Special Report - Session 4
PROTECTION, CONTROL & AUTOMATION

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Introduction

With the reshaping of the topics in the sessions of Cired, Session 4 has received new topics resulting from the division of Session 3 into 2 parts.

Thus Session 4 has been repositioned with the themes of PROTECTION, CONTROL and AUTOMATION.

For CIRED 2023 we received about 250 abstracts, which shows the high importance of the topics. The quality of the abstracts was very good throughout, although some good abstracts had to be rejected due to keep a manageable number of papers during the conference. 180 authors were asked to submit a full paper. Finally, 153 full papers have been accepted by National Committees and the Technical Committee (TC) Session 4 Team. **Fig. 1** gives an overview of the review process.

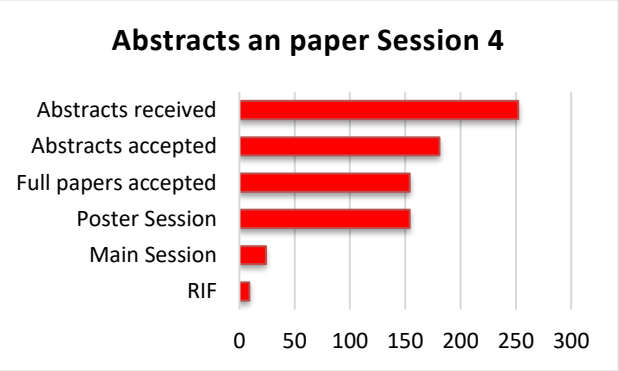

Fig. 1: Review process overview

Session 4 is organized in three thematic blocks, Protection, Control and Automation, the Communication thematic block has been added due to the recent contributions.

From the accepted papers, 24 were selected for a presentation in the main session. 9 young academics have the opportunity for a short presentation in the RIF session. All authors of the accepted papers are asked to present their work as a poster in the poster session. **Fig. 2** gives an overview.

The Session 4 is organized as follows:

Block 1 Protection

- General protection issues
- Virtualization
- Testing
- Algorithms
- Applications
- Earth fault
- Fault location

Block 2 Control

- General
- Artificial Intelligence
- Applications

Block 3 Automation

- General
- Artificial Intelligence
- Smart- and Microgrid
- Optimization

Block 4 Communication

- General
- Cyber Security

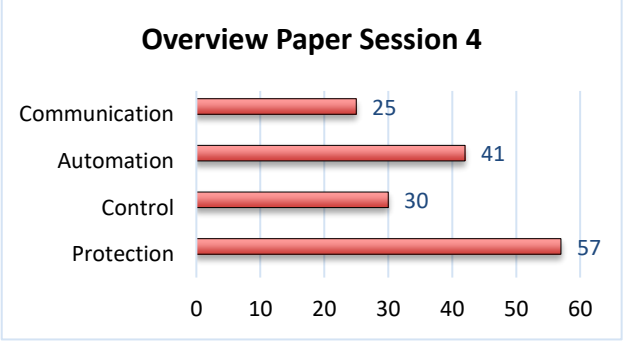

Fig. 2: Paper overview of blocks in Session 4

Block 1: "Protection "

In the block "Protection" we received 57 papers. In addition to general protection topics, we were able to summarize the topics "Virtualisation", "Algorithms", "Applications" and the new topic "Testing". Of course, we also had the never-ending topics of "Earth fault" and "Fault location". Communications technologies have become part of protection technology. The assignment of the received papers to the topics is shown in **Fig. 3**.

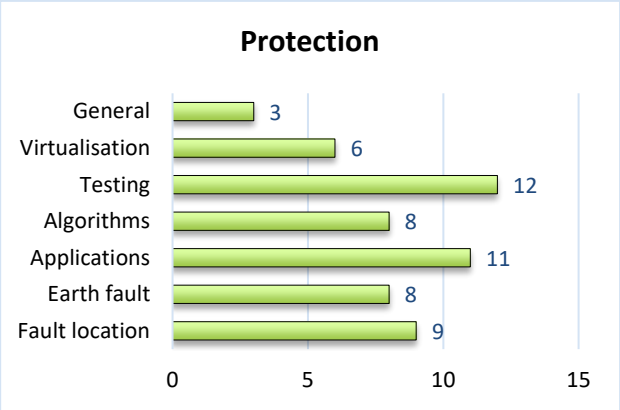

Fig. 3: Overview subtopics of the block "Protection"

Sub block 1: "General protection issues"

Paper 10344 from Italy has the focus on EN50549. CENELEC TC8X is actively cooperating with ENTSO-E and ACER in the Grid Connection European Stakeholder Committee and their Expert Groups. The requirements for generating plants to be connected in parallel with distribution networks and related tests are discussed in this paper.

In **paper 10717** from the Republic of Korea, a device for a "Networked Distribution System (NDS)" with a communication base and a backup protection scheme is described.

Paper 11311 presents the main outcomes of a study related to the analysis of protection system of the microgrids i.e., medium voltage (MV) and low-voltage (LV) networks of limited size that can be operated without a connection to the national grid.

Sub block 2: "Virtualisation"

The virtualization of protection, control and automation systems is highly topical and an emerging discipline with a lot of potential for research and development. 6 papers are summarized in this sub block and 4 papers will be presented in the main session and RIF.

In **paper 10451** from France, research work proposes a novel framework for engineering virtualized intelligent electronic devices (vIEDs) based on the existing IEC 61850 substation configuration language (SCL). SCL is complemented with hardware resources and virtual networking descriptors to represent a vIED image to be deployed. The descriptors are based on common information technology (IT) standards and are formalized in different data (meta) models. Complex configurations of vIEDs are automatically validated using machine-readable semantic constraints. The vIEDs will be integrated in platform-specific deployments for simulation purposes in laboratory or field environments.

Paper 10656 from Finland describes a virtualised centralised protection concept that has been developed as a part of Constellation innovation project. Protection functionalities include bay level protection functions that operate based on site local measurements and wide area protection functionality that utilises 5G communication between the distribution network substations and DER sites and aims to improve the operation of DER loss-of-mains protection and to reduce unnecessary curtailment of DER. A centralised protection concept is shown in **Fig. 4:** Centralized protection concept with redundancy.

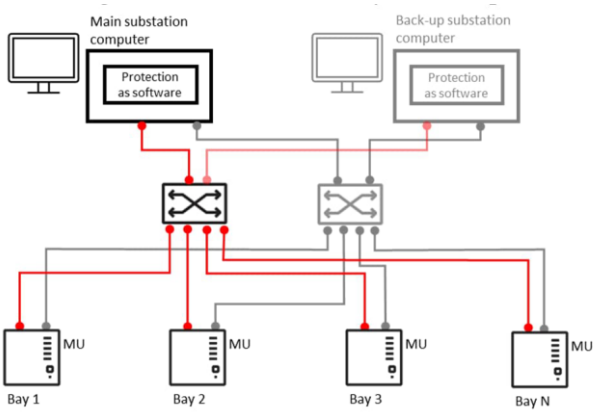

Fig. 4: Centralized protection concept with redundancy.

In **paper 10702** from Switzerland, we present an approach for running substation automation protection and control software in virtual environments. We contrast the real-time performance of different virtualization technologies under different workloads and focus on the performance evaluation of protection and control software in container-based solutions running on Linux with PREEMPT RT.

Paper 10855 from Finland describes the piloted virtualized protection and control (VPC) environment and the results from the piloting period. The results show that virtualization technology is suitable for time critical protection and control applications, with real-time performance comparable to existing nonvirtualized solutions.

Paper 11222, coming from Portugal, presents the implementation of next-generation centralized Protection, Automation, and Control (PAC) solution for Medium Voltage (MV) power grids, developed in the scope of the SCALE project. The main goals of the project are the development, testing, and field pilot deployment of an innovative, fully digital PAC system for Substation Automation (SAS), centralizing in a single device the functionalities of several bay-level Intelligent Electronic Devices (IED).

Paper 11227 from The Netherlands, introduces the Modular Process Interface based on the IoT concept of sensors and actuators combined with Software-Defined functionality, based on IEC 61850. It describes the journey made during various projects focusing on digitizing, centralizing, and virtualizing substation automation since 1998. This paper zooms in on Centralized Protection and Control rollouts and the lessons learned, leading towards a vision for Software-Defined Substation Automation and the Modular Process Interface in particular.

Sub block 3: "Testing"

In this sub block we received 12 papers that deal with the subject of testing. Three papers were selected to have a presentation in the main session and the RIF.
Paper 10187 from India shows the possibilities and challenges of testing self-powered relays. Tests of overcurrent relays, ground fault detection under various conditions are described. A typical test setup is shown in **Fig. 5:** Typical test setup: Self powered relays.

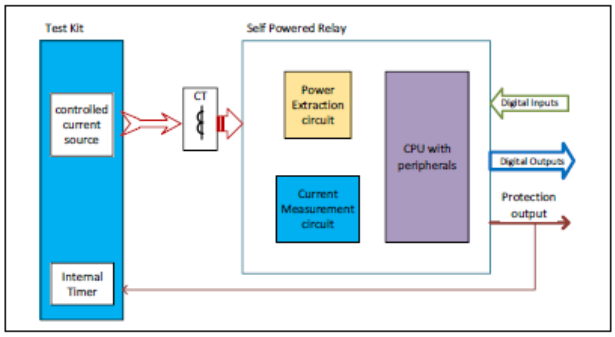

Fig. 5: Typical test setup: Self powered relays

Paper 10435 comes from Slovakia and presents open phase fault (OPF) analysis in MV distribution grids with resonant grounding. An example of a phase interruption you can see in **Fig. 6:** Phase interruption on the vertical sectionalizer The main goal is to summarize impacts of the OPF and to provide recommendations or mitigations that either decrease the chance of abnormal overvoltage or solve it in case of occurrence.

Fig. 6: Phase interruption on the vertical sectionalizer

In **paper 10551** (Republic of Korea) the protection scheme of a commercial building's low-voltage direct current (LVDC) distribution system is studied. The configuration of the LVDC system, fault current limiter (FCL) utilization for mechanical circuit breakers, high-speed fuse, and solid-state circuit breaker (SSCB) application for load-side protection, and the result of the DC protection coordination test were described.
In **paper 10582** from Switzerland, the frequency curve of the Iberian Peninsula grid separation of 2021 has been replicated on a reduced scale physical model with real UFLS (underfrequency load shedding) protection relays (**Fig. 7:** Hardware model for reproducing frequency events with UFLS relays at a reduced voltage/current scale.). Based on the experience of recent events with UFLS tripping, special attention must be paid to the correct setting of the voltage blocking criteria which ensure a correct dis-crimination between frequency and voltage stability effects.

Fig. 7: Hardware model for reproducing frequency events with UFLS relays at a reduced voltage/current scale.

Paper 10646 from Austria describes an efficient testing process with increasing workload or a decreasing number of staff and establish interactions of the domains "OT-Security" and "Protection". To handle the challenges, not only the maintenance phase but the whole life cycle of an IED must be considered - from "production at the manufacturer" over "put into operation" until "operation and maintenance".
In **paper 10877** from Austria, the performance of a digital distance protection relay during a short circuit in presence of a converter connected grid is described.
Different fault impedances of the phase-earth fault were investigated. In this context, the impact of the transformer`s neutral point treatment was studied. For this, the fault impedance based on the converter branch currents based on the phase-earth fault with different T1 neutral point treatment were examined.
Results make clear, that the neutral point treatment of the converter-branch's grid-connecting transformer can have – independent of the converters short circuit behaviour – a significant impact on the reliability of distance protection relays.
Paper 10995, coming from Germany, shows how important the reliability of frequency protection schemes is, due to their impact on emergency and restoration actions in the grid. Tests must be independent from specific manufacturer solutions ("black box" -tests). The aim is to identify settings to ensure an optimal performance, i.e., fast, and reliable functionality.
Some key performance indicators (KPI) for the testing process of an IED are presented in **paper 11037**, from Germany, which can be used to classify the quality of the testing process. Furthermore, with the introduction of standardized testing procedures it is discussed how the quality of testing process can be improved or assured with improvement of the KPIs at the same time. These facts are shown with some examples from life cycle of an asset, e.g. from factory acceptance testing (FAT), side acceptance testing (SAT), commissioning or out of the maintenance process.
Paper 11128 from Germany shows some studies about optimized low voltage power fuses for current requirements in low voltage power grids. With long-term tests, the influence of growing intermetallic compounds, electromigration and oxidation on the electric resistance and the fusing behaviour were analysed. Optimized fuse elements with a good long-term behaviour were determined. A reliable fusing behaviour after aging was confirmed for the optimized fuse geometry even under full switching capacity. **Fig. 8:** Opened pre-aged fuse-links after testing at minimum breaking shows the test result of optimized and not optimized fuse elements.

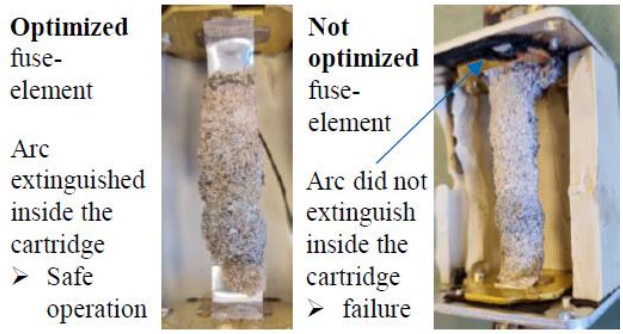

Fig. 8: Opened pre-aged fuse-links after testing at minimum breaking current.

The testing of an adaptive protection scheme is discussed in **paper 11200** from Germany. A reference grid for detailed study of protection behaviour based on real-world challenges encountered by German distribution grid operators is provided. The grid consists of a 110kV high-voltage system and a 20kV medium-voltage system, which both are dominated by DER installations and a divergence between generation and load centres. The grid models were developed in close coordination with DSOs and provide a facility to operate in specific scenarios, that could be utilised in future grid operations.
A completely different type of test, but no less important, is the wiring test of secondary devices, shown in **paper 11274** from Austria. The combination of a sawtooth-based polarity check signal, a voltmeter with a selectable low impedance mode and a current clamp allows to efficiently find the most common wiring errors. It does not need a phase reference for the polarity check, which simplifies the tests significantly. Furthermore, the voltage and current readings, combined with the polarity or direction of the signal provides additional information for the user, decreases the likelihood of wiring errors, identifying open and shorted circuits, saves time and increases circuit safety.
The functional testing of virtualized and centralized protection systems is the topic of **paper 11280** from Finland. This paper discusses the factors related to testing of protection and control systems on a primary distribution substation in case of fully digitalized application with centralized and virtualized protection. With a practical example to the topic, different test phases will be presented and considered.

Sub block 4: "Algorithms"

The algorithms sub-block contains new protection algorithms, automation and control functions, and simulations of these. We received 8 papers in this very interesting sub block, and we have 2 presentations on these topics.
Paper 10284 from India is not typical for network protection but has very interesting approaches for protection functions. This paper covers the experimental

validation of a new stator inter-turn short-circuit (SISC) detection method. The performance of the detection method is tested by simulating different fault scenarios in a 22kW three phase induction motor. The proposed method is also implemented and tested in a prototype protection relay to validate its feasibility for practical deployment.

The work in **paper 10541** from Spain analyses the applicability of three different inertia estimation algorithms in smart grids under the presence of converter-interfaced generators (CIGs).

Firstly, an analysis of a rate-of-change-of-frequency-based inertia estimator is conducted, showing that it is not applicable when fast frequency control of CIGs is activated. Secondly, two iterative system identification estimators are proposed, namely the output error (OE) and the equation error (EE) formulations. A comparison between OE and EE algorithms in terms of estimation accuracy, computational burden, and robustness to noise is conducted.

Paper 10729 from Germany has the topic "implementation and Test of frequency estimation methods for RoCoF-based load switching in islanded grids". This paper focuses on analysing the accuracy and settling time of the used frequency estimation algorithms and to test the implemented algorithms within a laboratory setup (**Fig. 9**). Two frequency estimation methods are analysed which reconstruct the input signal. At every cycle of the µC, a new frequency sample can be calculated and therefore, it is independent of the zero crossing of the input signal. In this section the structure of both methods is described briefly.

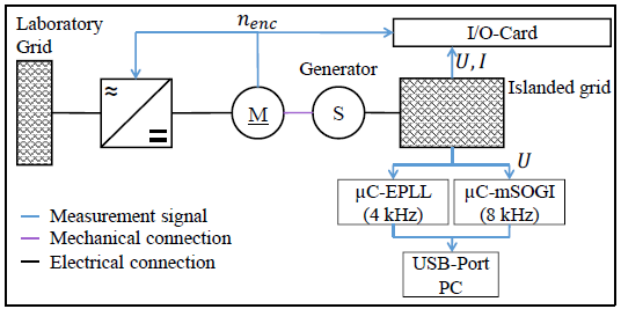

Fig. 9: Laboratory setup

Paper 10856 from Sweden proposes a machine learning based fault prediction method that aims to predict incipient faults, allowing TSO/DSOs to act before the fault occurs and prevent customer outages. The discussed model predict faults, based only on disturbance recordings, up to a week before they happen.

In **paper 10988** from Austria is the effect of a fault current feeding on present distance protection devices illustrated. The investigated grid topology is shown in **Fig. 10**. Two scenarios were considered, one with a fault clearance on both sides and one with a protection failure on one side.

On one hand, the impedance determination was reconstructed to show the effect of waveforms. On the other hand, a real protection device and a real PV converter were used to obtain realistic response characteristics and waveforms.

