Special Report - Session 3
OPERATION, CONTROL AND PROTECTION

Markus ZDRALLEK
Chairman – Germany
zdrallek@uni-wuppertal.com

Ignaz HÜBL
Special Rapporteur - Austria
ignaz.huebl@gmx.at

Carsten Böse
Special Rapporteur - Germany
Carsten.Boese@ESTW.de

Andreas Abart
Special Rapporteur - Austria
Andreas.Abart@netzooe.at

Introduction

For CIRED 2019 nearly 450 abstracts have been received in Session 3 showing the still enormous need of further development in the area of operation, control and protection of distribution grids. Due to this record number of abstracts, Session 3 Team (see Fig. 2) had to be stricter than ever in rejecting papers. Since the quality of abstracts and full papers has been constantly increasing during the last years, even well written abstracts had to be rejected in order to keep a manageable number of papers during the conference
Therefore 180 authors –about one third of the proposals– were asked to submit a full paper. Finally 156 full papers have been accepted by National Committees and the Technical Committee (TC) Session 3 Team.

Fig. 1 gives an overview of the review process.

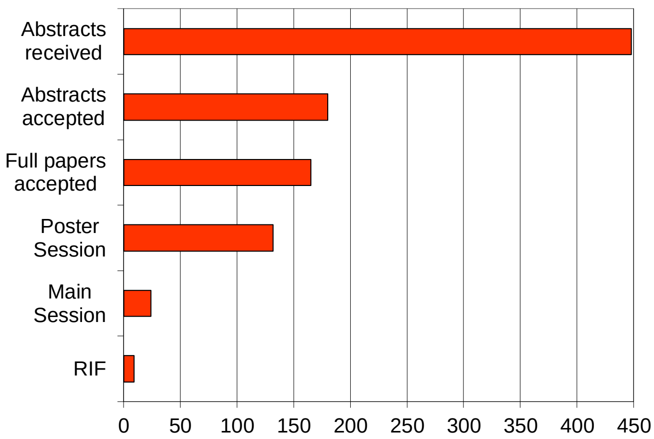

Fig. 1: Review process overview

Fig. 2: Session 3 Team looking forward to see you in Madrid (from left to right):
A. Abart, M. Zdrallek, I. Hübl, C. Böse

All authors are asked for a poster presentation during CIRED 2019, 24 of them will additionally present their paper in the Main Session and nine papers are allocated to the Research and Innovation Forums (RIF).
Traditionally and according to the topics of the papers submitted, Session 3 is structured into three blocks. While the Operation- and Control-blocks both are divided into five sub blocks, the Protection-block consists of three sub-blocks only.

The Session 3 structure of CIRED 2019 is as following:

Block 1 Operation

- Maintenance and Condition Assessment
- Distribution Management
- Crisis- & Workforce-Management
- Ancillary Services on Distribution Level
- Reactive Power Provision

Block 2 Control

- Medium-Voltage Automation
- Low-Voltage Automation
- Islanding
- SCADA / Distribution Management Systems
- Communication

Block 3 Protection

- Fault Location / Earth Fault
- Applications
- Algorithms and Simulations

An overview of the number of papers related to the different blocks and sub blocks is given in Fig. 3.

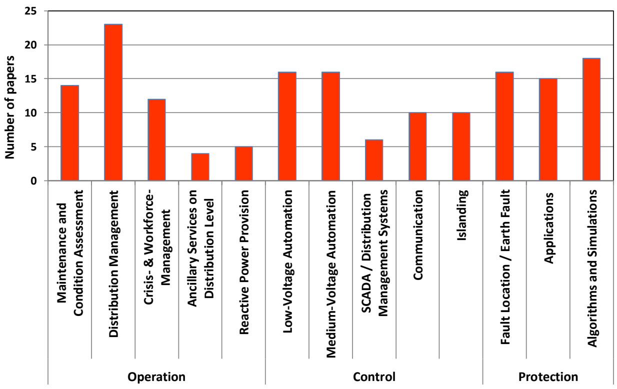

Fig. 3: Paper overview of blocks and sub blocks

Block 1 Operation

Block 1 at a glance

The topics of operation are covering a wide area starting from maintenance and condition assessment where papers are focusing on new methods as Augmented Reality, drones or complex methods (e.g. Partial Discharge) of component analysis to draw conclusions for condition assessment. For maintenance strategies the use of artificial intelligence, Data analytics and IOT is reported.

In the field of "Distribution Management" grid monitoring with data from smart meter up to topology and phase detection and proposals for congestion management by use of flexibility are giving insights to possible grid operation in future with increasing supervision, remote control and automation. Papers regarding work force management are dealing with tools and communication technology. Related to the topic Crisis several contribution report about improvements of prognosis of weather and even prognosis on faults expected to be used for best preparedness with human and material resources. Papers reporting about crisis management concepts are regarding risk assessment and optimization of restoration including automation, the roles of DG and machine learning algorithms supporting the decisions for repair. Some papers are discussing coordination of DSO and TSO, ICT-tools and interfaces pointing out the importance of common standards. Most of the Papers regarding ancillary services are presenting flexibility used to avoid congestion instead of reinforcement of lines. Also in the field of reactive power provision, the majority of papers focuses on congestions due to voltage violations. Enhanced concepts of voltage-var control, combined with optimized power flow as well as technical and economic performance are discussed. Overall, the contributions are providing lot of interesting and new information, concepts and ideas covering the wide field of operation.

Maintenance and Condition Assessment

Augmented Reality: Maintenance processes require lot of man-power due to training workers for a certain number of different systems getting more and more powerful but also complex as IT-based solutions are already standard today. Augmented reality promises solution effectively supporting workers by informing, training and online support by experts. With paper 1207 EDP Distribution reports about a successful pilot including Cost Benefit Analysis. The results are reduced numbers of experts' trips and saved time at preparing and reporting of any maintenance activities. A second paper from Austria (paper 0220) reports about application of Augmented Reality (AR) in the fields of operation and maintenance. In both cases, AR-glasses support the hands-free use of the system.

The use case for operation supports employees at switching by guiding step by step through the procedure, provides system parameters and indicates the components. Thus, mistakes can be avoided and the safety of workers as well as the quality of supply are increased.

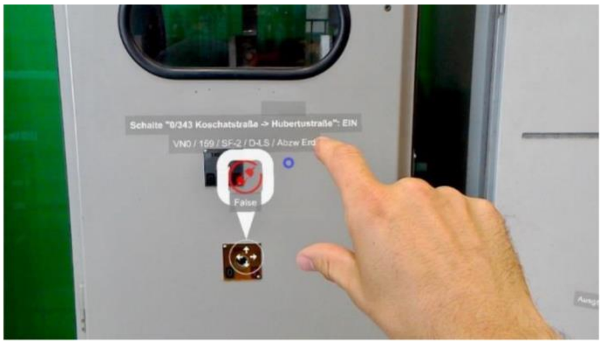

Fig. 4: Looking throug AR-glasses components are indicated (paper 220)

Paper 0584 presents a 3D VR labaroty simulation system to be used for teaching and training.

Line inspection and maintenance: Another field of maintenance activities requiring certain capacity of manpower is the inspection of lines. Therefore the upcoming technology of Unmanned Aerial Vehicles (UAV) is presented as a promising solution in paper 2070 from China. An AI based algorithm to detect de best flying route and positions for taking pictures for inspection on the screen in the backoffice is reported. Another contribution from China [paper 448] dealing with the developpement of a realtime control of UAV devices for inspection and even performing robotic functions as cleaning of insulators and bolt fastening. This paper focuses on the performance of communication technology and video compressing algorithms.

Cable Monitoring: Predictive maintenance for cables, joints and terminations requires condition assesment. Technically probably the best option is a continous monitoring of Partial Discharging (PD) but cost are very high. Paper 1894 from Spain discusses different concepts of spot measurements, temporal monitoring and continous monitoring on different voltage levels and for different types of cables regarding a total length of cables of 5.000 km at different utilites. To safe costs many utilities are applying a two steps strategy of PD detection and localization. Results of this analysis demonstrate that at voltage levels below 132 kV around 50% of PD are located at terminations while at higher voltage levels only 30% occure there. Authors further conclude that: „ the higher probability of human errors during accessory assembling depending on level of voltage of the installation due to the quality of technicians performing the job.“

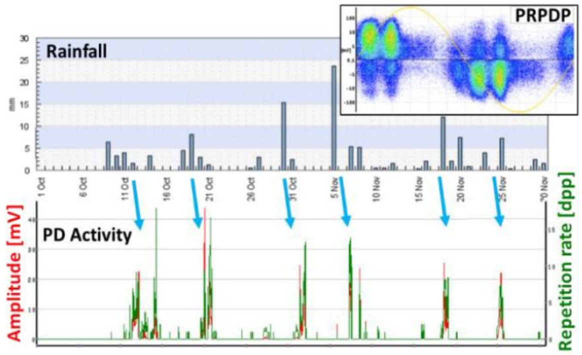

Fig. 5: PD activity at a 220-kV-cable versus rainfall (paper 1894)

Paper 1076 from Australia dives very deep in the methods of PD analysis and presents results of analysing errors. A case study in Jakarta (Indonesia) Medium voltage grid is reported in paper 1657. Replacing a time based maintenance by condition based maintenance applying PD-ultrasonic wave method and transient earth voltage the rate of outages could be successfuly reduced.

Condition Assessment for tap changer in OLTC, performed by vibroacoustic diagnostic method based on wavelet transformation enabling detection of degradation and anomalies is reported in paper 0547 from Germany. Artificial intelligence is used to learn from variations in patterns recorded for automated diagnosis.

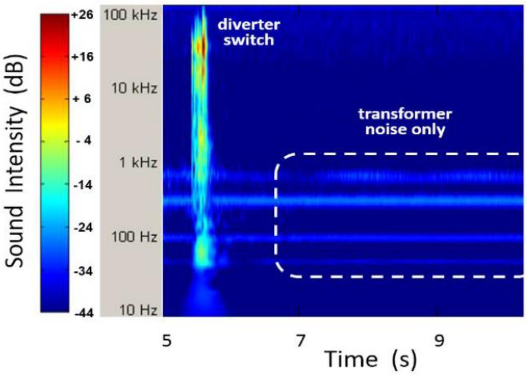

Fig. 6: Spectrum of vibroacoustic signal at head of tap changer (paper 547)

Paper 2061 from Iran reports about results from analysing motor startups and converter circuits stressing 20kV/400 V transformers at CNG stations after a critical disturbance at one station where the electric installation and the motor burnt.

Maintenance Strategies: A contribution from Iran (paper 1640) reports about developement and implementation of neural networks applying Analytical Hierarchy Process (AHP) as a decision making tool to prioritize maintainance to reduce the rate of outages most effectively.

A large DSO from finland reports about a pilot project applying data analytics and software robotics providing „added value to asset management for optimizing distribution network maintenance and to move from time- or condition-based maintenance schemes towards predictive maintenance“ (paper 1080). The paper focuses on additional sensors which are not based on traditional intelligent electronic device, connected to the SCADA but on IoT connected to a cloud based system for cost effective communication and use of sensors from mass market. Furtheron the same DSO reports about a self driven maintenance process with regional partner’s network in paper 1790.

Paper 1452 presents a set of measures identified by an Indian DSO for improoving the reliability of MV and LV grid, regarding jointing for LV cables, load monitoring of secondary substation and thermografy.

Paper 1086 from Netherlends is provoking with it’s title „Over-specification due to lack of knowledge“ and adresses manufacturers as well as utilities. The title is supported with three detailed notes discussed and some examples regarding rated withstand currents and voltages, earthing, switch gear internal arcs and losses, cable testing. The conclusions begin with the sentence „It’s a rat race to top with specifications“. At the end of this paper authors point out that the wish „to avoid any risk“ cannot be fulfilled and there are increased costs without any real gain of safety and reliability.

Distribution Management

Phase Balancing in LV Grid by using smart meters is adressed by paper 0136 from France. A Sucessfull phase detecting instrument „has enabled more than 375 phase swapping operations, reducing unbalanced loading and related problems in more than 150 secondary substations amongst 900 already identified by the Linky system as requiring on-site intervention.“ The french instrument is based on syncronization of the signal to the zero cross of the voltage. Paper 2068 fron Czech Republic presents a method detecting the phases by evaluation of voltage data from simple event recordings performed by smart meters.

Voltage range and capacity assessment for low voltage grids based on load profiles gathered with smart meters evaluated by a specific voltage measurement function of a smart meter in paper 0590. The results presented are demonstrating limited errors promising load flow calculations from load data as an appropriate method.

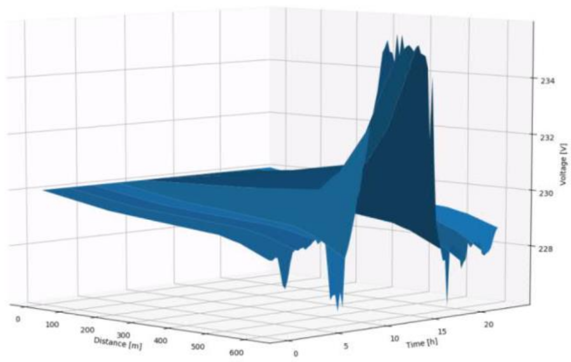

Fig. 7: Calculated voltage along a line to a PV installation 600m away from the transformer station (paper 590)

Paper 460 presents a novel tool for assessment of connection requests in LV grids including data from real operation, gathered with smart meters. A showcase for EV-charging demonstrates automatically reasonable identified options. Authors conclude from their results and experience a high potential for increased effectiveness in grid planning from automation, based on high quality data.

Another study case of using smart meter data to generate forecasts of LV load is reported in paper 0806 from Japan. Real load profiles gathered with smart meters are classified into seven groups to be used for estimations including new customers. Therefore, machine learning called decision tree was applied. Authors finally conclude that further investigations are required to avoid underestimations of peaks.

Topology Analysis for correcting data stored in GIS for low voltage grids performed by using voltage patterns from smart meter data is reported in the French paper 1789.

