
<thead>
<tr>
<th>Paper (No. and Title)</th>
<th>MS</th>
<th>RIF</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0030 Visualizing the Results from unsupervised Deep Learning for the Analysis of Power-Quality Data</td>
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<td></td>
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<tr>
<td>0049 Spectrum Analysis of Transients using the Short-Time Fourier Transform</td>
<td></td>
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<tr>
<td>0065 D-A-CH-CZ Survey on MV Grid Characteristics for the Improvement of Emission Limit-Allocation for large Customer Installations</td>
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<tr>
<td>0071 Graphical Methods for presenting time-varying Harmonics</td>
<td></td>
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<tr>
<td>0076 Estimation of safe harmonic Hosting Capacity</td>
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<tr>
<td>0080 Harmonic Correlations Matrices to present Measurement Results from single and multiple Locations</td>
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<td>X</td>
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<tr>
<td>0085 Mitigation of Inter-Area Power Oscillations in electrical Power System via fuzzy control based Battery Energy Storage Systems</td>
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<tr>
<td>0090 Risk Assessment of Server Outages due to Voltage Dips in the internal Power Supply System of a Data Center</td>
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<tr>
<td>0160 Deep Learning for Pattern Recognition of Interharmonics in Time-Series and Spectrograms</td>
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<tr>
<td>0191 Study of Disturbances in Low Voltage Supply and Proposal of Measures to reduce the Damage of Appliances</td>
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<tr>
<td>0192 Recommendations of best Practices to reduce Damage Claims in Power Appliances</td>
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<td>0274 Comparison of Algorithms for Flicker Irritation Assessment</td>
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<td>0370 A View of 2020 Power Quality within GB Distribution Networks</td>
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<td>0372 An integrated Platform for Power Quality Monitoring</td>
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<td>0438 Application of Measurement Methods for the Frequency Range 2-150 kHz to long-term Measurements in public Low Voltage Networks</td>
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<tr>
<td>0575 Harmonic Risk Estimation on LV Networks by Machine Learning</td>
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<td>0576 Automatic Identification of Correlations in large Amounts of Power Quality Data from long-term Measurement Campaigns</td>
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<tr>
<td>0689 Influence of Area-Structural Characteristics on Reliability of Supply of Electrical Distribution Networks</td>
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<tr>
<td>0727 First Steps towards a standardized Hosting Capacity Method</td>
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<td>0772 Assessment of harmonic Contribution of Customer Installations based on Field Measurements</td>
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<tr>
<td>0841 New interharmonic Subgroup Definitions for quantifying and limiting Distortion in Distribution Networks</td>
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<tr>
<td>0852 Overview of Standards Development within the Power Quality Subcommittee of the IEEE Power &amp; Energy Society</td>
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<td>0871 Enhanced Machine Learning Methods for nonlinear harmonic Source Modelling</td>
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<td>0907 Power Quality Impact Analysis of Measures to encourage MV Customers to perform periodic Secondary Substation Maintenance</td>
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<td>0932 A Comparison of Methods for calculating Harmonic Emission Limits for Customer Installations connected to MV/LV Systems used in Germany and United States</td>
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<td>0950 High-Order Harmonic Emission in Low Voltage Networks</td>
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<tr>
<td>1009 The third Edition of the Austrian-Czech-Swiss-German (D-A-CH-CZ) technical Rule for Assessment of Network Disturbances</td>
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<tr>
<td>1031 Presenting a new Correction factor for IEC 60364-5-52 Standard in Cable Calculations under harmonic Conditions</td>
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<td>1051</td>
<td>Power Quality Monitoring Data Management and Analysis for Distribution Networks</td>
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<td>1132</td>
<td>Site Indices for High Frequency Harmonics for Long Term Power Quality Monitoring</td>
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<tr>
<td>1150</td>
<td>Pre-Normalisation of Grid Impedance Measurement in the Power Line Communication Frequency Band</td>
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Power Quality and Electromagnetic Compatibility

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Luleå University of Technology, Sweden

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¹University of Sao Paulo, Brazil. ²CPFL, Brazil

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¹Politecnico di Torino, Italy. ²Universidad de Sevilla, Spain

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¹E.DIS Netz GmbH, Germany. ²Avacon Netz GmbH, Germany. ³TU Graz, Austria

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¹RINA UK Tech Ltd, United Kingdom. ²UK Power Networks, United Kingdom

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Carlos Cardoso¹, Andreia Leiria¹, Carlos Oliveira², Tiago de Vasconcelos³
¹EDP Labelec, Portugal. ²GENERG Serviços, Portugal. ³E-REDES, Portugal

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Joachim Przibylla¹, Rolf Witzmann¹, Mateo Lippich Golobart¹, Cornelius Biedermann², Gian-Luca di Modica²
¹Technische Universität München, Germany. ²Technische Universität Braunschweig, Germany

Decentralized earth fault compensation in MV-grids - challenges and solutions
Katrin Friedl¹, Robert Schürhuber¹, Lothar Fickert¹, René Braunstein¹, Walter Hipp²
¹Graz University of Technology, Austria. ²Energie Steiermark Technik GmbH, Austria

Passive loop mathematical model as a reduction method for overhead line magnetic field
Ahmad AH Ana
The Ministry of Electricity and Renewable Energy Egyptian Electricity Holding Company North Delta Electricity Distribution Co., Egypt

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Vineetha Ravindran, Sarah Rönningb, Math H. J. Bollen
Luleå University of Technology, Sweden

Harmonics and wind power installations
Math H J Bollen¹, Sarah K Rönningb¹, Daphne Schwanz², Naser Nakhodchi¹, Vineetha Ravindran¹
¹Luleå University of Technology, Sweden. ²Eirgrid, Ireland

Interharmonics under fundamental frequency variations
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Electronics Research Institute, Egypt

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Sandor Simon¹, Matthias Quester¹, Sriram Gurumurthy², Antonello Monti²
¹RWTH Aachen University, Institute for High Voltage Equipment and Grids, Digitalization and Energy Economics (IAEW), Germany. ²RWTH Aachen University, Institute for Automation of Complex Power Systems (ACS), Germany

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¹Alexandria Electricity Distribution Co., Egypt. ²Egyptera, Egypt

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¹Enexis, Netherlands. ²University of Technology, Eindhoven, Netherlands

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¹Swansea University, United Kingdom. ²TU Dresden, Germany

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Alexandria Electricity Distribution Company, Egypt
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Ana Maria Blanco¹, Shrinath Kannan¹, Moritz Meinck¹, Camilo A. Garzón², Miguel Fernando Romero², Vanessa Quintero², Andrés Pávás², Jan Meyer¹
¹Technische Universität Dresden, Germany. ²Universidad Nacional de Colombia, Colombia

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¹TU Wien, Austria. ²University of Vienna, Austria

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SPECIAL REPORT

Session 3
Operation, Control and Protection

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Introduction
For CIRED 2021 about 280 abstracts have been received in Session 3. This means – for the first time in the last 20 years of CIRED-history – we received less abstracts (about 200) than for the CIRED before, for sure due the Covid-Crisis. Since still about 180 authors have been asked to submit a full paper, the ratio of acceptance was much higher this time (about 2/3) as in the past (about 1/3). Unfortunately for around 40 accepted abstracts the authors did not deliver a full paper – probably due to the Covid-Crisis, too. Therefore 147 full papers have been finally accepted. Fig. 1 gives an overview of the review process.

Since CIRED 2021 was moved to an Online-Event 120 Poster presentations have been spread over nine Online Poster Streams, while 24 papers have been selected for an oral presentation in the Main Session and nine papers are allocated to the Research and Innovation Forums (RIF), of course Online, too.

Traditionally and according to the topics of the papers submitted, Session 3 is structured into three blocks: While the Operation-block contains four sub-blocks, the Control- and the Protection-block are divided into five respectively three sub-blocks.

The Session 3 structure of CIRED 2021 is as following:

**Block 1 Operation**
- TSO/DSO Interaction
- Workforce management & Crisis
- Maintenance
- Predictive Maintenance
- Distribution Management
- Forecasting & Demand Side management:

**Block 2 Control**
- Communication
- Cyber Security
- SCADA / Distribution Management Systems
- Flexibility
- Islanding
- Low Voltage Automation
- Medium Voltage Automation

**Block 3 Protection**
- Fault Location / Earth Fault
- Applications
- Algorithms & Simulations

An overview of the number of papers related to the different blocks and sub-blocks is given in Fig. 2.
The contributions in the field of operation are focusing on reactive power management, UPS issues and virtual reality in Training for crisis, operation and assembling as well as maintenance with drones, capturing and evaluating pictures automatically based on Artificial Intelligence (AI). Also in signal analysis and forecasting an upcoming use of AI can be observed. There is an interesting mix of contributions in the field Distribution management about digitization of grid including thermal rating in MV feeders, microgrid applications and even dynamic topology in LV grids with soft open points.

**Sub block 1: TSO/DSO Interaction**

Due to decentralized generation and upcoming cables in DS a significant change in reactive power flow can be observed. There is an upcoming need of tight cooperation between TSO and DSO. Paper 699 from Czech Republic. Fig 1 demonstrates the growth of reactive power flows from 110 kV to TS in CZ.

![Fig. 1: Growth of reactive power flows from 110 kV to TS in CZ (paper 699)](image)

**Recommendations for future Q-management**

are in planning and operation are given. The provision of reactive power from decentralized generation in LV and MV grids and its impact on node voltages in superimposed networks is presented in paper 515 from Germany. From various simulations at of EHV/HV transformers an amplification effect (+32%) across the voltage levels is shown. Portuguese DS reports in paper 770 about dynamic reactive power management, optimizing the powerflow between DSO and TSO resulting in a significant reduction of losses and penalty cost demonstrated in real world. Authors from TSO and University conclude that the most significant increase of adequacy indicators due to additional load rises from heat pumps as well as close to constant addition to the load due to data centers. In regards of improvement of adequacy indicators DSR is important and requires further investigations.

**Sub block 2: Workforce management & Crisis**

In case of planned maintenance or disturbance in substations a mobile UPS (DC/AC 12/24/48/110/120/220/230 V) is required. Paper 1061 from an Austria DSO and manufacturer presents a comfortable implementation.
Results for an UPS for datacenter under test including faults are reported in Paper 633 from US.
Paper 217 reports about a Swiss railway tunnel supply by 1 kV equipped with an emergency generator including blackout and black start functions under test. An improper transformer (much higher inrush than specified) damaging a circuit breaker was identified and had to be replaced.

From Portugal, paper 900 reports about an update in the DSO’s outage forecasting tool for heavy weather situations implementing successfully machine learning. Also from France a contribution (paper 154) introduce a comprehensive framework to forecast daily interruptions on the overhead network related to weather conditions using historical weather data from Météo-France and historical interruption data from French DSO.

Paper 345 reports about an successful experiment reorganizing operations teams from fixed to flexible ones resulting in saving time at increased number of kilometers but saving extra flexible teams and their vehicles.
From Slovenia, a dynamic Job-planning-tool aggregating the maintenance work to most efficient packages is presented in paper 773.
Virtual Reality in trainings for operations technicians is reported in paper 93 from Germany. DSO and University applied VR for training of emergency cases and installation of sensors for digital substation. The Authors conclude that VR-technology is ready for such applications and report a positive feedback from workers having completed the training.

Sub block 3: Maintenance
An Augmented reality experience for assembling complex components is reported from India in paper 494. The system supports the installation of products of one of the main manufacturers in the field of switchgears and offers also remote assistance.
Also in Portugal, an AR/VR-pilot with testing several use cases from simple assistance up to teaching has been implemented. Paper 394 reports besides advantages within the pandemic situation that execution time increases but lower error rates and more efficient and better documentation can be expected. The total evidence of benefit is not clear yet.
Drones (UAV) and artificial intelligent (AI) are used at a German DSO for inspection of overhead lines in MV and HV grid. The recognition of objects and condition required 1000 pictures for training the AI-system.

The authors of paper 7 report about successful use and further development towards flights
outside the visual range of drone controller, equipping substations with drone garages and setting up an event-oriented inspection. A very intensive use of UAVs is presented in paper 1114 from Malaysia reporting about decreasing outages and SAIDI as well as about reduced cost for inspection and savings in total.

![Fig. 8: Pictures from drones flight (paper 1114)](image)

Paper 638 from Norway presents a workflow for training and serving deep learning models for picture classification and object detection. This paper gives very interesting insights on the system behind AI applications in inspection using pictures. Paper 760 from Slovenia presents a DSO use of augmented and mixed reality in real time from geographical information system with mobiles, tablets and AR glasses. Authors somehow underline the potential of these technologies but also discuss difficulties and problems.

Maintenance of lines and stations sometimes requires customer interruptions, causes additional constraints or affect the secure supply. Paper 1028 reports from Belgium about a decision-supporting optimization software for planning maintenance. The tool succeeded to reduce the number of outages by -19%.

The safety of Workers against electric shock but also other impacts is addressed in paper 1066 from Brazil. A DSO and university report about investigations of use cases regarding wearable sensing.

For detection on PD on cables, a new method from an Austrian manufacturer for cable testing is presented in paper 866. Instead of a high-frequency-current-transformer a voltage detecting sensor can be used. Thus, the cable can be kept in operation.

![Fig. 9: Thermography for detection of bad connectors (paper 1016)](image)

Paper 2016 reports maintenance by thermographic pictures in Sao Paolo in Brazil combined with setting up a digital Twin (DT).

**Sub block 4: Predictive Maintenance**

Within the DT mentioned above IOT is implemented and used for a predictive maintenance 4.0 pilot. Authors of the related paper 1070 expect better power quality from improved asset management. From Japan, paper 186 reports the detection of faults in advance by detecting and analyzing transients. A travelling wave analysis combined with several further data are assessed in an AI supported system. This can be understood as a new age of operation as there are impacts on asset management as well as on operation resulting in preventive actions with at least less outages.

Prevention from faults caused by vegetation requires lot of maintenance by cutting trees and other plants. From Portugal, a new method of analyzing the vegetation from videos taken with moving vehicles is presented in paper 946. The solution is still under development and not ready to be deployed but seems to promises to become a helpful tool in future.

**Sub block 5: Distribution Management**

*Smart and intelligent grids:*

Within Paper 4 a couple of Austrian DSO report about the future challenge distribution system operation. DSOs will extend load-flow-forecast coordinate with TSO on a cascade principle. This will require additional financial and especially human resources for operational planning on a 24/7 schedule. Several sensors for grid operation (MV/LV) have been installed at French DSO are presented in paper 570 including ICT aspects. On overview of digitalization projects at French DSO is given by paper 533.

At any fault but also in normal conditions transients are occurring. From transients
travelling waves are resulting. Their characteristics and the propagation time can be used for localization and maybe even fault prediction (paper 194, Russia). A DSO from Brazil reports about thermal rating in MV Feeders in paper 925 using a limited number of temperature sensors as for feeders without sensors the temperature can be calculated from those with sensors. Paper 964 from Sweden presents a strategy to improve of SAIDI by sectionalizing and automating the MV Grid.

CIRED Working group 2018-03 (France, Spain, Italy and Portugal) has assessed several demonstrators for microgrid operation in connected and in islanded mode. As a result of this analysis paper 704 presents technical requirements for microgrids. Paper 786 (France) reports about a microgrid simulation tool applied for operation of a microgrid as a digital twin. The full balancing of a small grid requires relatively large storage. Paper 1072 from Pakistan reports about a soft load shedding instead of forced load shedding.

In Portugal alerts of events (e.g. bad power quality) detected by smart meters are used for grid diagnostic (paper 551). The idea to detect faulty conditions in LV Grids with data from distributed measurements is analyzed in Paper 811 from Czech Republic. The authors conclude, that using voltage data in highly connected mesh network cannot be reliable due to limited accuracy and recommend the use of total currents of MV/LV transformers.

Sub block 6: Forecasting & Demand Side management: Portuguese DSO has set up a large big data platform for generation and load forecasting (Paper 536). 13 different machine learning models were tested and validated. Different optimization targets and the robustness against abnormal conditions were investigated. Paper 255 presents a simple Dynamic Short Term Correction model allowing for dramatic improvements of consumption load forecasts compared to GAM forecasts. This paper emphasizes that it is especially efficient during times of consumption habits changes like the 2020 France lockdowns. From Portugal in Paper 778 reports about a Big Data application in forecasting.

Charging electric vehicle requires balancing of cost for wall boxes and grid with the expected quality of charging service. Paper 229 from Finland and Germany presents an algorithm using a charging price based prioritization resulting in a more efficient use of charging system. Paper 70 (Switzerland) presents results about different pricing for ancillary services and concludes that RES still need to be prioritized.

Paper 821 reports from Quality Of Service monitoring by the regulatory board in Cameroon. For three types of areas: metropolitan, urban and rural different SAIFI, a reliability rate as a percentage of feeders with a SAIFI less than 80h/year and the replacement delay of defect transformors is monitored.

For better finding of know how out of documents and reports a structured knowledgebase GENBERT is presented in paper 506 from Korea.

![Fig. 10: Installation of SOP (Soft Open Point), AC-DC-AC converter](image-url)
### Table 1: Block 1 OPERATION

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<th>Paper No.</th>
<th>Title</th>
<th>MS a.m.</th>
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<td>Experimental and HIL investigation of under-frequency and rate of change of frequency load shedding schemes in interconnected networks with high penetration of renewable generation.</td>
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<td>0515:</td>
<td>Impact of reactive power provision by distributed energy resources on superimposed voltage levels</td>
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<td>0521:</td>
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<td>0699:</td>
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<td>Resource Adequacy Methodologies – future flexibility options added to Austria's generation fleet and its impact on adequacy</td>
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<td><strong>Sub block 2: Workforce management &amp; Crisis</strong></td>
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<td>0093:</td>
<td>The implementation of immersive Virtual Reality trainings for the operation of the distribution grid – development and integration of two operational use cases</td>
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<td>0154:</td>
<td>Daily wind-based interruption prediction in Enedis’ Medium Voltage Overhead Lines using time series data</td>
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<td>0217:</td>
<td>Results of Blackout-Tests of 1 kV Supply for the New Swiss Railway Tunnel Eppenberg</td>
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<td>0345:</td>
<td>Survey on flexible operation technicians teams rounds</td>
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<td>0633:</td>
<td>System simulation and analysis of faults and transients in data center power distribution</td>
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<td>0773:</td>
<td>The use of job plans for dynamic calculation of resources</td>
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<td>0900:</td>
<td>Forecasting the number of outage affected clients in extreme weather conditions</td>
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<td>1061:</td>
<td>Implementation of a mobile uninterruptible power supply - device</td>
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<td><strong>Sub block 3: Maintenance</strong></td>
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<td>0007:</td>
<td>Automated overhead line inspection using UAVs and image recognition software</td>
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<td>0394:</td>
<td>Application of Assisted Reality at Maintenance Activities: EDP Distribuição's Pilot Project Results</td>
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<td>0494:</td>
<td>Assembly and Installation Guidance by Augmented Reality</td>
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<td>0638:</td>
<td>Workflow for training and serving deep learning models for image classification and object detection -- Application to fault detection on electric poles</td>
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<td>On-field asset &amp; GIS utilization in real-time</td>
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<td>0866:</td>
<td>A new method to measure online PD on MV power cables by connection of a measurement system to the voltage detection system (VDS) of a switchgear</td>
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<td>An Integrated Planning Approach for the Scheduling of Grid Activities requiring Outages</td>
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<td>Towards Distribution Network Enhanced Maintenance Regime for Medium Voltage Overhead Lines with the Deployment of Extended Applications of Unmanned Aerial System in TNB</td>
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<td><strong>Sub block 4: Predictive Maintenance</strong></td>
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<td>Computer vision model for low voltage vegetation management</td>
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<td>Future Challenges for Distribution System Operators</td>
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<td>Application of soft-open points for the interconnection of neighboring low voltage distribution networks</td>
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<td>RELATIONSHIP OF ESSENTIAL WAVEFORM PARAMETERS OF TRAVELING WAVE WITH THE CAUSE OF THEIR OCCURRENCE</td>
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<td>Industrialization of French Smart Grid solutions for a more efficient, digitalized Distribution Grid</td>
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<td>Diagnosing problematic LV grids using georeferenced Smart Meter data</td>
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<td>Enedis IoT smart grid solutions for more efficiency</td>
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<td>0704:</td>
<td>Technical requirements for the operation of microgrids in both interconnected and islanded modes - Presentation of the working group CIRED 2018-03</td>
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<td>0811:</td>
<td>Indication of abnormal operation conditions in a mesh network based on data from distributed measurement (LV)</td>
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<td>0925:</td>
<td>Intelligent System for MV Overhead Feeders Load Control for Emergency Operations</td>
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<td>0964:</td>
<td>Strategies for Implementing Monitoring and Remote Control Equipment in an Urban Distribution Network</td>
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<td>Soft Load Shedding based Demand Control of Residential Consumers</td>
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<td>Sub block 6: Forecasting &amp; Demand Side management</td>
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<td>0070:</td>
<td>Influence of network constraints and product split on the possible revenue of distributed generators providing ancillary services</td>
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<td>0229:</td>
<td>Realistic QoS optimization potential in commercial EV charging sites through electricity price-based prioritization</td>
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<td>Dynamic short term correction of energy consumption forecasts during CoViD-19 Epidemics</td>
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<td>0414:</td>
<td>Estimation of energy losses in LV networks using data mining algorithm</td>
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<td>Load forecasting optimization</td>
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<td>0712:</td>
<td>Study of several electric scales to optimise electric bus depot connections to the grid under normal and abnormal operation conditions</td>
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<td>0778:</td>
<td>PREDIS – State of the art cloud massive forecasting</td>
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<td>0821:</td>
<td>Development of a method for monitoring the quality of service of distribution networks in Cameroon</td>
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<td>0881:</td>
<td>Comprehensive large-scale distribution test networks</td>
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Block 2: “Control”

63 papers have been accepted for the block “Control” within 7 sub blocks:
- Communication (6 papers)
- Cyber Security (3 papers)
- SCADA / Distribution Management Systems (9 papers)
- Flexibility (8 papers)
- Islanding (7 papers)
- Low Voltage Automation (12 papers)
- Medium Voltage Automation (18 papers)

Compared to the previous conferences the two categories ‘Flexibility’ and ‘Cyber Security’ are added as new sub blocks in the control block of session 3.

The number of accepted papers is slightly higher than the number of selected control papers of the previous conference in Madrid. It can also be stated that the number papers in the sub blocks are similar to the previous conferences.

Sub block 1: Communication

Six papers representing the initiatives in the field of communication technologies.

Paper 523 from Spain shows the use of a Simple Network Management Protocol (SNMP) for monitoring and control in distribution automation systems. The paper shows a use case for a Spanish DSO with 250 devices.

The standard IEC 61850 is addressed by the paper 504 and 595. Paper 504 evaluates the applicability of IEC 61850 for SCADA system communication with centralized protection and control devices acting as communication gateway via public telecommunication networks. The authors describe the advantages of consolidation of multiple relays into one device and they stated that this will be paradigm shift to the traditional state of the art way we know from the communication between substations and control center.

First tests of IEC61850 with multi-vendors started about 25 years ago. Even if the standard is already well established in many utilities but it seems to need further testing in this area. The Portuguese paper 595 of EDP Labelec and E-REDES describe such a test with four well-known vendors. It shows the testsbed (see Fig. 11) and finally limits of IEC61850 between different vendors. The content of paper 595 covers real questions of utilities considering the growing number of IED in public grids.

Sub block 2: Cyber Security

Three papers deal with the topic of sub block cyber security. The improvements in monitoring and control lead to higher reliability in network operation. On the other hand cyber-attacks can...
lead to the opposite with high impacts that might cause long interrupts of the system. The main objective of the German paper 769 is to analyze security concerns that may raise by applying virtualization in cyber-physical energy systems (CPES). The participation of new actors like active customers lead to high challenges to protect the systems against cyber-attacks. The paper shows a multi-layer model with several potential attack scenarios (see Fig. 13) and gives an overview of a virtualized CPES concept.

Fig. 13: Multi-layer model with potential attack scenarios (paper 769)

A second German paper 916 also address the threats of cyber-attacks. The proposed approach provides flexible and scalable replication of multi-staged cyber-attacks in a smart grid co-simulation environment. The paper presents a detection system that analyses the network traffic with machine learning algorithms. The co-simulation allows a replication of attacks as well as the evaluation of countermeasures.

Paper 967 from UK investigates managing the access to the configuration computer on the host computer which can be interfaced with common access control strategies. It combines multiple existing technologies to manage access to the HMI. The validation of the proposed architecture is done by a virtual site acceptance testing and training.

This sub block contains 9 papers. The main portion of papers addresses the increasing need for better performance of SCADA systems due to new challenges and increasing number of available data. New ways to deal with new technologies are presented and it will be interesting to observe how utilities will accept these upcoming technologies in future.

When talking about reliability of power systems we normally use traditional figures about the probability of components to investigate the reliability of the whole system. But how can new challenges influence the system availability in future. The topic is addressed by several paper if different focus.

Paper 24 from Sweden addresses the reliability aspects of dynamic thermal rating. Due to increasing load and infeed the equipment loading is continuously increasing since years. Reliability analysis deals with the availability of components and systems and the effect to the power supply. Dynamic thermal rating increases the risk of unnecessary operation and lack of action in the system due to errors in the calculation. This is a new approach which must be considered if DTR is introduced into a public supply system.

The identification of critical events is also subject of paper 128. The increasing dynamic behavior of distribution grids necessitates the need to monitor distribution grid in real time. Nowadays the central control centers are not fitted to deal with high numbers of alarm messages. If critical alarm message cannot be immediately identified this might lead to an increase of customer interruptions. The authors propose a framework that uses machine learning. The system was tested in a pilot project by a Dutch DSO.

Next level reliability and resilience on a cloud-based substation control system is discussed in paper 162. The paper conducts a qualitative assessment in for substation control system architectures (see Fig. 14). Conclusion of the authors: “Cloud-based SCADA systems improves sustainably resilience, supports high level reliability, and brings great flexibility with the principle of on demand compared to traditional SCADA.” The future will show if and how SCADA as a Service will be established in the traditional utility business.

**Sub block 3: SCADA / Distribution Management System**
The authors of paper 870 from Germany propose a high-performance computing power flow calculations grid simulation approach. The increasing and huge number of DER has an impact of the control mode on the operation. Nowadays planning of the operation as well as real-time operation in quasi-static mode need a lot of simulations in parallel. The paper shows the modelling of DER as well as the simulation based on real data from a German MV grid.

As already discussed in the previous papers the high number of available information are critical to analyze with traditional methods to identify faults in the power system. Several papers address the topic of providing relevant data to human network operators.

Paper 363 from Portugal discusses a strategy to handle the increasing number of date nodes (e.g. smart meter) and how to capitalize value form data. Can these information be used to enable proactive action on grid constrains even before customers report them? The paper shows the operational processes and conclude that there is huge improvement potential regarding aggregation and process optimization.

Paper 513 present a hierarchical optimal power flow (OPF) algorithm implementation for active distribution networks of the future. The OPF uses decentralized field measurements (see Fig. 17) and provide a redundant solution to the centralized OPF approach. The algorithm is verified in a hardware-in-the-loop simulation and ready for a field test. Especially the flexibility and redundancy are promising for future implementation into the real world.
Fig. 17: Hierarchical OPF implementation (paper 513)

The Austrian and Chinese paper 63 show the difference in transient stability between grid forming and grid following. The emerging number grid forming inverters lead to completely different behavior in terms of synchronizing mechanisms. The paper analyses and compared the differences in transient stability between the two concepts. The paper shows that the robustness of synchronizing mechanism of grid forming inverters is better than that of grid following inverters.

Sub block 4: Flexibility

Eight Papers addresses the increasing needs for flexibility. This becomes more and more important of offer power system services based on the availability of flexible loads, generators and storages. Presently most of the approaches are still in the simulations phase and real time testing in the field is just starting.

Paper 882 from United Kingdom shows a technology assessment for flexible services in distribution grid. The paper offers a high-level view of the network flexibility procurement and use process which will feed into a DSO plan to procure flexibility services. It is a very good start into this sub block before going into the detailed simulations and flexibility tools.

Paper 198 from Switzerland proposes a DSO flexibility operation platform with DER management based on grid monitoring and control equipment at the secondary side of ML/LV transformers and LV street cabinets and DER. In this Horizon2020 project the benefits of reducing cost and improving hosting capacity of renewables are shown. The paper also shows that there is need to have knowledge of the LV system for grid operation. This is presently a discussion in many utilities.

French paper 205 present a modular mixed-integer linear programming (MILP) optimization motor for sort-term operational planning (see Fig. 18). The tool enables the DSO to adopt a global, techno-economic approach to solve network constraints through many available non-topological levers (including flexibility) and the rules related to their use.

Paper 388 from Germany introduces the implementation of an online aggregation of the flexibility potential in distribution grids. It shows how to combine state estimation with the aggregation of flexibility potential of DER as well as flexible power units (e.g. storage, loads and generators) to get from a passive distribution grid to flexible power grid. The algorithm will be tested in an online grid monitoring system.

Another approach of increasing flexibility in public grid is presented in paper 554 from Germany. In this paper, the application of self-learning algorithms based on reinforcement learning are applied for the task of optimally scheduling flexibility in distribution grids. It is shown that the methods are able to learn policies that control flexible devices in a way, such that the overall cost of operation is reduced.

The active response project described in paper 923 is implementing active management software to release constrains and mitigate the impacts of low carbon technologies by reconfiguring the network and actively controlling power flow. The algorithm was also tested against EV charging, which might lead to temporary overloading. In the scenario shown in
Paper 923, the network was able to cope with up to a 150% increase in load without upgrading the infrastructure.

The authors of paper 1013 present an approach for a framework to test multi-use concepts for the coordination of flexibility resources in distribution grids. It allows testing in a large-scale co-simulation environment and in a cyber-physical smart grid laboratory (see Fig. 19).

Fig. 19: Coupling point of the grid with measuring devices and broadband PLC modem (paper 1013)

Multi-agent systems have already been discussed in the previous two decades. Paper 963 from Finland and Iran took this topic to show an incentive-based management of multi-agent distribution systems in contingency conditions. In the proposed framework utilities provide incentives to agents collaborating in supplying isolated load demands as well as decreasing the operational costs of the grid during contingency conditions.

Sub block 5: Islanding

Islanding is also getting more important in well-developed power systems. 7 papers address this field. Two main aspects are discussed: islanding as a basis for black start restoration and the technical challenges of temporary islanded mode operation.

Paper 196 addresses feasibility and socioeconomic aspects of black start services. The Spanish authors analyzed the impact of distributed generation on restoration process and the capability of the DSO to provide energy to the customers before the TSO is able to restore generation (see Fig. 20).

Fig. 20: High level diagram of the proposed methodology (paper 196)

Also paper 782 from the United Kingdom investigates the capabilities for black start. The paper explores the necessary model consideration for black start studies using distributed energy resources. The learnings from the distributed restart innovation project on three network areas in the UK is shown. The authors describe the effects from voltage regulation up to protection setting and show that the success of the restoration will directly depend on the capability of the anchor generator.

The focus of paper 827 from Germany is to present a designed energy management algorithm for temporary islanded microgrid operation (see Fig. 21). The algorithm uses forecasts to calculate new power set points for the distributed generator units and is suitable to achieve a required minimum operating time of 24 hours in 70% of the investigated scenarios.

Fig. 21: Modular concept for temporary islanded mode operation (paper 827)
Paper 563 investigates the applicability of a distributed grid-forming control concept for the temporary islanded mode operation of existing medium voltage grid structures. Critical situations may occur after switching additional loads close to the grid forming converters. This load change has to be taken over by the grid forming converters completely as grid following converters increase the active power generation with time delay.

Operation principles for temporary islanded microgrids considering fairness of supply is described in paper 844. The paper introduces modelling techniques for technical constrains and degrees of freedom of temporary islanded microgrid operation by expanding algorithms for optimal distribution switching on medium voltage level. The authors introduce different measures of fairness and the effect on the operational scheme is assessed.

Paper 577 from Denmark describes experiments that were conducted with a commercially available current source PV inverter to characterize its behavior during loss-of-mains events using high-precision measurements in a controlled lab setting. The US paper 958 shows the implementation and technical challenges for utilizing cogeneration to provide enhanced resilience to a hospital. It details the experience of designing a CHP based microgrid and the lessons learned in the process.

Sub block 6: Low Voltage Automation

12 papers address the topic of low voltage automation. These paper cover wide area of LV automation starting from trolley busses up to self-designed Smart Grid box of an Italian utility. The challenges of overvoltage regulation and overloading of equipment is mainly discussed in this sub block.

A special case of LV automation is addressed by paper 330 and 331. Both papers address the optimization of the LVDC traction network of trolleybusses in Germany. The studies have been carried out with Stadtwerke Sollingen, the city with the largest operating trolleybus system in Germany (51 trolleybusses, 6 battery trolleybuses, 22 rectifier stations).

Paper 331 focuses on the methodical grid state evaluation of a 660 V low voltage direct current traction network which serves as a power source for battery-trolleybusses. The main aspect is to process forecast data in order to define the grid state.