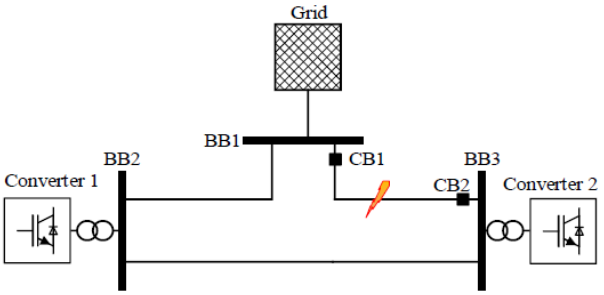

Fig. 10: Investigated grid topology.

Paper 11038 from Germany proposes a new idea of a novel ANSI 79 automatic reclosing function, which dead time is adaptive and dependent on the detection and duration of the secondary arc. In a case that the secondary arc extinguishes before the maximal dead has expired, the dead time will be shortened and the auto reclosure can be proceed earlier. If the secondary arc is still burning, reaching the maximal dead time, a final trip or a three-pole cycle will be proceeded.

Paper 11382 from The USA will discuss the modelling and simulation capabilities of Directional Overcurrent (DOC) protection elements recently developed in the open-source distribution system modelling and simulation software OpenDSS. Application examples are presented to illustrate the parametrization of the different operating modes of the DOC relay model using the IEEE 342 Node Test-Case.

Paper 11383 also coming from The USA presents a framework to automate the process of running studies about checking protection coordination and sensitivity and use the latest experience in human factors analysis and situational awareness to generate reports that are intuitive to follow and quick to understand. The framework also presents opportunities to use oscillographic data from protection devices to evaluate protection performance during system disturbances and using the same data to locate faults to assist in repair and recovery efforts following a disturbance.

Sub block 5: "Applications"

In the sub block "Applications" we received 11 papers with very different topics. The common topics of this papers are the practical tests or the implementation of functions in real systems.

Paper 10326 from Germany presents a conceptual design use case for high weather dependent renewable energy penetration in the transmission system. Communication architecture approaches are presented with fundamental functional and non-functional requirements to ensure reliable performance as well as flexibility and scalability for future integrations.

In **paper 10336** from Italy, a solution to reduce the cross-

country fault current value is presented. Different designs were studied as well as the influence of current limitation on the earthing system.
In **paper 10527** from France, line-side Arc Flash Incident Energy (AFIE) calculations on a main LV switchboard supplied by a dry or oil-type transformer with rated power up to 2 MVA and quantify the AFIE level for transformers. The transformer protection is realized by a fuse-switch with and without relay or a circuit breaker and a relay.
For each case, protection settings are optimized to ensure protection without unwanted tripping, as well as global selectivity (**Fig. 11:**).

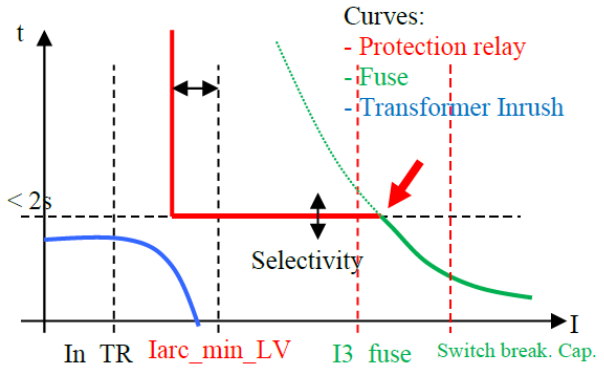

Fig. 11: Setting of a relay with a fuse-switch.

In **paper 10550** from Australia, an islanded microgrid (MG) with an inverter-based source (IBS) is analysed using sequence components for unbalanced fault conditions. The inverter based islanded MG exhibits a low fault current due to the current limitation of power electronic based sources. The design of the protection system for inverter based islanded MG is challenging since a conventional overcurrent protection system is not a viable option for low fault current conditions.
Paper10592 from France shows a methodology to study faulty power systems that can reach up to 100% IBG requiring minimal information on the sources and considering all possible controls and operating points. An application of the methodology is then proposed for two use cases: protection blinding and IBG sizing in a microgrid context.
Paper 10689 from Germany presents an online and adaptive protection system to resolve load blinding protection scheme limits in networks with highly integrated DERs. This paper investigates the challenges that directional overcurrent protection equipped with Load blinding function observes at parallel transformers linking 132kV and 33kV distribution levels in UK Power Networks.
Paper 10793 from Poland shows a Transient Voltage Protection (TVP) solution against switching transient voltages. Laboratory testing was performed focusing on energizing a liquid immersed Distribution transformer under no-load condition and disconnection of inductive load with surge arresters installed in various configurations to analyze benefits of TVP solution in terms of limiting transient over voltages caused by circuit breaker operations.
In **paper 10824** from Germany, short-circuit currents (SCCs) of future power system with generation mix of synchronous generation (SG), grid forming- and grid following generation are presented. At first, the classical definition from SG is used to define the SCC characteristics of converter-interfaced generators (CIGs) as initial, sub-transient, transient, steady-state and breaking current for fault location and for operating points. Then, SCC characteristics are presented for different generation mix, even for 100%CIGs. The significance of the change in SCC characteristics is also explained.
Paper 10953 from Germany provides a method for a complete analysis of the necessity of adaptive protection system. It can be applied for grids with ring structures and the protection design with overcurrent protection devices. Using this method, it is possible to identify grid states that require an adaptive protection parameterization. The application and further examination possibilities offered by this method in exemplary results are shown.
Paper 11326 from the U.K. describes the response based remedial action scheme (RAS) designed for detecting and mitigating the angle instability using synchrophasor measurements at the interconnection points of SP transmission network. In this paper, only generation outage/curtailment and load management actions have been considered however, in future more control actions e.g. generation and load dropping, turbine fast valving and phase shifter controller can also be considered.
Paper 11337 from Brazil presents studies of three-phase two-wire distribution system (TPTW) topologies and demonstrates the influence of fuses on its operation. At least the results of the TPTW protection schemes are demonstrated.

Sub block 6: "Earth fault"

The earth fault in the extinguished or isolated network is still a great challenge. The location of earth faults is a constant motivation for new developments. Practical experience also plays a major role in the development of new functions.
Eight papers deal specifically with this topic.
Paper 10266 from The Czech Republic is focused on the evaluation of the pilot test of the method Vdip, which was designed for localization of unsymmetrical faults, especially an earth fault, in resonant earthed distribution networks. The paper describes the concept of the proposed Vdip system (**Fig. 12**), and the evaluation of fault localization results accomplished with the Vdip system in a resonant earthed MV network.

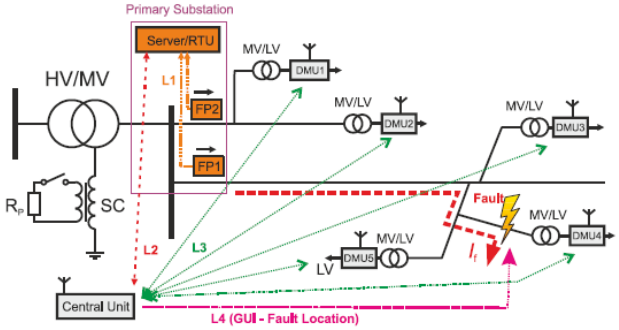

Fig. 12: Schematic principle of the system Vdip

Paper 10401 from Ireland addresses the challenge of optimising the Safety, Reliability and Efficiency (SRE) of rural distribution networks. Efficiency in returning supply to customers after outages is addressed, including the use of Synchronised Data Monitoring (SDM). The application of SDM can assist in mitigating the impact of increasing shares of Inverter Based Resources (IBRs) on traditional protection, utilizing advanced data analytics. The so-called "rear earth fault" with phase interruption is a very big protection challenge.

Paper 10504 from Brazil deals with this topic and presents a possibility to find such faults. The differential voltage grid protection technique comes as an important additional tool to detect broken conductors in high impedance earth faults. It works in parallel with the traditional overcurrent protection.

In **paper 10647** from Finland, first the identified challenges due to network transformation for earth-fault protection and electrical safety are explained. Next, the novel touch voltage-based earth-fault current protection is introduced to solve the identified shortcomings and challenges of traditional protection functions. With the novel method both dependable and precisely timely protection operation can be ensured in compliance with the applied legislation during all possible network operating conditions.

Paper 10655 from Sweden deals with the influence of neutral point treatment in the distribution grid. On the one hand, the historical development is considered, but safety and availability are also the focus of this paper. The goal is an earth fault protection that improves resilience and reliability.

Paper 10744 from France proposes a new approach of fault location in neutral compensated networks using a transient phenomenon that appears immediately after the fault inception. This phenomenon is characterized by a damping sinusoidal signal of medium frequency and high amplitude. The performance tests on the MV CIGRE benchmark network, show encouraging results.

Paper 11172 from Finland has the topic "Evaluation and Modelling of Harmonic Earth Fault Currents". Harmonic earth fault current and earthing voltage generated by pre-fault harmonic voltage is studied in MV networks. Influence of the frequency and fault location is also analysed and the effect of the pre-fault harmonic voltage to the neutral voltage during an earth fault is considered. A method for evaluating the harmonic earthing voltage and its influence is proposed. Also, results of the field measurements are presented.

Paper 11343 from Portugal shows the improvement of cable fault performance using a ground resistor in series with an artificial neutral. A pilot project was devised to change the neutral grounding type, presently with low impedance reactance, to a resistance (**Fig. 13**). The goal is to reduce, both the amplitude and duration, of the voltage transient associated with the establishment and clearance of a single phase to ground fault and, thus, to decrease the insulation stress on the healthy phases. In this paper the authors will present the problem, the solution proposed, and the first results obtained. Important is to refer that no changes to protection scheme where needed.

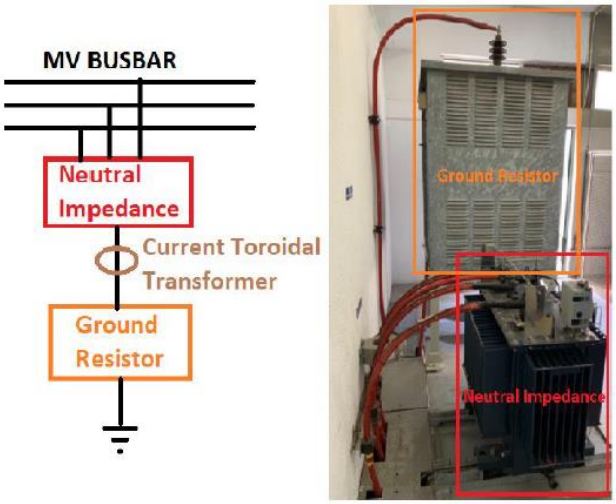

Fig. 13: Diagram of ground resistor connection (on the left) and a photo taken in the substation with the ground resistor already installed.

Sub block 7: "Fault location"

Fault location is a fundamental topic in protection technology, as one wants to locate every fault that occurs in the network as precisely as possible. We received 9 papers in this sub block.

Paper 10178 from Bosnia and Herzegovina considers the possibility of locating single phase faults in medium voltage distribution network with included distributed generation. Most of these faults occur over a certain value of fault resistance and they are accompanied by low values of currents and voltages. The detection and location of these faults can be difficult with the classic protection and location system. In this work, a method based on the analysis of transient phenomena is considered and the detection and estimation of fault location are done in the domain of traveling waves.

Paper 10210 from Korea a study on automatic fault isolation of closed loop system in power distribution system is discussed. Due to the conversion of the

distribution network from radial to closed-loop operation, it is also necessary to adapt the protection system. In addition, there are many decentralised generators. A special protection algorithm with direct communication between the protection devices was developed.
In **paper 10488** from Italy the estimation of temporary overvoltage (TOV) due to single earth fault is discussed.
The checking and verification of validity and reliance of a model of computing, it is a fundamental milestone for Enel Grids. The possibility to have available a simplified model of estimation of TOVs due to earth faults, using the data already presents in the grid DBs, determine a natural increasing of value of internal DSOs DB themselves and, at the same time, to start in a concrete way a designing for development of new evolved tools, able to support fully, how already explained, the Network Development and Operation & Maintenance processes, predictive and smart maintenance oriented. The other important aspect of this work, is, the exploiting of all new protection technologies.

Paper 10519 from France is an upgrade of a previous work on an impedance-based fault location method (FLM) designed for medium voltage (MV) distribution feeders using zero-sequence (ZS) components and distributed voltage measurements. This paper proposes to estimate ZS voltage probability density functions (PDFs) instead of a deterministic amplitude and phase angle value.
Paper 10526 proposes a novel online method to locate single-phase to ground faults on medium voltage (MV) cables. The proposed method exploits the relationship between the cable's voltage and current, in particular, the sheaths currents. As two major advantages, it is compatible with inverter-base generation and does not rely on real-time communication.
Paper 10788 from Switzerland presents successful field results of a novel fault location approach for active distribution networks, which exploits time-synchronized measurements from Phasor Measurement Units (PMUs).
In this respect, it is shown how a centralized approach combining synchrophasor measurements from multiple Distribution-PMUs (D-PMUs) allows to address the challenge of accurately locating many fault types (such as 3-phase, 2-phase, earth faults) in all grid topologies and grounding systems (such as radial or meshed as well as solidly grounded or isolated or compensated).

Paper 10951 from Germany presents the challenges of fault location systems for multi-terminal lines. Based on gathered experiences from the chosen network operator installations, the impact of different approaches of fault location on the fault location reliability, like impedance-based methods or travelling wave methods, is discussed. This paper presents real cases, with a detailed analysis of problems. Finally, suggestions are given how to implement an optimal fault locator approach for multi-terminal lines.

The waveform of voltage and current can strongly differ from sinusoidal waves during phase-to-earth short circuits in impedance earthed middle voltage systems. This effect can cause incorrect operation of the protection system. In **paper 10974** from Germany the effect is analyzed, and a testing procedure is described. This testing procedure can quantitatively determine the range of impact of the analyzed effect on the tested protection devices. The testing results are presented (including analysis and assessment) and deduced recommendations for protection are given.
Paper 11304 from Spain describes a High Impedance Fault (HIF) detection algorithm based on four methods: interharmonics (measures the change in the sum of several harmonics); harmonics (measures the ratio third harmonic / fundamental); waveshape analysis (detects a flatness close to the zero-crossing by measuring the current derivative); current level. The algorithm was tested with simulated and real HIFs and also with other events. It has given good security and dependability.

Potential scope of discussion

The topic of protection offers many opportunities for discussion. Especially new technologies (e.g., virtualization of protection, in central units) lead to intense disagreements and thus to discussions.
Also, the fact that communication is increasingly becoming part of protection functions leads to discussions about security, availability, and redundancy of protection systems.
Finally, the "never-ending story" of high-impedance fault location and earth faults will again be an exciting topic in the future.

Table 1: Papers of Block 1 "Protection"

Paper No.	Title	MS a.m.	MS p.m.	RIF	PS
Sub block1: General Protection Issues					
10344	Requirements for generating plants to be connected in parallel with distribution networks - focus on EN 50549 series.				X
10717	A Validation of IED for Networked Distribution System				X
11311	Protection System Analysis in Microgrids with DSO Static Generation				X
Sub block 2: Virtualization					
10451	A Novel Engineering Framework for Virtualized Protection, Automation, and Control Systems: An Interoperable Standards-Based Approach			X	X
10656	Virtualized Centralized Protection and Control – Constellation Project Case Study		X		X
10702	Real-Time Performance of Virtualized Protection and Control Software				X
10855	Real-Life Pilot of Virtual Protection and Control – Experiences and Performance Analysis				X
11222	Challenges and Considerations for the Design and Implementation of a Centralized Protection and Control Solution for MV Networks		X		X
11227	Software Defined Substation Automation		X		X
Sub block 3: Testing					
10187	Experience Sharing: Self Powered Relays - Simulated Over Current Phase & Earth Fault Testing				X
10435	Open Phase Fault Analysis in MV Distribution Grids with Resonant Grounding		X		X
10551	A Study on the Protection Scheme for LVDC Distribution System in Commercial Buildings				X
10582	HIL Testing and Future-Proofing of UFLS Schemes		X		X
10646	Multidomain Considerations of Secondary Maintenance Approaches to Ensure the Reliability of Network Protection Systems				X
10877	Performance of A Digital Distance Protection Relay During Short Circuits in Presence of a Converter Connected Grid			X	X
10995	Challenge: Frequency Measurement in Different Applications				X
11037	Key Performance Indicators (KPI) For the Testing Process of an IED				X
11128	Optimized Low Voltage Power Fuses for Current Requirements in Low Voltage Power Grids				X
11200	Interconnected Grid Protection Systems – Reference Grid for Testing an Adaptive Protection Scheme				X
11274	Secondary Wiring Checks by Combining Sawtooth Polarity Detection and Voltage Measurement				X
11280	Functional Testing of Virtualized and Centralized Protection Systems				X
Sub block 4: Algorithms					
10284	Experimental Validation of a Novel Stator Interturn Fault Detection Method in Induction Motor				X
10541	A Comparison Between Different Inertia Estimation Algorithms in Smart Grids Applications				X
10729	Implementation and Test of Frequency Estimation Methods for RoCoF-based Load Switching in Islanded Grids			X	X