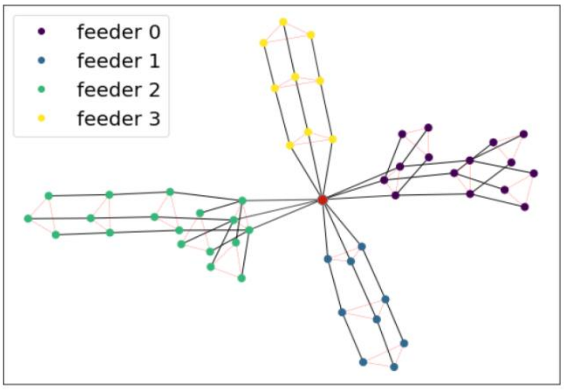

Fig. 8: Final tree reconstruction for LV-Grid calculated from smart meter voltage patterns (paper 1789)

Future System Operation is regarded in paper 0215 based on an Austrian report, published by the Austrian

association of electricity companies. A group of DSOs has elaborated future perspectives on changes of ancillary services and requirements for data exchange for TSO-DSO interface and on upcoming mapping of even LV grids with digitalization. Automation in the fields of work force management, customer interaction and information systems are discussed. Within this context paper 1038 presents analyses of the reliability of interconnected electrical power systems (EPS) and ICT systems from UK based on hybrid modelling of the cyber-physical-interdependencies including even the human operator. Results for different vulnerability scenarios are demonstrating the impact of ICT+EPS on outage characteristics i.e. duration and size of affected area.
As the measurement devices, a very high precision of time synchronisation and high-speed communication systems are available and costs have been decreasing, wide area PMU can be installed in sub-transmission-networks. Paper 1998 reports about development of a fault classifier and zone identification for fault localisation.

Resolving congestions and flexibility is an upcoming challenge for operation of distribution systems. Paper 0764 from France presents a method to optimize the choice of three levers available at operational planning for MV grid using day ahead and hour ahead forecasts and some formulas of the algorithm. Paper 0236 provides a simplified formula for effective calculation of closed loop currents in MV grids meeting the requirements for a reliable operation. For maximum utilization of grid paper 1957 discusses dynamic line rating used in short term operational planning combined with curtailment in order to postpone investments for expansion of transmission and sub transmission systems.

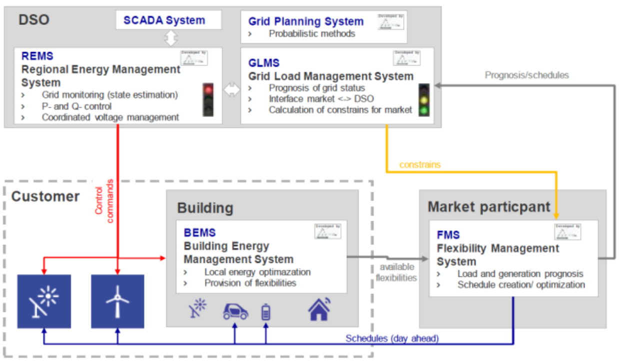

Fig. 9: Traffic light for congestion managment (paper 2022)

Paper 2022 reports about a field test regarding congestion management in a rural area applying a traffic light concept based on a quota model. During green light periods, customers can participate the market but have to accept, yellow and red light requirements. Results are promising a more efficient use of the grid and an increased hosting capacity for PV generators.

Paper 0823 from Croatia presents simulation results applying ABC (Artificial Bee Colony) algorithm for coordinated curtailment to avoid overvoltage in LV grid. The total infeed is maximised but customers are affected by different curtailments depending on their point of connection. Within the conclusions, authors point out that an appropriate communication system is required for real implementation.
The French paper 1962 provides a deep analysis of the variability of photovoltaic power output.
As in Portugal, the regulator requested for dynamic network tariffs a Portuguese DSO implemented two pilots for customers at HV- and MV-level. It is reported in paper 1214 that a long-term schedule with different tariffs depending on weekday and season was accepted but a second model, offering limitation of consumption only in case of congestions failed on recruiting participants. Within the project a powerful load, generation and load flow forecasting system was implemented.
The use of batteries with different technologies and sizes as flexible load and generation is addressed in paper 1567 from Korea. Investigations' results regarding installed batteries used in real cases for voltage control, congestion management and even islanding are presented.

Smart Cities are major part of future smart energy systems. The total consumption in urban areas is rather high and hybrid energy systems (electric & thermal) at a simple level have been used since decades. Now large thermal storages and electrical storage systems are set up and flexible loads e.g. heat pumps and EV-charging are upcoming. Scheduling of flexible loads, CHP, PV and exchange at PCCs to gas and electricity grid by linear optimization for real areas in Korea and Germany are presented in papers 0894 and 1906.

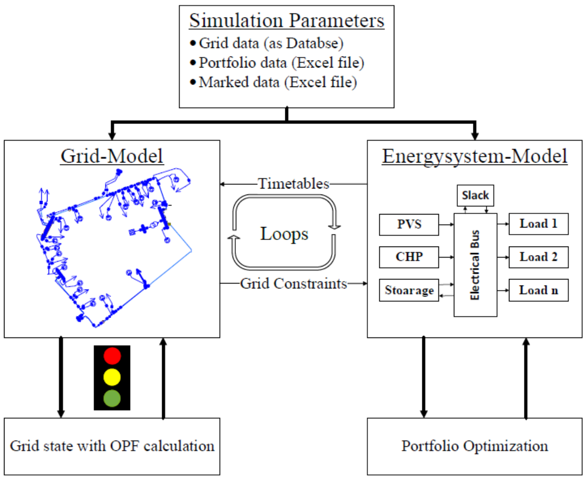

Fig. 10: Optimization Model (paper 1906)

Fig. 10 shows the optimization model for the German demo area, a low voltage grid of an urban district regarded as a virtual power plant. In this paper several

KPIs regarding ecologic, economic oprational and social aspects as well as the Cell-Performance are defined by equations. An economically optimized weighting of the KPIs leads to an exclusive use of the external network as energy supply for the district. But a more ecological weighting instead, results in a trade-off between local sustainable energy generation and low-cost external electricity supply.
Korean paper 0894 reports about investigations of a smart City area being large city regarding energy resources on system level only without any attention on grids. Results demonstrate that for maximum of energy independecy a huge thermal storage is required.
Paper 1919 from Russia presents an urban smart grid project for the whole city Ufa (1,150 km in the east from Moscow). Within the total refurbishment of electrical grid many substations have been equipped with sensors and remote control technique. Controllability and observability as well as new components have significantly increased reliabilty and network losses.

For upcoming smart home functionalities linked to the smart metering testing of these smart grid systems will be required. Paper 2313 from France reports about a comprehensive laboratory setup for physical hardware testing electrical and ICT system operation with smart metering for smart low voltage grid applications.

Crisis and Workforce Management

Workforce management: A comprehensive mobile application of GIS/NIS is reported from India (paper 0750). The application covers use cases regarding care and restoration of grid, patrol monitoring and meter commissioning. Paper 0751 from Finland deals with connectivity of ICT-equipment in the field. Connectivity is the basis of any mobile application requiring connection to central databases as well as e.g. for the dispatching centre of workforce management. There are dead zones in mobile communication networks especially in the rural areas. A finish DSO and a University department investigated a gain of signal level 20 to 30 dB by lifting the mobile phone with a drone. Authors report that the distance between the phone and the base station of the mobile communication network can be increased from 14 km up 39 km.

Crisis management: Within the last 20 years e.g. in Finland after heavy storms with long term outages (several days), for better preparedness a common project covering DSOs, fire and rescue services as well as authorities and media started. Paper 2085 from police university and rescue association reports about the Finish research (KIVI-project, meaning vulnerability of critical infrastructures and operational capability of authorities) and resulting concepts. Fig. 11 shows the general information concept.

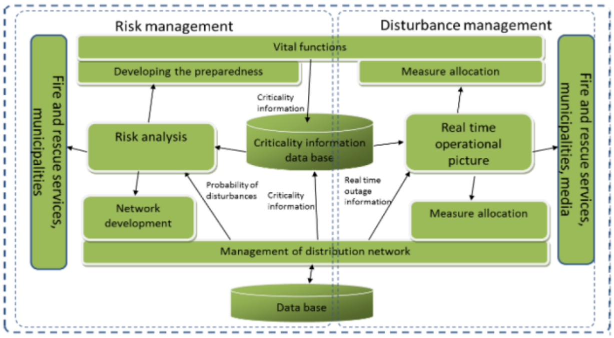

Fig. 11: General Information Concept for Crisis managent (paper 2085)

It has to be noted that well-founded risk analysis within this project demonstrates an increasing risk for urban areas at higher level compared to rural, as the impact is much worse.
Also from Finland paper 1602, discusses a modified FLIR (Fault Location, Isolation, Restoration) strategy during storms with many faults within short time where weatherproof zones are restored quickly case by case while faulty parts are restored later. This reduces the number of switching operations and accelerates the restoration process as a whole. The experiences from applying the storm mode demonstrate reduced SAIDI, reduced numbers of voltage dips as the number of auto reclosing is reduced and less stress for switches.

Battery performance test: A very important practical topic in respect to crisis is given with paper 2065 from Austria presenting investigations on deeply discharged batteries.

Forecasting of weather and outages: Three papers are discussing the forecasting heavy weather and its impact on the grid as a measure for better preparedness. Paper 0869 from China reports about more accurate prognosis (0.5 x 0.5 km) for heavy rainfalls in southern China by interpolation and presents results from detailed analysis of outages caused by the rain. The algorithms applied "can not only realize the flooding warning of specific power equipment, but also effectively reduce the false alarms and improve the reliability of the power grid."
In 2013 the Finnish government introduced the Electricity Market ACT (EMA) requiring maximum 6-hour-outage for urban areas and 36 hours in rural ones. Paper 925 from Finland reports about a NIS & DMS integrated tool for better allocation of the resources and prioritization within the restoration of the grid. The outlook of this paper is to improve the prediction of outages from historic data.
A contribution from Portugal where heavy weather affected the power system in recent years reports about data analytics and machine learning to aid in the decision-making process of operational planning activities (Paper 1209). Within a framework of activities

for improved crisis management an outage prediction tool has been developed.
Based on network data (GIS/NIS), terrain characteristics, historic outage data (OMS) and weather forecasts a knowledge database was set up a 3-days ahead prognosis for den expected number of outages within each 3-hour–interval is available. Fig. demonstrates the successful prediction as registered outages (blue line) and predicted ones (orange line) are well fitting. The increased number of registered outages includes the very short interruptions quickly restored by auto reclose operations.

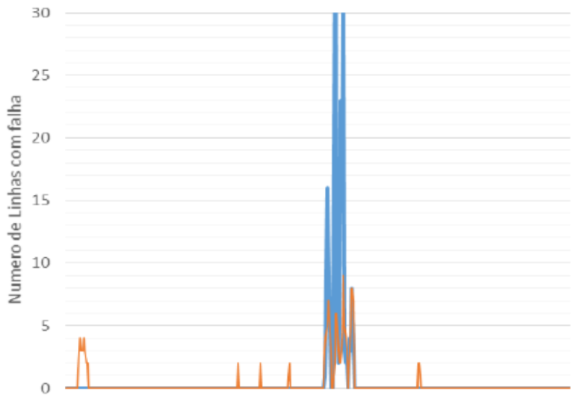

Fig. 12: Predicted number of outages (orange) and registered outages (blue) comparison for one operational area. (paper 1209)

One paper (2114) from Norway presents a concept based on machine learning (ML) for fault handling in LV Networks. The first step are features like fault identification, localization and classification based on GIS/NIS-data, smart meter last gasp (sent in case of loss of supply), weather data and experience. The second one is a case based reasoning (CBR) unit supporting the decisions for repair. Authors conclude that further development of these features in future will enable even self-healing LV grids.

Grid restoration and renewables: One of the core topics regarding future network resilience is the role of distributed generation (DG) from renewable energy (RES) sources in case of restoration. Paper 0537 from German and Austrian reports about "the cold load pickup behaviour as well as the gradual resynchronization and increasing power infeed of DG and RES, which can have a destabilizing effect on the system restoration process." These investigations have been performed within the project RestoreGrid4RES providing at its end an innovative tool to guide grid operators during the Power System Restoration process.

DSO-TSO communication in emergency case: a paper from Croatia reports about lacks of communication between TSO and DSO in recent cases of transmission system disturbances and underlines its importance.

DSO-TSO Interface
The evolution from TSO connected generation to DSO connection generation is resulting different challenges to DSOs and TSOs. Paper 0872 from Portugal presents a demonstration project of coordinated systems of TSO and DSO (as part of the European project TDX-Assist). "The main aim of this project is to design and develop novel ICT tools and techniques that facilitate scalable and secure information systems and data exchange between TSOs and DSOs." In the Portuguese demonstration-project, three main areas of data exchange are addressed: short circuit power, forecast of generation and improve of fault location. Authors concluded that in the foreground of increasing share of decentralized generation the bidirectional information between TSO and DSO is already important but will become more important in future. Paper 2060 from Norway (co-authors from Italy, UK, Spain and Belgium) addresses "architectures for optimised interaction between TSOs and DSOs" regarding "compliance with the present practice, regulation and roadmaps". This paper reports about H2020-project SmartNet where five different architectures of TSO/DSO-coordination are proposed integrating ancillary services. The aim of this project is an enhanced screening of legal and regulatory framework. The authors of this paper conclude, "Without common EU regulations different solutions will develop in the distribution areas, the most diverse and non-harmonized solutions will be implemented in agreement between DSOs and adjoining TSO (e.g. nation- or region-wise under influence of TSO). This will not necessarily hamper the utilisation of local flexibility in the transmission grids, but it will certainly make more difficult the development towards cross-border utilisation of distributed energy resources."

Ancillary Services
Due to decentralized generation and electric vehicle charging as well as heating in distribution congestions are an upcoming topic. Two papers from UK are dealing with ancillary services at the DSO level. Paper 1918 reports about a trial offering three different use cases of flexibility incentivized by probably attractive fees for availability and utilization. The three use cases defined in this project are "pre fault intervention", "post fault intervention" and "restoration". Authors are reporting about significant interest but a limited availability of volume in the service and long-term commitments and enhanced information about potential as measures to convince customers to participate. Paper 2036 (UK) presents an Active Network Management (ANM)-System to avoid network reinforcement (time delay and costs) with three strategies of full- and partial pre-event and post event curtailment. For detection of optimal generators to be curtailed sensitivity analyses are performed. The paper reports about a case study finding the DSO's ANM-System in a leading role but also showing the interdependency from TSO.

Paper 0049 from Germany discusses reactive power provision from flexible consumers operating converters (see next topic).

Reactive Power Provision

Paper 1871 from Austria presents preliminary results of the ERA-Net Smart Grids Plus and H2020 funded Project DeCAS regarding the reactive power management of Distribution System in the region of Salzburg.