Paper 330 improves a simulation model for battery-trolleybusses which operate in a low voltage direct current network. It considers three different methods for adjusting the maximum motor power in a time-critical manner to improve bus voltage profiles.

Paper 558 describes the verification of the simulation part of a universal control framework. In this regard, a key aspect for the accuracy is the modelling of latencies and dead times of control and communication of the devices involved. The paper proved that the time behavior can be reconstructed sufficiently, even if the particular inner workings are not known.
Paper 630 from Switzerland identifies and summarizes the technical characteristics of low power wide area network (LPWAN) technology needed for condition monitoring systems. It also presents a pilot project (see Fig. 23) to test the application of LoRaWAN in substations. The main goals of the pilot project are verifying building penetration in substations and assessing the deployment effort and scalability. The results of the pilot project demonstrate the outstanding building penetration capabilities of LoRaWAN.

The number of electric vehicles increase in nearly every country and therefore the challenges for public distribution grid. Paper 708 presents a framework for a multi-level analysis of control strategies for electric vehicle containing theoretical, a simulation-based and a practical analysis (see Fig. 24). It presents results from the German research project Charging Infrastructure 2.0. The paper shows that different strategies have been studied carefully before a decision can be made. With the present simulation system an efficient platform is demonstrated to analyse control strategies on operational aspects.

The Austrian authors of paper 720 present an automatic grid reconfiguration approach for smart grid challenges. On the one hand new kind of loads (e.g. EV, heat pumps, …) lead to overloading due to changing effects in regards of simultaneity, on the other hand distributed generation lead to power quality problems. The project ‘Power System Cognification’ defines six use cases to tackle these challenges. The paper is focusing on the use case of overload prevention by temporary meshing and investigates the use of remotely controlled switching devices.

The CIRED WG 2019-5 is working on the requirements for monitoring and controlling LV grids. The report of the group is nearly finished and will be available at the end of the year. The data survey of distribution systems operators (DSOs) is presented, analysed and discussed in paper 728, to demonstrate the current vision on the evolution of LV networks. The results of the WG will also be presented in separate RT during CIRED 2021.

Paper 735 introduces the principle of voltage regulating distribution transformers and sheds light on their application to substantially increase network hosting capacity in distribution networks with high penetration of distributed generation and other low carbon technologies. The main focus is on the application conservation voltage reduction in low voltage networks to reduce energy consumption and carbon dioxide emissions. These effects have been validated in Electricity North West’s 24-month trial project “Smart Street”.

With increasing numbers of renewables and of active components like transformers with on load tap changers, too, voltage regulation is getting more and more complex. The paper 741 presents a voltage regulation approach that uses the machine learning technique called Double Dueling Q-learning (DDQN) as an extremely fast and adaptable alternative to coordinate in real-time the OLTC and the power factor of PV inverters. The case study considers a real Brazilian MV/LV three-phase feeder with 123 customers, 365 days of 5-minute resolution demand and PV generation profiles, and 60% of PV penetration.

Detailed three-phase electrical models are not readily available for most distribution companies but smart meter data is able to close this gap. Paper 785 proposes an approach to calculate...
voltages without electrical models by capturing the nonlinear relationships among the historical data (demand and voltages) and the corresponding low voltage feeder using a Neural Network. The approach can make it possible for distribution companies to bypass the time-consuming process of producing LV network models and carry out accurate calculations for any type of scenario.

Paper 851 presents some obstacles faced during the development and implementation of the state estimation functionality into a real distribution network. A dedicated state estimation algorithm was developed and implemented into 2 MV and 3 LV Slovenian distribution networks.

In paper 989, e-distribuzione describes a new low voltage remote controlled grid node design, named Smart Street Box (see Fig. 25). The Smart Street Box design enables several functionalities relate to monitor and control, using a modular approach in order to gain flexibility and cost reduction. The communication is based on power line communication and it is design to robust against vandalism. The paper show and discusses all components needed in detail.

Fig. 25: Drawings of the junction board in remote control version (paper 989)

Sub block 6: Medium Voltage Automation

18 papers address topic of the MV automation sub block. This is slightly more than in 2019.

A very good start into the topic MV automation is paper 883. This Portuguese paper shows the past, present and future role of automation in the electrical grid. This article presents the evolutionary technological context for the Portuguese DSO and its contribution to the increase of service reliability. It also presents the development of technical specifications of equipment in alignment with the company strategies. The overview is starting in the late 70th of the 20th century and ends with outlook into the future (see Fig. 26).

Fig. 26: Automation strategy milestones (paper 883)

Reclosers are a very well-known technology in many countries and might be also very useful for MV automation. Paper 98 from India contains detail experience sharing of overhead recloser deployment in suburban network, which helps the DSO to automatize its fault detection, isolation and power restoration for critical feeders by effective deployment of reclosers, configured either as sectionalizers or as reclosers. The feeder automaton pilot thus has resulted in manifold advantages for improving the performance indices for suburban network involving bare overhead lines.
The Belgium paper 233 presents a quadratic optimization model for line parameter estimation, with smart meters and/or PMUs. Specifically, the line length of multi-phase distribution lines is estimated. The approach considers that phase angle measurements of, e.g., smart meters cannot be taken into account because of the accuracy of these devices. In a simulated setting, the line lengths are estimated with great accuracy.

Paper 427 from Slovenia shows a quality of dispatching algorithm that serves the dispatching department to validate the steps taken by the dispatchers. The algorithm considers the features of the event – if it is planned or unplanned, if the exact switching manipulations are taken by the dispatcher, if the users are notified for the planned work and if the users are supplied within the planned period. The algorithm is foundation to improving SAIFI/SAIDI and quality of power supply.

Paper 426 from Czech Republic presents a new decentralized method of power and voltage control in medium voltage distribution systems. The paper shows results of influence of voltage tolerance range in MV modelled supply area on the available reactive power reserve on the HV/MV boundary. Decentralization is the way to control MV supply areas using complex systems for voltage and reactive power flow control that are not burdening SCADA systems.

The Japanese paper 493 shows the development of an advanced voltage-estimation method for the control of the step voltage regulators based on a simple calculation using measurements, including the unit line impedances in the distribution system. In the study, the authors fabricated a prototype step voltage regulator using the new method and the conventional line drop compensator method. A prototype test in a test area (see Fig. 29) has been carried out.

The Portuguese paper 457 discusses self-Healing from theory to reality (see Fig. 30). It aims to detail the challenges of legacy equipment’s integration through a gateway of communications and lessons learned during the implementation of two distinct self-healing projects. The paper also discusses other rationales behind the decision making during the implementation stages as well as several technical insights.
Paper 511 presents results from pilot project and field tests of Smart MV switchgear technology, which was installed into Czech urban MV distribution grid. Main goal of the test was to verify reliability of fault detection based on MV sensor technology, in comparison with conventional MV measurement transformers. Furthermore, several other reliability aspects of Smart MV Switchgears were tested, as this technology is infrequent in Czech distribution networks.

In paper 579, the German author present an approach towards a dynamic description of an unbalanced distribution grid by an explicit ordinary differential equation model. The majority of monitoring and control applications at a distribution system control center rely on the assumption that the distribution network is in quasi steady-state. Known limitations of the quasi steady-state assumption are its inability to capture fast transients and harmonic distortion. The comparison between real measurement data and the model outputs demonstrates that the model can replicate the fast transients and harmonic distortion in the time-domain (see Fig. 31).

Interoperability of intelligent electrical devices (IED) of different vendors has to be guaranteed in modern Substation Automation Systems. Paper 589 presents an implementation of a solution for physical and electrical interoperability between IED set in a laboratory environment with a multi-vendor infrastructure called Smartlab-SAS (Substation Automation System). The laboratory should mirror an infrastructure where IED from different vendors function together without any issues, allowing for easy substitution from one IED to another from a different supplier and more maneuverability when facing IED failures.

The paper 645 is based on detailed restoration plans developed as part of the Distributed ReStart project to re-energize a distribution network under a grid supply point using DERs, after a complete system blackout. The restoration plans are developed considering the practical challenges around operation and control of a system which is traditionally restored by a top-down approach. The restoration strategies are guided by extensive steady state, dynamic and transient analyses undertaken on three case study networks in SP Energy Networks (SPEN) distribution license areas.

Paper 648 examines the impacts of autonomous smart inverter functions on the operation of a centralized voltage optimization scheme. The
paper outlines the methodology employed, including an overview of the case study distribution circuit, the assessed smart inverter functions and control scenarios and presents the results analyzing the impact of smart inverter functions with and without a voltage optimization scheme. The simultaneous charging process of multiple electric vehicles may cause violations of power distribution grids’ operational constraints. Paper 771 investigates the impact on a medium voltage distribution grid of uncoordinated charging, coordinated grid-aware charging and coordinated grid-aware charging of EVs with reactive power support for voltage regulation. In all these cases, the EVs’ charging policy is determined with an optimal power flow problem, where suitable sets of constraints are modeled to reproduce each specific case (see Fig. 32).

Fig. 32: Workflow problem formulation using OPF (paper 771)

Paper 800 presents a grid automation planning study for the Elektroistra Pula region (HEP ODS, Croatia) in order to increase the reliability by integrating automation functions into the medium voltage network. Based on network planning variants for the years 2022 and 2032 different automation scenarios with a changing degree of substation automation were proposed and analyzed. As a result, the technical and economic efficiency of the application of different standard and innovative solutions based on the synthetic network approach is compared and the optimal measures have been derived, in order to develop a methodology to transfer these results to additional networks.

Paper 818 proposes an innovative centralized approach for voltage constraints management in the medium-voltage distribution systems based on the use of deep reinforcement learning. This algorithm permits the distribution system operators to take control decisions in almost real-time, which are optimal in terms of operational costs, while being robust with respect to the model uncertainties. The developed control algorithm is tested on a real MV distribution system located in Benin.

Fig. 33: SAIDI depending on feeder length and number of secondary substations of a feeder (paper 800)

Paper 1024 from Finland and Denmark discusses the lessons learned in implementation of coordinated voltage control demonstration. In this paper, the challenges for integrating smart substation automation system into traditional substation is presented. The preparation of a long-term field demonstration for coordinated voltage control in distribution grid in western Denmark is used as a case study. One of the results really represents the target of CIRED conferences to bring academics, researches, developers and operators together: “Academic studies usually make unrealistic assumptions for proofing the smart functionalities: perfect communication (no delay), accurate, instantaneous measurement data always available and no human errors and always up to date grid data documentations and configuration of devices”.

The Brasilian paper 1053 presents a technique for optimizing voltage and reactive power control for medium-voltage power distribution grids, at
the distribution management system level, in the context of advanced distribution automation. The control technique was integrated with the utility's legacy systems through an interoperability bus which uses the Common Information Model. It was applied in a pilot area, composed by four substations and their respective 28 power distribution feeders, with 153,215 consumers and 2,488 kilometers of extension for primary distribution network. Paper 207 from Spain presents new embedded developments and algorithms for assessing parallel operation of power transformers in primary substations. Typical ENDESA's primary substations consist of two or three HV/MV transformers and several busbars (see Fig. 34). In order to reduce both complexity and investments, a new algorithm has been developed. This algorithm has been tested in over a dozen substation, being able to determine whether transformers are running in parallel just by checking online voltage and currents.

Fig. 34: Example of a single-line diagram of a 3-transformer primary substation (paper 207)
### Table 2: Block CONTROL

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**Sub Block 4: Flexibility**

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Block 3: “Protection”

In the block “Protection” we received 35 papers, covering the topics “Fault Location and Earth Faults”, “Applications” and “Algorithms and Simulations”. New developments and improvements of protection functions as well as methods how to detect faults easier and more reliable are discussed in some papers of this block. The upcoming communication technology 5G could be a part of protection-functions in the future, but IT-security will be a big issue. Also, very interesting are the result of practical field-tests and investigations in the MV and LV network.

Sub block 1 “Fault Location and Earth Faults”

The detection of faults in the grid is a big challenge till now and will be an area of research and development in the future. One topic is like a “never-ending story”, how to detect high impedance earth faults and locate the faulty point. 18 papers are selected in this sub-block.

Starting with 2 investigations about arc during power system faults.

Paper 3 from the Slovak Republic is showing us that the arc during a power system fault is not only a pure resistance. The aim of this paper is to point out the technical problem in locating phase-phase arc faults on power lines, which is caused by the very nature of the electric arc. In the theoretical part of the paper, the cause of incorrect evaluation of the arc fault distance by standard protection relays is derived (Fig. 35).

In the experimental part, these statements are confirmed by measuring an artificial arc fault on the real power line during full operation (Fig. 36).

Finally, improvements of the fault locator algorithms are proposed, which eliminate the influence of the electric arc at the fault location on the accuracy of the fault distance calculation.

New knowledge of the extinguishing of the freely burning arc in compensated and isolated networks is pointed out in paper 608 from Germany. The reason for the investigations was, that it was observed several times in the compensated 110 kV Network that in small networks with a size of approx. 30 A and with an overcompensation of approx. 30 A the arcs do not extinguish automatically. The very detailed transient earth fault tests in the compensated 110 kV Network of NetzOOE in Austria included 30 earth faults with different network size and tuning. To simulate real events, e.g., a tree falling into the line, a standard 110-kV-conductor support assembly was used and lifted with a mobile crane, see Fig. 37.

The first very interesting results are shown in this paper, more detailed investigations are needed.

The next papers are focused on arc suppression coils.

Paper 253 from the Czech Republic describes a
new method of arc suppression coil (ASC) tuning. A multifrequency current injector has been tested not only in the Laboratory, but also in real networks in several European countries. It was confirmed that the new method can be used very reliably for arc suppression coil tuning. In this paper you can find detailed testing results and the benefits of the new method.

In paper 732 from the UK we are coming to the advanced earth fault detection in compensated networks. Sensor sets have been installed on overhead lines using the hot stick method (Fig. 38). Each sensor in a set has a label indicating the assigned phase that it should be installed on (A, B or C). There is also an arrow next to the phase label that indicates the direction of positive power flow. A key learning outcome from the installation phase of the project is to determine a consistent sign convention for power flow prior to the sensor installations. This is relatively straightforward for networks with radial feeders; however, the St. Austell 33 kV network is meshed with several 33 kV rings.

The tests showed that the sensor units were able to successfully detect all applied faults. High impedance faults including a 10 kΩ phase-to-earth fault impedance with a fault current of less than 400 mA where also successfully detected.

The biggest challenge for traditional protection is to detect high impedance faults.

Paper 74 from Sweden describes new technologies to detect low and high impedance faults. Integrated fault locating is based on two detection schemes – a very fast transient detection mainly for re-striking cable faults and a highly sensitive adaptive zero sequence admittance scheme to detect both low and high impedance faults on overhead lines and cables. Common for the algorithms is the use of neutral voltage \(U_{en}\) and feeder summation currents as detection criteria. Details and experience about this new development you will find in the paper.

A Time Domain Reflectometry (TDR) measurement (Fig. 39) has been studied and is described in paper 420 from Japan.

Fig. 39: Image of TDR measurement to the cable

This paper provides a basic study for effectiveness of TDR measurement in the uncharged state for underground distribution system including multi switchgears and ground-mounted transformers. The final goal of this study is to identify the fault part by constant monitoring in the charged state. This paper confirmed the effectiveness of TDR measurement in the uncharged state as the first step. In the next step, whether TDR measurement works in charged state will be verified.

"Earth fault localization in isolated uninterruptible power supply (UPS) networks – a new approach" is the title of paper 894 from Austria. The focus is directed on isolated DC systems.

Due to the special properties of DC voltage networks, some of the protective measures customary for AC voltage networks cannot be implemented in the same way. The design of the electrical network, the consumers and the protective measures thus determine reactions to insulation faults against earth. The new approach shows a simple and easy possibility to detect the faulty branch. By use of components such as a simple switch and resistors as well as avoidance of active current injection not only the
earth fault can be detected but also the fault current at the fault point is reduced. Experiences after installations in several substations show a very high acceptance by operational staff. The required time for fault location is reduced significantly compared to previous monitoring systems.

In paper 1074 from Brazil, you can find an experience of locating high-impedance faults through smart meters’ alarms in power distribution networks. This paper researches a key Smart Grids’ component: Advanced Metering Infrastructure (AMI), which is driven by monitored smart meters (SM). Furthermore, this paper discusses the devised methodology and presents some case studies to illustrate the location of both cable breaks and fuse-cleared faults. Then, final comments on the methodology’s suitability to assist utility’s engineers in enhancing power outage management strategies are drawn.

“Transient Earth Fault Protection based on Instantaneous Values” is the title of paper 716 coming from Spain. This paper presents the principle of operation of a new algorithm based on instantaneous values to detect Transient Earth Faults, which has been validated by RTDS simulations and real cases from the field. The results of this study with RTDS (real time digital simulator) models confirms that the application field of the study of the Transient Earth Fault Protection (TEFP) unit includes all kind of systems where transient or intermittent earth faults appear, that is, high impedance systems with high capacitance in feeders, as i.e., isolated neutral system, compensated neutral system, resistive neutral system, inductive neutral system, or a combined neutral system.

Paper 501 from Finland describes how to improve earth-fault detection performance and supply security of cabled rural MV-networks with fault isolation. First the concept of fault isolation using ITRs is introduced, and the theory is discussed. The effect of MV/MV-isolation transformers (ITR) is studied both during earth faults and short circuits, including faults in the LV-distribution network. For this, simple hand calculation equations are derived. Techniques for fault detection in fault isolated networks are suggested and their performance demonstrated. The applied network data is obtained from practical networks of DSO Elenia Verkko Oyj in Finland enabling actual piloting and field testing of the proposed concept in later stage.

Fig. 40 shows an example of feeder distance protection application for a network of DSO Elenia Verkko Oyj. With proper settings, the protection zone covers the whole MV-OHL-section and can discriminate short-circuits faults from load currents in wide range of loading conditions. However, as the protection zone may also reach to the LV-side of the MV/LV-transformers, additional time co-ordination with LV-side protection may need to be considered.

**Fig. 40:** Principle of applying distance protection as time selective backup protection for OHL-sections behind ITR

In the proposed concept, the isolation transformer together with necessary protection and communication functions and devices are located in a dedicated compact secondary substation (CSS). The principal design illustrated in Fig. 41.
Paper 491 from France analyses the impact of a massive integration of distributed inverter-based resources (IBR), and of the reduced transmission system short-circuit power on the spread of voltage perturbation on the distribution grids and on their stability. A typical transmission network and generic distribution grids are modelled considering IBR connected at the medium voltage (MV) level. It was assumed a scenario in which a portion of the power system contains 100% of the generation interfaced by power electronic inverters and connected to the distribution grid. EMT simulations were carried out to assess the effect of the dynamic voltage support (DVS) capability of IBR. It was shown that in reduced short-circuit level conditions, the DVS helps to reduce the voltage dip during the fault and to ensure a fast voltage recovery after the fault while respecting the Over-Voltage Ride-Through (OVRT) profiles of IBR at MV level.

The simulation results indicate that a lower level in the short-circuit power of the transmission network may present risks of phase-locked loop (PLL) instabilities of IBR connected at distribution grids. It was also shown that the DVS capability of distributed IBR helps reducing the voltage dip during the fault and to ensure a fast and stable voltage recovery after the fault while respecting the OVRT profile. The risks of anti-islanding protection trip due to under-voltage were also discussed. The study highlights the need to delay anti-islanding protection of IBR connected at MV level.

The next paper 455 coming from the Czech Republic deals with the issue of utilization of faulty phase earthing (FPE) technique as alternative to single phase fault auto reclosing in resistor earthed medium voltage distribution network. Possible integration of this technique to common protection concept as well as fault current limitation efficiency is discussed in the paper. To evaluate the benefits flowing from FPE utilization, a sensitivity analysis of FPE in simple distribution network was performed focused mainly on FPE impact on voltage dips and swells invoked at low voltage level.

To evaluate the operational efficiency of FPE as substitute for the auto reclosing, the impedance conditions of network path and fault are very important, because they are related to fault current redistribution between fault location and FPE location after application of FPE during single-phase faults, see Fig. 42.

In paper 234 from Belgium a holistic study was carried out regarding the earth voltage rise due to earth faults in MV networks presenting either only underground cables or a mix of underground cables and aerial lines. The matter was investigated both via simulations with electrical models in a dedicated modelling tool (EMTP-RV) as well as via two dedicated field tests where a live MV cable was faulted (Fig. 43) via a dedicated cutting plyer and exhaustive measurements were carried out.
In this paper the modelling method and assumptions for the parametric simulations are first presented, followed by the simulations results as well as the field tests and measurements that ensued. It was observed that all else being equal, earth voltage rises are much higher in mixed networks than in pure underground cable networks, due to interruption of the metallic screens and the consequent obligation for the fault current to return via the earthing connections at some point. The earth voltage rises in the pure underground cable network were ultimately relatively low in most scenarios.

Paper 240 from Ireland shows “Optimised solutions for MV neutral treatment and earth fault detection”. This paper introduces a hybrid solution featuring arc suppression, supplemented by faulted phase earthing for standard risk feeders, or by selective tripping for high-risk feeders, supported by sophisticated fault location techniques. This is an elegant solution providing high levels of supply continuity, supply quality, safety, and operational simplicity. Future flexibility is provided to meet the ever-changing demands of distribution networks.

A new method for measuring the earth fault-distance in compensated and isolated networks is described in paper 600 from Germany. With the new method it is now possible to find a distinction and to carry out an earth fault distance measurement. The detailed results from real earth fault tests in a meshed 110-kV-network (ICE = 900 A) with overhead-lines and a 20-kV-network (ICE = 600A) with cables will be presented.

Paper 936 from Austria shows practical approaches and methods for determining additional thermal loads on equipment like cable shields or transformers and the proper continued functioning of existing systems such as the selective earth fault detection. Influences and limits are shown, and their results are used, to answer the open questions, considering existing framework conditions.

Cross-country faults (CCFs) in resonant-earthed networks are analyzed in paper 324 from Sweden. The approach of this paper focused mainly on evaluation of Distance Protection and its impedance measurement during CCFs.

In paper 922 from Norway a novel method for placement of intelligent electronic devices (IEDs) is proposed, where the IEDs are defined by a probability of failure to deliver the service required (due to internal failure or communication interruption). The solution of the optimization problem is based on the application of Genetic Algorithm, with the objective to minimize the total annual cost, which is a compromise between the interruption costs of energy not supplied (CENS) and the yearly expenses (and the reliability) of each IED installed.

Sub block 2 “Applications”
In the sub block “Applications” we received 13 papers with very different topics. The common topics of this papers the practical tests or the implementation of functions in real systems. Several papers are focused on protection, automation and control applications based on IEC 61850.

Paper 974 from the UK describes how to improve reliability on IEC 61850 substations. This paper focus on two aspects of LAN-integrated protection systems: Identifying which device should alarm each communication loss,
including IEDs and Switches. This paper also addresses monitoring strategies to enable early identification of conditions which could lead to a failure on demand. The objective is to increase availability even if the mean time between failures is reduced.

The importance of device and network monitoring, and how it can be used to identify malfunctions as soon as they happen to prompt maintenance and minimize the period of unavailability is highlighted.

Paper 1130 coming from France is titled with “Functional specification of protection, automation & control applications based on IEC 61850 independent of their implementation”. With the new possibilities described in this paper, a user will be able to use IEC 61850 file format to express automation application requirements, by expressing the electrical topology in the application scope, along with the functions used to manage this application & the data exchanged between functions to operate properly the application with the values of the application parameters.

Based on this standardized expression of the user requirement, a system engineering, equipped with correct tools, will easily use aggregation of application function specifications as system specification without need to redefine all requirements.

The European project H2020 Osmose task 7.1 is working on improvement of the specification process to provide such capability, and the result is directly reused by the IEC Technical Committee 57 to write the new standard part IEC 61850-6-100.

The next paper 1135 coming from Austria is focused on “Redundancy for Power Utility Communication Networks”. With the proliferation of IEC 61850 and moving the information transfer from hard-wired signals to message exchange over the power utility communication network, this network became a mission critical part, so redundancy was required for the communication network as well. This applies in particular when using Sampled Values for delivering the measurements from the power system to the protection relays. Thus, redundant communication networks are a precondition for the Digital Substation.

The redundancy mechanisms (Parallel Redundancy Protocol) PRP and (High-availability Seamless Redundancy) HSR serve this requirement. The two concepts have their specific strengths and can be even combined. But there is no ideal network architecture that serves every need equally well. Thorough thought must be given to select a design that best fits a specific protection, automation, and control system.

The two RedBoxes in Fig. 44 coupling the PRP and the HSR network operate in a special coupling mode. As they are both duplicating messages which are already duplicated in the PRP network, there would be four copies of a message in the HSR ring. The two RedBoxes are aware of each other and discard excessive duplicates, so that only one duplicate of a message is traversing the HSR ring in each direction.

In paper 334 from France is shown how designing a 5G based smart distribution grid protection system. Fault Detection, Isolation, and Service Restoration (FDIR) systems, which utilize real-time data exchange from various Intelligent Electronic Devices (IEDs), would require better communication technologies to this purpose. To mitigate these risks and provide new functionalities, a new paradigm could be considered for the design and operation of power distribution grids if all the devices could be interconnected through secure, reliable, and low latency communication infrastructure.
A 5G wide-area communication network has the potential to act as key enabler for future smart grid applications. Next generation of power protection schemes can leverage the use of 5G to become more efficient, faster, and less expensive. Therefore, the execution time of such FDIR system will be reduced from a few minutes to only a few seconds, and it will possibly embed advanced protection functionalities. The outage risk will be mitigated, and thus supply quality will improve considerably.

Paper 58 from Greece describes a solution against protection scheme design complexity in modern active distribution systems. To deal with protection scheme design complexity in modern active distribution systems, a plug-and-play (PnP) protection scheme is proposed. This protection scheme does not require any relay settings, traditionally resulting from a protection design study, and is, as far as possible, independent of a particular distribution system. This paper provides a high-level description of the plug-and-play protection concept and applies it to a real medium-voltage distribution system with distributed generation. The plug-and-play protection scheme proves effective under different fault/system scenarios, serving as a promising solution against the increased protection scheme design requirements of modern active distribution systems.

Paper 66 from Indonesia shows an implementation of non-cascade protection system on switchgear using the Half Down Section method. This protection system is made for backup when the main system is fault. So, the blackout area can be minimized (Fig. 45).

Fig. 45: Scheme of Half-Down Section Protection System

The Half-Down Section Protection System can be an alternative feature that can be used to mitigate mechanical failures that can occur in feeders. The System can be optimized using the IEC 61850 standard with Generic Object-Oriented Substation Event (GOOSE). The implementation using GOOSE can reduce the copper wiring for signal transfer between IED relay.

Paper 236 from Belgium has the title “False Tripping of a MV Bundle Feeder due to Inductive Coupling”. In this paper the field test and corresponding measurements setup are first exposed, followed by the measured results. The modelling method and assumptions are then detailed, before exposing the simulations results and comparing them with the field test measurements. A suitable use case for the field test was identified in an urban area near Antwerp in Flanders. A bundle feeder of roughly 2,5km is leaving the main HV/MV station and one of the two bundle cables is laying in the same trench as another feeder for a total of 650m. This latter feeder is where the controlled earth fault is to be performed, downward of the section of close parallelism between cables. A schematic illustrating the situation is shown in Fig. 46. The expectation in this case, based on previously observed occurrences and preliminary simulations on said occurrences, would be that the fault current in Feeder 3 induces a zero-sequence current circulating in the closed loop formed by Feeders 1 and 2.
A controlled single-phase earth fault was executed thanks to pneumatically controlled cutting plyers placed around one monopolar cable, as illustrated in Fig. 47. Finally, and since the previous mitigation measures are not always obvious to implement and/or verify, a final solution to avoid false tripping of bundle feeders in case of a fault on another feeder could be to wisely adapt the zero-sequence time thresholds for tripping on the breakers of the bundle feeder.

Paper 628 from Finland presents a concept where current circuit supervision is done in a substation level with new centralized protection system, by utilizing Six Sigma principles. This increases the overall visibility to the system and can be used for optimizing the scheduled testing procedures. The concept is tested based on data gathered from a substation pilot installation during a period of two years. In addition, recommendations are given for applicability of Six Sigma principles for measurement supervision, in terms of required data points and measurement intervals.

The main idea of the Centralized Protection and Control (CPC) concept is to move the protection and control functionality from multiple bay level devices to one central device within a substation, leaving only the process interface functionality in the bay level merging units (MU), see Fig. 48.

Paper 743 from the Czech Republic is focused
on “Control and Protection of AC/DC Hybrid Microgrids”.
In this paper, an internal protection of hybrid inverter was tested in a laboratory experiment. The experiment was focused on measuring the short-circuit current at AC bus of hybrid inverter working in off-grid mode. The result of the experiment refers to collision between TN networks standards and real fault clearing time, which was significantly longer than 0.4 s. The paper includes proposed recommendation to solve this issue.

Paper 862 from The Netherlands describes meshed operation of MV networks using intelligent RMU and innovative fault location. Traditionally, the Liander MV distribution networks have a meshed structure split into radial feeders by so called Normally Open Points (NOP). By implementing a combination of two technologies, intelligent Ring Main Unit (iRMU) and Smart Cable Guard (SCG), meshed operation of two or three feeders becomes feasible (Fig. 49). The intelligent Ring Main Unit with normally closed circuit-breakers is used to interconnect the feeders involved. The circuit breakers in this iRMU are controlled by fast operating protection. When a fault occurs these circuit breakers open almost immediately resulting in traditional radial operation, so the fault can be cleared using the default protection scheme. Smart Cable Guard is used to exactly locate the faulted cable section, resulting in fast isolation and network restoration. Measurements in an already operational meshed network confirm the expected advantages.

In paper 686 from Norway a mixed application of analog and process bus environment in transformer differential protection is tested. The transformer differential protection (87T) operates based on the summation of current at all terminals as shown in Fig. 50. An inaccuracy in measurement acquisition or network delays in one of the terminals may cause delayed or nuisance trip signals.
faults, operation, and switching scenarios Fig. 51. The results of the MU comparison show some deviations between vendors. This is particularly pronounced in the extracted 2nd and 5th harmonics used for inrush/over-excitation blocking. Although the protection IED operated correctly during inrush, internal/external faults with CT saturation, the protection relay had issues with inconsistent blocking of over-excitation. In addition, the result of network imperfection affected the protection IEDs and resulted in long delays in the relay response. The result obtained from this series of test indicates that some combination of vendors merging units in asymmetrical chain acquisition transformer protection may result in performance shortcomings. This shortcoming related to the blocking signal in over-excitation scenario.

Fig. 51: Test setup for testing mixed-application of analog and process bus.

Analysis of fault condition caused by phase interruption of HV overhead line are presented in paper 815 coming from the Czech Republic. The paper deals with the issue of single-phase interruption in HV distribution grid due to conductor rupture. Based on the real fault that occurred in the Czech distribution grid, a mathematical model was built to perform simulations and analysis of results were conducted. The main objective is to give recommendations to DSO how to identify this type of fault and reveal the risks of this fault for the grid operation.

Fig. 52: Single-line diagram of the grid model

The grid model used for the study was based on the real grid configuration before failure, which can be simplified into a radial operation as shown in Fig. 52. Note that the HV (110 kV) grid is operated as solidly grounded, the MV (22 kV) grid is operated as impedance grounded through an arc suppression coil (ASC) with an auxiliary resistor RA (used for a short-time increase of an earth fault current), which is typical configuration applied for Czech MV grids where predominate overhead lines. Fault location is at the beginning of the line. It is important to clearly distinguish between phase interruption on HV line and earth fault (EF) in MV grids. Key indicators are current unbalance on HV line and internal EF, i.e. EF is not identified on any MV feeder by EF protection. To prevent the grid from L-L overvoltage, it is important to control OLTC respecting level of all L-L voltages.

Sub block 3 “Algorithms & Simulations”

New developed algorithms or protection functions to solve challenges are presented in 4 papers of this sub block. Simulations are confirming the stability and functionality as a prerequisite for practical use. The commonality in this sub block is the development of new ideas and improvements in the field of protection.

Paper 169 from Egypt describes “An Innovated Adaptive Protection Algorithm for Distribution Networks Including DG Units”. In this paper, an adaptive overcurrent protection algorithm is presented. The algorithm relies on modifying the conventional inverse overcurrent protection settings to adapt with the on-going changes within the network. The proposed algorithm was tested on IEEE 34 system using MATLAB/SIMULINK for various fault cases with different locations and different fault resistances. The simulation results show the effectiveness of
using the adaptive over current relay in reducing the operating time through all simulated cases with different fault resistance. Also, the adaptive relay is higher sensitivity for severe cases of high impedance faults.

Paper 221 from Sweden is focused on “The Real Time Voltage Calculation Method of Series Compensation Circuits for Time Domain Protection Solution”. This paper proposes a real time calculation method which can be used to calculate the transient voltage waves during the fault period so that the core problem for the time domain distance protection based on compensated voltages calculated at reach point can be solved. It is obvious that the given real time calculation method for series compensation (SC) capacitor voltages is quite accurate to match the actual SC circuit voltage during the first 10ms period following the fault occurring time. Based on the given calculation, time domain protection with differential equations as given in equations could provide much accurate reaching point voltages so that the incremental voltages at the reach point could also be obtained with good accuracy in the first 10ms of the fault period. The given method has been verified with typical conditions of local compensated line and it could be used for time domain protection function for series compensated line protection purpose with accepted approximation for accurate calculation.

