Special Report

Your guide to Session 4

PROTECTION, CONTROL & AUTOMATION and COMMUNICATION

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Introduction

SESSION 4 deals with the topics **Protection, Control & Automation and Communication**.

For CIRED 2025 we received about 182 abstracts, which show the high importance of the topics. The quality of the abstracts was very good. 163 authors were asked to submit a full paper. Finally, we received 131 full papers. The abstract and paper selection was supported by the National Committees and the Session Advisory Group. The final decision has been made by the Technical Committee (TC) Session 4 Team. **Fig. 1** gives an overview of the reviewing process.

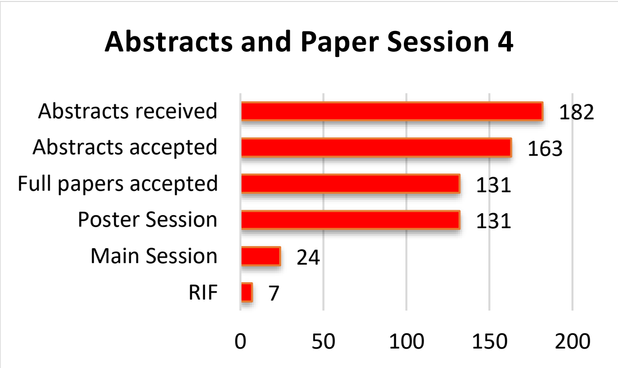

Fig. 1: *Review process overview*

Session 4 contains 3 thematic blocks, Protection, Control & Automation and Communication.

The topics of control and automation are very difficult to delineate and are therefore summarized in one topic block.

To provide a better overview, we have divided the main topics into subcategories.

From the accepted papers, 24 were selected for a presentation in the main session. 7 young academics have the opportunity for a presentation in the RIF session. All authors of the accepted papers are asked to present their work as a poster in the poster session. Error! Reference source not found. gives an overview.

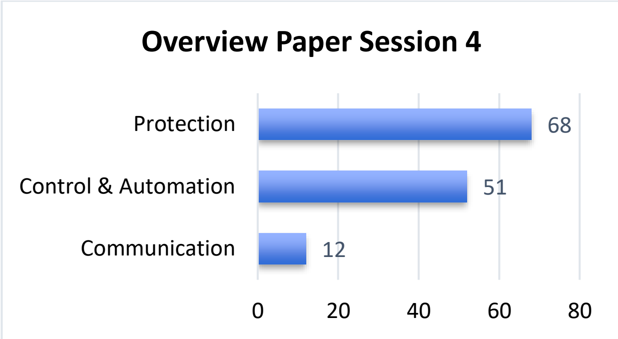

Fig. 2: *Paper overview of blocks in Session 4*

It can be seen that the focus is clearly on protection issues. As at previous Cired conferences the topics of earth faults and fault location take centre stage.

Session 4 is organized as follows:

Block 1 Protection

Sub blocks:

1 General
2 Algorithms, Simulation
3 Virtualization
4 Applications and Functionality
5 Earth fault
6 Fault detection and location
7 DC Protection
8 Testing

Block 2 Control and Automation

Sub blocks:

1 General
2 Application
3 Control Architecture
4 FLISR, ADMS
5 Control DER
6 Optimization, Algorithm

Block 3 Communication

Block 1: "Protection "

In the block "Protection" we received 68 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.**

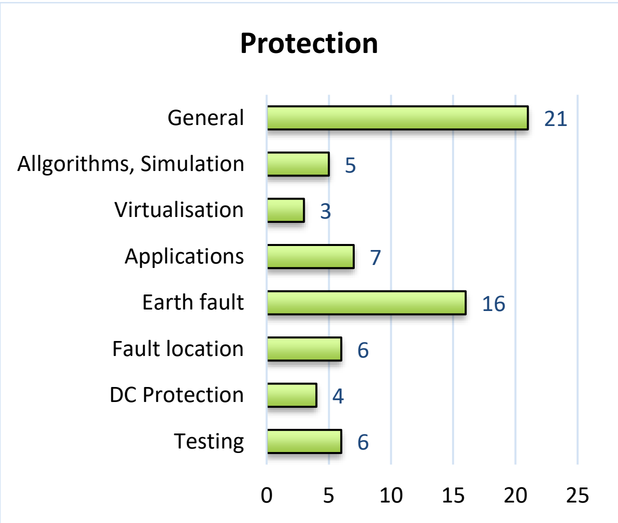

***Fig. 3:** Overview subtopics of the block "Protection"*

Sub block 1: "General protection issues"

In this subgroup we have summarised all contributions that cannot be assigned to any of the other blocks. These are general protection topics.
Faults in large rotating machines, generators and motors can have a major impact on the grid. **Paper 42** from India describes an air gap-based eccentricity detection for induction machines and its practical validation. The proposed method uses the external leakage flux information from multiple sensors to detect and classify the eccentricity conditions by evaluating specific signature components. **Paper 79**, also from India, analyses the energy of fault currents distributed over different frequencies to localise faults in induction motors.
Paper 212 from Germany describes how useful digital twins and test systems can be for fault analyses.
Paper 311 from Korea describes a comparison logic of the fundamental current magnitudes utilizing discrete fourier transform has been added to the conventional direction-based protection coordination algorithm. The goal is to detect protection coordination failures in a loop distribution system.

The **paper 446** from Portugal discusses technical and economic aspects of adapting the protection system, costing about 20% of line uprating expenses. It concludes with cost-effective strategies for enhancing system reliability and safety by focusing on protection system adjustments rather than extensive physical upgrades.

How to monitor and analyse the Underfrequency Load Shedding (UFLS) performance is the topic of **paper 456** from Portugal.

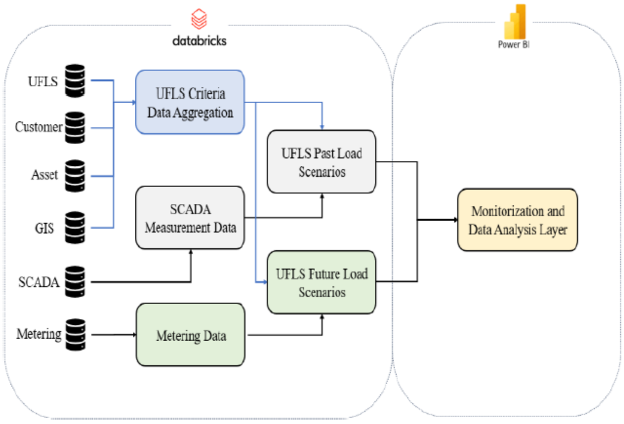

***Fig. 4:** Simplified diagram of the proposed algorithm*

E-REDES designed an algorithm that combines the calculation criteria data and current allocation of MV feeders to each frequency step with Supervisory Control and Data Acquisition (SCADA) historical measurements or MV site metering (**Fig. 4**: Simplified diagram of the proposed algorithm). The UFLS topic is also discussed in **paper 579** from Portugal. A Databricks platform is used to utilise data from various E-Redes systems and incorporate it into the UFLS algorithm.
Paper 545 from the USA presents multiple case studies where high-fidelity waveform data was used to diagnose medium-voltage protection misoperations, and, in some cases, correct the underlying causes. Two examples where advanced waveform monitoring notified utilities proactively about protection misoperations, are presented.
Paper 553 from India attempts to showcase protection validation through SCADA ADMS system on real time network & actual data. The Protection Validation application of SCADA ADMS identifies unprotected or improperly protected zones.

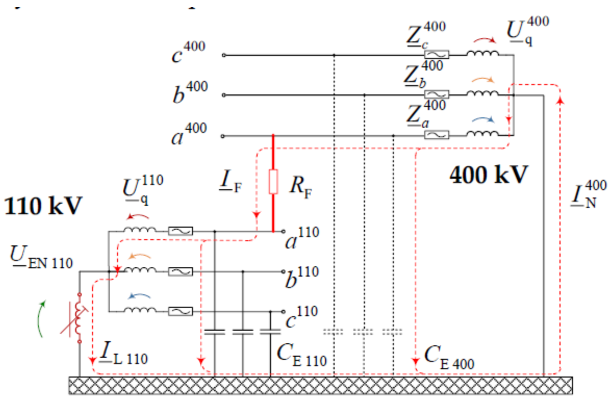

Fig. 5: Circuit for description of system contacts

A very different topic but even more interesting in **Paper 653** from Germany is described. Based on real faults, the paper shows the consequences of system contact between a 400 kV and a 110 kV overhead line. Fault records and equipment failures in the networks involved are analysed. Analytical calculation methods based on symmetrical components are presented to estimate the maximum overvoltage. The schematic diagram used for the calculations is shown in **Fig. 5**.

Paper 691 from Japan deals with methods for recognising unwanted islanding in networks. Japan developed a Frequency Feedback (FFB) method which detect islanding operations at high speeds.

Paper 768 from Austria describes the comparison between conventional current transformers in Holmgreen formation and cable-type current transformers in an isolated grid. The motivation of this paper is to find out whether the accuracy of the existing CTs with higher transformation ratio is still enough to reliably detect the earth fault direction. Three different measurement setups were compared; the results are shown in the paper.

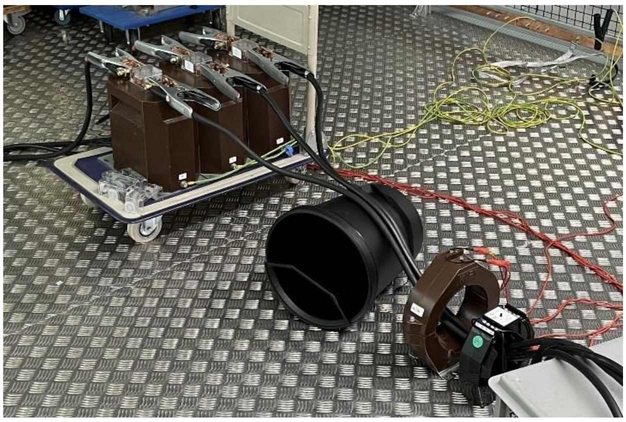

Fig. 6: Laboratory test setup

Paper 866 coming from France presents a comparative study of different methods for optimal D-PMU placement. The objective is to minimize the expected size of the fault solution zone, determined by a voltage-based fault location method.

Paper 897 from Spain outlines a strategy for monitoring earth loop impedance and ensuring compliance with step and touch voltage limits in distribution networks using insulated cables with monitoring systems.

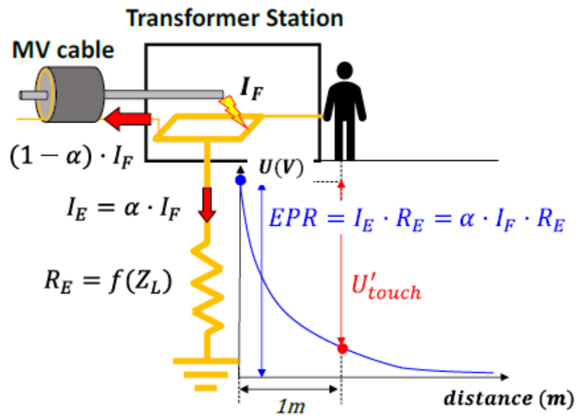

Fig. 7: Earth potential rise and touch voltage during an earth fault.

Paper 1000 from the Netherlands presents findings from comprehensive tests aimed at evaluating the performance and interoperability of various Intelligent Electronic Devices (IEDs) within digital substations, including the concept of a Modular Merging Unit (MMU). The tests, conducted by Alliander and Grid to Great, utilized 30 sampled value streams generated by Current and Voltage Measurement Stand Alone Merging Units (CMS and VMSs) processed by a centralized protection and control system (CPC).

Paper 1009 from Greece describes an extended reconstruction of passive anti-islanding protection of renewable energy sources (RES) stations in Greek distribution network.

Paper 1024 from Switzerland explores how switchgear and protective devices in transformer stations can be optimized to ensure reliable protection against malfunctions, with a particular focus on mitigating switching failures. The goal is to implement protective measures and to propose a new standard concept for transformer stations.

Paper 1033 from Germany reviews the state-of-the-art FRT strategies, their compliance with emerging grid code, and the impact of grid-forming converters on fault current contribution and current protection schemes. Moreover, this paper discusses the need for grid codes revision and the development of standardized testing protocols to address these challenges.

A completely different topic is discussed in **paper 1078** from Portugal. This paper presents the promising results of the experiments carried out at PNDC (University of Strathclyde, Scotland) and a performance assessment of the LV Broken Neutral detection method developed by Eneida. The small test network, under different earthing systems and load configurations is shown in **Fig. 8.**

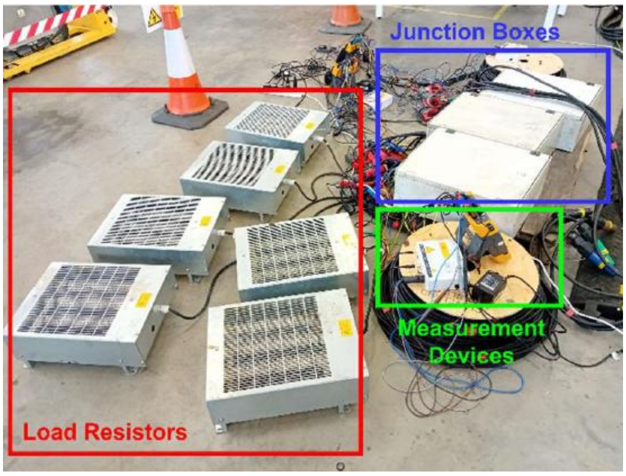

Fig. 8: Test setup at the PNDC LV Bay

Paper 1093 from Sri Lanka describes a key challenge arising from a high level of embedded generation and the need to design a protection system that effectively handles bi-directional power flow at low fault current levels, without causing false or nuisance tripping of protective devices, or blinding the protection system.
Paper 1293 from Switzerland shows the dynamic behaviour of generators during short-circuits and its impact on directional protection systems.

Sub block 2: "Algorithms, Simulation"

Paper 576 from Germany focuses on the investigation of the overcurrent relay blinding effect due to distributed generation. Since the overcurrent protection is the most popular protection function on the distribution level, such investigations are very practical for the understanding of selectivity problems which can repeatedly happen in the future. The protection blinding problem is graphically explained based on the **Fig. 9:** Overcurrent protection blinding due to distributed generation.

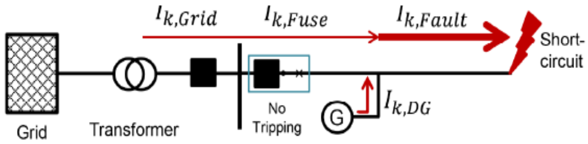

Fig. 9: Overcurrent protection blinding due to distributed generation

Because of active supplying of the distributed generation into the fault and therefore supporting the voltage, the observed current by overcurrent protection can be lower than threshold. In this case the protection does not pick up and does not trip. The authors of the paper emphasize that not only the presence of disturbed generation but also location of DG and faults as well as fault impedance have influence on protection blinding. The influence of these parameters was tested on the part of a 20kV distribution network located in South Germany. The output of this contribution is that the proper coordination of the overcurrent-based protection can be a very challenging process and, in many cases, can impact the penetration level of distributed generation. The remedies against the overcurrent protection blinding can be solved using additional information from distributed generation (**Fig. 10:** Single feeder protection with communication interface between protection and DG). This idea comes from the **Paper 284** in cooperation between Switzerland and Finland. In this contribution the adaptive overcurrent protection is proposed. Using information from DGs the threshold of the overcurrent protection can be continuously adapted to the actual condition.

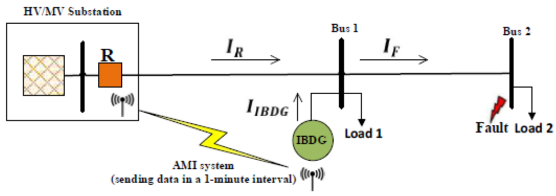

Fig. 10: Single feeder protection with communication interface between protection and DG

This proposed adaptive function can be implemented in the market with existing protection devices using the settings groups and standardized communication protocol IEC 61850, what makes this idea very practicable. An example of the adaptive change process of IEC overcurrent protection curves is presented in **Fig. 11:** Adaptive characteristic of overcurrent relay, where based on supply information from DG the pick-up curve with the same end time was new calculated and adopted to the ruling state.

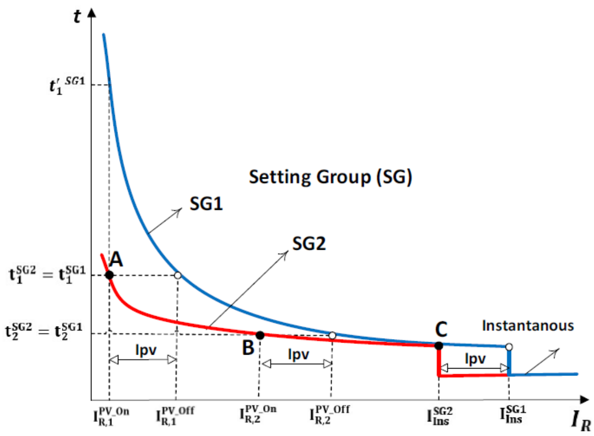

Fig. 11: Adaptive characteristic of overcurrent relay

The authors conclude that the results from the case study, supported by the real-time simulation and hardware-in-the-loop testing validate the practicality and efficacy of the method, offering a robust solution to enhance the reliability and safety of modern distribution networks. The topic of the optimized protection schema is handled in the **Paper 1210** from Iran. The authors propose dual setting over current characteristic which acts either as primary in forward direction or as backup protection in reverse direction (**Fig. 12:** Double characteristic of overcurrent protection).