Fig. 13: Shape of reactive power exchange limits (paper 1871)

Fig. 13 shows the total demand of reactive power of the two sections of the 110-kV-grid in the region of Salzburg. The major part of the capacitive reactive power (over excited) occurs at lower load when the reactive power provision (under excited) from transformers is low. The reactive power dominantly results from line capacitance - mainly MV-cables, followed by HV Cables. Within the next steps of DeCAS-project the power flows and the impacts from Voltage-Var-Control are analysed.

Paper 0343 from UK, Scotland compares STATCOMs with mechanically switched capacitors and hybrid solutions of both technologies used to eliminate voltage violations without investment for reinforcement of the grid. The dynamic response of the STATCOM is the basis for its effectiveness. It is technically feasible and the CBA presented in this paper demonstrates STATCOM as cost effective solution strongly dependent on the scale. Authors conclude that for large interventions reinforcement of lines and stations is still the appropriate solution.

A reactive power provision from distributed sources is topic of paper 0049. Based on studies about usage of solar inverters for the purpose of reactive power this paper regards all other converters especially of industrial appliances, e.g. variable speed drives. These converters usually are rated to peak power demand of the connected motor but most of the time operated at much lower power. The paper reports about a study case with a factory model of complete steel production empowered by converters with a model power of 65 kW and 2 CHPs are operated. From the results of this study, authors conclude that it is possible to gather a provision from industry customers, but especially in case inductive power grid losses will be increased.

To increase the hosting capacity for decentralized generation by voltage drop due to reactive power consumption has been upcoming within last ten years. A contribution from China (paper 1395) presents the CAO (Cluster Autonomous Optimization) to reduce losses caused by reactive power flow and demonstrates a compensation of voltage rise in the range of 1%. Another important advantage of this method is that no inter-cluster-communication is required.

STATCOMS are not only a solution for dynamic reactive power compensation and voltage stabilisation. Paper 0703 from Argentina presents STATCOMS also as an appropriate solution to improve the response on transient events. This paper explains relevant details of STATCOMS and its modelling as well as the results.

Table 1: Papers of Block "Operation"

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
Maintenance and Condition Assessment				
0136: Phase Detection in PLC-based Advanced Metering Infrastructures				X
0220: Augmented Reality in Grid Operation - A New Approach to Increase Occupational Safety	X			
0488: Real-time Image Transmission and Operation Control for Power Transmission Line Patrol using Unmanned Aerial Vehicle				X
0547: Driving Reliability with Machine Learning and Improving Operation by Digitalization of Medium Power Transformers	X			
0775: Measurement, Modelling and Real-time Calculation of Medium Voltage Cable Temperatures				X
1076: Comparative Study of Partial Discharge Localization based on UHF Detection Methods				X
1080: Defining a Digitalization Concept for Electricity Distribution Network Maintenance				X
1207: Augmented Reality Opportunities in EDP Distribuição	X			
1452: Best Practices for Reliability Improvement of LT network in Tata Power, Mumbai				X
1640: Design and Implementation of an Optimal Algorithm for Urban Medium Voltage Overhead Lines Preventive Maintenance Using Neural Network and AHP Model				X
1657: Partial Discharge Assessment with Ultrasound and TEV (Transient Earth Voltage) in Medium Voltage Substation for Power Distribution Systems Reliability of 18th Asian Games 2018	X			
1790: Improving Distribution Network Maintenance Process with Self-Driven Maintenance Actions by Contractor Partners				X
1894: Relevant Experiences of Online PD Monitoring of MV and HV Cable Systems				X
2070: A Camera-based Tracking System for Distribution Network Inspection Based on Unmanned Aerial Vehicles				X
Distribution Management				
0215: Grid Operation 2025 - Digitalisation for Distribution System Operators	X			
0236: Study of Calculation of Current Induced by Closing-loop Operation in Medium-Voltage Distribution Grids				X
0460: Automation of DSO Processes Combining Grid Planning and Operation: An Efficient Way to Handle Large Numbers of Connection Requests				X
0584: Implementation of 3D Modelling for Simulation Laboratory Based on Unity and 3DMAX				X
0590: LV Grid Data Analysis Demonstrated at DSO Arbon Energie	X			
0764: Levers Optimization in Short-Term Operational Planning for Real Distribution Systems				X
0806: Forecasting Method of LV Distribution's Load Curve By Means of Machine Learning Utilizing Smart Meter Data				X
0823: Optimization of Photovoltaics Active Power Curtailment in Low Voltage Networks by Using Artificial Bee Colony Method				X
0894: Research on the Optimization of the District Energy Mix for Smart City Operation				X
1038: Reliability Analysis of Interconnected Electrical Power and ICT Systems using Hybrid Object-oriented Modelling Approach				X
1086: Over-Specification due to Lack of Knowledge	X			

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
1214: Forecasted Chronological Power Flow for Enabling Timely Dynamic Tariff Activation				X
1567: Demonstration Results of Energy Storage System for Multi-Purpose Utilization in Distribution Network				X
1773: Multi-Energy Microgrid Scheduling: A Multi-Vector Demonstrator Case Study				X
1789: Analysis of Voltage Patterns for Topology Identification and GIS Correction	X			
1906: Approach for Multi Criteria Optimization and Performance Monitoring of a Virtual Power Plant with Urban Structures				X
1919: Experience of SmartGrid Implementation in Ufa City Power Grid for Optimization of the Distributive Electric System Operation Expenses				X
1957: Dynamic Line Rating Operational Planning: Issues and Challenges				X
1962: Method to Characterize Variability of Photovoltaics Power Output				X
1998: Fault Zone Performance Improvement of PMU-Enabled Distribution Systems though Feature Engineering				X
2022: Managing Local Flexible Generation and Consumption Units Using a Quota-based Grid Traffic Light Approach				X
2068: Phase Identification in Smart Metering Pilot Project Komorany				X
2313: Designing Laboratory Setup to Experiment with Smart Metering for Smart Low Voltage Grid Applications			X	
Crisis- & Workforce Management				
0537: Impact of Renewable and Distributed Generation on Grid Restoration Strategies				X
0750: Mobile-GIS Evolving as a Key Tool for Field Workforce Management				X
0751: Distribution Network Maintenance Work Enhancement with Drones During Limited Mobile Network Access				X
0896: Research on Power Equipment Rainstorm Warning Combined with Weather Forecast Data Interpolation and Regional Assessment	X			
0925: Predicting the Impacts of the Major Disturbances for Better Resource Management and Situational Awareness				X
0935: Coordination of the Transmission Control Center Management and Distribution Control Center Management for Disturbances in the Regional Parts of Power System				X
1209: "Outage Forecast" – A Real Application of Machine Learning on Grid Operation Management Strategies	X			
1602: Storm-Proof Automatic Fault Isolation and Restoration System for Medium Voltage Networks				X
2061: Evaluate and Analysis the Reason of Distribution Transformers Burn Near the Compressed Natural Gas Station in Tabriz City				X
2085: Improving Crisis Management in the Case of Blackout by Ensuring Operational Capability of the Authorities				X
2114: Use Cases Applying Machine-learning Techniques for Improving Operation of the Distribution Network				X
2165: Investigation on Operating Behavior of Selected DC-provided Components of a Substation at Depth Discharge				X

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
Ancillary Services in Distribution Level				
0872: TDX-Assist: Beyond State of Art in TSO-DSO Interoperability – The Portuguese Demonstrator	X			
1918: The Development of DNO Flexibility Services to Fit within the Existing UK Market for Ancillary Services	X			
2036: Analysis of the Potential Uncertainty in Accommodation of TSO Dispatched Services in DSO Controlled Networks				X
2060: Architectures for Optimised Interaction Between TSOs and DSOs: Compliance with the Present Practice, Regulation and Roadmaps				X
Reactive Power Provision				
0049: Reactive Power Provision by Means of Flexible Industry Consumers				X
0343: Cost Benefit Analysis (CBA) approach of Non-Conventional STATCOM Applications				X
0703: Operation of Distribution Power Systems with Dynamic Compensators to Integrate Intermittent Energy Sources				X
1395: Cluster Autonomous Optimization of Distribution Networks with High Penetration of Distributed PV Units				X
1871: Reactive Power Flow over System Boundaries in the Distribution Grid				X

Block 2: Control

58 papers have been accepted for the block “Control”. This block has five sub blocks:

- Low Voltage Automation
- Medium Voltage Automation
- Islanding
- SCADA & Distribution Management Systems
- Communication

Most of the papers are dealing with automation of medium and low voltage networks (16 papers of each) followed by communication and islanding discussion (10 papers of each). The number of papers on SCADA and distribution automation topics (6 papers) has decreased since the last CIRED conference in Glasgow.

Sub block 1: Low Voltage Automation

Since a decade, intelligent electronic devices (IED) have been installed in LV grids and the discussion of using these devices to establish new future oriented control functions is still ongoing. In the past, the observability of LV networks was not possible due to missing equipment in LV grids. LV networks are still a black box in the control centres of many distribution system operators. *What kind of control functionality can be established using the available information?* In particular, the integration of distributed energy resources is the main driver for new control system applications and investigations.

Field tests are showing the benefits of integration of IEDs into network control systems. The papers of sub block LV automation are showing an overview about IEDs, their functions and implementation.

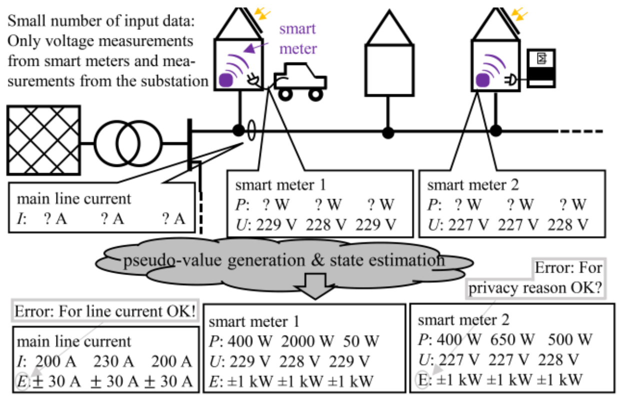

Fig. 14: Example for LV grid state estimation considering privacy issues (paper 176)

The papers 176 and 223 are dealing with state estimation functionalities. State estimations is well-known from HV grid control based on measured values coming from devices of the TSO. The use of smart meter information is one possibility way to calculate the utilisation of LV networks. The German authors of paper 176 discuss state estimation with a focus on guaranteeing the privacy of used information from smart meters. This method does not use the real power of household and is based on voltages and additional currents of main lines. The performance test has been done in a real network of the German DSO Amprion.

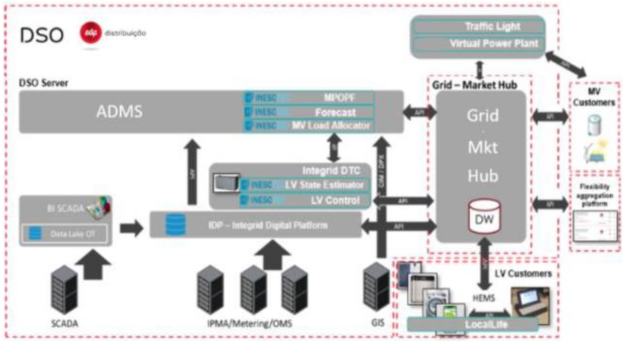

Fig. 15: InteGrid solution architecture (paper 1586)

A state estimation method for PV installations is discussed in paper 223 from Japan. In the paper, a novel voltage estimation method is proposed for the distribution system with large scale PV installations. The state estimator is used to optimize the operation of step-voltage regulators to guarantee the operation within the voltage band of ± 10%.

Results from the research project “Verteilnetz 2020” are presented in paper 831. A proof-of-concept of the superordinate voltage controller is realized in the grid integration laboratory at Technical University of Munich and implemented in a real low-voltage grid with about 400 consumers and 50 PV plants. The advantages of centralized superordinate voltage controller as compared to Volt-VAR control are presented.

Control of LV grids to avoid voltage problems is also part of paper 1586 from Portugal. The paper describes the approach taken in the InteGrid project to perform the active management of low voltage grids with low levels of observability, exploiting the flexibility provided by the distribution system operator’s resources and private consumers. Presently the control is tested in INESC TEC laboratory and will be deployed in a live test environment by EDP Distribuição.

Micro grid and islanding are topics of paper 1603. The authors are presenting the application of a previously developed model predictive control (MPC) based energy management system (EMS) to a demonstration network under construction.

With the increasing number of DC loads and the installation of DC generation like PV and batteries, establishing DC grids is discussed by many scientists. Paper 867 from Korea and Finland focuses the behaviour of the distribution grid of a large-scale residential building during grid-connected as well as during islanded mode. A simulation model of a DC micro grid is shown to demonstrate control and management strategies.

Also, paper 1800 from Korea is dealing with DC distribution systems. The paper presents the implementation of a hierarchical control algorithm to

coordinate multiple AC/DC converters and multiple distributed energy resources for LVDC systems. The concept considers a multi-agent system and the performance of the system is demonstrated by practical cases.
The paper 1520 of three German universities presents the field test experiences and results from a multi-agent based grid state control in a real low voltage distribution grid. Specific scenarios of grid state violations (capacity overload and lower voltage violation) are generated to show how decentralized agents collectively find a control decision using an agent-based negotiation protocol.
What happens to the prosumers after voltage dips when short-circuits occurs? The Technical University of Vienna analysed this behaviour in paper 408. The paper studies the reactive power response of low voltage grids with connected prosumers to a voltage dip provoked by a three-phase fault in the superordinate grid.
Within the project DeCAS, the Austrian authors of paper 1238 analysed a concept for monitoring LV grids. Due to the increasing amounts of data as well as the complex LV systems, operators need intelligent control functionalities to monitor and control LV grid in order to maintain the stability of distribution systems to identify and mitigate faults. The paper presents a prototypical realisation.
Paper 2255 from Canada investigates the voltage and phase dynamics of a low inertia inverter based microgrid in islanded operation. The strong coupling impedance of the primary distribution transmission lines and the implementation of robust droop control provides an appropriate means for rural and suburban neighbourhoods to operate independently.

