Special Report - Session 3
OPERATION

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Introduction

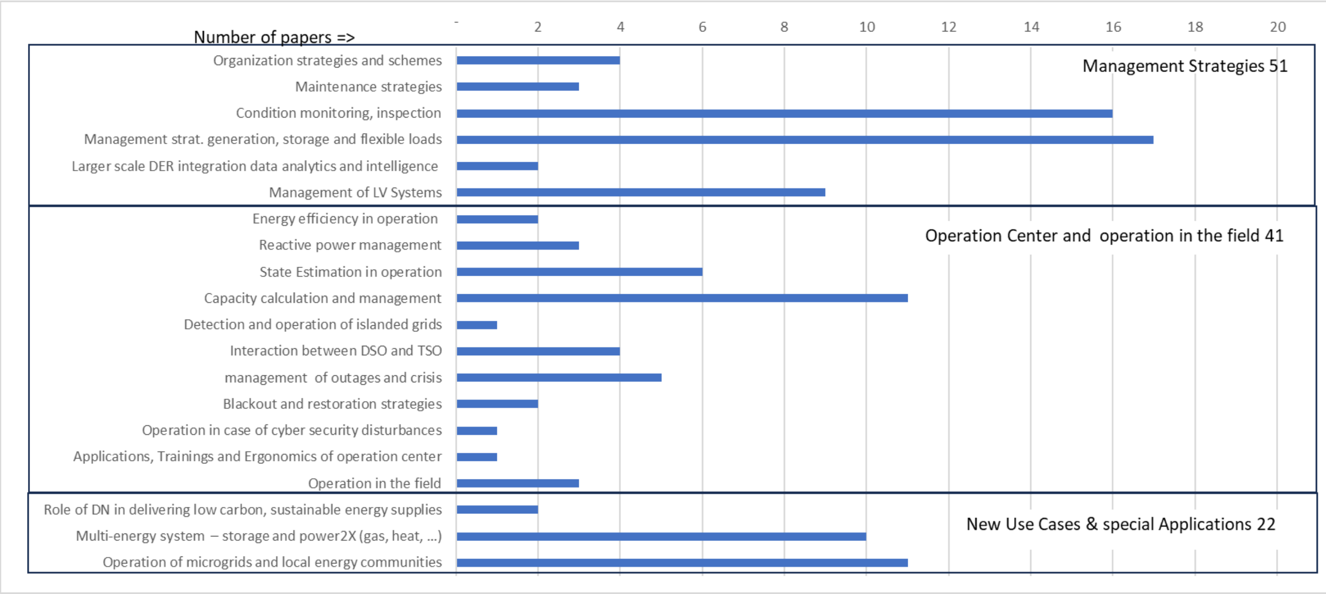
The operation of electrical energy supply networks is becoming increasingly important. Increasing utilisation of existing infrastructure and increased flexibility of consumers and generating units contradict the information available in many networks, especially low-voltage networks.

Session 3 is divided into the following blocks:

- Block 1: Strategies and Management
  - Organization strategies and schemes for grid operation,
  - Training and Education
  - Maintenance strategies
  - Condition monitoring
  - Management strategies for generation, storage and flexible loads
  - Larger scale DER integration data analytics and intelligence for distribution network management
  - Management of LV Systems
- Block 2: Operation Center
  - Energy efficiency in operation
  - Reactive power management
  - Capacity calculation and management
  - Planning of operation
  - Detection and operation of islanded grids
  - Interaction between DSO and TSO
  - Crisis management, Blackout and restoration strategies
  - Blackout and restoration strategies
  - Operation in case of cyber security disturbances
  - Ergonomics of operation center
  - State Estimation
- Block 3: Operation in the Field
  - Occupational safety, augmented and extended reality workforce management
  - Augmented reality in manual operation and for inspection
  - Workforce management tools and techniques to improve operation efficiency
- Block 4: New Use Cases & Special Applications
  - New applications in grid operation
  - Role of distribution networks in delivering low carbon, sustainable energy supplies
  - Multi-energy system operation – storage and power2X (gas, heat, …)
  - Operation of microgrids and local energy communities

For the CIRED Conference 2025, 113 papers were submitted and accepted. About half (51 papers) of these contributions relate to the topic "Strategies and Management". 41 Papers belong to the topic block "Operation Centre and Operation in the field". 22 papers deal with novel applications.
This year's Main Session 3 will deal with the topics of strategies and management in the first and in the first half of the second block of the main session. In the second half of the second block and in the third block, papers on the topic block Operations Centre will be presented. In the last block, the authors will discuss the topics of field operation and special applications.
This year, the following topics will be covered in three roundtables:

- Modelling of customer profile and response to optimise network operation,
- Management of Distribution System Operation during Crisis
- Thermal rating in distribution systems


Number of papers =>
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Multi-energy system – storage and power2X (gas, heat, ...)
Operation of microgrids and local energy communities

Block 1: "Strategies and Management"

Sub block: Organization strategies and schemes for grid operation

The integration of decentralized generation from renewable sources requires several measures addressed in paper 858, a contribution from the majority of Austrian DSOs.

Sub block: Maintenance Strategies

Vegetation is a risk causing faults and prawning at the right time is supporting quality of supply at minimized cost. A contribution from Portugal (763 and 654) are reporting about AI based vegetation management learning from satellite images and climate data.

Sub block: Condition monitoring, inspection

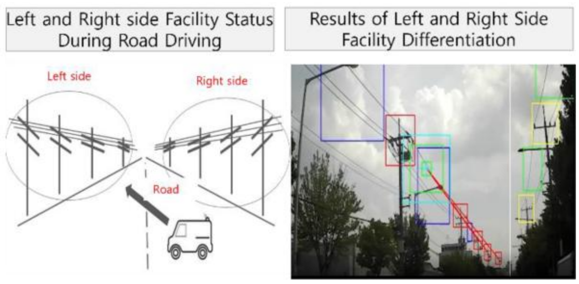

Figure 1: roadside line inspection with car and AI (139)

Also based on AI are the methods presented in paper 139 using pictures automatically taken during driving a car for inspection of roadside overhead lines in Korea. The method is 5 fold more efficient and improves inspection compared to traditional method.

About inspection by AI based analyzing pictures from MV overhead lines taken by drones paper 205 from Malaysia reports.

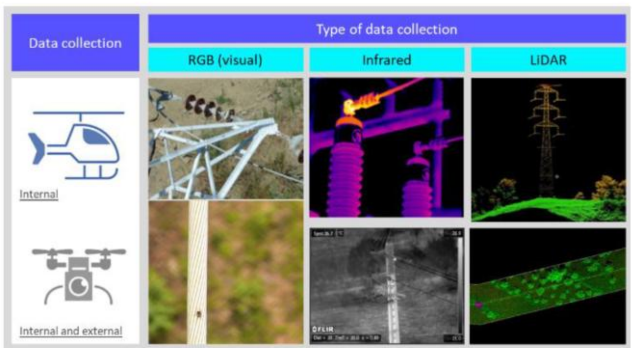

Figure 2: drones and helicopters for line inspection (353)

Also paper 353 reports about daylight, infrared and laser scanned (LIDAR) inspectionpromising improved quality at lower cost.

Degradation analysis of cables and joints in LV networks by detailed thermal modeling is the topic of paper 285 from UK promising a enhanced use of LV network but also improving the quality of supply by detection of points with thermal stress which was up till now not expected. Another contribution regarding thermal effects in low voltage grids from Spain (844) presents simulations of hot spots at LV switchboards at secondary substations potentially damaging or even causing fire. The condition of mounting lines in LV grid typically can cause neutral loss resulting in high voltages potentially causing damage at customers sites. Paper 176 from Portugal reports real time detection with smart meter in a successful pilot application.