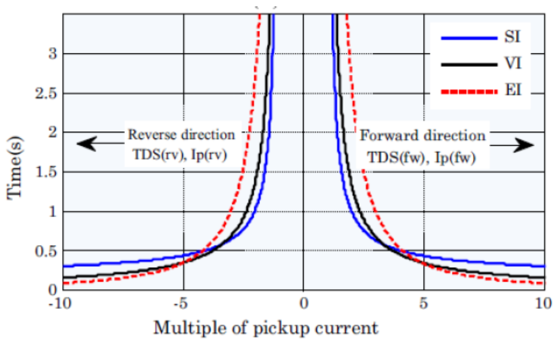

Fig. 12: Double characteristic of overcurrent protection

Involving optimization methods under supporting the simulation tools, the setting for the overcurrent function in different network configuration were calculated and applied to the protection units. Obtained settings were tested in simulation and confirmed.

The reliable decision of the protection devices is only possible if the correct fault classification inside the protection function appeared. The increasing complexity of the power grid with DG can cause failure in fault type classification. It can contribute to under- and over-function. The authors of the **Paper 761** from India and Poland introduce the modified voltage-angle method using the selected ratios between negative-, zero- and superimposed positive sequence components. The classification areas for phase-to-ground and phase-to-phase faults are presented in **Fig. 13**: Fault type zones created from voltage symmetrical componentsand are similar to the conventional current phase selection algorithm which in the case of the network with high penetration of DG is not robust enough.

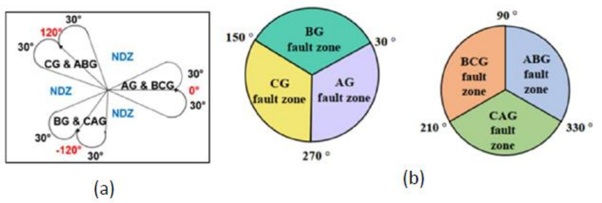

Fig. 13: Fault type zones created from voltage symmetrical components

The algorithm response was validated and compared with others method designed for the power grind with significant penetration of distributed generation. Simulated and cases for field were considered. The results are very promising as can be observed in **Fig. 14:** Comparative assessment of the methods. Proposed solution exhibits optimal response on the fault type.

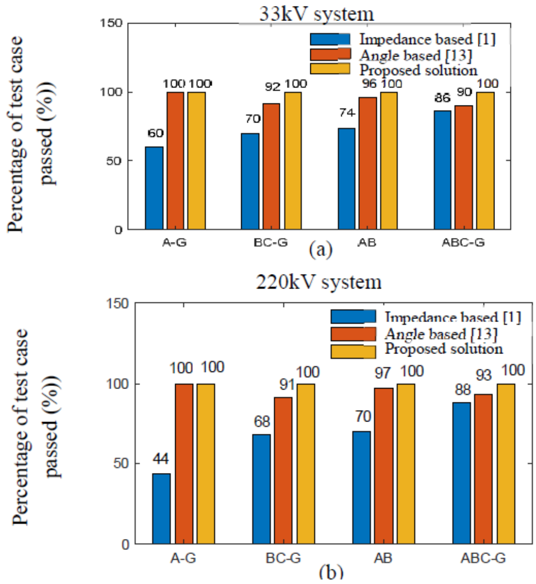

Fig. 14: Comparative assessment of the methods

The distributed generation can also impact the conventional directional algorithms which are applied for the protection function operating both with currents and voltages. **Paper 767** from India focuses on investigation of directional element for grid with significant penetration of DGs. The authors propose an application of reactive power quantities as criteria for detection of the fault direction. An evaluation of the fault direction can be performed by placing of the apparent power on the complex coordination system as can be observed in **Fig. 15**.

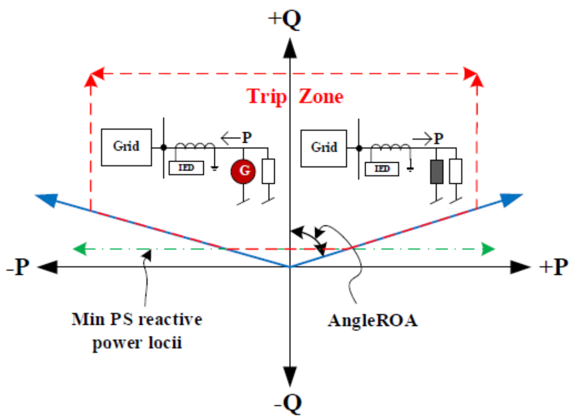

Fig. 15: Operating characteristic of directional element based on reactive power

The authors validated an algorithm for the 220kV as well as for 110kV/20kV distribution systems. In addition, IEEE 39-bus benchmark system with added wind turbine plants was investigated with focus on directional elements as well. The simulation results from various case studies demonstrate the effectiveness of proposed reactive power directional element.

Sub block 3: "Virtualisation"

This sub block contains three papers discussing virtualized protection. It should be noticed that virtualization is discussed also in several papers included in Automation and control sub block "Control architecture".
Paper 701 from Finland describes piloting of virtualized protection in two trial areas in the UK. The piloted virtualized protection is centralized on site level and consists of virtualized bay protection including, for instance, overcurrent and earth fault protection, and a wide area protection scheme that enhances the operation of DER loss-of-mains protection and utilizes 5G communication between the substations and DER sites. The virtualized protection solutions have already been tested and verified at laboratory tests in a test environment that was set up in a similar fashion as the real setup at the pilot sites. The first pilot area is already set up and the passive network trials have already begun on site, while the second pilot area is nearing completion. After sufficient confidence in the solution has been gained, the network trials will proceed to the active phase.

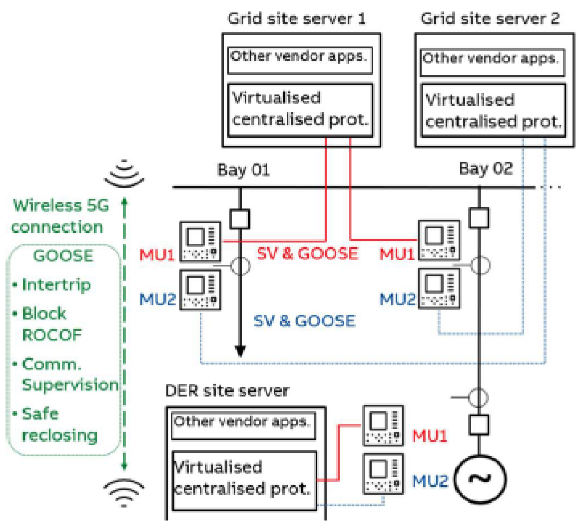

Fig. 16: Principle of the piloted virtualized protection scheme in paper 701

Also, **paper 880** from Finland considers centralized virtualized protection solutions. The paper describes a laboratory setup used to test virtualized protection solutions both from performance and cybersecurity viewpoints. The results demonstrate that the tested virtualized protection solutions perform identically to a commercial relay. The paper proposes to utilize moving target defense techniques to enhance power system resiliency.
Paper 890 from France implements virtualized/containerized protection with a different approach than the previous two papers. The approach in this paper is to deploy functionality of each bay IED in its own container whereas in the previous papers, protection functionality of a substation is centralized as one entity. In this paper, simple overcurrent functionality has been implemented within each virtual IED on a server and tests have been conducted to study receiving sampled value streams and protection operation.

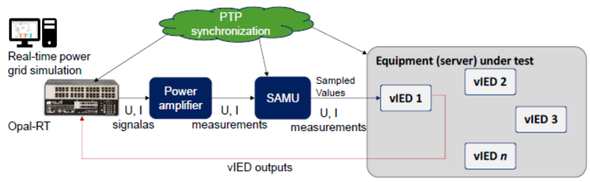

Fig. 17: Example of a real-time simulation setup from paper 890

Sub block 4: "Applications and Functionality"

In the **Paper 26** from the Czech Republic the authors present the comparison between non-directional ground overcurrent protection and negative sequence current protection. One of them should act as the backup protection for the directional ground overcurrent function. Since the network is operated predominantly as compensated (see **Fig. 18** b and c), single pole fault location and single pole fault handling procedure act properly if the earthing resistor is switch on. This happens if wattmetric method detects the single-pole-to-ground fault.

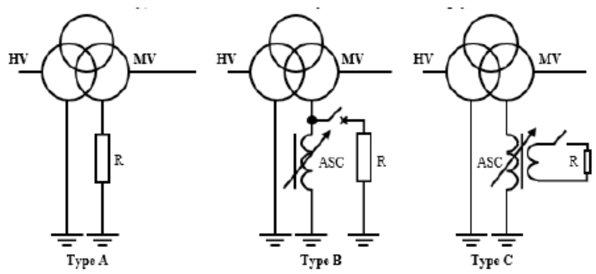

Fig. 18: Medium voltage grounding cases

The single-phase-to-ground faults as well as open conductor cases are classified as relevant and detailed investigated in this paper. Symmetrical components equivalent circuit was considered as basis for theoretical analysis. Not only theoretical approaches with extensive simulation were carried out but also the field cases were tested for both these protection functions. The investigation showed that negative sequence protection is much more robust in comparison to the earth-overcurrent protection. The earth overcurrent protection exhibits problem and recognized single pole faults on the healthy lines what is critical for the network operation. Therefore, the network operator recommends the negative sequence overcurrent protection as secure backup for proven conventional ground directional overcurrent function. The advantages of the negative sequence overcurrent protection, also in the network with integrated inverters, were determined in **Paper 252** from France. The researchers concentrated on this contribution on the double-phase and double-phase-ground faults. For these cases, "protection blinding" is also a potential problem. Based on the detailed theoretical consideration (**Fig. 19:** Equivalent network for LL fault) supported by the simulation it was recognized that even by current injection by inverters, the level of the negative sequence current remains constant if the distributed plant is connected at the head of the feeder.

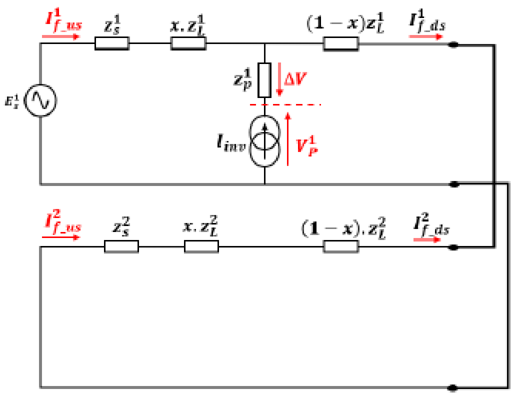

Fig. 19: *Equivalent network for LL fault*

As the plant is positioned further away from substation, the negative sequence current increases and reaches its maximum value, when the plant is at the end of the feeder. This behavior has advantages for negative sequence relay as it ensures reliable detection of the faults and eliminates the protection blinding problem. **Paper 202** from China deals with the identification of the permanent phase-to-phase faults. Here a very unconventional method is proposed in which sequential reclosing of the line is performed to detect if the feeder still experiences the permanent fault (**Fig. 20**).

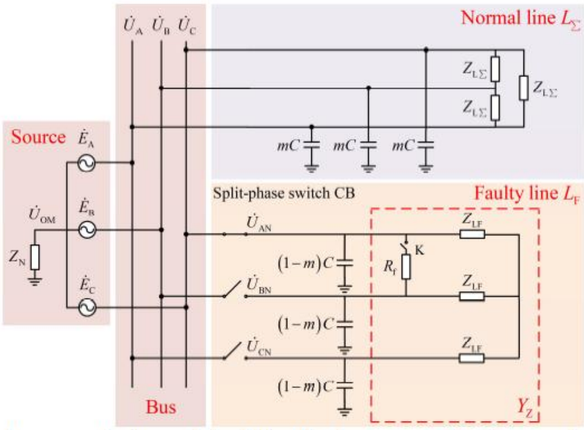

Fig. 20: *Analysis model of the distribution network of sequential reclosing*

For detection of the phase-to-phase fault the voltage for non-reclosing fault is applied as criteria. According to authors, the method delivers very promising results but more investigation with parameters variation needs to be performed to confirm the method practicability. **Paper 518** from Spain touch the problem of the internal ground fault detection in Zig-zag grounding transformer (**Fig. 21**).

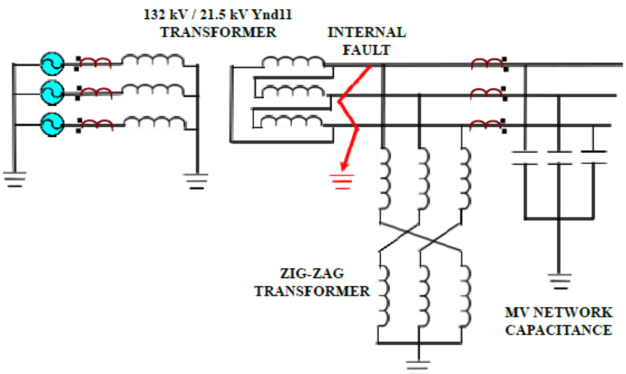

Fig. 21: *Diagram of studied circuit*

The authors suggest that transformer differential units do not have enough sensitivity to detect internal ground faults. The differential current is often lower than typical setting of 0.3 p.u. Restricted earth fault protection can properly recognize the internal earth fault but carries a risk of the operation for external phase-to-phase-ground faults with CT saturation effects. Instead, it is proposed to use the external fault detection mechanism that supervises the operation of transformer differential protection and block REF unit when external faults are detected. Interoperability topic of line differential protection is handled in the **Paper 495** from Finland. The authors propose application of the IEC 61850-9-2 sample values and GOOSE protocol to create the line differential protection scheme. In this case the capturing device is the merging unit which streams the samples value inside the station but also the values are published outside the station as routable SMV stream (**Fig. 22**). The authors not only theoretically analyzed the idea but also, they implemented the schema and tested it carefully. The important issues with communication supervision were handled in this paper as well. The proposed solution was verified and confirmed as stable. The authors concluded that test results show that using the standardized communication protocol does not impact visible the performance of the differential protection and the trip time were comparable with the differential protection using the proprietary interfaces for the communication. Using the SMV standardized protocol for the communication between devices of different manufacturer can contribute to introduction of much reliable applications in scope of the differential algorithms.

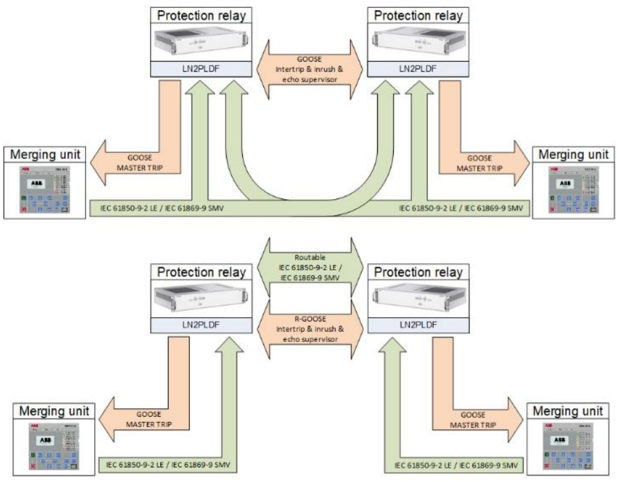

Fig. 22: *SMV and GOOSE configuration options*

The quality of the measurement is crucial for the protection units. There are existing effects in conventional instrument transformers (saturations, ferro-resonances) which need to be recognized, and protection function must be delayed or completely blocked. The non-conventional instrument transformer offers better performance according to accuracy and many nonlinear effects are not topic anymore. Besides, due to small dimensions they are good suited for full digital and compact switchgear solution. **Paper 493** describes the pilot installation of the fully digital 61860 based substation where non-conventional instrument transformers were applied. In the paper many advantages of the proposed and implemented solution against conventional substation can be experienced. The **Paper 0148** from Malaysia presents positive experience in the implementation of the IEC 61850 GOOSE in the station of 33kV/11kV network. Many protections applications could be simple realized under support of the 61850 protocols, what is mentioned in this contribution. The authors describe more deeply the solution of the Zone Selection Schema for the handling of the faults on the busbar and confirm by many tests that the proposed solution is much reliable against conventional approach.

Sub block 5: "Earth fault"

Paper 123, from the Czech Republic, focuses on evaluating a method for estimating residual current during earth faults in MV networks. Earth faults are the most common type of fault at the MV level, and accurately estimating the fault current is crucial for assessing the hazard posed by step and touch voltages. The study uses fault records obtained from real faults and experimental measurements conducted over the past decade in collaboration with EG.D (E.ON). These records include data from various types of compensated distribution systems and different locations. The method evaluated in the study involves analyzing data stored in fault records to estimate the residual current. The authors conducted 12 experimental measurements, recording fault currents, voltages, and currents at the faulty feeder in the supply substation. The time-synchronized data collected were used to calculate the residual current and compare the estimated values with the actual measured fault currents. Results indicate that the If Harm method, which accounts for harmonic distortion without the delta criterion, provides the most accurate fault current estimation. This method was able to estimate the fault current in 80% of the experiments with an error margin of ±4.7 A. The study highlights the importance of accurate fault current estimation for ensuring the safety of earthing systems in MV networks.

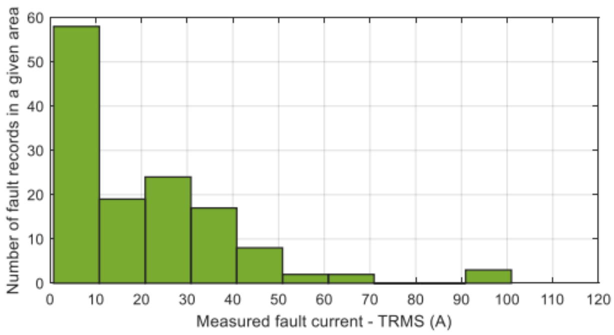

Fig. 23: *The histogram of fault (residual) current levels from all available fault records from paper 123*

With the diversification of power loads and the shift towards a competitive electricity market, traditional fault detection methods have become inadequate.
Paper 130, from South Korea, explores the improvement of HIF detection accuracy in power distribution systems. The study emphasizes the necessity of real-time system environment assessment to enhance fault detection accuracy. By measuring the size and phase of the current

over specific periods and incorporating these measurements into automatic settings, the authors propose a method to improve HIF detection. This approach aims to adapt to the volatile nature of distribution systems, ensuring operational flexibility and resilience. The effectiveness of this method was verified through practical application, demonstrating significant improvements in fault detection. Additionally, the study suggests that collecting diverse power data could lay the foundation for developing AI technologies for power systems through deep learning techniques. The importance of adapting power systems to changing environments to prevent faults and ensure continuous power supply is underscored, particularly in regions prone to natural disasters, as evidenced by a major fire incident in Gangwon Province, South Korea, in 2019.