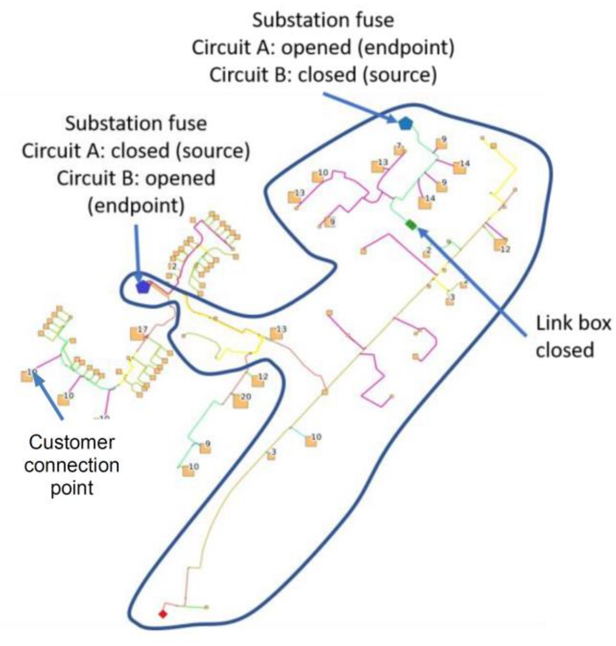

Fig. 16: Example of network configuration for autonomous reconfiguration (paper 1510)

Due to changing conditions between high load and high infeed, the optimal configuration might be different for different conditions. Paper 1510 of the Scottish authors shows the benefits of autonomous reconfigurations of LV networks. The reconfiguration between LV networks is done via a link box as shown in Fig. 16. It will be interesting if these devices will lead to reduced installations of new cables in the future.
Technologies, applications and deployment are necessary to establish new control and supervision. This is the content of the Spanish paper 396. It gives an overview about the devices in secondary substations and an advanced distribution management system. Also, the implication during the planning phase is highlighted in paper 396.

Fig. 17: Test bed of the software-defined networking controller (paper 741)

Authors from the Islamic Republic of Iran show the design and implementation of a data centre for smart grids. The main objective of this paper is to implement a software-centric data centre (SDN) for the smart grid. Paper 741 shows the design and implementation of a test bed for a software-centric data centre into an Iranian smart distribution grid based on four different architectures.
Paper 730 describes the specification and implementation of a low voltage network management system as part of a large-scale trial covering a large metropolitan area with close to 400,000 customers. The LV management system as well as the project trial is shown.
Another demonstrator is discussed by the authors of paper 1928. The paper does not only focus on the operation in dispatch centres but also the need for mobile applications which can be used by field teams. The demonstration has been done in a real case of a Portuguese DSO.
The authors of LV automation sub block focus on the needs for new functionalities due to the increasing number of distributed generation as well as new possibilities for grid automation based on the growing amounts of smart meter information. Finally, the question of cost-efficient solutions for DSO as well as sustainable use-cases is an open point which has to be solved before widespread implementations will be started.

Sub block 2: Medium Voltage Automation

The integration of intelligent electrical devices leads to new functions in MV network control. The sub block medium voltage automations shows diverse contents starting with the equipment needed to establish higher degrees of automation to use-cases and control centre applications.

Paper 1195 discusses the evolution of HV/MV substations from today's standards of a Portuguese DSO to future structures and gives outlook of a cloud-based communication structure. According to the authors, modern technologies will allow a more simple and flexible structure for substation automation systems.

Testing of new automation systems is essential as the behaviour of most use-cases are not yet known. The authors from France and USA of paper 138 show the results of an acceptance test of a distribution automation project. The paper discusses the overall requirements and design of the protection system and its related hardware, the concepts, development, and layout of the system-wide acceptance testing, the execution and results from the site acceptance testing, and lessons learned in the process.

Paper 1850 presents a semi-autonomous power system control suite. By implementing the control suite, manual data management for operation is minimized. The semi-autonomous control is seen as a key concept towards fully automated LV and MV networks.

Paper 1097 proposes a fully autonomous controlled distribution network compared to the semi-autonomous control of Paper 1850. The requirements and benefits of implementing an autonomous network control system on an existing distribution network is discussed in paper 1097.

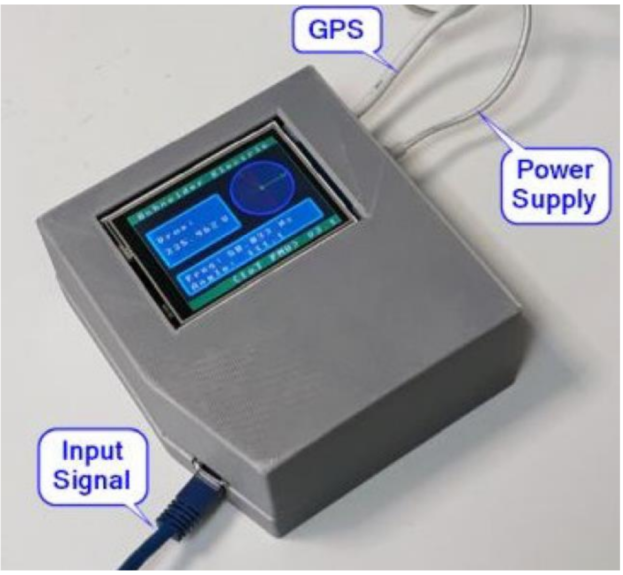

Fig. 18: PMU prototype (paper 998)

One challenge in distribution networks is voltage control due to increasing amounts of distributed generation. Paper 869 presents the trial results of a real-time, centralized control system. The proposal uses the on-load tap changer of the infeeding HV/MV transformers to reduce the incoming voltage in case of DER infeed.

On the example of wide area voltage control, paper 47 presents the operation of extensive grid automation. The paper focuses on reviewing description options for automation solutions and evaluating their applicability.

The next two papers are dealing with the use of phasor measurement units. Paper 998 from Spain addresses the introduction of Internet of Things-PMU device in the distribution networks as an extra source of information and shows the performance of the concept with reference to phasor, magnitude, angle and frequency measurements accuracy. The test of a prototype (Fig. 18) is presented.

The second paper from Belgium (paper 232) presents applications of phasor measurement units in distribution networks.

The paper addresses the challenge of observing the phase angle in case of coupling medium voltage network.

Paper 232 shows the PMU architectures with PMUs in LV and MV networks. Based on the phase angles the exchange currents between the networks can be calculated.

Six papers present strategies to improve the quality of supply using self-healing strategies after failures in MV networks. Paper 552 deals with implementation techniques of multi-station line transfer functions. The author from Thailand demonstrates the behaviour of this function in an 115kV network. Failures in the radial operated network will be detected, separated and finally resupply will be done by closing the normal open point.

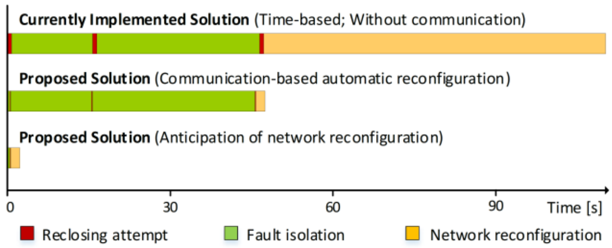

Fig. 19: Reduction of FDIR duration for three reconfiguration solutions (paper 1138)

The Portuguese paper 1138 shows decentralized protection, control and monitoring strategies. Three different distribution automation applications (power system protection coordination, automatic network reconfiguration and anticipation of network reconfiguration) have been compared using reclosers in MV networks. The target of the reconfiguration strategies is to reduce the duration for fault detection, isolation and service restoration (FDIR).

A real case of a centralized self-healing architecture is the focus of paper 2162. The self-healing module is integrated into the SCADA system of the Brazilian DSO Energisa S.A. Nearly one year ago, the self-healing module had its first operation and after 40 seconds, 316 of 594 customers had been resupplied. The paper describes the integration as well as field tests of the

module.
Paper 1083 shows new protection and control concepts implemented in a pilot project in the network of the Croatian DSO HEP. The system is based on IEC 61850 and uses wireless communication within the field of energy and communication technologies. The paper presents the technology as well as the results of the implementation of this new concept. For the self-healing approach a new hybrid protection method called jump differential protection has been developed by a relay manufacturer.
The Egyptian authors of paper 46 use a backtracking search technique for feeder reconfiguration. The target of this feeder reconfiguration is minimizing power losses of the network. This topic has not been addressed by any paper since years within CIRED, but it is still a major topic in developing countries. The technique has been analysed with a digital model of a real network and leads to a reduction of power losses of 20%.

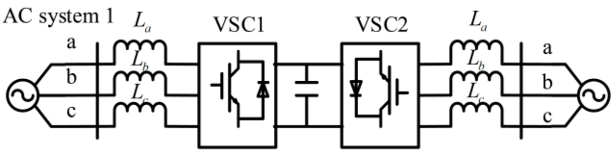

Fig. 20: Back-to-Back VSC-based SOP (paper 395)

The next three papers are showing the use of soft open points (SOP). Soft open points are power electronic devices (e.g. based on voltage source converters (VSC) as shown in Fig. 20) that replace traditional switches. The main target of using SOPs is power flow control in distribution networks.
A network restoration strategy with distributed energy resources and soft open points is presented in paper 395. Under normal conditions, the SOPs can be used for power flow control and under fault conditions, SOP can isolate the fault locations. The paper shows the model of SOP, the service restoration, the optimization algorithm as well as the results of a case study in detail.
Another case-study of SOP is presented in paper 1222 from Switzerland. Two control modes for the SOP have been investigated: power quality mode and switch mode. The effects of voltage and line loading as well as the fault behaviour have been analysed and demonstrated.
Paper 1362 shows the use of a multi-terminal SOP. In this paper, the potential benefits of using multi-terminal SOPs are investigated to improve the performance of pilot distribution networks constructed in Tianjin, China. The optimization strategy includes the optimization of power loss reduction, feeder load balance, voltage violation and the improvement of power system reliability.

Sub block 3: Islanding
Since several years, islanding has been one of the topics in the field of distribution network control. Due to the increasing amount of distributed generation, the possibility to operate planed and un-planed islanding increases. 10 papers of this sub block address this islanding of distribution networks.
In the previous CIRED conference in Glasgow, a round table of session 3 discussed the use of ROCOF protection (rate of change of frequency) to detect islanded networks. This protection function is also addressed by paper 1730 from Croatia to guarantee anti-islanding. The target is the tripping of generator protection in case of an islanding situation in the distribution network. The paper shows different ROCOF methods and settings, and operational results of small hydro and thermal power plants.
Evaluation of islanding detection methods is also the content of paper 241. In this paper, undetected unintentional electrical islands as well as the speed of successful islanding detections are analysed by dynamic simulations and the individual Non Detection Zones. It is shown that additional islanding detection modes lead to significant improvements in the behavior. At the same time, however, it could be shown that there are certain combinations of electrical loads and distributed generation for all island detection methods, which lead to a detection being impossible.
Protection of networks against islanding is also the content of paper 1109. Possible solutions utilizing communication aided automation in the IEC 61850 standard are presented. The paper presents a hybrid adaptive islanding detection method and advanced network automation features by adaptive protection and distribution management system.

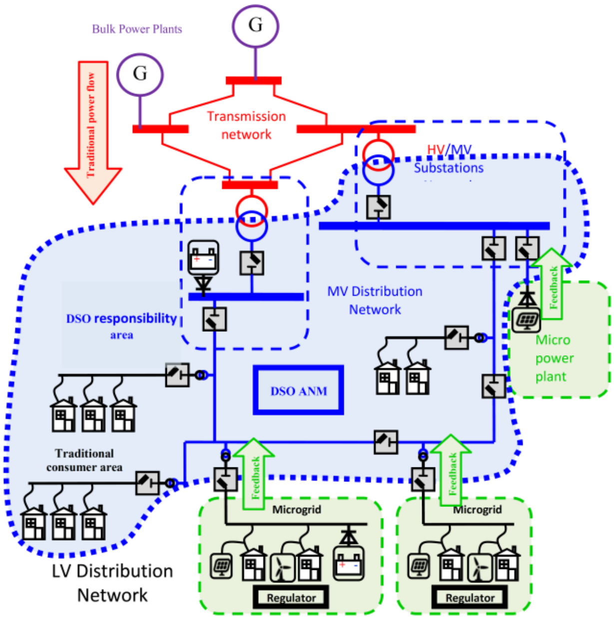

Fig. 21: Power system to simulate islanding in distribution networks (paper 1903)

In comparison to avoiding islanding of power systems, the question of operating stable islanded microgrids is addressed by paper 586. In this paper, the impact of synchronous and distributed generation unit characteristics in low voltage islanded microgrids is evaluated focussing on the influence of the frequency dependent active power reduction of photovoltaic converters.

Most of the papers address simulations of islanded networks to demonstrate the effects of a stable operation of islanded networks. Paper 1903 uses an existing network training simulator to model islanded networks. It describes simulation studies investigating different operational modes, including islanding. The main objective of the simulation is to define the technical requirements of islanding, the necessary coordination between MV restoration and distributed generation, the required control system actions and microgrid regulations.

Paper 2293 from USA and a French DSO describes and analyses the performance of a microgrid controller for different use-cases. The performance verification using a hardware-in-the-loop controller considers the specific requirements of the DSO. The tests presented in paper 2293 shows that the performance of the microgrid controller does not fulfil all requirements of the DSO and only adjustments of the controller settings lead to better results.

Effective synchronization of microgrids with the public distribution network is the content of paper 1912. The Portuguese DSO installed energy storage systems in distribution networks and studied the operation of the storage systems in islanded and grid connected modes. This paper focuses on the synchronization check functionality and shows the performance by optimizing setpoints of the storage system to facilitate synchronism conditions.

Paper 1908 presents a case study of two approaches for optimal microgrid control based on a real test site located in Sweden. One of the two presented models replicates the actual implemented rule based control that is currently realized on the test site. The second model applies a model predictive control scheme assuming the same system and boundary conditions. The performance is assessed in terms of maximizing the islanding time, signifying the time the microgrid (MG) can disconnect from the remaining distribution grid.

Paper 558 discuss the experimental investigation of distribution grid restoration concepts using neighbouring islanded low voltage microgrids. In paper 558, a restoration concept is experimentally investigated with special focus in the start-up process of a microgrid until the successful synchronization of a neighbouring microgrid. A special focus is on the in-rush phenomena of distribution transformer which has been solved by using a soft-start function.

Experience from a real island is presented in paper 1355. On most islands, electrical energy was produced by diesel generators in the past. Nowadays renewable sources are getting more popular to supply small areas with low population. Replacement of diesel generation led to decreasing inertia and reduced stability of the systems. The paper presents the necessary function and strategies for construction and operation of an off-grid microgrid for Gapa Island.

In the past the focus of the papers about islanding was very often on the detection of islanded grid. Presently more papers are dealing with stable operation in islanded and not-islanded modes. The ten papers in this sub block give a broad overview about the needs to establish islanding in existing networks.

Sub block 4: SCADA & Distribution Management

In many papers of the previous described blocks, distribution management systems (DMS) and SCADA systems are used to establish LV and MV automation as well as to operate islanded networks. The six papers of this sub block address these two topics.