10856	Distribution Network Fault Prediction Utilizing Protection Relay Disturbance Recordings and Machine Learning				X
10988	Hardware-In-The-Loop Investigation of Distance Protection Algorithm in Grids with Dominant Decentralized Generation Units				X
11038	A New Adaptive Auto Reclosure Approach with Secondary Arc Detection				X
11382	Advancing the Capabilities of Open DSS: A Directional Overcurrent Relay Feature for Modelling Modern Microprocessor Network Protection Operation Modes		X		X
11383	EPRI Distribution Protection Analysis Toolkit				X
Sub block 5: Applications					
10326	Special Protection Scheme: A Use Case for Enhancing High Distributed Energy Resources Integration				X
10336	Evaluation Effects and Preliminary Designing of Shield Reactors for Mitigation of Overcurrent Flowing Through the Earthed Elements of Underground Cables Following Cross Country Faults on MV Network				X
10527	Arc Flash Mitigation on Main LV Switchboards by Protection HV/LV Transformers Using Circuit Breakers				X
10550	Characterisation of Sequence Components for a Standalone Microgrid with Low Fault Current		X		X
10592	Generic Methodology for Protection Plan Analysis with Inverter-Based Grid Forming and Grid Feeding Resources				X
10689	On-line and Adaptive Load Blinding Protection Scheme to Resolve Protection Limits in Networks with Highly Integrated DERs				X
10793	TVP Liquid Immersed Transformers Protection Against Fast Transients				X
10824	Short-Circuit Currents Characterization for Future Converter-Based Power Systems				X
10953	Investigating the Impact of Topology Changes and Distributed Renewable generation on the Protection Behavior at High- and Medium-voltage Level				X
11326	Centre of Angles based Remedial Action Scheme using Synchrophasor Measurements in SP Transmission Network		X		X
11337	Three-phase Two-wire Distribution System: Protection schemes in unconventional networks.				X
Sub block 6: Earth fault					
10266	Pilot Test of the Method Vdip for an Earth Fault Localization		X		X
10401	Optimizing the Safety, Reliability and Efficiency of rural distribution networks				X
10504	Differential Voltage Grid Protection				X
10647	Novel Touch Voltage-Based Earth-Fault Current Protection for Ensuring Dependability and Electrical Safety in Modern Compensated MV-Distribution Networks				X
10655	The impact of Neutral Treatment and Earth Fault Protection on Resilience and Reliability of High Voltage Grid				X
10744	Improved Method for Earth Fault Location in MV Distribution Networks with Compensated Neutral Grounding			X	X
11172	Evaluation and Influences of the Harmonic Earth Fault Currents				X
11343	Improvement of Cable Fault Performance Using a Ground Resistor in Series with An Artificial Neutral				X
Sub block 7: Fault location					
10178	Detection and Location of Single-Phase Faults in New 10(20) kV Distribution Networks		X		X
10210	A Study on Automatic Fault Isolation of Closed Loop System in Power Distribution System				X

10488	Estimation of TOVs Due to Single Phase to Earth Fault by Means Validated Model by Comparison with Measurements from Real Fault Tests				X
10519	A Robust Fault Location Method for MV Distribution Feeders				X
10526	Fault Location Method for Medium Voltage Cables Using Measured Sheaths Current in the Presence of Renewable Energy Resources				X
10788	Novel Fault Location Techniques for Medium-Voltage Distribution Grids Using D-PMUs				X
10951	Fault Location for Multi-Terminal Lines				X
10974	Phase-to-Earth Faults Causing Inaccuracy of Distance Protection in Low Impedance Earthed Power Systems				X
11304	High Impedance Fault Detection for MV Distribution Networks				X

Block 2: "Control"

The second block covers all topics around control systems in any kind. Control take place at so many places in the distribution grid, beginning at the customer or in active distribution grids better known as prosumer, in the different voltage levels from low until up to the high voltage level and finally also in centralized systems like a Scada- or FLSR-System. In the different voltage level, we can find control systems on the one hand with a local geographic boundary within the voltage level but on the other hand often also in the whole voltage level of a grid. The following discussion of the papers of block 2 addresses all the before mentioned perspectives. It contains in sum 30 papers (**Fig. 14**: Overview block "Control" with subtopics).

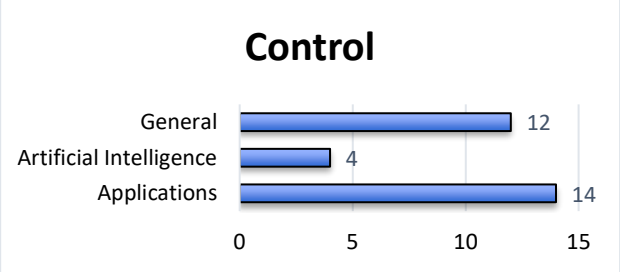

Fig. 14: Overview block "Control" with subtopics

Sub block 1: "Control in general"

On the subject of control systems in general, 12 paper were submitted. All these papers address either the optimization or stability.

Paper 10481 from Germany used for example a multi-agent approach for an information exchange, directly between the nearby situated generation and load units, in combination with load forecast to improve the operational management by using decentralized control algorithm.

Many optimization strategies require a lot of information from a wide variety of network nodes from the distribution network. In contrast to this, the **paper 10602** from Iran describes a different approach for the optimized use of decentralized generation. They only need the phase angle difference between the busbar of the point of infeed and the busbar of the main node in the substation with the connection to the upper voltage level.

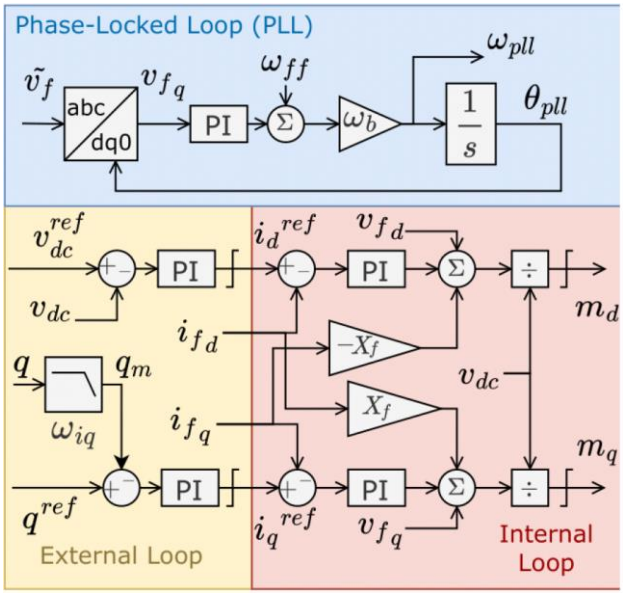

Fig. 15: Control diagram of GFL inverter (paper10736)

More and more decentralized generation is produced by inverter driven generation. The behavior of such a generator is defined by software, ether more the software also defines if the generator works as a grid following device or as a grid forming device, which can also be the master of an islanding grid. In the **paper 10736** the authors from France are concerned with the stability of such a distribution grid, consisting of a mixed of grid-following and grid-forming inverters. They investigate the behavior and the stability in case of slow interactions in several use cases and give some conclusions, based on the simulations that have been carried out (**Fig. 15**).

Another optimization solution is presented in **paper 10815** from Portugal. This paper deals with a self-healing architecture, based on the steps of fault location, fault isolation and followed by the restoration of the service. The aim in this case is the additional optimization of the restoration time by using an adaptive strategy right after the fault occurrence. The key feature can be also seen in the assistance of the system operator due to the not unnecessary manual fault analysis and no manual reconfiguration work by the operator. Like **paper 10815**, **paper 11218** from Indonesia also deals with the automatic reconfiguration of a disturbed grid state. In comparison to the previous one, this work is a practical adaptation of an existing scada system under consideration of a recovery scenarios for each line segment. The presented concept provides to the self-healing-process an additional benefit by the extended integration of events as e.g., motor supply fault in order to detect errors nearby assets early on that can cause incorrect behavior in the event of a fault.

One possible kind to transfer more Energy through an existing transmission system, without the need of timely long and complex rebuilding measures is to leave the alternating signal form (AC) and switch over to direct voltage and current (DC). This sounds easy but there are

also in this domain, especially in the medium voltage level some major issues like the switching of short circle current or the limiting and damping of such currents still to solve. Therefore, the **paper 10955** from Korea compare three different topologies, consisting of a combination of a circle breaker, a reactor, and a fault limiter, to give an overview about the different behavior in switching direct currents.

Today the use of phasor measurement units not just only take place in transmission grids, they also find their way to the distribution grid and furthermore down to the low voltage grid. In the **paper 11144** from Greece there can be found a use case for distributed phasor measurement units (PMU) in the medium voltage grid to do state estimation and also fault analysis. The paper show on the example of Kythnos, that a state estimation, based on distributed PMU's can work very well and also a fault analysis is fine possible. Finally, it should be mentioned, that the presented system can deal with a combination of synchronized and also conventional measurements.

For future application, but also for today's investigations for DC-coupled grids, it is from interest to know the equal impedance of the DC side from an inverter, which causes the same system behavior as on the AC side. That's why **paper 11189** from Belgium set the focus on this topic and do many investigations on this. They transfer the AC impedance by mathematic methods to the DC side and verify the result, which is a combination of resistance and inductance, with several experimental implementations.

Control brings a lot of new assets like remote terminal units but also other technical secondary devices which must be implemented in case of an integration. But they also must be maintenance and served by the continuously shrinking staff. To be more efficient it is necessary to save time, especially travelling time, which makes secure remote maintenance necessary, which is described in the **paper 11248** from Canada. The authors have a lot of experience in this field, and they describe in detail the stages to get an effective and secure remote-control access in advanced, taking into account actually security requirements.

In the most applications of control, there is a necessary need of communication between the sensors and the control system itself. But this communication is often a weakness in the system and can cause unintended unavailability's in centrally located controls with decentralized sensors like meter. To prevent this problem there is an approach suggested in **paper 11306** from Spain. This paper recommends moving the control function, in the example the advanced distribution management systems services, from a central location to an edge area, e.g. as edge computing service in a substation, to avoid the mentioned issues, to reduce the risk of missing control and highly up the availability.

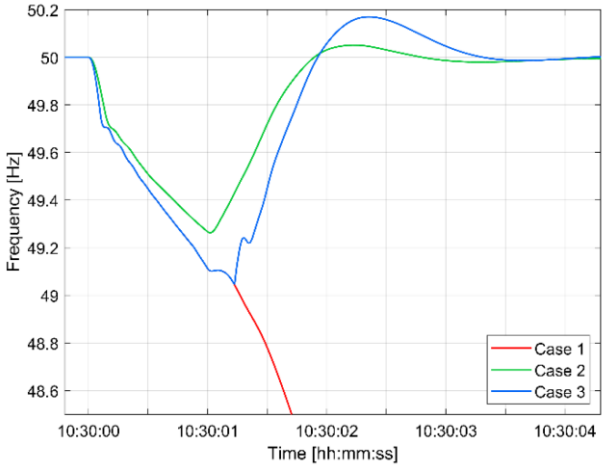

Fig. 16: Frequency dynamics, analyzed in paper 11318.

Paper 11318 from Italy provides a standardized control architecture as well as a control algorithm for micro grids with a centralized approach, which is designed for both, conventional and renewable generation. It also includes energy storage systems and dispatchable loads. The hole smart grid project was done in laboratory, supported by an additional hardware in loop setup (**Fig. 16**).

Many techniques work today at solutions to integrate more renewable generation into the existing, outdated distribution grids. But there is also another question to ask, namely, how to manage all the upcoming online data from those, daily increasing renewables in real time? This interesting research question is the content of the **paper 11401** from Germany. It presents a solution using an improved time series database, which is, compared to previous time series systems, more flexibly in handling data from different sources by the proposed energy data management framework.

Sub block 2: "Artificial intelligence in use within control"

As in other disciplines the use of artificial intelligence is not longer to think away in the field of control, especially in the area of classification and detection. Artificial intelligence offers in these fields very good performances in relation to time behavior in normally computationally intensive processes and also in their reliability, if the learning phases have been well chosen. In **paper 10958** from Netherland, the artificial intelligence is used to reach an accurate fault classification in case of fault location. The presented approach consists of two steps, the first one is the determination of the degree of stability in the fault waveform and the second one the classification itself by the use of a machine learning model. The stability for example is rated by a windowed Fourier analysis and the assessment of strength of the fundamental frequency component. Some further knowledges from this work are, that with the presented approach in the classification an

accuracy of 95% can be achieved and that an adding of small subsets of synthetically developed fault data to the training data sets can improve the accuracy in classification.

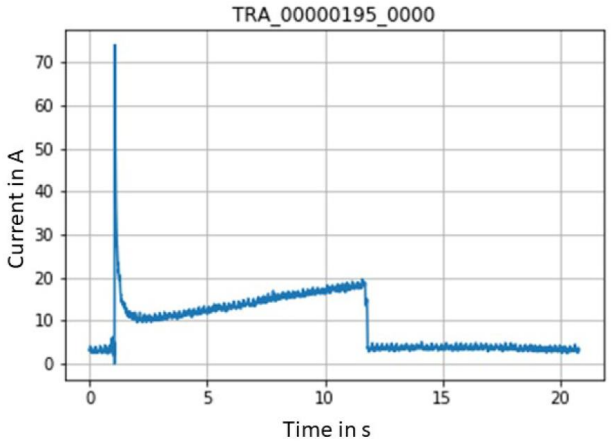

Fig. 17: Current of motor while switching of a circuit breaker (paper 11293)

Another use case for artificial intelligence is discussed in **paper 11293** from Austria. In this paper a novel approach is presented, which use this artificial technic as an observation method for detecting abnormal behavior during switching operation in any kind of switching (**Fig. 17**). In this way, it is not only possible to detect a fault only after it has already occurred, but it is often possible to detect a small deviation or a small misbehavior within the last switching operations in advance. So, this could be an important feature for future predictive maintenance strategies to improve the reliability and robustness. One of the new findings is also, that the sensor for measuring current and voltage must only be installed one time if all switching devices in a substation or switchgear have the same central secured power supply. The sensitivity for the classification at each switch is given by an information exchange between the new detection framework and the Scada system or a telecontrol connection that enables a switch selective footprint for each switching operation (**Fig. 18**).

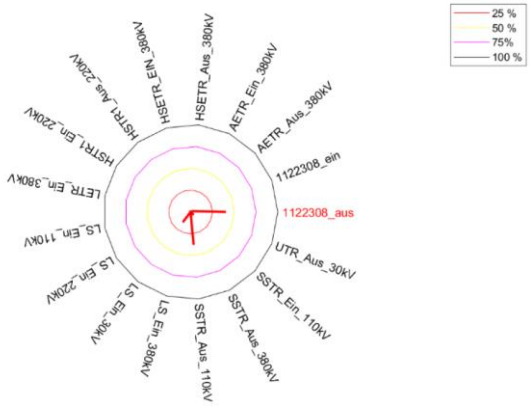

Fig. 18: Evaluation of an abnormal switching operation (paper 11293)

As also in the last paper mentioned, the authors of **paper 11370** from Finland likewise deal with the detection of slowly "growing" faults. But in their case, they try to predict faults on cable, which is a real big problem in today's distribution grids with a constant growing ratio of cable to overhead lines. As a common experience of system operator shows, mostly, after less or more one minute, a further fault occurs and produce an outage. By this way the featured monitoring system can help a system operator in planning maintenance and also in reducing interruptions in power supply. One reason why the authors had chosen the artificial intelligence driven approaches for their work was, that this is real good suitable for such complex issues. The research in the paper focus on medium and low voltage grids and it is using a voting classification technique for monitoring and prediction of faults, especially the earth faults (**Fig. 19**). Another feature of this work that should be mentioned is the communication, which is using IEC61850 sampled values for measurement transmission, but the main content of the paper focus on the voting classification, on the case study and the test system as well as the testing results.

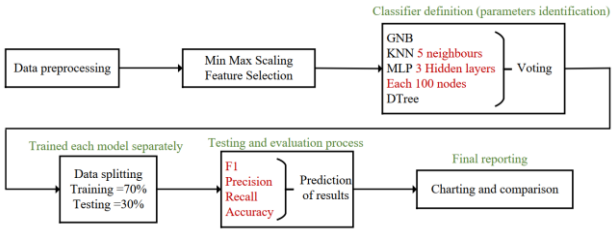

Fig. 19: Proposed flowchart for the intermittent fault detection methodology from paper 11370.

The final paper in this section, the **paper 11384** from France, deals with a nearby real time state estimation to manage flexibility orders. To make it possible to act in real time, the observation of the grid, which is used for the demonstration, is done with the help of artificial intelligence, namely by machine learned sessions. The goal they want to reach out is among other things avoiding congestions on critical asset and also to hold voltage within the allowed band wide. The main contribution of the paper still focuses on the integration of the machine learned observability as well as on all components border to this. The presented work shows that it is possible to implement such complex observability and continuously provide cyclically information for any following system. With the given output, there are also all necessary information's for the management of the local flexibility market available to place appropriate measures for flexibility while also preventing the before mentioned issues of congestions and in the voltage boundary.

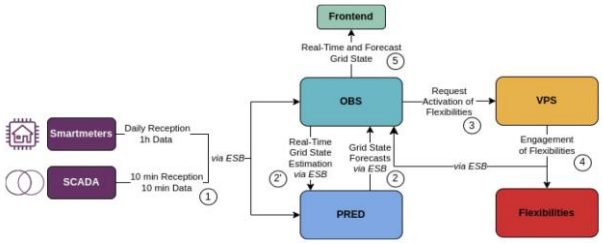

Fig. 20: Scheme of integration the observability part (OBS) out of paper 11384.