Modelling of active zero-sequence currents in distribution grids mixing overhead and underground segments is the title of paper 463 coming from France. The DSOs face new challenges with the rapid development of the distribution grid and the extensive use of cables in some countries. In case of a different modelling options fault, they are more and more likely to meet a reconfiguration scheme where the system capacitive and active currents might be close to the acceptable limits required by protection scheme.

In this paper, we carry out a comparison of different modelling options with a few field measurements. To validate the accuracy of the proposed modelling options, a wider set of networks should be tested and correlated with field measurements.

Paper 789 from Germany presents a new version of the DEFIT (Determination of Earth Fault Inception Time) algorithm whose task is to determine the inception time of earth faults. The task of the Detection Earth Fault algorithm is to check for each sampling point \( t_k \) whether there is a transient event, which may be an earth fault. Input variable of the algorithm is the zero-sequence voltage \( U_0 \). Consequently, transient events that do not affect the fundamental frequency component of the zero-sequence voltage are not detected. Examples for such transient events are short-time arcs and switching operations at other locations in the system. The difference in the zero-sequence voltage \( U_0 \) at sampling point \( t_k \) with respect to the preceding sampling point \( t_k - T_{\text{DEF}} \) is calculated according to equation (2). For this calculation, the time \( T_{\text{DEF}} \) should be chosen as a multiple of the period \( T \) of the fundamental component.

\[
\Delta U_0 (t_k) = U_0 (t_k) - U_0 (t_k - T_{\text{DEF}})
\]

This difference is compared with the threshold \( \Delta U_0_{\text{DEF}} \), as depicted in Fig. 53. The sampling point \( t_k \) at which the difference in the zero-sequence voltage \( \Delta U_0 \) exceeds the threshold \( \Delta U_0_{\text{DEF}} \) is set as the start time \( t_{\text{DEF}} \) for the Search Inception Time algorithm.

Being tested with several thousand records, the new version of the DEFIT algorithm shows very good results for a wide range of different transient events.
### Table 3: Block PROTECTION

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<tr>
<th>Paper No.</th>
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<th>PS</th>
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Thomas Offergeld\textsuperscript{1,2}, Dominik Willenberg\textsuperscript{1}, Philipp Linnartz\textsuperscript{1}
\textsuperscript{1}IAEW at RWTH Aachen University, Germany. \textsuperscript{2}Fraunhofer Institute for Applied Information Technology FIT, Germany

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Zhengqi Wang\textsuperscript{1,2}, Zheng Liu\textsuperscript{1}, Markus Kraiczzy\textsuperscript{2}, Nils Bornhorst\textsuperscript{1}, Sebastian Wende-von Berg\textsuperscript{1,2}, Martin Braun\textsuperscript{1,2}
\textsuperscript{1}University of Kassel, Department of Energy Management and Power System Operation, Germany. \textsuperscript{2}Fraunhofer Institute for Energy Economics and Energy System Technology, Germany

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\textsuperscript{1}EA Technology, United Kingdom. \textsuperscript{2}NIE Networks, United Kingdom
The past, present and future role of automation in the electricity grid – A Portuguese perspective
José Gonçalves¹, Pedro Miguel², Luís Neves³, Fernando Ramalheira¹, João Rosa⁴, Bruno Oliveira Santos⁵
¹Innovation and Technological Development at E-REDES, Portugal. ²Institute for Systems Engineering and Computers at Coimbra, Portugal. ³School of Technology and Management, Polytechnic Institute of Leiria, Portugal. ⁴High Voltage Assets Services at E-REDES, Portugal. ⁵Asset Management And Network Planning at E-REDES, Portugal

An approach of replicating multi-staged cyber-attacks and countermeasures in a smart grid co-simulation environment
Ömer Sen¹, Dennis van der Velde¹, Sebastian N. Peters², Martin Henze³
¹Fraunhofer FIT, Germany. ²RWTH Aachen University, Germany. ³Fraunhofer FKIE, Germany

Implementation of the active network management scheme for the active response to distribution network constraints project
Hamdi Shishtawi¹, Luca Grela¹, Mark Jaggassar², Fernando Magnago³, Nadim Al-Hariri⁴
¹UK Power Networks, United Kingdom. ²Smarter Grid Solutions, United Kingdom. ³Nexant Inc., USA. ⁴CGI, United Kingdom

Utilizing cogeneration to provide enhanced resilience to a hospital campus: Implementation and technical challenges
Gaurav Singh¹, Arindam Maitra¹, Michael Bonnell²
¹Electric Power Research Institute, USA. ²Black and Veatch, USA

Incentive-based management of multi-agent distribution systems in contingency conditions
Sajjad Fattaheian-Dehkordi¹, Ali Abbaspour², Mahmud Fotuhi-Firuzabadi²,¹, Matti Lehtonen¹
¹Aalto University, Finland. ²Sharif University of Technology, Iran, Islamic Republic of

Enabling cybersecurity features using a layered connectivity to promote secure remote operation and maintenance
Daniel T. Dantas¹, Kaelan Thijs Fouwels², Haiyu Li², Thomas Charton³, Linwei Chen³
¹University of Manchester, United Kingdom. ²Lagoni Engineering, United Kingdom. ³National Grid, United Kingdom

“Smart Street Box”: an innovative approach to remote control, monitoring & automation for LV Smart Grids
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¹E-Distribuzione SpA, Italy. ²Enel Global Infrastructure and Networks Srl, Italy.
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Immanuel Hacker\textsuperscript{1,2}, Florian Schmidtke\textsuperscript{2}, Dennis van der Velde\textsuperscript{1}, Sasha Toni Czymik\textsuperscript{2}
\textsuperscript{1}Fraunhofer FIT, Germany. \textsuperscript{2}RWTH Aachen University, Germany

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\textsuperscript{1}Tampere University, Finland. \textsuperscript{2}Danish Energy Association, Denmark. \textsuperscript{3}RAH, Denmark

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\textsuperscript{1}Universidade de São Paulo, Brazil. \textsuperscript{2}Neoenergia, Brazil

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Martin Horák, Tomáš Škumát
Západoslovenská distribučná, a.s., Slovakia

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\textsuperscript{1}Democritus University of Thrace, Greece. \textsuperscript{2}PROTASIS SA, Greece

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\textsuperscript{1}PT PLN (Persero) UP2D Jakarta, Indonesia. \textsuperscript{2}PT PLN (Persero) UIT JBB, Indonesia

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¹Faculty of Engineering, Egyptian Russian University, Egypt. ²Egyptian Electricity Transmission Company, Central Sector for Protection, Measurement and Testing, Egypt. ³Faculty of Engineering at Shoubra, Banha University, Egypt

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Jianping Wang, You Yi Li
Hitachi ABB Power Grids, Sweden

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¹ENGIE Laborelec, Belgium. ²Fluvius, Belgium. ³Resa, Belgium. ⁴Ores, Belgium

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Quentin Antoine¹, David Lopez Martinez¹, Pieter Lindeboom²
¹ENGIE Laborelec, Belgium. ²Fluvius, Belgium

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Hugh Borland
ESB Networks, Ireland

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¹Hitachi ABB Power Grids, Sweden. ²KTH Royal Institute of Technology, Sweden

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¹EDF, France. ²Gustave Eiffel University, France

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¹Kansai Transmission and Distribution Inc., Japan. ²Kyoto University, Japan. ³Kyushu Institute of Technology, Japan
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David Topolanek, Michal Ptacek, Vit Krcal, Jiri Drapela, Petr Toman
Brno University of Technology, Czech Republic

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¹EDF R&D, France. ²Enedis, France

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EDF R&D, France

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Ari Wahlroos¹, Janne Altonen¹, Hanna-Mari Aalto²
¹ABB Oy, Distribution Solutions, Finland. ²Elenia Verkko Oyj, Finland

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Gernot Druml¹, Philipp Stachel¹, Siegfried Gebhard², Wolfgang Leitner³, Oliver Skrbinjek⁴, Georg Achleitner⁵, Uwe Schmidt⁶, Peter Schegner⁷
¹Sprecher Automation GmbH, Germany. ²KNG-Kärnten Netz, Austria. ³Netze Oberösterreich, Austria. ⁴Energie Steiermark, Austria. ⁵Austrian Power Grid AG, Austria. ⁶HS Zittau/Görlitz, Germany. ⁷TU-Dresden, Germany

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Gernot Druml¹, Wolfgang Leitner², Robert Steinbichler², Andreas Abart², Oliver Skrbinjek³, Peter Zeller⁴, Werner Schöffer⁴, Peter Schegner⁷
¹Sprecher Automation, Germany. ²Netze Oberösterreich, Austria. ³Energienetze Steiermark GmbH, Austria. ⁴University of Applied Sciences Wels, Austria. ⁵Artemes, Austria. ⁶TU-Dresden, Germany

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Jani Valtari
ABB Oy, Finland

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¹NTNU, Norway. ²SINTEF Energy Research, Norway
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Stefan Eichner¹, Muhammad Arslan Arshad¹, Robin Grab¹, Andreas Jahr²
¹Fraunhofer Institute for Solar Energy Systems ISE, Germany. ²Siemens AG, Germany

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ZIV, Spain

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Daniel Hardman¹, Yiango Mavrocostanti², Jon Sleep², Neil Murdoch¹
¹GHD, United Kingdom. ²Western Power Distribution, United Kingdom

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Brno University of Technology, Czech Republic

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Ludwig Döring¹, Benjamin Braun¹, Klaus Böhme², Matthias Kereit², Stefan Werben², Jutta Hanson¹
¹Technical University of Darmstadt, Germany. ²Siemens AG, Germany

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Jan Koudelka¹, David Topolanek¹, Petr Toman¹, Martin Fabian²
¹Brno University of Technology, Czech Republic. ²EG.D, a. s., Czech Republic

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Frans Provoost¹, Denny Harmsen¹, Stefan Lamboo²
¹Qirion, Netherlands. ²Liander, Netherlands

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¹NTNU, Norway. ²SINTEF Energy Research, Norway

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Proof of load on cable shield and cables with decentralized compensation as well as reliable earth fault detection
Oliver Skrbinjek¹, Walter Hipp², Gernot Druml³, Lothar Fickert⁴, Katrin Friedl⁴
¹Energienetze Steiermark GmbH, Austria. ²Energie Steiermark Technik GmbH, Austria. ³Sprecher-Automation GmbH, Austria. ⁴Technische Universität Graz, Austria
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How to improve reliability on IEC 61850 substations
Daniel Texidor Dantas¹, Haiyu Li¹, Thomas Charton², Linwei Chen²
¹University of Manchester, United Kingdom. ²National Grid, United Kingdom

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An experience of locating high-impedance faults through smart meters’ alarms in power distribution networks
Danilo S. Pereira¹, Carlos F.M. Almeida¹, Luiz H.L. Rosa¹, Nelson Kagan¹, Alexandre Dominice²
¹Polytechnical School of University of Sao Paulo, Brazil. ²EDP Brasil, Brazil

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Functional specification of protection, automation & control applications based on IEC 61850 independent of their implementation
Navdeep Ahuja, Camille Bloch
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An experience of locating high-impedance faults through smart meters’ alarms in power distribution networks
Danilo S. Pereira¹, Carlos F.M. Almeida¹, Luiz H.L. Rosa¹, Nelson Kagan¹, Alexandre Dominice²
¹Polytechnical School of University of Sao Paulo, Brazil. ²EDP Brasil, Brazil
SPECIAL REPORT

Session 4
Distributed Energy Resources and Efficient Utilisation of Electricity

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Introduction

Session 4 examines the challenges of adapting distribution networks to facilitate the integration of low carbon, renewable and distributed energy resources (DER). These include distributed generation (DG), energy storage, new loads (e.g. electric heating and electric vehicles), active demand, and aggregation of DER (e.g. Virtual Power Plants).

DER integration challenges feature in some way across all CIRED sessions so Session 4 specifically focuses on new concepts, emerging technologies and solutions, results from research, development or demonstration programmes, with results from network and system integration trials being particularly valued. Various DER integration and solution studies also feature.

Session 4 papers highlight the integration of DER within distribution networks through technical, commercial and regulatory solutions. Papers describe developments in network management, active demand side response, energy storage integration, network monitoring, telecommunications and data analytics and the role of DER in wider DSO business operations.

Session 4 Paper Evaluation and Selection

Session 4 received 242 abstracts and this has produced good quality and diverse contributions to the final conference proceedings where 127 full papers have been accepted and will be presented at CIRED 2021. The review process first selected abstracts on the basis of potential, clarity of contribution, quality and early stage content already in the extended abstract. The full papers were reviewed by at least two Session 4 members. Full papers were accepted based on value of contributions to Session 4 scope, well-founded on robust research, experimental and demonstration methods, well referenced, highlighted emerging topics and provided interesting ideas and insight to the CIRED community. The most novel research and innovation stage papers have been invited to present in the Research and Innovation Forum (RIF). The overall best quality papers have been selected for Oral presentation in the Main Sessions.

Session 4 Special Report Organisation

This Session 4 Special Report provides summaries of all accepted full papers organized into four blocks as follows:

Block 1: “Modelling, Optimisation and Planning”

Block 2: “Flexibility coordination, markets and solutions”

Block 3: “Case Studies, Industrial applications and Field Tests”

Block 4: “Storage Solutions and Integrations”

The accepted papers are listed in tables in each Block and Poster, RIF and Oral presentation are noted there.

Finally, the Session 4 team would like to thank all the abstract and paper contributors for an excellent array of high-quality contributions that have been a pleasure to review and assimilate. We look forward to an excellent CIRED 2021 and have the chance to discuss these papers with authors and audience members.

The Session 4 Chairman and Special Rapporteurs would also like to thank the Session Advisory Group who played a very active and valuable role in abstract and paper review and who will support the Oral, RIF and Poster sessions at CIRED 2021 in September.
Block 1 – Modelling, Optimisation and Planning

- Sub block 1: Modelling
- Sub block 2: Optimization
- Sub block 3: Planning

Sub block 1: Modelling

Paper 0014 transforms reactive, load-serving, and outage-mitigation focused methods. It includes an integrated approach to develop sensor-rich and learning-ready system models, state estimation, optimal scheduling, and system-level control strategies for dispatchable resources.

Paper 0304 presents a study on how innovative approaches (multi-energy systems) and tools (cellular-based electrical networks with network reduction and the hybrid modelling framework HyFlow) can help overcome the challenges of a sustainable energy future. The results obtained show, that hybrid conversion technologies can be used to stabilize voltages and increase power quality.

Paper 0348 investigates the influence of the spatial distribution of voltage source converters with grid-following and direct voltage control in a medium-voltage benchmark grid is evaluated. The RoCoF and the frequency nadir in the overlaying low-inertia high-voltage grid are investigated in order to verify whether the spatial distribution and different control strategies should be considered when using aggregated models.


In paper 0584, a qualitative analysis of the impact of wind farm feed-ins (Power-to-Gas) into the gas grid is carried out on an illustrative case. A model is implemented for the analysis of transient gas flows in the pipelines.

Paper 0676 proposes a machine learning based e-vehicle (EV) profiling technique to better understand the information behind the random probability and irregularity of EV load. The proposed method considers the time-varying, dynamic character and the complex temporal correlation of EV loads. A series of different EV load profiles is created.

Paper 0696 proposes a heuristic to determine target demand thresholds using a linear programming model based on the site’s energy consumption profile from the previous year. Furthermore, the effectiveness of the obtained values is assessed through a detailed full-year simulation study. Compared to demand charge thresholds obtained from a simpler heuristic, this assessment indicates an additional saving potential of 10% for the microgrid energy bill.

Paper 0807 shows how the use of probabilistic forecasts instead of deterministic forecasts of the wind power production may improve the detection of congestion situations in the grid. Key challenge is to detect the unusual and sudden production changes that can create a constraint on the grid, in order to resolve a congestion problem that may appear.

Paper 0812 explores the dynamics of the daily peak demands of renewable energy communities under aggregation, as multiple countries are introducing capacity-based grid tariffs for residential consumers. Both the aggregation level and yearly consumption of the households comprising it are shown to have a significant impact on the timing of the daily peak demands.

Paper 0910 uses the LINK-based holistic architecture to extend the lumped model of low voltage grids by variable boundary voltage limits (BVL). This ensures internal limit compliance without involving safety margins when calculating and operating medium voltage grid. The BVLs are quantified for different test grids and the effect of the feeder properties on the limit deformation is identified.

Paper 0938 describes the use of quotas to manage predicted congestion and optimise the utilisation of the existing grids. The advantages and disadvantages of formerly used calculation methods and a refined quota calculation method are compared. The refined method will be implemented and validated in another comprehensive field test.

In Paper 1081 a new features selection
framework is applied to satellite-derived information in the context of PV production forecasting. The proposed approach permits to select a subset of low-correlated variables, which ensure spatially distributed pixels around the power unit.

Paper 1121 proposes a model of electrical technification to improve the efficiency and sustainability of a shrimp company in Ecuador through the use of photovoltaic panels for shrimp production, which will determine whether or not it is sustainable for this sector.

**Sub block 2: Optimisation**

Paper 0081 introduces a new modified optimization methodology called Modified Moth Flame Optimization Algorithm (MMFO) for determining the optimal Distributed Generation resources mix sizing and siting into the distribution networks. It provides significant outcomes regarding improving the voltage stability, minimizing the power losses and achieve a promising voltage profile enhancement with competent stability margin at all busbars.

Paper 0114 presents a novel, simple, reliable and cost-effective intelligent power controller to be installed at the consumer side. The paper explores the impact of the proposed controller in peak load shaving and load shifting with consequent improving of energy efficiency and cutting electricity bills. Besides, it investigates its readiness for demand response programs applications and connectivity with the innovative cloud computing platform.

Figure 1: (Paper 0114) Power controller system schematic diagram integrating Microgrid sources

Paper 0231 firstly analyses the demand of 5G network and the difference between its 4G counterpart, then aims at minimizing the station backup energy and hence the operating cost of telecommunication company. This paper proposes the DC power feeding scheme and integrates the concept of virtual energy backup i.e., by connecting the 5G stations and energy storage to the DC network, the centralized energy storage act as an energy backup to the distributed 5G stations. The benefit of the proposed scheme is demonstrated by a full day simulation, and the result shows a very good energy and cost saving. The study has the extensive applicability and practical significance to both the research and construction of 5G dense network.

Paper 0286 introduces a strategy for optimal reconfiguration of MV distribution networks with photovoltaic systems using signals from smart meters and earth fault indicator to identify the faulty cable. Simulation studies are performed to investigate all possible scenarios for system restoration.

In paper 0465 a novel strategy for charging/discharging electric energy storages (EES) in a community structure which are designed to flatten the aggregate load curve in a smart grid. An evolutionary modified water-filling algorithm is supposed to optimally assign the recharged/discharged power of each EES in the scheduling time horizon.

Paper 0474 aims to minimize losses in distribution networks with a large share of wind
Paper 0578 presents a novel approach to manage and implement advanced monitoring solutions in a flexible, scalable and intelligent distributed way using a distributed architecture based on an open cross-platform that can integrate and link smart nodes to the centralized SCADA system without the risk for data overflow. In addition, it presents functionalities that have been developed and integrated in a toolbox, which has been deployed into the open cross-platform.

Paper 0695 presents the impact of EV integration in a real LV Portuguese urban network. It analyses the network loading, energy...
losses, and voltage imbalances, under different scenarios of EV charging location and phase connection.

Paper 0700 introduces a tool providing a multi-layered interactive heatmap that will highlight the areas where demand for chargers is high and electricity network capacity is available. The tool designed to support a range of stakeholder groups in deploying the right public EV charging infrastructure, in the right place at the right time.

Paper 0710 presents a framework to analyse not only the potential impact of the integration of RES into the network but also to quantify their impact in combination with their respective control strategies which will be implemented when the devices are deployed at MV or LV. A scalability and replicability framework is presented providing a standardized approach enabling it.

Paper 0749 present the results of an extensive study carried out to assess the Power Quality present in grids that are heavily impacted by EV charging, and assess the compliance with the existing regulations, namely EN 50160 standard.

Paper 0874 describes the use cases designed, developed, and experimented aiming at the reduction of outages' frequency due to local overloads. A smart metering infrastructure and analytic services are deployed in a neighbourhood in Burkina Faso.

Paper 0979 presents a planning tool for low voltage photovoltaic connections. It shows a way to digitize LV networks, where the network model is entirely built from smart meters data. The resulting model can be used to precisely estimate the impact of any change in power, including new productions.

Paper 1084 discusses an approach to improve resilience at remote rural communities and a related case study. Aim is to employ microgrids that provide electric service capacity during blackouts. Once the microgrid is designed to meet the minimum reliability target of the critical facility, it can also be used for other secondary applications which increase the economic value that the microgrid offers to the customer.

Paper 1119 presents an open-source software tool called Distributed Energy Resource Value Estimation Tool (DER-VET) that can optimally size DERs for a given location and estimate the net life cycle cost of a microgrid over a given analysis horizon.

**Potential scope of discussion.**

The block describes techniques for understanding the impact of DER, and maximising its benefit. Discussion around the challenges of implementing a co-ordinated approach, given the number of stakeholders involved, could be encountered.
### Table 1: Papers of Block 1 (Modelling, Optimisation and Planning) assigned to the Session

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<th>Title</th>
<th>MS a.m.</th>
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<th>RIF</th>
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<td>Network evaluation with power tracing and visualisation tool</td>
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<td>Innovations in sensor enabled modeling of future distribution systems with distributed energy resources</td>
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<td>Multi distributed generation categories integration into distribution networks via MMFO algorithm based on techno-economic benefits: a real Egyptian case study</td>
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<td>On the optimization of investments in distributed energy resources in a low voltage energy community</td>
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<td>212</td>
<td>Effect of distributed energy resources integration in the distribution system</td>
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<td>Bi level allocation procedure of distributed generators and fault current limiter sites in radial distribution feeders</td>
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<td>231</td>
<td>An optimal power distribution scheme for the dense network composed of 5G base stations based on virtual energy backup</td>
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<td>Assessment of multi-energy flow in coupled networks with power-to-hydrogen and power-to-heat</td>
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<td>Optimal reconfiguration strategy for distribution networks with PV connected systems</td>
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<td>Equivalent cellular-based electrical network models for voltage regulation using hybrid conversion technologies at the medium-voltage level</td>
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<td>Optimal operation of electrical distribution networks including distributed generation units using trader optimization algorithm</td>
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<td>Influence of the spatial distribution of grid-forming converter-based generation on the frequency support in a medium-voltage benchmark grid</td>
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<td>465</td>
<td>An efficient charging/discharging strategy for a community of EESs in a smart grid based on a modified water-filling algorithm</td>
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<td>Optimised reactive power dispatch to increase network’s electric vehicle hosting capacity</td>
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<td>Optimized operation of local energy community with</td>
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<td>Unsupervised machine learning-based EV load profile generation for efficient distribution system operation</td>
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<td>Supporting EV infrastructure rollout using interactive network heatmaps</td>
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<td>Power quality impact analysis of different types of LV-connected EV charging stations</td>
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<td>Modelling and control of the low voltage network with smart-meters to improve the reliability of supply in Burkina Faso, the Africit-e project</td>
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<td>Avoiding congestion and optimising grid utilisation - an advanced multilevel quota realised in a comprehensive smart grid demonstrator</td>
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<td>New planning tool for low voltage photovoltaic connection – large scale experimentation</td>
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<td>1081</td>
<td>Short-term photovoltaic generation forecasting enhanced by satellite-derived irradiance</td>
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<td>1084</td>
<td>Optimal microgrid design for community resilience improvement and stacked benefit analysis</td>
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<td>1119</td>
<td>A planning tool to valuate resilient microgrid design</td>
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<td>1121</td>
<td>Proposal of an electric technical model for the improvement of efficiency and environmental sustainability in shrimp production</td>
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**Total**: 6

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Block 2: “Flexibility coordination, markets and solutions”

Paper 0044 describes the potential usage of electric vehicles (EV) in providing ancillary services based on V2G technologies, with a focus on the estimated ancillary services demand for 2030 (automatic frequency restoration reserve – AFRR and manual frequency restoration reserve – MFRR). It also analyses how local grid constraints might impose limitations on the provision of those ancillary services.

Paper 0164 presents a methodology that enables to decrease the complexity of modelling grid constraints, through a clustering algorithm prior to grid modelling, when assessing the usage of dispersed flexibility, tested with DSOs from the German state of Baden-Württemberg, with reproducibility and scalability issues considered. The results also demonstrate that grid topologies can have a decisive influence on the redispatch potential of flexibility at the PCC between DSO and TSO.

Paper 0267 introduces a smart energy management of multiple BESS types, for aggregators, considering contracts established with the DSO and battery degradation, in systems with PV production. The methodology developed sets an optimum operation set of the BESS, considering the trade-off between profit and lifetime of the BESS.

Paper 0310 discusses the detailed, dynamic modelling of distribution networks with large amounts of DER, through equivalent grey-box models which retain the characteristics of lower voltage levels. The paper presents three different approaches for the required modelling depth of those systems.

Paper 0341 presents TABEDE, a solution for demand response for buildings developed under a 2020 Horizon R&D program. It controls and optimizes building loads in response to grid signals, also being able to forecast and optimize energy consumption, incorporating DER requests.

Paper 0373 describes 2020 Horizon R&D project DOMINOES, aiming at the development of an integrated operation and management of local markets in the energy market environment, enabling the usage of flexibility and energy potential, which could not be fully exploited under isolated local markets.

Paper 0385 introduces a case-study in Austria associated with flexibility scheduling of distribution systems, associated with a 2020 Horizon R&D project. Flexibility is used based on BESS, EV and residential building energy management systems to maintain voltage level on each bus within ±2% of the nominal value, through a scheduling system that incorporates uncertainty and demonstrated on a distribution network.

Paper 0409 describes a flexible load management pilot project developed in Portugal associated with the management of residential electric hot water systems. These heaters were used for peak shaving, with the goal of assessing the potential for DSO investment deferral. The pilot demonstrated a positive business case associated with the installation of devices guaranteeing the usage of the flexibility potential associated with water heaters, which also can reduce residential peak loads.

Paper 0441 discusses the opportunity for households with DER of providing bottom-up services through aggregators – and how the simultaneous provision of energy supplied by DER might violate the design limits of distribution networks. The paper proposes the usage of operating envelopes (individualised time-varying limits to the energy exported) to
guarantee network integrity. These envelops are broadcasted to DER aggregators, which used them to manage the portfolio. Results were simulated on a MV-LV network.

Paper 0488 provides a Hardware in the Loop (HIL) simulation example of a microgrid, allowing an extensive testing in laboratory conditions performed by Schneider, before actual deployment in India. The simulations done through HIL allow to test complex architectures, validating the microgrid controller before on-site implementation.

Paper 0492 develops a solution for the integration of microgrids and their observability and control by the DSO, able to interface with the PV inverters associated with residential rooftop systems. The approach will empower LV dispatch centres, fostering the usage of flexibility in the grid. The presented project contemplated two pilots in Portugal, with promising results.

Paper 0516 presents a technical demonstrator of the usage of EV charging stations with BESS to provide flexibility services in Frequency Containment Reserve for Disturbances and Frequency Containment Reserve for Normal operation in Finland, presenting the potential revenue associated with service provision and an estimation of activation time frames.

Paper 0519 describes results from the Italian demonstrator of the H2020 R&D project SysFlex, in which smart grid devices are integrated with SCADA to provide flexibility both to the TSO and the DSO on the ancillary services market, considering constraints. The demonstrator used PV generators, BESS, on-load tap changers and STATCOMs (static synchronous compensators).

Paper 0546 presents the results from H2020 R&D project BD4NRG, making a case for federated learning – a decentralized machine learning technique –, of flexibility prediction in smart grids, addressing the intermittency challenge. The paper concludes that federated learning is a promising approach for building privacy-preserving energy portfolios of aggregated demand data.

Paper 0586 describes a study of flexibility service mechanisms in active distribution grids, considering the operational (P, Q) capabilities of DER inverters in Germany. It assesses the cost-optimized and (N-1) feasible operating points, visualizing flexibility resources in a real-time situation, considering also restrictions on the calculation time associated with the flexibility service mechanisms used.

Paper 0591 discusses the grid integration of DER, addressing the connection of wind and solar power plants according to the European Network Code requirements, adapted to the Portuguese electrical system, through simulation studies evaluating the plant performance, prior to the connection with the grid of those plants. The developed methodologies are based on dynamic digital simulation and a case-study of the application is also presented.

Paper 0598 introduces the R&D project NYSERDA, associated with the New York distribution system, developing the concept of flexible interconnection capacity solutions, with active management of DER output to avoid network violations. Assesses the trade-off between lost PV production and interconnection cost savings enabled by the DER management system. Also presents simulation results for various scenarios and sensitivities, identifying when the concept is more valuable.

Paper 0610 discusses how to reduce the risk of penalty costs faced by aggregators, associated with imbalances when pooling several RES in regions with frequent grid congestion, through flexible DER systems, whose flexibility constraints are communicated day-ahead.

Paper 0678 presents a comparative analysis of the curtailment rules for flexible DER. LIFO and pro-rata schemes are compared from several perspectives, including capacity factors and
network utilization, including considerations on the role of sensitivity factors.

Paper 0682 describes an offline simulation platform developed under H2020 R&D project SysFlex, to test in realistic conditions the energy management system software for operating an VPP, with an industry-scale demonstration. The demonstration aims at optimally operating a VPP to provide multiple services to the system, simulating 1-second behaviour of the system, from one day to several months.

Paper 0688 proposes common services attributes, for DER-provided distribution grid services, which can be used by distribution planners to characterize the location, timing and magnitude aspects of a distribution service opportunity. It also discusses performance verification, on an EPRI-led working group supported by the U.S. Department of Energy.

Paper 0726 presents three coordinated EV charging algorithm, preventing the appearance of overloads on LV grids. The algorithms differ in the number of control signals they specify: the usage of one global control signal, on control signal per feeder, or one per charging station. The performance of each algorithm is then compared. The more individual control signals are specified, the lower the average charging time.

Paper 0756 introduces a DER integration solution in the aggregator platform for the optimal participation in the wholesale and local electricity markets, through an optimization model. The model enables the consideration of dispatchable and non-dispatchable DER, as well as BESS, also enabling the participation of the resources in the wholesale market through a bi-level programming approach.

Paper 0790 describes a flexible grid-connected microgrid which participates in energy and ancillary services markets, considering different variables (uncertainty of energy prices, wind speed, solar irradiation and call for ancillary services provision).

Paper 0868 discusses the secure communication with decentralized prosumer applications through home area networks and wide area networks, considering the aspects of responsibility and definition of boundaries of the ICT network.

Paper 0899 presents a study, based on Finland data, on the behaviour of domestic electrical heating systems with spot-based price signals. Concludes that electric heating or cooling consumption may not change, considerably, peak loads in the distribution grid level.

Paper 0906 describes sector-coupled energy (multi-commodity) systems, using flexibility of smart DSM, developed through a German-Finish R&D project, FUSE. It uses AI-based DSM methods to increase the resiliency of distribution grids, considering multi-energy applications and local network conditions, evaluated in laboratory.

Paper 0948 introduces the H2020 R&D project Coordinet, analysing power flexibility at different voltage levels, with the aim of demonstrating how TSOs and DSOs can act in a coordinated manner, purchasing and activating system services, enabling the integration of DER in the market. The paper describes the Greek
Paper 0970 considers the impact of ageing assets on distribution network locational marginal costs, focusing on the quantification of ageing as a short-run network variable cost, influencing optimal DER scheduling.

Paper 0986 discusses the optimization of load demand response in support of the national grid, through a methodology developed and implemented in the North West distribution networks (UK), through the fast reserve market. The paper describes the branch-and-bound based optimal strategy to improve load demand response, whose results are compared with the rule-base method, concluding that the optimised method improves load demand reductions, helping the TSO to mitigate frequency drop due to low generation production.

Paper 0988 presents the H2020 R&D project IElectrix, dedicated to demand response and customer engagement, with a demonstrator set up in Delhi to explore innovative solutions allowing the implementation of local energy communities with PV and BESS. Analysis behavioural response of residential consumers to peak pricing.

Paper 0998 describes an assessment of the impact of reliability on the provision of operating reserve from smart grids. Examines the conditions for the provision of operating reserve, considering the reliability of the grid and congestion management measures. Concludes that current grid usage and generation technologies have an impact on reliability and operating reserve potential.

Paper 1064 compares a local versus centralized control of flexible loads in a power grid. Three different strategies for controlling EV charging, based on grid frequency, are compared: 1 utilizing DSO’s existing metering infrastructure; 2: using centralized measurement with dedicated flexibility server; 3: using local measurement and control. Concludes that dedicated systems built for EV charging power control offers faster response, better reliability and control.

Paper 1112 presents a risk-based framework that automates management of the demand side response between consumers and DSO, based on a fuzzy-logic controller optimizing the usage of consumers’ assets. A case-study is presented, involving an unexpected increase in EV penetration causing grid overload. The risk-based methodology successfully mitigated the stress in the grid, meeting consumers expectations regarding EV charging. The project was supported by the U.S Department of Energy.