A systematic condition based maintenance applied on HV air insulated circuit breakers in a field trial is reported in paper 505 from Germany. Gas analysis, partial discharge and thermography are used to manage measures for limiting the risk of failure and the life cycle management. From same manufacturer the method of vibro acoustic measurements of diverter switch in OLTCs for condition assessment of the switch (paper 485)

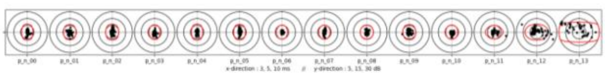

Figure 3: target shooting diagrams for comparison of event positions with their expected values at OLTCs diverter Switches (485)

A new "stethoscope" applied at the surface of power transformers for analyzing the acoustics from partial discharge to perform monitoring of health status is presented in paper 317 from Netherlands.

Paper 736 from Austria addresses the testing of MV cable impedance applying an optimized approach with reduced effort. MV cable diagnostic from live monitoring based on reflectometry promises a secure method supporting the continuity of supply for condition assessment in paper 824 from France, Norway and India.

Paper 426 from Germany presents a monitoring system including sensors for all parts of MV/LV substations and discusses the uses cases targeting optimized use of network and improved reliability.

Repair before fault is occurring - is the idea of HV Pinpoint presented in paper 39 from UK by detecting and locating pre-fault transients in cables. Successful demonstrations are promising more reliable grids. Paper 745 and 915 from Finland are reporting about recognition of events and anomalies. Estimations regarding risk of fault locally but also merging the data at central deep learning module being in future integrated in SCADA/DMS are presented.

Sub block 5: Management strategies for DER

E-vehicle management

Paper 64 presents the result of a simulation study for a scenario with 400 EVs based on a real-world office parking lot in the Netherlands. The analysis focuses on the impact of using flattening or carbon objectives for the coordination of EV charging, as well as the potential of optimizing for a weighted combination of both objectives.

Paper 1079 examines a charging management strategy for electric vehicles, incorporating uncertainties to evaluate estimated flexibility potentials. Using real data collected from a German workplace, the analysis identifies typical patterns and uncertainties in arrival and parking times. A probabilistic approach is adopted to model parking time distributions and to develop a stochastic optimisation strategy to minimise the costs for charging demands.

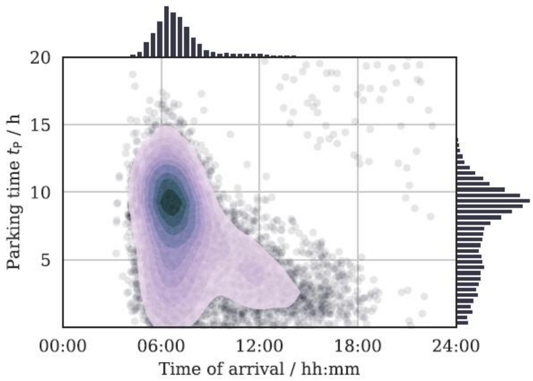

Figure 4: Distribution of parking duration times over the course of a day, Paper 1079

Paper 100 reports a non discriminatory distributed grid congestion management for LV grids based on §14a Energy Industry AcT (EnWG) in Germany applied on electric vehicles. To concepts for control are presented, one strictly following the legal requirements and a second with additional measures to enhance financial and comfort benefits for vehicle users and increases the utilization of renewable energy.

Paper 839 leverages the case study of São Miguel Island, a geographically and electrically isolated region in the Azores, Portugal, under the scope of firm electric mobility adoption governmental commitments. It analyses the impact of EV integration on future demand, whilst focusing on EV demand-side management via smart charging control strategies to minimize investments in local distribution grid reinforcement.

Paper 628 explores managing medium and heavy-duty electric vehicles fleet charging using dynamic operating envelopes (DOEs), which set operational limits to enable more EVs to charge within existing system capacities. DOEs define upper and lower operating limits for distributed energy resources (DERs) over time.

PV management

Paper 225 summarizes some EU initiatives to implement alternative controls in low voltage inverters, assesses the efficiency of cos(φ)-based and droop controls to solve voltage issues, and highlights production losses for different irradiance levels.

Paper 597 addresses overvoltage challenges due to massive PV integration in Belgium´s low voltage grids. Field demonstrations are used to validate theoretical simulations using grid state estimation and active power curtailment in real-world conditions with actual households.

DER and grid capacity management

Paper 270 examines the impact of induction motors, electric vehicles, and heat pumps on load controllability, alongside the variability introduced by solar photovoltaics and wind generation. The results demonstrate that demand-side management effectively flattens load profiles, mitigates renewable-induced fluctuations, and enhances load flexibility by dynamically adjusting controllable loads.

Paper 604 introduces the MiNDFlex project, aiming at performing congestion management and voltage control through the modulation of distributed energy resources' energy exchanges. The project involves a significant portion of Milan's medium voltage distribution grid, where frequent overloads have been identified in the past by analyzing historical current flows. It focuses on the approach adopted to evaluate flexibility needs, based on the contingencies recorded, the underlying DERs, and the electrical consumption of end-users.

Paper 655 evaluates DSO models for enabling DER grid services through simulation studies in a coordinated transmission and distribution test platform. The resulting dynamic DER control and management performance are compared through analysis using actual NYISO system and New York feeder data in reference DSO models developed.

Paper 447 compares the performance of four different approaches to calculate Operational Envelopes in Australia - Asset Capacity, Asset Capacity & Critical Voltage, Asset Capacity & Delta Voltage, and Ideal - using different forecast methods: Persistence, Multiple Linear Regression, Random Forest, k-Nearest Neighbours, and an Ensemble.

	AC	AC_CrV	AC_ΔV	Ideal
Complexity	Low	Low-Medium	Low-Medium	High
Inputs	• Transformer (Tx) Capacity, P & Q • Flex customers' aggregated P	• Tx Capacity, P & Q • Flex customers' aggregated P • Critical customer (CC) historical P & V	• Tx Capacity, P & Q • Flex customers' aggregated P • CC's historical V • Tx historical P & V	• Full 3-phase LV network model • P & Q of fixed customers • Q of flex customers • Tx V
OE Calculation	1. Calculate the spare capacity of the transformer 2. Allocate spare capacity to flexible customers	1. & 2. Same as AC OE 3. Estimate CC voltage using the P_{tx}-V_{tx} sensitivity curve 4. If voltage issues occur, lower the OE and repeat step 3; else, the OE is correct	1. & 2. Same as AC OE 3. Estimate CC voltage using the P_{tx}-V_{tx} and P_{tx}-ΔV curves 4. If voltage issues occur, lower the OE and repeat step 3; else, the OE is correct	1. Set all flex customers' OE to maximum 2. Run the power flow 3. Check for thermal and voltage problems 4. If issues arise, reduce the OE and repeat step 2; else, the OE is correct
Technical Aspects	• Thermal at the Tx	• Thermal at the Tx • Voltage at the CC	• Thermal at the Tx • Voltage at the CC	• Thermal at all lines • Thermal at the Tx • Voltages at all customers

Figure 5: Methods to calculate operational envelopes, Paper 447

Paper 77 proposes an estimation method by the measured data from switch with VCT sensors and facility information acquired by DSO to estimate the unbalanced line-voltage. The proposed method estimates a width of unbalanced line-voltages by both a positive voltage calculated by the facility data in the power distribution system and each line-voltage satisfying with an unbalanced factor defined by DSO and the calculated positive voltage.

Paper 179 further develops the TSO-DSO coordinated, frequency-dependent distributed energy resources and on-load-tap-changers' control scheme for the future electricity distribution networks. Aim is to enable prioritized flexibility services provision for the TSOs and DSOs by proposing dynamic adaptive and frequency-dependent current/thermal limits utilization for distribution network lines, cables and transformers as part of the overall scheme.

Flexibility and test platforms

Transitioning to an active grid operation strategy with real-time measures requires new workflows for distribution system operators, innovative decision support tools for grid operators, and local flexibility market platforms. Paper 749 describes how these aspects are considered in a concept of active grid operation.