Sub block 3: "Control in Applications"

There are many different requirements for the electrical behavior of significant grid users. Additional there must be noted, that these requirements are not everywhere the same, especially not over the border of different countries. So, it is hardly unable for the grid operator to check all the requirements, even more under the knowledge that the number of these grid users rise up faster than they can count. Exactly this issue of recognizing a wrong behavior of e.g., a decentralized generation, is addressed by the **paper 10126** from Austria.

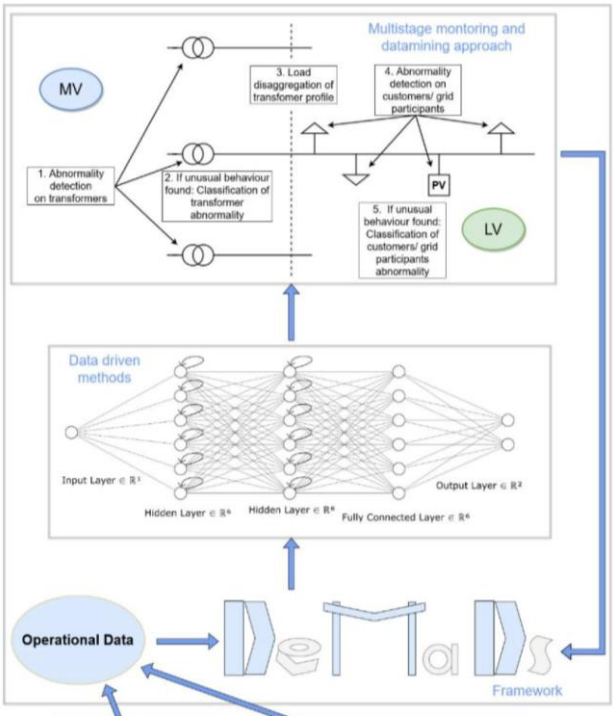

Fig. 21: Sketch of functionality of the malfunction detection framework from paper10126

The authors present a framework, which provides detection methods for recognizing such wrong system behavior, based on already existing operational data. Another property of the present framework to be mentioned is, that due to the low data density in the low voltage the control method is data driven. Also, **paper 10769** from the United States of America addresses the same goal as **paper 10126**, namely the autonomous detection of the wrong behavior of a decentralized generation unit in relation to the requirements to interconnection. In this paper, there is not only the framework for detection in focus but also the required hardware for the measurement equipment under consideration of cost efficiency.

Flexibility control is often seen in relation to observing, managing and, if necessary, limiting the loads on assets in the distribution grid. Limiting of load is usually necessary to ensure e.g. the required distance form an overhead line to the ground, but it is a really difficult process to define the right threshold which not effect falling below the minimum distance to ground and also not restrict the maximum transferrable power. In **paper 10478** from Poland such an approach is presented, which determines a maximum allowed load capacity on overhead lines, based on parameters such as weather data and laser-measured geometries and distances. The result of such a calculated dynamic line rating can subsequently be used as basis for the flexibility market.

Fig. 22: Time schedule of a semi distributed self-healing recovery sequence from paper 10562.

Paper 10562 from Indonesia discuss different approaches to the development of self-healing networks in the view of an electric utility company with consideration of understanding the unique characteristic of each method and also taking into account some issues like e.g., the ease of implementation and the interoperability from engineering side on the one hand and on the other hand the recovery time form the side of operational. A content that should be emphasized in this contribution is the comparison of the central and semi-distributed approaches.

In **Paper 10590** from France, which focus to dynamic voltage control in low voltage grids, is an approach of a practical and cost-effective solution for implementing non-firm connected decentralized generation units presented. In this case a non-firm connection could be defined as an additional contract between generation owner and the grid operator which allows the grid operator to make a control intervention in the generation system to influence the voltage in the grid. The approach presented for optimization is built on the existing meter infrastructure, which means that no additional sensor technology is required. The paper also describes a therefor developed experimental platform for testing and validating the proposed solution.

Nowadays it is often not furthermore possible to lead a save and stable low voltage grid with today's information

in existing Scada systems. In some cases, it seems as if the operator is completely blind to low voltage observability. Today's grids and furthermore tomorrow's grids need more visibility because the transmission from passive to active low voltage grid operation has already taken place. Exactly this issue is investigated in **paper 10628** from Finland. The paper highlights the need of novel functionalities in the low voltage level and presents the case of the local distribution system operator in Helsinki. His future development has the goal to let operate different control systems on a common platform and user interface in the Advanced Distribution Management System. A benefit of this integration is seen, for example, in the more efficient use of data.

There are a lot of paper which are setting the focus of content to self-healing network methods with the aim to reach a reduction of well-known indexes like SAIDI or ASIDI. This self-healing technology need a lot of information from the grid in case of a disturbance to work well. There are also often additional information's available to the location of a disturbance. In many cases each of these information's for itself is helpfully, but it also can be seemed that one of them as single information is not enough for a clear verification of a failure. To solve this issue or furthermore to improve this deficit, in **paper 10751** from the United Kingdom, is a development presented which introduce a common disturbance information system that can collect data and information from different source-assets in different voltage levels, independent of the geographic location. The paper focus on the central platform of such a common disturbance information system and also on the development of an algorithm to accurately determine the distance to the fault location which consider all incoming information of the whole system to improve the reliability and the accuracy of the presented system.

As in **paper 10751** before also the **Paper 11180** from France deals with the topic of the location, isolation and the followed restoration of the services in case of a failure. But in this work the authors set the focus on the protection scheme as well as the impact of decentralized generation plants on the protection scheme and on the architecture of the physical communication, more specifically on communication via 5G, which is used to collect all real-time data from measurement components like protection devices or fault detectors. A highlight to be mentioned in this paper is also the use of edge computing and virtualization concepts for the test scenario.

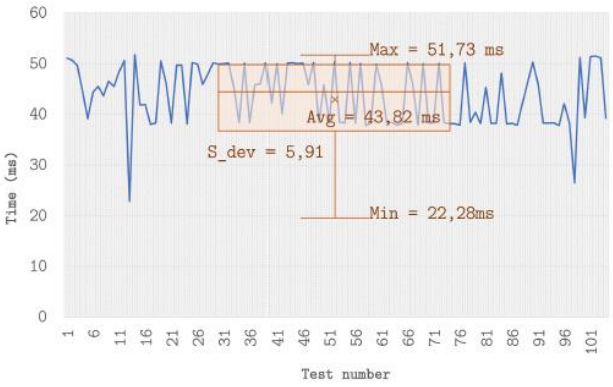

Fig. 23: Remote tripping delay via 5G (paper 11180)

Virtual power plants are well known from the past, but with the increasing number of decentralized generation plants, they become even more important because there is a new business case by aggregation these geographically distributed plants in different voltage levels. **Paper 10773** from France puts up exactly this topic and investigate it regarding optimizing profit on global energy marked and providing system services. Therefore, the authors propose a generic model for the virtual power plan and in a following step a sequential strategy for managing which consist of long-term bidding and real time control via economic model predictive control.

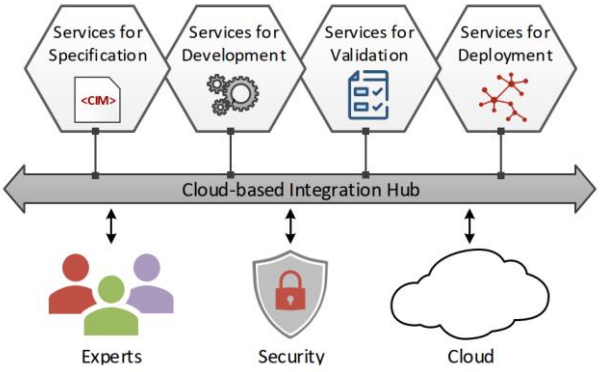

Fig. 24: Core elements of a service orientated and cloud-based integration hub (paper 11040)

Cyber security not only take place in the primary operational to ensure, in the point of view of the OT-security, the availability, the integrity and the confidentially. It must also take place in the secondary technologies the domain, where especially in the field of smart grids all the engineering is done e.g., by different experts from many independent teams. Therefore, is in **paper 11040** from Austria a cloud-based concept of a model-based and service-oriented platform proposed, which gives the possibility of cooperative development and validation of management and engineering data. This allows a continuous, transparent, and interoperable digitalization of the whole smart grid system. A further advantage of the presented work to mention is the possibility of a secure geographic distributed collaboration

from different teams and employees.

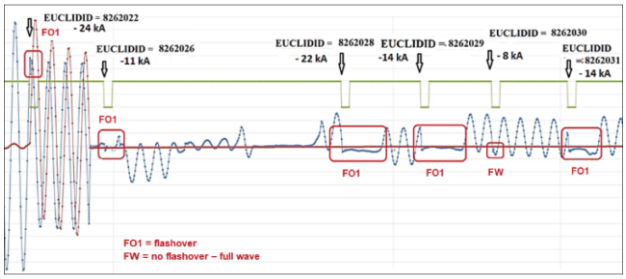

Fig. 25: Analyzed record set regarding flash over detection (paper 11125)

Paper 11125 from Czech Republic present a concept for the localization and evaluation of lightning phenomena in power grids. The authors have developed an advanced algorithm, based on many long-term data recordings in real grids, which allows to report an event in nearby real time. But they not only report the event itself and its location, but the report also contains extended information like a risk analyses for affected equipment or a recommendation for current operations. The paper also contains two examples for illustration, one of a fast identification of the course of an outage and one of an early prediction of surge arrester failure.

To build smart grids, including smart meter and integrate there a large number of distributed regenerative power generation, is often a challenge like you can read in many presented papers. It is all the more of a challenge to do this in a developing country where are also poorer framework conditions such as e.g., missing communication given. Exactly there the demonstration side of the field test of **paper 11156** from Slovenia takes place. The content of the paper examines the influence of demand-side flexibility in an urban area to the resilience and the number of outages of the local grid. Therefore, they analyze the level of demand, the availability of supply and the ability of the grid to connect both previously mentioned. In further steps planning, the design and the implementation are descripted in more detail. As one of the keys for success there is mentioned that it is crucial to involve the grid users from beginning to get their comprehension in case of user behavior. They must understand how to go from consumer to prosumer.

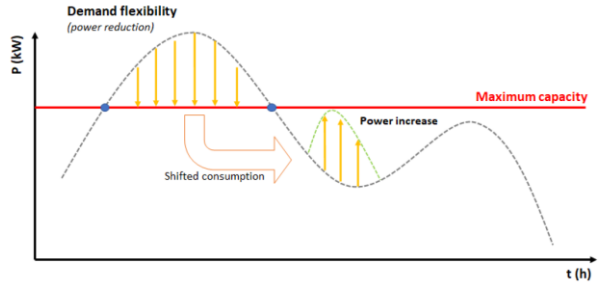

Fig. 26: Energy shifting by demand (paper 11156)

Paper 11214 from Denmark suggest an exchange framework solution for a secure middleware to provide a common platform for different operators and stakeholder. This allows a better service and an improvement in using flexibility in today grid, whereby the authors refer in topic to the low-voltage grid. The middleware must support the security and it should be scalable and interoperable. The suggested solution does in essence share information's and data from different voltage levels as well as from included smart meter and involved energy management systems between many connected applications. Further goals which were focused on this paper are the so given provision of more observability as well as the better monitoring and control possibilities to the stakeholders, such as distribution system operators and aggregators. By this way, free as well as missing capacities can be determined and made available for the flexibility market. Another goal to mention is the approach to equip information from the low-level side by IoT devices and controls to the system, which could be from several vendors and manufactures.

As already discussed in many other papers, such as **paper 10126** or **10769**, the monitoring of conformity and the controlling of decentralized power generation is one of the big challenges in the future. If we look to the low voltage level, this issue is becoming more and more difficult because the number of smaller systems is increasing really fast and a large number of different manufacturers is here in use. Therefore, a standardization of the interface to the customer is a necessary key to success. Exactly this issue is addressed in **paper 11284** from Germany by developing an architecture for such communication, including practical tests with EE-Bus applications and also tests for interoperability between different components. When developing the process between the centralized monitoring and management system of the smart grid operator and the decentralized manageable grid user, a blueprint for sustainable network management was used. Based on this a frame for curative measures, such as compliance regarding to regulations and customer contracts is also possible as mentioned before.

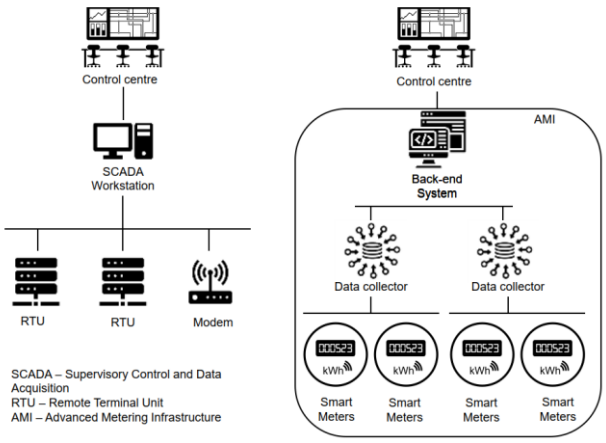

Fig. 27: Suggested configuration for data flow regarding paper 11284. Left via Scada for medium and high voltage and right via AMI in the low voltage area.

An additional extended benefit of this paper is the investigation to transmit also time series data which could be used in future for variable energy prices and network charges.

Potential scope of discussion

Some kind of Control can be found almost everywhere in each application. Today we can find control often caused by the permanent increasing of decentralized generation in all voltage levels. Therefore, in the view of the research one of the main questions to be ask is, where is the best position for it. Decentralized nearby the process with maybe missing information on the interaction with other control circles or maybe better centrally in a common system design e.g., Scada- or ADMS-systems, but with the main disadvantage of a necessary communication and the possibility of missing reliability caused by no availability.

But there are many other facts which must be considered. For example, the quality and the quantity of necessary measurement data for the control algorithm, because for the technical requirements for the transmission facility it is essential if there is a single value, e.g. meter data, to transmit each Minute or if the control system needs continuous streams of values every 10 milliseconds. Therefore, in some papers already architectures based on wireless communication standard 5G were discussed. It is also crucial to know the compellability of the control system.

Some presented paper focus on artificial intelligence, because sometimes a task is to complex or for a real time critical application to slow, so that it is not possible to solve it in a conventional way. Another reason to use new methods like the artificial intelligence, presented in one paper, was a time critical pre-processing of input variables for a following control algorithm. Such a process is also often called as machine learned which is actually a subordinate group of artificial intelligence.

Finally, it can be said that control will be a today and furthermore tomorrow even more necessary tool, it enables in future also further integration from active grid users like generation plants of any kind also as prosumer. The second goal, why control cannot be ignored is because it is an enabler for controlling overloading's as well as do congestion management and not at least to ensure compliance with the regulative given voltage range. Control cannot replace any grid expansion or re-enforcement, but control helps to compensate the rather sluggish process of grid expansion or re-enforcement. The solution must be found in a reasonable mix of both.

Table 2: Papers of Block 2 "Control"

Paper No.	Title	MS a.m.	MS p.m.	RIF	PS
Sub block 1: Control in General					
10481	Optimised Operational Management of Distribution Grids by Utilising Flexibilities Through Automation of Electrical Assets Using a Multi-Agent-System Approach				X
10602	A Real-Time Optimal Operation Strategy for Active and Reactive Power Sources in Smart Distribution Systems				X
10736	Converter-Driven Stability in A Distribution Grid with High Penetration of Inverter-Based Generation				X
10815	Selfhealing - FLISR in Underground and Overhead Real the First Performance Results	X			X
10955	A Study on the Fault Current Limiting and Interrupting Operation Technology of MVDC Systems Using a Protection Equipment				X
11144	PMU-Based State Estimation and Fault Analysis in Active Distribution Grids: A Case Study for Kythnos Island, Greece	X			X
11189	Equivalent DC Impedance of a Three-phase Impedance through an Inverter				X
11218	Semi-Distributed Automatic Scheme for Self-Healing Implementation in Distribution System				X
11248	Implementation of An Advanced Remote Engineering Platform				X
11306	An Edge-Fog Computing Approach for Advanced Distribution Management Systems for The Low-Voltage Network				X
11318	Control Architecture and Algorithms for Isolated Microgrids				X

11401	Demonstration of a Concept for the Data Management and Monitoring of Larger Scale DER Utilizing a Time-series Database				X
Sub block 2: Artificial Intelligence in Control					
10958	Supervised Learning for Fault Classification Using Hybrid Training Datasets				X
11293	AI To Detect Anormal Switching Operations				X
11370	Intermittent Earth Fault Detection in Distribution Network based on the voting classification technique				X
11384	Solving Issues of The Distribution Network of Harstad (Norway) In Real Time Using Machine Learning-Based Observability to Place Flexibility Orders				X
Sub block 3: Control in Applications					
10126	An Operational Data-Driven Malfunction Detection Framework for Enhanced Power Distribution System Monitoring – The DeMaDs Approach	X			X
10478	DLR as the Tool for Providing Flexibility Services in the Distribution Network				X
10562	Distribution Automation System Field Test in Jakarta MV Network				X
10590	A Dynamic Voltage Controller for LV Grids Based on Flexible PV Systems and The Smart Metering Infrastructure				X
10628	Developing Low-Voltage Operational Functionalities				X
10751	Delivering the Benefits from A Common Disturbance Information Platform to Prevent Unplanned Outages				X
10769	Automated Detection of Non-Compliance with DER Interconnection Requirements and the Laboratory Testing of an EDF developed solution				X
10773	Economic Model Predictive Control for the Energy Management Problem of a Virtual Power Plant Including Resources at Different Voltage Levels				X
11040	A Collaborative Engineering and Validation Framework for Smart Grid Automation Applications – The PowerTeams Approach				X
11125	Automatic System for Evaluation of Lightning Events in Power Grid				X
11156	From blackouts to flexibility: case study from Burkina Faso				X
11180	5G-Based Fault location, Isolation, and Service Recovery	X			X
11214	A secure Automation Solution to Provide Flexibility at Low-Level Grid – Middleware Services				X
11284	First Practical Results of Continuous Grid-Serving Power Control in Low-Voltage Network Via Novel Power Management Concept				X

Block 3: "Automation"

In the block "Automation" we received 41 papers. These papers were organised under the subtopics "Optimization", "Smart and Microgrid", "Artificial Intelligence" and a fourth category "General", aggregating the remaining Automation papers that are not included in the previous categories, but which relate with digitalisation, IEC 61850, frequency regulation and decentralized management of power systems. The assignment of received papers is shown in **Fig. 28:**.