The study, conducted by Malaysian authors in **paper 158**, delves into the impact of cross-country faults on power cables and the effectiveness of protection strategies to mitigate these effects. Cross-country faults, characterized by simultaneous phase-to-phase faults at different locations, can lead to excessive earth fault currents. These high earth fault currents cause significant thermal and mechanical stress on cables, potentially resulting in insulation breakdown and equipment failure. The research emphasizes the importance of implementing protective measures, particularly the use of earth fault high set elements, which have proven effective in detecting and isolating fault conditions promptly. This minimizes damage and maintains system reliability. Real case evidence is presented to demonstrate the adverse effects of high earth fault currents and the remedial impact of introducing earth fault high set elements. The study also highlights the vulnerability of neutral and earthing connections during high EF current events, necessitating a focus on improving the resilience of these components. Overall, the paper underscores the critical need for effective protection strategies in power systems to manage the risks associated with cross-country faults, ensuring the integrity and reliability of electrical infrastructure.

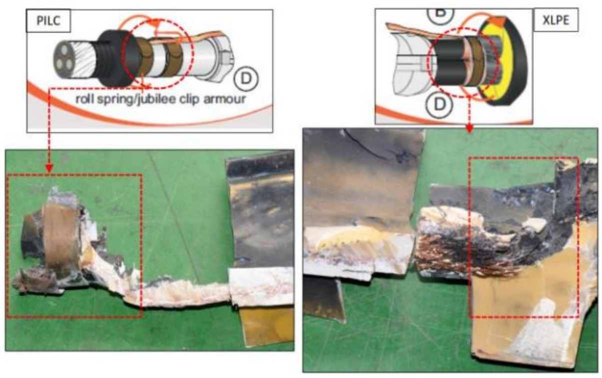

Fig. 24: *The roll spring at the PILC and XLPE side was damaged by the arcing from paper 158*

Paper 215, from Germany, focuses on the detection of restriking earth faults in distribution grids with resonant earthed or isolated neutral points, which are commonly used in Europe. The detection of earth faults is crucial for identifying the faulty feeder or grid section. The paper explains that an arc fault can extinguish itself after the transient currents have subsided. In grids with resonant earthed neutral points, the zero-sequence voltage decreases with an eigen frequency oscillation. If the recovery voltage exceeds the reduced breakdown voltage, a restrike occurs, leading to intermittent earth faults. The time of restrikes varies due to system parameters such as damping, detuning, and breakdown voltage. The paper describes the conditions of restriking earth faults and emphasizes the importance of detecting these restrikes. The authors conducted numerous simulations and analyzed fault records to validate their approach. They found that their method delivers good results in estimating the limits of zero-sequence voltage and dielectric strength at the fault location. The research contributes to improving the protection and reliability of resonant earthed grids by providing valuable information about earth fault characteristics and detection methods.

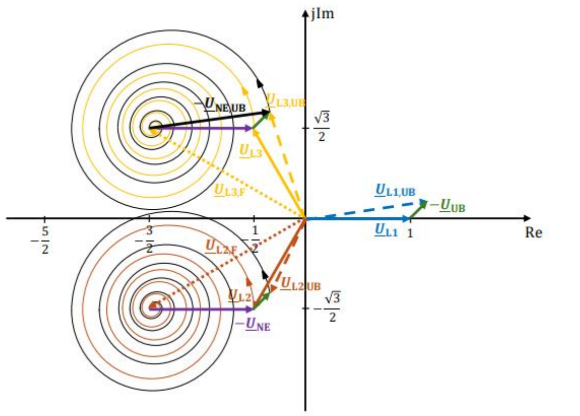

Fig. 25: *Transient response with and without unbalance from paper 314*

The application limits for transient earth-fault analysis of symmetrical components in compensated grids under unbalanced conditions is addressed in **paper 314**, from Austria. The study highlights the deviations that arise between the symmetrical component model and reality due to variations in line and coupling impedances, as well as capacitances in unbalanced grids. These deviations are demonstrated on a medium-voltage grid, and their respective values are determined. The paper emphasizes the occurrence of zero-sequence voltage, which varies with grid conditions, and explores alternative methods to balance the grid and reduce unbalances. Additionally, the authors investigate the impact of grid unbalances on the transient behavior during earth-fault initiation and clearing. They note that cable shield currents must be determined separately, as they are not directly obtained using symmetrical components. The research contributes to a better understanding of the transient earth-fault voltages under unbalanced conditions and provides insights into the oscillation process, insulation stress, and transient fault currents. The findings are crucial for improving the reliability and protection of compensated grids operating under unbalanced conditions.

The next paper, from Portugal, explores algorithms for detecting intermittent faults in electrical distribution grids with high-impedance neutral-to-ground regimes**. Paper 390** addresses the challenges posed by the extensive integration of DER, which necessitates the expansion of the power grid and increases the likelihood of both permanent and intermittent faults. Traditional algorithms for detecting permanent faults are not effective for intermittent faults due to their time-varying spectrum characteristics. Therefore, the authors propose new algorithms that can be integrated into IED in substations. The paper details the simulation of intermittent faults in a distribution grid topology, including the generation of fault pulses and the measurement of phase voltages and currents to calculate zero-sequence voltages and currents. The authors evaluate the effectiveness of two time-frequency dependent algorithms: one using the Hilbert transform and the other verifying the derivative sign variation for quasi-instantaneous frequency detection. Both algorithms demonstrate effectiveness in simulations, activating the IED cut off only after detecting a given number of frequency peaks around the grid's natural oscillating frequency. This research contributes to enhancing the reliability and protection of electrical distribution grids by providing advanced methods for intermittent fault detection.

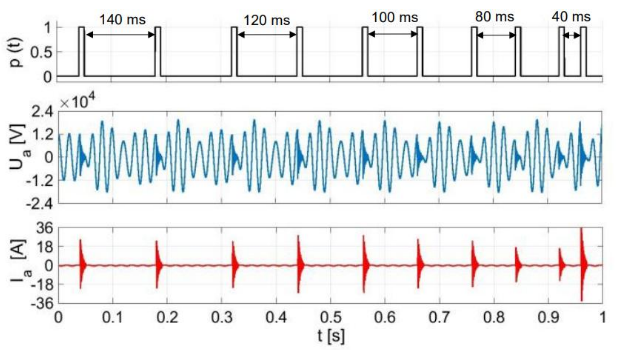

Fig. 26: *Ua and Ia from the faulty phase a without IED cut off from paper 390*

Offshore medium-voltage windfarm collector systems often have unusual grounding impedance arrangements. **Paper 417**, from Sweden, addresses the challenges of earth-fault protection in modern distribution power systems, particularly those with high impedance grounded networks. The paper explains the basic physics behind earth-faults in these networks and discusses when and how earth-fault protection relays based on steady-state 3Io and 3Uo quantities can be used effectively. A universal transient-based earth-fault protection method is introduced, which determines the earth-fault direction based on the short-term built-up transient at the beginning of the fault. This transient is largely independent of the neutral point treatment, allowing the same principles to be applied across various high impedance grounded or isolated power systems. The method is also effective in detecting and clearing restriking or intermittent earth-faults, emphasizing the importance of transient earth-fault protection, which operates correctly regardless of the type of grounding impedance used. This protection is particularly advantageous in complex installations where traditional steady-state earth-fault protection may not be reliable. The research contributes to improving the reliability and protection of modern distribution power systems by providing advanced methods for earth-fault detection and protection.

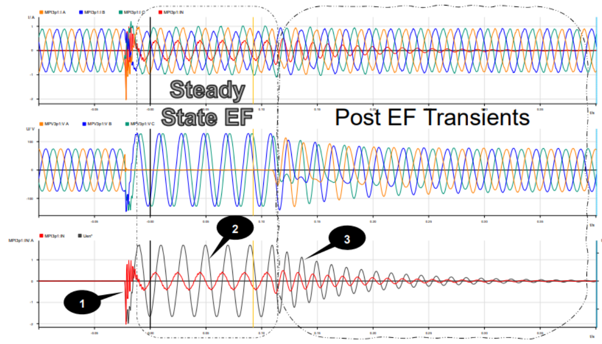

Fig. 27: L1-Gnd Fault record for a Healthy Feeder from paper 417

Paper 538, from Finland, focuses on enhancing earth-fault protection in high impedance earthed networks using modern low-power passive voltage transformers (LPVTs) and protection relays. The study examines the measurement technology of neutral point Uo in compensated and unearthed networks. Traditional inductive VTs and modern LPVTs are introduced, and their technical properties are explained. The measurement performance of VTs and LPVTs is evaluated and compared using actual measurement data from staged field tests conducted in a 20kV compensated and unearthed network. The paper highlights the benefits of LPVTs in combination with modern protection relays, including improved measurement accuracy, protection performance, and ferro resonance mitigation. During an earth fault, the increase of Uo provides a dependable and sensitive indication of insulation failure somewhere in the galvanically connected network. Residual over-voltage protection and various directional earth-fault protection functions utilize Uo as a polarizing quantity. The accuracy of Uo measurement is critical, and amplitude and phase angle errors must comply with the accuracy classes specified by the manufacturer of the applied protection relay and functions. The research demonstrates that LPVTs offer higher sensitivity in earth-fault protection compared to VTs, without introducing risks for unwanted operation during healthy states. This study contributes to improving the reliability and protection of high impedance earthed networks by providing advanced methods for earth-fault detection and protection.

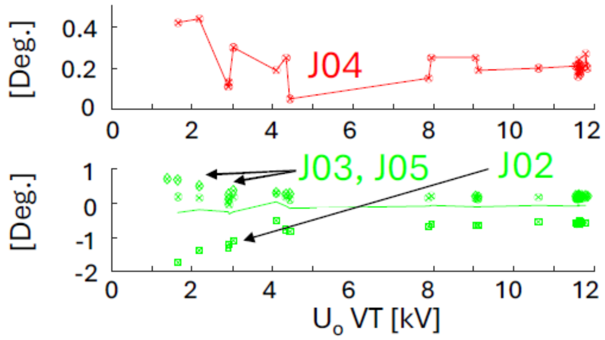

Fig. 28: *Comparison of phase angle of Uo between VTs and LPVTs as a function of Uo magnitude. dPhi[deg.]=angle(Uo (LPVT) / Uo (VT)), solid line is the mean value of measurements from paper 538*

Implementation and effectiveness of the Advanced Residual Current Compensation (ARCC) system in resonance-grounded medium-voltage networks in Australia, specifically for bushfire prevention, is presented in **paper 552**, from Australia and Austria. The ARCC system combines Arc Suppression Coils and single-phase power inverters to compensate for both capacitive and active fault currents, achieving near-zero residual current. This is crucial for compliance with bushfire safety regulations in Victoria, Australia, which mandate significant reduction in fault voltage to mitigate ignition risks. The authors present real-world data from controlled earth fault scenarios to validate the system's reliability and rapid response. The findings highlight the ARCC system's effectiveness in fulfilling bushfire safety regulations, thereby reducing bushfire risk in resonance-grounded networks. The paper emphasizes the importance of advanced earth fault protection systems in hot and dry regions, where the risk of bushfires is heightened due to global warming. The ARCC system has been operational at AusNet since 2019, providing valuable experience and test data. It reliably detects and compensates for earth faults, ensuring safety in bushfire-prone regions by minimizing fault current energy and reducing the risk of ignition at fault locations.

A novel approach to detecting high impedance earth faults in MV networks, which is a significant challenge, is addressed in **paper 584** from Ireland, Poland and China. These faults, often occurring when conductors fall on high resistance surfaces, pose safety risks and can lead to wildfires. The authors, hailing from Ireland, the UK, Poland, and China, propose a new earth fault protection relay platform that combines established fundamental frequency detection algorithms, an enhanced fault inception transient detection method, and a unique signal comparison algorithm. This solution is designed to be easily retrofitted to existing networks, using standalone relays per feeder for maximum convenience. The approach is independent of the system neutral treatment, applicable to both 3-wire and 4-wire constructions, and suitable for various load connections, including three-phase, phase-phase, and phase-neutral. The innovation promises to identify and alert for recurring transient earth faults and incipient permanent earth faults, ensuring minimal disruption to customers during installation.

Reliably locating high resistance earth faults in medium MV networks is a challenge. **Paper 590**, from the UK, Ireland, Poland, and China, presents a universal fault location system that operates effectively regardless of the system's neutral treatment. This system is highly sensitive, utilizing advanced algorithms to detect high resistance faults, and is applicable to both three- and four-wire systems, whether the load is connected three-phase, phase-phase, or phase-neutral. The methodology involves capturing data using distributed network sensors, which are time-synchronized using GPS clocking to within 1µs. The master station applies fault capture algorithms, including fundamental frequency detection, augmented fault inception transient detection, and a novel waveform comparison technique. Results from MATLAB simulations demonstrate sensitivity of at least 5 kΩ up to more than 10 kΩ, achieving accurate and reliable localization for various fault conditions, including downed conductors and broken conductor conditions. Optional traveling wave sensors can be installed at strategic locations to provide precise fault location results.

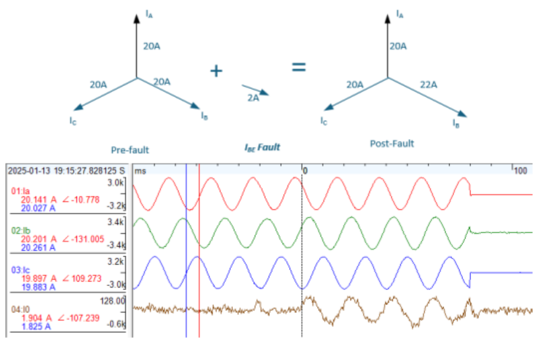

Fig. 29: *Derivation of 3I0 by the LDCU from paper 590*

Paper 1047, from China, presents a method for fault line selection in MV low-current grounding faults, focusing on coordinated multi-point measurements on the LV side. The authors propose using the improved Prony analysis to decompose the negative sequence current of faults, fitting equidistant sampled current data with a linear combination of exponential functions. This technique allows for the derivation of amplitude, phase, and other relevant signal information, facilitating the analysis of fault characteristic patterns and feature comparisons. By utilizing electrical data from multiple measurement points on the LV side, accurate fault line selection on the MV side is achieved based on the amplitude features of the fault's negative sequence current. Simulation experiments confirmed the effectiveness of this method, enhancing fault characteristic salience and enabling precise fault line identification on the MV side. The approach does not require MV feeder sensors and communication devices, thus reducing investment, operational, and maintenance costs. Instead, it leverages the rich measurement data from intelligent terminals on the low-voltage side of the distribution network.

Increasing non-operations of directional earth fault protection, which led to longer fault clearing times, motivated the search to alternatives in Portugal. **Paper 1117** presents a study on the performance of zero-sequence admittance protection in electrical systems. The primary cause identified was an increase in the quality factor of the neutral reactance used, resulting in a discrimination problem. To address this, the E-REDES team decided to explore zero-sequence admittance-based protection. Over a one-year observation period, admittance measurements were collected during real earth-fault occurrences in five different networks. The study aimed to present considerations for the application of this function, possible settings, and results obtained from the admittance measurements. Findings confirmed that the proposed settings were well adjusted to multiple grid topologies and different low impedance grounding systems. The results also showed that transversal selectivity was ensured, preventing unwanted trips in healthy lines. Future work involves implementing this protection function in a pilot case, running parallel to the existing system without tripping the circuit breaker. If successful, the project will extend to more substations, where the zero-sequence admittance function will actively trip the feeder's circuit breaker.

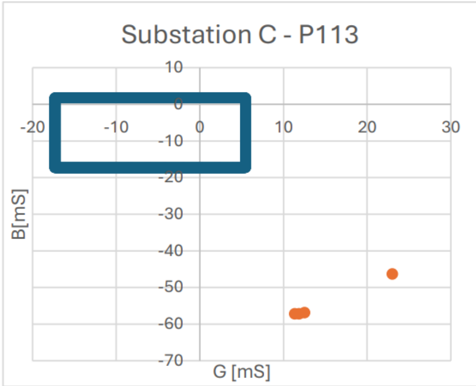

Fig. 30: *Plotting of the results obtained on Substation C -P113 on the admittance plane from paper 1117*

Traditional methods of earth fault measurement based on symmetrical components struggle in compensated systems due to the small steady-state currents at the fault location compared to load currents, making it difficult to distinguish between the two. **Paper 1118**, from Austria, Switzerland and Germany, presents a study on a new method for measuring earth fault distance in non-solid grounded networks. The study introduced two new methods for determining the distance from the fault location to the busbar, which are effective even for transient earth faults lasting less than 10 milliseconds. Extensive transient earth fault measurements were carried out in compensated 30 kV networks, recorded at a sampling rate of 40 kHz. The methods leverage the large transient current or charging current, which is significantly greater than the load current and the steady-state compensated fault current, which can also be applied to isolated networks. The study highlighted the importance of considering the injected current flowing in the healthy phases and suggested improvements in accuracy based on additional efforts to determine coupled currents and voltages.

Paper 1134, from Austria, Switzerland and Germany, aimed to replicate the advantages of earth fault compensation for overhead line networks in cable and mixed networks. The primary benefit of earth fault compensation for overhead lines is the self-extinguishing of the arc without intervention from protection systems or operating personnel. Over the past decades, standardization for the operation of compensated networks as overhead line networks has been adapted. The study found that small air gaps or isolation distances, such as those created by grass under overhead lines, support the behavior of FPE. The research included extensive field tests, which showed that the combination of Petersen coil and FPE can completely eliminate re-ignition problems in cable networks and significantly improve earth fault behavior in continuous earth faults. Future work involves presenting results from a large installation in an isolated grid and associated earth fault measurements at the conference. The findings offer promising improvements for earth fault management in various network types.