Potential scope of discussion
Flexibility topics are still novel, involving several concepts and simulations optimizing the potential usage both from a consumer and from the system perspective. Flexibility is a crucial tool to support energy transition technologies and will mature, in order to be used as a network planning tool, used as an alternative to network reinforcements, while also guaranteeing systems stability through ancillary service provision to the system.

Table 2: Papers of Block 2 assigned to the Session

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<th>Paper No.</th>
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<tr>
<td>0044:</td>
<td>Evaluating the potential of future e-mobility use cases for providing grid ancillary services</td>
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<td>0164</td>
<td>Influence of clustered distribution grid characteristics on redispatch potential of dispersed flexibility</td>
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<td>0267</td>
<td>Smart energy management of multiple battery types for aggregators use considering negotiated contracts with the distribution system operator and battery degradation</td>
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<td>0310</td>
<td>Impact of the modelling depth of distribution grids on the accuracy of aggregated distribution networks</td>
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<td>0341</td>
<td>TABEDE: A new solution to advance demand response, clean energy and cost savings</td>
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<td>0373</td>
<td>DOMINOES – a roadmap to integrated local energy market operation and management</td>
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<td>0385</td>
<td>Flexibility scheduling for distribution systems: A case study in Austria</td>
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<td>0409</td>
<td>Flexible load management: How DSOs can benefit from energy efficiency plugs for water heating management</td>
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<td>0441</td>
<td>Bottom-up services &amp; network integrity: the need for operating envelopes</td>
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<td>0488</td>
<td>Hardware in the loop for microgrid control validation in IEELECTRIX project</td>
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<td>0492</td>
<td>Centralized observation and control of rooftop photovoltaics</td>
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<td>0516</td>
<td>Demonstration of reserve market operation and local flexibility in a smart office environment</td>
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<td>0519</td>
<td>Set-up of a new coordinated process for ancillary services provision from DSO to the TSO: an innovative approach to the exploitation of flexibilities connected to the distribution grid</td>
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<td>0546</td>
<td>Flexibility prediction in smart grids, making a case for federated learning</td>
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<td>0586</td>
<td>Development of a flexibility service mechanism for the determination and exploitation of flexibility in active distribution network through parallelized optimal power flow calculations</td>
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<td>0591</td>
<td>Grid integration of renewable energy power plants according to the Portuguese regulation</td>
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<td>0598</td>
<td>Techno-economic value of DERMS for flexible interconnection of solar photovoltaics</td>
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<td>0610</td>
<td>Provision and value of flexibility for reducing financial risks caused by prognosis uncertainties</td>
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<td>Rules of curtailment for flexible DER connection: A comparative analysis</td>
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<td>0682</td>
<td>An advanced offline simulation platform to test in realistic conditions the energy management system software for operating a virtual power plant</td>
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<td>0688</td>
<td>Distribution grid services: Requirements, procurement, and performance assessment</td>
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<td>0726</td>
<td>Coordinated electric vehicle charging – performance analysis of developed algorithms</td>
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<td>0756</td>
<td>Integration of DERs in the aggregator platform for the optimal participation in wholesale and local electricity markets</td>
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<td>0790</td>
<td>Optimal microgrid participation in coupled energy and ancillary services markets considering uncertainties using CvaR approach</td>
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<td>0868</td>
<td>Considerations on communicating with decentralized prosumer applications through home area network and wide area network</td>
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<td>0899</td>
<td>Will the SPOT-price-based demand response overload the distribution network?</td>
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<td>0906</td>
<td>Sector-coupled energy systems using the flexibility of smart DSM</td>
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<td>0948:</td>
<td>Coordinet project: Unlocking power flexibility at different voltage levels</td>
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<td>Impact of transformer and cable aging on distribution locational marginal costs in active distribution networks</td>
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<td>1064:</td>
<td>Local versus centralised control of flexible loads in power grid</td>
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<td>1112:</td>
<td>Risk-based residential demand side response</td>
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Block 3: “Case Studies, Industrial Applications and field tests”

Paper 0045 presents a comparison of deterministic, stochastic and time-series methods to assess the PV hosting capacity networks. Differences between the scientific and industrial application of the hosting capacity methods are discussed. The paper concludes it is not possible to point at a method as the most suitable one for quantifying the hosting capacity. To point at such a method would require an exhaustive application of the methods to a large number of the low-voltage distribution grid and a qualitative comparison of the results.

Paper 54 describes a project in Innsbruck that trialled a hybrid grid with a focus on shifting the needs for heat production and heat consumption. The main goal of the project was the development and implementation of an energy management system to fully automate and optimize cross-sectoral energy flows. Based on generation- and consumption forecasts, an algorithm creates optimized schedules for the individual units and storage facilities, saving 310 tons of carbon dioxide emissions annually compared to the previously installed natural gas fired heating system.

Paper 59 presents the results of studies into the impact of an energy return system for efficient management of regeneration in modern metro railway networks. This system will be capable of returning the regenerated train braking energy from the metro network to the 20kV distribution grid that is otherwise wasted in on-board braking resistors in the form of power losses (heat). It determines yearly cost savings of the order of € 1 m / year for the case of a 12.9 km line with 15 stations, proving a viable energy return system for implementation.

Paper 068 presents the application of dynamic rating to increase the available transfer capacity and to enable increased EV charging capacity. Through stochastic calculation the hourly available capacity is estimated and then used to calculate the hosting capacity. In this sense, the probability of overloading considering different EV types is calculated. The results show that the probabilistic hosting capacity would be a better indication to estimate the minimum and maximum EV load demand in the coming hours.

Paper 116 examines utilisation of EV Charging flexibility to reduce grid constraints. Most of the time charging flexibility is not required for grid support, so it can be used for a spot market optimized energy procurement. By calculating the load flow based on the cost-optimized charging schedule, the impacts on the extent and number of critical grid states of two low voltage distribution grids for the year 2050 are presented. The implemented charging management system is able to solve all critical grid states. Based on that the effects on the energy procurement savings for a charging point aggregator manifest themselves in a decrease of 5% on average in comparison to the optimization without taking into account the grid constraints.

Paper 118 describes how to face the challenge of interoperability between microgrid components based on the coming IEC 61850-7-420 object model standard, especially for meeting IEEE 1547 and EN 50549 grid code requirements. A specific focus explains how to benefit from the IEC 61850 based data models in non-IEC 61850 based systems and highlights the potential benefits.

Figure 7. (Paper 118) Smart Grid Architecture Model

Paper 148 also discusses the challenges and opportunities associated with the entry of CPOs into the flexibility trading domain. A CPO situated in Norway - a country with a particularly high electric vehicles (EVs) uptake rate - is used as a reference case for the investigations carried out, thus ensuring the high relevance and real-life applicability of the discussed topic, strengthening the future role of CPOs as flexibility aggregators and help adapt the market.
environment to ease the participation of CPOs as flexibility providers.

Paper 158 presents a case study conducted by EPRI to determine the best control settings for a large group of PV systems connected to a distribution circuit. In this study, different weather conditions are evaluated combined with a set of control settings for the smart inverter deployed in the distribution system. This study identifies the impact of smart inverters when added to the PV installation. The distribution system benefits when these devices are well coordinated with the existing system voltage control technologies is showcased.

Paper 225 illustrates the necessity of defining the optimal technology mix of Hybrid Renewable Energy Sources for certain system conditions from the perspective of both economy and system dynamic behaviour. In this study, the focus is on transient system stability. The methodology for developing dynamic equivalent of the whole HRES plant for transient stability studies in the form of a low-order transfer function model is presented. Illustrative results are obtained using an HRES plant consisting of several non-dispatchable renewable generation technologies.

Paper 245 presents a replicability and portability methodology of a virtual synchronous generator (VSG) to facilitate its development in an industrial context. This solution is designed to improve the electrical grid stability when facing a high penetration rate of renewable energies. In order to validate both the methodology and the portability of the proposed model, the VSG-based inverter is tested at different scales of inverters. The solutions are integrated in an experimental grid for validation.

Paper 271 presents a methodology for increasing the hosting capacity of the grid for distributed energy generation, using an autonomous grid voltage control for PV-installations and wind turbines. The control is a combination of reactive power absorption by a fixed \( \cos(\phi) \) of 0.9, and a \( P(U) \)-control. This choice is based on the results of various case studies combined with load-flow simulations. The main criteria used for the selection of the control are MV-grid voltage, amount of curtailment, and robustness for implementation. The prediction of the curtailment caused by this control is based on a simulation model in which accuracy is increased by using metering data at the point of common coupling (PCC). As the voltage violations occur in the MV-grid, the setpoints of the control have to be corrected to be able to use the local voltage at the DER installations as input for the voltage control. To verify that the voltage control in the customer installation remains operational and meets the agreements of the DSO, a daily monitoring method for the grid connection is developed. The developed solution can solve ca. 30% of the voltage related transport restrictions in the grid with an average expected curtailment of ca. 8%.

Paper 340 describes the real-time, virtual-physical simulation environment developed to validate a cloud-based Distributed Energy Resource Management System (DERMS). This work forms part of the ‘ScotCLUE’ project which resides within the wider ERA-NET Smart Energy Systems CLUE consortium. CLUE aims to develop and validate a tool kit, across five European demonstration sites, which supports the implementation of sustainable local energy while considering future ICT architectures and the interaction with surrounding electricity systems. The benefit of this hybrid virtual-physical demonstration approach will allow real-world distributed energy assets to be used in parallel with software models. This allows de-risking of future investment in energy assets by verifying their operation/performance prior to installation.

Paper 374 introduces a tool for the automatic detection of such "hidden" behind-the-meter solar generation. It is designed to discriminate the nodes with and without PV generation and is aimed at a high accuracy. The tool consists of a neural network coupled with an analytical classification algorithm, which considers an exogenous information (i.e. node consumption and temperature data). Open-access data about consumption and solar radiation were used to simulate the electrical grid and validate the proposed approach. The implemented solution was tested across all the nodes of the grid and its sensitivity has been analysed with regard to the level of PV penetration and period of observation. The tool is able to recognize the nodes with a new PV installation with an accuracy of up to 100%, depending on the exogenous conditions.
Paper 0380 studies the combined impact of PV, EV, and HP on the stability of LV grids, through the analysis of a typical LB Belgic rural grid. The effect of a smart charging strategy was evaluated. The main impact on the grid comes from HP integration, with a potential to overload the transformer. To effectively reduce grid constraints from PV and HP integration, EV should actively act to reduce grid instability. Also, flexibility should be considered both for EV and HP.

Paper 0390 presents a methodology for the evaluation of MV voltage levels, recurring to LV measurements. This state estimation methodology is presented theoretically and compared with results obtained in a real French grid, proving that with a lower cost state estimation methodology (due to the lower cost of LV sensors), it is possible to obtain results with a 1% precision.

Paper 399 describes how an efficient use of solar energy can be achieved by operating Photovoltaic (PV) panels at the maximum power point (MPP) for powering an induction motor. This paper discusses multiple techniques for computational demonstrating of Maximum Power Point Tracking like Perturb & Observe (P&O) and Incremental Conductance (Inc.) with Field Oriented Control Drive. The control techniques are implemented by using Matlab/Simulink. The simulation results clarify the effectiveness of the controllers based on Incremental Conductance techniques with Field Oriented Control for each performance index as it provides lower overshoot value and lower rising time and high dynamic response.

Paper 0403 describes de set-up for energy-efficient residential buildings for Nigeria and Sub-Saharan Africa, considering insulation to improve energy efficiency. It then proposes the combination of PV and BESS, allowing to achieve energy self-sufficiency.

Paper 418 proposes an efficient algorithm to recognize the digital currency mining consumption using the smart meter data. Current consumption, power factor and power consumption are considered as the main parameters. Accurate analyses are performed for the miner’s behaviour and some principal criterion are proposed to identify miner’s consumptions. Moreover, the proposed algorithm is implemented to recognize miner’s consumptions in Mashhad Electric Energy Distribution Company (MEEDC). The final results show the applicability and proper performance of the proposed solution in energy management and providing a new source of earning money for the utilities.

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Paper 574 describes how Smart Meter data was gathered, structured and analysed, allowing the proactive identification of distributed generation and electric vehicle’s charging stations that can potentially cause voltage non-conformities in the LV-grid. The authors present the approach, main conclusions and benefits that were found by developing a platform in which Smart Meter data is used to identify and preventively act eliminating abnormal voltage conditions in the LV-grid.

Paper 640 aims at developing an islanding solution based on already installed photovoltaic (PV) plants and that would require a minimum amount of changes in the existing distribution grids. More specifically, this paper proposes a control structure for a PV-based grid-forming system that can be used as a building block for the pursued islanding solution. A set of simulation results demonstrates that the proposed system is capable of withstanding...
severe perturbations while functioning in stand-alone mode.

Paper 0643 describes multi-energy systems in green airports through mathematical modelling, which would include multi-energy systems for the operation of the airport and meeting electric aircraft charging loads and fuelling stations producing hydrogen through electrolysis from wind and solar energy. It uses Kansai airport (Japan) as a case-study.

Paper 647 presents an integrated tool that facilitates the estimation of the installed capacity of rooftop solar PV systems connected to low voltage networks, thus increasing the visibility of these networks. The integral tool proposes the joint analysis of three methods to take advantage of their individual strengths and to compensate for their respective weaknesses: 1) aerial image analysis, 2) reverse power flow analysis and 3) a novel technique referred to as mean power generation analysis. The results show that a more accurate estimate of the installed capacity of the PV systems connected to each feeder phase was obtained when using the integral tool, despite the strong load-masking effect observed in some feeders.

Paper 651 explains how applications are needed to analyse the effects of multiple Distributed Energy Resources (DER) on transmission and distribution networks. These must estimate the behaviour of many types of DER autonomous control functions. DER controllers are expected to receive setpoints, curves and schedules sent from higher level management systems. DERs are often managed in groups which makes the control systems even more complicated. This paper describes a modelling approach for describing these autonomous control systems for integration with network analysis. This uses a design pattern with function blocks similar to the approach of PLC programming languages and simulation applications.

Paper 714 illustrate a practical design-to-cost approach to iteratively find the optimal techno-economic solution which fulfills the customer constraints. To support this approach, EDF R&D has developed PREMO, a microgrid techno-economic predesigning tool presenting a low technical complexity level paired with reliable technical and financial results. The paper describes the main functionalities, the modelling aspects and the gap PREMO intends to address. Performance is then demonstrated on a real EDF project, in South America.

Paper 721 describes a standardized set of power flow models for typical Dutch LV distribution networks is developed using real networks and operational data provided by a Dutch DSO. These network models are used to assess if typical Dutch LV distribution networks are ready to operate with large penetration of low-carbon energy technologies (e.g. PV systems, electric heat pumps, EVs). According to the obtained results, simulations of all the modelled networks showed the same behaviour for the power flow at the head of the distribution system and the voltage magnitude level. The changes in voltage magnitude however is dependent on the size of the network, resulting in larger changes in the larger networks. While the voltage magnitude level of the smaller networks stays within the ± 10% range, the larger networks encounter voltage magnitude violations. Thus, it can be concluded that the larger networks are not ready (under the current conditions) for large penetrations of low-carbon energy technologies, while the smaller networks appear to be ready.

Paper 803 shows how inverter-based microgrid operating at constant frequency performs under various transient and dynamic events, including islanding, fault inside the microgrid, loss of its primary grid-forming unit and rapid load changes. The microgrid comprehends one grid-forming unit, one grid-supporting/grid-forming unit, one grid-feeding unit and variable loads. Firstly, transient response of the microgrid during islanding to stand-alone operational mode is analysed. Results show how the main grid-forming unit can restore the voltage and balance active and reactive power fluctuations in stand-alone mode. Secondly, a fault inside the microgrid is applied when the microgrid operates in steady state and stand-alone mode. During the fault, the main grid-forming unit disconnects, and the grid-supporting unit changes its mode to grid-forming and restores the voltage and stabilizes the microgrid.

Paper 854 presents the domOS solution, which brings three mains contributions to the digitalization of buildings:
• it specifies an IoT ecosystem enabling the decoupling of the infrastructure layer (in-building sensors and actuators, smart appliances, gateways) and the service layer;
• it develops a set of compliant services for energy efficiency, energy flexibility and demand-side management; and
• it tests services and infrastructure on significant scale demonstrators.

The paper focuses on the implemented methodology and preliminary results of the solution’s implementation in a Swiss site. A Living Lab approach which uses methods to co-design services with users is also applied. The expected outcome of the methodological approach is new user centred business models for smart energy services.

Paper 0875 describes a model developed to assess the stability of microgrids, through the interaction of synchronous machines and virtual inertia emulators associated with inverters connected with distributed resources (generation or storage).

Paper 887 discusses a tool for simulating various charging scenarios of large centralized electric vehicle parking solutions and compares the outcome with respect to the simultaneity factor to current planning rules and real-world experiences. Additionally, the involvement of charging algorithms is simulated and the impact on needed power capacity for local transformers is analysed. Besides verifying that the observable simultaneity of charging is mostly in line with other studies, this work provides a more detailed investigation of different use cases such as home, work and shop charging. Furthermore, it is proven that simple peak shaving can drastically reduce the maximum power of EV parks without interfering with the usage patterns of the vast majority of EV owners.

Paper 898 explores different strategies (renewable capacity augmentation, battery augmentation, optimized energy management algorithms…) and simulates their impact using an in-house microgrid model for Saint-Nicolas Island, (Brittany, France). The simulation results suggest that the innovative solution of coupling a small Li-ion battery to a larger pre-existing lead-acid battery - combined with a limited increase of the installed photovoltaic capacity – would make the 100% renewable electricity mix possible. Following this study outcomes, Enedis engaged several actions to further increase the renewable share in the electricity consumption.

Paper 927 outlines an intelligent active network management (ANM) platform which will be designed and implemented by SPEN to solve the challenges for new distributed generation connection.

The roll-out of the ANM platform across SPEN network can bring significant benefits including:
• addressing network constraint problems,
• establish an industry leading, wide scale ANM solution,
• facilitating connection of more renewable generation with carbon benefits, and
• reduce customer connection costs.

In addition, the ANM platform will be the enabler for the future DSO function (e.g. dispatch flexibility service). The DER coordination between ESO and DNO through ANM platform is also explored.

Paper 0933 presents a DC microgrid concept aimed at maximising energy efficiency in transportation systems. Integrates energy supply to DC urban trains with PV, BESS and bus charging stations, allowing to use train braking energy in the network, using it to charge buses' batteries.

Paper 0954 describes a novel digital communication interface, based on an interface to be installed on the DER site and enabling the communication up to the DSO management centre. It has interoperability based on IEC 61850 and cybersecurity-enabled functions.

Paper 972 presents a power flow analysis of the LVDC backbone in order to determine the appropriate cable size. Based on this analysis the energy losses are computed for a LVDC backbone architecture. Subsequently, the benefit in terms of energy savings, self-consumption and self-sufficiency is investigated compared to a traditional grid architecture.

Paper 1006 describes several pathways analysed with the goal of transiting the energy production system of the island of Miquelon (France) towards a 100% renewable electrical energy mix.
Paper 1030 highlights the advantages of using sensors using a case study of introducing/upgrading a renewable energy grid. This is required to ensure system reliably, as live data on power flow direction, distortion and other parameters is essential. The paper includes specific applications such as cable pooling of multiple sources on a single grid connection and power factor improvement providing the possibility to actively request reactive power from renewables.

Paper 1039 provides the description of a model to control a microgrid with several different resources associates (PV, wind, fuel-cell, battery), ensuring an adequate dynamic response of the system during transient peak power demand changes.

Paper 1077 describes the usage of a lab testbed for active distribution networks and the results of several experiments, including a physical validation of a control algorithm of DER according with the voltage levels observed by each, observing the interactions between OLTC and reactive power of multiple DER; a trade permission system aimed at mitigation insufficient coordination between DSO and other actors of the system, avoiding the emergence of congestion issues on DSO grid originated by flexible services procured by TSO; and on direct load frequency control.

Figure 9. (Paper 1077) Physical setup for the HOLISTICA experiment, testing the performance of OLTC and multiple DER.

Paper 1113 presents the development and application of a method to estimate the technical and nontechnical loss in real distribution systems. The proposed methodology realises the energy balance with real-time measurement given by the Supervisory Control and Data Acquisition (SCADA) system and the energy billed in the consumers units by the Energy Metering and Billing System (EMBS). For simulation and results, two real Brazilian distribution system are analysed in order to demonstrate the benefit and efficiency of proposed methodology. The calculus of energy balance in real-time environment and the power flow results showed precise and reliability, enables the utility to define a proper control action.

Potential scope of discussion

The Block provides insight into simulations and real world trials of solutions for managing renewable energy sources. Discussion topics include the challenges for utilities and users in making use of the solutions at the scale required, and the need to adapt codes and policy to reflect the changing landscape.
### Table 3: Papers of Block 3 (Case Studies, Industrial applications and field tests) assigned to the Session

<table>
<thead>
<tr>
<th>Paper No</th>
<th>Title</th>
<th>MS a.m.</th>
<th>MS p.m.</th>
<th>RIF</th>
<th>PS</th>
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<tr>
<td>45</td>
<td>Solar PV hosting capacity methods and industrial application gaps</td>
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<td>54</td>
<td>Innsbruck’s prototype for a cross-linked energy system</td>
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<td>59</td>
<td>Energy Benefits from Bidirectional Electrical Substations in Metro Railway Systems</td>
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<td>68</td>
<td>Increasing the grid capacity for electric vehicle charging using dynamic rating</td>
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<tr>
<td>116</td>
<td>Impacts of spot market optimized energy procurement for private electric vehicle charging points on the distribution grid</td>
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<tr>
<td>118</td>
<td>Facilitating the operation and integration of DER and microgrids using the IEC 61850-7-420 standard data models, especially for meeting IEEE 1547 and EN 50549 grid code requirements</td>
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<tr>
<td>148</td>
<td>The entry of charging point operators into the flexibility trading domain – challenges and opportunities</td>
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<tr>
<td>158</td>
<td>Grid voltage control incorporating hybrid control devices exposed to variable weather conditions</td>
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<tr>
<td>225</td>
<td>Limitations of the applicability of the concept of hybrid renewable energy source plant in practical implementation</td>
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<tr>
<td>245</td>
<td>Replicability and portability of an advanced grid-forming VSG control for electrical grid with high rate of renewable energies</td>
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<td>271</td>
<td>Increasing hosting capacity for distributed generation by using local autonomous voltage controls, from case study to DSO-product</td>
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<td>340</td>
<td>Initial validation of a real-time cloud-based ‘web-of-cells’ energy management system</td>
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<tr>
<td>374</td>
<td>Automatic detection of distributed solar generation based on exogenous information</td>
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<tr>
<td>380</td>
<td>Impact of distributed energy resources and electric vehicle smart charging on low voltage grid stability</td>
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<td>390</td>
<td>Use of LV measurements in order to feed a state estimator aiming at evaluating the MV voltage with a 1% precision</td>
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<td>399</td>
<td>Advanced control of industrial solar variable speed drive for three phase induction motor</td>
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<td>403</td>
<td>Designing energy-efficient residential buildings for Nigeria and sub-Saharan Africa considering aerogel thermal insulation material and photovoltaic power generation</td>
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<td>418</td>
<td>Identification of unauthorized mining farms using smart metering data</td>
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<td>574</td>
<td>Improving power quality through the analysis of smart meter data</td>
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<td>640</td>
<td>Photovoltaic-based storage-less system to support islanding in distribution grids</td>
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<td>643</td>
<td>Multi-energy systems in green airports</td>
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<td>647</td>
<td>Increasing the visibility of low-voltage networks through data analytics</td>
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<td>651</td>
<td>Extending the IEC common information model with functions for planning and optimization of distributed energy resources</td>
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<tr>
<td>714</td>
<td>A design to cost approach applied to isolated microgrids</td>
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<td>721</td>
<td>Assessing the operation of typical Dutch distribution systems with large penetration of low-carbon energy technologies</td>
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<td>803</td>
<td>Islanding of a microgrid operating at constant frequency with two grid-forming inverters</td>
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<td>854</td>
<td>Developing new smart services in buildings for demand side management in the municipality of Sion, Switzerland</td>
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<td>875</td>
<td>Impact of the interaction of synchronous machines and virtual inertia provisions on the small-signal stability of microgrids</td>
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<td>887</td>
<td>Electric vehicle car park charging simultaneity and grid connection power requirement analysis</td>
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<td>898</td>
<td>The island of Saint-Nicolas on its path towards a 100% renewable energy territory</td>
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<td>927</td>
<td>Design and implement intelligent active network management (ANM) platform for network constraints</td>
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<tr>
<td>933</td>
<td>Electric bus charging station supplied by urban electrical DC railway network</td>
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<td>954</td>
<td>A new cyber secured and interoperable communication interface to enable the management of remote distributed energy resources by DSOs</td>
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<td>972</td>
<td>RE/SOURCED pilot project: Design and power flow analysis of a LVDC-backbone with hybrid energy system</td>
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<td>1006</td>
<td>The road towards a 100% renewable electricity mix in the French island of Miquelon</td>
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<td>1030</td>
<td>Sensor technology in a changing electrical grid</td>
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<tr>
<td>1039</td>
<td>Fractional order PID controller design via Tabu search algorithm in a hybrid renewable energy system</td>
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<tr>
<td>1077</td>
<td>Testbeds for active distribution networks: case experience from SYSLAB</td>
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<tr>
<td>1113</td>
<td>Technical and nontechnical power loss estimation using real-time access to distribution system</td>
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<td><strong>Total</strong></td>
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</table>
Block 4: “Storage Solutions and integration”

Paper 0052 contributes to the research on the determination of residential flexibility, achieved through loads with storage capability through Thermal Energy Storage loads (TES), monitored in laboratory to provide a model to evaluate demand response option. The model can thus be used to evaluate energy efficiency and demand response (DR) policies. The potential benefits accrued by this DR might achieve a 17% peak shaving, while saving money for end-users.

Paper 0096 studies the optimal demand charge threshold tuning for a microgrid, minimizing the energy bill while considering the management of a genset, a battery and a PV system combined with the site load.

Paper 0201 analyses LV networks with high penetration of residential batteries (BESS), PV and EV, for different operational strategies, which are simulated for a residential feeder in Northern Ireland. The results demonstrate that BESS can support the network, mitigating the negative impacts of PV and EV. Nevertheless, their unsupervised large-scale operation can have negative impacts on the network operation.

Paper 0211 illustrates the sizing of BESS that would be necessary on a LV transformer to delay asset upgrades, preventing voltage constraints and optimizing renewable energy generation, suggesting the usage of 2nd life BESS with varying state of health.

Paper 0384 examines the role of centralized and distributed short-term storage technologies in Austria, at the transmission grid level, to maximise renewable energy generation. The developed model results show that the potential of centralized is, in general, sufficient for balancing short-term power fluctuations when renewables dominate the overall generation portfolio.

Paper 0502 presents a case-study developed in Australia, demonstrating the usage of BESS with microgrid control to maximise renewable hosting capacity, realize tariff benefits, enhancing reliability and running 100% green processes – including the production of green hydrogen.

Figure 11. (Paper 0502) 260 kVA controllable hydrogen electrolyser (front left) and 30-bar high-pressure hydrogen storage vessel (centre)

Paper 0666 analyses the usage of residential batteries to provide primary frequency response (PFR) through droop settings. The proposed methodology is tested on a realistic Australian MV-LV grid, yielding results showing that by calculating droop settings with individual time-varying export limits, it is possible to achieve larger PFR contributions while ensuring grid integrity.

Paper 0713 provides an analysis of the usage of residential home batteries for balancing the Swedish power grid, considering the expected PV production and residential batteries deployment in 2040 and the need for these batteries to contribute to both primary frequency reserves (normal and disturbed), including an economic assessment of the PV system payback when the provision of those ancillary systems is considered.

Paper 0796 introduces a novel concept to increase battery supply time during network outages by deploying residential demand response, which would normally be used for primary frequency regulation markets, but which during an outage could be rented for the DSO to maximise the battery supply time for its customers.

Paper 0836 presents a pilot project carried on in Finland to verify a distribution network and electricity markets integrated BESS concept, based on shared ownership of the equipment, dual use of the system resources and a new service market model. The overall technical
structure of the BESS, learnings from the pilot, key results from the commission tests and experiences gained are described in the paper.

Paper 0909 evaluates the impacts of a storage system on a typical secondary distribution network, with different consumers and with the presence of distributed solar generation. The network is simulated for normal conditions, with generation, with generation and storage and with centralized dispatch.

Paper 0919 presents a concept and market model for the utilisation of BESS in distribution networks, describing the long-term utilisation potential of the concept. The purpose was to investigate potential locations for BESS in Elenia’s (Finland) network, showing that service charge and savings on regulatory outage costs have the greater influence on the number and location of BESS.

Figure 12. (Paper 0919) 10 most profitable locations for placing batteries in Elenia’s network

Paper 1002 introduces a reinforcement learning method for developing an operational strategy for an Energy Storage System (ESS) to achieve energy arbitrage in a power system, maximising profit for different scenarios, while comparing the performance of the proposed model with that of optimization-based methods.

Paper 1032 describes a prediction model for the deterioration of a Li-Ion BESS associated with a hybrid PV system installed in Corsica Island. Different estimation models were developed to predict the thermal behaviour and state of charge of 5 hybrid RES power plants with a Li-Ion BESS associated. These approaches improve the understanding of the evolution and degradation of the systems, providing insights used for optimized management system of each power plant.

Paper 1055 presents a pilot-project developed in Brazil that includes the installation of a BESS in a LV network with large PV penetration, describing a testing procedure developed to allow the commissioning of the equipment. The paper describes the key challenges and experience acquired through the installation of the system.

Paper 1062 describes a deep learning-based methodology for PV power quality control in systems with associated BESS. A machine learning model (neural network) allows to capture the dynamics of the PV, delivering accurate predictions, stabilizing the state of charge of the BESS notwithstanding the variations of PV production.

Paper 1100 presents a methodology for sizing BESS systems on MV grids connected with PV. The storage systems can help to smooth the production diagram associated with PV generators, while controlling the volt-var characteristics of the network.

Paper 1138 introduces a methodology for frequency regulation stabilization, through the association of a BESS and a supercapacitor with a system fed through a wind power generator. The capacity of the BESS and of the supercapacitor are optimized through nonlinear programming.