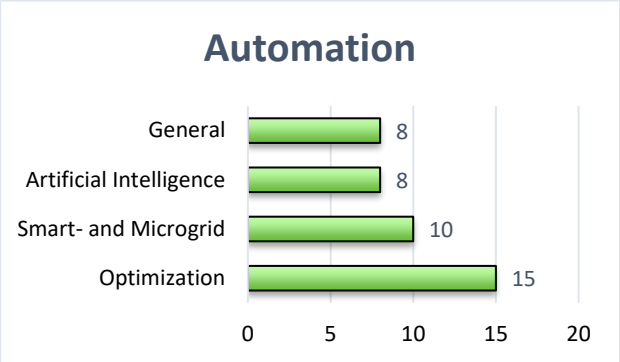

Fig. 28: Overview of the block "Automation", with sub blocks

Sub block 1: "General Topics in Automation"

This subblock includes papers that are different among them and do not fit into the previously described categories. Includes papers addressing IEC 61850 topics, digitalization, frequency regulation and decentralized management of DER.

Paper **10116** (The Netherlands) presents a solution developed by the collective Dutch DSOs (Netbeheer Netherland – NBNL), in collaboration with market prices, for the development of a real-time interface to enable SOs and connected costumers to communicate in a real-time domain. The initial use cases of the domain are the creation of a fallback mechanism for congestion management (e.g., curtailment) and connecting generation without redundancy ("N-0"). The interface is specified using the Smart Grid Architecture Model, using IEC 61850 for communication and data model.

Paper 10276 (Vietnam) describes the deployment of 6 digital 110 kV substations, observing IEC 61850 standard. The paper describes the design principles, architecture adopted, reliability analysis of protection and control scheme, as well as lessons learned.

Paper 10314 (Egypt) provides a solution to address the challenge associated with increasing low inertia RES generation, to preserve the system dynamic stability. The solution is based on the coordination of the load frequency control using a fractional order controller whose parameters are tuned through an optimization technique in addition to the cooperation of a superconducting magnetic energy storage (SMES) system. A robustness analysis is conducted, assessing the frequency response of the system to random changes in load, comparing the results with a system having just the SMES and the SMES with the proposed controller.

Paper 10473 (Belgium) presents the current state of multi-vendor interoperability for digital substations and describes the opportunities and challenges when designing, testing, and commissioning a digital substation through a lab-scale multi-vendor digital substation which was commissioned, and successfully tested. The paper highlights challenges in configuring multi-vendor Sampled Measured Values (SMV) when redundancy fails, and the necessity of retesting after configuration changes, with the setting presented in **Fig. 29:**.

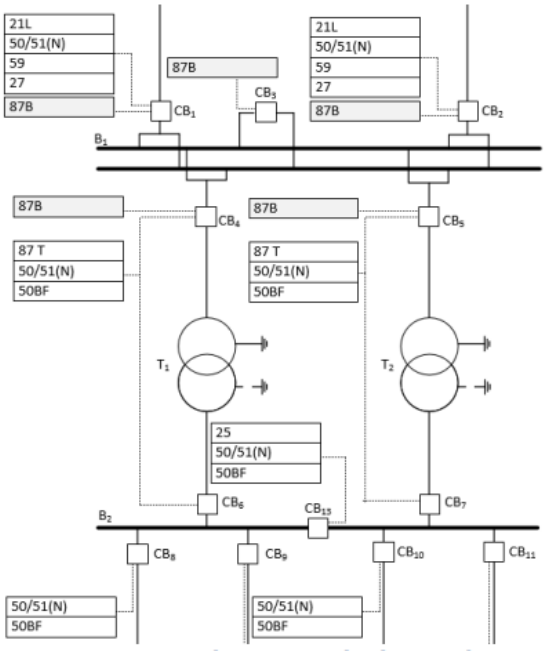

Fig. 29: Overview of the proposed modelling and forecasting approach and the underlying modules.

Paper 10690 (Germany) describes a hybrid mobile generator under development, consisting of a grid forming inverter and a battery storage system and that allows to perform maintenance operation in networks, for which the operation in islanded mode is necessary, without having to disconnected distributed generation systems due to the concern that they might destabilize those islanded grids. The system was tested in real LV grids that demonstrated that limiting and decreasing the power output of distributed generation systems by increasing the islanded grid frequency can lead to higher system stability. To assure a stable operation of the hybrid mobile generator a frequency droop characteristic was developed.

Paper 11018 (U.K.) discusses a solution addressing Low-

Frequency Demand Disconnection (LFDD) protection relays, which have no visibility of DG connected to the network in the area each relay protects. That would cause DG within protection areas to be disconnected from the network along with demand, causing a larger generation deficit. The solution presented presents new alternative LFDD solutions minimizing power interruption, thus contributing to frequency stabilization following unplanned frequency events.

Paper 11033 (Finland) presents a concept for decentralized power system management, addressing the new challenges associated with increasing penetration of intermittent DER, based in edge computing. The concept acknowledges the increasing amount of complexity and data that is needed to operate systems efficiently by forming sub-systems that communicate with the main system but are optimized locally, with the paper describing the realm of frequency regulation.

Paper 11078 (Portugal) describes an AMI solution than enhances observability over LV grids. Also, MV self-healing projects have been developed by DSOs. The paper presents a theoretical model and process flow that merges the capabilities for both concepts: the reconfiguration of MV networks in order to solve voltage problems detected by the AMI infrastructure.

Sub block 2: "Artificial Intelligence"

Artificial Intelligence is becoming more used in load forecasting, state estimation, enabling the control of distribution grids or other complex optimization uses, like supporting in maintenance operations.

Paper 10104 (Spain) describes a method to obtain an extended database of fault signals to use Neural Networks (NN) to process them. The presented solution enables to obtain a database of simulated signals from a real modelled electrical grid and extend it using Generative Adversarial Networks (GAN).

Paper 10191 (Germany) addresses the challenges associated with the increasing number of DERs through a method based on artificial neural networks to find optimal control measures for a large number of applications in real-time. The method considers different switching states, user-specific boundary conditions and user tariffs to ensure a non-discriminatory control operation, with the concept being demonstrated in a test grid.

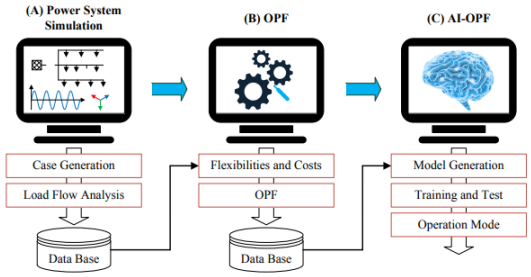

Fig. 30: Structure of the AI-OPF (Optimal Power Flow)

Paper 10378 (Finland) presents a solution for short-term load forecasting using a state-space physical model for thermostatically controlled load modelling, combined with a neural network-based forecaster to forecast the consumption of the other domestic appliances. The result is an algorithm to identify physical models based on neural networks from the aggregated smart meter data.

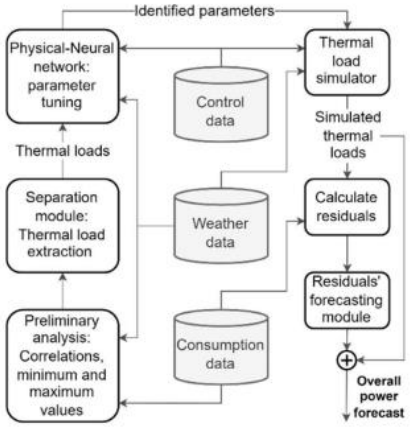

Fig. 31: Overview of the proposed modelling and forecasting approach and the underlying modules.

Paper 10450 from France describes a performance evaluation of an autoencoder state estimator for low voltage grids, reconstructed from open data. The state estimator developed ensures LV grid observability. The state estimator performance for a realistic LV grid is done through the autoencoder based sate estimator presented in the paper.

Paper 10524 (France) presents two artificial-intelligence based controllers for grid-forming inverter-based generators in a simplified microgrid. The training datasets were collected from an experimentally validated virtual synchronous generator controller. The controllers are then tested under a black start, load variations and a three-phase short circuit at the inverter's output.

Paper 10597 (Austria) proposes an approach for state estimation using machine learning methods, based on

topological information as the sole input, without requiring measurement data. The predictability of unknown quantities in low observability grid settings was studied in two test grids and one real-world example in various scenarios of observed and unobserved grid positions and loading configurations, allowing to conclude the feasibility of state estimation in low observability systems.

Paper 11022 (France) focuses on maintenance, describing an application which enables local authorities to report asset failures and incidents in the electrical network. The reports are often provided with photos. An AI-based object detection algorithm was tested to pre-identify the types of damaged asset, whose results are presents in the paper and illustrated in **Fig. 32:**.

Fig. 32: Overview of the proposed modelling and forecasting approach and the underlying modules.

Paper 11276 (Norway) presents a solution to enable energy consumption forecasting efficiently and preserving data privacy constraints. It is based in a federated machine-learning scheme for forecasting the energy consumption of households, which is tested with a real dataset of energy consumption from 51 households.

Sub block 3: "Smart- and Microgrids"

Smart grid infrastructure creates an opportunity for the operation of LV grids and microgrids integrating more distributed energy resources, while facilitating seamless operation between grid connection and isolated modes, and as well as providing enhanced LV modelling capabilities and state estimation.

Paper 10249 (Germany) addresses the usage of smart meters and smart meter gateway technology for grid state identification in LV grids with reduced metering inputs, assessing the methodology results in a simulation environment. Concludes that a smart meter infrastructure can replace a topology measurement infrastructure, enabling a grid state identification that can be used to implement local flexibility markets. **Fig. 33:** shows the load distribution process used for a linear load distribution.

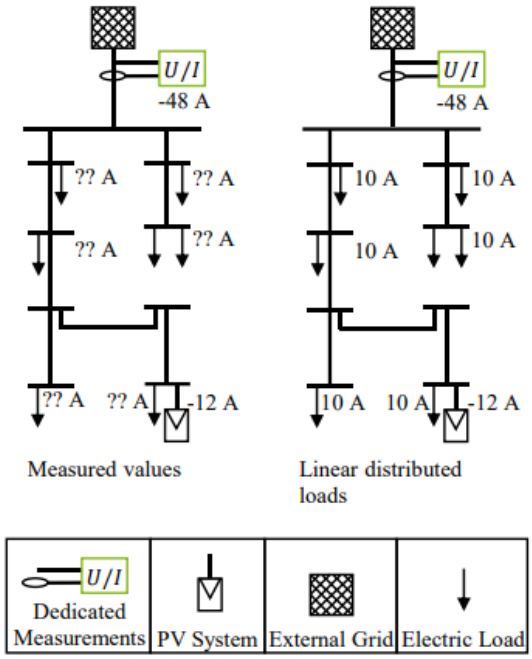

Fig. 33: Linear distribution process.

Paper 10286 (Iran) presents an implementation of smart metering for a street lighting system, therefore improving maintenance and energy efficiency, enabling load shedding programs.

Paper 10305 (Germany) proposes a metric to compare algorithms that control the tertiary frequency. These algorithms are important to control microgrids, which might have large amounts of generation and consumption, using decentral optimization algorithms, which can be classified into cooperative and competitive algorithms that – for each – provide individual benefits. The authors proceed to present eight requirements for the definition of KPIs in energy control environments.

Paper 10600 (Austria) addresses the challenges associated with interoperability to achieve a seamless integration between smart grid solutions through a view of system first so that the functional objectives can be aligned with the needs to be implemented. The methodology is being used in the H2020 project SENDER.

Paper 10603 (France) presents a system for seamless transition between grid connected operation and microgrid (islanded) operation. It is composed by energy storage system, inverter, and static switch, coordinated by a fault detection algorithm and advanced inverter controller. The contribution is concerned with fast transitions, less than 20ms between the grid following and grid forming operations when a fault occurs on the utility network.

Paper 10604 (France) is concerned with a control design for microgrids with PV production and electrical energy storage. The control system architecture developed by the

authors is a complete multi-level control system, while the paper focuses on the operation control short-term development and validation through simulation validation and experimentation.

Paper 10971 (Spain) describes an integrated supervision and automation solution to allow LV distribution network to provide a flexible and resilient grid in the context of the integration of RES and transport electrification. The paper shows various LV automation solutions (OLTC transformer, income switch-disconnector, phase, and feeder switch disconnector).

Paper 11058 (Norway) presents a scheme where the energy consumption pattern of several household appliances is clustered, enabling to assess the relation between different appliances, which are used to improve day-ahead forecasting of the appliances for utilization in practical scenarios to enhance flexibility in smart homes.

Paper 11368 (USA) proposes a design of a grid-forming (GFM)-capable inverter control scheme to reliably operate in distribution systems with networked microgrids. Control mechanisms between grid-following (GFL) and GFM inverter modes are presented. The control mechanism is tested on a two-source power system.

Paper 11480 (Germany) describes how the Internet of Things (IoT) associated with smart grids, using sensors, data transmission, data processing and actuators allow a much more efficient use of existing infrastructure, increasing the transportation capabilities, as illustrated in **Fig. 34:**. A real LV smart grid, on a Lab in Hess, with customizable prosumers, including all IT and OT components was built, with an appropriate control algorithm. Also, the impact of non-authorized data and information misuse is analyzed and strategies for data and information security are described.

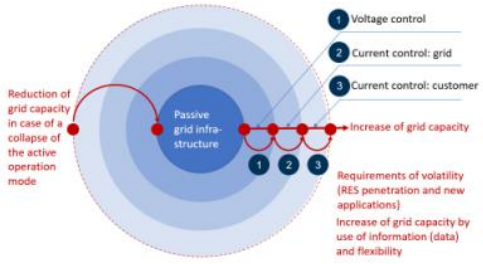

Fig. 34: Increase transportation capabilities of existing grids.

Sub block 4: "Optimization"

With more complex electrical distribution systems, control and optimization algorithms, as well as coordination and ancillary system provision allow to efficiently manage these systems.

Paper 10156 (Switzerland) deals with a real case where large PV panels are associated with a LV network. The DSO has implemented two initiatives to deal with voltage variation issues. One consisted in the replacement of the MV/LV transformer by an OLTC distribution transformer. After that, a low voltage regulator was installed near a critical zone with PV. The paper thus analyses if the solutions are robust to further PV installation and how these solutions react to high heating loads during Winter.

Paper 10166 (Germany) defines control algorithms for flexible loads, for diverse low voltage grid configurations, without having to set individual parameters. Based on a laboratory analysis with measurement data, various variations of grid behavior are used to define grid clusters. The grid clusters are represented by three modules (urban, rural with low PV and rural with high PV), for which data is measured assessing the conditions of the network in four zones. Three algorithm variations are applied to these, and the behavior analyzed, with some results presented in **Fig. 35:**.

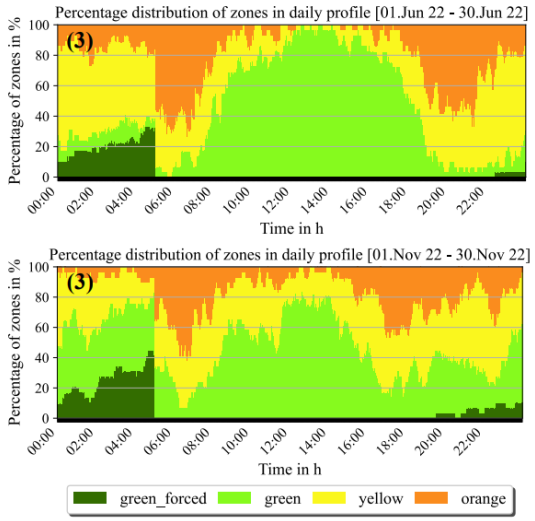

Fig. 35: Module (3), Rural PV – percentage distribution of zones per minute of a day over June and November.

Paper 10189 (Spain) proposes a method for detection and prevention of faults due to neutral interruption in low voltage networks, based on smart meter voltage records. The method uses data associated with customer overvoltage detection through alarms deployed by smart meter, or a combination of overvoltage and undervoltage in a LV feeder.

Paper 10226 (Germany) describes a model for the centrally coordinated recognition and cost-optimal provision of local ancillary services in LV grids. It uses grid-related sensitivity factors and simulations. The presented results show a positive impact of the coordinated ancillary service provision on voltage band violations and congestion management. It concludes that the use of prosumer flexibility as local ancillary services for the coordinated mitigation of violations in LV grids is beneficial for grid stability.