Fig. 31: *Cable and OHL after field tests from paper 1134*

Sub block 6: "Fault detection and location"

Most papers from this subblock come from protection manufacturers or universities. They communicate modern technology as well as new ideas for detection and fault location. **Paper 19** from Germany deals with travelling wave technology applied for fault location. In previous CIRED conferences this technology was already presented, and it was shown that the approach delivers very accurate results independent from network character (solid-grounded or isolated, compensated network). The insights from previous investigations were used to improve the fault location algorithm with focus on more accurate detection of the traveling wave fronts as well as simplification of the fault location schema with reducing the number of measurements points to one. In this way the single-sided-fault location travelling-wave-based function was proposed.

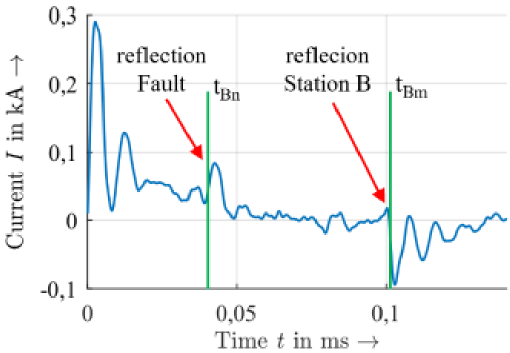

Fig. 32: *Typical travelling wave signal capturing by travelling wave recorder in real power grid*

The new approach uses information from reflected waves, which arise on the discontinuous points of the network like fault place and busbars. The big challenge was here, accurately detecting the reflected travelling wave as well differentiating between reflection from busbar and fault place. These factors have a significant impact on the accuracy as well as reliability of the fault location results. The authors of the paper emphasize that the presented algorithm is very promising but also some improvements are necessary to guarantee more reliability, especially in network with short lines and with significant number of reflection points.

Paper 532 from Switzerland describes different way for the fault location estimation. Here the higher number of measurement devices (D-PMU) are involved in fault location procedures. The proposed centralized solution can accurately locate many fault types in all the grid topologies and grounding systems. A major advantage is the easy installation and deployment since the algorithm needs only a single voltage measurement at the primary substation, and it is not required to install voltage sensors inside distribution feeders. The D-PMUs at MV/LV nodes inside the feeders need only to measure currents.

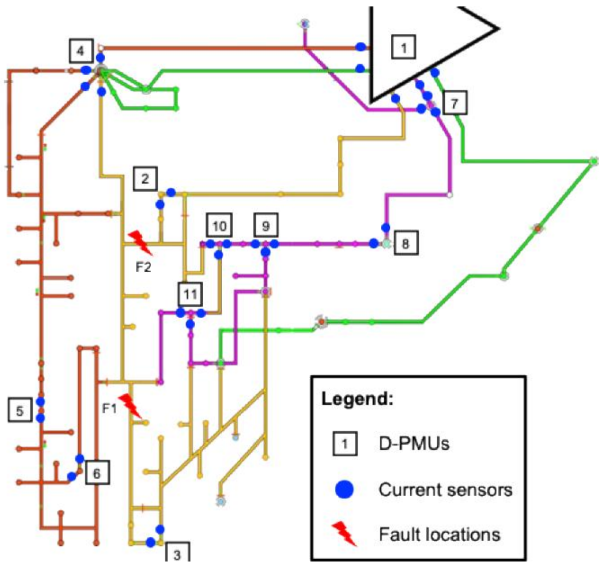

Fig. 33: *Monitored grid topology with D-PMU positions and locations of the two captured faults.*

The system was successfully tested on the real network (**Fig. 33**), where two faults happened last time. The implemented algorithm localizes these events with high accuracies under 200m and seems to be a very promising solution for meshed power grids.

Three different types of open conductor faults (OCF) are discussed in **Paper 240** from Korea. Such situations can result in substantial socio-economic losses owing to secondary damage such as wildfires. The authors emphasis that according to the reports by EPRI, OCFs account for approximately 7-15% of all faults in distribution systems. In **Fig. 34** you can see the three types of OCF.

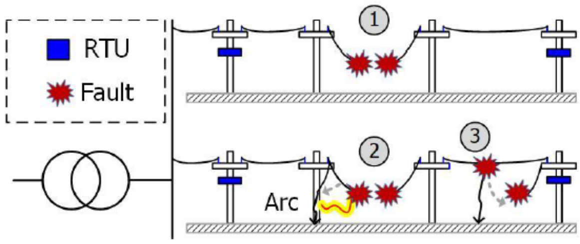

Fig. 34: Electrical characteristic of an OCF

Due to these different behavior types the clear detection of OCF is very challenging and using the measurement form single feeder remote terminal unit (FRTU). The authors propose a more secure method which applies the measurement from higher numbers of FRTUs. The final decision process according to the OCF location is centralized and performed in the distribution management system. The authors used fuzzy logic technology to involve empirical rules (experts' knowledge) in the decision process. As a result, the proposed method strongly improves the detection and OCF location.

Paper 1250 from Brazil describes the problem of the neutral loss in distribution substation transformers. The loss of neutral has occurred repeatedly due to theft, but it also happens due to conductor breakage. This repeatedly happening situation forces the network operator to deal with this problem. The paper shows the investigations of the network operator with the goal of better understanding the effects in the network operation with more or less isolated grounding. The authors of the paper signalize starting the development of the method for detection of neutral loss.

Paper 1251 from Sweden deals with the issue of intermittent fault location. Since the conventional method for location of the intermittent fault often fails, the author of this paper poses to use AI-driven technology to localize the intermittent faults. Over a continuous six-month period, the proposed system recorded over 45,000 intermittent fault events due to 9 main issues, capturing both their primary occurrences and subsequent reflections. This dataset was used for the development of a data-driven location strategy.

Paper 786 from India deals with the detection of the high impedance fault (HIF) in the traction systems. Traditional protection function e.g., overcurrent, ground fault and in some cases distance protection exhibit significant problems in detection of HIFs. The paper describes the delta current approach to more reliable detection of these critical fault types. The process of creation of the delta quantities is presented in the **Fig. 35**, where difference between actual value und 3 cycle period delayed signal works as a high pass filter.

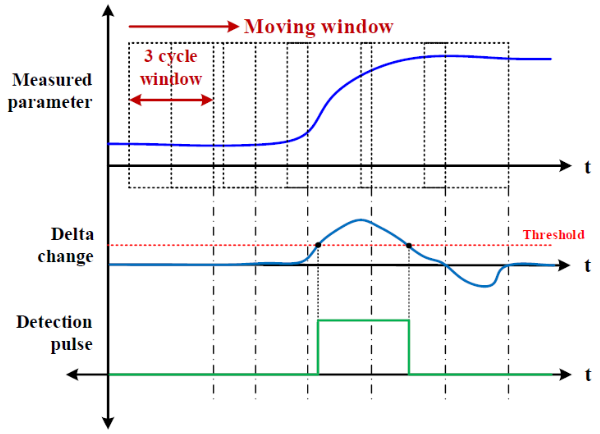

Fig. 35: *Delta change detection principle*

The authors propose calculation of numerous quantities like delta changes in the active and reactive power or current angle which allows for more reliable detection of the high impedance fault. The validation of the algorithm was performed based on the field generated disturbances as well as MatLab simulations. The results obtained confirmed the effectiveness of the proposed delta-based approach.

Sub block 7: "DC Protection"

Four papers deal with very innovative topics of DC protection. In **Paper 520** form China actual status of DC protection development and challenges are detailed described. The authors emphasize the biggest challenge is the fact that due to short circuits the DC converters block the high currents and therefore conventional magnitude-based protection function is in such cases unreliable. The problem with the selectivity of the protection in case of the multi-power infeed can appear as well. Also, the application travelling wave-based technologies have a risk of maloperation and some improvements are necessary to make this technology fit for DC applications.

Paper 323 and Paper 541 also from China deals with the fault isolation strategy on DC side. The authors of both contributions propose application of the fault current limiter and DC circuit breaker to clear the fault on the DC side. Both papers present very comprehensive study of current behavior during the fault and propose innovative countermeasures. Now the presented ideas are in the phase of simulations and testing. Performance of current-breaker technologies for LVDC is discussed in **Paper 783** from France. This paper gives a good overview of which technologies are already available and which protection strategy can be used in connection with different behaviors of converters and energy sources or loads.

Sub block 8: "Testing"

All six contributions on the topic of protection testing show how important this part is for the successful implementation of the protection concept in the power grid. New algorithms and protection schemes must be carefully tested to proof if a high degree of selectivity while simultaneously meeting the requirement of an appropriate protection speed and reliability are achieved. Due to the high complexity of protection function and its large parameterization range, the protection test is a challenging process and time consuming. Therefore, optimization methods are necessary in this area.
Paper 224, from Germany deals with the issues of the reducing time expenses of protection test. As example the directional element applied for the compensated network is being investigated in this paper. Many aspects impact the behavior of this element, and a combination of different factors must be validated (**Fig. 36**). In this paper the approach (so called Design-of Experiments) is presented, which allows reducing the number of test cases. Statistical procedures are explained and comprehensively investigated, which significantly reduces the number of test cases. It was shown that the reduction factor for test cases lies between 15 up to 50.

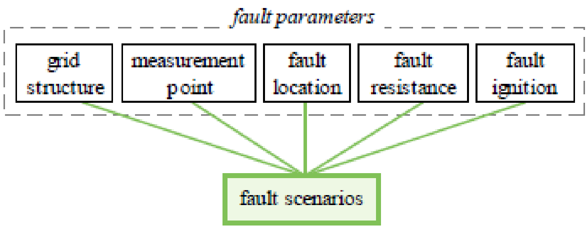

Fig. 36: Graphical overview different DoEs

In **Paper 757** (coming from India) the authors concentrate on the development of a test automation system which allows the testing of the different protection algorithms based on the standard IEC 60255-1XX. This standard is particularly for releasing protection units for power grid applications. Also, in this case the testing time plays an important role and optimization of this process can be helpful for releasing speed of new protection functions. In this paper the testing procedure on developed automatic test systems with achieved results for the different protection functions is discussed.

The aspect of certification of the protection for the power grid application is considered in **Paper 469** from Finland. The operation requirements defined in EN50549-1 and EN50549-2 for the networks with renewable energy sources must be met. These requirements include fault-ride-through (FRT) capability in terms of voltage, frequency rate of change of frequency reactive and negative sequence fault current injection principles during unbalanced faults. The authors present an easy-to-use model for grid code certification of grid-connected inverters. This system is based on the hardware-in-the-loop testing procedure. The test results of the undervoltage ride through capacity are presented in paper as well (**Fig. 37**).

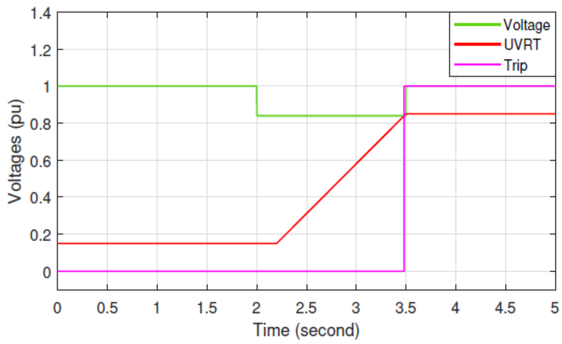

Fig. 37: Voltage dip and correct protection response

The topic of System Integrity Protection Schemes (SIPS) is handled in **Paper 1145** from Germany. The complexity of modern power systems demands SIPS to operate with different wide area protection technologies. The authors emphasize that traditional testing methods fail to holistically validate SIPS. The main problem is here the neglecting coordination and communication between protection equipment, sensors and actuators. The development and certification of the wide area protection concept should be supported using the real time simulation under consideration the communication issues. Authors propose iterative SIPS development process in form of V-Modell allowing continual refinement during the simulation and prototyping stages as illustrated in **Fig. 38**.

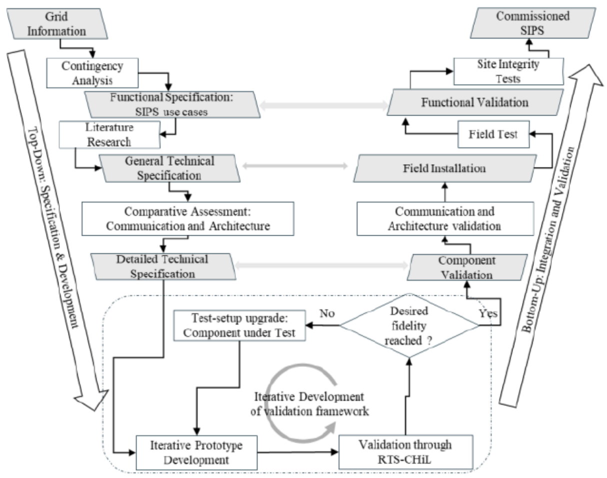

Fig. 38: Validation method with iterative SIPS development

Paper 800 from Portugal concentrates on the description of the self-developed tool for the integration of the distance protection function into the power grid. Due to many different algorithms for distance calculation as well as different parametrization philosophy of the zone setting the exchange of the distance protection function in power grid must be carefully validated. The presented tool in the paper allows automatic recalculation of the zone settings as well as relevant parameter between different distance protection suppliers and therefore avoid the error due to manual reparameterization of protection. The described procedure allows fast commissioning of the distance protection in power grid.

Paper 472 from Sweden and Germany presents an approach of the protection testing in virtual environment. In this paper digital-twin-technology is applied to evaluate the reliability of protection. The authors describe the test of busbar protection applied for the busbar with 6 feeders what results in 18 current inputs. Normally such tests with physical devices are costly and challenging to perform. Virtual test significantly reduces these issues and allows for more intensive investigation of the different scenarios. The digital equivalent of the complex protection device can be simpler integrated into simulation of the power grid and can be used for validation of protection concepts considering all relevant protection devices.

Conclusion

To summarize, it can be said that protection technology is on the verge of a shift towards virtual technology. Reliable communication between the individual system components is very important for the protective functions. You could say that communication is increasingly becoming part of the protective functions.

However, there is also a whole range of new protection functions and improvements. The interaction of many years of experience and real tests of new functions are of great importance.

Table 1: Papers of Block 1 "Protection" assigned to Session 4

Paper No. Title		MS a.m.	MS p.m.	RIF	PS
Sub block 1 General Protection Issues					
0042.:	Novel non-invasive flux-based airgap eccentricity detection for induction machines and its practical validation				X
0079.:	Wavelet feature analysis-based induction motor internal fault identification using experimental data				X
0212.:	Efficient Fault Detection: An Operational Blueprint				X
0311.:	Fault Section Identification Method for Loop Distribution Systems in Korea				X
0446.:	Enhancing Safety and Reliability in the Portuguese Subtransmission Network: E-REDES Cost-Effective Strategies for Managing Increased Short Circuit Levels		X		X
0456.:	E-REDES Solution to Monitor and Analyze Underfrequency Load Shedding Performance				X
0545.:	Using high-fidelity waveform data to diagnose medium-voltage protection mis-operations				X
0553.:	Protection Result Validation (PRV) and Reconfiguration of Protection Setting remotely through SCADA ADMS				X
0579.:	Revolutionizing Underfrequency Load Shedding Scheme - The E-REDIS Initiative				X
0653.:	Effects of system contacts between 400 and 110 kV systems in transmission and distribution networks	X			X
0691.:	Active method for unintentional islanding detection and associated power quality issue in Japan				X
0768.:	Comparison between Conventional Current Transformers in Holmgreen Formation and Cable Type Current Transformers in an Insulated Grid				X
0866.:	Optimal D-PMU placement for Improved voltage-based MV earth fault localization				X
0897.:	New method for step and touch voltages verification by continuous loop impedance monitoring				X
1000.:	Performance and Interoperability testing of a Modular Merging Unit and (virtual) IEDs with Over 40 Sampled Value Streams.		X		X
1009.:	Extended reconfiguration of passive anti-islanding protections of RES Stations in Greek Distribution Network	X			X
1024.:	Considerations for switching and protective device combinations in the NE6 transformer station				X
1033.:	Investigations of the impact of grid-forming converters on current protection schemes in distribution systems				X
1078.:	Detection of broken neutral conductor in LV networks to ensure customer safety				X
1093.:	Practical Approach on Protection Coordination of Medium Voltage Network with Embedded Generation				X
1293.:	Dynamic behavior of generators during short-circuits and its impact on directional protection systems		X		X

Sub block 2: Algorithms, Simulation					
0284.: Adaptive IEC61850-based Protection in Active Distribution Systems Using Automated Overcurrent Function	X			X
0576.: Impact of distributed generation on the blinding of an overcurrent relay in a distribution network				X
0761.: Fault Classification for Medium Voltage Networks Connected with Conventional and Renewable Resources	X			X
0767.: Reactive power based directional protection for distributed generation in case of undervoltage condition at the PCC			X	X
1210.: Optimal adaptive protection scheme for microgrids using a smart selection of relay tripping characteristics, considering different configurations and modes				X
Sub block 3: Virtualization				
0701.: Experiences in piloting virtualized centralized protection and 5G-based wide area protection in real live distribution network in UK		X		X
0880.: This is the title of my abstract Prototyping and Performance Analysis of Virtualized Central Adaptive Protection and Control Systems: Resiliency Against Cybercrime				X
0890.: VirtuozLab: An advanced testing platform for virtual IED and PAC functions		X		X
Sub block 4: Applications and Functionality				
0029.: Analysis of ANSI 67N backup protection scheme for MV grids				X
0148.: A more robust reverse blocking scheme using IEC61850 GOOSE messaging				X
0202.: A Permanent Phase-to-phase Fault Identification Method for Distribution Line Based on Sequential Reclosing				X
0252.: Implementation and Settings of Negative Sequence Current Protection in Distribution Systems with Integrated Inverters			X	X
0493.: Enhancing Reliability and Flexibility: The Kalasatama Smart Grid Project				X
0495.: Interoperable line differential protection with advanced communication supervisor and test mode	X			X
0518.: Protection of MV Networks including Zig-Zag Grounding Transformers				X
Sub block 5: Earth fault				
0123.: Evaluation of earth fault current estimation method in resonant earth network				X
0130.: A Study on improving HIF detection accuracy through automated settings based on power data				X
0158.: Impact of Cross-Country Fault on Power Cable: Mitigation by Protection Strategies				X
0215.: Challenges on the detection of restriking earth faults in resonant earthed neutral systems				X