Paper 873 introduces an active power control methodology for renewable energy plants to address technical and market-driven requirements. The proposed framework processes inputs from power system measurements to generate forecasts using two distinct approaches, optimizing setpoints for energy dispatch and control processes. Four optimization methods are employed to maximize power utilization while adhering to system constraints.

Paper 1242 paper explores the innovative technology and delivery methods developed by UK Power Networks in designing the MW Dispatch service. It´s service addresses the significant constraints caused by increasing distributed generation penetration and reverse power flows in southeast England. The paper presents an industry first practical implementation of a "Whole System Thinking" using a non-traditional utility approach of employing cloud native microservices architecture, agile methodologies, platform engineering and a multi-squad software engineering approach.

Paper 1032 introduces a cyber-physical test platform to evaluate communication and control architectures for DER in residential settings. The platform integrates hardware-in-the-loop simulations, real-time network modelling, and standardised communication protocols, including IEEE 2030.5 and SunSpec Modbus.

Sub block 6: Large scale DER integration, data analytics and intelligence for distribution network management

Paper 430 proposes a data-model hybrid-driven supply restoration method for active distribution networks with soft open points (SOP) considering distributed generation fluctuations. The framework is designed to coordinate switches and SOP. Subsequently, a data-driven load restoration method based on measurement feedback is proposed for strategy calculation after fault occurrence.

Paper 809 presents a three-phase four-wire local transformer state estimator that integrates an electrical-thermal transformer model to determine a MV/LV transformer's voltages, currents, power values, and losses under varying sets of measurements. Additional functionalities include tap position and wire temperature estimation, along with erroneous measurement detection.

Sub block 7: Management of low voltage networks

LV grid voltage band management

A comparison of options to mitigate overvoltage in low voltage systems due to PV is proposed in paper 419. Insights are provided based on Monte-Carlo simulation results, notably regarding the best implementation practices. The comparative analysis highlights that some technologies can either be very effective or not at all depending on the feeder circumstances, such as the potential role of phase unbalance in the overvoltage issue. A simplified decision-making process for DSOs is also proposed to help in the selection of the most suitable solution on a case-by-case approach.

Paper 305 proposes a method for estimating the voltage range in the low-voltage network, including unmeasured points, by utilizing the available measurement data from the distribution network. A supervised learning model is developed to estimate the distribution of low-voltage network voltages based on measurements from the medium-voltage (MV) network. Actual network data from Korea is utilized for training and validation of the model.

Paper 498 systematically assess the performance of data-driven state estimation (SE) applied to the estimation of voltage magnitudes at smart meter nodes. For cases showing low accuracy, a data-driven optimization heuristic is proposed for the systematic placement of additional real-time measurement devices. Simulation experiments on benchmark LV grids with different topologies, measurement configurations, and DER shares show that data-driven SE can achieve a maximum estimation error of less than 0.014 p.u. for all examined scenarios.

Paper 122 introduces an approach for improving LV networks hosting capacity for PV via manual phase switching of households. Monte-Carlo simulations were performed to statistically assess the benefits of using phase switching of households. Based on typical LV feeder scenarios found in Belgium, it was shown that a single 1ph switch can already provide a significant gain in voltage reduction.**LV grid management**

Paper 234 discusses the challenges of DSO in managing low-voltage grids by analyzing the current regulatory framework in Germany and identifying key issues such as increasing grid connection requests, outdated grid data, and the rising share of electric vehicles and heat pumps. The paper describes a set of use-cases, including grid digitalization, grid state estimation, and load management as well as an IT/OT architecture for implementing load management and provides a roadmap for upgrading low-voltage grids by 2030.

In Paper 359, E-REDES presents an algorithm to identify proactively and automatically voltage violations, load imbalance, low short-circuit power, neutral loss and overvoltage caused by excess distributed generation in low voltage grids. The algorithm combines the voltage alarms and measurements of smart meters and secondary substations and their geographical locations in an innovative approach using geospatial clustering concepts to pinpoint LV circuits with these issues. Once identified, the algorithm automatically updates an internal maintenance web platform to dispatch field teams based on case priority.

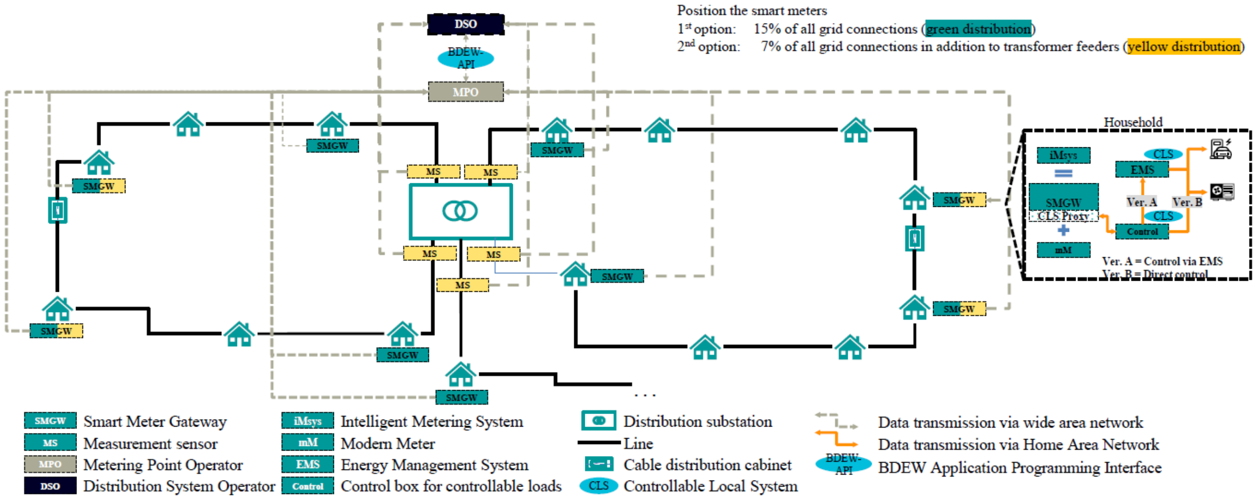

Figure 6: IT/OT architecture for implementing load management according to the German regulations, Paper 234

Paper 423 presents and approach for identification and correction of meter-transformer associations in residential LV networks. Principal component analysis and agglomerative nesting techniques are used to identify false associations, which are then corrected by reassigning to their actual transformer using a correlation-based method. The effectiveness of the methodology is demonstrated through a case study if of an Australian grid with three scenarios.

Paper 976 presents a management strategy for resources “behind-the-meters” along with preliminary field tests on an actual distribution grid. The overall objective is to manage a pool of distributed assets (e.g. storage systems), located in the user’s premises to satisfy metrics at the networks scales (e.g. reduced transformer loading and backfeed power). The proposed operational strategy relies on a two-stages decision making process starting with a first look-ahead step optimizing the storage schedule and a near real-time stage running locally at the scale of every user, based on actual measurements.

Paper 1064 proposes a method leveraging smart meter data to automatically identify switches states and correct the geographical information system. The method has been tested with GreenAlp, a DSO in the French Alps, over an area featuring 2,695 meters. Open switches could systematically be correctly identified except in specific cases (where there is not at least two meters on each side of the switch under consideration).