Paper 10238 (USA) evaluates state estimation performance on distribution circuits with high PV penetration. The simulation-based solution developed informs sensor deployment decisions for state estimations, thus avoiding overinvesting in telemetry and avoiding overloading or voltage violations that could result from lack of telemetry. The results presented evaluate the performance of the state estimator in a residential circuit with high PV penetration under both clear-sky and cloudy-sky conditions and for different sensor deployment scenarios.

Paper 10291 (U.K.) presents QUEST, a methodology enabling the control and coordination of multiple operational systems and control method objectives upon the network. The paper thus highlights the operational control methodologies associated and the creation of a digital twin to validate functional specifications of voltage control and provide KPIs associated with network operations.

Paper 10296 (UK) introduces a smart management system that addresses the challenges associated with rapid increase of onshore wind resources. It consists of the monitorization of loading at certain boundary points with the TSO network to find whether certain boundary parameters are exceeded. If they are, then instructions are sent to generators to reduce output. These instructions are based on price provided by the ESO. Therefore, the Generator Export management Scheme (GEMS) is a wide area digital management scheme delivered by the TSO interfacing closely with the ESO and the DSO, which is modular and radial to allow for the expansion to more boundaries as the increase in generators recommends it to. **Fig. 36:** provides a GEMS instruction example and the corresponding output.

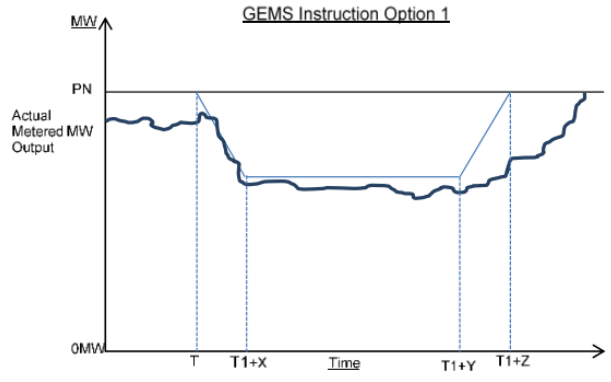

Fig. 36: GEMS instruction profile example.

Paper 10303 (France) proposes a nonlinear optimization model for finding values of control commands allowing a real-time voltage regulation of LV grids subject to increasing RES and EV units. The algorithm, based on the successive linearization of the nonlinear model, yields the optimal regulation commands. It was tested through simulation.

Paper 10880 (Poland) presents the use of a distribution transformer (MV/LV) with and On-Load Tap Changer (OLTC) to mitigate voltage issues and maximize PV production, describing a detailed voltage control algorithm. The description includes the criteria for selecting measurement points and IT security assurance of the smart metering infrastructure implemented at a DSO. Furthermore, the paper presents results of the pilot installations concerning the quality of voltage regulation and the possibility of increasing the RES hosting capacity.

Paper 11085 (Malaysia) adopts a model-based Volt Var Optimization (VVO) in a pilot project for a 33/11 kV substation, 30 MVA. The authors were confronted with lack of GIS and real-time telemetry information during the implementation period, which was essential for the model. Hence a solution for load modeling under limited telemetry and GIS information, using a polynomial load model using historic load response was developed, allowing the reduction of the risk of voltage constraints violations that would otherwise result from the lack of network observability.

Paper 11173 (Japan) describes the control of the reactive power flow from a solar inverter. The conventional method is based on a function suppressing voltage rise, which might lead to a bias since it is bases on the connection voltage. In order to address that bias, a local autonomous cooperative control method for solar inverters was developed, by sharing the information of each solar inverter. The method can also be used to control EV charging and was tested on a model including a distribution substation and LV grid, comparing it with the conventional solution.

Paper 11216 (Finland) concerns a hierarchical control architecture of primary, secondary, and tertiary controls, based on an edge computing solution, with the objective of increasing hosting capacity for DG, EV, and heat pumps. The solution was demonstrated in a real-life distribution grid in Denmark, during 2021. The paper describes the demonstration experiences and critically analysis the voltage control solution.

Paper 11419 (Germany) proposes a decentralized power grid control using a Swarm-Grid approach, which includes an exchange of measured data between components and a state grid estimation. It includes the description of the methods for calculating grid state estimation and for generating pseudo measurements in case of non-convergence of the algorithm. Additionally, worst-case assumptions are presented, which help to achieve estimates of the unknown voltages and currents, and the impact of unknown phase information is derived.

Paper 11434 (Czech Republic) describes the current state of the art in the field of energy management for three-phase asymmetrical inverters. The authors state that, due to a lack of standardization in the field, power redistribution algorithms into the three phases are done by manufacturers, hence considering the stress on the inverter

power electronics, but not the effect on LV grids. The paper presents techniques that minimize the effects on LV grids, while actively compensates for amplitude asymmetry. The technique is tested in a laboratory as shown in **Fig. 37:**.

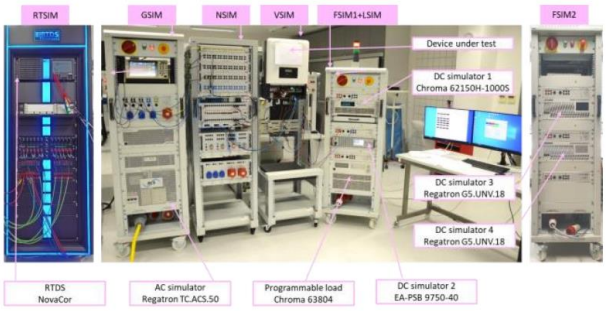

Fig. 37: Modular laboratory installation.

Paper 11479 (Japan) presents a decomposition method for determining the output of PV generation from power flow data acquired in section switches equipped with voltage and current sensors. It addresses the challenge of separating load demand estimates and PV output values from the data obtained in switches. Therefore, the authors propose a vector decomposition method that was verified to accurately decompose the power flow data into PV output and load demand using a simple distribution system model.

Potential scope of discussion

The topical of "Automation" addresses several challenges associated with Energy Transition, which increase the complexity of electrical energy distribution systems.

The increasing connection of distributed generation, particularly associated with LV grids, storage systems and new loads, including EV, demand an increase in automation. Therefore, research trends include digitalization of distribution systems, how to deal with low inertia systems in controlling frequency droop, how to use artificial intelligence tools to allow for better simulation and control of distribution networks, particularly in real-time, which is also required to enable flexibility solutions.

Smart grids also provide a tool to foster solutions to integrate renewable generation and EV, helping to manage LV networks, which are the ones where the complexity increase is more accentuated. Also, storage solutions enable the development of microgrids, which can operate in grid-connection mode or offline, with control strategies that enable a seamless transition between those two modes.

All these topics are ripe for optimization methods and algorithms, as well as state estimation algorithms based on the increasing trove of data that can be reached in real-time.

Table 3: Papers of Block 3 "Automation"

Paper No.	Title	MS a.m.	MS p.m.	RIF	PS
Sub block 1: General topics in Automation					
10116	Standard IEC 61850 based Real-Time DER Interface for the Netherlands				X
10276	Success deployment of 6 digital substations in Vietnam 2020-21 – Return of experience				X
10314	An Efficient Hybrid Control and Protection Strategy for Frequency Regulation of Low-Inertia Power System				X
10473	Practical Review and Advancements in Testing Multi-Vendor Digital Substations	X			X
10690	Frequency Droop Characteristic for Grid Forming Battery Inverters – Operation in Islanded Grids with the Infeed of Distributed Generation Systems				X
11018	Alternative Low-Frequency Demand Disconnection (LFDD) Solutions for UK Distribution Networks Implementation				X
11033	Decentralized Management of Distributed Energy Resources for Frequency Support – Finnish Pilot				X
11078	Automated MV Switching Based on AMI Data				X
Sub block 2: Artificial Intelligence					
10104	Generation of Synthetic Examples Using Generative Adversarial Networks (GAN) to Extend a Database of Fault Signals on Power Distribution Lines				X

10191	Machine Learning Based Grid Optimization Algorithm for Real-Time Applications			X	X
10378	A Physical-Neural Network Approach for Residential Load Forecasting with Dynamic Load Control	X			X
10450	Performance Evaluation of an Autoencoder State Estimator with Realistic Low Voltage Grids Reconstructed from Open Data				X
10524	AI-Based Controller for Grid-forming Inverter-Based Generators Under Extreme Dynamics				X
10597	Machine-Learnt State Estimation for Optimization in Low Voltage Distribution Grids				X
11022	Object Detection Algorithms Applied on Low Voltage Grid Equipment			X	X
11276	Edge Computing for Improving Energy Management in Smart Homes				X
Sub block 3: Smart- and Microgrids					
10249	Smart Meters for Grid State Identification with Use Case for Agent-based Local Energy and Flexibility Markets	X			X
10286	Using Smart Meters Infrastructure to Implement Smart Street Lighting				X
10305	Metric for Analysing Cooperative and Competitive Algorithms for Distributed Frequency Control in Microgrids				X
10600	An Interoperability-by-Design Approach for Designing Smart Grid Solutions				X
10603	Microgrid Control Strategy to Achieve Seamless Transition from Grid Connected to Islanded Mode				X
10604	Microgrid Realtime Control for Transient Modes: Development, Simulation and Experimental Validation in Full-scale				X
10971	LV Automation Solutions for Resilient, Flexible and Optimized Smart Distribution Grids				X
11058	Cognitive Data Fusion for Improving Flexibility in Smart Homes				X
11368	Grid-Forming Control Modelling and Validation for Distribution Systems with Networkable Microgrids				X
11480	The Smart Grid Lab in Hesse – Active Maximization of Annual Usage Time of Electrical Grids Using Flexibilities while Ensuring Data Security and Resilience at the same time	X			X
Sub block 4: Optimization					
10156	Voltage Regulations Solutions for Low Voltage Distribution Network with Large PVs Integration: Performance Analysis with A Real Swiss Case				X
10166	Analysis of Control Algorithms on Different Low-Voltage Grid Clusters			X	X
10189	Detection of Neutral Loss in Distribution Networks Using Smart Meters Records				X
10226	Optimized Provision of Local Ancillary Services with Sensitivity Factors Using Prosumer Flexibility				X
10238	Evaluating State Estimation Performance on Distribution Circuits with High PV Penetration				X
10291	QUEST – An Overarching Control Solution				X
10296	GEMS: Development of Automated Generator Dispatch for The Purpose of Maximising Built Asset Utilization	X			
10303	Voltage Regulation in a LV Distribution Network (With Renewables, Storage Systems and Electric Vehicles) – An Optimization Formulation				X
10880	Voltage Regulation in the LV Network with Variable Generation Based on Online Measurements from Smart Meters with the use of the On-Load Tap Changer				X
11085	Load Modelling for Volt-var Optimization Control in Limited Network Visibility – a Case Study in Malaysia				X

11173	Development of Local Autonomous Method for Power Distribution System with Battery Storage System				X
11216	Architecture of Advanced Distribution Grid Voltage Control Method Utilizing Edge Computing Solution				X
11419	Decentralized Grid Control Using Power Grid State Estimation				X
11434	Impact of Three-Phase Inverter-Based Generating Units with Asymmetrical Power Redistribution on the Low-Voltage Network Operation	X			X
11479	Development of Photovoltaic Power Generation Output Estimation Method Using Distribution System Sensor Information				X

Block 4: "Cyber Security and Communication"

Today, there is nearly no application in the field of the distribution grid which can live without any kind of communication. Only some local processes, mostly process with a security or safety background, can live without it. The easiest application is the integration of a sensor from the field to a control system outside from field on station side. But communication is not reduced do local application it also takes place between substation, switchgears, and mainly central situated management side where you can find Scada- or other centralized systems. Well known technologies therefore are from historically side the SDH technology which are more and more replaced by new technologies like MPLS-systems or wireless based transmission systems like 4G and nowadays 5G. But there are even more technologies and a lot of different protocols in use in the field and as we can observed there are coming many more from the side of IoT like e.g., MQTT.
The following discussion of block 3 includes these mentioned facts and also deals with the topic of cyber security, which today can no longer be separated from communication, and it is also an integral part of our current and future systems.

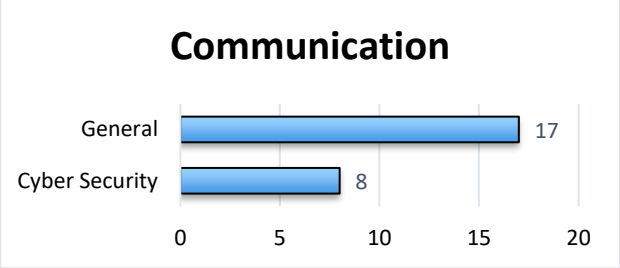

Fig. 38: Overview block "Communication" and subtopics

Sub block 1: "Communication in general"

In many cases the first difficulties start up with the integration of a new device, when new connections must be established. Even if both, the manufacture of the new devise as well as the manufacture of the existing system, e.g. a well-known control device confirmed that their devices is conformal a regarding standard or guideline, it is not sure that the connection work with a default configuration without troubles. Sometimes standards and guidelines provide a band wide which can be interpreted differently. The actual situation related to the energy transition brings the system operator increasingly more into the situation to have to integrate new participants like decentralized generation units and prosumer.

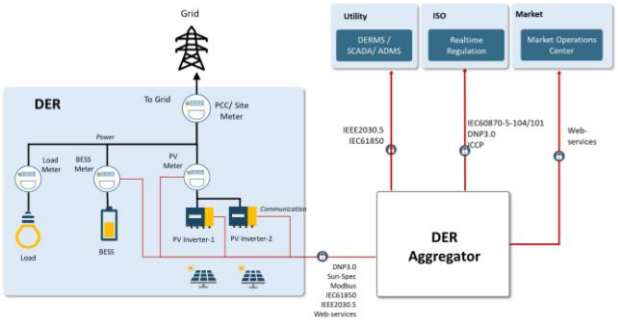

Fig. 39: Data aggregation of distributed energy resources (paper 10115)

In **Paper 10115** from India a helpfully tool, called data-hub is presented, which allows the integration of several protocols outside of well-known like IEC61850 or IEC80670-5-101/104 to integrate. It supports among other things protocols of the domains from smart inverters and IoT but also from battery storage systems, electro vehicles, consumer loads and other from the domain OT - independent of the vendor. The paper discusses furthermore how a utility data hub architecture can help the system operator to aggregate data from various devises and multi vendors. All the collected and aggregated data can be shared with a e.g., distributed energy resources management systems or virtual power plan. There is also a look to the architecture, which allows by their layered design an easy maintenance and update, which protect the investment made by utilities for a longer time.

Latency distribution	Percent of packets	
	Before packet filling	After packet filling
<10ms	14.01%	11.59%
10~20ms	69.57%	69.19%
20~30ms	12.16%	14.37%
30~40ms	3.52%	4.08%
40~50ms	0.71%	0.75%
50~60ms	0.01%	0.01%
>60ms	0.00%	0.00%

Fig. 40: Latency distribution of validity test of slicing out of paper 10128.

Today's physical communication layer in the field of electrical energy supply is mostly build on fiber optical connections between the communication nodes. Wireless transmission over the air via radio technology is nowadays still viewed critical, because of availability and reliability. But there was a big step done in direction of bandwidth, latency and reliability with the 5G standard, compared to 4G. In **paper 10128** from China the authors have done an investigation of the suitability of 5G for protection and control task. Therefore, in a first step is a definition of requirement done, because depending on the application there are quite different requirements to the communication. This is, in the view of the authors, also a reason for the partial lack of acceptance. Communication service provider often do not know the quantity and quality requirements of the application behind the communication

in the field of distribution system operator and for the supplier there are to less tests on communication available for wireless communication solution in the protection and control area. So, in the paper the latency and 5G timing accuracy requirements are analyzed depending on the network schemes and the application behind. One knowledge out of this work is very simple, namely that a direct transforming one by one from communication schemes from previous protection functionalities to 5G is possible but it does not ensure the best performance. There were done a lot of other tests in the paper e.g. for a feeder automation, for a distributed self-healing system, for the current differential principle and also for phasor measurement units in the distribution grid.

As well as paper 10128, also the authors of **paper 10204** from France propose a 5G solution on their issues. They use it for the protection of islanding grid. The requirements are e.g., to switch off in case of an outage to the connected voltage level within 50 milliseconds. Said in a simple form that is the maximum allowed time for telecontrol tripping. The goal of the presented paper is also to demonstrate the availability of 5G and also to show that this technique is sufficient enough to detect an islanding grid by a save way. The objectives set for this paper are furthermore the validation of the correct operation of telecontrol trip commands, more knowledge about latency and stability and at least a very interest point of view, the comparison of the performance and of stability between 5G and the elder 4G-technology.

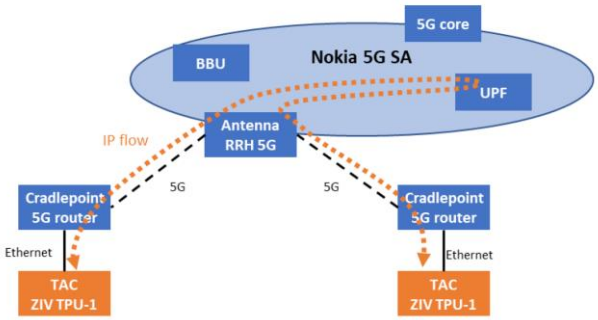

Fig. 41: Cellular connectivity setup out of paper 10204.