0314.:	Application limits for transient earth-fault analysis of symmetrical components in compensated grids under unbalanced conditions			X	X
0390.:	Algorithms for intermittent fault detection with high-impedance neutral-to-ground regimes		X		X
0417.:	Earth-Fault Protection Challenges for Modern Distribution Power Systems				X
0538.:	Enhancing earth-fault protection in high impedance earthed networks with modern low-power passive voltage transformers and protection relays		X		X
0540.:	Multi-functional earth-fault protection scheme for compensated MV-networks using novel touch voltage and admittance-based functions				X
0552.:	Practical experience with advanced residual current compensation in a resonance-grounded MV network in Australia for bushfire prevention		X		X
0584.:	A universal solution to the detection of high resistance earth faults – the ultimate retrofit				X
0590.:	Utilizing synchronized data for the localization of high resistance earth faults irrespective of neutral treatment and type of load connection				X
1047.:	Fault Line Selection Method of Medium-voltage Small Current Grounding Fault based on Coordinated Multiple Measurements from the Low-voltage Side				X
1117.:	E-REDES test “Zero sequence Admittance Protection” vs “Directional Earth fault Protection”		X		X
1118.:	New Improved Method for Measuring the Earthfault-Distance in Non-Solid Grounded Networks		X		X
1134.:	New Results of Earth Fault Tests: Earthing the Faulted Phase in Isolated and Compensated Networks				X
Sub block 6: Fault detection and location					
0019.:	Development of a one-sided fault localization method using travelling waves		X		X
0240.:	Integrated Detection and Location Estimation Method of Open Conductor Faults in Power Distribution Networks				X
0532.:	Field validation of a novel PMU-based fault distance estimation solution for distribution networks				X
0786.:	Delta I based approach to detect high impedance faults in traction systems				X
1250.:	Loss of Neutral in Distribution Substation Transformers: Analysis of the Impacts of an Actual Event and Experimental Studies on a Reduced-Scale Distribution Network				X
1251.:	On Sensor Less and AI-driven locating the Intermittent Faults				X
Sub block 7: DC Protection					
0323.:	Fault Isolation Study of Low Voltage DC Distribution Networks				X
0520.:	Current status and challenges of relay protection technologies in MVDC				X

	distribution networks				
0541.:	A Novel Modular Fault Limiting Strategy for LVDC Distribution Networks			X	X
0783.:	Performance of circuit breaker technologies for LVDC electrical distribution protection and selectivity: DC building use case	X			X
Sub block 8: Testing					
0224.:	Efficient testing of Fault Direction Algorithms based on Design of Experiments Methods		X		X
0469.:	Grid Codes Certification by Simulation				X
0472.:	Evolution in closed-loop relay protection testing with Digital Twin Technology.				X
0757.:	Improved testing of relays under the aegis of IEC 60255-1xx and a comprehensive study on performance of protection functions				X
0800.:	E-REDES integration tool for distance protection tests				X
1145.:	Comparative analysis and iterative validation of System Integrity Protection Scheme architecture				X

Block 2: "Control and Automation"

The frame of the second block covers everything which is dealing with automation or control, independent if the automation or control is on centralized position like on the level of a SCADA/ADMS system or in a substation or in the depth of the grid at the customers side like at a DER. A lot of the submitted papers do not only focus on one mentioned level, the most of them make holistic investigations and propose combined solutions on multi levels of the distribution grid.

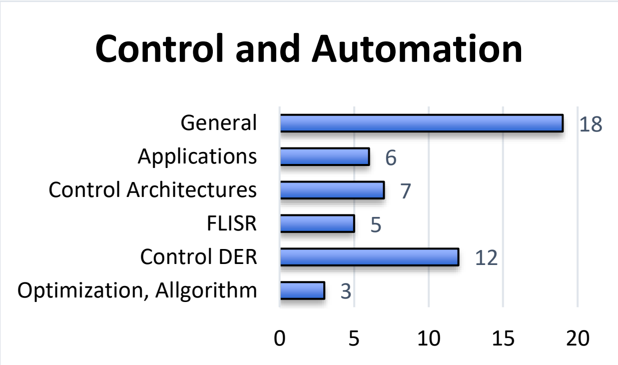

Fig. 39: Overview subtopics of the block "Control & Automation"

Sub block 1: "General"

The first contribution in this sub block, **paper 8** from Serbia, makes an investigation on the possibility of observing and checking the plausibility of the tap changer position of transformers. The investigation shows, that a simple calculation taking into account the voltage of the upper and lower voltage side as well as the current is not purposeful, because there are a lot of parameters like transformer turn ratio errors, accuracy errors of the instrument transformers, errors due to the magnetizing currents as well as errors from the tap changer position depending short circle voltage and from the apparent power including the power factor.

As the paper before also for the authors of **paper 580** from Portugal the on-load tap changer is an important resource in the distribution system. The focus of this paper is not as before on the monitoring of the right step position; it is even more in the monitoring of conditional properties and assessment criteria for flexible maintenance intervals aiming to guarantee a stable and reliable state of the tap changer. The proposed online conditional monitoring techniques analyses the currents and voltages from the upper and lower voltage side during the transition of switching. During this period, which is round about 7 seconds, a highly sampled fault record set with 25k samples/second for all tracks is recorded. The main research is on the algorithm which analyzes the dynamic impedance, which is based on an electrical model of the tap changer. Here the pattern of typical curves of state transitions within this process are evaluated. This gives insights into important conditional stats of the tap changer. This Methode is, in the point of view of the authors very efficient, it is easy to implement, uncomplicated to calculate and it is noninvasive.

It can be observed that a lot of investigation is done in the control of DC-or combined DC- and AC grids to use the advantages of DC. One of this investigation is **paper 209** from China, where the authors research focus on a combined AC- and DC-grid with a high penetration of DER's. In their contribution they point out that it is essential to take care of the real time coordination of the different sources, the loads and the storage, independent from their connection point (AC, DC). They present a three-layer, two-stage control architecture with a control strategy to coordinate all AC- and DC-partitions as well as an optimization strategy for multi energy participant.

At an integration of decentralized energy resources (DER) a lot of requirements and rules from the regulation but also from the side of responsible grid operators must be fulfilled. Preferred larger DER's, with machine transformers, often need to use functionalities like controlled switching to prevent grid perturbations from e.g. inrush currents by residual magnetizations. This is, beside other ones, one contends of **paper 268** from the United Kingdom. The paper discusses practical experience and the performance of this controlled switching device in combination with low power instrument transformers (LPIT's). The authors focus also on the specification on the switch gear and the machine transformers or the testing and the commissioning. They highlighted that assessing transformer energizations makes it clear that the presence of residual flux is an important cause of inrush currents. In the chapter of instrument transformers, a comparison of inductive, low power and a combination of both can be found. Here the authors present a clear overview of the advantages but also of disadvantages of these technologies in relation to the use case of controlled switching.

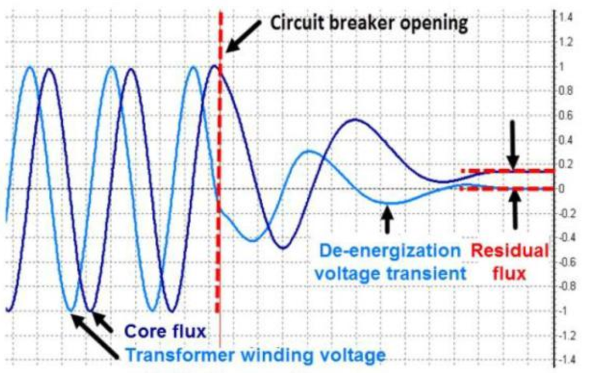

Fig. 40: Relationship between winding voltage and core flux

from paper 268

Faults and malfunctions in substations and distribution grids normally are detected and clarified by protection devices. Often, there is an additional combination with communication and/or logical to improve protection behavior.

As already mentioned in many cases before, the visibility and controllability of DER's is still an essential component to ensure secure and stable grid operation as well as a sustainable energy future. In general, missing observability leads typically to the necessary reduction of infeed. Here, often bigger DER's must be reduced because the enormous value of small and smallest DER's is not visible and controllable. This issue is pointed out in **paper 387** from Irland, where the authors present research on the integration of advanced observe and control measures to increase the grid transparency, especially in lower voltage levels. Their investigation includes e.g. the modelling of DER’s into distribution grids to improve stationery as well as dynamic analyses to ensure an assessment of robustness and stability. The presented proactive approach should harden the grid’s reliability under consideration of rising need of energy by ensuring the managing of energy system in real time as well as by improved forecasts and models of future energy system.

We already discussed that observability of the low voltage grid in real time is one of the main futures success keys. A lot of distribution operators try to solve this issue using smart meter data. In **paper 407** from Slovenia, the author presents a solution which is not only collection the daily meter data. They also collect in time intervals of approximately 1 second data and use them to trip real time alerts. By connecting these alerts with special events in the distribution grid, another improvement in alerting is possible. Using a meter, which can support push-protocols, outages could be recognized which supports the system operator and the service employee. Therefore, an interconnection with another information system like e.g. a SCADA system is required. The paper presents the described content as well as the information technology architecture behind this application and the lessons learned.

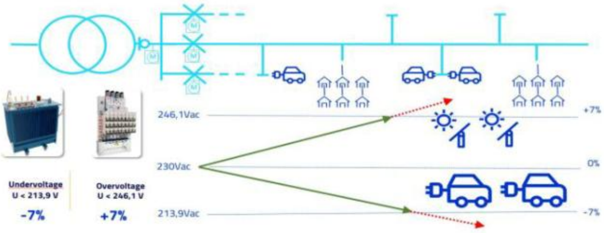

Fig. 41: *Effect of DER, EV and customers on voltage band from paper 731*

Even **paper 731** from Spain, set the focus on the observability and automation of the low voltage grid, but with the point of view of integration of e-mobility, additional to DER's. The authors clearly highlight that the low voltage grid must be developed further to aim the demand on integration of DER's, of charging points for electro vehicle (EV) and other active grid components. They focus on an optimization of the existing infrastructure as well as on an extension of existing functionality which finally results in more digitalization, more automation and standardized cyber security measures, which must be considered. In the further content they address the necessary remote-control units (RTU) and intelligent electronic devices (IED's) e.g. protection and automation devices. Regarding protection, which is mostly connected to short circle currents, one focus is also on the overload and on thermal characteristics of the low voltage switchgear as well as on over temperature. The report resumes different use cases which all evaluate service quality indicators like SAIDI or CAIDI, economics indicators like OPEX as well as the afford for service restoration. The contribution mentioned additionally the advantages of remote control, automated low voltage panels.

In the environment of automation different components are used to build control processes. If we are looking at any control algorithm in active energy grids, we will find sources as well as loads to archive a balance to ensure an allowed voltage- and frequency band. A load can be represented by a well-known load like a heat-pump, but it can be also represented by storage in load mode. This storage must not always be an electrical storage, considering "sector coupling" this can also be e.g. a boiler, as it is investigated and presented in **paper 602** from Netherland. The paper presents the development of a general model for such a boiler, which can be integrated into other simulations or investigations. Here the accuracy prediction of the state of charge (SoC) is evaluated by real world data and results are highlighted.

To get the energy transition, the "visibility" of medium and low voltage grids must be increased. Because of, it is not always possible to build new substations and switchgears, especially from the point of view of economics as well as the resource of manpower, also an applicable solution for retrofit measures of existing assets must be established, like it is mentioned in **paper 663** from Portugal. The content of this paper focuses on the development of an improved remote-control unit (RTU) and on the evaluation and integration of new measurement transformers. Because of the limited space in legacy systems, the technology of low power instrument transformers (LPVT, LPCT) was chosen and tested in different scenarios which are mentioned out in the paper. Another challenge, which is discussed in the paper, is the independent secure supply of components like a meter, RTU or amplifiers and converters. But not only challenges but also advantages like new functionality e.g. directed fault detection, a comparison of phase angles or an earth fault location, is highlighted in the paper.

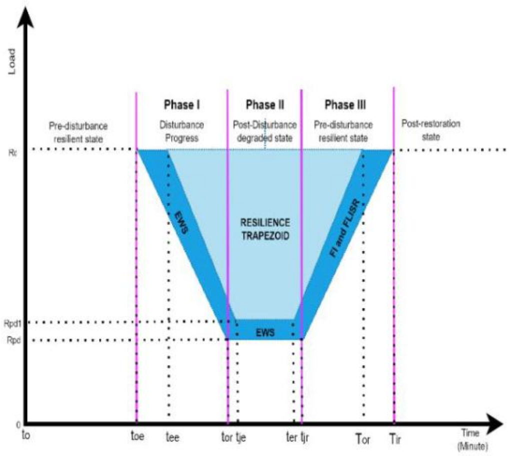

Fig. 42: Resilience trapeze from paper 694

One goal of automation and control is the support of resilience, especially of distribution. In **paper 694** from Indonesia, the authors describe the influence of natural disasters, which causes several flooding and inundations to several substations with a lot of outages (e.g. >3000 substations in 2020). To overcome this, the supplier who is responsible installed several measures to improve resilience against such events which are explained in detail in the paper. This is among other things an early alerting system (EWS) in primary substations to detect floodings before they cause outages. So, they can make countermeasures in time if it is possible. Another measure is the integration of fault indicators (FI), e.g. short circuit indicators, which gives a better overview of affected districts and areas. Finally, they also integrate a traditional fault location, isolation and service restoration system (FLISR) which consists of various components and states which are described in the paper in detail. In conclusion it could be pointed out that the increase in resilience takes place in 3 steps. The first one is in the phase of disturbance by early alerts which makes it possible to delay or prevent outages. The second one is the post-disturbance phase, the degraded state, where e.g. load reduction prevents further outages. Finaly the third state uses FI and FLISR to ensure a high level of renewed supply for the remaining customers.

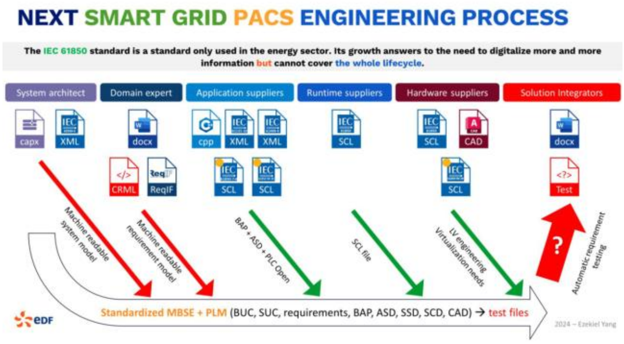

Fig. 43: Overview of standardized and general file formats within the digital eco system for system specification in the field of station automation from paper 795

The ongoing process of digitalization in den environment of automation and control offers a lot of new possibilities to solve many complex tasks, automated follow up switching as well as control engineering tasks for defining threshold and setpoints of following processes. Even complex is testing such functionalities. New IT-technologies, rules for cyber security or the upcoming migration of physical devices to virtualization technologies, also well known as application as a service (AaaS), make specification and standardization for testing processes difficult. The authors of **paper 795** from France have made it to their goal, to suggest an IEC and ISO based standardized framework which covers the modeling of the engineering requests from the application as well as the requests for testing in one working task. Therefore, they choose the principle of model-based system engineering (MBSE) combined with the common requirement of modelling language (CRML) to ensure a simplified, efficient and flexible developing process. The paper brings an overview of existing and established standards regarding this topic, it suggests MBSE for the engineering process for substations and it highlights the identified heaviest problems in the process. The work is finished with tests and with integration of additional tools to the process to demonstrate the stable feasibility of integration.

In comparison to the previous paper, **paper 848** from Austria sets the focus only on the testing process and they try to use a holistic approach to reduce the efforts at every once again coming task. They consider that testing becomes more and more complex and abstract. They focus only on substation which are conform to IEC61850, so they can concentrate on testing the SCL-files (substation configuration language), based on messages on the network (station bus, process bus). The suggested solution in this paper addresses exactly this method and they aim to engineer the test process by a way which can be re-used for similar fields in the same, but also in other substations. But this places a requirement on the user, that the engineering of substations is standardized and each substation, especially each field is the same. Because this is not really realistic in real life, at least similar fields should be a part of the same template to reduce the test templates. They also mention out that advanced tools like intelligent I/O-devices can simplify the test process, if this I/O-devices replace e.g. mechanical switches. Automated simulation of process signals also supports. The authors take even care of closed-loop-tests, including the evaluation of device communication (GOOSE, MMS) and ethernet based SCADA-Gateway protocols like e.g. IEC60870-5-104.

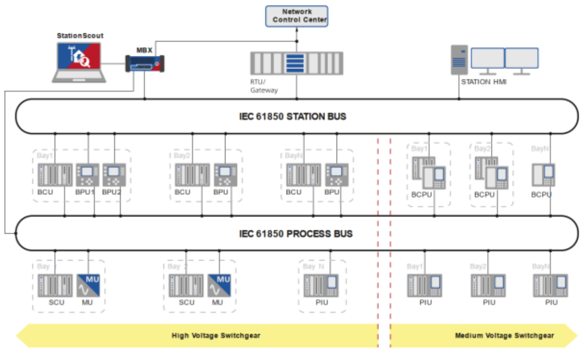

***Fig. 44:** Typical digital substation topology from paper 848*

Testing of automation and control can mean a big effort which was already in the above contribution the reason to do a regarding investigation. **Paper 900** from Spain pick up once again this topic and highlight the benefits and the necessity of an automated test tool for the validation process which is bases on IEC61850. The unique feature of the tool presented in this paper is in the point of view of the author, compared to other current available tools, in full support of an automated check, the faster reachable validation process and the fact that there is no deeper need of knowledge of IEC61850 necessary. With the presented tool it is also possible to interpret the results automatically at the same time. To be able to do this, the tool connected itself to various devices via the MMS-protocol, it evaluates the contents of reported messages, observed GOOSE messages, and it is also capable of injecting reports, GOOSE messages and more via an application programming Interface (API) of suitable test equipment to any devices. For the end user, aspects like a little necessary knowledge of IEC61850, real time visualization of results or faster evaluation means less effort are very important.