Paper No. Title	Main Session	RIF	Poster
39: HV Pinpoint for precise location of transient events for repair before failure			3
64: Integrating carbon intensity in electric vehicle charging at office parking lots			5
77: Development of unbalanced voltage estimation method using sensor switches for enhancing HC			1
100: Non-Discriminatory Distributed Grid Congestion Management for Low-Voltage Networks Considering Prosumers Preferences: A Practical Approach			5
122: Improving LV networks hosting capacity via manual phase switching of households A Monte-Carlo analysis			1
139: AI-based Technology for Automatically diagnosing power facilities in Vehicle(AI-based Moving Deep-Learning Defect Inspection System : MDI)			3
176: E-REDES solution for real-time overvoltage monitoring in LV grid | Pilot results			3
179: Frequency-dependent Control of DERs and OLTCs in the Future Distribution Networks			5
205: ADVANCE ANALYTICS USING ARTIFICAL INTILEGENT (AI) IN UNMANNED AERIAL SYSTEM (UAS) FOR DEFECT DETECTION IN MV OVERHEAD LINE SYSTEM			3
225: Improving LV networks hosting capacity via the use of PV and BESS inverters controls – A Monte-Carlo analysis			5
234: Framework Conditions, Use Case Analysis and IT/OT Architecture for LV Management in Germany	B		1
262: IoT-integrated asset test recording for predictive maintenance: enhancing work management and asset analytics			3
270: Advanced demand side management in distribution networks with low carbon technologies			5
285: Further integrated physical and probabilistic modelling of low voltage cable degradation with a view to future technologies and asset management strategies	A		1
305: Voltage Range Estimation in Low-Voltage Networks Including Unmeasured Points through Voltage Distribution Estimation			1
317: Online Partial Discharge Monitoring and Localization in Power Transformers Using Fiber Optic-based Acoustic Emission Sensing Technology			3
341: Prioritization and reports processing improve maintenance decisions			1
353: Leveraging overhead powerline inspection using drones and digitalization			1

Paper No. Title	Main Session	RIF	Poster
359: ADDRESSING OPERATIONAL CHALLENGES IN LOW-VOLTAGE GRIDS – E-REDES' INNOVATIVE USE OF GEOSPATIAL CLUSTERING AND SMART METER DATA			1
419: Tackling PV-caused overvoltages – Synthesis of Monte-Carlo simulations outputs and multi-criteria assessment of mitigation measures	B		1
423: Identification and Correction of Meter-Transformer Associations in Residential LV Networks			1
426: Efficient and sustainable digitalisation of smart secondary substations with current and voltage sensors integrated in cable connection bushings			3
430: Data-Model Hybrid-Driven Supply Restoration of Active Distribution Networks with Soft Open Points	B		1
447: A Comparison of Forecasts Methods for the Calculation of Operating Envelopes		X	5
485: Identification and interpretation of the signal from the diverter switch in the vibro-acoustic measurements of the OLTC			3
498: Assessing data-driven state estimation performance in low-voltage distribution grids		X	1
505: Two-dimensional approach for condition assessment of high voltage air-insulated circuit breakers	A		3
597: SOLORMAX Project - A Real-Time Digital Twin Demonstrator for Renewable Curtailment Optimization in Low Voltage Networks Based on Grid State Estimation	A		5
604: Implementation of A Real Flexibility Application on the Milan’s Distribution Network: The MiNDFlex Approach			5
628: Flexible Energization of Electric Vehicle Fleet Charging Load using Dynamic Operating Envelopes			5
654: E-REDES Implement advanced analytics applied to satellite imagery to Optimize Vegetation Management	A		
655: Evaluation of DSO Models for Enabling DER Grid Services			5
736: A time, cost and safety optimized approach for cable impedance measurements			3
745: Transparent and explainable AI for fault prediction in distribution networks			1
749: Next generation active distribution grid operation using local flexibility markets			5
763: Advanced Vegetation Management in Overhead Lines: E-REDES Analytics4Vegetation 2.0 – AI, Satellite Imagery, and Sustainability	A		1
809: Local transformer state estimation: a smart way to purify non-consistent multiple data sources in secondary substations			1
824: Improving reliability of overhead and underground distribution networks using advanced fault diagnostics techniques			3
839: Predicting and Mitigating the Effects of Large-Scale EV Integration on Low Voltage Distribution Grids: The Azores Case Study	A		5
844: Tool for detecting external hot spots in a Low Voltage Switchboard to facilitate asset management and maintenance tasks.			3
858: The Transition from DNO to DSO for an active system operation in Austria			1
873: Renewable Energy Management Systems - Methodological Aspects for Active Power Control			5

Paper No. Title	Main Session	RIF	Poster
915: Concept for improving grid resilience with sampled value data analytics			3
976: A Two-Stage Operational Strategy for the Control of Distributed Storage in a Low Voltage Network			1
1032: Cyber-Physical Test Platform for Characterisation of DER Communications and Control Architectures			5
1064: Automatic identification of low-voltage grids switches states using smart-meters data – Grenoble experiment			
1079: Probabilistic Charging Management of Electric Vehicles with Stochastic Optimization and Flexibility Analysis under Consideration of Uncertainties		X	5
1242: Accelerating Grid Connections for Over 1.5 Gigawatts of Distributed Generation and Energy Storage Using Market-Based Customer Offering and Advanced Technology Solutions			5
1272: Resilience and Reliability Analysis of Medium Voltage Distribution Network			1

Block 2: Operation Center and Operation in the field

Sub block: energy efficiency

Energy efficiency and net zero are upcoming issues. Paper 812 from Norway presents an analysis about reducing losses by optimizing setpoints regarding losses. Also, paper 337 presents results about savings of cost and carbon benefits by 3% voltage optimization. Simply regarded higher voltages are resulting in lower losses but looking more into detail, a discussion with various aspects is opened.

Sub block: reactive power management

Paper 444 from Netherlands and Finland reports about a reactive power estimation for large customers using machine learning. Different models are compared, and authors recommend first to test if simple assumptions are accurate enough and in case not to create a targeted learning model. To fix the topic of reactive power management an Austrian DSO presents practice of reactive power management based on measured reactive power data for more than 1000 data points in network planning and operation.

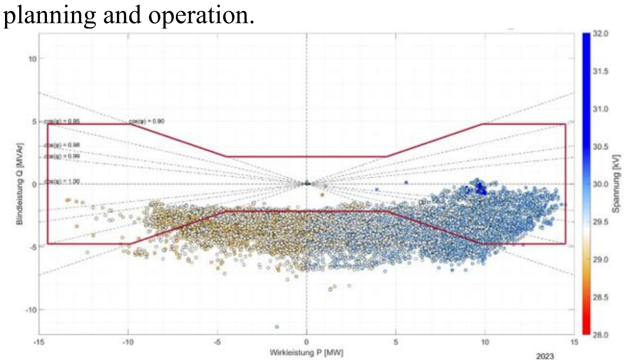

Figure 7: Optimized sensor location in MV Grid (paper 094)

Paper 168 from Germany reports about investigations of distribution grid supporting transmission grid voltage control.

Sub block: State Estimation

Automated and manual control has been based on limited observability at certain selected points in the network (e.g. loading of feeders at prim. substation). Results from planning of the network are used for roughly estimating loadings and voltage levels at points without observation.

Paper 44 from Austria deals with the ideal placement of sensors in LV grids based on large monte-carlo-simulation and an established machine learning state estimation tool at an early step of development.

For an area of five MV/LV grids measured data and pseudo-data are aggregated to anonymized patterns and applied on topology and asset data in a state estimator in the Netherlands. The results from the estimators as they are applied in transmission grids are compared to measured ones in paper 1148 and are demonstrating significant errors indicating the need of further development for the lower voltage levels. From Germany in paper 589 DSO and SCADA developers are reporting a so called preventive automated network control for enhanced low voltage grid management successfully tested and validated under real conditions in a German LV grid. The presented solution and further steps based on a large amount of real time data and AI seem to be promising for quite good state estimation.

A specific genetic algorithm for sensor placement in MV grids feeders for state estimation is applied in France and reported in paper 094.