A digital twin is a detailed digital copy of the reality outside to analyse the electrical behaviour of power systems. All electrical data, load profile and sensor information have to be converted to be used in a detailed simulation model. Paper 1396 describes the state of development to apply the concept of digital twin proposed with IoT (internet of things) technologies for operation and control in distribution systems, and future development.

IoT offers the possibility to improve the reliability of power systems. This impact is presented in paper 1427 from India. Tata Power, the DSO of Mumbai, equipped 38% of all customer substations with automation technology and can identify defects as well as to restore power supply remotely. The paper shows how the power system control centre monitors and operates automated substations.

Paper 79 from Iran addresses the enhancement of distribution system resilience. Resilience means to withstand extreme events and to guarantee resupply especially of critical loads. In paper 79, a systematic approach for restoration of a distribution grid with integrated distributed generation (renewable and non-renewable) after a severe disaster is proposed. The proposed method attempts to restore the critical loads first by using the available tie-switches.

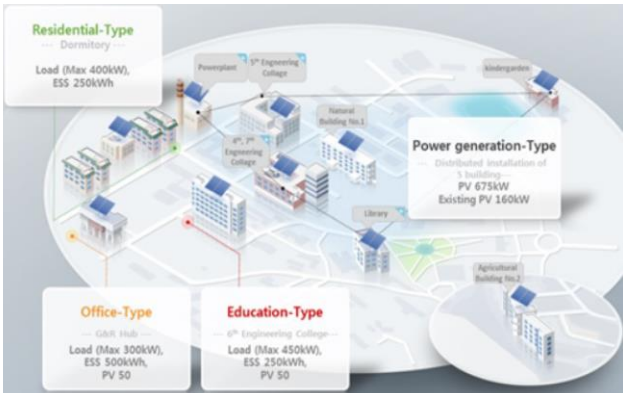

Fig. 22: Structure of microgrid cell (paper 663)

Most of the microgrid projects are focusing on stable supply. Paper 663 describes the implementation and operation of a campus microgrid energy management system considering multi-microgrid power trading. In the whole campus four different micrograds (office, education, residential and generation) are operated in parallel. The key components in the microgrids are energy storage systems. The management system optimizes the scheduling of the energy storage systems based on PV and load forecast.
A real-time information system that uses a supervised machine learning algorithms is the content of paper 68 from Brazil. This information system is used to decide whether a problem in the power system has to be solved by the maintenance teams or if it is out of the company's scope. This decision support leads to reduction in costs.
One future-oriented approach which has already been heavily discussed within previous CIRED conferences are multi-agent systems. Paper 669 gives a broad overview about multi-agent systems starting with the description of agents and then progressing with the approach to build this system. It presents different examples of multi-agent systems and discusses their implementation.

Internet of things (IoT) is a technology which is getting more relevance in distribution network control functions. The second main topic in the field of SCADA functions and distribution management systems is the control of microgrids. A promising control strategy seems to be that of multi-agent control systems.

Sub block 5: Communication
The sub block "communication" covered a wide range of communication technologies including case studies, gateway functions, smart meter readings and standards as well as wireless communication via the new 5G communication standard. Ten papers are addressed in this sub block.

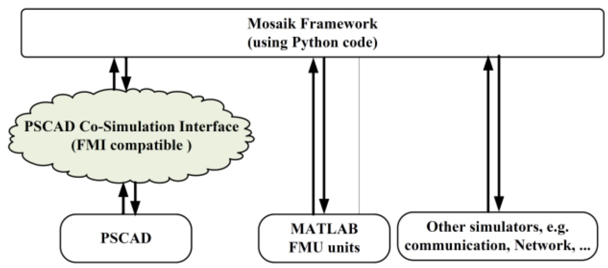

Fig. 23: Co-simulation structure (paper 849)

Paper 1335 from Senegal presents a case study of the transition to smart grids in developing countries. The paper demonstrates how important it is to use modern mobile communication for reliable power system operation. The Senegal DSO implemented distribution automation based on a 3G mobile communication infrastructure in a pilot project. With this new observability, the system average interruption duration indices SAIDI could be reduced by more than 80%.
To analyse the behaviour of a smart grid, it is necessary to simulate its functions. Paper 849 presents a part of the development of a smart grid simulation environment by implementing a co-simulation interface. As smart grid simulations include different domains, a co-simulation interface couples power system to other domains, such as ICT and control.
IEC 61850-9-2 Sampled Values (SV) communication can be used within a substation such as for protection schemes, but also from several substations to a centre which performs SV evaluation for real-time state estimation in the network. The aim of paper 1067 is to compare different communication technologies for the long distance transfer of IEC 61850-9-2 SV, which were evaluated during an experiment in a real substation. The measurements have shown that wireless communication technologies are also able to transfer SV over a long distance.

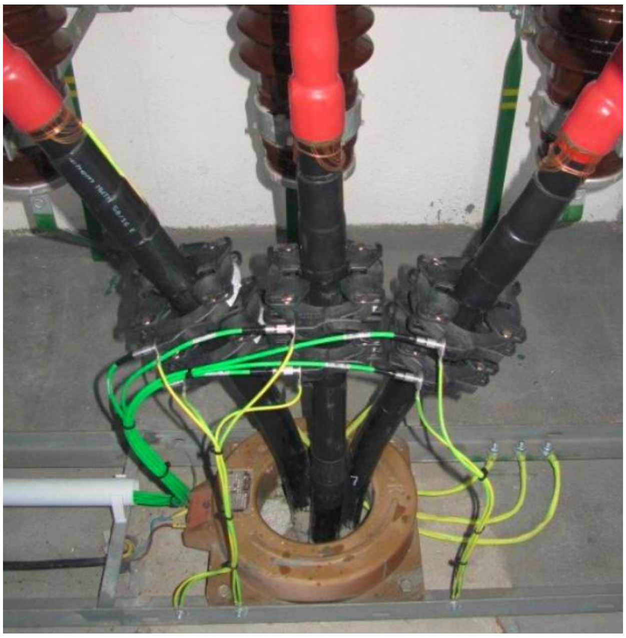
Fig. 24: Current sensors installed on power cables (paper 1067)

Network SCADA centres associated with DMS often use remote terminal units (RTU) as protocol gateways deployed in substations to send and receive data for operation-related applications. The heterogeneous requirements from power system operation-related applications together with less critical enterprise DMS services, impose different functionalities on the substation data gateways. Paper 968 presents an investigation about the imposed duties associated with these services, revealing the necessary data gateway functionalities for a Nordic Distribution System Operator. The paper addresses several requirements including a detailed identification and classification of data flows.
Utilities operating in weak networks can benefit from

Wide Area Monitoring Systems (WAMS) installations to improve grid voltage reliability through increased network observability. Paper 2122 focus on the cost-effectiveness of using WAMS in developing countries, especially in terms of fiscal capability. Limited-budget, limited-channel WAMS placement problems are introduced, and factors affecting continued installations are discussed.
The focus of paper 1368 is on IEC 62361, a technical standard that describes mapping for information exchange between power system installations based on IEC 61850 and business systems based on IEC CIM. The French author explains the key mapping principles and recommendations for future editions of the standards.
Cyber security is a very important topic when operating critical infrastructures like distribution networks. Unfortunately, cyber security counter measurements also impact the system performance. Paper 1917 describes a platform developed to measure the impact of cyber security measures indicated by the transport layer security profiles specified by the IEC 62351 standard series. The experimental platform is described and the performances of different cypher suites supported by the standard are reported for communications using an IEC 61850 protocol stack.

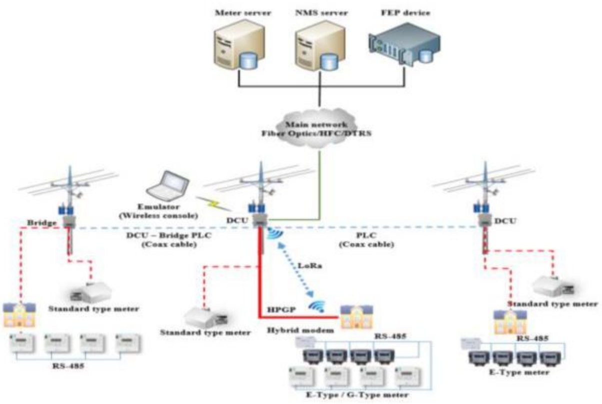

Fig. 25: Low pressure remote meter reading system configuration (paper 740)

Paper 740 addresses the challenges of remote meter reading. Power line communication has the great advantage that each DSO can use this technology without any additional communication network but in case of large power line noise or where costumers are scattered this method is difficult to service. The paper shows a method to distribute data by using wired and wireless communication in order to maximize the performance of the convergence system. The approach avoids the needs to use two separate data communication units for wired and non-wired communication. The Korean authors developed a data communication unit which allows both communication channels within one unit only and present the experimental results.
Private field area network for next generation smart grids is the topic of paper 1551 from Slovenia. The authors describe the results from a pilot project of 4G LTE private field area network. The pilot project covers different aspects including technology, cost and benefits. Another important aspect is reliability and coherence of wireless technologies to the main distribution grid control and acquisition technologies. Regulatory issues are also covered in the pilot project.
The step from 4G to 5G is covered by paper 1952. The paper proposes a scalable communication architecture which can provide customized communication services according to the diverse performance requirements demanded by future smart distribution grid. It recommends the use of 5G network slicing to provide for the necessary communication services, proposing a network slice template to comprehend with respective requirements.

Table 2: Papers of Block "Control"

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
Low Voltage Automation				
0176: Investigation and Comparison of Different Methods for LV Grid State Estimation considering Privacy Issues				X
0223: Development of a Novel Voltage-Estimation Method Corresponding to the Large-Amount PVs Installation Condition				X
0396: Low Voltage Supervision Systems: Technology, Applications, Use Cases and Deployment				X
0408: Response of Low Voltage Grids with connected Prosumers to a Voltage Dip				X
0730: Real Smart Grid: Advanced Operation and Exploitation of LV Networks				X
0741: Design and Implementation of a Data Centre for Smart Grids based on Software Defined Network Technology (SDN)				X
0831: Superordinate Voltage Control in Smart Low-Voltage Grids – Laboratory and Field Test Results				X
0867: Modelling and Control of DC Microgrids in Residential Buildings			X	
1238: Reactive operation for Smart LV Grids		X		
1510: Enabling Autonomous Reconfiguration of LV Networks				X
1520: Multi-Agent-Based Grid Automation: Field Test Experiences of the Distributed Grid State Control				X
1586: Avoid Technical Problems in LV Networks: From Data-Driven Monitoring to Predictive Control			X	
1603: A study of Model Predictive Control applied to the French Demo of InterFlex				X
1800: Analysis of Practical Issues in the Development of Voltage Control System for Low Voltage DC Distribution System			X	
1928: Improved Supervision and Control of the LV Portuguese Network		X		
2255: Voltage-Frequency Stability Analysis of a Low Inertia Electrical Grid using a Kuramoto-Like Model				X
Medium Voltage Automation				
0046: Enhanced Feeder Reconfiguration in Primary Distribution Networks using Backtracking Search Technique				X
0047: Operation of Extensive Grid Automation: Challenges on the Example of Voltage Control				X
0138: Site Acceptance Testing of a Duke Energy Automation Project Utilizing a Simulation Based Test Approach				X
0232: Applications of Phasor Measurement Units in Distribution Grids - Practical Return of Experience		X		
0395: Adaptive Service Restoration of Distribution Networks with Distributed Energy Resources and Soft Open Points				X
0552: Implementation Techniques of Multistation Line Transfer Function with Fault Tolerance in MEA's Distribution System				X
0869: Implementation and Trial of Centralised Voltage Control in 33kV and 11kV Electricity Distribution Networks				X
0998 IoT-PMU. How to Improve the Observability on the Distribution Networks				X
1083: Self-Healing Distribution Grid Based on Adaptive Protection and IEC61850 Decentralized Architecture		X		
1097: The Need Case and Benefits of an Autonomously Controlled Active Distribution Network				X

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
1138: Advanced Decentralized Protection, Control and Monitoring Strategies for Distribution Automation				X
1195: EDGE Digital Substation – A Disruptive Automation Field Project				X
1222: Soft-Open Points for Medium Voltage Networks – A Case Study			X	
1362: Operation and Optimization of Active Distribution Network with Multi-Terminal Soft Open Points				X
1850: Enhancing Operational Awareness of Distribution System Operators with a Semi-Autonomous Intelligent Grid Operation Suite				X
2162: Applying a Centralized Self-Healing Architecture to a Distribution Network – A Real Case				X
Islanding				
0241: Evaluation and Comparison of Islanding Detection Methods by extended Analysis of the Non Detection Zone			X	
0558: Experimental Investigation of Distribution Grid Restoration Concepts using Neighbouring Islanded LV-Microgrids			X	
0586: Impact of Synchronous and Distributed Generation Unit Characteristics onto the Stable Operation of Low Voltage Islanded Microgrids				X
1109: IEC 61850 GOOSE Messaging Applications in Distribution Network Protection				X
1355: Function and Operation Plan for Stable Off-Grid Microgrid				X
1730: Anti-Islanding Protection in Distributed Generation with Synchronous Generators				X
1903: Simulation of Islanding in Distribution Networks				X
1908: MPC Based Energy Management Optimization for a European Microgrid Implementation				X
1912: Analysis and Test of Effective Synchronization of Microgrid with the Upstream Network Enabled by a Recloser				X
2293: Microgrid Controller and Distributed Energy Resource Functionality Verification via Laboratory and Field Verification		X		
SCADA & Distribution Management Systems				
0068: Real-time Decision Support System Applied to Distribution Utility Dispatches				X
0079: Enhancement of Distribution System Resiliency by Forming Networked Self-Adequate Microgrids to Restore Critical Loads				X
0663: Implementation and Optimal Operation of Campus MicroGrid-EMS System Considering Multi-MG Power Trading		X		
0669: Application of Multi-Agent System to Aid the Transition to a Distribution System Operator				X
1396: Development of Digital Twin Technology for Operation and Control in Distribution System				X
1427: IOT Enabled Monitoring System for Non-Automated Unmanned Substations for Reliability Improvement				X

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
Communication				
0740: A Study on Wired and Wireless Automatic Meter Reading System Applying Data Distribution Technique				X
0849: Smart Grid Co-Simulation by Developing an FMI-Compliant Interface for PSCAD				X
0968: An Investigation on Functionalities on Data Gateway for Enterprise Ancillary System Services in Digital Substation				X
1067: Sampled Measured Values Long Distance Transfer Experiment				X
1335: Transition to Smartgrids in Developing Countries, Contributions from Telco Operator in Telecontrol of Electricity Distribution Networks: Senegal Case Study				X
1368: Introduction to IEC 62361-102 CIM - 61850 Harmonization				X
1551: Private FAN (Field Area Network) for Next Generation Smart Grids				
1917: Impact Evaluation of IEC 62351 Cybersecurity on IEC 61850 Communications Performance				X
1952: 5G Network Slicing for Smart Distribution Grid Operations				X
2122: On the Cost-Effectiveness of Multistage Deployment of Wide Area Monitoring Systems in Weak Networks under Limited Channel Availability				X

Block 3: "Protection"

In the block "Protection" we received 49 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 results of practical field-tests and investigations in the MV and LV network.