The testing of higher logic functionalities is mostly a difficult and complex process which needs consequent planning and engineering. In **Paper 1035** from Portugal such a process for testing the load shedding and voltage restoration is the content. The goal of the authors is to evaluate the scheme of load shedding, as well as the scheme of voltage restoration, both developed by the distribution system operator, in two different intelligent electronic devices (IED) and analyze them. The paper details the procedures adopted, the results obtained, and the conclusions obtained from the test. One fact to be considered is that load shedding happens decentralized on field level and voltage restoration happens centralized. The results of the presented proof of concept show that the interoperability of the logic functionality between the two vendors of the IED's is present and that it is also possible to transfer functionality from centralized execution to decentralized execution. Another founding, descripting more in detail in the paper, was that not every logic functionality can be done and solved with the language function block diagram (FBD) because of limitation of the supported logical blocks of the configuration tool. The evaluation also shows that the logical association of the restoration process is completely similar for both vendors.

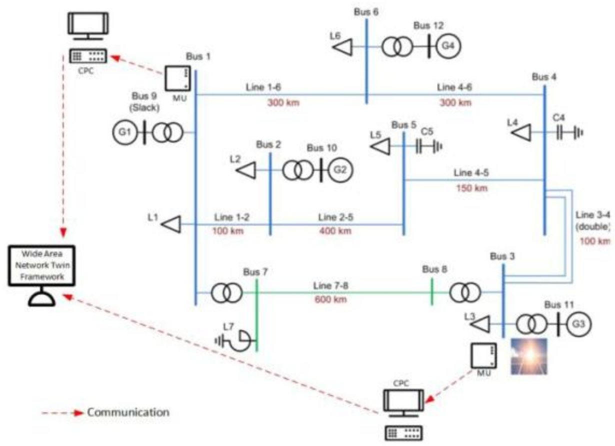

***Fig. 45:** Example grid from paper 830*

In a lot of applications of different domains, virtualization is already a daily business. A digital image, also often called digital twin, is also in use in applications of protection, automation and control. But in real life more or less in single use cases and not so often in productive environments of substations. The authors of **paper 830** from India are thinking much bigger, because in their presented approach they suggest an intelligent framework for a digital twin of a widespread, large distribution grid. That can be e.g. the whole distribution grid from a supplier. Further input parameters of the framework are live data (e.g. breaker states, measurements, ...) from the physical substation and the grid as well as much information's from various databases like e.g. a weather database. The interface to the substation is realized with IEC61850 routable GOOSE mechanism, other interfaces to e.g. databases use standard protocols. Because of this work is a simulation, a MATLAB model is used to simulate the real grid, and this model also controls an amplifier which builds the bridge to real life. With the virtualized twin of the whole grid, the life update of the grid's parameters and additional data from various databases, it is possible to do precision forecasts and state estimations. Even if this is a small, scaled prototype, in the future such frameworks can improve and help system operators to manage their grids more resiliently. Additionally artificial intelligence, especially machine learned methods, can further improve this.

Without standardization it would not be possible to build all necessary substations and do all the necessary maintenance with today's available employees. It has already known for a long time that standardization is besides many other things, like e.g. organization, one success key in operation. But standardization is also a longer and labor-intensive stack. In **Paper 898** from Switzerland the authors from a distribution system operator (DSO) descript their way of standardization in the secondar technology as well as their earned knowledge and the advantage which could be seen. With the introduction of the IEC 61850 standard, the person responsible decided to bring their ratio-of-standardization again to a higher level and with this also the decision to build all necessary knowledge inside the company. To do this, they must address tasks on an organizational level, and they must build a company standard für protection, automation and control systems. This includes also the following pillars of selecting the engineering tool set, establishing an IED qualification process, building a laboratory for test sets and addressing sustainability from economic as well as from technical side. In the paper the authors describe aside from that detailed the challenges they had but also the advantages they earn with their standardization, which are much more than the disadvantages.

SCADA systems are typically designed as a software application with a front end, mostly with a database behind this front end and with a lot of interfaces to connect to several substations or systems to be controlled. **Paper 1004** from Brazil propose a new approach instead the typical front end as human machine interface (HMI). They propose to use internet standards like HTML5, JavaScript and CSS-style for a modern SCADA-HMI concept with a focus on improving the user experience. One reason because they suggest this is that HTML5 has new features, which support native browsers, especially for graphic resources. The paper provides an overview of the technology and system designs of typical SCADA systems as well as of web applications and scalable vector graphics, which are often used in HMI visualizations. The paper discusses also the topic of internet technologies in the environment of automation and brings services from the automation and control side in relation to similar services in the side of internet technology. Finaly the paper introduces the idea of the web-based approach in detail and highlight advantages like better graphical user interface, faster detection of elements and their state, reduced time afford for navigation and filtering of important information's, and so on. But the authors announced that from user side there is still a missing in acceptance. Probably through security gaps known from previews versions of HTML. At the same time, they are confident that trust will grow with more knowledge about this technology and recognizing the advantages that technology brings with it.

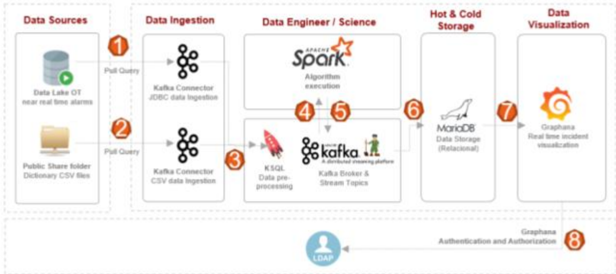

Fig. 46: System architecture of the alerting application from paper 1113

In **paper 1113** from Portugal, the authors present a use case, a new control algorithm to detect miscoordinations in the operations of medium voltage recloser. In 2021 in the SCADA system of the system operator an additional application was launched, which brings an alert in nearly real time when an outage happens or an eye-catching grid behavior analysis in the medium or high voltage level occurs. As a follow-up they recognized in the medium voltage network a significant increase in reclosing's as well as not selective disconnections and outages, which can be attributed to a misconfiguration of reclosers. The paper describes the development of the new algorithm and the experience they have had since they launched it. The paper also covers the functionality of the reclosers, the strategy of overcurrent tripping, the coordination of the reclosers regarding selectivity, taking care of past knowledge of misconfigurations e.g. between feeder and reclosers (trip time, direction, and so on). Also, the alerting correlation tool and the architecture of this are mentioned out in the presented work. Finaly the authors present the results after launching the new functionality of detection misconfigurations. It can be clearly seen that the number of events caused by misconfiguration was significantly lower than before.

Sub block 2: "Application"

This sub block contains six papers describing applications for automation and control.

As already discussed during the previous sub block, monitoring and control of also low voltage networks is becoming increasingly important. **Paper 83** from Germany proposes a decentralized control method for flexible consumers and studies the performance of several alternative control solutions using simulations. The simulations, build on top of field test results and enable extending the study cases e.g. to include more controllable resources. In the example study case, the differences between the alternative control strategies are quite small but for instance the catch-up effect of loads is visible in the simulations results.

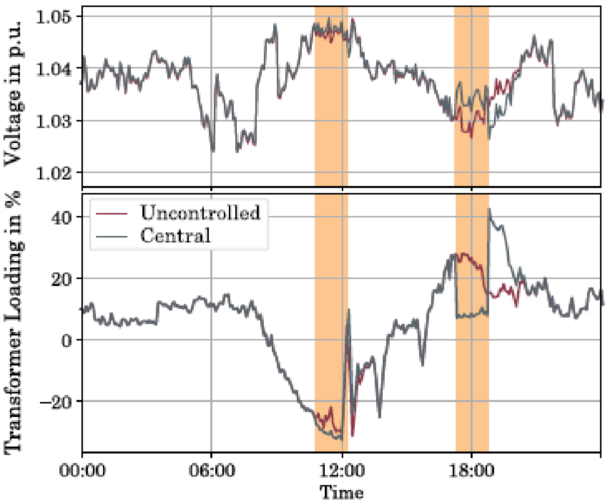

Fig. 47: Peak loading due to catch-up effect from paper 83

Artificial intelligence provides new possibilities for power system operation. **Paper 601** from China and **paper 750** from Sweden propose methodologies to detect incipient faults before they evolve into outages. **Paper 601** introduces a single-sample self-learning fault detection technology for individual power system components. The method can utilize data e.g. from vibration and acoustic sensors and different types of cameras and will gradually learn the abnormal states in power equipment through a multi-stage heuristic approach. **Paper 750**, on the other hand, discusses fault prediction for the whole distribution network using anomaly/disturbance recordings from existing protection relays i.e. without a need to add additional sensors for the fault prediction application. The paper proposes an autoencoder based feature extractor that uses unlabeled disturbance recordings for automatic feature extraction. Both **papers 601 and 750** aim at reducing the need for labeled data which makes deploying these technologies in real applications more feasible.

Papers 785 and 798 from Spain propose methodologies for on-load tap changers (OLTC) of MV/LV and HV/MV transformers, respectively. **Paper 785** utilises artificial intelligence for LV network voltage control. The paper proposes an algorithm to optimally control on-load tap changers of MV/LV transformers which do not, at the moment, exist in high volume but might become more common in the future. Double Deep Q-learning (DDQL) is utilized with the objective of keeping the voltages in the whole LV network at an acceptable level and minimizing losses and tap adjustments.

Paper 798 proposes a more traditional method for HV/MV transformers. OLTC voltage setpoints are optimized using a sensitivity-based Optimal Power Flow (SBOPF) approach. Both papers show that improved OLTC control can keep the voltages in an acceptable range and can also positively affect system losses.

Paper 1096 from Brazil introduces the development process and outcome of an automation asset management and data collection system (SAGA, Automation Access and Management System) taken into use at a major Brazilian multi-service company. The system enables user access to and data collection from automation assets. The paper discusses the functionality of the system, and the process of implementing it. The paper also discusses the cybersecurity measures required for this kind of system, one of the current hot topics in the energy sector.

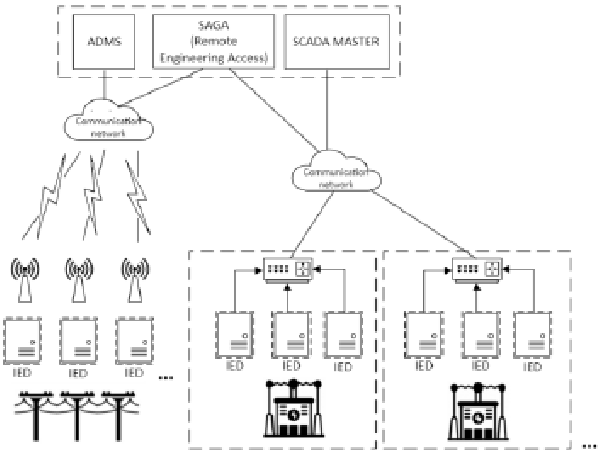

Fig. 48: SAGA (Automation Access and Management System) architecture from paper 1096

Sub block 3: "Control Architecture"

This sub block contains seven papers discussing distribution network control architectures from various viewpoints. Some provide a holistic view on how the whole control architecture should be constructed and others concentrate e.g. on substation architecture. The recurring themes in the papers include virtualization, edge-cloud computing and standardized data interfaces. When the amount of controllable resources in distribution networks increases and new smart grid functionalities are taken into use, efficient methods to add new resources and functionalities are a necessity.

Paper 233 from Germany introduces a concept for distributed digital twin architecture that uses containerized microservices, edge and cloud computing and standardized data models and communication. The idea is to enable deploying different power system functionalities such as state estimation as modular microservices using Kubernetes as the orchestration tool. The next step is to move from conceptual level towards laboratory testing and finally to real LV grids in field tests.

Paper 304 from China proposes an integrated energy management system (IEMS) that aims to provide a more flexible environment for application collaboration and rapid iterative upgrades through using cloud-edge-end collaboration technology. The architecture is modular and utilizes standardized data models. The aim is to provide plug-and-play of devices and to have the capabilities to train AI models on cloud level and to deploy the trained models also on edge. An example energy park simulation has been also included in the paper.

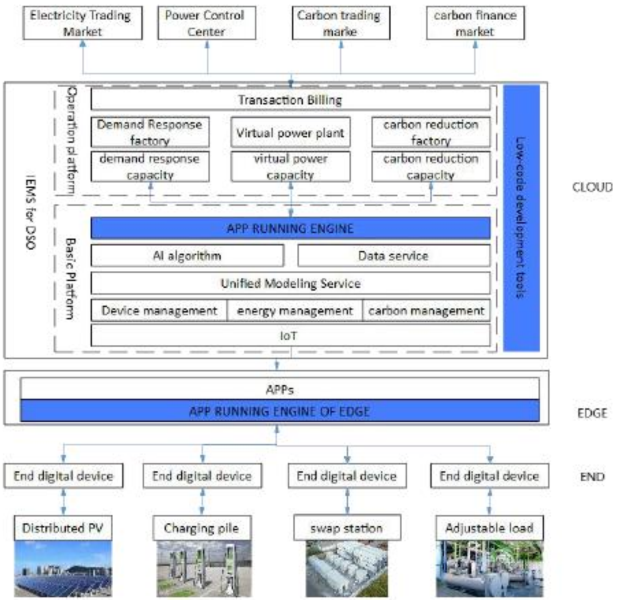

Fig. 49: IEMS functional architecture from paper 304

Paper 722 from Finland describes a concept that utilizes virtualization technology and IEC 61850 process bus capabilities to enable centralizing various smart grid functionalities on an edge server. Data is gathered from different sources (IEDs, SCADA systems, cloud services) and is utilized in a flexible and efficient manner both at edge and on the cloud. Constructing a real distribution network pilot that will utilize the proposed architecture for two use cases (anomaly detection and fault forecasting and congestion management) is ongoing. In the pilot setup, the edge server is located at a server room remote to the substation and sampled value (SV) streams and GOOSE status information are transferred through an advanced fiber network utilizing multiprotocol label switching (MPLS) technology between the primary substations and the server room. Time synchronization is provided by remote network clocks.

Paper 1008 also from Finland describes in detail the congestion management use case to be piloted on the architecture proposed in **paper 722**. The congestion management functionality consists of real-time and predictive timeframes. The predictive congestion management operates on cloud level and its objective is to predict a potential congestion problem in its grid during the next day and to plan a solution in advance. Real-time congestion management operates on edge and is responsible for identifying and addressing any congestion problems as they occur.

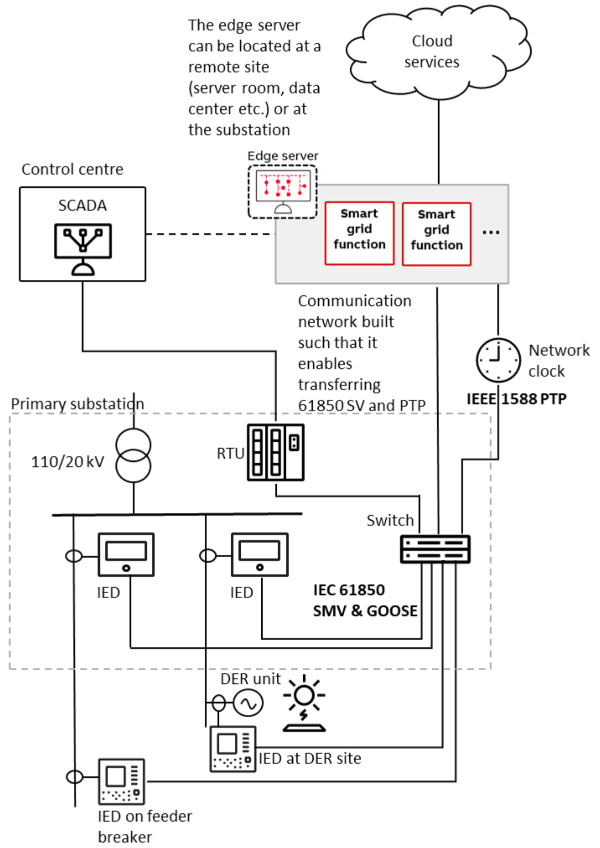

Fig. 50: Concept for centralizing services for remote digital substations from paper 722

Paper 971 from France describes the Edge for Smart Secondary Substations (E4S) architecture in which the hardware to be used at secondary substations is standardized and various functions can be deployed on it as microservices. The idea is to combine various LV network related functionalities such as LV supervisor and outage identification and reporting on a shared hardware. The aim of the E4S alliance is to drive a standards-based, open, interoperable, and secure architecture for the utilities industry.

Paper 1053 from Germany introduces an EDGE breaker concept in which merging unit capabilities and sensoring are integrated in the breakers. When combined with centralized protection and control, the substation architecture can be significantly simplified and reduction in wiring is substantial. The benefits for the proposed approach are illustrated using a simplistic framework for analysis of the mean time to failure and maintenance hours for different substation architectures.