**Potential scope of discussion**

Integration of RES with BESS systems, enabling flexibility and RES hosting capacity maximization. More efficient solutions from and end-user and DSO, also considering power quality and ancillary service provision. Efficient sizing and location of BESS on DSO networks. Challenges associated with the operation of isolated systems with 100% RES generation.
Table 4: Papers of Block Storage Solutions and integration assigned to the Session

<table>
<thead>
<tr>
<th>Paper No.</th>
<th>Title</th>
<th>MS a.m.</th>
<th>MS p.m.</th>
<th>RIF</th>
<th>PS</th>
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<tr>
<td>0052:</td>
<td>Description of a residential thermal energy storage demonstrator: modelling, identification, validation, aggregation and validation of DR performance</td>
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<tr>
<td>0096:</td>
<td>Improving energy efficiency in DC microgrids with integrated energy storage</td>
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<tr>
<td>0201:</td>
<td>Understanding the impact of high penetration residential batteries with low carbon technologies on the low voltage networks</td>
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<td>0211:</td>
<td>Balancing second life batteries with different SOH for use in stationary storage systems</td>
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<td>0384:</td>
<td>Compensation of short-term power fluctuations at the transmission grid level by centralized and distributed short-term storage technologies on the example of Austria</td>
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<tr>
<td>0502:</td>
<td>Grid forming energy storage with microgrid controls provides green hydrogen, enhanced reliability, reduced site costs and lower emissions. ATCO Clean Energy Innovation Hub (A Case Study)</td>
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<tr>
<td>0666:</td>
<td>Using residential batteries for primary frequency response: Time-varying export limits and active droop calculations</td>
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<tr>
<td>0713:</td>
<td>The potential for balancing the Swedish power grid with residential home batteries</td>
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<td>0796:</td>
<td>Extending grid battery supply time by controlling residential heating loads</td>
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<td>0836:</td>
<td>Experiences from implementation and operation of a distribution network and electricity markets integrated battery energy storage system</td>
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<td>0909:</td>
<td>Centralized distributed storage dispatch</td>
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<tr>
<td>0919:</td>
<td>The utilisation potential of battery energy storage systems in rural distribution network</td>
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<td>1032:</td>
<td>State of charge and thermal-related deterioration prediction for li-ion storage systems in hybrid photovoltaic systems in the island of Corsica</td>
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<td>1055:</td>
<td>Challenges and experiences in installing a battery energy storage system connected to a low voltage network</td>
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<td>1062:</td>
<td>Deep learning based intelligent methodology for photovoltaic power quality control with energy storage</td>
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<td>1100:</td>
<td>Methodology for sizing battery energy storage systems to support the 13.8 kV distribution grid</td>
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<td>1138:</td>
<td>An optimal hybrid battery energy storage system and a supercapacitor framework for frequency regulation in presence of wind power</td>
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Session 4
Distributed Energy Resources and Efficient Utilisation of Electricity

Block 1: Modelling, Optimisation and Planning

14
Innovations in sensor enabled modeling of future distribution systems with distributed energy resources
John Dirkman
Nexant, Inc, USA

81
Multi distributed generation categories integration into distribution networks via MMFO algorithm based on techno-economic benefits: a real Egyptian case study
Ahmed S. Hassan¹, Aly M. Adbelfattah¹, ElSaeed Othman², Fahmy Bendary³, Mohammed Ebrahim³
¹Ministry of Electricity and Renewable Energy, Egypt. ²Faculty of Engineering - Al Azhar University, Egypt. ³Faculty of Engineering at Shoubra - Benha University, Egypt

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On the optimization of investments in distributed energy resources in a low-voltage energy community
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1Universidad Politécnica de Cartagena, Spain. 2Universidad Politécnica de Valencia, Spain. 3Universidad de Sevilla, Spain. 4Universidad de La Rioja, Spain. 5Institute for Energy Engineering, Spain
96 Improving energy efficiency in DC microgrids with integrated energy storage
Seongil Kim¹, Jakub Kucka¹, Soo-Nam Kim², Drazen Dujic¹
¹EPFL, Switzerland. ²Hyundai Electric and Energy Systems, Korea, Republic of

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¹Hitachi ABB Power Grids, Australia. ²ATCO Gas, Australia

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¹KTH Royal Institute of Technology, Sweden. ²Vattenfall R&D, Sweden

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Pekka Manner¹, Ilari Alaperä³, Samuli Honkapuro²
¹Fortum Power and Heat Oy, Finland. ²LUT University, Finland

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Tomi Hakala¹, Tero Kaipia², Ilari Alaperä³
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Alberto Vazquez-Rodriguez1,2, François-Pascal Neirac1, Georges Kariniotakis1
1MINES ParisTech, PSL University, Centre PERSEE, France. 2SPIE Industrie & Tertiaire – Division Industrie, SPIE France, France

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Victor B. Riboldi1,2, Tiago R. Ricciardi3, Guilherme F. Rissi1, Pedro A. B. Block3, Tuo Ji1, Jiyong Chai1
1CPFL Energia, Brazil. 2University of Campinas, Brazil. 3LACTEC Institutes, Brazil

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Miswar A. Syed1, Muhammad Khalid1,2, Fahad Alismail1,2
1King Fahd University of Petroleum and Minerals (KFUPM), Saudi Arabia. 2K.A. CARE Energy Research and Innovation Center, Saudi Arabia

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Mariana M Cavalcanti1, Andrea SM Vasconcelos1, Washington A Silva Júnior1, Danilo DS Alves2, Wallace C Boaventura3, Leonardo HM Leite4, Guilherme EM Campos5
1Instituto de Tecnologia Edson Mororó Moura, Brazil. 2Companhia Energética de Minas Gerais, Brazil. 3Universidade Federal de Minas Gerais, Brazil. 4Fudações para Inovações Tecnológicas, Brazil. 5Concert Technologies, Brazil

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Frequency regulation coordinated framework: Hybrid battery energy storage system and supercapacitor
Salem Alshahrani1, Muhammad Khalid2,1, Mohamed Abido1,2
1King Fahd University of Petroleum & Minerals (KFUPM), Saudi Arabia. 2K.A.CARE Energy Research Innovation Center (ERIC), Saudi Arabia
SPECIAL REPORT

Session 5
Planning of Power Distribution Systems

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Session Program and Organization
The session accepted 143 high-level papers (acceptance rate around 60%) divided into four blocks that reflect the S5 traditional topics. General papers are selected to stimulate the discussion in the Main Session with oral presentations; papers with the highest research content are selected for oral presentation in the RIF session. Each oral presentation lasts ten minutes; interactive posters have two minutes presentations followed by a Q&A session.

Block 1: Risk Assessment and Asset Management
- Sub block 1: Risk Assessment and Reliability Assessment
- Sub block 2: Resiliency
- Sub block 3: Asset Management and Maintenance Strategies

Block 2: Network Development
- Sub block 1: Innovative Power Distribution
- Sub block 2: Smart Grid Systems and Applications
- Sub block 3: DC Distribution Systems and Microgrids

Block 3: Distribution Planning
- Sub block 1: Advanced Planning
- Sub block 2: Smart Grid Planning
- Sub block 3: Optimal Placement of Power and Control discrete Components
- Sub block 4: EV Accommodation Planning

Block 4: Methods and Tools
- Sub block 1: Load/Generation Modeling and Forecasting
- Sub block 2: Network Modeling and Representation
- Sub block 3: Load Flow and Short-Circuit Calculations
- Sub block 4: Energy Losses

The S5 papers will be discussed in three events:
- MS (September 22, 9:00-12:30 and 14:30-18:00),
- PS (September 23, 9:00-12:30 and 14:30-18:00),
- RIF (September 21, 09:00-10:30).

Round Tables are organized by S5 or jointly organized with other Sessions:
- RT1: DC Networks (September 21, 09:00-10:30)
- RT3: Distribution Planning and E-Mobility (September 21, 11:00-12:30)
- RT5: Flexibility and Digital DSO (September 21, 14:30-16:00)
- RT6: Hosting Capacity (September 21, 16:30-18:00).

Introduction
The energy transition in distribution systems claims vast infrastructural investments in a highly uncertain scenario, making planning and decision-making a risky exercise in the expected uncertain and volatile scenarios. Thus, forecasts and scenarios development are crucial to transpose country-level decarbonization goals down to the smallest LV network for finding bottlenecks and planning investments. Smart grid technologies are an opportunity to fix the temporary consequences of high demand and renewable generation. Still, DSOs continue to suffer from Regulatory impediments that the Literature and EU directives suggest eliminating. The S5 papers give a contribution to these general topics. Electromobility and heat-pumps impact forecast highly improved with AI combined with geo-referenced and socioeconomic databases and electrical calculations. The energy transition burden on the distribution systems is predicted with accuracy. Many industrial papers propose an excellent combination of practical approach and scientific rigour for dealing with the complexity of new planning. The first attempts to use AI for the automatic planning are a sign of future trends. Microgrids and DC distribution continue to interest, but real-life applications are still few besides the realizations in rural electrification. Local energy communities are the emerging option to foster sector coupling and increase flexibility using P2P markets and blockchain. The resiliency of distribution systems as a development driver is covered by few good papers only. Looking at the received contributions, the planners' interest (and concern) is more on the short-term challenge of enabling the energy transition without rebuilding the system entirely and jeopardizing the quality level. Finally, a panoply of different mathematic approaches to deal with uncertainty and risk, optimally allocate resources and reduce technical and non-technical losses is proposed in the Session. In conclusion, considering the pivotal role of non-wires planning alternatives, two complementary topics are emerging: integration planning and flexibility markets and the TSO/DSO coordination. The research on these two key topics will undoubtedly increase with the progress of energy transition.
Block 1: Risk Assessment and Asset Management

Sub block 1: Risk Assessment and Reliability Assessment

The "Evaluation of Reliability Index for Electric Systems" (ERIS) to ensure efficient grid development based on its reliability is the Paper 0327 focus. ERIS proposes an integrated approach to support investment decisions by quantifying the benefits of investments on load flow, topology and condition of the grid. By considering the ERIS indexes into the long-term asset analysis of the infrastructure, it is possible to analyse grid reliability and the financial effects of integrated scenarios.

Fig. 1: Identity actions required based on ERIS score, as in Paper 0327.

Paper 0840 deals with a method to localize in different countries the Common Network Asset Indices Methodology (CNAIM), which is a framework to consistently model asset risks and to make risk-based decisions, developed by the English DSOs on RA (OFGEM) request. The localisation work within five Danish DSOs has shown that CNAIM is transferrable to other countries by applying a structured methodology to ensure that all local aspects are checked and taken into account.

Sub block 2: Resiliency

Possible evolutions around 2050 of strong winds, heavy precipitations, wet snow, extreme hot temperature and wildfire are evaluated by Paper 0468 authors to assess distribution network adaptation needs. The changes in the occurrence and intensity of these events have been studied using climate simulations under RCP8.5 and RCP4.5 IPCC emission scenarios. An increase in flash river flooding is likely to happen as well as extreme hot temperatures and fire risk.

Observations
Projected 2036-2065, RCP8.5

<table>
<thead>
<tr>
<th>Observations 1976-2005</th>
<th>Projections 2036-2065, RCP8.5</th>
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<tr>
<td>IPSL-CM5A-MR</td>
<td>HadGEM2-ES</td>
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</table>

Fig. 2: Mean annual number of days at risk of wet snow for both historical and future periods according to two climate models with emission scenario RCP8.5. as in Paper 0468.

Paper 0829 focuses on developing a method to accurately classify the overhead line section’s susceptibility to stormwind damage by combining forest data and DSO interruption data. The categorization results corresponded to expectations and DSO’s internal information. The data uncertainty and the small sample size impedes definitive conclusions, but the methodology developed in this paper can be used for further developments.

A framework for evaluating the resilience in a distribution network serving a given geographical area is proposed in Paper 0978. The potential impact of different network and non-network measures for improving system resilience is investigated with a probabilistic approach. Results derived by testing the methodology on a case study demonstrate the model effectiveness for planning applications.

Sub block 3: Asset Management and Maintenance Strategies

Paper 0018 analyses the lifetime estimation and lifetime planning of MV cables and cable accessories in the Helsinki network. The loading rate and the material types in use, and own fault statistics are taken into account to estimate the optimal technical lifetime of the MV cable. Anyway, the study proves that the new technical
lifetime of the MV cable and cable accessories is also economically viable and supported in the Finnish regulation.

An asset management strategy for reducing the number of Medium Voltage (MV) levels in the Stedin distribution network is described in Paper 0431. Progressive load development due to energy transition and increasing voltage problems due to Renewable Energy Sources (RES) necessitate a review of the existing voltage level of MV grids. The first step was to convert the 10 kV network of Rotterdam city centre to 20 kV. Research has been done to scale up the other 10, 13, 23 and 25 kV grids to the 20 kV level.

Paper 0436 proposes a comprehensive analytics method to calculate the probability of failure or the health index of single network equipment and for a group of assets as substations, transformers, etc. Asset health modelling, probability of failure modelling (degradation curve derivation) and asset criticality calculation are combined to formulate an overall risk index of each asset/type of asset of the grid.

The benefits that tan δ measurement can bring and the evaluation software features and its results are discussed in Paper 0766. The potential savings that data analysis opens up and draws upon the case study of a German distribution network operator are described to illustrate its economic benefits.

Paper 0801 deals with the digitalization and 3D modelling of the power distribution network through a Mobile Mapping System (MMS) with different technologies like high-resolution cameras, LiDAR (Light Detection and Ranging) and thermographic cameras. The MMS helps utility companies inspect their network faster and more accurately and store all the information on a common platform where all users can access. The expected result is an improvement in the grid inspection and maintenance based on real field information.

The choice of an optimal ageing limit of transformers in flexible power systems by using a maximal energy transfer as a criterion for defining the optimal ageing limit of transformers (both the existing and new ones) is investigated by Paper 0897. Results show that the optimal ageing limit for transformers should be equal to the ratio between the remaining insulation life and the remaining calendar life. Moreover, the paper presents the energy transfer through a new transformer as a function of various ageing limits and different durations of a calendar life.

A thermographic inspection is an effective way for the energy distributor to carry out preventive maintenance on the power grid, avoid problems in transformers, connections, and protective equipment, thus preventing consumers’ lack of power supply.

Paper 1076 presents the Asset Investment Management/Condition Based Risk Management methodology adopted by a Croatian DSO that combines asset information, engineering knowledge and practical experience to define the current and future condition, performance and risk of network assets. It has been applied for prioritizing the investment portfolio of transition from 10 kV to 20 kV. The methodology will be now used for planning the refurbishment of 35 kV overhead lines.

An optimal stochastic Reliability-Centered Maintenance approach in which online and offline monitoring techniques are combined to reduce costs and enhance reliability is proposed by paper 1131. The reliability level of the distribution network components is evaluated according to the three-state Markov model, considering the uncertainty of repair time for maintenance actions. The proposed approach has been tested within the Birka Nat distribution system in Sweden.
The potential scope of the discussion

Resiliency is crucial in modern distribution due to a clear trend leading to a greater frequency of extreme events. How can the different dimensions of resiliency be included in planning? Is cost/benefit analysis suitable to guide the decision making if applied to projects for improving resiliency? Can the smart grid and digitalization have a significant role in improving resiliency? Is it time to include safety as a topic for CIRED?

Table 1: Papers of Block 1 assigned to the Session

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<thead>
<tr>
<th>Paper No.</th>
<th>Title</th>
<th>MS a.m.</th>
<th>MS p.m.</th>
<th>RIF</th>
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<tr>
<td>0018</td>
<td>Estimating the lifetime of medium voltage cables and cable accessories in an urban environment</td>
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<td>0327</td>
<td>Combining the evaluation of reliability index for electric systems with the long-term analysis of infrastructures</td>
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<td>0431</td>
<td>Grid planning in the midst of several existing voltage levels</td>
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<tr>
<td>0436</td>
<td>Asset management system in DSO using business intelligence tools and advanced analytics</td>
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<td>0468</td>
<td>Resilience of the French distribution network to climate change: Projected changes for 5 main meteorological hazards around 2050</td>
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<td>0766</td>
<td>Case study: More cost-efficient asset management by prediction the remaining lifetime of medium voltage underground cables</td>
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<tr>
<td>0801</td>
<td>Mobile mapping system in a power distribution network</td>
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<tr>
<td>0829</td>
<td>Assessing overhead line's susceptibility to stormwind damage using open data</td>
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<td>0840</td>
<td>Global application of the British CNAIM for asset risk modelling – A case study from Denmark</td>
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<tr>
<td>0897</td>
<td>Optimal ageing limit of oil-immersed transformers in flexible power systems</td>
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<tr>
<td>0978</td>
<td>Application of resilience triangle model to the electric distribution system</td>
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<tr>
<td>1076</td>
<td>Asset management in HEP DSO: from development of methodologies towards application</td>
<td>X</td>
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<tr>
<td>1131</td>
<td>A stochastic Markov model for reliability-centered maintenance approach in electrical distribution networks</td>
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Block 2: Network Development

DSOs have been the most innovative among electricity operators in the last ten years: lower costs and reduced size made previously unavailable functionalities at hand deployed in everyday operation. New materials, components and systems are constantly tested and introduced, expanding DSOs’ possibilities in network management.

Most of the innovation in distribution is centred on the contribution of new equipment, either owned by the network operator or run by individual network users to manage the distribution system. In terms of planning, it implies new reflections on how to take these capabilities into account while designing future grids.

Sub block 1: Innovative Power Distribution

Sub block 1 deals with all kinds of innovation not explicitly connected with "mainstream" topics; it
may deal with specific, Country-based projects including multi-source energy systems or be related to the adoption of a specific new component and technical solution.

In **Paper 0219**, a comparison among different bonding techniques for HV and MV cables is presented. The most common practices (Solid Bonding, Single Side Bonding and Cross Bonding) are evaluated regarding investment and operational costs (ampacity, losses, etc.). The strengths and weaknesses of different techniques are detailed depending on the specific component, installation type and size. Finally, some general recommendations are made regarding the best suitable solutions according to operational conditions.

**Paper 0134** focuses on the Zero Down Time (ZDT) concept, referring to network architecture and configuration intended to minimize the interruption time by looping pairs of MV feeders coming from the same MV busbar and HV/MV transformer. The protection system uses Line Current Differential between two secondary substations on each feeder. This approach is being developed in the distribution system of the New State Capital City of Indonesia.

**Paper 0722** investigates the effects of static and dynamically meshed grid topologies on the short-circuit current situation and power supply reliability of medium voltage grids. As expected, the meshed operation significantly increases the short-circuit currents (but these generally do not exceed the critical limit values). It brings the power supply reliability to almost the same level as in the initial topology in static meshing by applying a loose coupling. A significant expansion cost reduction (up to 63%) is also expected both in the case of static and dynamic meshing.

In **Paper 0180**, a change of paradigm in the KEPCO’s approach to the connection of large customers is described: instead of supplying them at MV voltage level, forcing them to manage their transformation, the idea is to ensure a low voltage supply, installing compact substations that can be buried underground. The architectural solution adopted to deliver optimal service quality by using RMU and RING configuration is then described.

**Fig. 4: KEPCO underground distribution network reference scheme according to Paper 0180.**

**Paper 0392** examines Power-to-Hydrogen solutions as possible measures to relieve the HV grid in case of a massive penetration of PV-based generation. By installing small scale electrolyzers in the proximity of existing PV sites, the possible strain on the HV network can be significantly relieved. The benefits persist with no significant increase of stress on the network scaling up the electrolyzers size, thus showing that the electrolyzers’ contribution is more dependent on their location than on their power.

In **Paper 0649**, a solar-hydrogen-storage (SHS)-EV charging station with photovoltaic power, battery storage, hydrogen generation and storage system is presented. The system is designed to be operated, minimizing the operation costs, including hydrogen fuel costs and electricity purchase. In detail, the system operation is simulated through MATLAB to verify the renewable energy operation method in terms of cost and payoff period. Results show that compared with the traditional charging system, the cost of this SHS charging station is greatly reduced, the energy reserves are always guaranteed at the expected level, the utilization rate of the hydrogen storage system is high, and the reliability of the system is increased.

In **Paper 1049**, a technical, economic, and feasibility study of a PV-BESS system to support the diffusion of EV charging stations in Brazil is presented. The system includes a PV system, a BESS, and EV fast chargers connected to the power grid; the load can be supplied by the PV system when available or by the grid or BESS when energy prices are high. The system optimization has been performed, finding a return on the initial investment of seven years,
besides 10% of ROI and 0.28% of LCOE.

Fig. 5: Flowchart of the algorithm to determine the Hosting Capacity according to Paper 0391.

**Paper 0391** deals with the hosting capacity increase that can be achieved in an LV grid through the flexibility that storage systems and smart inverters can ensure. The proposed methodology provides a reliable estimation of the hosting capacity and can be ordinarily used while evaluating a new generation connection. As expected in LV, the most effective measure happens to be Volt-Watt regulation, while Volt-VAR is not always beneficial as it. However, it does not limit generation but may significantly increase losses.

**Paper 0490** describes a pilot project where parts of the LV grid of Mainz have been monitored over a period of about 1.5 years. Evidence coming from the collected data shows that an accurate understanding of the grid status may lead to better decisions regarding asset usage and grid reinforcement in the connection process and operation. Finally, the authors state that digitalising the LV grid may lead to automatising some common processes that DSOs are executing daily.

**Paper 0583** discusses technical, economic, and other types of Non-Wires Alternatives (NWA) screening criteria and methods that can be applied to streamline the NWA evaluation process. The abovementioned techniques can be applied to assess NWA potential to defer or avoid conventional distribution system investments. Notwithstanding the authors exploring several key types of NWA screening criteria, they foresee the need for more research to refine the processes, methods, and criteria and develop software support tools.

In **Paper 0715**, the LENI Least cost ElectrificatioN decision support tool for the optimisation of LV electrification is presented. The idea behind LENI is to develop a flexible approach for determining the best electrification solution within unelectrified villages: the tool provides the grid design. It performs a techno-economical optimisation of the LV grid and individual solutions such as solar home systems or microgrids. Future LENI developments include a techno-economical arbitration between on-grid and off-grid solutions.

**Paper 0996** introduces a simple (naïve) methodology to select characteristics network nodes, in which smart meters should be installed with high priority to achieving effective coverage of the LV network for DSO monitoring purposes. The idea behind the initiative is to assess possible problems with voltage quality while keeping the necessary initial investment low. The simplicity of the method also allows easy automation of the selection process. By applying it in the smart metering project Komorany, it was found that the success rate is quite far from outstanding.

**Sub block 2: Smart Grid Systems and Applications**

Sub block 2 includes papers explicitly dealing with Smart Grid topics, ranging from strategic development plans to infrastructures and architectural novelties to specific functionalities’ delivery. It must be appreciated that LV networks are also considered.

**Paper 0715** deals with Smart Grid Architecture Model (SGAM), an already established tool supporting standardization in the Smart Grid technical design. The authors present a methodology that is aimed at including the social perspective in the development of a Smart Grid project: this is increasingly needed as, due to decentralisation and the development of new business models in the energy system, stakeholders are becoming increasingly dependent on each other, and the agreement on interoperable solutions represent an
organizational as well as a technical issue.

In Paper 0573, the implementation of self-healing concepts to the LV grid is discussed. The extension to the lower voltage levels to operational practices already introduced in MV networks may seem almost natural; however, technological challenges exist. The economic viability of the investment needed to establish a self-healing infrastructure is not immediately clear. The authors argue that possible synergies with other concepts that are being developed (microgrids, EV, Demand Response, etc.) will eventually help to implement the elements (such as telecommunication capabilities) needed to boost self-healing in LV.

Paper 0138 presents the results of the SERVING project. A platform has been developed within this project that aggregates the flexibility of individual loads (night storage heaters, heat pumps, water pumps, etc.) for optimized energy procurement, considering grid constraints. During the pilot project with 50 customers, water pumps and night storage heaters were controlled, but the platform can easily integrate other flexibilities like electric vehicles or heat pumps. Challenges to gather data and control a large mass of flexibilities in rural networks are presented, and the solutions developed.

Fig. 6: Functional interactions of the SERVING platform as described in Paper 0138.

Paper 0740 presents an optimization model to derive the load profiles of future active domestic customers. It compares different incentive-based control strategies to meet the challenges of these developments from a grid perspective. The advantages, disadvantages and interactions of different incentive-based grid control strategies are then analyzed. The results show how different incentive strategies have different effects on the load profiles of active customers. In particular, price tariffs that contain power-related elements or thresholds for energy prices seem more effective, from the grid point of view, compared to time-variable price tariffs about voltage quality and grid utilisation.

Paper 1085 describes an agent-based model for simulating participants’ offering mechanism in a Local Energy Market (LEM). The market users’ behaviours are simulated through a decentralized version of the common genetic algorithm (DGA), implemented on a Real-Time Digital Simulator (RTDS), capable of inspecting the grid dynamics. To test the proposed model, approximately an hour of simulation with three users was performed. As the next steps, the authors want to improve the full Hardware In the Loop (HIL) process to simulate one or more days of operation of the system.

Sub block 3: DC Distribution Systems and Microgrids

There is already enough technical literature about DC distribution systems that have been largely investigated during the last years due to the characteristics of many new loads that intrinsically reminded DC distribution to be supplied. It must be noted that DC systems can also be used in an off-grid solution powered by RES, hence the inclusion, in the same Sub-block 3, of the wider Microgrid topic.

In Paper 0450, a technical solution to perform the conversion of portions of LVAC network in DC grid is examined. Authors show that transforming some parts of a conventional LV system into DC-operated ones is more convenient than ordinary reinforcing to reduce voltage violations and mitigate overloading, especially when future developments and learning curves of DC technologies are considered.

Paper 0383 proposes a procedure for designing an electrification project in a remote rural area, relying on distributed resources of energy and information from the studied area supported in the geographic information systems (GIS). Based on information available about the location of users, paths, forests, access roads, land use, contour lines, solar radiation, wind
speed, and rivers, the most appropriate radial distribution network is designed. AC, as well as DC installations, are considered and ranked to find the optimal techno-economical solution.

**Fig. 7: Methodology for electrification projects in rural areas, as in Paper 0383.**

In **Paper 0360**, a methodology to design and operate rural microgrids, particularly suitable for off-grid areas in emerging or developing countries and island communities, is presented. Firstly, three use cases (off-grid microgrid, connected/island-mode microgrid, community microgrid) are introduced. Secondly, a seven-step process to perform the design and implementation of a specific microgrid is described. Finally, some practical applications are detailed. Further investigation will be devoted to finding a suitable business model to support the sustainable industrialization of the proposed solutions.

**Paper 0602** presents a new AC/DC microgrid topology as an alternative to the traditional AC network in the context of developing countries' electrification. DC loads are firstly grouped using K-means clustering. Next, a minimum spanning tree (MST) algorithm is applied to the clusters to get the minimum length of DC conductors. Hence, using the shortest path (SP), the closest electrical poles connected to a cluster where the AC/DC converter is placed are found and then balanced by the mixed-integer linear programming (MILP). Finally, the AC lines connecting all poles and clusters are designed with the MST. The optimal cost of the complete AC/DC microgrid is determined for 20 years of operation.

In **Paper 0817**, a comprehensive electrification strategy to grant universal energy access in Zambia in 2030 is presented. Based on an available grid and off-grid solutions, an investment plan is developed, in which different architectures are adopted according to population density and proximity to an existing network. The result is a least-cost study of MV grid extension feeders and areas for off-grid electrification.

**Paper 1011** describes the main results of the POSEIDON project. The project aims at defining optimal control strategies of microgrids in the port area, including the management of electric vehicles with public charging stations, energy storage systems installed on boats, flexible loads and Renewable Energy Sources (RES). The planning studies will evaluate, by considering the use of vehicle-to-grid and boat-to-grid paradigms, the positive impact of electric vehicles and boats in terms of better exploitation of RES, energy efficiency and reduction of the polluting emission.

**The potential scope of the discussion**

Microgrids are already planned as a viable solution for isolated areas electrification due to their modular structure and relative ease of installation. Can we imagine the same microgrid structure as the atomic element to build larger distribution architectures, being able to operate both as a standalone entity and as an inter-connected sub-system?

**Table 2: Papers of Block 2 assigned to the Session**

<table>
<thead>
<tr>
<th>Paper No.</th>
<th>Title</th>
<th>MS a.m.</th>
<th>MS p.m.</th>
<th>Rif</th>
<th>PS</th>
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<tr>
<td>0134</td>
<td>Zero downtime (ZDT) network topology for reliability supply in new capital city of Indonesia</td>
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<tr>
<td>0138</td>
<td>Combined market and grid oriented operation of distributed flexibilities</td>
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</table>
The Hosting Capacity of distribution networks has been debated for a long time. The expected connection of new distributed generation for the energy transition is attracting new research on the field covering a range that spans from the HC definition to some practical applications.

**Block 3: Distribution Planning**

**Sub block 1: Advanced Planning**

The Hosting Capacity of distribution networks has been debated for a long time. The expected connection of new distributed generation for the energy transition is attracting new research on the field covering a range that spans from the HC definition to some practical applications.

**Paper 0046** defines HC as the amount of PV generation connected to a network that does not cause an overload of lines or equipment. The authors propose a methodology to estimate the HC of any distribution network, and map zones with the highest overload risk can be easily prepared. One significant result is that according to the examined data, transformers are more prone to overloads than the cables feeding a
cabinet. **Paper 0029** deals with the case of reverse power flow from LV to MV network. Reverse power flow is not an issue for the distribution transformer. Problems can arise if a negative load happens on an intentionally isolated distribution network energised by a rotating generator during maintenance. In this case, the concept of Hosting Capacity is used to identify the maximum level of PV generation that allows using a backup generator to supply loads. In conclusion, the authors find that for small distribution transformers, where backup generation is most often needed, it will often simply not be possible. For larger distribution transformers, backup generation during the summer months becomes a serious challenge with tens of kW installed capacity.

Distribution planners seek new tools and methodologies capable of considering at the same time different objectives that include reliability and resiliency besides economy and energy efficiency. **Paper 0064** proposes a new algorithm for distribution planning capable of finding the optimal network expansion and breaker and switches position simultaneously. The proposed procedure obtains the Pareto set of the integrated network development plans. It provides a decision-maker to determine the best network development plan by integrating the network expansion and network automation planning in radial distribution networks with distributed generators. The topic is not new (the first contributions of integrated network/automation planning were proposed in 1997-1999), but the authors significantly improved using a novel methodology.

The electrification of energy consumption is one of the success keys for the energy transition. Load demand is expected to grow as well as the power injected by generators connected. Old models based on average data and single point representation of customers’ needs are no longer suitable and cannot help planners in the existing context. Furthermore, tools to assess the worth of flexibility, related costs and inherent risk are crucial to modern planning and fulfilment, such as recent EU directives. Indeed, non-network solutions are progressively being considered by distribution and transmission planners for economically addressing acknowledged grid limitations. Gaining popularity due to technological advancements, falling costs, and supportive regulatory orders, regulators in several jurisdictions are now mandating that utilities evaluate the feasibility of DER-based alternatives before conducting any major grid reinforcement. Non-network solutions significantly impact the complexity of the planning process and pose new challenges to associated analytics, tools, and business processes. Many CIRED 2021 papers give significant contributions to the topic of modern distribution planning working in this field. **Paper 0358** brilliantly shows how to bridge the gap between national energy transition goals and distribution planning. It proposes an approach based on geographic and statistical data to distribute national projections for distributed generation and consumption into five distinct distribution grid types. Geographic data analysis is used to categorize areas into these five grid types. National projections are used to determine the needed number of EV chargers for distributing roof-top and large-scale PVs and individual heat pumps.

**Fig. 8: Example of network classification with GIS in the area of Roskilde Fjord in Denmark (Paper 0358).**

**Paper 0157** is another example of advanced planning to include non-wires alternatives within distribution planning with a multi-dimensional planning technique. With this technique, planning studies can be as detailed as needed for integrating new technologies, visualizing their effect on current and future distribution systems. The multiple dimensions generated can be compared economically to obtain the best investment plan for the next years based on the load growth forecast, the technologies used to relieve the power system and the circuit model used for the planning study. The method
proposed is a graphical framework for describing the relationship, progression, and dependencies between the power system state through time and the alternatives needed to solve the violations found during the analysis period.

**Fig. 9: Example of graphical representation relationship, progression, and dependencies between the power system state through time (Paper 0157).**

**Paper 0611** is an example applied to the long-term planning of active distribution networks (ADN). The authors propose a step-by-step methodology that aims at tackling the problem of efficiency in long term planning based on the ADN concept. Therefore, ADN planning (ADNP) extends the complexity of conventional planning with additional operational considerations, such as switching regulation taps of distribution transformers, the curtailment of distributed generation (DG) or active and passive feed-in management, as well as the operation of demand response. The methodology builds on the ADN concept as a strong candidate to defer network investments common practice in usual business scenarios. Its application to the case study of a medium-size Spanish city highlights the economic advantages already on a horizon of 10 years. Assuming a moderate engagement of 15% of the loads connected to the network into demand response mechanisms results in a 7% reduction of operational costs and 14% reduction for conventional expansion investments than the expansion strategy without DR.

**Fig. 10: Albacete: HV, MV and LV network model (Paper 611).**

**Paper 0719** contributes to flexibility in distribution planning by showing the Enedis approach to the problem. Enedis has issued a request for proposals of flexibility services with an online tool that would enable actors to bid with any kind of services. The tool enables the actors to evaluate the performance of their services, and Enedis to assess the collective value of each bided service. Enedis awards the flexibility contract yielding the greatest collective savings based on the score, the hidden point value, and the bid price. The network solution has an optimal balance between costs and benefits for the collective value in the studied case. Flexibility service providers, on the contrary, must aggregate a large amount of consumption curtailment services to beat the efficiency of the investment. Thus, in this case, flexibility is not a good option. However, the methodology and the online tool developed can sustain pedagogy on local flexibility and help actors improve their proposals to the DSO.

**Fig. 11: The cost balances with investment or with different flexibility services (Paper 719).**
Paper 0757 demonstrates the potential benefits of integrating demand forecasting, flexibility service providers and system network models. Western Power Distribution (WPD) proposes developing an automated tool as part of a project termed the Electricity Flexibility and Forecasting System (EFFS). EFFS interfaces with the market platforms to request flexibility requirements, receive the available flexibility and returning the final selection of services. Thus, the optimisation process is distinguished into two stages: procurement and selection. An optimisation algorithm takes place for the optimum selection of services based on a ranking system where for each service, a total score is calculated. Finally, a validation process is launched. The EFFS optimisation algorithm runs power system analysis and contingency analysis to determine network constraints and select optimal flexibility services to resolve the constraints. The EFFS tool has the potential to be further developed into a fully automated end-to-end system that could be used as a real-time system tool. It could be utilised to identify future network constraints in a distribution network or to process flexibility services and select the optimum solution.

<table>
<thead>
<tr>
<th>Primary Substation</th>
<th>Primary Transformer Loading (in %)</th>
<th>Remaining Constraint (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eggbuckland</td>
<td>83.2</td>
<td>0.74</td>
</tr>
<tr>
<td>Longbridge</td>
<td>&lt;75</td>
<td>None</td>
</tr>
</tbody>
</table>

Fig. 12: Example of network constraints reduction after selecting flexibility in services in the UK test case proposed by Paper 0757.