Sub block "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. 16 papers are selected in this sub-block, 7 of them are focused on the topic of earth fault.
Beginning with paper 0019 from Slovakia, the location of earth faults in compensated MV networks using hand-held measuring devices is shown. Experimental measuring tests in a real MV-grid shows the function of the hand-held device. The earth fault was created by connecting a water resistor to the MV-grid. The earth fault is detected with the measuring devise as shown in (Fig. 26). The fault record can be stored and may be analyzed later.

Fig. 26: Measurement with device (paper 19)

Paper 0065 and paper 0066, both are coming from Germany and describes the localization of earth faults in two different ways. The first paper shows the method on injection of a zero-sequence current during an earth fault by tuning the Petersen-Coil. Using this method, an identification of the faulty feeder as well as a distance estimation up to the earth fault location is possible. The second paper deals with another method of earth fault localization. Measuring the travelling waves with single-ended or double-ended measurement is shown in this paper. A practical field test in the 20 kV-network showed that this method is basically possible.
Paper 0094 from the Czech Republic presents results from the first application of the new method "Vdip" for an earth fault location. The "Vdip" method is based on evaluation of the change of negative sequence voltage recorded on LV side of distribution transformers (Fig. 27).

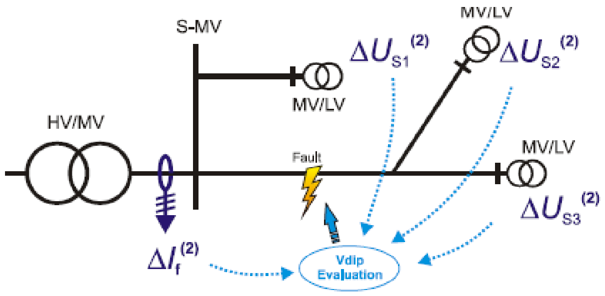

Fig. 27: Schematic principle of the Vdip method (paper 94)

Different types of earth faults are tested in field tests (Fig. 28).

Fig. 28: Preparation of an earth fault ignition (paper 94)

Paper 0402 from the Czech Republic presents a new method of Arc Suppression Coil (ASC) tuning, based on the injection of the multifrequency current signal into zero sequence system through network's neutral point. Measuring of voltage response in zero sequence system (Neutral Voltage Displacement) enables then to evaluate the tuning status of the ASC very precisely. The introduced innovative tuning method has been tested in real distribution networks. A new device is being developed using this new method in cooperation with the leading manufacturer of ASC controllers.
High Impedance Fault (HIF) detection is the topic of

paper 0490 coming from China. This paper introduces the research and demonstration in three cities of Fujian province, including the ungrounded system in Quanzhou, the arc-suppression coil grounding system in Longyan, and the low-resistance grounding system in Xiamen. The paper also introduces the advanced technology in this field in China. The detection principle is based on a transient current algorithm. Fault passage indicators as shown in (Fig. 29) were installed in feeder lines.

Fig. 29: Site installation (paper 490)

An analytical calculation of the neutral point displacement voltage in a resonant earthed neutral system in case of a single-phase earth fault is discussed in paper 0531 from Germany. The results of the parameter analysis and implications for the operation of distribution systems are discussed. Furthermore, a new quantity for the evaluation of a single-phase earth fault in resonant earthed neutral systems is introduced.
In paper 0695 from Finland, a novel method for earth-fault (EF) protection applicable in high-impedance earthed networks, especially in resonant earthed networks, is described. The innovative method is not based on traditional zero-sequence quantities (U_o, I_o), but on accurate estimation of EF-current (IF) flowing at the fault location. The results of field tests show that the novel algorithm estimates the earth-fault current very accurately regardless of fault type or network parameters.
The topic of paper 0833 from Greece is very different to the papers before. This paper examines the repercussions of an interruption of the neutral conductor on the upstream network of the electric meter on a TN network, considering that a DG unit is connected to the electrical installation. The developed potential on the protective conductor is computed, examining the impact of the injected current by the DG unit, the load power and the grounding resistance. In addition, a methodology for the detection of neutral conductor loss in TN systems is proposed and simulation results are presented.
In paper 0917 from Japan a study on accuracy of distribution fault point localization by resonance frequency analyses is discussed. The purpose of this study is to examining the characteristic of the method to estimate the accident point applying resonance frequency analysis using current waveform in the accident and to verify the accuracy of the fault point localization and the effectiveness of the method through fault tests in the simulated distribution line.
Paper 0945 from Sweden describes how Exeri AB has applied the classic OODA (Observe-Orient-Decide-Act) loop to Smart Grids, making it possible to not only know the status of the grid at all times but also to get decision support in when, where and how to respond to problems. The product Smart Grids SurveillanceTM has been deployed by Skellefteå Kraft AB, where it is currently monitoring a grid that has earlier been prone to problems. The results of this project and future developments are also discussed in this paper.
The paper 1049 from Germany presents the experiences with travelling wave technology for fault location in compensated and isolated power grids. Moreover, the installed pilot monitoring system as well as the background of the fault location with travelling waves is presented in detail. Some typical cases of successful fault locating and the potential of collecting additional information from the captured records are discussed. This is the first time the travelling wave technology is applied successfully for the localization of short-term single phase-to-earth faults in a compensated network.

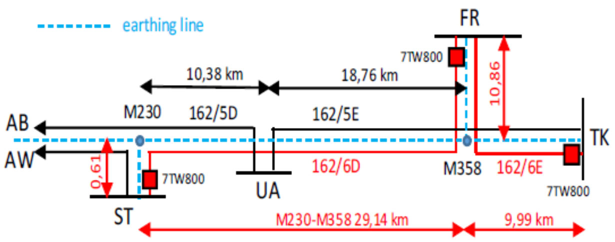

Fig. 30: Field installation in a compensated network for the testing of the reliability of the travelling wave technology (paper 1049)

For data acquisition three travelling wave pilot prototype devices, GNSS-synchronized with sampling rate of 10MHz were installed at the ends of two 110-kVoverhead lines with a total length exceeding 60km. The installation was made in stations ST, FR and TK (see Fig. 30).

Paper 1055 from Japan shows a new method for locating fault points by injecting high-frequency short pulse into overhead distribution lines. This TDR (Time Domain Reflectometry) measurement method, enables to detect the fault point easily by measuring propagation time of the pulse reflected due to impedance change at the fault point.
Paper 1973 from France has demonstrated the capacity of an on-the-shelf portable system to make an on-line detection of transient faults in a complex network. First, a test was performed on a 2.5 km MV network in Switzerland by short-circuiting to the ground a phase of a power supply system. The proposed monitoring system

successfully detected the transient fault through its distributed sensors, and, thanks to a high-quality time synchronization combined with the FasTR method developed by Nexans and CEATech, it was able to locate the source location with good reliability. Then a campaign of online measurement was realized for a duration of 3 months. Exploitation events were recorded along the campaign. The monitoring system was able to sort them in three categories based on the shape of their signals and FasTR localization showed a consistency for each type of event, thus proving its capability to detect small transient perturbations.
In paper 2110 from Lithuania the first Lithuanian open energy sandbox, called LE Sandbox, which provides the innovative technology developers an easy and open access to the gas and electricity production, distribution and supply infrastructure and data, is presented. In addition, the paper includes the results of the first proof-of-concept "SIEMENS" SICAM Fault Collector Getaway pilot project developed under the LE Sandbox framework. The paper presents the benefits and findings of real environment testing as well as the growing market need for the open access to the energy infrastructure and data.
How to improve your SAIDI with "Advanced Fault Passage Indication" is discussed in paper 2323, coming from France. This paper describes an innovative solution how to detect earth-faults on compensated networks and highly resistive faults due to broken conductor (BC) occurrence.

Sub block "Applications"

In the sub block "Applications" we received 15 papers with very different topics. The common topics of this papers the practical tests or the implementation of functions in real systems.

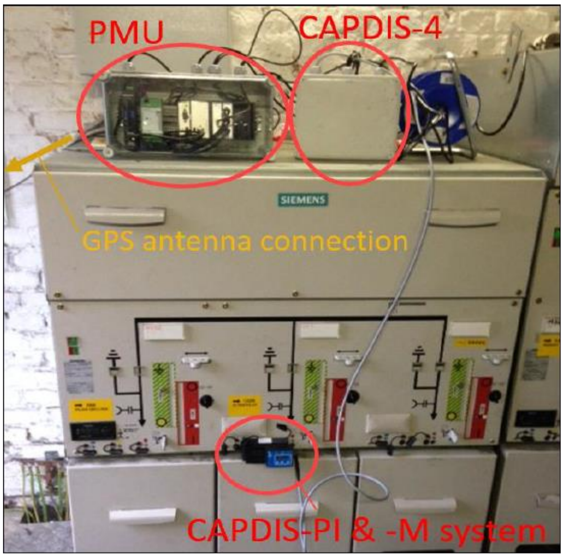

Fig. 31: Example of PMU installation in a MV cabinet (paper 114)

Paper 0114 from Belgium describes the use of Voltage Detection Systems (VDS). Two concrete applications have been tested at length and yielded mixed results. The use of VDS as a transducer for PMU measurements in MV cabinets (Fig. 31) is unfortunately not a valid use case due to the accuracy limit of the phase angle measurements, which is an order of magnitude higher than the observed magnitudes. Their use for directional relays phase angle measurements proved however successful and was validated in various test set-ups. This is due to much larger phase angle shifts expected in case of a fault, the limited accuracy of the phase angle measurements thus being high enough in this case.
Paper 0250 from the UK presents a "Real Time Fault Level Monitoring (RTFLM)". The development of Real Time Fault Level Monitoring equipment is seen as one way to free up capacity on networks constrained by fault level. Through the development and deployment of this innovative technology it is expected that DNOs will be able to actively manage the network fault level and the contribution from customers. SP Energy Networks in collaboration with Outram Research Ltd are leading the way with the development and trialling of this technology with initial results obtained from real world 11kV trials indicating that the technology is capable of generating accurate and reliable results (Fig. 32).

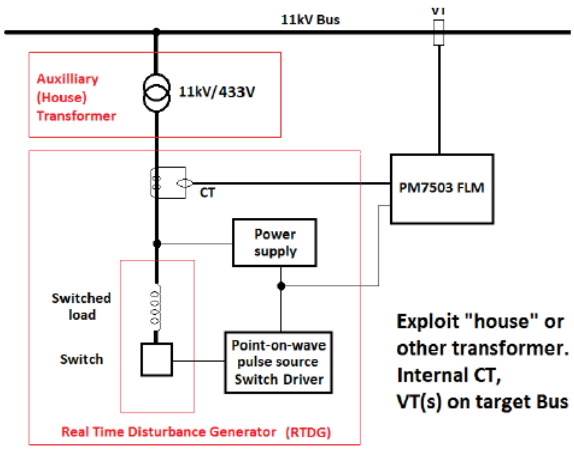

Fig. 32: RTFLM Installation Single Line Diagram (paper 250)

In paper 0292 from Finland the "Utilization of a Mixture of CTS and Current Sensors in Line Differential Protection Applications" is presented. The studies were based on tests conducted in a laboratory test setup consisting of a real-time simulator, commercial Rogowski current sensors and line differential protection IEDs. With the help of this unique test setup, it was possible to study the functioning of line differential protection realistically in cases where the measurements are based on a mixture of CTs and current sensors. Based on the conducted experimental studies, it appears that the use of a mixture of CTs and current sensors could be a feasible option in line differential protection applications

without endangering protection dependability or security. However, it is crucial to ensure that the CTs are correctly dimensioned and protection settings are chosen carefully.
Paper 0661from Hungary gives a brief overview of the different earth fault protection methods used on resonant-grounded systems all over the world and introduces a new method for earth fault detection. It also demonstrates the results of its successful real-life application. The new earth fault protection function can be implemented in a feeder protection or in a transformer protection relay as well, which measures the zero-sequence voltage and the current of the Petersen coil.
In paper 0837 from Spain the question "IEC 61850: Believe or don't Believe in Testing" is discussed. The paper describes how the testing process was done in past, how it has evolved, how it is done today and how we forecast that it will be done in future, analysing the impact in our minds and believes. As IEC 61850 is being implemented in areas before dominated exclusively by electricity, the need of signals, now optical and digital to do testing has been increased exponentially and the process on how the testing must be done. With new devices, where the communication aspects become crucial, testing procedure approaches more and more with the one used to test software than hardware and now electrical engineers faced a dilemma: How confident we feel in the fact that new process is giving us the expected results? Answer to these questions you can find in the paper.
Paper 0863 from China introduces the operational status and problems with residual current protection in LV distribution network, provides successful case studies in the reform process, and proposes measures for further improvement. In conclusion, among the existing three levels of protection, only the last level of the household protection can guarantee personal safety.
Paper 1079 from Argentina shows an application of fuse autopsy methodology to estimate protected element type of failure. The study is divided in two parts, the analysis of fuses of high and of low breaking capacity, since their constructive characteristics differ significantly.

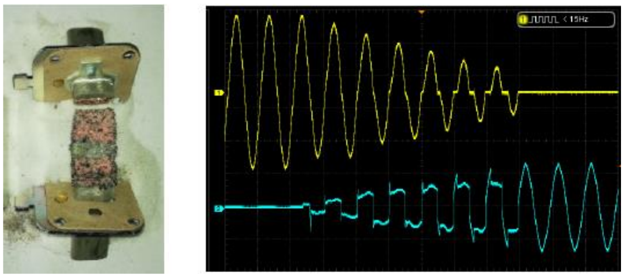

Fig. 33: Fulgurite and timeline of an overload operation (upper line: current, lower line: voltage) (paper 1079)

The fulgurite formation phenomena, has been investigated by several researchers, being determined the relationship between the fulgurite weight and the absorbed energy.