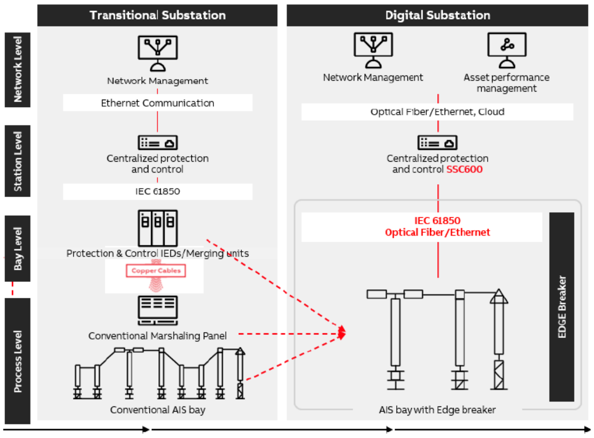

Fig. 51: Architecture simplification obtained with the proposed edge breaker combined with centralized protection and control from paper 1053

Paper 1077 from Italy also proposes an edge-cloud architecture and describes the FLUIDOS computing continuum that utilizes Kubernetes clusters. Synchrophasor-based monitoring system is deployed on the computing continuum in a lab environment and the resiliency of the system is studied by introducing different kinds of failures (application, cluster, multiple). The studies demonstrated a significantly enhanced level of resiliency.

Sub block 4: "FLISR, ADMS"

Paper 708, from Sweden and Finland, discusses advancements in Fault Location, Isolation, and Service Restoration (FLISR) systems, emphasizing the transition from manual to automated processes through remote-controlled switching and advanced communication networks. Automated FLISR systems enhance grid reliability by minimizing stress on primary equipment and ensuring high service availability. Traditional FLISR implementations rely on centralized systems, where decision-making is semi-automated and dependent on communication networks. Decentralized FLISR systems leverage adjacent devices in open-loop and radial configurations to autonomously identify and isolate faults, significantly reducing restoration times and improving overall system availability. These systems operate independently of SCADA or ADMS systems, enhancing scalability and resilience against communication disruptions. The paper details the implementation of decentralized FLISR in commercial installations, demonstrating its capability to restore service in less than 200 milliseconds using circuit breakers. It also introduces a novel fault detection method that reliably identifies high-ohmic earth faults using only three-phase current measurements, eliminating the need for zero sequence current or polarizing voltage. This approach simplifies configuration and maintenance, making decentralized FLISR a cost-effective solution for modern distribution networks.

The challenges faced by DSOs in managing LV networks during the energy transition is the object of **paper 1138** from Italy. The integration of distributed energy resources has increased the complexity of fault management and the frequency of contingencies in aging power systems. While MV networks benefit from intelligent devices and automation for fault location, isolation, and service restoration, LV networks often rely on manual interventions, which are time-consuming. The authors, who are Italian, present a solution developed by Gridspertise to enhance LV network operations. This solution includes an LV SCADA system that provides DSOs with remote monitoring and control capabilities. The SCADA system integrates seamlessly into existing DSO infrastructures using industry-standard protocols and interfaces with Remote Terminal Units (RTUs) housed in street cabinets. These RTUs run automation logics designed by Gridspertise to improve system restoration after power outages. Test results demonstrate the effectiveness of the automation logic in minimizing power outages. The paper also examines the performance of the proposed automation logics under simulated overload and short-circuit scenarios, highlighting the benefits of automatic reclosure and fast reclosure during faults.

An automation system was designed to manage fault events in islanded power grids operating with a ring topology. The study aims to enhance the resilience of small, isolated power systems by implementing a ring scheme, which requires smart devices equipped with functionalities for fault detection and isolation. This automation, proposed in **paper 1141** from Italy, ensures higher continuity and quality of power supply to the maximum number of grid-connected users. The ringed operating mode, combined with the proposed automation, helps maintain frequency and voltage stability due to reduced electromechanical stresses on generating units. The automation system is tested on a small microgrid simulated in a real-time digital simulator interfaced with physical smart devices. The results demonstrate the effectiveness of the automation in preserving power supply during fault events, particularly in comparison to radial schemes where downstream users may experience power outages. The study highlights the benefits of ringed grids, including better continuity and quality of service, and reduced outage durations. The authors of the paper are Italian, and their work builds on previous implementations of fault automations in ringed grids within Italy.

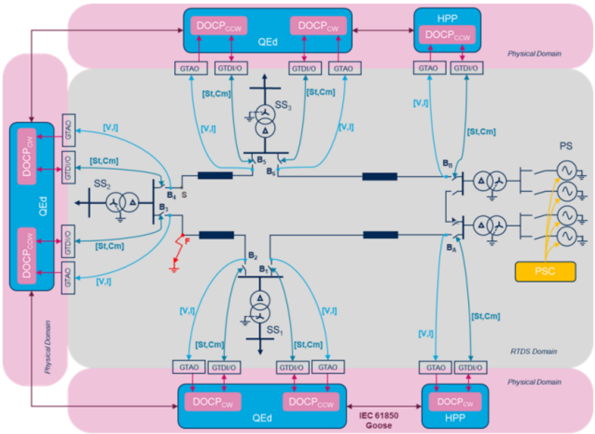

Fig. 52: Experimental setup arranged to test the automation for islanded, ringed distribution systems from paper 1141

Paper 1174, from Brazil, discusses the implementation of an automatic load transfer system in medium voltage networks. This system was developed to address the limitations of conventional local logics by utilizing a SCADA system for efficient and safe energy redistribution. The methodology involves evaluating feeder currents, cable diameters, and operational conditions to prevent overloading and enhance network reliability. The implementation in the Brazilian electricity distribution network has led to a significant reduction in the SAIFI, benefiting a substantial portion of connected consumers. The paper highlights the system's effectiveness in improving the reliability and efficiency of electrical networks, with future challenges including the integration of renewable energy sources and the enhancement of cybersecurity measures. The authors also suggest exploring the use of artificial intelligence for fault prediction and performance optimization, demonstrating how centralized automation can transform the operation of electrical networks to meet the increasing demand for intelligent energy solutions.

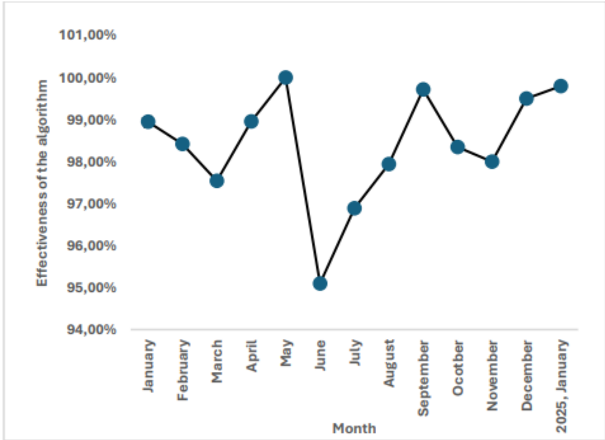

Fig. 53: Monthly Effectiveness Curve of the Algorithm from paper 1174

There is focus on the advanced automation solutions for the MV electric distribution network in Belgrade, Serbia, given by **paper 1235**. The paper discusses the implementation of a "self-healing" grid, which is designed to automatically detect and isolate faults in the network, thereby minimizing the impact on end users. The concept of automation for the MV distribution network was initially adopted at the beginning of the century, leading to the reconstruction of many MV/LV substations with automated MV switchyards integrated into the SCADA system. The paper highlights the evolution from a decentralized automation concept to an advanced automation concept, which involves a larger amount of process information from automated substations and transformer stations. This advanced concept ensures complete observability over the MV island, allowing for better fault isolation and power restoration. The results of applying this advanced automation concept show improved reliability indicators, such as CAIDI, for individual power supply transformer stations.

Sub block 5: "Control DER"

This sub block includes twelve papers discussing control solutions for DER. DER has been defined in a broad sense to mean any controllable resource and, hence, this sub block includes papers discussing inverter control strategies, microgrid control, control of industrial sites, PV power plant control and EV charging control.

Paper 65 from Ireland proposes a control architecture for industrial sites that can contain various types of controllable resources. The control solution optimizes energy production, consumption and storage of each resource in real-time and interacts with also external stakeholders such as energy markets. Towards the distribution network and the markets, the industrial site is considered as one resource whose operation is measured at the point of common coupling. Since maintaining proper operation of the industrial process is the most important factor at industrial sites, a key component of the architecture is digital twin technology that accurately models the primary process. Other objectives such as market participation are secondary and actions related to them can be taken only if business activities are not compromised.

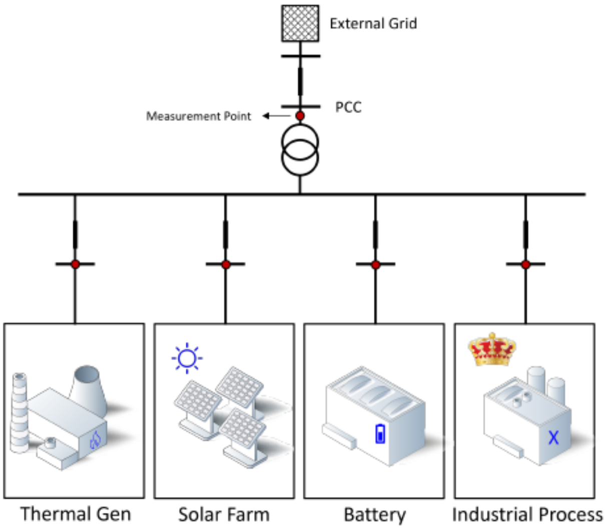

Fig. 54: Conceptual industrial hybrid power system from paper 65

The increasing amount of inverter-based generation resources decreases power system inertia and can cause stability issues. The two main categories for inverter control strategies are grid-forming (GFM) and grid-following (GFL). Grid-forming inverters participate directly in voltage and frequency control whereas grid following inverters synchronize to the grid frequency and control their real and reactive power, possibly including droop.

Paper 349 from Germany evaluates the performance of GFM and GFL inverter control strategies in providing virtual inertia for frequency stabilization in distribution networks. Virtual synchronous machine (VSM) control is also studied and compared to GFM with P/f droop and GFL. Laboratory studies are conducted to evaluate, on one hand, step responses of the different control strategies and, on the other hand, transfer functions of them. In the conducted studies, GFM controls, particularly VSM, outperformed the delayed responses of GFL controls.

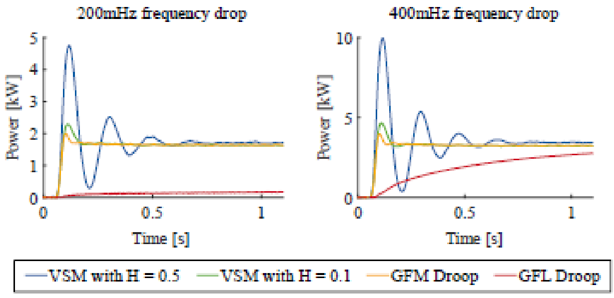

Fig. 55: Responses to frequency drops from paper 349

Inverter-based resources (IBRs) can also lead to new kind of stability challenges as discussed in **paper 1076** from France. At the moment, power system stability is considered mainly a TSO problem but when the amount of IBRs connected to distribution networks constantly increases, also DSOs are faced with stability questions. New types of tools and studies are required so that also the faster dynamics of IBR controls are taken into account.

Paper 1076 utilises EMT time-domain simulations and small-signal linearized models to study the dynamic interactions introduced by the increasing penetration of IBRs in combination with the upstream transmission network whose inertia and strength are reducing. Two new categories of interactions are highlighted: Slow oscillations between GFM IBRs and fast interactions between GFM IBR units, SM units and network dynamics.

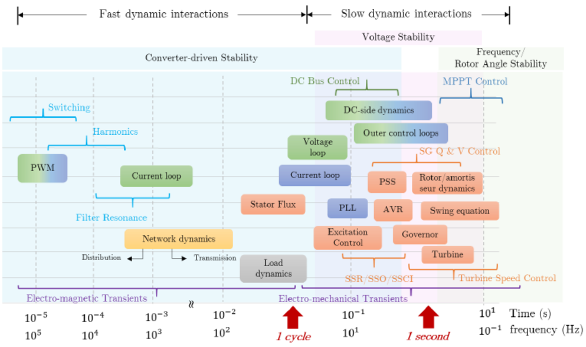

Fig. 56: Map summarizing the timescales of the different dynamics prevalent in the networks considered in paper 1076

Paper 422 from China continues the topic of inverter control but moves towards islanded microgrids. The paper investigates a synchronous current source (SCS) control method that enhances islanding capabilities of inverter dominated microgrids. The current control loop keeps the frequency at a fixed value and I/V droop control is adopted to ensure even power sharing among different inverters in the microgrid.

Microgrids are studied also in **paper 544** from Egypt. The paper proposes a microgrid control strategy that combines the cooperation of electric vehicles (EVs) with the coordination of load frequency control (LFC) using a fractional order tilt-integral-derivative (FOTID) controller.

DC grids remain a research topic also in this Cired. **Paper 593** from France proposes a hybrid control strategy for MVDC collection network of a linear PV power plant. The control strategy includes a centralized part that defines the network state and manages the operation references, and distributed control that relies on local measurements.

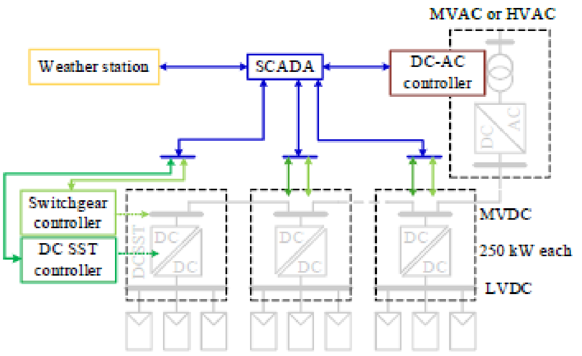

***Fig. 57:** Simplified control architecture of the MVDC network from paper 593*

Algorithms that utilize DERs for distribution and/or transmission network needs are described in several papers. Interesting algorithms are proposed, and the next step would be to consider the practical aspects on implementing the algorithms as a part of real operational systems (required input data, communication needs, etc.).

Paper 698 from China proposes a method for evaluating the maximum frequency regulation capability of DER clusters taking into account also power flow security. The method optimizes the P/f and Q/V droop coefficients of each DER to maximize the aggregated P/f droop coefficient.

Also, **paper 1234** from Egypt considers load frequency control but with a different viewpoint. It proposes a new type of controller to address frequency deviations in low inertia power grids by using fractional-order proportional-derivative (FO-PD) controller in cascade with a fractional-order tilt-integral (FO-TI) controller. Simulation results indicate that the controller can reduce frequency oscillations and enhance system stability.

Paper 743 from Slovenia describes a voltage control method for LV networks in which PV curtailment is used to keep the voltages within acceptable limits. The proposed method utilizes neural networks for predicting the voltages and sensitivity-based algorithms to calculate the required PV curtailment for each PV unit. The difference to many sensitivity-based algorithms is that the objective is to divide the PV curtailment evenly between prosumers which can lead to higher social acceptance with also adequate technical performance, even if not optimal.

Paper 914 from Netherlands proposes a fully distributed agent-based methodology for demand-side management (DSM) and uses EV charging as an example case. The agents formulate and constantly update a coordination tree. Control actions are optimized using profile steering (PS) that is an iterative optimization algorithm that uses communication between agents and can reach solutions that are close to the global optimum. The paper discusses formulating and updating the coordination tree and how it can be used for DSM.

Also, **paper 1088** from Switzerland discusses EV charging control but with a totally different approach. In this paper, centralized model predictive control (MPC) is combined with individual forecasting modules for each EV. The forecasting module forecasts for each EV the location, state of charge (SoC) and whether the EV is plugged or unplugged using a Markov chain model coupled with a neural stochastic differential equation model. Optimal charging dispatch is then defined by the MPC approach that takes into account substation level constraints and comfort of end users.

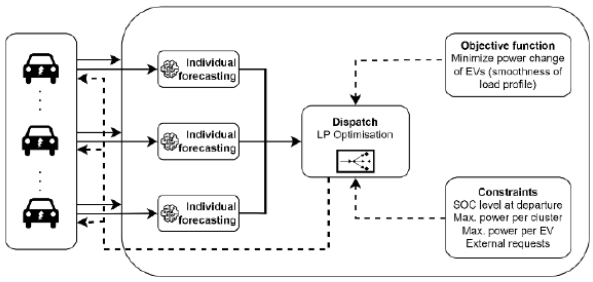

***Fig. 58:** Block diagram of the solution of paper 1088.*

Paper 1291 from the UK describes trials that investigated voltage manipulation techniques, such as transformer tap decrement, tap staggering, and transformer tripping to manage the demand and reactive power within distribution networks. Transformer tap reduction proved to be an effective tool for demand reduction, but its effect is, naturally, heavily dependent on the load composition. Tap staggering proved to be an effective tool for reactive power control. Transformer tripping did not produce the expected benefits and could lead to overloading of the remaining transformer and, hence, was not considered a viable option for future roll-outs.

Sub block 6: "Optimization, Algorithm"

The first research focuses on optimizing the performance of organic PV systems using a chaotic neural network-based nonlinear model predictive controller (NMPC). **Paper 86,** from Turkey, study addresses the challenges posed by variable solar irradiations, demand variations, and transient states, which affect the accuracy of traditional methods in tracking maximum power points (MPP). The proposed NMPC approach offers a suitable tracking speed and utilizes artificial neural networks (ANNs) to estimate future system states, enhancing the system's fault ride-through capabilities. The research highlights the benefits of using chaotic-based activation functions in ANNs to improve convergence rates under undesired disturbances. The methodology involves using a reverse double-diode model of organic PV panels, known for their low weight, high flexibility, simple production process, and recyclability. The control strategy aims to extract MPP under normal conditions, update model parameters using ANNs, and control injected reactive power during severe fault conditions. The results demonstrate that the proposed approach effectively maintains voltage ranges within allowable limits and utilizes inverter capacities to recover normal status during faults.