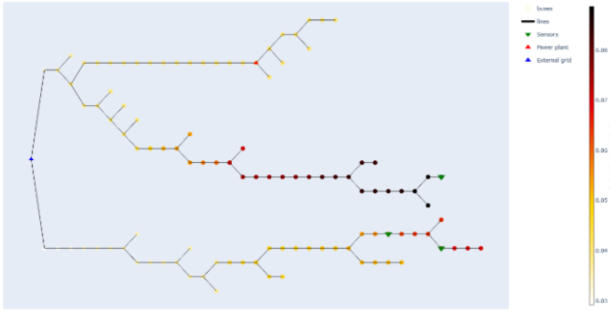

Figure 8: Optimized sensor location in MV Grid (paper 094)

A scientific analysis on effect of time resolution of data is presented in paper 1021 from German University and DSO concluding that for MV the resolution of 15-min is quite suitable but lower resolution seems to be required for low voltage grids. Based on simulations with the IEEE 33 bus model paper 1003 from Iran demonstrates that from voltage monitoring at 8 nodes only a quite accurate voltage profiles and network losses can be calculated.

Sub block: Capacity calculation and management

Paper 872, from Austria presents the practical application of quasi measurement data derived from real smart metering data compared with errors depending on the size of the regarded network. For large LV networks' total load the error is clearly below 10% but at more than 60% for small rural networks. Based on these data the authors present a quite successful two day ahead forecast for urban LV network's total loading (+/-5% of quasi measurement and 20% of calculated PV generation).

From Latvian DSO and Denish forecasting service company paper 1090 reports about short term load forecasting (STLF – 48 hrs.) applied to primary substations of distribution grid for dispatchers to take network control actions like line switching, transformer operation or activation of flexibility. RMSE and MAE optimized forecasts for different quantiles where under test resulting in the recommendation to apply both or even combined quantiles (P5 and P10) to get experience which one fits better.

From Belgium and Netherlands paper 142 presents congestion management in MV networks regarding N and N-1 cases based on day ahead processes. In the network investigated some congestion service providers can be

activated. Authors conclude that future work should include dynamic thermal limits and node voltages via dedicated sensitivity matrices.
From Belgium and US paper 1290 after an interesting background discussion presents a dynamic line rating system and application based on real time measured and forecasted weather data. For applying thermal rating on medium voltage underground cables DSO and University from Belgium are reporting in paper 266 results from analyzing the thermal conductivity of the soil with particle based inversion method. This work provides an important background for modelling the thermal behavior of underground cables to enable thermal rating without risk of damage or early aging.
As the modelling of thermal properties of cables and the soil around can be very challenging a monitoring solutions are of interest. Paper 598 from Netherlands present a Time Domain Reflectory method where reflections of electric pulses are evaluated and can be used to estimate a temperature (+- 4 °C) of the conductor in mixed cable systems as they can be found in MV distribution grids.
A DSO from Netherlands has successfully applied dynamic limits (DL) in operation with quite accurate thermal models resulting in up +50% of loadability of the already existing grid.

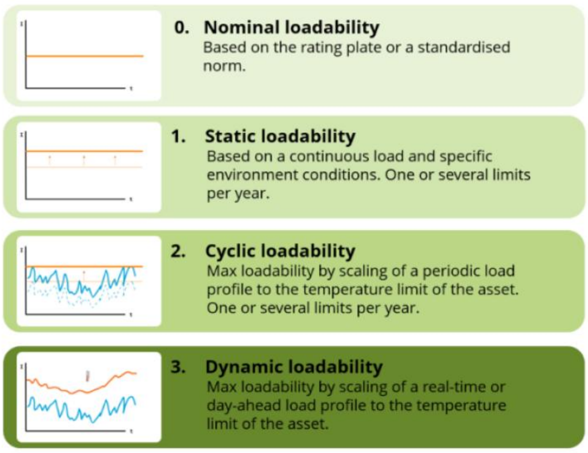

Figure 9: Increasing levels of loadability by utilizing asset's thermal mass via more accurate, more complex assumptions on asset parameters and environmental conditions (paper 102)

Secondary substations transformer 50kVA in small cases were under test in China and compared with model developed within this work. The errors of results from modelling reported in paper 003 are below 5%.

Paper 747 from Hungary presents easy to handle and cost effective sensors for overhead lines combined with the cost reducing concept of AI based virtual sensors.

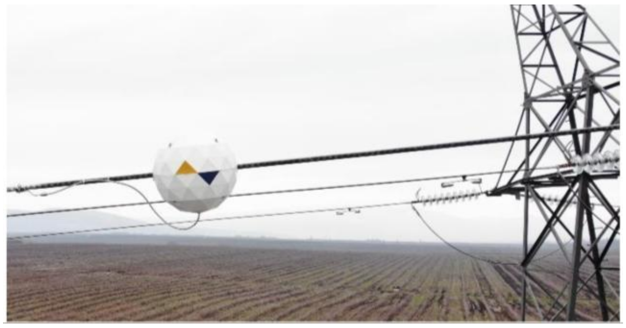

Figure 10: Optimized sensor location in MV Grid (paper 094

Paper 1095 from German TSO admissible transmission loading is regarded as permanent and temporary. For temporary one thermal models are set up and neural networks are used to improve the accuracy of this capacity estimator.

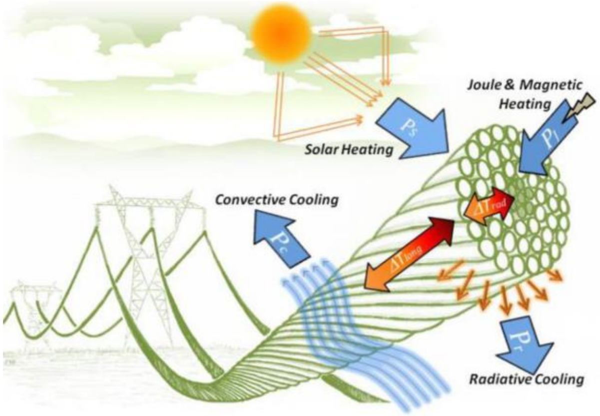

Figure 11: modelling the thermal capacity of transmission line (paper 1095)

Sub block: Detection and operation of islanded grid
Decentralized generation with hydro and thermal generators traditionally has been regarded as a risk for unintended islanding most of these plants were designed for islands at the beginning of electricity supply. Paper 1006 from Germany reports analyses of grid forming converters'(GFC) potential cause of unintended islanding. This is expected even at a share of GFCs below 25% at MV and LV grid. The paper mainly refers on actual german study at university RWTH Aachen. The authors conlclude that a mass integration of GFCs requires further investigations and the development of operation principles.

Sub block: Interaction between DSO and TSO
Paper 97 from France presents the results of investigations regarding distribution networks in parallel to transmission lines and the resulting transfer of reactive load flow. The highest voltage rise obtained from various calculation is 1,419% but related to an unrealistic X/R ratio. The authors conclude that further investigations with realistic X/R and shunt capacitance of lines should be undertaken.

Aggregated flexibilities from distribution level potentially can support transmission to avoid congestion or even manage it.
Feasible Operation Regions – FORs at the points of connection are analyzed and calculated in papers 88 and 435 from Germany. Paper 88 focuses on the parameters of the distributed slacks from superordinated transmission grid and the accuracy dependent from number of clusters. Paper 435 proposes a novel heuristic-based dynamic sampling strategy using the REvol evolutionary algorithm to walk along the FOR boundary efficiently. This method begins by finding an initial boundary point and dynamically adapts its search direction using domain knowledge and population reuse to improve overall performance. At further work the method will be applied to real world active distribution grid.

A performant TSO-DSO coordination for flexibility management is presented in paper 557 from Netherlands starting from a total centralized approach developed towards a fully decentralized one named as the “Link-Chain”.

Sub block: management of outage, crisis and reliability
Quick reaction on faults to minimize the effect on customers, reducing the outage time and improving the power quality indices. Paper 992 reports about an AI based system for fault location and restoration. This was undertaken as a measure against compensations which had to be paid to customers before.