At the integration of renewable generation, but also at the resulting consequence of microgrids that can be arise as follow-up, must be concerned to be as well observant and controllable as practical and manageable in a usable way. There are several approaches how to do this. One such approach, which is considering interoperability, flexibility and reliability is presented in **paper 10256** from Sweden. This one is based on IEC61850. Although IEC61850 is more or less established, there is still potential left to improve the data model for the distributed energy resources regarding to micro grid applications. The authors present a step wise controller architecture on three levels as well as associated communication architecture with a IEC61850 based data modelling. The result is a suggestion to all concerned grid operators and to the development.

In many cases the physical communication connection to all the new participance in an active power grid is a big challenge. One the one hand, sometimes they must be built firstly and on the other hand sometimes, already existing connections cannot be used because their latency or band wide is not sufficient for the desired application. Paper 10299 from Italy focus exactly this topic and gives a suggestion for a strategy to design and handle different physical communication links like fiber optical, wireless via LTE and even so via satellites. They take into account properties like the before mentioned latency or the band wide and they rate these different kinds of connection in relation to economics, territory population density (rural, urban) and finally also by the necessary quality of the service.

Like the previous paper, also the **paper 10352** from Finland set its focus on the suitability of different communication technologies in relation to todays and tomorrows requirements in critical parts of system operation but also in not so critical parts. It contains an overview of the latest communication technologies and present as outcoming the presumably necessary technology for the most critical part and also the most likely sufficient technology for the rapidly expanding automation technology in the distribution grids. In comparison to the previous paper here is the consideration additional to fiber optical, cellular mobile and satellite also on technologies like other mobile and local wireless area networks as well as on ultra-high frequency radio, cloud computing and edge computing. They compare these technologies, give for each one a use case and also a commendation regarding the benefit of using this technology.

Missing communication connections can be built today, under neglect of reliability and availability, easily by cellular mobile connections. Especially if they are in urban areas where you can find typical anywhere a well network coverage. But in consideration to the costs, the solution presented in **paper 10643** from India is probably more economical, since it is built with very simple and provider-independent means. The paper introduces a mesh network, based on radio frequency connection at 866MHz, which is in India and also in many other countries a free usable radio frequency. The built mesh grid has a relay node of the mesh in every low voltage distribution box. These ones are typical not more than some hundred meters from each other, so this fits well with the reachable range of the used band wide. The featured applications are e.g. transmitting current and voltage measurements or binary information like fuse states and short circuit indicators. This communication design can be seen as last mile from a nearby substation or switchgear to any sensor in the field of low voltage.

SMU -> SSC600	Mean [ms]	StDev	Median [ms]	90-tile [ms]	< 5 ms [%]	< 10 ms [%]	< 20 ms [%]	< 30 ms [%]	< 40 ms [%]	< 50 ms [%]
UL delay	10.55	2.58	10.17	13.85	0.46	46.90	99.57	99.99	99.99	99.99
UL jitter (abs.)	0.43	0.81	0.22	0.33	99.34	99.99	100.00	100.00	100.00	100.00
SSC600 -> SMU	**Mean [ms]**	**StDev**	**Median [ms]**	**90-tile [ms]**	**< 5 ms [%]**	**< 10 ms [%]**	**< 20 ms [%]**	**< 30 ms [%]**	**< 40 ms [%]**	**< 50 ms [%]**
DL delay	7.91	1.78	7.95	10.25	3.44	85.82	99.99	100.00	100.00	100.00
DL jitter (abs.)	1.95	1.48	1.97	3.89	98.94	99.94	100.00	100.00	100.00	100.00

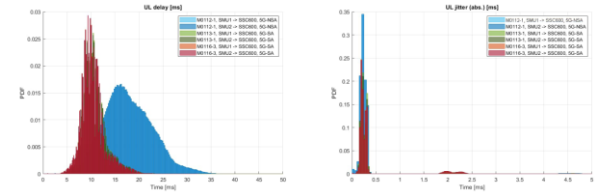

Fig. 42: Distribution of uplink latency and jitter for sampled value streams in 5G networks out of paper 10725.

To operate a smart gird the observation and control is on task that must be solved. There are many different ways to do this, and many solutions are using cellular wireless technologies like 4G or 5G. But behind a 5G network in most cases there is today still an ordinary core network which restricts the communicated benefits of 5G such as latency, response, and transmission performance to a level of 4G. Exactly this issue is one of the core contents of **paper 10725** from Finland. They have done an investigation of the potential of 5G SA (standalone) in combination with EDGE-computing for smart grid applications and did this by building a pilot application on which many related measurements have be done. The paper shows perspectives that can be derived from the data obtained. A second aim of the paper is to highlight differences in the communication between 5G SA and ordinary 5G NSA (not standalone) based on preliminary measurements in quality of services in commercial 5G SA networks.

Standardization in communication had become a very important role, because without standardization more or less no communication among different manufacturers take place. But despite standardization, e.g., through IEC61850 interoperability cannot taking place in each use case because there are degrees of freedom in each standardization. Therefore, from a user point of view, a further additional standardization on the level of user must be done to close and clarify these gaps to reach the state of interoperability. The **paper 10760** from Portugal is addressing this topic because they have recognized that it become an increasingly relevant to reach the real level of integrability. In their opinion without a real interoperability no fully digital substation is possible. The paper describes the strategy to specify the necessary parameters of IEC61850 which must be fit to transform the standard in a way of interoperability for the utility in use. Therefore, a definition and revision of all necessary signals, independent if they are transferred by MMS or GOOSE, was done, and based on this new logical nodes and data objects, according to IEC61850 standard were built. Beside the goals of interoperability, they also will reach at the end an easier implementation, independent of the integration by manufacturer or system integrators, in case of different use cases of implementations, as well as a more automatically maintenance in the authors meaning.

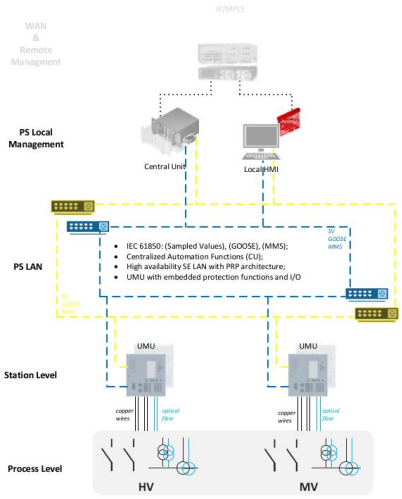

Fig. 43: Proposed high-level substation architecture for protection and control systems from paper 10816.

Paper 10816 from Portugal deals with the question of the future system design in primary substations. As they mentioned in their paper a suitable design and the architecture of future devices for protection, automation and control systems are a key aspect in improvement and optimization of tomorrows digital substations. The paper analyses today's secondary system designs based on capabilities of nowadays protection and control devices and proposes an architecture for future implementations with an interesting discussion of the expected advantages but also disadvantages. The main different to other proposes, which often consist of specific devices for protection and measurement units for each bay in a redundancy way and which also need an accurate time synchronization is, that the proposed design in this paper focus on an multi device which merges all protection and control functions as well as further different digital and analog interfaces in the same device which they call Unified Merging Unit or in a short way UMU. It is also shown that the proposed approach needs no major changes in embedded systems and so a feasibility is given.

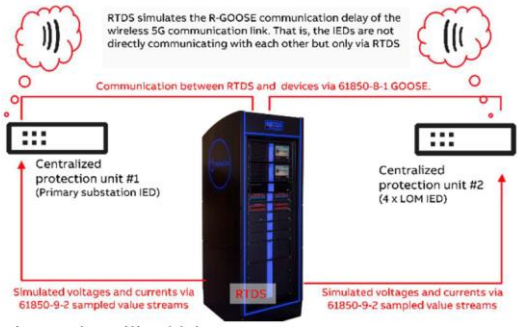

Fig. 44: Utilized laboratory test setup out of paper 10999.

Islanding grid segments as part of smart grids are involving in the operator's view, who is primary responsible for the compliance of voltage and frequency band, new challenges. Not only the mentioned legal requirements must be fulfilled also the resulting changes in operation,

like a missing neutral point connection in the islanding grid, which influence essential the behavior of operation must be managed and in not to forget the human safety as follow up. For this reason, the **paper 10999** from Finland deals with the question how to detect a loss of main grid by unwanted tripping and how to continue an ordinary and stabile grid operation. For this reason, the paper presents a concept for a wide area protection design to reach enhanced resiliency against losing the main grid and also against system wide events in voltage and frequency. The proposed method includes a 5G based intertripping function to decentralized electrical resources, furthermore the whole communication of the proposed approach is built on 5G communication and one further main content inside the paper is the suitability of 5G for such an application. The presented scheme was additionally verified by a hardware-in-the-loop simulation. It is to be mentioned that on the one hand the content focuses on the possibility of a fast detection of islanding over 5G communication and that all generating grid users are disconnected via inter-tripping signal in case of such a detection if the availability of 5G is given at that moment. On the other hand, the focus is on supporting grid stability and resiliency in case of recognized events on the side of the main grid by a centralized detection and decentralized blocking of protected generation unit also via 5G based telecontrol inter-tripping to avoid an over functionality.

The communication in the field of system operation was being also transformed by the time, starting from wired communication connections over direct fiber optic links as well as links on multiplexing techniques (e.g., synchronous digital hierarchy – SDH) for critical services, to nowadays IP-based communication on switched networks like multiprotocol label switching networks (MPLS) in different versions (e.g., MPLS-TP, IP-MPLS).

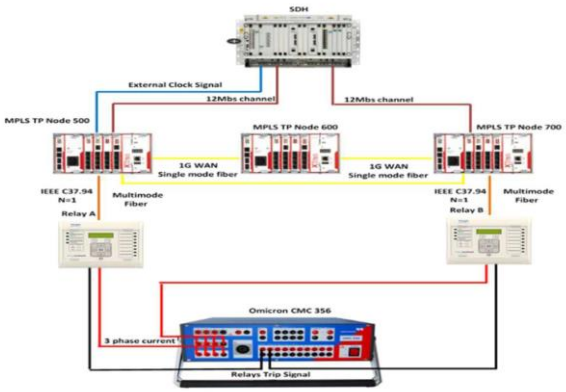

Fig. 45: Test architecture for a proof of concept with SDH live communication network out of paper 11042.

In **Paper 11042** from Belgium, the Performance of the MPLS-TP technology is tested in a proof of concept for usability for tele-protection applications. Therefore, they investigate different proper's like the general timing behavior but also the timing behavior in case of a rerouting process as well as the service reliability and availability. In additional to considering the automatic protection switching with always constant and symmetrical round-trip times they set the focus in their test also to zero packet loss. During the proof of concept, they tried to address testing the communication, simulating the power grid by a real time simulation system and the integration of the calculated signals to the test process via amplifier. By this way the whole functionality of the system and the behavior of involved protection relays from different manufactures could be tested.

As the paper before, also **paper 11124** from Spain focus the work on properties of a special communication technology namely the communication on power line (PLC) which is today a recognized technology for the last mile communication from substations to the point of smart meter. Meter data should no longer only be used for billing systems and services like remote connect and disconnect operations, they can be further used for e.g., state estimation applications in the field of system operation. But powerline communication has also some disadvantages like significant latency as well as differences in the latency itself, which in turn makes optimized state estimation difficult. Therefore, to learn the behavior on one side of communication and on other side of state estimation systems in case of different latency, a tool was developed which can emulate this behavior of different types of latency in PLC-communication in a flexible and accurate way. By this way a modelling of time delay in measurements can be simulated and other applications, which based on this data can be easily optimized. One main property of the presented simulation system to mentioned is the capability of emulating communication delay of real systems based on statistics extracted from real measurements.

First papers to the todays standard IEC61850 were published nearby 20 years ago. It has been announced as the "standard" in power engineering. If we look nowadays, we can find many applications based on IEC61850 but there are in minimum as many applications without IEC61850 because the acceptance is not in the minds of every people involved. **Paper 11207** from Austria collect and discuss exactly this topic by pointing out 4 main topics which may be a cause of this. Many problems of acceptance and usability according to the engineering process already could be solved in the past but there are still many issues left. The first one, focused on the paper is the often differently seen term of the centralized protection. This is mostly seen indirectly with the term of virtualization and in real not right because centralized could also be a physical device. The second Topic the author addressed is a resilient time synchronization, which is an essential content of IEC61850 based communication structures. In the third chapter the focus is laid on the process of measurement delivering, in particular on a holistic application of sampled values. Finally, the author highlights an often-discussed topic of testing in combination with possible data encryption. In this last chapter, a clarification regarding the convergence between testing and cyber security can be found.

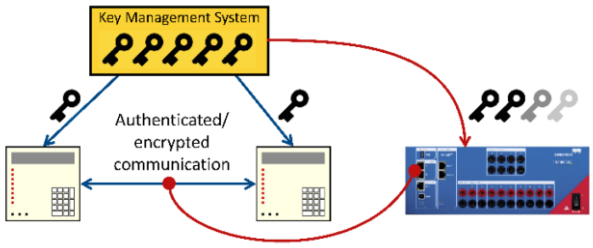

Fig. 46: Key management system and test set obtaining decryption keys out of paper 11207.

As mentioned in the previous paper, the standard IEC61850 is not yet used across the board but in areas of research and development it can be found in many applications. Also, in **paper 11373** from Germany, where it is used for the whole communication. The paper presents a framework for a virtualization-based simulation of smart grids with the possibility of a scalable integration of participance of generation and prosumer, including their load profiles. The suggested approach also includes a setup of a dynamic software-in-the-loop simulation environment with the possibility of integration a high penetration of decentralized generation. The communication between the virtualized grid users and the distribution grid management system is realized on IEC61850 and the standard is also used to model the data structure and logic of the field communication units. The author also mentioned, that in the real time software-in-the-loop environment all virtualized logical systems are running as intelligent electronic device (IED), which contains also a simplified IEC61850 data model structure. As well as the observation and monitoring, also the control of PV-container are executed by the same IEC61850 communication connection. The paper shows, that the proposed framework can handle a high scalable arrange of devices because one featured simulation model contains 100 PV container and 200 household as a container, each presented by an own load profile.

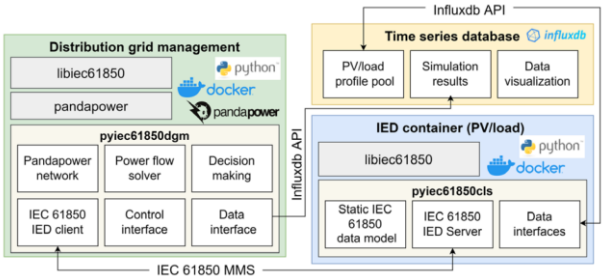

Fig. 47: Schematic representation of the software-in-the-loop simulation setup out of paper 11373.

Building and integration of smart meter and the therefore necessary communication started in many countries 12 to 15 years ago or may be in some places that took place earlier. Today, the therefore responsible technique in system operational are talking again about this topic because there is a necessary system renewal (end-of-life circuit is reached) in the meter infrastructure and also in the system design of communication, including a new hardware on actual technical standards, required. The challenges of this change, but also all the resulting new possibilities regarding an increase in visibility and observability in the lower voltage level is discussed in **paper 11389** from Spain. The paper mainly focusses on broadband over power line (BPL) with much higher bitrates in the range of megabit per second in comparison to today's ordinary power line communication (PLC). This could be an enabler for an additional providing of real time services for automation and control through the low voltage grid assets, to the well-established communication services for the smart meter infrastructure. Such a solution can bring by side the voltage and load values important information's like fuse- and protection-states but even more states of voltage regulators and line coupling positions to the system operator's control center (Scada), which enhance the visibility, the observability, and the possibility of control to the system operator. The authors describe in their paper further an approach of architecture for the expected evolution in the low voltage grid which gives a better understanding to recognize and understand the benefits, but also the limits of such an approach.

The final paper in the subsection of the general communication set back the focus to the standard of IEC61850 according to the part IEC61850-9-2 for sampled values. As well as Goose from part 8 which is nowadays on many places in use, also the part 9-2 for sampled values should be established and that means an engineer or user have to understand that part in practical use because otherwise there will be no acceptance like already mentioned in paper 11207. To do this, in **paper 11506** from Brazil an interoperability test is presented, which combines the IEC61850 sampled value stream with a real-time hardware-in-the-loop simulation in one test set, because a real-time simulation and the IEC61850 is in the view of many technicians a perfect match. These tests were done several times in real-time with two different real-time simulations manufacturers, namely OPAL-RT and Typhoon HIL. The simulation allows engineers to get a better understanding in an easy, reliable, and affordable way. Out of the business point of view the simulation can reduce risk associated with interoperability issues and safe up investment by getting preliminary studies involving accurate time simulation.

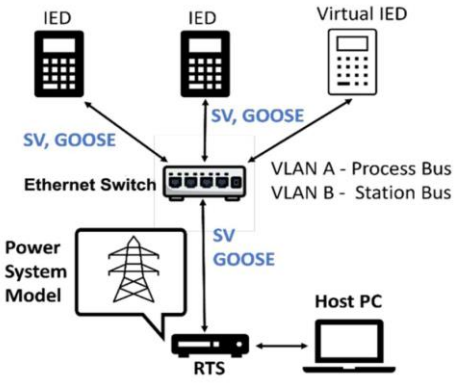

Fig. 48: Scheme of a hardware-in-the-loop test-set for IEC61850 testing out of paper 11506.