Paper 0956 deals with a platform focused on flexibility for integrating RES. The EU platform METIS II is capable of increasing the resolution on electrical transmission and distribution grids with the detailed representation of European distribution networks using archetypes and climatic zones. Concerning the EUCO3232.5, both load shifting and EV charging flexibility are activated to reduce distribution network generation curtailment and load shedding. Thus, flexible distribution network assets help to integrate more renewables without having to invest further in infrastructure. Heat pumps and hot water demand have a limited contribution to reducing renewable generation curtailment because of seasonality. Anyway, besides many restrictions, the flexibility helps reduce the generation curtailment by 37% and load shedding by 100% in some of the examined networks.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Load shedding (TWh)</th>
<th>Generation curtailment (TWh)</th>
<th>Load shifting (TWh)</th>
<th>EV load shifting (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No flexibility</td>
<td>12.5</td>
<td>71.0</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Flexibility</td>
<td>10.1</td>
<td>68.3</td>
<td>3.0</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Fig. 13: Impact of flexibility on reducing load shedding and generation curtailment in the EU (Paper 0956).

Paper 1040 proposes a DSO portfolio composition method to secure flexibility in the cooperative operation with an aggregator. The proposed method simultaneously reduces the computation time and satisfies the technical constraints. Since the DSO does not control individual DERs, neutrality in the cooperative operation with the aggregator is guaranteed. In the portfolio composition process, the DSO provides for each zone the flexibility type required for the target epoch. The aggregator provides the amount of available flexibility and the unit price for each zone, which the DSO considers to compose the flexibility portfolio of the distribution system. This approach can reduce the complexity of the portfolio construction.

Fig. 14: Flowchart of the cooperative approach between DSO and Aggregator for the flexibility portfolio (Paper 1040).
Paper 0867 analyses the worth of flexibility from the reliability point of view. Flexibility with respect to the reliability of supply means that the distribution utility agrees with the end-customer. The customer takes the risk of long interruptions but receives monetary compensation for them. The economic value of flexibility can be significantly high in sparsely populated rural areas with challenges in supply reliability (risk of major storms) and depopulation. By selecting the best few per cent of all customers to the flexibility agreement, a relatively high share of network investments can be reconsidered from the perspective of scheduling, placement and technological choices of the network renewal. However, the results support a preliminary estimate that flexibility targets (customer nodes) have to be defined by the utility. Otherwise, if customer nodes are selected randomly, network areas committed to flexibility are not uniform enough to take them effectively into account in the long-term development of the network infrastructure.

The economic feasibility of customer flexibility, i.e., the present value savings and losses, is based on five factors. These are 1. network technology-based savings, 2. network age-based savings, 3. lifetime savings, 4. age-based saving (difference in present value), and 5. value of major area of disturbance.

![Image](https://ciired.org/online-paper-0867/)

**Fig. 15:** Two alternative paths from the present operating point to the level where the network has to be renovated to satisfy the requirements of the law (Paper 0867).

Flexibility is not infinite and, if used by DSO for distribution network operation and planning, there will be less flexibility for the TSO. TSO/DSO integration is crucial. A compromise must be found between the investment cost minimisation and the maximisation of distribution flexibility for transmission services. Paper 0976 gives an original contribution on this crucial point with an algorithm that supports cooperative (but decoupled) planning for both distribution and transmission systems. The planning strategy for distribution networks can explore several planning options to minimise the operational/investment costs and maximise local flexibility for the provision of services to the upstream transmission network. The complex procedure explores different options regarding the required regulation reserve for transmission services and optimises the distribution planning. The cooperation between system operators is expected to be simple and efficient since the identified distribution planning options can be negotiated with a limited exchange of standard and non-sensitive information. The proposed algorithm avoids solving a fully coupled joint optimization problem while still considering the interactions among different voltage levels.

Paper 0543 is an original contribution that shows a different approach to planning based on the extensive inclusion of communities and open data sharing. Distributed open data is key to planning how the electricity distribution network develops to accommodate different visions of local stakeholders. The paper describes a real application in the UK that trials open data, visualisation tools and common languages for mutually sharing disparate data sets associated with distribution future energy scenarios (DFES). One example of specific feedback came from the local industry about plans to switch fuel in glass furnaces. This resulted in a special sensitivity on the load impacts of large industrial fuel-switching strategies being carried out and included in the following year’s DFES publication (DFES 2020).

![Image](https://ciired.org/online-paper-0543/)

**Fig. 16:** Primary substation DFES view (Paper 543)

Paper 0483 is another high-level contribution
that aims at giving distribution planners data to produce significant load patterns. In particular, the authors focused on the forecast of temperature because of climate change. The paper is particularly relevant for countries with power demand highly linked to temperature. The current practice for forecasting is based on historical data. Paper 0483 first examines the adequacy of indicators based on historical data and suggests a methodology to anticipate future low and high temperatures better. The authors show that the current methodology underestimates the risk in the next decade linked to warm temperature levels. The study has shown that the estimation of very low and very high percentiles of the temperature distribution over a historical past 30-year period may not fully represent what could be expected in the following decade. The proposed approach to produce temperature time series seems to improve the anticipation of near-future conditions.

Fig. 17: Comparison of the frequency of higher temperatures than the 99.7% percentile estimated over 30 years in the following decade to that of each of the three decades of the considered 30-year period. An upward triangle means a higher frequency, a downward triangle a lower frequency, and a circle no significant change (Paper 0483).

Paper 0190 is an interesting example of long-term planning that uses network and non-network options for finding the optimal expansion plan. The uncertainty due to the variability of production and consumption profiles and producers’ arrival (date, technology, installed power, location) is considered. Since scenarios are randomly produced and optimized, the optimization is based on stochastic planning. More precisely, the optimization problem is a stochastic, multi-objective optimisation problem, with expensive-to-evaluate objective functions solved with the Bayesian optimization technique. The paper’s main result is that the proposed technique can dramatically reduce computing time compared to Monte Carlo. The procedure is suitable for the application in real-world problems with many contrasting objectives and planning parameters.

Fig. 18: (a) Illustration of the optimisation process of the input parameters of a stochastic simulator and (b) example of resulting network planning decisions for a given scenario and set of network planning parameters (Paper 0190)

Paper 141 presents a very good prototype that leverages customer times series to provide the grid planner with the information necessary. Furthermore, an analysis of how flexibility could be leveraged to alleviate the capacity needs is also available.

Fig. 19: Conceptual design of the tool proposed by Paper 0141.

Paper 0257 proposes an innovative holistic approach to planning that improves the traditional planning and development process. The proposed method is capable of identifying grid hotspots in future supply tasks. Providing and combining real grid and asset data with forecast scenarios into a multi-scenario analysis
empowers grid planners to focus on hotspots. The resulting complexity of such a multivariate method is controlled by using the concept of hierarchical KPI navigation and aggregation carrying the planner to the most relevant grid issues. The tool will be applied to the entire Westnetz MV (E.ON) grid. Automatic optimization tools are still missing in the model, and their development will increase the model worth.

Paper 0565 presents an ant algorithm that optimises the costs of a medium-voltage power network structure while complying with the electrical specifications for several given scenarios. The increasingly used holistic planning approach requires several criteria to be considered at the same time. Therefore, the given technology is extended for an application in multi-criteria optimisation. The criteria selected for this paper are cost minimisation, reliability maximisation, and minimisation of the number of sectioning points to increase network operation efficiency. Thus, optimisation provides a variety of solutions to choose from depending on individual preferences. The paper has been tested with a greenfield optimization. The use of multi-objective programming is very promising, but the algorithm does not explicitly consider uncertainty and the role of flexibility as a planning option. Anyway, the authors show that by using multi-objective-oriented algorithms, the decision making is more transparent, and planners can find a compromise among several contrasting goals objectively.

**Fig. 20: Hierarchical Scenario Management as in Paper 0257.**

**Paper 0565**

**Fig. 21: Impact of different criteria in distribution planning: a) cost criterion and b) reliability criterion (Paper 0565).**
Paper 0395 also describes a planning methodology for supporting the technical/economic analyses to choose interventions on the distribution network. The genetic algorithm exploits AI techniques for the multi-objective optimization of the grid configuration, aiming to optimize costs, quality of service and load KPIs simultaneously. The use of GA and AI for distribution planning is not original, but the algorithm developed is a very good step towards considering flexibility services offered by distributed energy resources as an alternative to traditional infrastructure solutions.

![Image](51x646)

Fig. 22: Example of network optimization from Paper 0395.

Paper 0685 is a very good contribution to improving a typical automated network planning process, such as the cost estimation of new underground cable routes. The traditional approach of calculating these costs based on rough average cost assumptions fails to consider each individual case's specific geographical and geological conditions. It can therefore compromise the quality of network planning, especially when applied to heterogeneous supply areas. The proposed algorithm enables an individualized cost estimation for each possible new underground cable route using the least-cost path algorithm on a calculated cost raster, covering the whole supply area and including all relevant geological and geographical information. To this scope, the entire supply area has been divided into 334 million raster cells of 25 m² each (5x5 meters). A new underground cable route cost is calculated for each cell, using as inputs mostly publicly available geodata from different sources. The developed algorithm enables an individualized estimation for any arbitrary route considering all relevant geographical and geological conditions. The accuracy of the model in the vast majority of the "normal" cable routes lies within +/-25% accuracy, providing reliable input for the MV network's automated planning and a useful tool for the daily business of operative asset management and engineering.

In the early phase of planning, an optimization algorithm can trace the least cost path between two points, avoiding using the most expensive pixels. The same approach is also used for more automated planning of MV distribution planning.

![Image](312x123)

Fig. 23: Optimal route calculated in an urban area (Paper 0685).

Papers 0322 highlights the need for new tools and methodologies capable of assessing the impact of new loads. The paper uses the data from AMR to build a better load pattern that can be used to assess voltage regulation, and power flows in MV and LV networks. Furthermore, EV demand is included in the model with the complete electrification of heating demand in Denmark. The number of feeders and transformers expected not to meet the load, and the voltage criteria are significant. The voltage criterion is the most critical for 0.4 kV radials. The paper demonstrates the positive impact of flexibility that can reduce the harmful impact of new loads and electric vehicles.

![Image](313x451)

Fig. 24: The percentage of LV radials that do not meet voltage criteria according to Paper 0322.

Paper 0472 investigates the role of operating points in urban LV planning. Peak load and peak
generation are considered assuming different scenarios for heat pumps, EV charging points, and PV generation. The peak load operating point is relevant for equipment dimensioning in the examined test case. The peak generation operating point is particularly relevant in networks strongly penetrated by detached and semi-detached houses in suburban areas. The paper considers innovative planning actions such as regulated distribution transformers (RDT), energy storage systems (ESS), and static or dynamic load and DG management systems. The voltage regulating measures are recommended the transformer substitution.

The uncertainty associated with loading demand, generation, and even network elements can affect the results of distribution planning and make decision-making a too much risky activity. Paper 0823 gives an original way to fix this issue regarding the French case by assessing the impact of models and related uncertainties. The method uses a Global Sensitivity Analysis to characterize the impact of any model on the decision criteria. Several modelling hypotheses are considered in the paper, and their impact on a French low voltage network is assessed. The dependence of the decision criteria on the models considered in the LV grid planning process is the main paper result. The methodology can assess the impact of models and related uncertainty when flexibility is used to operate LV distribution networks.

**Fig. 25: Expected voltage violations for LV networks in different operating points (Paper 0472).**

**Paper 0552** proposes an online interface for distribution planning of LV unbalanced distribution networks. A stochastic load simulator generates accurate and tailored load profiles at a resolution down to one minute for a neighbourhood. New and upcoming load and source technologies, such as electric vehicles and photovoltaic panels, can be forecasted. The control strategy of demand with an accurate representation of tariffs can be used to plan, delay, or avoid grid reinforcements. If a user already has power time series (such as smart meter data), they can be used directly for power flow optimization and assess the worth of flexibility control.

**Fig. 26: Example of undergoing node voltage drop and line overloading from Paper 0552.**

**Fig. 27: The General Global Sensitivity approach used by Paper 0823.**

**Paper 1071** is another interesting contribution, including flexibility from loads with higher nominal powers and stochastic behaviour, such as electric vehicles and heat pumps. Conventional concepts of network planning typically do not consider the potential flexibility of newly introduced loads, which can lead to
unnecessary network investments and oversized networks. For this reason, a methodology, which considers the possible flexibility potential of loads and uses a probabilistic approach to network planning is introduced and applied on a model of a real LV network. The proposed methodology utilises the Monte Carlo method for performing load flow analysis. The simulation platform developed integrates GIS data, Powerfactory and Matlab, and enables analysing a system with stochastic consumption and production. The potential impact of flexibility services provided by prosumers on distribution network operation is assessed. As part of the methodology, weekly quasi-dynamic Monte Carlo simulations are performed, thus including the unpredictability of consumption and location of individual loads in the planning process. Simulations showed that modernization would enable better utilisation of infrastructure and the reduction or postponement of investments.

Paper 0347 describes the process developed by authors for analyzing distribution in a German distribution network with suitable algorithms capable of detecting ageing and electrical usage issues. The combined results of a long-term infrastructure analysis and electrical analysis deliver various evaluation opportunities. Vulnerabilities regarding reliability on the medium-voltage level are revealed, and, for the low-voltage level, critical assets are discovered with a grid overview. A sound basis for short-term measures and the development of “optimized” medium- and long-term measures (including optimising the grid structure reflecting the dependencies between medium- and low-voltage levels) is proposed.

Paper 0406 proposes a methodology for expansion planning of systems with increasing participation of renewable generation, linking a long-term expansion planning model to a day-ahead operation model. The last enables adjustments in the expansion plan considering the uncertainty of the intermittent generation and the hourly operational constraints of thermal generation. The methodology was applied to an expansion plan of the Brazilian system, where the increase of wind generation would imply problems in the daily operation of the final years. The results show the importance of considering the daily operation constraints of distributed energy resources in long-term expansion planning.

Fig. 28: The block diagram of the platform used in Paper 1071 for studying flexibility impact on LV networks.

Paper 0752 deals with developing synthetic network models for studying HV and MV distribution networks and their mutual interaction during faults in the presence of decentralised generation. Therefore, detailed mapping of the high-voltage level is crucial, but no holistic, publicly available grid data set is accessible for high voltage networks. Existing models are often simplified or, in real grid data, focusing on limited network sections with a lack of representativity. Synthetic grids can offer an alternative to this problem. Modelling synthetic grids aims to generate fictitious test systems but capable of representing characteristics of actual power grids. An approach to model current and future synthetic high voltage grids based on open data.

Fig. 29: Flowchart of the methodology proposed by Paper 0406.
is developed. In addition, an existing method for modelling synthetic grids of the medium voltage level is integrated into the model to obtain linked synthetic MV and LV distribution networks.

The energy transition will impact HV sub-transmission grids, namely 150 kV, concerning underground cables with a long life. Assets have a long service life, and therefore the correct choice of requirements for new cables is crucial for grid operators. The ampacity of HV cables put into service in the present impacts the target grid planned. Paper 0777 presents a structured analysis procedure to establish the requirements for new HV cables for planning a target grid in Zurich. A reference power flow scenario with estimations on population growth and development of EV was established as starting point. According to the municipal structure plan of Zurich, the allowable build space for the future and, therefore, the maximum expected load is determined. Domestic, commercial and EV loads have been estimated for 2050 and distributed to the substations in the city. They were combined with corresponding load profiles to generate 24h load profiles. With the cable requirements obtained by load flow calculations, the Zurich 150kV target grid is being developed.

Fig. 30: The process to find the HV synthetic networks as in Paper 0752.

One of the most innovative planning methods proposed in CIRED 2021 is the one in Paper 0350 that combines traditional distribution planning with AI and Machine Learning (Q-learning approach). The effectiveness and feasibility of the proposed model are proved in practical applications with the aid of simple examples. The Q-learning model obtained several excellent alternatives, and the adjusted Q-learning model even obtained an identical scheme to that of the mechanistic model. The process of using ML in distribution planning is still at the beginning, but it is quite easy to see the benefit of a new approach in computing time and transparency of results.

Fig. 31: The process to find the cable requirements used in Paper 0777.

Fig. 32: Example of optimal distribution network discovered by a non-mechanistic algorithm (Paper 0350).
Sub block 2: Smart Grid Planning

The papers in the Sub block deal with the use of the smart grid in planning without the flexibility offered by service providers. Paper 1059 proposes a new model for the operational planning of Smart Grid with DG generation interfaced with power electronics and study the instability of inverters connected to high impedance networks. The proposed method can evaluate the stability of a nonlinear and time-varying system. Therefore, it can be useful in evaluating the stability of nonlinear power electronic components at different grid connection points under changing conditions.

Paper 0518 is an interesting application of machine learning to solve dynamic network reconfiguration and avoid the generation curtailment of PV power plants. The impact on planning is evident since the non-network solutions used can avoid or postpone network investments without penalising the power producers. Dynamic network reconfiguration (DNR) controls the network topology by controlling sectionalizing and tie switches to reduce PV curtailment as changing the power flow in the network and the joule losses. The problem is modelled as a Markov decision process (MDP) and uses a deep Q-network (DQN) to solve it. DQN algorithm is a data-driven approach for MDP, so it does not require topology information, and this is an important benefit from machine learning.

Paper 1126 presents a process that allows a semi-automated analysis of cross-system KPIs of given Use Cases (UC) managed within a UC Management Repository based on the IEC 62559 and SGAM standard. The examples demonstrate how the SGAM framework can utilize existing domain knowledge as a Reference Designation System to compute quality indicators. Finally, a concrete example was given based on the i-Score methodology. However, the presented example shows that existing UCs can be analysed with minimum effort. Complementing single metrics on Smart Grid architectures, the SGAM KPI-Dashboard can be applied as an expert system to support the decision-maker by analyzing and comparing different options.

**Fig. 33: The method proposed by Paper 0159 to evaluate the stability of non-linear and time-varying systems.**

**Fig. 34: The overall process proposed by Paper 1126.**

Paper 0353 proposes the use of autonomous web-of-cell (AWoC), a new connection scheme that aims to connect RES and energy storage to the grid. The "gathering and dispersing" multi-state control operation mode of AWoC based on coupling point and tie-line control is proposed innovatively. The AWoC division can provide a reference for Micro-Grid planning. Thanks to its flexibility and expansibility, AWoC can provide a
new idea for developing power systems under the trend imposed by the energy transition.

Paper 0975 addresses the topic of sector coupling in local energy communities to increase the level of self-consumption. A residential subnetwork with installed photovoltaic systems and central storage connected to a low voltage network is considered a reference. An electrolyser, a fuel cell and a hydrogen pressure storage are added to the model, determining the global solution of the multi-period optimal power flow problem. Different households and photovoltaic power supply scenarios are analysed. Two cases (photovoltaic, battery storage vs. photovoltaic, battery storage, polymer electrolyte fuel cell) are analysed, and seasonal influences are considered for an optimization horizon of an entire year. One result is that the H2 storage reduces the maximum voltages, and it improves the design and operation of the system. Future works should extend the analysis to multi-energy systems excessing heat of the polymer electrolyte fuel cell to be integrated into the system and taking additional loads such as heat pumps and electric vehicles into account.

**Fig. 35: Concept diagram of AWoC as proposed by Paper 0353.**

**Fig. 36: LCOE in the multi-energy local energy community simulated in Paper 0975.**

**Sub block 3: Optimal Placement of Power and Control discrete Components**

Papers in this subblock deal with allocating distributed resources and their use to solve specific network problems. A typical example dealt with by Paper 0167 is the use of SVC in MV distribution networks. This paper proposes a strategy to optimize the performance of distribution networks through the optimal coordination among Stationary Shunt Capacitors (SSCs), Dispersed Energy Sources (DESs) and Static VAR Compensator modules (SVCs). Several objectives are merged in one multi-objective function with the weighted sum method. A theoretical process is used to calculate the weights adequately. The original contribution is the use of Grey Wolf Optimization that is a relatively new optimization algorithm. Various regular loadings are further combined to investigate the influences of varying loading conditions. The reactive power compensation using SVCs leads to major quality improvements of the nodal voltage with variations of loads.

Paper 0170 proposed another optimization algorithm to find the optimal allocation of capacitor banks (CB), distributed generation (DG), and automatic voltage regulators (AVR). The paper uses the hybrid statistical Rough Set theory and Grasshopper Optimization algorithm to optimise the distribution system optimal planning and automation. Multi-objective functions of power loss minimization and cost minimization are proposed for the optimal allocation and control of CBs, DGs, and AVRs simultaneously.
Paper 0280 proposes the optimal siting and sizing of distributed generation for resilience enhancement in power distribution systems against volcanic eruptions focusing on the lahars occurrence. The proposed methodology includes the concept of vulnerability curves to determine the unavailability of the distribution system elements. The Monte-Carlo simulation method (MCS) and a stochastic optimization problem (SOP) characterize the volcanic lahars and optimally allocate DG. The results reveal that DG is critical for the resilience enhancement of a PDS against lahars formed by a volcanic eruption. Preliminary results refer to the distribution network in Cotopaxi-Ecuador, which is vulnerable to lahar in the case of Cotopaxi volcano eruptions.

Paper 0333 proposes the optimal allocation of switches in a distribution network to optimize the post-fault reconfiguration. The switch placement problem determines the optimal configuration of manual and remote-controlled switches (MSs and RCSs) and field circuit breakers (FCBs). The objective is to minimize the installation and operation costs of switches together with the reliability-oriented costs, which include the distribution company’s lost revenue due to the undelivered energy and the regulatory incentives (or penalties) associated with service reliability indices. The paper demonstrates that it is essential to consider the placement of FCBs concurrent with that of MSs and RCSs. Modelling the malfunctioning in RCSs and FCBs is crucial in switch optimisation models. Finally, the selection of the reliability index and incentive rates in reward-penalty schemes are essential in imposing an effective incentive reliability regulation.

The optimal allocation of energy storage is a topic that gained the attention of many researchers in recent years. Paper 0457 deals with the algorithm differently and proposes a physic-guided algorithm instead of more traditional approaches that need better network observability and a large amount of data. The novel method for the distribution network voltage prediction based on Physic-guided machine learning modelling is the algorithm's core. The accurate model of the distribution network gives the power flow boundaries estimation. The estimated power flow boundaries allow finding the optimal size and control energy storage system.

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Paper 0940 evaluates the techno-economic benefits of advanced PV forecasts for predictive congestion management at the distribution level. The effectiveness of predictive congestion management at the distribution level strongly depends on the congestion forecast accuracy, thus in PV dominated grid sections, especially on the PV forecast accuracy. Furthermore, the paper gives insights into the evaluation chain of PV-forecasting applications for distribution system operation. One important message is that the accuracy of (PV) forecasts must also be evaluated on the application effect. Four different performance indicators are proposed: PV forecast accuracy, congestion forecast accuracy, DER energy curtailment, and DER energy curtailment costs.

**Fig. 41: Flowchart of the predictive congestion management method for one-time step (Paper 0940).**

Paper 0562 addresses the topic of finding the optimal phase for the connection of LV loads that could be adapted to the connection of PV and EV charging points. A recommendation algorithm is proposed that is based on the improvement in neutral current minimization.

**Sub block 4: EV Accommodation Planning**

This Sub-block focuses on specific planning problems related to the connection to the distribution grid of specific user typologies: electric vehicles and charging stations. Topics span from mobility analyses to load forecast to the optimal location of charging infrastructure to hosting capacity evaluation to integrated connection solution.

Paper 0783 proposes a procedure to characterize charging stations based on relevant parts of their neighbourhood, defined as “service areas”. The procedure starts from the zoning plan of a German city to generate location-dependent features for several charging stations that allow a categorisation by the most dominant land use designation types in the neighbourhood. This categorisation is, in most cases, sufficient for analysing location-based influences as distinct user behaviour and power consumption patterns can be found for different categories.

Paper 1136 focuses on a specific charging process, i.e. work-based EV charging. The paper presents the results of a study about expanding EV charging at a 750-acre industrial/commercial site with over 5.500 employees, 6.000 parking spaces, approximately 10 MW of peak power consumption and 4 MW of CHP generation. A load flow analysis has been performed on the 11 kV distribution, and the impact of increased load from EV charging on the thermal limits of the main transformer has been investigated. Results show significant differences in EV charging capacity between peak winter and peak summer due to the lower availability of CHP during summer. Recommendations are also provided on how best to equip future distribution systems for increased EV charging.

**Fig. 42: EV charging scheme with DC fast charger as in Paper 1136.**

To simulate the mobility behaviour of both private and commercial electric vehicles, Paper 1043 proposes two different stochastic models; each one of the two relies on available public databases containing mobility behaviours of individual private drivers and commercial vehicles. The models provide a simulation of realistic mobility profiles and the extraction of respective charging schedules; the results of the two simulations are then compared to obtain the
desired coincidence factor. Results show that the proposed models can represent private and commercial mobility, respectively. The resulting coincidence factors show differences depending on the settlement structure; in particular, metropolitan regions show a lower coincidence factor than other areas.

![Diagram of settlement structure, number of persons per household, and temperature impact on charging profile.]

**Fig. 43: Process of the simulation of individual charging profiles for private vehicles as in Paper 1043.**

**Paper 0161** examines the impact on electrical networks of the connections of service areas in motorways to develop EVs, coming from a joint evaluation between French main DSO Enedis and French TSO RTE. The first evaluations focus on light vehicles. In the future, analysis on lorries and coaches’ needs will be developed; national roads will also be considered.

**Paper 0107** analyzes the different effects in network planning arising from developing a comprehensive model for the EV charging process compared to adopting a simplified one. Different assumptions were implemented in the two case studies, with specific reference to charging losses and the charging method for the battery. Results show that simplified models lead to a higher load than the comprehensive ones, suitable for worst-case scenario planning. In contrast, the application of comprehensive models in a specific planning exercise leads to a significant reduction of the estimated cost for grid enhancement.

In **Paper 0123**, a probabilistic model is presented to estimate the primary substation load from the diffusion of electric vehicles. Authors analyze the differences between substations with mainly residential and working place/service type customers, determining charging peaks and energy patterns; the estimation is based on specific Helsinki data. Results show that residential charging load is more significant even if primary substations have relatively high service customers.

**Paper 0226** presents a detailed analysis of the impact of EV charging points on a real MV distribution network located in Northern Italy. The study considers different deployment scenarios and alternative charging strategies; such operating conditions are then simulated to identify the most impacted parts of the network. The most critical components happen to be the MV/LV transformers due to the high nominal power of fast charging points.

**Paper 0301** deals with estimating the load related to the charging process of vehicles for public transportation in 15 cities in Sweden. The study shows that the peak charging load is significant, eventually even bigger than the existing peak demand. Passenger cars and lorries account for most of it; the demand from electric busses is much less. To manage the network avoiding overloading conditions, a curtailment strategy has been defined. The hosting capacity of the grid for electric vehicle charging is then calculated based on the acceptable amount of curtailment in terms of hours per year to establish the need for new primary infrastructure.

**Paper 0470** introduces a methodology to determine the load increase in a distribution system due to the charging stations for EVs. The process described begins with the appropriate distribution of charging points in the different voltage levels depending on the characteristics of the existing grid. The demand factor for each charging point is then determined. Finally, the demand factors are used to calculate the load demand in an exemplary LV distribution system.

**Paper 1140** describes the results of Project PACE, delivered by SP Energy Networks, a UK Distribution Network Operator (DNO), together with the Scottish Government and local authorities. Project PACE is a pilot project demonstrating the benefits of DNO-led site selection and delivery of electric vehicle (EV) charging infrastructure for local communities. The project explores the strategic role a DNO...
can play in planning and delivering a public EV charging network. By a sophisticated site selection exercise, where optimum sites were identified, problematic sites were eliminated, and legal, planning and land rights agreements were agreed on upfront, optimum sites were identified, allowing significant time savings in the end-to-end delivery of the EV charging hubs.

**Fig. 44: The public charging infrastructure site selection process according to Paper 1140.**

**Paper 0832** introduces a methodology to identify potential locations for public charging infrastructure based on publicly available data. Information is derived from OpenStreetMap, and the quality of data is improved by neural networks, through which missing information is also predicted. The methodology allows determining location, capacity and individual suitability of georeferenced car parks. A simulation was conducted, based on a study case in Germany, in which approximately 400,000 car parks were extracted from OpenStreetMap and evaluated in terms of car park capacity and suitability.

In **Paper 0724**, the ‘Take Charge’ project is described, an initiative by Western Power Distribution to design and test a highly innovative standardized, pre-constructed and pre-packaged 33/11 kV compact connection solution to support large scale, high power, rapid EV charging at motorway service areas. In particular, the paper focuses on the methodology developed to identify a suitable site for the project trials and the process used to calculate the required electrical capacity for the new solution.

In **Paper 0025**, a model for estimating the EV hosting capacity of a given MV/LV network considering weather conditions (namely, temperature) is presented. A deterministic approach was developed and applied in a real MV/LV distribution grid in northern Sweden to support network planning activities. Results show that considering temperature impact by introducing a K coefficient leads to an approximate 30% reduction in hosting capacity during colder months due to the fast discharge of the battery.

**Fig. 45: Hosting capacity of EVs for 24 hours and 12 months according to Paper 0025.**

**Paper 1110** presents a model that estimates the investments needed to upgrade primary and secondary substations, reinforce MV and LV grids and connect new charging points, both normal and fast. The process starts from input data such as annual adoption curve, load peak values registered at DSO installations (primary and secondary substations) and a predefined set of parameterizable assumptions. Results show that EVs’ full adoption and integration require an upgrade or reinforcement of around 20% of the entire MV and LV grid, representing around 18% of the required investment. The remaining share of 82% is associated with the new connections for charging points. A sensitivity analysis has also been performed, resulting in an estimated investment ranging from 19% higher or 5% lower. It must be noticed that smart charging technologies if used to support grid management and operation in real-time, may help to reduce such impact.

**The potential scope of the discussion**

The transition from deterministic worst-case analyses to probabilistic network planning has just started.
Yet, it already seems that an accurate evaluation of network criticalities requires serial load flow calculations based on time series made available by, or determined through, Smart Meters’ measurements for both final and active customers. This implies new tools, new algorithms but, even before that, the huge amount of data to be managed and handled: is distribution ready for Big Data and Artificial Intelligence or, maybe better said, is Big Data “big” enough for the distribution business? Can data-driven models substitute system models? Is it possible to manage complexity with data analysis? What’s the role of AI and ML in planning?
Is distribution planning going to be more and more influenced by the use of flexibility products? The first big revolution on distribution planning is the inclusion of operational options in planning. Is it now to model in planning the market of flexibility? What about TDSO and DSO integration? Integrated planning or coordinated? Priorities on flexibility usage?

Table 3: Papers of Block 3 assigned to the Session

<table>
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<tr>
<th>Paper No.</th>
<th>Title</th>
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<td>0025:</td>
<td>Estimation of electric vehicle hosting capacity of a distribution network based on ambient temperature</td>
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<td>0029:</td>
<td>Risk of negative net consumption during backup-generator operation of LV distribution with solar PV</td>
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<td>0046:</td>
<td>Likelihood of overload due to connected solar PV</td>
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<td>0064:</td>
<td>Integrated approach for expansion and reliability planning of radial distribution networks with island operation of distributed generators</td>
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<td>0107:</td>
<td>Impact of different electric vehicle charging models on distribution grid planning</td>
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<td>0123:</td>
<td>Prediction of primary substation demands with EV charging in urban city environment: Case study Helsinki</td>
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<td>0141:</td>
<td>A time series based tool for capacity and flexibility forecasting in the power grid</td>
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<td>0157:</td>
<td>Multi-dimensional method for assessing non-wires alternatives within distribution system planning</td>
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<td>0161:</td>
<td>Characterisation of long-term demand on French motorways for long-distance mobility of EVs and evaluation of the impact on French distribution networks</td>
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<td>0167:</td>
<td>Optimum coordination of SVC modules in mv distribution systems (a real case study)</td>
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<td>0170:</td>
<td>Optimal planning and automation of distribution systems using a hybrid statistical rough set theory, and grasshopper optimization algorithm</td>
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<td>0190:</td>
<td>A Bayesian approach for the optimal integration of renewable energy sources in distribution networks over multi-year horizons</td>
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<td>0226:</td>
<td>Evaluation of the future impact of electric vehicles on the distribution network of Brescia</td>
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<td>0257:</td>
<td>Integrated network development and planning - from forecasting to grid screening and concepts</td>
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<td>0280:</td>
<td>Optimal placement and sizing of distributed generation (DG) in a radial distribution system for resilience enhancement against volcanic eruptions</td>
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<td>0301:</td>
<td>Risk of overloading and hosting capacity under charging load for nordic cities</td>
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<td>0322:</td>
<td>Grid planning MV/LV by combining smart meter data with greenhouse gas reduction changers as EV, PV and heat pump conversion</td>
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<td>0333:</td>
<td>Optimal distribution network switch planning considering malfunction of switches</td>
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<td>0347: “Integrated electrical and long-term analysis” for the medium and low voltage grids of KWH Netz</td>
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<td>0350: Study on non-mechanistic modelling in distribution network structure planning</td>
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<td>0353: Research on patterns and planning method of autonomous web-of-cell</td>
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<td>0358: A robust approach for determining future projections for the distribution grid based on national projections</td>
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<td>0395: Development of an advanced planning tool for supporting the choice of optimal investments aimed at optimizing the infrastructure of power distribution systems in future scenarios</td>
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<td>0406: Expansion planning considering daily operation programming of distributed energy resources</td>
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<td>0459: A physic-informed machine learning approach for distribution network modeling: Application on optimal storage sizing and control</td>
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<td>0470: Demand factor identification of electric vehicle charging points for distribution system planning</td>
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<td>0472: Relevant operating points for future grid planning of urban low-voltage grids</td>
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<td>0483: Climate change and the lowest and highest temperatures to be expected in the next decade</td>
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<td>0518: DQN based dynamic distribution network reconfiguration for energy loss minimization considering DGS</td>
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<td>0543: Using open data in planning the net zero distribution network</td>
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<td>0552: Grid Scope – an online platform for better distribution system planning</td>
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<td>0565: Multi-criteria optimization in automated medium-voltage network planning</td>
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<td>0611: Achieving active distribution networks through operational and architectural aspects analysis: A methodology for long term planning</td>
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<td>0685: Automated cost estimation for new underground MV cable routes through geoanalysis</td>
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<td>0724: Site selection and assessment of required system capacity for rapid EV charging at motorway service areas (take charge project)</td>
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<td>0752: Modelling of synthetic high voltage networks based on open data and integration into a modular synthetic distribution grid generator</td>
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<td>0777: Establishing HV cable requirements to develop an urban 150kV target grid</td>
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<td>0783: Analysis of the service area of public charging stations for electric vehicles in urban areas</td>
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<td>0793: Flexible planning of integrated energy systems under long term uncertainties</td>
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<td>0823: Sensitivity of LV grid planning to load modelling</td>
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<td>0832: Georeferenced determination of the potential of public charging infrastructure</td>
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<td>0867: Value of customer flexibility regarding reliability of supply in the rural area electricity distribution</td>
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<td>0940: Techno-economic assessment of PV forecast accuracy for a predictive</td>
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congestion management at the distribution level

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<th>Paper</th>
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<td>0956:</td>
<td>Quantitative assessment of the role of flexibility measures in the integration of renewables using the upgraded METIS platform</td>
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<td>0975:</td>
<td>Multi-period optimal power flow in low voltage grids for a high degree of self-sufficiency</td>
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<td>0976:</td>
<td>Planning of distribution networks considering flexibility of local resources: how to deal with transmission system services</td>
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<td>1040:</td>
<td>Techno-economic approach of appropriate flexibility portfolio for distribution system operators (DSO)</td>
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<td>1043:</td>
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<td>Expanding EV charging capacity in distribution networks: a case study for charging EVs at work</td>
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<td>1140:</td>
<td>DNO-led site selection for public electric vehicle charging infrastructure</td>
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**Block 4: Methods and Tools**

**Sub block 1: Load/Generation Modeling and Forecasting**

**Paper 0033** presents a method to determine the individual demand of the average residential user using probability distribution functions to solve an LV network with Monte Carlo method scenarios. The statistical user demand characterization allows establishing LV distribution network power scenarios, considering various DG penetration levels, and carrying out electric current calculus, network node voltages, electric losses, and obtaining results with a statistical distribution. An aggregate load model is presented in **paper 0084**, considering the peculiar characteristics of 210 European regions hourly along one year from the perspective of the high, medium, and low voltage levels. The proposed load model is used to understand better the influence of regional characteristics on voltage recovery during a short-circuit event, as well as the static point of voltage collapse. The conducted study demonstrates that regional differences in the composition of demand highly impact local voltage stability.