In case of critical load peaks at time of lack of generation and all other load reduction mechanisms are exhausted in France temporarily consumptions limit can be applied for a few hours per year. Paper 739 reports results from testing of customers’ behaveour. The data from this testing supports to predict a 3 GW reduction of load from 10 mio of households. This might be sufficient to prevent the system from blackout.

Paper 221from Sweden presents a machine learning–based method with data for one decade for predicting feeder-level faults within a 14-day horizon, focusing on high precision to reduce false alarms and better align with operational realities. In future the system could become more powerful by including data from weather forecast and former sensors like partial discharge.

Power quality indices can be improved by optimal segmentation of grid and placement of reclosers in case of faults. A DSO from Brazil reports in paper 578 about successfully applying AI on millions of scenarios to determine best solutions.

Paper 60 from Switzerland provides an Analysis of reliability of the 110-kV-lines in the City of Zurich. In this study after calculation a large number of critical cases the contribution to critical cases for all lines was analyses by applying DC lowd flow calculation. The critical cases could be reduced by shifting loads between different primary substations.

Sub block: blackout and restoration strategies

Restoration of Grid after Blackout including decentralized generation was tested in simulations with a modified IEEE 34 bus model in Germany. The results in paper 1229 demonstrate successful inclusion of decentralized generation within 3 hours by sectionalizing the network in three sections.
The potential use of decentralized generation from renewables for frequency containment reserve was investigated in Germany. Authors of paper 259 conclude that in summer PV and BESS and in winter CHP and Run of River hydro power plants could take part in this market with limited impact on loading of lines.

Sub block: Operation in case of cyber security disturbances
Novel concepts of operation are more and more based on even real time data. In case of loss of communication actual plans intend to activate a fail-safe mode applying limits for generation and load. Paper 986 from UK presents a machine learning based system providing predictions being accurate enough even to be used in case of loss of communication.

Sub block: Application, Trainings and Ergonomics of operation center
Advanced distribution management systems containing SCADA, outage management system, distribution management system and each of these equipped with lot of functionalities. In paper 963 from Portugal these are listed in detail and a comprehensive dashboard monitoring the system effectively. The authors are describing concepts with open architecture for integration of all subsystems mentioned above.

Figure 12: Dashboard of Advanced distribution management system supporting the remote operation (paper 936)

Sub block: "Operation in the field"

The French DSO reports in paper 367 about investigations in the field of utilization of mobile generators during maintenance to continuous supply of customers. In most cases oversized capacity results in low efficiency. By Using smart meter data for modelling 50% of cases can be supplied with optimal size. Next step will be the modelling of unbalance. The impact on carbon footprint and costs by saving 71% of fuel is supporting the realization of this concept.

Wasted interventions due to misinterpretation of customer's claims are the topic of paper 192 from French DSO. To avoid trips for visiting customers without being able to solve their problem rises very high costs. The method based on AI has been deployed all over France. The estimated gain in 2023 is 3.7 M €.

Figure 13: switch gear for secondary substation with panel for full control on site (paper 787)

A fully local controlled secondary substation (MV/LV) is presented in paper 787 from France and Spain for simplified deployment of digital substations. The major advantage is that at each single substation for operation the digital features can provide benefits. The major challenge for design is to keep it simple in the field but provide all functions of real-time monitoring and SCADA integeration.

Paper No. Title	Main Session	RIF	Poster
3: Adaptive dynamic estimation on the operational capacity margin of distribution transformers			2
37: Visualisation of 15min time series for the efficient analysis of the electricity distribution network	C		2
44: Ideal sensor placement and state estimation in distribution grids		X	4
60: Reliability Verification of a High Voltage Target Grid for Urban Operation	C		4
88: Parametrisation of Superordinate Grid Representations in the Calculation of Feasible Operating Regions			2
94: OPTIMAL SENSOR PLACEMENT FOR STATE ESTIMATION OF DISTRIBUTION NETWORKS USING A GENETIC ALGORITHM			4
97: Impact of Reactive Power Transfer among Transmission to Distribution Substations on the Transmission Network's Voltage		X	2
102: Continuous determination of assets' dynamic loadability by using thermal inertia and real-time conditions	B		2
142: Congestion management in medium voltage networks in N and N-1 situation	B		2
168: Use of online feedback optimisation in active distribution grids for voltage support in the transmission grid			2
192: Detecting potential wasted interventions on customer premises with natural language processing	C		6

Paper No. Title	Main Session	RIF	Poster
204: How to build an efficient virtual training?			3
221: Enhanced Power Grid Reliability through 14-Day Machine Learning Predictions for Proactive Fault Management			4
259: Potential analysis of renewable Distributed Energy Resources for Frequency Containment Reserve provision		X	2
266: Application of particle-based Bayesian inversion to underground medium voltage power cables in the Netherlands		X	2
335: The Role of Asset and Network Resilience in Electricity System Restoration 'Black Start'			4
337: Boston Spa Energy Efficiency Trial – A novel method to implement conservation voltage reduction using smart meter voltage data			2
367: Sizing optimization of Generator sets for LV grid maintenance interventions			3
444: Reactive Power Estimation for Large-Scale Consumers Using Machine Learning methods			2
453: Dynamic optimization-based method for determining the flexibility potential at vertical system interconnections		X	2
557: Link chain design framework for a performant TSO-DSO coordination			2
578: Segmentation of Distribution Grids: Prescribing Automatic Reclosers as a Prescriptive Maintenance Strategy			4
589: Preventive Automated Network Control: Enhancing Low Voltage Grid Management with Recurrent Neural Networks	C		2
598: Towards Real-Time Estimation of Cable Temperatures in Mixed Circuits using Time Domain Reflectometry and Machine Learning			2
739: Protecting the national electricity grid balance by temporarily limiting residential customers' available power: a large-scale experiment	C		4
747: Cost-Effective Strategies for Enhancing DSO Flexibility: Exploring Sensor Rental and Virtual Sensors in DLR Systems			2
787: Integrated protection and control for MV/LV substations			3
812: ACTIVE VOLTAGE REGULATION TO ENHANCE ENERGY EFFICIENCY IN ACTIVE DISTRIBUTION GRIDS OPERATION			2
872: Enhance distribution grid observability			2
963: Improved ADMS with an operator friendly interface			4
986: Remote Power Flow Prediction Using PMU Data and ML for Enhanced DER Resilience in Communication Loss Scenarios	C		4
992: APPLIED ARTIFICIAL INTELLIGENCE TO OPTIMIZED POWER DISTRIBUTION OPERATION: SIMULATION OF SWITCHING AND FAULT LOCATION MODULES INTEGRATED TO CORPORATIVE IT SYSTEMS			4
1003: A Novel Approach to Distribution Network Modeling with Limited Online Data			4
1006: Addressing future power system stability challenges as distribution system operator – current status and priorities			2
1021: Effects of the measurement data resolution on the derivable value of information		X	4
1090: Dynamic safety thresholds as a measure to mitigate short-term load			2

Paper No. Title	Main Session	RIF	Poster
forecasting (STLF) errors for distribution system flexibility services			
1095: Determining Temporary Admissible Transmission Loading (TATL) Using Neural Networks for Curative Congestion Management			2
1148: "Data-Driven State Estimation and Smart Meter Data Privacy Preservation for Low-Voltage Distribution Grids'' is the title of our abstract.			4
1229: Parallel power system restoration planning at distribution level considering uncertainty of renewable generation			4
1290: Dynamic Line Rating: Benefits and Challenges from Global Case Studies			2

Block 3 "New Use Cases & Special Applications"

Sub block 1: New applications in grid operation

New operation functions based on smart meter

Paper 61 realized two experiments in the field to test an LV voltage control of PV generators using the advanced metering infrastructure (AMI). As depicted *Figure 14*, a local communication gateway between the smart meter and the inverter is added (Raspberry Pi) as well as a main controller, in the data concentrator, which estimates the state of the network based on smart meter information, computes and sends the setpoints to the smart meters. These experiments enable to show the risk of PLC quality degradation during sunny hours.