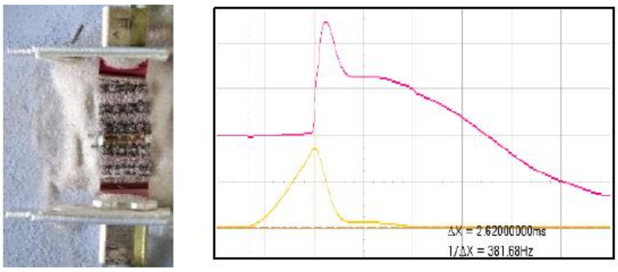

Fig. 34: Fulgurite and timeline of a high current interruption (upper line: voltage, lower line: current) (paper 1079)

In order to confirm the estimations made based on the operation of fuses in the field, a series of tests under controlled conditions, were carried out in the power laboratory of the Rio Cuarto National University, where the involved parameters were adjusted and measured as needed (Fig. 33 and Fig. 34). Knowing the state of the operated fuse can reduce the costs of damage and delay in the supply restoration and therefore the costs of the disturbance.
In order to ensure long-term protection against electric shock, a periodic verification of the protective measures for safety for DC charging stations for electric vehicles is essential. Paper 1307 from Austria provides a contribution to possible fault scenarios and related test routines as well as a concept of a testing device for DC charging stations. The goal of the presented project is to design and construct such a testing device to ensure the operator protection as well as installation safety and availability.

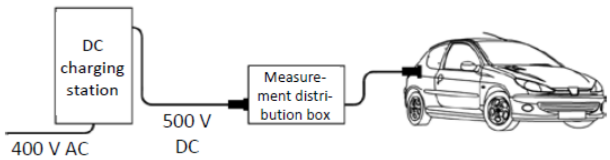

Fig. 35: Principle measurement arrangement (paper 1307)

With the distribution box measurements (Fig. 35) and analyses faultless and faulty charging processes can be carried out at charging stations of different manufacturers. A selected normal operation as well as a selected fault situation and the corresponding analysis are presented in the paper.
Paper 1341 from Portugal aims to present the Portuguese DSO (Distribution System Operator) EDP Distribuição (EDPD) reality and experience in maintaining in-service Protection System units, on the one hand, focusing on the actual maintenance strategy approach and possible future changes, in order to provide highest levels of service and security within the electrical system, and, on the other hand, considering a strict alignment with operational and economic efficiency as these are an ever-increasing concern for every utility company.

In paper 1570 from Switzerland a very different topic is presented. The title is "Protection Coordination in DC Shipboard Power Systems". This paper presents benefits and protection difficulties of DC shipboard power systems (Fig. 36), and current protection schemes, commercially available, with three different classification: bus protection with solid-state bus-tie breakers, feeder protection with high-speed fuses and generator-rectifier fault blocking functions. In addition, two new protection methods recently proposed are introduced: additional bus capacitance for the bus protection and artificial short-circuit for the generator-rectifier protection. Lastly, possibility of a modular multi-level converter for the DC shipboard power systems is discussed with its pros and cons.

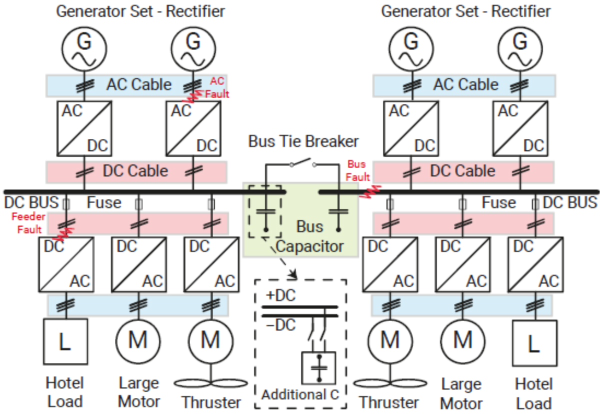

Fig. 36: Simplified schematic of DC SPS. Additional bus capacitor introduced in the paper is also illustrated (paper 1570)

Paper 1583 from Italy addresses the challenge of distribution grid digitalization starting from the HV/MV substation, by presenting the Enel Global Infrastructure and Networks strategy. This strategy is based on the introduction of multifunctional control and protection devices, extended interoperability along the distribution grid (by using IEC 61850) and high-speed communication (by including the LTE). This approach was tested in the Enel smart grid laboratories and it was validated in large scale implementations.
Paper 1620 from the UK proposes the design and architecture for a Dynamic Protection System (DPS). DPS is an adaptive protection system that autonomously calculates the optimum protection functions and settings in real-time as the distribution network changes configuration. DPS has the capability to bring increased protection system sensitivity and selectivity over traditional protection schemes, facilitate increased DG connections to the network and automate aspects of the protection system design process. The key design requirements for the proposed DPS are discussed and the detailed benefits of the system are described.
The title of paper 1761 from Italy is "Smart Fault Selection through Smart Protection Devices using IEC 61850" and describes how the first pilot project in the medium voltage network of e-distribuzione started on 2010, testing the fast fault selection logic and it shows the results of a large-scale deployment in Apulia.

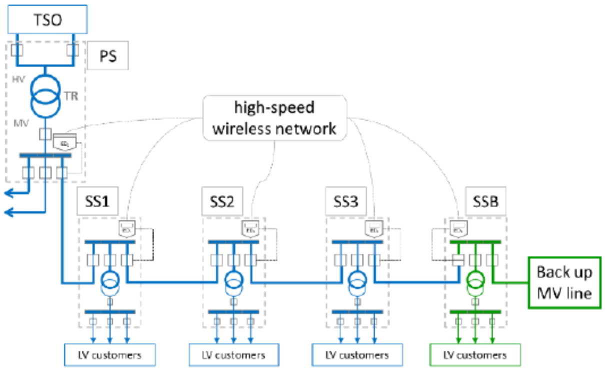

Fig. 37: e-distributione network (paper 1761)

The aim to select, insulate and restore energy in less than 1 second is demonstrated by the field experience (Fig. 37). This new technology is a step forward on the long automation experience of e-distribuzione. The classic automation system is not discarded but continues to operate in back up mode.
Paper 2004, coming from Germany, is proposing an integrated digital toolchain for the design and parametrization of protection relays. The process flow is fully digitized and automated. It considers the grid and the protection behaviour as a whole with the use of integrated grid and protection models. Thus, it can be adapted highly flexible to frequent changing grid conditions. Moreover, an optimization tool finds the best feasible solution of the protection system concerning the supply reliability under diverse grid conditions. A case study illustrates the functioning of that process and the results to be achieved.
Based on user expectations and requirements, paper 2217 from the Netherlands proposes use-cases for measurements of power system frequency and rate-of-change-of-frequency (ROCOF) measurements, specifying accuracy and latency requirement for each use case. A proposed set of realistic test conditions is given, extending those of the present IEEE C37.118.1 standard, to ensure ROCOF measuring instruments are adequately tested. The paper effectively sets a challenge to instrument designers to optimise the filters for PMU/ROCOF instruments for each of the various use cases and achieve the desired accuracies (better than 0.05 Hz/s) and latencies. The tests presented in the paper can be used to verify whether the proposed solution meets the performance requirements under various realistic power system conditions. It is realised that it may not be possible to achieve the desired accuracy for tests involving phase steps; low-latency PMUs may in addition fail tests with noise and interharmonics. Further discussion is needed on what the exact test limits for these particular cases should become.

Sub block "Algorithms and Simulations"

New developed algorithms or protection functions to solve challenges are presented in 18 papers of this sub block. Simulations are confirming the stability and functionality as a prerequisite for practical use. The fifth generation (5G) wireless communication becomes an option for use cases in electricity distribution. The commonality in this sub block is the development of new ideas and improvements in the field of protection.

In paper 0341 from Finland describes how 5G networks enables new smart grid protection solutions. This paper introduces one of the most demanding communication-based protection principles – line differential protection including intertrip between circuit breakers (Fig. 38), as a benchmark application for the evolved fifth generation (5G) wireless communication and an extensive test environment to validate its system and communication performance.

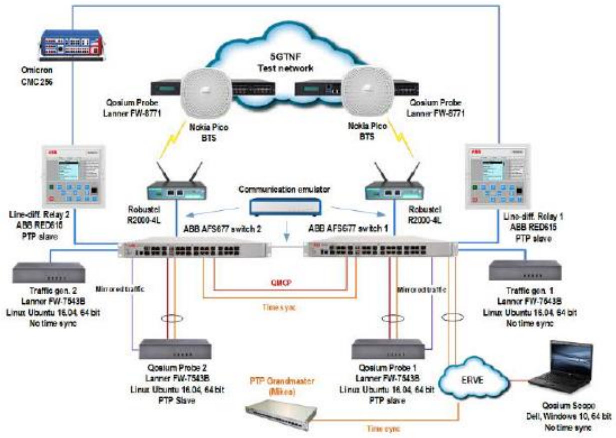

Fig. 38: The measurement setup for the line differential protection scenario (paper 341)

The use of 5G technologies will drive the implementation of advanced distributed solutions reliant on the high-speed transmission of power system quantities, such as line current and voltage values, which are currently dependent on the existence of a physical communication infrastructure. The work being carried out by Efacec and Altice Labs in the scope of the SliceNet project will study the viability of using 5G networks for demanding communication-based Distribution Automation (DA) algorithms that include Phasor Measuring Unit (PMU) based differential protection and high-speed protection coordination. Paper 1537 from Portugal is focused on presenting the ongoing work, on describing the smart grid self-healing use case and lab-based testbed in which these DA solutions are being simulated and validated, and on exposing the outcome expected from the upcoming project phases.

Paper 0403 from Greece demonstrates the problem of improper (early) fuse operation, with regard to the low-voltage-ride-through requirements, through simulations in a test distribution feeder with photovoltaic generators. A preliminary solution to this problem is examined, based on proper short-circuit current limitation. Two different approaches of this solution are described and compared. Potential techniques for the detailed implementation of the proposed concept are finally discussed. Low-voltage-ride-through (LVRT) can be realized by using a current-limiting-device (CLD) as shown in Fig. 39.

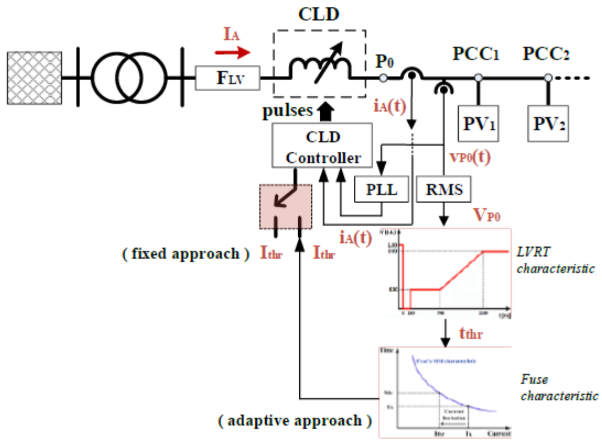

Fig. 39: Generic control scheme of CLD (paper 403)

Paper 0454 from Egypt has the target, minimizing DG impacts on protection systems using fault current limiters (FCL). For this goal, a feeder is modeled while a considerable DG unit is inserted. An experimental work is done to verify the proposed relay setting and to evaluate the FCL performance. Using Digital Signal Processing (DSP) board, overcurrent inverse characteristic is implemented experimentally. A scale down of the distribution network is designed and implemented in the laboratory.

In paper 0801 from France the frequency and ROCOF protection functions is discussed. The new IEC 60255-181 standard defines several tests to evaluate this protection functions but the computational speed of the protection is an important characteristic to be considered. The rapidity of the protection can be decomposed in two types: delays (intentional or not) and computational speed. In the paper, the authors argue in a first section why this computational speed is essential. However, it is not effectively evaluated by any test of the standard as seen in the second section. To evaluate the computation rapidity, the measure of the bandwidth is chosen. Then, a test is proposed to measure it as described in the third section.

Fault detection in low voltage networks with smart meters and machine learning techniques is the topic of paper 0851 from Spain. Based on the analysis of smart meter events, an automatic learning system has been implemented that groups and orders overvoltage and undervoltage events helping the grid distribution operator to drive the network technician to the more urgent place where a grid failure is happening, starts to happen or will happen. The Network Technicians (NT) achieved the right results in 2 out of 3 grid failures forecasting based on smart meter quality service events (overvoltage and undervoltage events). The right results were: high priority intervention (10%), such as network failures (generally neutral losses or lost connections, Fig. 40), medium priority intervention (44%), such as situations in which the transformer tapping at the head-end was high, or low priority (46%) as the need for reinforcement on some lines.

Fig. 40: Neutral loss detected (high priority intervention) (paper 851)

As a result, the new smart grid system has improved the quality of service, in terms of customer satisfaction and in terms of predictive maintenance.

Paper 1075 from Australia shows that DC arc fault protection is becoming increasingly important for delivering electricity in a safe and reliable manner. Unlike AC arc faults, the absence of current zero-crossing makes DC arc fault more sustainable and difficult to be suppressed. DC arc fault can happen in DC systems with different voltage levels, such as 270 V electrical aircraft systems, 380 V DC distribution systems, photovoltaic (PV) systems ranging from tens to hundreds of volts [1-2]. There is an increasing risk of DC arc faults because of the increasing DC operating voltage levels. If an arcing incident remains undetected, it will ignite and burn surrounding materials and finally leading to a fire. Therefore, such a dangerous event is required to be detected and interrupted at its early stage. Arcing is a very complex physical phenomenon. Nowadays, most arc studies are based on observation of experiments and analysis of acquired data, and scholars mainly use the U-I curve to characterize this phenomenon. The arc can be then treated as a non-linear resistance. In this paper, the experimental data is fitted to the Nottingham arc model, which is suitable for gap length from 1mm to 10 mm. One of the results of this studies is that the arc current and its spectrum show dependency on the source voltage, load current and gap length. Very interesting are also the evaluations of the frequency spectrum of the DC arc (Fig. 41).