Sub block 2: "Cyber Security"

A topic that is nowadays in each application present is the cyber security. As well as system operators have to operate an electrical grid, they also have to operate the data grid behind this electrical task with all its facets. So, the collecting electrical data from the distribution grid turn over to an additional collecting and analyzing of data flow in central but also in decentralized communication networks as well as observing the wide area links to interconnect this links. But there are still some more actions necessary to build a resilient data communication grid like reconsidered network architectures that take into account horizontal and vertical segmentation, centralized managed systems and role based access control on devices, encryption in critical communication links preferably in the area of public hosted communication equipment's, a public key infrastructure for automatically exchange and managing of public and private keys to ensure the goal of integrity and confidentiality, the often forgotten physical access control and many protective measures more which must be combined, into several layers of protection that build on one another in order to achieve a specific protection goal, which must be defined in accordance with a risk-based approach.

An active network management strategy as well as the control of those participance require accurate data and strong defense against cyber-attacks. **Paper 10429** from Belgium is an answer from the side of cyber security to the increasing complexity of power flow in distribution systems and the therefore needed communication to new participance without an established trust status. The main question this paper aims is, if it is possible to monitor the contractual requirements of the grid user, e.g., a renewable generation, within the therefore essential framework for active network management with sufficient resilience to the cyber security. The author's investigation on the emergence of distributed ledger technology, such as blockchain technology, shows that this one could have potential regarding data storage and monitoring while offering a high degree of resilience against cyber-attacks. In the paper they give an overview about distributed ledger technology and highlight the functional features to be implemented. Further they also comment the implementation and finally the assessment on cyber security.

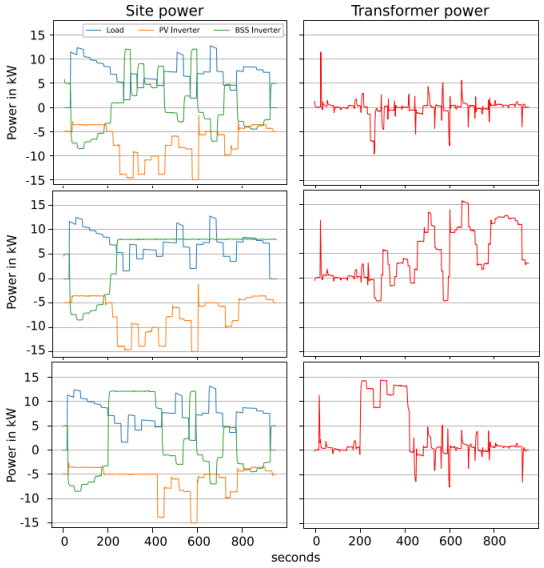

Fig. 49: Testbed results out of paper 11506. First row without attacks, second row with DoS-attacks and third row with command manipulation.

As the previous paper also, the **paper 10446** from Germany addresses the upcoming and continuously increasing risk on cyber security. As well as the integration of communication technologies in distribution grids presents new opportunities for active grid management, it also increases the need for security against outage and cyber security in the authors meaning. Investigation on life systems in operation are in case of testing cyber security, e.g. in kind of penetration test, not welcome from operator side because they involve high risk of unforeseeable events. That's why the suggested solution in this paper replicate the test scenario into the virtualization to a 1-by-1 replicate of the system to be tested within a laboratory environment as digital twin. By simulations in this environment the communication infrastructure for secure operation can be study in a safe way. Further, the presented cyber physical approach combines the emulation of communication environment as well as the simulation of the power grid in a common module.

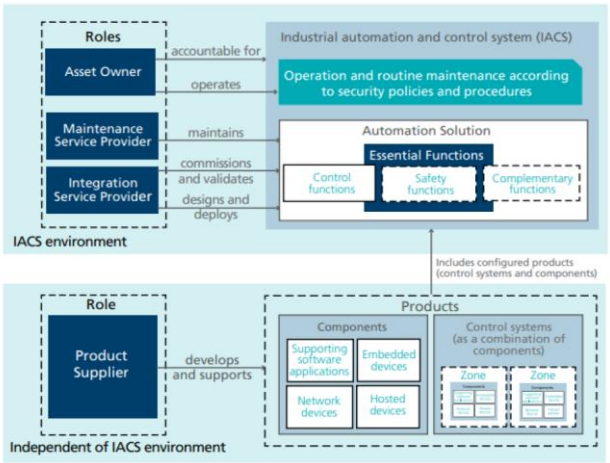

Fig. 50: Different stakeholders, defined by IEC62443 (paper 10612).

As well as standards like IEC61850 or IEC60870-5-104 are needed to definite the communication between two participance, there are also standards like IEC62351 or IEC62443 necessary to ensure a common understanding and level of security. Especially the last mentioned is one which is permanently in discussion in the field of transmission and distribution system operation even if this is actually designed for industrial automation and control systems. So, not each part of this standard can be mapped to applications in distribution systems but there are many parts that make sense that can be used. Exactly this topic is addressed in **paper 10612** from Finland. They do an investigation on how far the standard IEC62443 is useable in power grid systems. Analyses shows that the domain of operational technologies is more vulnerable as conventional information technology because in operational technologies the ratio of benefit to cost is not given and also necessary measures like applying patch or change managements is a big challenge. There is also in most fields of operation a gap to cyber security knowledge to be bridged but this cannot be done in a short term of time. A possible bridging to a final solution is following standards. Looking forward to cyber security this standard is IEC62443, which provides a series of requirements and methods to manage security challenges in the before mentioned field of industrial automation and control systems. Since not all parts are useable for electrical distribution systems, the authors have analyzed 14 different security measures that a system operator shall adopt as minimum baseline controls and how IEC62433 standard with different parts of it can support the baseline controls.

When we talk about cyber security not only the communication environment of the high and medium voltage level is in focus, also the low voltage level must be considered within all its prosumer like decentralized energy resources, activatable loads and also the whole charging systems of electro vehicle, which seems to be more and more important with constantly increasing participants in this field. Therefore **paper 10777** from Italy picks up this topic and considers the interconnection between smart electric vehicle charging devices and the operational grid behind the charging point, which builds a complex and cyber physical exposed risk to new threats and vulnerabilities. The authors pointed out that cybersecurity and resilience aspects have to be addressed at different levels in this environment. So, the paper presents a secure and resilient IoT and cloud-based infrastructure for electric vehicle recharge systems and focuses on real-time collection and analysis of network traffic features to evaluate appropriate resilience indicators. The paper also pursues the approach of the security-by-design principle where the cybersecurity measures and anomaly detection capabilities have to be considered and implemented starting from the first stages of the infrastructure development.

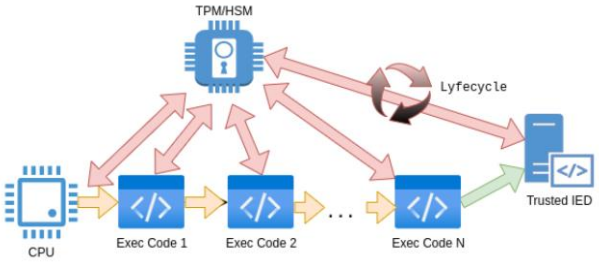

Fig. 51: Trust maintenance along a software chain of necessary components (paper 10808).

Today, security is a basic need in the whole communication of a system operator. To reach security it is important to start with it in the system design of product development. At this point, there starts the chain of trust because trust is one basic to gain integrity and confidentiality. In **paper 10808** from Spain the chain of trust is discussed, furthermore they focus also on the root of trust. The paper deals with the subtopics of a concept of trust and the root of trust in energy distribution grids as well as with the chain of trust in the energy distribution grids. Therefore, the authors show several examples like e.g. the process of trusted boot with the help of a trusted platform or a hardware security module. Also, in case of chain of trust there is given an illustrative example of an initial verification which is chaining to the subsequent software modules. Another important issue which is addressed in this paper is the necessary possibility of maintenance of trust along the whole lifetime of the devices and components in use. That is one of the biggest challenges in the environment of the rapidly developing information security because the average lifetime of technical devices for protection, automation and control functionalities is clearly more than this. Looking ahead services like public key infrastructure and mechanisms like chain of trust get more and more relevant because it can be already today seen, that in future for example executable code not only depend on local code, code will be dynamically added to devices and functionalities during run time at user request. The source of that code can be found inside the domain of system operation, but it can also be outside on manufacture or service provider side. One discussed approach for solving this use case could be the block chain technology. Finally, the authors address the to do's on manufacture side by mentioning the need in change in future device design. Here it will be necessary to separate critical applications and isolate them into trusted zones.

In practical use the topic of cyber security is not easy to integrate in substation and switchgears but today's increasing convergence of IT- and OT-domain make it necessary. So, the need of available information without compromising the integrity or the confidentially lead to strict focusing of security within the secondary technology. In **Paper 11181** from United Kingdom is done an investigation on the practical implication of creating and managing cyber security solutions in protection and

control devices (IED) of today's substations. The paper discusses a suggested system concept which addresses the defense in depth principle for the environment of substations and the authors also present a secure architecture for this. One of many challenges which is also discussed, is the managing of security features within the substation, containing products of several vendors. This covers topics like role base access control, authentication server, event logs and firewall. But in many minds the most important fact is to involve human resources. The authors point out that in practice it is absolutely required to have domain experts for each technical domain, especially for the security aspects. But there is also the need to have open minded protection and automation experts which work hand in hand with the experts of the other domains. In summary, this paper deals with the question how to bring technology, processes, and different employees together so, that they work towards the same goal.

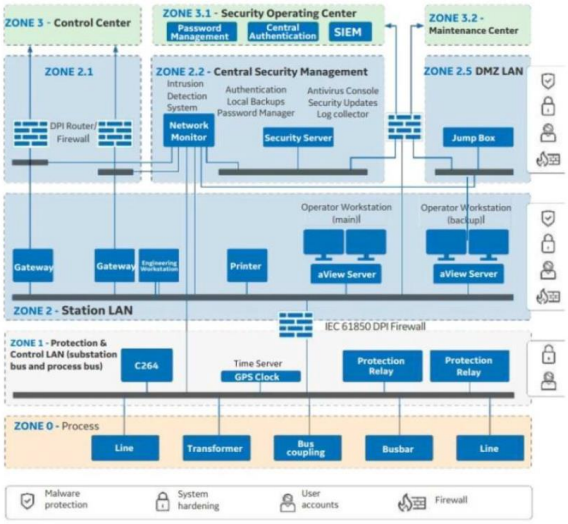

Fig. 52: Example of a secure system architecture mentioned in paper 11181.

As already some of the papers before, also **paper 11197** from France set the Focus once again on the topic interoperability. On the one hand you can found end of life circles of around 15 years and more, which encourages slow evolutions of the systems in favor of more stability, and on the other hand, driven by the increasing digitalization in the field of power grids, systems get more and more open (e.g., remote maintenance) and give in this case more risk potential for cyber security. In the paper the authors consider the combination of necessary remote maintenance, aging devices and resulting vulnerability regarding to cyber security, which represents a certain potential for conflict. Further it must be considered that these systems contain a large number of manufacturers and suppliers which also have once again different end of life cycles. In detail the paper highlight in this context three challenges, namely flexibility to remain future-proof and interoperable, simplicity to ensure future maintainability with reduced human resources as well as competency and skills of operator staff. The paper suggests there for three keys to manage this. The first one addresses the maintenance tools and processes with a reference to IEC62443 and IEC62351. The second one addresses the innovation e.g., virtualization technologies which can also be a disruptive lever and the third on is the further standardization which is strong required to reach interoperability. One of the core statements of the paper is that a multi-vendor system should be increased regarding cyber security step-by-step throughout its whole life circle, starting by simple and pragmatic measures like secure architecture and going on by defense-in-depth as basic for following measures which are possible from device or vendor side.

Fig. 53: Why IEC62443 (paper 11197)

As many times in previous papers mentioned the standardization is a great enabler in the communication and the security but it also costs system resources e.g. for date encryption. The way how different measures should be done is defined in the standard IEC62351. But there are still degrees of freedom in the standard which allows a manufacture or system integrator to choose between a couple of different profiles in their execution. And exactly these choices make a main different in the performance of security measures in operational. In **paper 11474** from Italy a software tool is presented which allows an evaluation of different kinds of implementation of security measurement regarding the performance of each measure in view. The software is implemented on laboratory and designed to carries out monitoring the communication between electrical substations and multiple distributed resources by using IEC61850 as communication standard, security is applied according to IEC62351-3. Within the shown test scenario, the authors use transport layer security (TLS) to provide integrity and confidentially in communication. As mentioned before the standard allows different profiles which ends in different performances in operation. With the developed software solution, it is possible to measure several indicators to classify the different profiles using key performance indicators (KPI's) for this evaluation. Thereby the authors could detect significant performance differences which can be further influenced by system communication design and operational choices. The presented paper also highlights that along the communication link the latency is not linear and constant. Whit this knowledge and the possibility of use of various communication technologies like Ethernet, WiFi, ADSL or 4G and the knowledge of their behavior it

is possible to optimize the process despite security measures regarding performance. There are many other highlights and possibilities that the developed platform offers, which can be read in the paper itself.

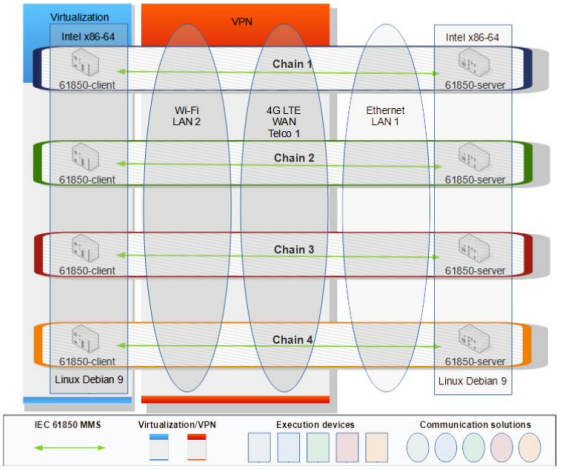

Fig. 54: Adapted 4G LTE WAN connection between a physical and a virtualized machine, protected by VPN solution out of paper 11474.

Potential scope of discussion

The topic of communication for themselves, independent of any other protection, automation, or control functionality, becomes in combination with the information security in the technical environment, that can no longer be ignored today, even more importance.
Legal requirements and technical rules have given this topic a framework on a new stage during the last view years. But it is recognizable, that the ordinary information technology departments and their devices and concepts, regarding to security, have been dealing with it for many years and the technical sector is only at the beginning or is just getting going.
The presented papers address as well practical as scientific topics in relation to communication and cyber security. Some of them are already in the field and some others are in laboratory environment in test state may be close to operational use. It can be seen that regarding to communication the standard IEC61850 is more or less the only one to which references are made in different papers. In the field of cyber security, regarding to standards, there can be mentioned IEC62443 in the organizational point of view and IEC62351 in the operational point of view. The main topics in the general communication can be found in the system design and the architecture of today's communication platforms as well as in up-to-date technologies regarding the physical connection like MPLS and 5G. Nearly the same image can be found in the field of cyber security. Here also a main topic is given by the system design as an enabler for the integration of security measurements. This should also be designed in a way to guarantee exchangeability because there is not such big end of life cycles as the technicians know it from existing secondary technology. Finally, it is to emphasize that testing of security in the meantime take also place in virtualization environment and at the block of communication not really present but in real already in operation is artifice intelligence regarding to anomaly detection - perhaps an interesting topic for future events.

Table 4: Papers of Block 4 "Communication and Cyber Security"

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
Sub block 1: *Communication*				
10115: Data hub based secure integration of DER Assets with Utilities, DSO and Retail				X
10128: Shanghai Science and Technology Committee Rising-Star Program(20QB1400500)				X
10204: Innovative 5G Transmission for Anti-islanding Protection in MV Distributive Network				X
10256: An Implementation of IEC 61850 for Microgrid Control		X		X
10299: TLC Strategy for Power Distribution Grids				X
10352: The Potential of Emerging Communications Technologies in Distribution Grid Management				X
10643: Use of Low-Cost RF Mesh WAN Based Feeder Pillar Monitoring System				X
10725: 5G Edge for Power System Applications			X	X
10760: E-REDES' IEC61850 Specification for PAS Interoperability				X

10816:	Primary Substation Protection and Control System: Future Architecture Proposal				X
10999:	A 5G Communication-Based Wide Area Protection Concept for Enabling Resilient and Reliable Loss of Mains Protection				X
11042:	Validation Of MPLS-TP For Tele-Protection / Current Differential Protection Services Via Proof of Concept				X
11124:	Building a Realistic Sampler to Emulate Communication Delays in PLC-Operated Low Voltage Networks				X
11207:	Four Problems for Digital Substations I wish to be solved		X		X
11373:	Concept and Implementation of a Gird Simulation Framework Utilizing Containerized IEC 61850 Compatible IED				X
11389:	Low Voltage as the final frontier for Broadband over Power Line				X
11506:	Real Time Digital Simulation and IEC 61850 Standard: Interoperability Test Between OPAL-RT and Typhoon HIL Simulators				X
Sub block 2: *Cyber Security*					
10429:	Distributed Ledger Technology for Monitoring Operations Carried out on the Embedded Generation Units				X
10446:	A Cyber-Physical Twin Approach to Replicating Realistic Multi-Stage Cyberattacks on Smart Grids	X			X
10612:	Is the Cybersecurity Standard IEC62443 Applicable to Distribution Substations?				X
10777:	Secure and Resilient IoT and Cloud-Based Infrastructure for Electric Vehicles Recharge Systems				X
10808:	Root/Chain of Trust in Complex Energy Distribution Systems			X	X
11181:	Operational Considerations for Substation Security				X
11197:	Interoperability Raises Two Challenges: Cybersecurity & Maintenance				X
11474:	Performance Evaluations for The Configuration of IEC 62351 Cybersecurity Profiles In Energy Telecontrol Scenarios	X			X