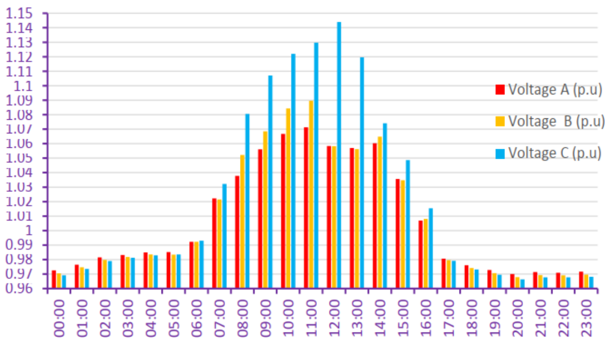

Fig. 59: *Voltage unbalance Factor (Pen: 100%) from paper 86*

Extensive cabling and expanding network sizes are creating challenges in tuning arc suppression coils (ASC) in distribution networks. The increased grid symmetry increases damping and detuning levels, complicating the tuning process.

The authors of **paper 477**, from Finland, propose a novel method for ASC tuning that involves injecting a current signal into the network's zero-sequence system via the power auxiliary winding of the ASC. Unlike traditional methods that use constant pre-selected frequencies, this new approach dynamically selects the most optimal frequencies based on the prevailing damping and detuning values of the primary network. This ensures optimal conditions for evaluating the tuning status of the ASC. The method's minimal power demand allows for a compact design of the current injection device, which can be integrated into existing protective relaying products. A prototype of this relay-integrated current injection-based ASC tuning solution was developed and successfully tested, verifying the theoretical background and the validity of the integrated current injection device concept.

As the integration of DERs increases and interactions with TSOs become more frequent, DSOs must adapt their decision support tools to meet regulatory and quality standards.

Paper 1215, from France, present an advanced optimization model designed to manage electrical constraints on voltage and current across various time horizons and geographical scales. This model aims to provide an optimal set of levers to activate, following real DSO rules and considering different types of flexibility. The paper emphasizes the importance of selecting the right levers based on specific objectives, such as load shedding index or protection plan constraints. The results demonstrate that topological actions are essential and can lead to optimal solutions with minimal disconnected clients and energy not injected. The optimizer successfully finds solutions that satisfy the DSO's requirements in middle-size real cases, showcasing the effectiveness of the proposed model in practical applications

Conclusion

In the field of automation and control you can find still a lot of research and investigations on control engineering for decentralized energy resources (DER), but not so many as in the last period of years. It is to observe that the focus changes more to the managing systems for DER's, e.g. classic advanced distribution system management systems (ADMS) as well as further supporting tools like fault location isolation and service restoration tools (FLISR). With this you can find a lot of suggestions for various system architecture, which all take into account several aspects like communication or cyber security as essential basics. Some of them are characterized by a distributed system design with centralized management systems and decentralized edge computing support.

It can be recognized that the headline of "fault detection" is no longer only a protection topic, no, also the automation is a player in this field. Using e.g. phasor management units (PMU) it is not only easy to observe the grid regarding voltage band, no, this technology in combination with automation technology can also be used to detect and localize faults of any kind.

There are also some very interesting contributions present with the main focus on the stable control of DC grids as well as combined AC and DC grids. As above, also in this case the fault location, especially the behavior of the inverter as an active player in the grid must be considered.

Besides the lots of applications in the presented papers to various automation and control tasks in the environment of distribution, it must be mentioned out, that the interest on testing is a more and more important task. Today's automation becomes, because of her never-ending possibilities, increasingly complex, combined with communication it is hard to test and valid all the functionality behind to correctness. This was also in the focus of many papers which mentioned the necessity of more standardization, starting at the process of engineering where the concept for system testing already must be considered.

Table 1: Papers of Block 2 "Control and Automation" assigned to Session 4

Paper No.	Title	MS a.m.	MS p.m.	RIF	PS
	Sub block 1: General				
0008.:	Practical check of tap changer position determination using currents and voltages and correction possibilities				X
0209.:	Complementary and Optimization Operation Control Technology for AC-DC Regional Power Grids with High-penetration Renewable Energy				X
0268.:	Grid Integration of DER - Grid Code Compliance Energizing Transformers in Wind Turbine Generators Industrialized Applications and Operation of Low-Power Instrument Transformers, Three-Pole Operated Vacuum Circuit Breakers and Controlled Switching Devices to Mitigate Transformer Inrush Currents and Voltage Dips.				X
0387.:	Controllability, visibility, forecasting and modelling strategies to increase distributed energy resources integration in Ireland				X
0407.:	Real-time monitoring of the LV network with smart meter alarms				X
0580.:	Online Condition Monitoring of On-load Tap Changer in Power Transformers Based on an Electrical Analysis				X
0602.:	Development and validation of a realistic electric boiler model for application in EMS software				X
0663.:	E-REDES | Using Legacy Technology to foster Electricity Distribution Network Evolution				X
0694.:	Leveraging Distribution Automation to Enhance Grid Resilience in Jakarta as a Flood-Prone Area				X
0731.:	Success in real use-cases of low voltage network automation to accomplish the integration of e-mobility and DER				X
0795.:	Standardized Model-Based Systems Engineering (SMBSE) applied to Substation Automation System (SAS) Testing				X
0830.:	Wide area network twins for enabling energy transition by integration of different forecast databases and AI applications				X
0848.:	From Process Terminals to Control Center: Fully Automated Substation Automation System (SAS) Testing				X
0898.:	PAC standardization at a Swiss DSO - journey, lessons learned and benefits				X
0900.:	Benefits of implementing an automation IEC61850 based testing tool				X
1004.:	Web/HTML5 interfaces as a new paradigm for SCADA systems				X
1035.:	E-REDES' Logic Interoperability Specification for PAS: Testing and Validation				X

1113.:	E-REDES implement automatic detection for miscoordination operations of medium voltage reclosers				X
	Sub block 2: Application				
0083.:	Analyzing of Decentralized Low-Voltage Control in Grid Calculation	X			X
0601.:	Research on Single-sample Self-learning Fault Detection for Power Equipment				X
0750.:	Unsupervised Learning of Latent Features for Fault Root Cause Analysis				X
0785.:	Voltage control in distribution networks using a model free OLTC transformer based on Reinforcement Learning techniques				X
0798.:	OLTC voltage setpoint calculation using a sensitivity-based Optimal Power Flow: a novel real-time voltage control strategy for distribution networks.				X
1096.:	OT Cybersecurity and Device Integration for an Electrical Utility Critical Infrastructure				X
	Sub block 3: Control Architecture				
0223.:	Management of Active Distribution Grids using Distributed Digital Twin Architecture				X
0304.:	Intelligent IEMS system for DSO based on cloud-edge collaboration architecture	X			X
0722.:	Piloting centralized services for remote digital substations				X
0971.:	E4S Alliance –Protection and Control virtualization				X
1008.:	Predictive and real-time congestion management to enhance grid hosting capacity				X
1053.:	Optimized EDGE breaker to enable new digital substation architecture with centralized/virtualized protection	X			X
1077.:	Emerging ICT Technologies To Improve Resilience of Power Grid Monitoring Systems				X
	Sub block 4: FLISR, ADMS				
0708.:	Ultra-fast FLISR in Practice				X
1138.:	LV Grid Automation, Protection, Monitoring and Control: The Gridspertise's approach				X
1141.:	An automation for the management of fault events in islanded grids operated with a ring topology				X
1174.:	Implementation of Automatic Load Transfer in Medium Voltage Networks				X
1235.:	One of the advanced automation solutions ("Self-Healing") of MV electric distribution network of the city of Belgrade				X
	Sub block 5: Control DER				
0065.:	Towards Industrial Agility: Control Architectures for Electricity-Intensive Facilities				X
0349.:	Investigating the Capabilities of Virtual Synchronous Machines to Provide Instantaneous Reserve in a Laboratory Environment			X	X
0422.:	A Synchronized Current Source Control Method for the Islanding operation of Microgrids			X	X
0544.:	Coordination of Optimal Frequency Stability and DFR Protection Operation with Prevalence of EVs and High RESs Integration for the Microgrid				X
0593.:	Hybrid, centralized and distributed, control of MVDC network for linear PV power plant				X
0698.:	Frequency Response Feasible Region of DER Cluster				X

	Based on Tightened Convex Relaxation in Transformed Power Flow Space				
0743.:	Simplified Approach to PV Curtailment (border determination) in Low Voltage Distribution Networks				X
0914.:	Distributed Asynchronous Energy Management for Dynamic Large-scale Energy Networks				X
1076.:	Stability Of Distribution Networks Under High Penetration of Inverter-Based Resources: Highlight Of Novel Interactions				X
1088.:	Predictive control of eV charging for wide-area reduction in grid congestion				X
1234.:	Enhanced Frequency Stability in Low-Inertia Power Grids Using FO-(PD-TI) Control and Supercapacitors				X
1291.:	Enabling Demand Reduction through Voltage Control in Power Distribution Systems	X			X
Sub block 6: Optimization, Algorithm					
0086.:	Performance optimization of an organic PV system by using chaotic neural network-based nonlinear model predictive controller				X
0477.:	New method for arc suppression coil tuning using current injection				X
1215.:	Power flow management for the DSO: Advanced Techniques for Managing Voltage and Current in Distribution Networks				X

Block 3: "Communication"

This block deals with any kind of communications, which are not directly a particular part of an application for the fields of protection, automation or control. In comparison to the papers received at the last conference in 2023, in 2025 communication is as mentioned in most cases only a small part of the application. Maybe, one reason could be found in the ongoing available standardization which gives in many cases the necessary framework, without any further need for investigations in communication. Even this, there are still a lot of questions to be answered, for example how to ensure the integrity of data and the secure operation of the grids.

Exactly this is the content of **paper 48** from USA, where the authors present a concept to detect attacks on the data content, as well on measurements like active or reactive power as on switch states. They also did an investigation into the correction of these manipulated data on different methodologies, if there was a possibility.

Even though a lot of people try to solve many communication tasks with IEC 61850, there are still some other well useable protocols which are also designed to make an integration of decentralized energy resources (DER) like e.g. IEEE 2030.5. In **paper 63** from Germany, the researchers do a comparison on IEC 61850 an IEC 2030.5 on real use cases at the environment of smart grids. They are using a virtual test environment, where they are taking into account the influence on data networks, the testability, the performance and finally the stability for their assessment.

There are also many other papers presenting an investigation on an interface for DER's, but they are mostly all using IEC 61850 as communication frame. One of these papers is **paper 91** from Netherland, which sets the focus on the gateway functionality at the point of infeed. The design of the gateway is to ensure security while dealing with signals from the market and at the same time considering thresholds from the DSO e.g. for congestion management. Another one is **paper 188**, which is also from Netherland. This paper sets the focus on the implementation of the above-mentioned interface from the point of view of a DSO side, especially on the technical process using the smart grid architecture model (SGAM). Another big part of the content of this paper focuses on the experience of piloting and testing. Also, as with the two papers before, **paper 218** from Netherland addresses once again the topic of the interface between a DSO and a DER. The main focus of this paper is set on the further development of the Netherland's standard, especially on the communication layer and on the comparison of web-socket protocols and IEC61850 data models to reach more scalability. Finaly, also **paper 451**, once again from Netherland, presents an implementation of the real time interface (RTI) between the DSO SCADA-system and the DER. In this study the authors present the real end to end solution, including the integration in their SCADA system. They also present their thoughts for the decisions of integration, and they focus on the virtualized gateway as front end to the SCADA system to ensure the scalability as well as the communication concept via 4G, knowing the leak of availability in this solution.

Not only the Netherlands but also France, where **paper 1066** comes from, has conducted investigations on the interface to DER's. Their proposed solution is based on IEC62746-4 which defines the exchange of messages, using information models from IEC62325. They use two roles, the one of the DSO and the one of the energies resources, to do demand requests in the form of small sequences. To meet also other requirements, the standard support still other message structures like publishing grid service prices, communicating offers and self-scheduling information or sending setpoints for control or limiting power.

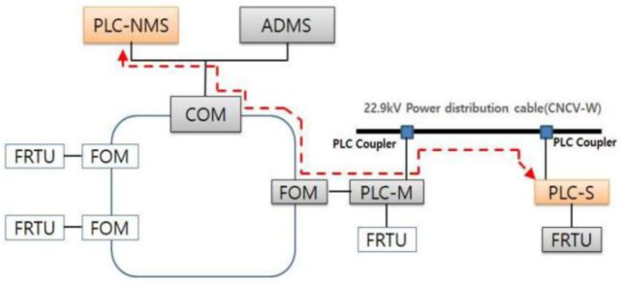

***Fig. 60:** Block diagram of a PLC bridge including the network management system (NMS) from Paper 377*

Often in urban areas it is not always possible to install new communication connections. Also, wireless connections didn't work reliably because of physical obstacles between the sender and the receiver. A well-known problem which is addressed in **paper 377** from the Republic of Korea. The paper presents an investigation on a power line communication solution (PLC) which uses the neutral wire of the power line as a physical carrier. This provides a communication bridge between otherwise unconnectable points in urban districts. Even if the possible distance is limited to only approximately 550m, this idea can close gaps in communication with a reliability rate of more than 99,9% and a bandwidth of 10 MBit/s.

Wireless technologies are becoming more and more important as enabler for many applications in the field of protection, automation and control. They are often the foundation for the functionality that is possible to support. Therefore, it is even more important that these communications fulfill the requirements of the functionality behind.

Paper 773 from Finland present an analysis of the 5G technology, the functionalities of 5G itself and the challenges which are connected while using this technology in the environment of distribution systems. The authors compare here different aspects of 5G from the point of a DSO and they also focus on topics which guarantee service quality like network slicing, which are essential for protection functions like differential protection.

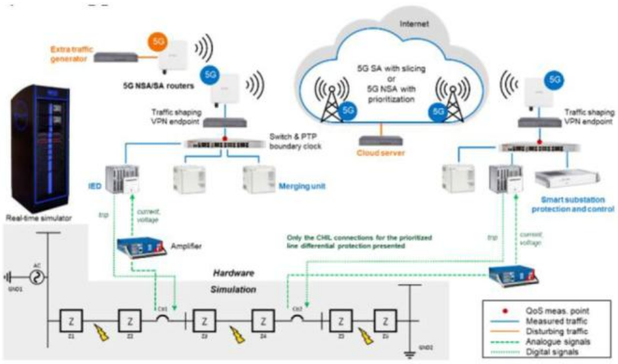

Fig. 61: Test setup for the 5G–Communication from the controller-hardware-in-loop (CHIL) perspective from ***paper 773***

Also, **paper 1107** from Italy presents once again a 5G based communication infrastructure which is concepted as a local private communication network. The goal of this presented architecture is to support a phasor measurement unit (PMU) based monitoring and control system. The system design aims to provide low latency as well as an optimization regarding faster data transmission. The author also presents the usage of their observation and control application as a service on the introduced platform, where 5G is used to transmit PMU-data to phasor data concentrators (PDC). Advantages, but also disadvantages and challenges are highlighted in this contribution.

The last two papers in this section address current topics of information security and life circle management in critical infrastructures. The first one, **paper 442** from Germany, deals with the secure exchange of keys in the environment of an energy control system, by implementing a quantum key distribution (QKD). Looking forward, today's methodology of an asymmetrically cryptographical algorithm will no longer be secure against hacking attacks, if quantum computers are available. The QKD method can be used to distribute symmetrically cryptographical keys in a quantum secure way. The contribution describes the implementation of a prototype of QKD to ensure security in key distribution as fundamental for e.g. to guarantee the integrity or the confidentiality of data between two SCADA systems.

The second paper, **paper 952** from Slovenia, describes the engineering of new packetized orientated data network, as a replacement for an outdated system. The new architecture covers the fundamental data network of different domains, from the IT- as well as from the OT-Domain, like the core network, the hole OT network (central overlay and decentral substation network), the DSO data center network and the network of the distribution control center (ADMS), as well as the interconnections of theses domains (as a backbone) including the aggregation level, the access level and finally the user level. By designing the network they take care of redundancy, fail over mechanisms and on physical distributed topology to achieve high availability. Cyber security measurements were implemented on network level by using standard protocols and services. In the paper the authors also discuss the phase of implementation, especially the challenge in ensuring the continuing of all processes and services.

Conclusion

Even though there were not as many papers submitted on the topic of communication itself as at the last conference, communication has a very important role in today's applications. Mostly communication is already seen as part of the application and is no longer treated separately because it is essential to adjust the different properties of communication to the application.

The investigations of the submitted paper show that 5G as a communication layer is more and more used for protection applications besides the already usage in automation and control tasks.

The many discussions round about the topic of communication with DER's show that there is always a need for individual solutions for non-daily applications. Another outcome of this section can be found in individual communication solutions for special applications, where conventional communication solutions are not really applicable.

Also, cyber security has become a fixed and indispensable importance in communication, independent of the level in the data network. But cyber security must develop further, because new possibilities, especially performances of hardware and new knowledge in all domains, change the state of secure of today's secure estimations.

Table 3: Papers of Block 3 "Communication" assigned to Session 4

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
0048.: Cybersecurity of distribution network real time monitoring: a parameter error correction model against false data injections attacks				X
0063.: Use-Case Based Evaluation of Communication Protocols IEEE 2030.5 and IEC 61850 for Grid Integration and Market Registration of Distributed Energy Resources				X
0091.: Development and deployment of a Realtime Interface customer endpoint for enhancing grid stability and congestion management in the Dutch energy sector				X
0188.: Unveiling the Dutch IEC 61850 DSO-DER Realtime Interface: Practical Insights and Experiences				X
0218.: Preparing Dutch DSO-DER interface for large-scale rollout using IEC 61850 and WebSocket	X			X
0377.: Development and field demonstration of PLC communication bridge for distribution automation system				X
0442.: Implementation of Quantum Key Distribution in an Energy Control System Environment			X	X
0451.: Implementing the Dutch IEC 61850 Realtime Interface: Direct control of individual customers through virtualization in the SCADA landscape				X
0773.: 5G in transition to provide services for protection communication	X			X
0952.: Automated, resilient and secure ICT network of a new generation for a modern DSO				X
1066.: Introduction to IEC 62746-4 communication for demand response				X
1107.: 5G communication infrastructure for PMU-based monitoring and control systems				X