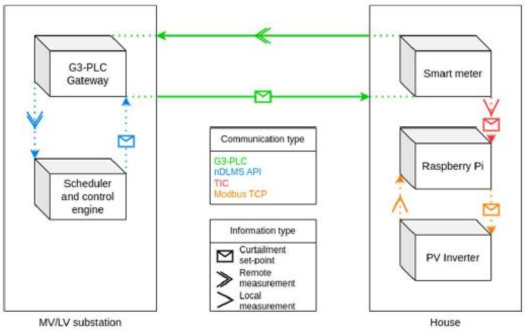

Figure 14: Control architecture

Paper 421 presents the results of the monitoring of generations equipped with meters connected to the distribution system in the Republic of Croatia. Voltages, currents and powers are measured and analyzed in order to detect weak or constrained areas. These measurements are coupled with secondary substation measurements in order to identify locations for future generation connections. All the algorithms developed are based on open-source software.

Paper 560 investigates five use cases based on data provided by smart meters and smart secondary substation in Czech Republic. Power outages, thief, data for investment planning, power quality and PV inverters behavior were investigated based on a data set collected in 2024. The next step will the validation under real-world operational conditions.

Paper 596 describes algorithms to improve fault detection (fault positive minimization, fault area identification and merging multiple alarms corresponding to the same event) in the LV networks based on both smart meters and distribution transformer controllers' alarms. First results from a field pilot are promising. Further improvements of algorithms have been identified as well as their integration into daily operations on a larger scale.

Paper 1126 compares two curtailment methods for customers equipped with smart meters via a home energy management system (HEMS) prototype: (i) reduction of the settings of the internal protection of smart meters located in the constrained area and (ii) curtailment command sent directly to the concerned customers. Lab experiments enable to identify improvements and next step will be real-test experiment.

Digital twins

Paper 248 proposed an exact digital twin (DT) of MV/LV secondary substations as well as an approximate evolutionary DT for LV networks using data-driven strategies. The paper proposes 4 LV networks algorithms based on these DTs: transformer overload management (OLTC), voltage control strategies, erroneous measurement detection, and network parameter estimations. Validation has been done both in laboratory and real environments.

Paper 274 proposes a Power-Hardware-in-the-Loop (P-HiL) testbed and their corresponding platforms to test and validate smart functions before implementing them in the field (see *Figure 15*). An example of Smart grid platform with its IT systems in interaction with various data sources and sinks are shown. The LV grid is simulated using a DT, and real devices are connected through amplifiers.

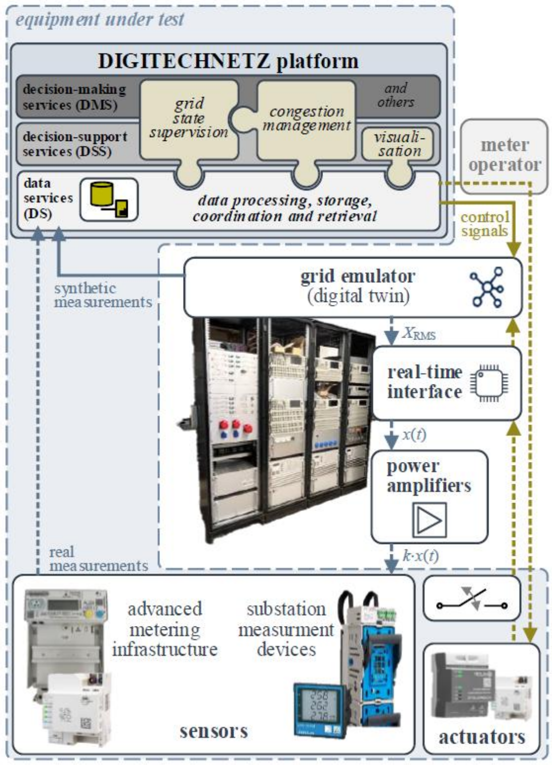

Figure 15: Interaction between the platform and the laboratory setup

Paper 458 presents a digital twin trial to validate a co-ordination algorithm to arbitrate between several control functions in a distribution grid. Four operational trials are described (set up and control variables): (i) existing control method and existing network, demand response (DR) and smart street, (ii) existing thermal control method and existing network, DR and Active Network Management (ANM) flexible connection, (iii) potential voltage control method and existing network, DR and Network efficiency mode (NEM), (iv) potential voltage control method and potential network, NEM for voltage constraint management.

Smart power electronic devices for distribution network

Paper 1253 presents the results of a real field test of advanced algorithms for the operation of distribution systems included in a DERMS. These algorithms perform state estimation and optimal power flow to calculate the setpoints of soft open bridges (SOB), soft open points (SOP) and normally open point switching (reconfiguration) in order to increase the hosting capacity of the network in terms of renewable and electric vehicles. 4 trials of feeder balancing have been studied (i) between HV substations, (ii) between HV substations and LV feeder heads, (iii) between two MV feeders through SOB and SOP and (iv) all combined.

Communication infrastructure for new network operation

Paper 51 presents the EEBUS technology and solutions to help in the energy management between resources (including the distribution network). It consists of a communication interface ensuring interoperability of all the devices interconnected. Three solutions are proposed and described in the paper: power limitation, dynamic pricing and self-consumption. For each solution, tables summarizing the information exchanges between devices and which use cases are concerned. Finally, standards used are described.

Sub block 4: Operation of microgrids and local energy communities

Local energy communities

Paper 109 proposes a controller of a residential photovoltaic and battery system based on reinforcement learning to deal with uncertainties. The objective of the control is to reduce the end-user's consumption uncertainty for the DSO to better predict grid power profiles. Such control has been compared to a perfect forecast and a rule-based approach and depicted in *Figure 16*. The mean squared energy deviation of the proposed control is improved by 21.62% compared to the rule-based method.

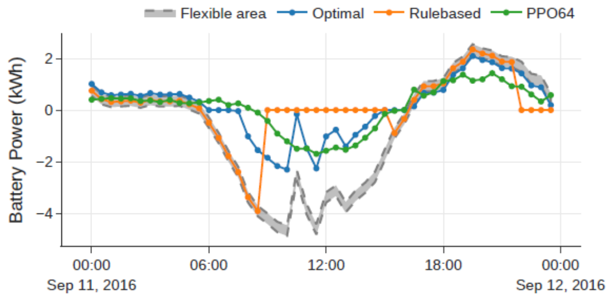

Figure 16: Sample of the power control sequence on one day

Paper 734 presents an ontology-based EMS for the interoperability and optimization of hybrid energy storage systems in energy communities. The objective is to provide a unified vocabulary that ensures semantic interoperability across the data model and information layers. In this way, seamless real-time communication and data exchange among devices and interfaces can be deployed in project pilots. Examples of results of an Austrian pilot are provided: measured voltages of community members MV/LV transformer and the optimized HESS schedule considering grid capacity limit.

Paper 1101 deals with the optimal management of local energy communities considering network constraints. The proposed deterministic method integrates day-ahead scheduling (cost minimization and self-consumption optimization) and real-time control (minimization of the deviation to the schedule). Three methods are compared to generate input data : (i) use of a forecasting module trained with historical data, (ii) real time data and (iii) combination of both. This method is applied to a community of 20 participants. Results show that, due to uncertainties, the efficiency of the third method is worse than the others, leading to an increase of about 5% in demand.

Microgrids operation

Paper 1097 addresses the topic of port electrification. A microgrid consisting of the shore-charging infrastructure for ferries, a PV, a battery and connected to the main grid is proposed. The shore-charging infrastructure integrates a model predictive control (MPC) strategy. The objective is to optimize power dispatch between all the resources using linear programming. This EMS is validated on real data from the Intra port on Maggiore Lake in Italy following several charging scenarios.