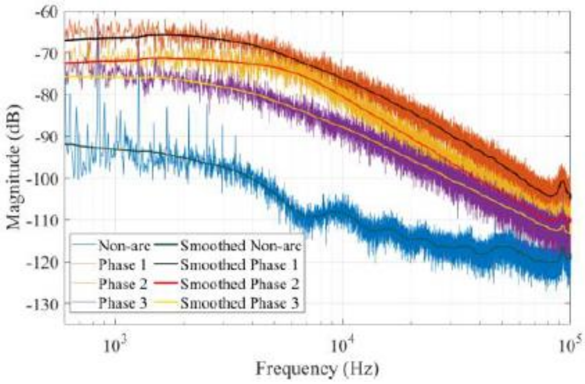

Fig. 41: Average frequency spectrum of different phases (paper 1075)

Another very different but interesting topic ("Return Paths of Earth Faults Current in MV-Grids with Underground Shielded Cables") is discusses in paper 1081 from Belgium. New simulation tools lately have allowed for a more detailed modelling and analysis of the fault current return paths and it appears that the impacts of the conductors' metallic screens have been underestimated. The results of the studies with the simulation tools EMTP-RV and NEPLAN shows that most of the single-pole fault current goes back via the cable shields instead via the earthing connections as it should have been thought before, when only thinking in terms of least-impedance paths.

Under-Frequency Load Shedding (UFLS) is the topic of paper 1093, coming from France. In France, UFLS is implemented by disconnecting pre-selected MV feeders from the distribution system. The feeders taking part in the UFLS scheme are chosen according to a specific objective in terms of total amount of power to be shed. The Network Code on Emergency and Restoration (NC-ER) – which entered into force in December 2017 – redefines the framework of the UFLS schemes across Europe. Especially, the load to shed (i.e. the objective) is now defined as a ratio of the total load at the national level. The purpose of this paper is to quantify this impact by calculating the evolution of the net demand at different levels from two different given points: the feeder and the substation. The considered levels are varying from feeder to a 6-regions aggregation via substation and "department" (French administrative subdivision). This paper is organized in two parts. The first section deals with the principle of the UFLS, the structure of the French Electrical Power System (EPS) and the various notions of consumption which can be considered in the objective of the UFLS. The second part investigates the influence of the point of calculation on the objective. The two objectives are calculated at different levels to confirm the proper functioning of the UFLS in the case of a large insertion of DG.

Paper 1141 from Germany proposes a voltage-less distance protection method which complies with closed loop structures and inter infeeds properly in case of unbalanced faults. The proposed approach is based on current comparison and negative-sequence system quantities. Thus, it remains unaffected from inter infeeds and fault resistances. The approach serves as a supplement to conventional distance protection methods which are applied for symmetrical faults and if the closed-ring structure is dissolved. Finally, the paper presents a protection grading strategy that significantly reduces the average fault clearing time.

A hardware level study, performed at the Power Networks Demonstration Centre (PNDC), testing seven off-the-shelf PV inverters is introduced in paper 1194 from the UK. The objective of this work is to characterise the connection stability limits of the small-scale grid-tied PV inverters under a variety of network disturbances represented by step changes in voltage magnitude and phase angle (referred to as Vector Shift - VS) applied on the LV AC terminals of the inverter. Such conditions, often caused by faults in the transmission network, can compromise the connection stability of the PV inverters and potentially exacerbate the network instability if large loss of PV generation ensues. The results presented in this paper reflect a future grid dominated by inverter connected generation with a wide range of inverters behaviours observed under the imposed testing scenarios. The test setup (Fig. 42) incorporates a Real-Time Digital Simulator (RTDS) for modelling the AC network to which the inverter under test is connected via an amplifier. The amplifier is a Triphase bi-directional AC grid emulator which uses the RTDS simulated voltage as a reference. The RTDS voltage set-point signal is transmitted to the Triphase through an optical fibre using the Aurora protocol. Voltage amplitude, vector shift and selected asymmetrical fault events simulated within the RTDS model are reflected in the Triphase voltage output (i.e. inverter terminal AC voltage).

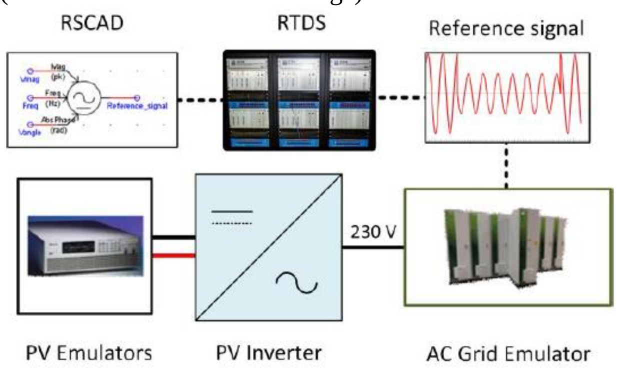

Fig. 42: Test configuration for vector shift and voltage depression and asymmetrical fault conditions tests (paper 1194)

Functional and application testing is the most widely accepted testing practice for protection and control systems and is required to ensure that the Distribution Protection and Automation System (DPAS) and each of its components are going to operate as designed under different system conditions. Paper 1351 from the USA discusses the requirements for functional testing of the protection of distribution systems with high penetration of Distributed Energy Resources. Functional testing methods and how they can be used for the different types of tests are also described.

In paper 1386 from Finland, the findings of Caruna's field tests were presented. Caruna is Finland’s largest electricity distribution company. Based on field test results, touch voltages in Caruna's rural large-scale underground cable networks with connected earthing systems stay in low values. The measured touch voltages during earth faults were extremely low when comparing to the permissible standard values. The increase in reactive and resistive earth fault currents caused by the underground cabling can be kept in control with combined centralized and distributed compensation. The possible growth of resistive earth fault currents can be significant and should be considered in network planning and operation. It was also noticed that the reduction factor in the fault point was not constant and could be affected by the network compensation and switching state.

In paper 1391 from China, the types and causes of DC faults and the characteristics of DC faults and their transformation relationship are analysed and studied. An active protection technology based on power electronics and digital control technology is proposed in this paper. Further the active protection topology structure, function and implementation principle studied and analysed, and the test environment is built to verify the relevant experiments. The active protection proposed has been applied in LVDC system of buildings. After more than one year's operation practice, the theory and technology of Active Comprehensive Protection (ACP) are proved to be feasible. ACP can realize fast protection for distributed DC generation, DC bus and DC load, and the action time of short circuit protection is very short. ACP can effectively isolate faults of DC system, and limit faults within fault branches, synchronously give fault alarm signals, and realize fast line selection of fault branches and optimal configuration of system topology (Fig. 43).

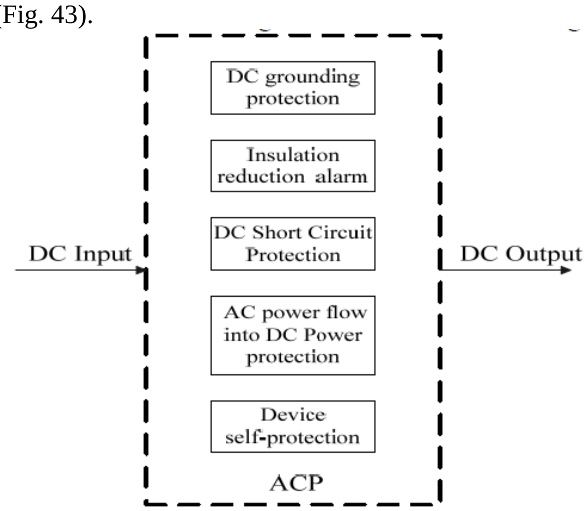

Fig. 43: Function block diagram of ACP (paper 1391)

Paper 1499 from China shows the results obtained in the tests applied to four different vendors, especially for distance protection, which performance was problematic under fault current contribution coming from Type-4 Wind Turbine. To solve these issues found in the tests, a new algorithm has been developed and its results are shown in this paper.
The title of paper 2002 from the UK is "Protection and Earthing Requirements of Low Voltage AC and DC Distribution Networks Interfaced by a Smart Transformer". The paper has investigated through detailed fault and protection simulation studies the impact of deployment of smart transformer at a typical distribution secondary substation on existing conventional overcurrent protection. It has been demonstrated that such deployment can impose a radical change in the nature of faults on the associated LV networks. Typical 1 MVA smart transformer with fault current rating ranges from 1.1 to 2.5 per unit (p.u.) of its full load current will reduce prospective fault levels at the point of common coupling (PCC) 8 to 15 times in comparison to conventional substation. Such a significant change in the fault level has made a significant reduction in the operating time of inverse time-current protection of the main feeders of the LV networks. The paper studies have also proven that overcurrent-based MV CB is unlikely to trip for faults on the LVDC internal links of the smart transformer. More advance protection will be required to detect internal faults within the smart transformer and provide reliable and selective protection operation. In addition to these challenges, there is a need to radically change the earthing arrangement of LV networks on the supply and customer sides for smart transformers with LVDC outputs. The paper has provided a number of different earthing arrangements which can be considered to provide protection for safety, eliminate the risk of corrosion, and minimise the common mode noise.

In paper 2084 from Iran an improved control method for hybrid AC/DC microgrids, focusing on interlinking converter control is proposed. The modification of interlinking converter control is based on considering transient fault situations in both AC and DC sub-grids for grid connected mode. According to the main role of interlinking converter as a gateway to deal with bidirectional power transfer control and both ac and dc side voltage control, the transients of AC or DC side faults can be transferred through the converter and harms the other sub-grid and even worsening the fault situation. Thus, the effect of AC and DC side faults on the performance of interlinking converter and the main parameters of both sub-grids are investigated. Then, a supplementary control is proposed to be capable of distinguishing the fault situations. Finally, in order to prevent transient fault transfer and improve the capability of interlinking converter, a downstream fault limiting function has been added to its operation. A hybrid ac/dc microgrid is simulated and simulation results for ac and dc faults are presented to validate the effectiveness and advantages of the proposed control method using PSCAD/EMTDC software. The simulation results demonstrate appropriate performance of interlinking converter on fault bypass and fault current limitations especially in DC sub-grid faults.

"Comparison of Decentralised and Centralised Under-Frequency-Load-Shedding (UFLS)" is the intensively discussed topic of paper 2142 from the Czech Republic. The paper deals with two concepts of the under-frequency load shedding. The first one is a conventional scheme based on frequency deviation measuring and no intentional delay and the second one is based on the measurement of frequency derivation with variable intentional time delay. The case studies of system wide and local disturbances proved that these concepts can coexist and solve frequency stability issues in transmission and distribution systems.

Table 3: Papers of Block "Protection"

Paper No. Title		MS a.m.	MS p.m.	RIF	PS
Fault Location / Earth Fault					
0019:	Earth fault location in compensated MV network using a hand-held measuring device				X
0065:	New method for identification and localisation of an earthfault in compensated networks				X
0066:	First results concerning localisation of earthfaults in compensated 20-kV-networks based on travelling waves		X		X
0094:	Evaluation of the new method Vdip for an earth fault location		X		X
0402:	New method of arc suppression coil tuning using truly multifrequency current signal				X
0490:	Practical Demonstration of High-impedance Fault Detection Technology in MV Distribution Network				X
0531:	Analytical calculation of the neutral-point displacement voltage for high impedance earth faults in resonant earthed neutral systems				X
0695:	Improving personal safety in MV-networks through novel earth-fault current based feeder protection				X
0833:	Loss of Neutral in Low Voltage Electrical Installation with connected DG units – Consequences and Solutions				X
0917:	Study on Accuracy of Distribution Fault Point Localization by Resonance Frequency Analysis		X		X
0945:	Using Smart Grid SurveillanceTM to detect and localize failures in the overhead medium voltage grid				X
1049:	Locating Single Phase-to-Earth Faults in Compensated and Isolated Distribution Networks Applying Travelling Wave Technology		X		X
1055:	Prognostic failure detection on overhead power distribution grid utilizing TDR measurement method				X
1973:	Real Time detection and localization of self-extinguishing defects on a MV network				X
2110:	SIEMENS Fault Collector Gateway Test On "ESO Sandbox" – The First Open National Distribution Network Sandbox In Europe				X
2323:	Improve your SAIDI with Advanced Fault Passage Indication				X
Applications					
0114:	Use of Voltage Detection Systems as transducer – Practical return of experience				X
0250:	Real Time Fault Level Monitoring				X
0292:	Utilization of a mixture of CTs and current sensors in line differential protection applications				X
0661:	New solution for detecting single phase-to-ground faults in resonant-grounded systems				X
0837:	IEC 61850: Believe or don´t believe in testing. That is the question!				X
0863:	Operation Analysis and Improvement Measures of Residual Current Protection of Low Voltage Distribution Network				X
1079:	Application of fuse autopsy methodology to estimate protected element type of failure				X
1307:	Verification of protective measures for safety of DC charging stations for electric vehicles				X

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
1341: Exploring IED data management and IEC 61850 features to introduce a condition based maintenance approach in the Portuguese DSO				X
1570: Protection Coordination in DC Shipboard Power Systems: Challenges, Current Status and New Technologies				X
1583: Enel grid digitalization through multifunctional control and protection devices				X
1620: The Benefits and Design of a Dynamic Protection System for the Distribution Network				X
1761: Smart fault selection through smart protection devices using IEC61850				X
2004: Digital System Protection Design – A new Toolchain for Protection System Automation				X
2217: Reliable Rate of Change of Frequency (RoCoF) measurements: use cases, operational parameters and test conditions				X
Algorithms and Simulations				
0341: 5G networks enabling new smart grid protection solutions		X		X
0403: Investigating adaptation of line protection means to low-voltage-ride-through requirements in low-voltage distribution feeders with photovoltaic generators				X
0454: Minimizing Distributed Generation Impacts on Protection Systems using Fault Current Limiters Experimentally				X
0801: Frequency & ROCOF protections: toward a better evaluation of their dynamics				X
0851: Fault detection in Low Voltage networks with smart meters and machine learning techniques				X
1075: An Experimental Study of Low-Current DC Series Arc Faults for Condition Monitoring Purpose				X
1081: Return paths of earth faults current in medium voltage grids with underground shielded cables				X
1093: Scales and Objectives for Under-frequency Load Shedding				X
1141: Voltage-Less Distance Protection in Closed-Ring Grids with Distributed Generation			X	X
1194: Characterising Grid Connection Stability of Low Voltage PV Inverters through Real-time Hardware Testing				X
1351: Functional Testing of Distribution Systems with High Penetration of Distributed Energy Resources				X
1386: Touch voltages and earth fault currents in a rural large-scale underground cable network with connected earthing systems				X
1391: Research and application of active protection technology in LVDC system				X
1499: New faulted phase selector solution for dealing with the effects of Type-4 Wind Turbine on present protection relaying algorithms				X
1537: Smart Grid Protection and Automation Enabled by IEC 61850 Communications Over 5G Networks		X		X
2002: Protection and Earthing Requirements of Low Voltage AC and DC Distribution Networks Interfaced by Smart Transformers				X
2084: Improved Control System for Hybrid AC/DC microgrids considering Transient Short Circuit Faults				X
2142: Comparison of decentralised and centralised under-frequency load shedding				X