**Paper 0126** presents a stochastic modelling approach based on Markov chain Monte Carlo simulation to model the aggregated EV load profile and calculate the overloading probability of the distribution transformers. Historical data of seven different charging stations have been used to develop the model. The DSOs could use the proposed methodology for planning their network development. The charging behaviour at public charging stations regarding temporal and location-based dependencies is examined in **Paper 0082**. Load profiles for typical days of the week and characteristic land uses have been created for public AC charging stations. The application of these load profiles is suitable to estimate the impact of a larger number of charging stations on medium and high voltage grids. Moreover, the distribution of plug-in events can provide input data for stochastic models valid at the LV level. Three different charging location types were analysed with regards to charging flexibility and simultaneity factors in **Paper 0247**. According to the simulation results, due to the high level of
flexibility, the use of charging management systems seems to be more effective for locations of the types “Courier and Parcel Service” and “Employees Parking Area” than “Shopping Centre” one.

**Paper 0326** proposes a method to analyze the smart meter data collected for each customer and the attribute information to calculate representative profiles. Then machine learning is performed to generate a regression tree that allows estimating the maximum power in the connection point. This makes it possible to design LV distribution with higher accuracy than the conventional method.

A method to model households and commercial loads on the level of individual buildings is presented in **Paper 0428**. Geo-referencing, building footprints, points of interest, and land uses for the area under investigation are combined to georeferenced socioeconomic data. Then consumers are allocated to individual buildings, and load time series are assigned. The calculated loads are aggregated to match the supply area of a German distribution grid operator to compare the modelled data with the measured load time series. **Paper 0454** proposes demand and generation forecasting models for distribution systems, each employing a different artificial neural networks architecture. The models have been developed on real data of an Austrian distribution system. The adaptability of the models to the changes in demand during the Covid-19 lockdown is investigated.

**Fig. 46**: Average daily load profile for a charging station concerning (a) the day of the week, (b) dominating land use type, according to Paper 0082.

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**An approach** to model the forthcoming electrical flexibility and energy demand of electric vehicles and to analyze future grid loads and the potential of different types of load management is the **Paper 0508** focus. The basis of this approach is the detail of load and driving profiles. The energy demand is derived from historical user data. The plausibility of the generated load profiles is demonstrated in a real application.

The widespread deployment of DER provides challenges in both real-time operational and long-term planning situations, some of which can be mitigated using time-series data collection and forecasting. In the **Paper 0528** investigation, three artificial intelligence forecasting methods, AutoRegressive Integrated Moving Average (ARIMA), Holt-Winters Exponential Smoothing (HWES) and Box-Jenkins Adjusted ARIMA (BOXJ), are evaluated for their relative effectiveness in real-time and long-term situations using various datasets from UK electricity industry innovation projects. **Paper 0510** deals with EV charging infrastructure modelling. The model is based on mobility behaviour and predicts charging processes. For scenarios with more than 20 charging points, parameters of the grid load (e.g. simultaneity factor, load profile) are predicted to
be used in the planning process of charging infrastructure in cities and suburbs.

Paper 0556 goal. A data-driven approach was adopted. The hourly load measurements of 5,000 customers for three years from a suburban area and of 14,000 customers for six years in a rural area were used for the study.

Fig. 48: Determination of simultaneity factor of grid load including EV contribution, according to Paper 510.

The research conducted in Paper 0520 shows significant errors for power forecasts on the distribution level. The study also quantifies the effect of various influencing variables on forecast accuracy. The forecast horizon and aggregation level dependence on the forecast quality is evident, and forecast errors could be significant. If neglected, they can lead to an underestimation of the probability of critical situations.

Paper 0532 applies interval optimization to schedule a multi-carrier system while considering the uncertainty of photovoltaic (PV) energy generation, represented by a predicted interval obtained from a non-parametric distribution. At the same time, the quantile function is estimated to predict the distribution. The proposed method is applied to the data set of an industrial site. The simulation results show that the forecasting is reliable to obtain predicted intervals for a PV system.

Paper 0581 presents a method for decoupling the injected power by photovoltaic systems in an LV network from the total load measured at the transformer. This makes use of solar irradiance information and provides the injection profile and the actual power consumption in a given feeder/phase. Based on uncorrelated series, this method allows forecasting these decoupled profiles and using them for network planning and management.

Paper 0631 considers deep neural networks with convolutional and recurrent layers to investigate the inclusion of various data types as inputs to a load forecasting model by evaluating 24-hour ahead predictions of electricity demand. Using two case studies in Durham, UK, this paper evaluates the benefits of including temporal and meteorological data and proposes a novel approach to incorporating social media data into a load forecasting model.

A methodology based on spatial regression associated with transport modelling to obtain databases and heat maps with flow information of EVs and their State Of Charge (SOC) is presented in paper 0621. With the results obtained, the streets with the highest flow of the...
lowest SOC can be superimposed to determine places with greater attractiveness and the need to install public charging stations.

A model for forecasting disruptive events, such as the COVID-19, is described in Paper 0895. As there is no historical data, the authors propose a novel source of information: media monitoring, complemented by observation of other countries' load evolution. The complete model uses a customized collaborative technique (Multi-Task Learning) designed for lack-of-data problems. Test results show that this approach successfully captures consumer's perceptions before their actions, anticipating the impact of abrupt moves and offering precise and reliable forecasts.

A domestic electricity demand forecasting model based on detailed physical model simulations has been presented in Paper 0636. In this study, key factors that influence household electricity consumption in the UK have been investigated. The simulation model maps occupant activities to appliance use. The study results are used to analyse the impact of energy efficiency schemes and demand response on the grid and the planning and operation of district-level low-voltage grid considering the flexibility offered by the houses.

The authors of Paper 0690 implemented an automated algorithm that enables an individualized forecast for undeveloped areas, considering the current load and customer density of each building zone as indicators for its future development. The new automated approach increases the forecast's accuracy, providing reliable input for the automated planning of the medium voltage network and a useful tool for the daily business of operative asset management and engineering.

Paper 0848 presents a generic agent architecture aiming at holistic modelling of human activity based on cognitive ergonomics work. This architecture, applied to residential energy consumption simulations, allowed the generation of coherent load curves at both individual and aggregated levels. This model was extended to simulate EV use and charging profiles for each EV present in a given population. This EV model still lacks validation with a good data set, but its ability to reproduce aggregated data from an emergent bottom-up perspective has been verified.
Smart-meters data and, more generally, IoT devices are now widely deployed and can enable techno-explicit models for long term forecasting, which are the focus of Paper 0994. Indeed, these models allow for studying sensitivity under a single parameter change. Furthermore, they are explainable and can account for the effects of rapid transitions of any type. This is especially useful to assess politics and public funding.

Paper 1045 presents the solutions on renewable energy forecasting proposed by the Horizon2020 Project Smart4RES. They are based on the latest progress in meteorology and original use of data science (combination of multiple data sources, data-driven approaches for trading and grid management). Solutions such as flexibility forecast of distributed resources and data markets are oriented towards value for power system stakeholders.

Sub block 2: Network Modeling and Representation

Paper 0039 gives a detailed analysis of the radiation terms in the heating balance for overhead conductors. The terms in the radiation balance determine the rating of an overhead line for use in dynamic line rating schemes. These radiation terms are often not considered since there is a relatively big uncertainty. The available knowledge and the different uncertainties are summarized, for radiation from the environment reaching the conductor, for thermal emission from the conductor and heating of the conductor due to direct and indicated solar irradiation.

The analysis of the behaviour of an Active Distribution Network and the analysis of the properties of common equivalent model types and procedures for their parameterization using operational measurement data is carried out in Paper 0452. In determining equivalent models, the properties and conditions for the parameterization of the quasi-stationary nonlinearity are discussed in the most common equivalent model types in literature, the black-box models based on artificial neural networks (ANN) and the grey-box models based on parametric models.

Paper 0560 presents a method to find the corresponding LV substation, phase and feeder of a given Energy Box using only its voltage and active power series, along with measurements from a sensor at the substation. The method has been applied to two real Portuguese LV networks, for which a preliminary analysis of the energy balance is also shown.

A methodology for assessing the share between the flexibility used by the LV system and the residual flexibility available for other uses is presented in Paper 1093. It has been assumed that the LV networks are equipped with an energy management system to assess the flexibility needed and available. The energy management system is a multi-agent system capable of handling the small resources’ flexibility with a master-client scheme that mimics a possible aggregator-client link. An exemplary Italian LV distribution network is used to test the procedure.

In Paper 0952, a comparison of the needed network reinforcements of a distribution grid considering the static seasonal and the dynamic current ratings for overhead lines was carried out. For this purpose, the different current ratings for the lines of a real high-voltage distribution grid have been calculated in network planning. Synergies between the static seasonal and the dynamic current ratings and dynamic curtailment, and an economic evaluation of the different combinations have been presented.
Sub block 3: Load Flow and Short-Circuit Calculations

Sub block 3 deals with the real core of network planning: electrical calculation performed to determine the load conditions and all other relevant parameters of the state estimation, such as load factors, voltages, currents, etc. Two main focuses may be outlined for the papers presented: the Smart Meter data use and the deepening of the knowledge of LV grids.

Paper 0412 proposes a methodology to combine two different ways to analyze distribution systems: a system study software, OpenDSS, and a real-time simulation environment, named RTDS. OpenDSS covers a wider range of study subject areas in more detail, while RTDS allows more detailed attention to the smaller portion of the study subject area. The connections between the two environments were established through various inter-process communication methods, namely COM interface and TCP socket communication. The effectiveness of the proposed method was tested on two example circuit simulations, the first one representing a trivial circuit for the purpose of proof of concept, the other being the IEEE 13 Node Test Feeder System. The maximum error was less than 0.2%, showing the method achieved acceptable performance.

In Paper 0127, a calculation approach to calculate peak powers and diversity factors in unbalanced three-phase four-wire LV grids is presented. Worst-case scenarios are investigated for under- and overvoltage, loading of lines and utilization of MV/LV transformer, and maximum voltage unbalances. In the case of under- and overvoltage, additional power flow calculations were needed. The results, that have been validated against probabilistic simulations, show that the assumption of a balanced power flow may lead to significant errors, the adoption of new approaches like the one exposed may increase accuracy in grid planning processes.

Paper 0626 benefits from smart meter data to deal with the typical distribution problem of LV feeder mapping, implying the knowledge of the connectivity model, i.e. the whole set of connections between consumers and their corresponding transformer feeder. The paper proposes Feeder Mapping (FM) algorithms developed to resolve the connectivity model based on AMI time series data. Algorithms that exploit energy conservation, such as Mixed Integer Linear Programming, Genetic Algorithms and the Colony of Ants, have been developed and evaluated. A Load-Flow model using the derived connectivity models and based on the Backward-Forward Sweep is proposed, integrating the Fortescue transform for handling load imbalance. Results proved very accurate through a limited number of iterations with the load on each line, the losses through the neutral wire and the voltage drop in each node.

Paper 0568 describes a methodology to automatically detect the customer phase grouping in a given PV-rich LV feeder without the need for prior knowledge. The approach is based on time-series voltage magnitude data extracted from single-phase smart meters and relies on the Principal Component Analysis (PCA) method and an unconstrained \( k \)-Means clustering technique. The approach has been tested on a realistic Australian LV feeder hosting 29 single-phase customers, with PV penetrations ranging from 0 to 100%. Results show the effectiveness and accuracy of the proposed phase grouping approach in allocating...
the customers to their correct phase group without or with PV (even with 100% of PV penetration). It must be noted that the time series of smart meter data needed to perform the grouping proved to be limited both in terms of history and in terms of hours per day. **Paper 0499** summarizes the results of several research projects performed in Salzburg Netz, describing a GIS-based system for analyzing low voltage grids using real-time data provided by measurements in secondary substations, Smart Meters and digital switching records. The system allows better integration of technologies, like charging stations, heat pumps and PV systems, in the LV grid. By managing in an integrated manner all measurements provided through different sources, state estimation is provided, filtering the collected data and excluding irrelevant ones, such as the load and voltage data of unsupplied customers. The resulting information is used to supplement traditional grid calculations to rank more accurately priorities and pain points in voltage quality and load criticalities.

**Fig. 55: The Smart Grid real LAB described in Paper 0423.**

**Paper 0423** presents a monitoring concept developed by ewz, the distribution operator of Zurich, to observe and possibly control the state of the low voltage grid. Starting from voltage and current measurements in a low voltage network of the city, temporal aggregation on the accuracy of the approximation of the measured data was first analyzed. Then the accuracy of power flow calculations was evaluated through a comparison with real measurement data. Finally, the optimal location of measurement equipment and the data resolution needed to determine the state of the grid were defined effectively. The analysis showed that: a 15 min resolution is sufficient for monitoring applications; a 1 min resolution is a reasonable compromise for control applications; the results from the power flow calculations were close to real measurements.

In **Paper 1036**, the results of power flow simulations and actual measurement data from a well-monitored suburban distribution grid area of EKZ, the Electric Utility of the Canton of Zurich, are analyzed to determine how varying measured variables and sensor locations impact the result accuracy. Results show that satisfactory power flow calculation accuracies can be achieved with a smart meter coverage of around 80% of residential customers. It is also shown that an effective algorithm for load profile synthesis is key to achieve high-quality results with incomplete measurement coverage. Voltage and power at the transformer stations proved to be the most important single measurement for power flow calculation accuracy.

**Sub block 4: Energy Losses**

Facing a consumption reduction due to COVID impact on the world economy, it seems that efficiency in network operation through losses reduction has somehow lost its priority within DSOs. Most papers included in Sub block 4, devoted to losses, mainly relate to Non-Technical ones, introducing algorithms to evaluate, identify and reduce them. **Paper 0041** presents a methodology for detecting Non-Technical Losses (NTL) of electrical energy in power utilities using machine learning classifiers. It enhances data-oriented analysis and high hit ratio along with less cost and workforce requirements. This approach implies three steps: firstly, a non-supervised clustering of consumption profiles based on a hybrid algorithm using Self-Organizing Maps (SOM) and Discrete Cosine Transform (DCT) is performed. Secondly, further classification is operated based on location, infrastructure, and consumption profile. The final steps include supervised classifiers to detect NTL in the customers. The proposed approach was trained and tested with real data from Ceará-Brazil (149,000 customers). Results show, among others, an average overall performance
of 85% in the detection process of NTL.

**Paper 0659** presents a data mining methodology to identify correlations and patterns associated with living conditions in rural areas, considering meteorological and power consumption data in the irrigation period. Results obtained in a case study, where situations of NTL were simulated, show great recognition capacity after the application of data mining and reduction of the considered variables. Discrepancies of 10% or higher are detected for all considered rural customers, showing that irrigation activities have a relatively high potential in NTL.

**Paper 0564**, by the same authors, also presents a methodology to detect NTL in rural consumers with irrigation-based crops using fuzzy logic, artificial neural network and deep learning. According to reference data, consumption forecasting is performed in four clusters: Satellite images, Weather data, Crop data and Historical power consumption data. According to the forecasted consumption, the methodology suggests proper indicators of NTL and efficiency that will assist utility company decision making. Based on data from three harvests of rice crops in southern Brazil from 2011 to 2014, results achieved showed a percentage less than 10%, which was ranked as a tolerable risk according to the limits defined.

The potential scope of the discussion

Smart Grids imply flexibility and adaptability are brought into distribution networks. The new paradigm of distribution management is based on the capability of the network to understand operational conditions and modify them according to predefined guidelines. However, to get the full benefits of this evolution, we must consider the expected, and possibly the unexpected, flexibility patterns. How can we represent the adaptive strategies a Smart Grid can pursue to make optimal use of them in planning, avoiding unnecessary oversizing of equipment? How can be obtained reliable profile of EV consumption? What is the expected level of confidence?

**Table 4: Papers of Block 4 assigned to the Session**

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<tr>
<th>Paper No.</th>
<th>Title</th>
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<td>0033:</td>
<td>Demand statistical characterization of low voltage users in Argentinian distribution networks for distributed generation studies purposes</td>
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<td>0039:</td>
<td>Uncertainties in radiation modelling for overhead lines and their impact on ampacity</td>
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<td>0041:</td>
<td>NTL detection: A intelligent system using a non-supervised clustering of consumption profiles</td>
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<td>0082:</td>
<td>Time-dependent and location-based analysis of power consumption at public charging stations in urban areas</td>
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<td>Modelling the aggregate load behaviour of European regions and its influence on dynamic and static voltage stability</td>
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<td>0126:</td>
<td>A stochastic modelling of electrical vehicle load and its impacts on a</td>
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**Swedish distribution network**

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<td>Verification of a low-voltage monitoring concept using high-resolution measurements in the distribution grid of Zurich</td>
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<td>Spatial modelling of electrical loads in distribution grids based on socioeconomic data</td>
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<td>A comparison of artificial intelligence time-series data analysis techniques for load demand forecasting</td>
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Planning of Power Distribution Systems

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Helen Electricity Network Ltd, Finland

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¹Axpo Grid AG, Switzerland. ²entelgenio GmbH, Germany

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Bart Kers¹, Hugo Vergnes¹, Edward Coster¹, Jos van Gelderen²
¹Asset Management Stedin Netbeheer, Netherlands. ²Faculty of Electrical Engineering, Netherlands

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¹ČEZ Distribuce, a.s., Czech Republic. ²IBM Czech Republic, Czech Republic

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Sylvie Parey¹, Alain Marty²
¹EDF/R&D, France. ²ENEDIS, France

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Beatriz B. Cardoso¹, Eduardo L. Martins¹, Marcos A. I. Martins¹, Nathalia T. Rosa¹, Kleber D. Tomaz², Silvia de Francisci²
¹CERTI, Brazil. ²Enel Distribuição São Paulo, Brazil

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Otto Räisänen¹, Jouni Haapaniemi¹, Juha Haakana¹, Jukka Lassila¹, Jukka Ahonen², Lauri Kurki², Jarmo Partanen¹
¹LUT University, Finland. ²PKS Sähkönsiirto Oy, Finland

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¹Copperleaf, Germany. ²Visue, Denmark
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Ildar Daminov¹ ², Anton Prokhorov², Raphael Caire³, Marie-Cécile Alvarez-Herault⁴
¹Univ. Grenoble Alpes, France. ²Tomsk Polytechnic University, Russian Federation. ³Univ. Grenoble Alpes, France. ⁴Grenoble INP, France

Application of resilience triangle model to the electric distribution system
Gianni Celli, Fabrizio Pilo, Giuditta Pisano, Gian Giuseppe Soma
University of Cagliari, Italy

Asset management in HEP DSO: From development of methodologies towards application
Tomislav Baricevic¹, Željko Plantić¹, Andelko Tunjić², Mladen Vuksanić², Goran Vidmar², Joanne Peacock³, Tracy Pears³
¹Energelski Institut Hrvote Požar (EIHP), Croatia. ²HEP Operator distribučiskog sustava d.o.o., Croatia. ³EA Technology, United Kingdom

A stochastic Markov model for reliability-centered maintenance approach in electrical distribution networks
Habib Allah Ravaghi Ardabili¹ ², Mahmoud Reza Haghifam³ ², Seyyed Mostafa Abedi²
¹Great Tehran Electrical Distribution Co, Iran, Islamic Republic of. ²Islamic Azad University, Iran, Islamic Republic of. ³Tarbiat Modares University, Iran, Islamic Republic of

Block 2: Network Development

Zero down time (ZDT) network topology for reliability supply in new capital city of Indonesia
Ricky Cahya Andrian
Perusahaan Listrik Negara (PLN), Indonesia

Combined market and grid oriented operation of distributed flexibilities – results of a pilot project
Matthias Hable¹, Robert Knoll¹, Thomas Darda², Holger Hänchen³, Maximilian Schmidt³, Marcus Kreutziger⁴, Peter Schegner⁴, Jörg Lässig⁵
¹SachsenNetze HS.HD GmbH, Germany. ²SachsenEnergie AG, Germany. ³SachsenNetze GmbH, Germany. ⁴TU Dresden, Germany. ⁵University of Applied Sciences Zittau / Görlitzu / Görlitz, Germany

Power flow and economics analysis for RMU-based low-voltage distribution networks operation.
Boo-hyun Shin, Gi-dae Oh, Seung-chul Kim, Kwang-hun Jung
KEPCO, Republic of Korea

Influence of bonding of medium and high voltage cables on annual costs
Damian Aegerter
Braavos GmbH, Switzerland. Cableizer, Switzerland
Methodology for rural microgrids development
Victoria Tan, Antoine Trobois, Laurent Karsenti, Stéphane Jamet
Enedis, France

Electrification projects in remote rural areas using geographic information systems
Diana S. Garcia Miranda, Cesar Trujillo, Francisco Santamaria
Universidad Distrital Francisco José de Caldas, Colombia

Is power to hydrogen an appropriate approach to mitigate PV-induced strain on 110 kV high-voltage grids?
Thomas Kienberger¹, Matthias Greiml¹, René Braunstein²
¹Montanuniversitaet Leoben, Austria. ²Energie Steiermark, Austria

Digitalisation of urban grid for better grid planning purposes
Christina Tzanetopoulou¹, Alix Sarrazin¹, Tobias Stahn², Omid Alizadeh-Mousavi¹, Antony Pinto¹,
Gerhard Schmitz²
¹depsys SA, Switzerland. ²Mainzer Netze GmbH, Germany

Screening criteria and methods to aid the integration of non-wires alternatives in distribution planning
Jouni Peppanen¹, Alison O’Connell², Jason Taylor¹
¹Electric Power Research Institute, USA. ²Electric Power Research Institute, Ireland

Planning low voltage AC/DC microgrids for un-electrified areas
Kimsrornn Khon¹,², Vannak Vai¹, Marie-Cécile Alvarez-Harault², Long Bun¹, Bertrand Raison²
¹Electrical and Energy Engineering Department, Energy Technology and Management Unit, Institute of Technology of Cambodia, 120404 Phnom Penh, Cambodia, Cambodia. ²Univ. Grenoble Alpes, CNRS, Grenoble INP*, G2Elab, 38000 Grenoble, France ³Institute of Engineering Univ. Grenoble Alpes, Grenoble, France

Design and operation of solar-hydrogen-storage integrated electric vehicle charging station in smart city
Lijia Duan¹, Xin Zhang²,¹, Nazmiye Balta-Ozkan¹, Sina Etminan³
¹Cranfield University, United Kingdom. ²Brunel University London, United Kingdom. ³High Voltage Substation Services Ltd, United Kingdom

Perspectives on the Social Embeddedness of the Smart Grid Architecture Model in Innovation Projects
Julia P Kähler¹,², Sabrina Paustian¹, Jannika Mattes¹, Sebastian Lehnhoff¹,², Mathias Uslar²
¹Carl von Ossietzky University of Oldenburg, Germany. ²OFFIS Institute for Information Technology, Germany
Modelling the demand behaviour of active customer and the impact of price incentive based strategies
Alexander Vanselow¹, Dirk Lehmann¹, Simon Krahl¹, Prof. Dr. Albert Moser²
¹FGH e. V., Germany. ²RWTH Aachen University, Germany

LEN1: an example of development of least cost electrification approach
Bruno Pechine¹, Isaac Boates², Marie Sevenet², Ali El Akoum¹, Mathieu Caujolle¹, David Eyler², Elodie Jeandel², Elsy El Sayegh¹, Sarah Nasr¹, Enrique Kremers²
¹EDF R&D, France. ²EIFER, Germany

Geospatial least-cost study for on and off-grid electrification to achieve universal electricity access in Zambia by 2030
Guillaume Dekelver1, Midas Caubergs1, Lloyd Ngo2
¹ENGIE Impact, Belgium. 2Rural Electrification Authority, Zambia

The proposal for reduction of regularly monitored consumers in smart metering project
Komorany
Vaclav Vycital¹, David Topolanek¹, Michal Ptacek¹, Vit Krcal¹, Petr Toman¹, Juan Zamphiropolos²
¹Bno University of Technology, Czech Republic. ²E.ON Distribuce, Czech Republic

Optimal planning of port microgrids to improve energy efficiency by the integration of RES, flexible loads and smart mobility - POSEIDON
Susanna Mocci, Fabrizio Pilo, Gian Giuseppe Soma
University of Cagliari, Italy

A proposal for technical and economic sizing of energy storage systems and PV for EV charger-stations with reduced impacts on the distribution network
Aleff VPG Araújo¹, Danielly N Araujo¹, Andrea SM Vasconcelos¹, Washington de A Silva Júnior¹, Pedro AC Rosas², Luiz HA de Medeiros², Júlia BR da Conceição³, Tuo Ji³
¹Instituto de Tecnologia Edson Mororó Moura, Brazil. ²Universidade Federal de Pernambuco, Brazil. ³Companhia Paulista de Força e Luz, Brazil

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Marco Galici, Mario Mureddu, Emilio Ghiani, Fabrizio Pilo
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¹Faculty of technical sciences, University of Novi Sad, Serbia. ²Schneider Electric DMS NS, Serbia

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Tobias Müller¹, Michael Becker¹, Christian Möller¹, Shawki Alsayed Ali¹, Markus Zdrallek¹, Christian Knoll², Ekkehard Boden²
¹Institute of Electrical Power Systems Engineering, University of Wuppertal, Germany. ²Stadtwerke Neuss GmbH, Germany

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Vincent Glinewicz¹, Axel Eriksson¹, Hilda Dahlsten², Camilla Hansson³
¹Vattenfall R&D, Sweden. ²Vattenfall Eldistribution AB, Sweden. ³Vattenfall Eldistribution, Sweden

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¹Enedis, France. ²Ecole Normale Supérieure, France

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Simon Camal¹, Fabrizio Sossan¹, George Kariniotakis¹, Ricardo Bessa², Pierre Pinson³, Gregor Giebel³, Quentin Libois⁴, Matthias Lange⁵, Bijan Nouri², Alexandre Neto⁷, Remco Verzijlbergh⁸, Marcel Eijgelaar⁸, Nikos Hatziargyriou¹⁰, Christos Vitellas¹¹, Laure Raynaud⁴, Marie Cassas⁴, Marie Cassas⁴, Amandine Pierrot⁵, Tuhfe Gocmen⁵, Ricardo Manuel Santos⁶, Gisela Mendes⁷, Jorge Lezaca⁶, Gerrit Deen⁹, George Sideratos¹⁰, Ganesh Sauba⁹, Stephanie Petit¹², Raphael Legrand⁴, Annah Mehrens⁵, Jose Gouveia², Luis Teixeira²
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Gianni Celli, Fabrizio Pilo, Giuditta Pisano, Simona Ruggeri, Gian Giuseppe Soma
University of Cagliari, Italy
SPECIAL REPORT

Session 6

Dso Customers, Regulation and Business Models

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Introduction

The business environment and the role of the DSO is substantially changing in the ongoing energy transition.

Session 6 focuses on the evolving business environment and regulation of the DSO to support active customer’s and society’s energy transition.

This includes a wide variety of topics: digitalization, circular economy, customer flexibility incentives and services, microgrids, integration of storage, e-mobility issues and more – all necessary to ensure a sustainable and efficient electricity distribution infrastructure.

It is important to share experiences and perspectives to better understand the impacts of various strategic choices. Important sources for knowledge are results from demonstration projects and case studies.

Within this changing frame, Session 6 has chosen four blocks of papers:

- Block 1 Regulation enabling flexibility and new business models
- Block 2 DSO risk management in a disruptive environment
- Block 3 Electrification, active customers and local energy communities
- Block 4 Information and digitalization driving the future DSO business

The blocks address each important issues related to the DSO business – both today and in the future.

In the review process, Session 6 has accounted for several different stakeholders all the way from governments/regulators, through competitive market players to academia. This variety of stakeholders makes Session 6 unique in the CIRED context – covering a very broad span of stakeholders and interests.

In total Session 6 has accepted 86 papers. In the following each of the blocks of papers are presented, with briefs comments related to the contents of each paper.

Block 1: Regulation enabling flexibility and new business models

The transformation of the energy system has put the spotlight on the need for flexibility and related business models. The topic in itself can be regarded as a revolution under which there is a evolution happening from year to year.

In Europe the implementation of the Clean Energy Package is the main driver and definition for flexibility, however much remains to innovate and develop to find the rules, regulations and business models that will be viable for the energy transformation.

Below is a short summary of the papers attached to this block;

Paper 34: Analyze of reducing losses, improving efficiency and increasing network utilization in low voltage utility networks in Argentina when distributed plug-in EV are randomly connected.

Paper 222: Introduces a quota-based local market between residential and semi-commercial consumers, prosumers and producers to show how this allows forecasted congestion to be prevented by intra-low voltage grid trading.

Paper 311: Explains how the Covid-19 pandemic the challenged DSOs to rethink the operation both in terms of the provision of the service, reorganizing it, as well as the relationship with users.

Paper 377: The paper provides a needed classification of innovation and shows a range of options to tackle hurdles in the German regulatory framework.

Paper 437: Developed a methodology to analyse and estimate the long-term day-ahead electricity market. The methodology used data of Finnish electricity market to show the performance.
Paper 448: The paper presents an evaluation method as well as the associated results of the energy renovation in 2016 - 2017 of the low-rent housing units of the city of Longjumeau.

Paper 456: The paper visualizes the impact of Covid-19 on society by using smart meter data, and the results confirm the restrictions.

Paper 486: Discusses several classic examples of network effects that are especially useful for clarifying how and when network effects benefit customers.

Paper 489: Provides a comparison of an energy community energy trading under different regulations and trading structures.

Paper 529: Blockchain-based approach to improve the communication between transmission system operators (TSOs), distribution system operators (DSOs), and control reserve providers (CRPs).

Paper 561: Presents an analysis of the potential profits yielded from the operation of a large-scale battery in the Finnish Frequency Containment Reserves for Normal Operations market and an overview of dimensioning the power and energy capacity of the battery is presented.

Paper 580: Introduces the Portuguese case for self-consumption and shows how the implementation of relies on a deep involvement of DSO in the whole process for the collection and validation of the data required by the different stakeholders.

Paper 582: Based on 31 interviews from a broad range of the stakeholders in the energy business four business models are presented and discussed from the perspective of different stakeholders or actors in the ecosystem, either because they are involved in their implementation or affected by them.