Paper 141 details with the black start of microgrids after a disconnection from the main grid (fault on the upstream grid or maintenance). It first characterizes the behavior of domestic loads during the re-energization process using electromagnetic transient (EMT) models and measurements conducted with real-life loads at the EDF lab. Three types of loads are considered: resistive, switch ode power supply and motor. Also, the impact of a voltage ramp on the current transient produced during the re-energization of domestic loads is studied. Some no-cost to recommendations were driven from this study mitigate the stress on the inverters due to the current transient.

Paper 333 aims at increasing the island duration of a temporary 100 % inverter-based MV microgrid by (i) controlling the battery LV side voltage using the OLTC, (ii) controlling the voltage level of the microgrid thanks to the battery PU-control and (iii) adding a local under-voltage level-dependent disconnection/reconnection logic for controllable loads. Simulations show that depending on the voltage settings selected, the needed current from the battery can be reduced by 11 to 19%.

Paper 695 proposes to add a PV limitation algorithm into diesel generator so that they can stay connected can stay connected, in case of a microgrids creation, reenergized by a diesel generator. In case of lower consumption or higher production, the power produced by the diesel generator will decrease. A f(P) control is added so that the frequency increases leading to the limitation or disconnection or some PV in the microgrid. This control has been implemented in a 100 kVA diesel generator and successfully tested in the concept grid lab.

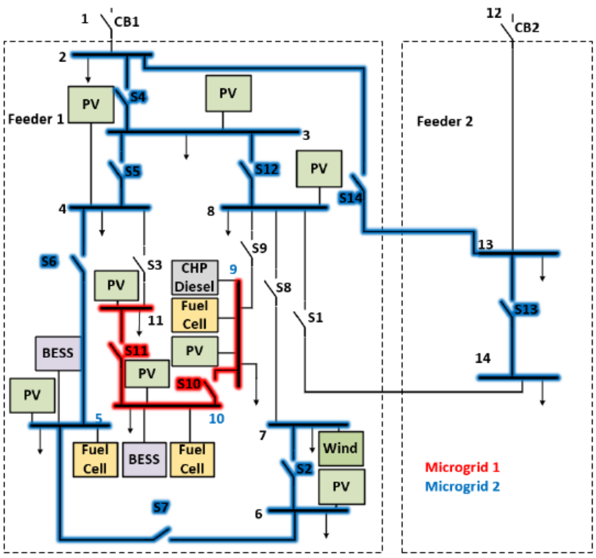

Figure 17: Example of creation of MV microgrids. (paper 870)

Paper 870 presents a dynamic distribution network reconfiguration (creation of microgrids) in the event of main grid failures (disconnection from the main grid). An algorithm based on reinforcement learning enables to autonomously reconfigure the network to form self-sufficient microgrids in real-time and prioritizes critical loads and maintains system stability. *Figure 17* shows an example of creation of 2 microgrids. The use of convolutional neural network for Q-value estimation improves the optimal switch operation even under complex operational conditions. This algorithm has been successfully applied to a modified CIGRE MV considering 3 scenarios: balancing between load and generation and demand excess generation capacity (2 scenarios).

<u>Real microgrids deployment (laboratories or field)</u>

Paper 283 presents the first LVDC network managed by a public distribution system operator in Belgium and to be used as a living lab. All the technical choices (operating voltage level, cable sizing, protection scheme and grounding) are described, making this DC micrigrids replicable. Also, ongoing and future experiments are described.

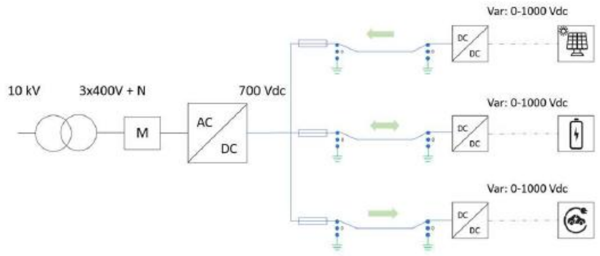

Figure 18: Real LVDC microgrids

Paper 591 describes in detail the installation of distribution phase measurement units (D-PMUs) in an MV private microgrid as well as the communication infrastructure as shown in *Figure 19*. The collection, processing and storing of D-PMU data are done by a dedicated server in the main EPFL data center. Three use cases are presented: network observability for asset monitoring, power dispatch of controllable resources, and fault location analysis.

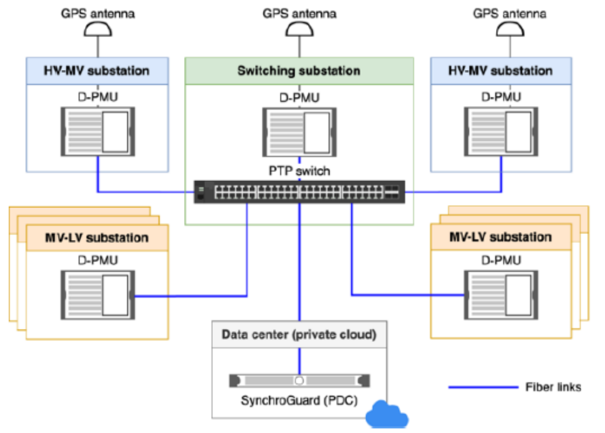

Figure 19: Simplified system architecture

Paper 331 presents the concept of MicroResilience which consists of a seamless transition from the main grid to a battery in case of outages for example. All the required elements are described in details: the battery, the power electronic device, the microgrid controller, loss of mains detection unit, synchronization check relay and communication infrastructure as well as the utility company control room. This microgrid has been successfully tested in a village in England of about 55 homes, a school and a hall.

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Paper No. Title	Main Session	RIF	Poster
51: The Role of EEBUS Technology for Efficient Energy Management and Grid Interaction			6
61: AMI-based non-firm LV grid connection for PV generators: first real-world experiments	D		6
109: Versatile, self-adapting smart home control	D		6
141: inverter-Based Black Start of Domestic Loads: Behavior and Inrush Current			6
248: IDENTICAL project: Increasing Distribution Network Hosting Capacity by means of an innovative application of an Smart Transformer (with OLTC) combined with electric distribution Digital Twins.			6
274: DIGITECHNETZ – A flexible testbed for smart grid platforms using digital twins of low voltage grids			6
283: RE/SOURCED pilot: Practical implementation of a DC microgrid	D		6
331: The MicroResilience Solution: Mitigating Grid Outage Impacts for Rural Customers			6
333: Novel DER and OLTC Management During Islanded Operation of MV Microgrid			6
421: Advanced system for automated monitoring of voltage conditions through the analysis of time series from smart meters of power plants in the distribution network of the Republic of Croatia	D		6
458: QUEST - An Overarching System Control Solution Operational Trials			6
560: Grid Analysis and Operation Optimization by Using Data from Smart Meters and Smart Secondary Substations			6
591: Distribution-PMUs deployment and applications in microgrids: the EPFL university campus case	D		6
596: E-REDES - Low Voltage Fault and Restoration Detection with Smart Grid Infrastructure			6
695: Using grid frequency variations to limit PV production in a diesel generator-powered microgrid			6
734: Enhancing Interoperability and Optimization of Hybrid Energy Storage Systems through Ontology-Based Energy Management Systems	D		6
870: Enhancing resilience and prioritizing critical infrastructure through deep reinforcement learning-based network reconfiguration in islanded microgrid networks			6
1097: An MPC-Based Energy Management System for Fast Shore Charging of Ferries at a Smart Port			6
1101: Optimal Management of Energy Communities considering Electric Mobility			6
1126: Congestion management on LV networks by controlling customer assets using a HEMS (SIBELBox ©) developed by the Sibelga DSO			6
1253: Active Response: Operational Optimisation of Soft Power Bridges & Soft Open Points on Distribution Systems			6