Paper 619: Instead of studying individual indexes or average indexes to recognize performance the paper presents a machine-based clustering approach for recognizing frontiers from large datasets and demonstrates the method with an example on pricing.

Paper 658: The paper analyzes and tries to formulate which electrification business models are the most appropriate for the off-grid rural areas in Colombia.

Paper 762: Assess policy and regulatory environment concerning implementation of local multi-energy systems (MES) in several European countries.

Figure 3: Paper 762, A three-step approach to assess regulatory impact.
Paper 808: Analyzes distribution network pricing in the presence of energy communities as new emerging user types.

Paper 809: Defines the flexibility value chain and the required roles. It also brings forward the importance of sub-aggregators as key enablers for harnessing flexibility in a cost-efficient manner.

Paper 831: Review of recent national approaches to build regulatory sandboxes in the electricity sector and documentation of best practices.

Paper 856: Results of H2020 project PANTERA uncovering the main barriers limiting R&I activities in the domain of Smart Grids, storage and distributed energy with focusing on the countries that show low R&I activity into the related fields.

Paper 858: Describes four scenarios for the future electricity distribution grid in Norway, which are made up in a foresight process.

Paper 911: Insights from the ongoing European H2020 MERLON project covering the potential of local energy systems, business models and identifies barriers to the development of local energy systems.

Paper 1001: Present technical challenges that DSO’s will encounter in the near future while integrating DERs into LV grids and possible solutions that would make this integration feasible in the Netherlands.

Paper 1010: Present a study by Enedis which, with the implementation of data visualization, enables French territories to better understand their consumption and production.

Figure 4: Paper 1010, First dashboard: data of the whole town.

Paper 1044: An formalization and resolution for a bi-level optimization approach that solves for a set of non-linear tariffs, from which each customer can freely choose the more advantageous for one’s demand profile.

Paper 1088: Proposal to improve the Brazilian regulatory framework about the incentive/penalty mechanism, in order to encourage the improvement of service quality in technical and commercial aspects.

Paper 1098: Analyze of the Brazilian Regulatory Agency proposed novel methodology to determine the Reference Price Bank to be considered for asset valuation recognition in upcoming tariff revision.

Discussion

Based on the activities in the business and the papers submitted it is clear that business models around flexibility is a large area where there still is uncertainties when digging below the conceptual level. Regulations or the interpretation of the regulation is still a grey zone with a significant need for further innovation, development and especially real life demonstrations.

Table 1: Papers of Block 1 assigned to the Session

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<td>377: Evaluation of innovation approaches as additional regulatory</td>
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<td>437: Day-ahead electricity market estimation of Finland in 2030</td>
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<td>448: Evaluation of energy savings using customer meter data</td>
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<td>456: Impact assessment of COVID-19 on electricity demand by utilizing</td>
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<td>supply continuity in Brazil</td>
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<td>1098: Adequate statistical approach for outliers removal in tariff</td>
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Block 2: DSO risk management in a disruptive environment

The changing business environment are challenging for the DSO’s in terms of a robust risk management that matches business needs and the society expectations. Changes are happening much faster than the traditional risk management is covering today risking short term risk minimization at the cost of long term optimization and risk minimization. Key is to align on long-term expectations on the DSO services provided without reducing flexibility to adapt to disruptive changes.

Below is a short summary of the papers attached to this block;

Paper 119: The paper presents a strategic asset management framework for the sub-transmission and distribution level including a suggestion for integration of the framework into the existing process landscape of the utility.

Paper 187: Describes a pilot project for a sophisticated asset simulation model to support long-term asset decisions. The results are used to prioritize measures as well as to identify the most efficient investments.

Paper 283: The paper proposes a method for effectively detect non-technical losses of meter manipulating/malfunctioning and adapting the honesty coefficient attribution method.

Paper 337: This paper describes the implemented information system for advanced business analysis and reporting in business processes at DSO JP Elektroprivreda B&H and its application in improving the efficiency of these processes.

Paper 368: Developed a multivariate linear regression model for the monthly electricity demand of customers supplied at 400 V that includes a number of weather conditions as explanatory variables.

Paper 375: The paper presents a methodology for determining the usage pattern of the relevant consumers considering type of the building, minimum yearly consumption, as well as the potential of available roof area for PVs installation.

Paper 572: The paper uses a geographic multi-agent system to simulate restoration processes after a storm. This approach allows to combine multiple domains (organization process, electro-technical system, geographic system and road network) in a combined model.

Paper 620: The paper presents the experiences from E-REDES using their developed Equipment and Materials Specification and Qualification Process (EMSPQ).

Paper 629: Presents a comprehensive revenue optimization model is presented which links several optimization models by modelling their interdependencies to enable a coherent overall simulation of the distribution system operation.

Paper 680: The paper examines the principles that define how future grid upgrades will impact flexible connection customers and provides advantages and disadvantages of cost allocation and financial risk management strategies relevant to flexible connection solutions.

Figure 5: Paper 680, conventional (fixed capacity) vs. flexible interconnection.

Paper 730: This paper investigates whether intentional islanding of certain sections of the network could yield significant benefits for customers and assist Distribution Network Operators (DNOs) with the transition to Distribution System Operator (DSO).

Paper 779: The paper presents the impact of COVID-19 pandemic on daily load profile patterns in the distribution grid of Slovenian DSO Elektro Celje.

Paper 828: The paper estimates the effect of post-outage consumption peaks and shows that approximately 0.3–2.5% of customers whose distribution bill would be affected by post-outage consumption peak if power-based tariff was introduced.

Paper 1004: This work provides a discussion on
the European regulatory framework regarding
the reactive power procurement and on new
means for system operators to respond to the
new regulatory requirements.

Paper 1095: The paper shows the experience of
E-REDES climate resilience in the context of the
energy transition.

Figure 6: Paper 1095, E-REDES’ climate
adaptation dimensions

Paper 1123: The paper develops the
conceptualizations and results related to the
successful implementation of a training program
and training of human resources of an electric
power distribution company through virtual
platforms in a restrictive environment due to the
COVID-19 pandemic.

Discussion
The variety of the papers in this block shows the
many aspects of risk management in the DSOs.
Significant work to adapt and improve the risk
management processes are ongoing to match
the disruptive changes happening. Experience
exchange and alignment is probably an
important success factor to match the energy
transition with DSO’s risk minimization and
society need and expectations.

Table 2: Papers of Block 2 assigned to the Session

<table>
<thead>
<tr>
<th>Paper No. Title</th>
<th>MS a.m.</th>
<th>MS p.m.</th>
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<tr>
<td>119: Adopting state-of-the-art asset management theory to create added value in a utility setting</td>
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<td>187: Integrated approach to handling risks in critical infrastructures – pilot for transformers</td>
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<td>283: Detection of Frauds and Other Non-Technical Losses in Medium and Low Voltage Distribution Systems: Improvement of the Honesty Coefficient Attribution Method</td>
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<td>337: Application of business intelligence tools for efficient managing business processes and data in distributed system operator Elektroprivreda B&amp;H</td>
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<td>368: Forecasting electricity demand at low voltage using a multivariate model</td>
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<td>375: Estimated impact of self-generation and prosumers to DSO and TSO in Croatia</td>
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<td>572: Use of multi agents systems in a crisis management context</td>
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<td>620: Innovative tools accomplished with NP EN ISO 9001 to retain technical specification and qualification knowledge</td>
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<td>629: A comprehensive revenue optimization model for DSOs</td>
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<td>680: Cost allocation mechanisms and financial risk management for flexible connection solutions</td>
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<td>730: Investigation of technical, legal, regulatory and commercial considerations of intentional network islanding</td>
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<td>779: Simple and effective analyses of COVID-19 impact on load profile patterns in DSO Elektro Celje</td>
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<td>828: Estimating the effect of post-outage consumption peaks on customers’ peak power-based tariff costs</td>
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<td>1004: Regulatory, technical, and market developments of reactive power procurement</td>
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The evolution of the distribution networks through increased electrification and new load and generation technologies and patterns, calls for an increased overall need for flexibility in the operation and planning of distribution networks.

In addition to technological solutions, there is also a clear need for new ways of thinking and innovative solutions regarding how to solve increased electrification and involvement of active customers.

Below is a short summary of the papers attached to this block;

Paper 129: This paper presents a study of two different EV charging concepts were evaluated, addressing the challenges related to profitability for the charging concepts within the existing framework conditions.

Paper 142: The paper reports from the H2020 project Flexigrid, aiming to facilitate energy sector stakeholders to create and utilize advanced Energy Services (ESs). The paper presents the flexibility market architectures that FLEXGRID develops, discussing requirements, advantages, disadvantages and their compatibility with today’s smart grids.

Paper 182: This paper from Germany reports on revenue potential of prosumers types in local flexibility markets, where flexible grid users can offer their flexibility and thereby avoid critical grid states. The price of the offered flexibility decides whether the local flexibility market is an economical solution for the congestion management of the distribution system operator.

Paper 213: This paper reviews recent studies investigating the benefits and challenges of utilizing different demand response programs in the planning and operation of renewable-based microgrids. It shows that mechanisms such as incentives and penalties, curtailment requests, market structure for energy balancing, and power trading should be developed further to make the utilization of demand response programs more affordable. The paper presents a framework to help system operators consider these demand response programs in the planning and operation stage of a renewable-based microgrid.

Paper 264: This paper from Brazil reports on the perspectives of how distributed energy resources will the boundaries of the distribution utilities companies. Observing how technology improvements changes other monopolies, it is possible to conclude that some activities now typically executed by distribution companies will be done by the DER owners, unbundling the actual concept of electricity distribution.

Paper 275: The work presented in this paper addresses the participation of the distributed renewable energy resources (DRES) in the provision of ancillary services at distribution grid level. Since the DRES have an intermittent nature, auxiliary storage systems should also be added, which cost may differentiate according to nominal capacity and voltage level.

Paper 332: This paper from the H2020 project DOMINONES reports on demand response modes designed for the local energy and flexibility markets, stating that the sustainability of the investment deeply depends on a comprehensive assessment over the fundamental revenue sources and relevant costs to consider, being influenced by a number of key parameters.

Paper 352: This paper presents how the H2020 project InterConnect is enhancing the relationship between smart buildings, energy communities and grids, enabling the potential of interoperable flexibility mechanisms and new energy and non-energy services, presenting a technical definition of the DSO Interface that will ensure interoperable integration of flexibility services between DSOs and the different market.
Paper 354: The paper from UK reports on the IntraFlex project which is developing a market to test nearer to real time flexibility procurement and the potential for supplier imbalances to be minimised through market mechanisms.

Paper 355: This paper presents an overview of ongoing projects (H2020 projects InterConnect, EUUniversal and OneNet) that aim to deliver and demonstrate interoperable solutions across the full value chain of the energy sector.

Paper 378: This paper discusses ICT tools designed to assist network operators, flexibility suppliers and market operators, and make the flexibility markets both efficient and attractive, proposing new market architectures to facilitate the exchange of flexibility services at the distribution level.

Paper 387: This paper from Thailand presents the status of experiences of demand response in Thailand, showing customer daily load profiling analysis by using a K-Means clustering algorithm profile data includes 15-minute.

Figure 7: Paper 387, Conceptual diagram of power consumption reduction

Paper 433: This paper from Finland addresses results of a comprehensive demand-side management survey and research of customer’s decision-making related to their flexibility potentials, highlighting one major challenge which is to improve the customers’ knowledge related to demand-side management.

Paper 467: The paper presents the “flexicurity” potential of energy assets – addressing flexibility and security capabilities of each energy asset, grading their “performance” according to these.

Paper 522: This paper from Belgium addresses a method for how to minimize the investment risk from an investor perspective in Residential Energy Communities.

Paper 530: The French study presented in this paper compares costs of supplying a grid-connected or off-grid microgrid powered by photovoltaics and a storage system, in order to determine which is more cost-efficient.

Paper 531: This paper presents results from Mission Innovation IC#1 Smart Grids, where a global survey has been conducted in order to clarify the current status of demand response as well as to identify common challenges for its integration.

Paper 668: The paper presents a state-of-the-art review about the Local Energy Marketplaces concept and use of Blockchain in energy trading, and a trading mechanism based on blockchain technology and an energy traceability technology for distributed energy systems.

Paper 718: This paper from Sweden describes requirements for a standardised hosting capacity method, outlining the needs and requirements for such a standardised methodology as well as ongoing and upcoming standardisation activities in IEEE and IEC.

Paper 737: The paper addresses performance trade-offs between an introduced linear flexibility market model for congestion management and a benchmark second-order cone programming (SOCP) formulation, providing a structured comparison of the two models.

Paper 814: This paper from Finland presents results from a pilot project that took place in Finland in 2019, where flexibility was activated in real households using a commercial platform.

Paper 834: The paper compares three different value sharing methods in energy communities and what kind of customer proposition they represent: a static model, a dynamic model; and local energy markets.

Paper 857: This paper from Austria addresses ongoing national transpositions, regarding integration in the electricity network structure and related grid tariffs.

Paper 1038: This paper from Saudi Arabia
presents a study performed to give residential and commercial load customers a clear methodology to size their solar PV system based on their yearly load profile to minimize their payback period.

Paper 1067: This Finnish paper summarizes a qualitative analysis of stakeholder interactions and coordination concepts in respect to four major congestion management solutions of distribution system operators, with regards to benefits and drawbacks of congestion management solution.

Paper 1144: This paper from Norway reports from experiences using a common process for distribution system pilot projects, which has been established in a national research centre CINELDI.

Table 3: Papers of Block 3 assigned to the Session

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<th>Paper No.</th>
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<td>Economic and technological evaluation of charging concepts for high-density urban areas based on real mobility and charging profiles of battery electric vehicles</td>
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<td>Flexgrid - development and comparison of distribution network flexibility market architectures</td>
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<td>Revenue potential of different prosumer types at local flexibility markets</td>
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<td>The utilization of demand response programs in renewable-based microgrids: benefits and challenges</td>
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<td>Demand response modes of use in local energy and flexibility markets, enabling system operator, community and energy provider oriented business models</td>
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<td>Enabling interoperable flexibility and standardized grid support service</td>
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<td>814: Business model for household flexibility - a case study</td>
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<td>834: Forming collective self-consumption models: How the end user sees them?</td>
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<td>857: Implementation of self-consumption and energy communities in Austria’s and EU member states’ national law: A perspective on system integration and grid tariffs</td>
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<td>1038: Optimizing a residential solar PV system based on net-metering approaches</td>
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<td>1067: Coordination concepts for interactions between energy communities, markets and distribution grids</td>
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<td>1144: Experience from Norwegian intelligent electricity distribution pilot projects</td>
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Block 4: Information and digitalization driving the future DSO business

Digitalization is here to stay, and the use of information and data in combination with new digital solutions, platforms and services have a huge potential to drive efficiency and optimize the DSO business.

Data from smart meters with respect of the European General Data Protection Regulation (GDPR) enables a number of new possibilities.

However, new digital possibilities comes with a drawback; the threat from cyber space.

Below is a short summary of the papers attached to this block;

Paper 36: This paper presents a technique to locate faults by combining smart metering alarm and PLC communication data (path requests).

Paper 109: This paper proposes a qualification verification system using deep learning-based face recognition technology as a legal basis for authorized personnel to perform their assigned duties.

Paper 122: The paper illustrates how the innovative blockchain platform proposed in the project helps the European distributors to implement these use cases in real network and identifies the regulatory parameters that shall support the large scale deployment of the Platone solution.

Paper 329: This paper presents a developed Central Energy Meter application and its pilot installation in the campus of Brno University of Technology, Czech Republic.

Paper 443: In this paper, real measurements of conventional mechanical power-consuming meters for a residential compound’s electricity consumption over twelve months were taken and are compared to the prepaid smart meters’ readings over the same period for the same residential compound.

Paper 481: In this paper, the authors investigate advanced cyber attack tactics and techniques to exploit Ripple20 and IEC 61850 vulnerabilities through various attack vectors. The presented cyber-physical attack scenarios focus on gaining unauthorised access from pole-mounted reclosers in MV networks to the control centre and substation Operational Technology (OT) systems.

Paper 555: The paper details the comprehensive data use case development the Presumed Open Data project has undertaken and the production of a generic methodology to establish the 'openness' of energy industry data.

Paper 618: This paper presents the software architecture of the Open Innovation Marketplace being developed under the BD4OPEM project, based on the 4+1 View Model methodology of software architecture definition. According to this methodology, the Logical View of the BD4OPEM Platform architecture is structured into four piled up layers and one cross-cut layer addressing the architecture security and privacy needs.

Paper 764: This paper presents a web application for use by half-hourly metered customers which sizes a combined electric vehicle charging, solar photovoltaic and battery energy storage system. The optimisation objective is to maximise self-consumption, thereby alleviating impact on DSO networks without requiring any specific DSO action.

Paper 819: This paper proposes a clustering solution for chosen High Consumption Customers, according to their payment profile, dividing them into groups with similar behaviour and default risk. Different clustering methods were applied for two separate datasets and, from the business perspective, both methods delivered similar conclusions.

Paper 830: This paper presents the process, which led to the founding of the Danish EnergyCERT (Computer Emergency Response Team), which was established in Denmark in April 2020. The
Danish EnergyCERT is established as an independent Center of Excellence focusing on cyber security in the energy sectors (electricity, natural gas and district heating) with a main focus on operational technology (OT) systems.

Paper 839: This paper presents a set of developments that show DSO as a proactive agent of transition by fostering new digitalized services that serve the market and the Customer (videocall support, a token for process status tracking, chatbot, work order tracking).

Paper 853: This paper demonstrates how the DSO can evolve its capacity to bring forward new and exciting developments that are aligned with Customer needs and pave the road for a Customer centric approach able to create value for Customers, DSO, and other market players.

Paper 903: The paper describes the development of the design and implementation of an Integrated Network Model (INM), providing a single source of truth (SSOT) for asset and connectivity data from a number of legacy asset capture and management systems.

Paper 915: This paper discusses the design and evaluation of internet of things (IoT) applications and business models for the operation and maintenance of future substations from a design-oriented approach.

Paper 962: In this paper a new two-step approach for data protection for publication purpose is presented. The protected aggregated curves obtained with the proposed method can then be published with limited risk of privacy leaks.

Paper 973: This paper discusses the new opportunities which smart metering data analysis may bring to customers and DSOs.

Paper 1090: This paper proposes the design and development of a smart metering system capable of actively and remotely managing energy consumption to enhance user experience and improve energy efficiency.

**Table 4: Papers of Block 4 assigned to the Session**

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<td>109:</td>
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<td>Exploiting Ripple20 to compromise power grid cyber security and impact system operations</td>
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<td>Maximising the benefits of open data within the energy industry</td>
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<td>618:</td>
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<td>Smart metering data analysis - benefits for customers and DSOs</td>
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<td>Design and development of a smart metering system with direct load control devices for energy efficiency and user experience in power distribution utilities</td>
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DSO Customers, Regulation and Business Models

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Alejandro Jurado, Edgardo Vinson, Fernando Nicchi
Universidad de Buenos Aires, Argentina

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Electric energy distribution in the context of economic recession, the COVID 19 pandemic and the quarantine
Miguel Pulice
Edenor S.A., Argentina

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Evaluation of innovation approaches as additional regulatory instruments for the incentive regulation of grid operators in Germany
Nathalie Reuter¹, Stefan Nykamp², Oliver Franz²
¹Amprion GmbH, Germany. ²Innogy SE/E.ON, Germany

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Day-ahead electricity market estimation of Finland in 2030
Poria Hasanpor Divshali¹, Nida Riaz², Anna Kulmala¹, Sami Repo²
¹VTT Research Centre of Finland, Finland. ²Tampere University, Finland

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Evaluation of energy savings using customer meter data
Philippe Charpentier¹, Cyprien Donon²
¹EDF R&D, France. ²ENEDIS, France

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Impact assessment of COVID-19 on electricity demand by utilizing smart meter
Shinichi Takemoto¹, Yasuo Matsuura¹, Kengo Kimura¹, Jun Takamiya¹, Kento Uehara², Masaru Ohnishi²
¹Kansai Transmission and Distribution Inc., Japan. ²Kansai Transmission and Distribution, Japan

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Network effects from electricity grid connections: from traditional grids to smart grids
Cristina Vila Castro¹, Maria Martinez Yáñez¹, Rodolfo Martinez Campillo¹, David Rubio Miguel¹, Kenneth Gillingham², Marten Ovaere³
¹i-DE Redes Eléctricas Inteligentes, Spain. ²Yale University, USA. ³Ghent University, Belgium
Comparison of optimized operation of energy community’s flexibility considering different regulations and trading structures
Hosna Khajeh, Hooman Firoozi, Hannu Laaksonen, Miadreza Shafie-khah
School of Technology and Innovations, University of Vaasa, Finland

Platform for vertical coordination of secondary control reserve using blockchain technology
Hui Cai, Xinya Song, Teng Jiang, Qing Zhao, Steffen Schlegel, Dirk Westermann
Technical University Ilmenau, Germany

An alternative approach for regulatory evaluation of non-technical losses in Brazil
Jonatas Pulz, Carlos Frederico Meschini Almeida
Escola Politécnica da Universidade de São Paulo, Brazil

A cost-benefit analysis of large-scale battery energy storage systems for frequency markets
Sergio Motta¹², Matti Aro¹, Corentin Evens¹, Ari Hentunen¹, Jussi Iikäheimo¹
¹VTT Technical Research Center of Finland, Finland. ²Aalto University, Finland

DSO as a key facilitator of the energy sharing and self-consumption revolution
Eduardo Francisco, Gonçalo Faria, Filipe Matos, Tiago Simão, Rui Bernardo, Pedro Matos, Anderson Soares
E-REDES, Portugal

New business models at distribution grids: a stakeholder consultation
Leandro Lind¹, Carmen Valor², Rafael Cossent¹, Victoria Labajo², Carmen Escudero²
¹IIT - Comillas University, Spain. ²ICADE - Comillas University, Spain

Data-based method for analysing steering mechanisms of the distribution network business regulation
Joel Seppälä¹, Joonas Kari¹, Antti Mutanen², Perni Järventausta²
¹Energy Authority, Finland. ²Tampere University, Finland

Electrification business models in rural off-grid communities, International and Colombian scope
Andres Garcia, Julian Blanco, Diana Garcia, William Riaño
Universidad Distrital Francisco Jose de Caldas, Colombia

The implementation of multi-energy systems - policy and regulatory implications
Iliana Ilieva¹, Sanket Purank¹, Farhan Farrukh¹, Mirza Haider²
¹Smart Innovation Norway, Norway. ²Grenoble Institute of Technology, France
Towards practical typology of energy communities: Main differentiating elements and examples of promising implementations
Jussi Valta\textsuperscript{1}, Anna Kulmala\textsuperscript{2}, Pertti Järventaus\textsuperscript{1}, Johanna Kirjavainen\textsuperscript{1}, Saku Mäkinen\textsuperscript{1}, Tomas Björkqvist\textsuperscript{1}, Kari Systä\textsuperscript{1}, Sakari Uusitalo\textsuperscript{2}, Sami Repo\textsuperscript{1}
\textsuperscript{1}Tampere University, Finland. \textsuperscript{2}VTT Technical Research Centre of Finland, Finland. \textsuperscript{3}Tampere University of Applied Sciences, Finland

Regulatory sandboxes in the energy sector – review and learnings for the case of Switzerland
Fabian Heymann\textsuperscript{1}, Matthias Galus\textsuperscript{1}, Miguel Vasquez\textsuperscript{2}, Jonas Schmid\textsuperscript{1}
\textsuperscript{1}Swiss Federal Office for Energy, Switzerland. \textsuperscript{2}Florence School of Regulation (European University Institute), Italy

Implementing the clean energy package: best practices in overcoming barriers
Andrei Morch\textsuperscript{1}, Venizelos Efthymiou\textsuperscript{2}, Christina Papadimitriou\textsuperscript{2}, Anna Mutule\textsuperscript{3}, Kjersti Berg\textsuperscript{1}
\textsuperscript{1}SINTEF Energy Research, Norway. \textsuperscript{2}FOSS Research Centre for Sustainable Energy, Cyprus. \textsuperscript{3}Institute of Physical Energetics (IPE), Latvia

Scenarios for the future electricity distribution grid
Gerd Kjølle\textsuperscript{1}, Kjell Sand\textsuperscript{2}, Eivind Gramme\textsuperscript{3}
\textsuperscript{1}SINTEF Energy Research, Norway. \textsuperscript{2}Norwegian University of Science and Technology (NTNU), Norway. \textsuperscript{3}Lede, Norway

Business models and barriers towards the development of local energy systems in Europe: Insights from the MERLON project
Dimitrios Papadaskalopoulos, Matt Woolf, Nikolaos Chrysanthopoulos, Goran Strbac
Imperial College London, United Kingdom

Challenges, barriers & possible solutions for future distribution grids- an insight for the Netherlands
Anuradha Tomar\textsuperscript{1}, Joni Rossi\textsuperscript{2}, Phuong Nguyen\textsuperscript{1}
\textsuperscript{1}Eindhoven University of Technology, Netherlands. \textsuperscript{2}RISE, Sweden

Illustration of a territory’s energy footprint using electric consumption data
Judith Vancsa\textsuperscript{1}, Claire Bonhomme\textsuperscript{2}
\textsuperscript{1}EDF, France. \textsuperscript{2}Enedis, France

Optimal distribution network tariffs computation with a bi-level optimisation approach
Ksenia Syrtseva\textsuperscript{1}, Clémence Alassaire\textsuperscript{1}, Mathieu Bordigoni\textsuperscript{2}, Laurent Gilotte\textsuperscript{2}, Riadh Zorgati\textsuperscript{1}
\textsuperscript{1}EDF R&D, France. \textsuperscript{2}Enedis, France
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Ednelson de Moraes1,2, Jenny P.G. Pérez2, Carlos F.M. Almeida1, Carlos M.V. Tahan1, Marcos R. Gouvea1, Nelson Kagan1
1Escola Politécnica da USP (Universidade de São Paulo), Brazil. 2Enel Brasil, Brazil

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Thilo Krause1, Carsten Schroeder2
1Elektrizitätswerk der Stadt Zürich (ewz), Switzerland. 2ewz, Switzerland

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Simon Marwitz1, Matthias Hopfensitz2, Heiko Spitzer2
1TransnetBW GmbH, Germany. 2entilgenio GmbH, Germany

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Saad Ouali1, Abdeljabbar Cherkaoui2
1Abdelmalek Essaadi University, Morocco. 2Abdelmalek Essaadi University, Morocco

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1Public Enterprise Elektroprivreda B&H, Sarajevo, Bosnia and Herzegovina. 2Faculty of Electrical Engineering University of Ljubljana, Slovenia

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Cerius, Denmark

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1Energy Institute "Hrvoje Požar", Croatia. 2Croatian Energy Regulatory Agency, Croatia

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Robin Schubert, Markus Zdrallek
Institute of Power Systems Engineering, University of Wuppertal, Germany

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Tanguy Hubert, Steven Coley
Electric Power Research Institute (EPRI), USA

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MIET, United Kingdom

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Elektro Celje, Slovenia

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BearingPoint GmbH, Germany

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Inês C. Silva, Paulo Alberto, Inês Gomes
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Jujeña Energy Company S.A, Argentina
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Markus Fischer¹, Klaus Bogenberger¹, Jörg Elias³, Simon Schramm²
¹Technical University of Munich, Germany. ²University of Applied Sciences Munich, Germany

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Nikolaos Efthymiopoulos¹, Konstantinos Steriotis¹, Prodromos Makris¹, Georgios Tsaousoglou¹,
Konstantinos Seklos¹, Konstantinos Smpoukis¹, Maria Ethymioiopoulou¹, Dimitrios Vergados²,
Emmanouel Varvarigos¹
¹National Technical University of Athens, Greece. ²University of Western Macedonia, Greece

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Sven Pack¹, Kevin Kotthaus¹, Jessica Hermanns¹, Markus Zdrallek¹, Fritz Schweiger², Christoph Baumeister³
¹University of Wuppertal, Germany. ²E-Werk Schweiger oHG, Germany. ³SPIE SAG GmbH,
Germany

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Hamed Bakhtiari¹, Jin Zhong², Manuel Alvarez¹
¹Lulea university of technology, Sweden. ²University of Hong Kong, Hong Kong

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Davi Leite, Carlos Mattar
Brazilian National Electricity Agency - ANEEL, Brazil

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Eduardo Rodrigues, Gisela Mendes
EDP NEW R&D, Portugal

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Enabling interoperable flexibility and standardized grid support services
João Falcão¹, Carlos Cândido¹, Diogo Silva¹, José Sousa¹, Mário Pereira¹, David Rua², Clara Gouveia², Fábio Coelho², Ricardo Bessa², Alexandre Lucas²
¹E-Redes, Portugal. ²INESC-TEC, Portugal
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Matthew Watson¹, Sofia Eng², Gary Swandells³, David Penfold³, Stuart Fowler¹
¹Western Power Distribution, United Kingdom. ²NODES, Norway. ³Smart Grid Consultancy, United Kingdom

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Pedro Marques¹, João Falcão¹, Susete Albuquerque¹, Ricardo Bessa², Clara Gouveia², David Rua², José Chaves Ávila², Helena Gerard³, Kris Kessels³, Kirsten Glennung⁴, Antonello Monti⁵,⁶, José Pablo Chaves⁷
¹E-REDES, Portugal. ²INESC-TEC, Portugal. ³VITO, Belgium. ⁴EDSO, Belgium. ⁵RWTH Aachen, Germany. ⁶Fraunhofer FIT, Germany. ⁷COMILLAS, Spain

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Bryan Pellerin¹, Farhan Farrukh¹, Iliana Ilieva¹, Prodromos Makris², Emmanouel (Manos) Varvarigos², Nikolaos Efthymiopoulos², Mihai Calin³, Malte Thoma⁴
¹Smart Innovation Norway, Norway. ²National Technical University of Athens (NTUA), Greece. ³Austrian Institute of Technology, Austria. ⁴badenova AG & Co. AG, Germany

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Customer segmentation and targeting for demand response in Thailand
Siriwan Kaewchird
Metropolitan Electricity Authority, Thailand

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Akseli Lahti¹,², Pirjo Heine¹, Samuli Honkapuro³
¹Helen Electricity Network Ltd., Finland. ²Helen Ltd., Finland. ³Lappeenranta-Lahti University of Technology LUT, Finland

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Iason-Iraklis Avramidis¹,², Gerasimos Takis-Defteraios³
¹Luxembourg Institute of Science and Technology, Luxembourg. ²KU Leuven, Belgium. ³Statkraft A.S., United Kingdom

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David Vangulick¹,², Miguel Manuel de Villena¹, Rafael Fonteneau³, Ernst Damien³
¹ULIEGE, Belgium. ²ORES, Belgium. ³ULIEGE / Montéfiore, Belgium
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Cost comparison of connected and isolated microgridS in realistic cases including load modeling and demand side management
Xavier Le Pivert1, Thai-Phuong Do1, Philippe Marechal1, Manuel Billaud2, Florian Perrotton2
1CEA, LITEN, DTS, LSEI, INES, F-73370, Le Bourget-du-Lac, France. 2ENEDIS, France

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Kari Mäki1, Matti Aro1, Henrik Bindner2
1VTT Technical Research Centre of Finland, Finland. 2DTU Elektro, Denmark

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Unlocking the potential of flexibility
Nicholas Etherden1, Benjamin Nestorovic2, Christoffer Isendahl3, Yvonne Ruwaida2
1Vattenfall R&D, Sweden. 2Vattenfall Distribution Sweden, Sweden. 3E.ON Energidistribution AB, Sweden

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A linear model for distributed flexibility markets and DLMPs: A comparison with the SOCP formulation
Anibal Sanjab1,2, Yuting Mou1,2, Ana Virag1,2, Kris Kessels1,2
1Flemish Institute for Technological Research (VITO), Belgium. 2EnergyVille, Belgium

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Business model for household flexibility - A case study
Matti Aro, Kalevi Piira, Kari Mäki
VTT Technical Research Centre of Finland Ltd., Finland

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Forming collective self-consumption models: How the end user sees them?
Jussi Valta1, Anna Kulmala2, Perti Järventausta1, Tomas Björkqvist1, Saku Mäkinen1
1Tampere University, Finland. 2VTT, Finland

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Implementation of self-consumption and energy communities in Austria’s and EU member states’ national law: A perspective on system integration and grid tariffs
Stephan Cejka1, Dorian Frieden2, Kaleb Kitzmüller3
1Siemens AG Österreich, Austria. 2JOANNEUM RESEARCH Forschungsgesellschaft mbH, Austria. 3Haslinger/Nagele Rechtsanwälte GmbH, Austria

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Optimizing a residential solar PV system based on net-metering approaches
Abdul Rauf, Ali T Awami, Mahmood Kassas, Muhammad Khalid
King Fahd University of Petroleum and Minerals, Saudi Arabia

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Coordination concepts for interactions between energy communities, markets and distribution grids
Sami Repo1, Mehdi Attar1, Antti Supponen1, Antti Keski-Koukkari2, Amir Safdarian2, Anna Kulmala2, Matti Vilkko1
1Tampere University, Finland. 2VTT Technical Research Centre of Finland, Finland
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