Special Report - Session 1
NETWORK COMPONENTS

Christophe BOISSEAU
Chair - France
christophe.boisseau@enedis.fr

Arnaud ALLAIS
Rapporteur - France
arnaud.allais@nexans.com

François GENTILS
Rapporteur - France
francois.gentils@se.com

Introduction

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

- cables,
- overhead lines,
- primary and secondary substations,
- transformers, switchgear,
- protection and monitoring systems,
- power electronics.

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

138 communications were selected for Session 1.

The presentation is structured in four blocks, which are the same for this special report, for the main session and for the poster session.

The structure adopted for these blocks is as follows:

Block 1 “Disruptive innovation, new usages and prospective” (37)

- DC components (11)
- Power Electronic (5)
- Superconductivity (2)
- Storage (5)
- Charging stations (4)
- Prospective (7)
- Performances upgrade (5)

Block 2 “Monitoring and diagnostics” (34)

- Sensors for condition monitoring (8)
- Specific sub-block on Partial Discharge, due to the large number of papers dealing with PD (11)
- Metering, fault localization and DLR, especially for cables and lines (7)
- Use case experiences in testing and maintenance (8)

Block 3 “Context evolution driving development and studies on components” (33)

- Environment friendly equipment (4)
- SF6 Alternatives (8)
- Life Cycle Analysis & Carbon Footprint (5)
- Circular Economy (4)
- New Materials (9)
- Resilience (3)

Block 4 “Data, models and prediction for components” (34)

- Data & models at edge: feature extraction, local algorithms (4)
- Big data for asset management (14)
- Models and tools for components (8)
- Digital twins (4)
- IT/OT infrastructure (4)

6 papers per block have been selected for oral presentation in the main session (MS) and 6 other papers have been selected for presentation in the Research and Innovation Forum (RIF) focused on research findings in the field of network components.

In addition, all publications are presented in the interactive poster session (PS) to promote an exchange with the authors.

In addition to the main, RIF and Poster sessions, three round tables (RT) take place during session 1:

- RT14 “Smart Networks: from the secondary station to the LV networks”,
- RT16 “Lifetime extension options for electrical equipment” (main results of WG 2020-1),
- RT18 “Green Network Solutions”.

Block 1: "Disruptive innovation, new usages and prospective"

Sub block 1 : DC components (11 papers)

The perspective of the deployment of DC network is raising questions about which AC components can be used for DC application with minor changes. And indeed cables seem to be apparently a good candidates when looking only at energy distribution main function and making the hypothesis that AC insulation are suitable for DC electric field. Therefore **papers 11264** and **10403** propose to assign the phases of a DC circuit to the insulated conductors of LVAC cables (see table 1 below) and MVAC cables (see table 2 below). The characteristics at different frequencies are studied to cover the full scope of harmonic and transient phenomena in LVDC grid.

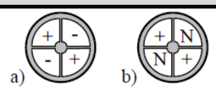
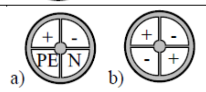
application	voltage	cable configuration	grid
charging infra-structure	unipolar 1500 V bipolar ±750 V		a) TT b) IT
household supply	bipolar ±750 V		TN-S
industrial grid	bipolar ±750 V		a) TN-S b) TT

Table 1 of paper 11264 : Selection of relevant cables and grid configurations for different applications in LV-DC grids

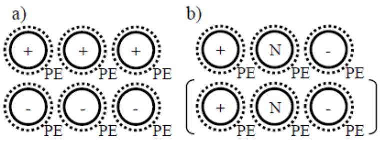
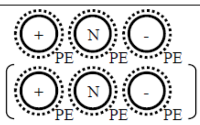
application	voltage	cable configuration
galvanically separated	bipolar ±55 kV	
galvanically coupled	bipolar ±55 kV	

Table 2 of paper 11264 : Selection of relevant cables and grid configurations for different applications in MV-DC grids

Paper 10403 has a deeper look to the difference in term of breakdown and arc tracking mechanism between DC and AC cables, showing that PVC sheathed cables are not suitable for LVDC networks. A design of 1MW class cable optimized for DC conditions is proposed in paper **10610** based on PP insulation.

In **paper 10466**, the performances of different types of AC fuses are evaluated when submitted to DC short circuits. The aR (only short circuit) fuse shows the best behaviour compared to gG fuse (overcurrent and short circuit) and further studies are necessary to ensure a reliable assessment.

Several ways of improving DC circuit breakers (CB) performances are investigated. A higher compactness is obtained by choosing a tubular chamber including dielectric barriers combined with splitter plates in **paper 11254**, with a prototype at 3 kV / 3 kA that can be upscaled to higher voltage. Or in **paper 10584**, by reducing the arc quenching time by introducing hydrogen in the gas mixture instead of air in a switching device for a battery disconnecting unit implemented in EV charging system. The design and testing of adjustable current injection in **paper 10897** confirms the feasibility to interrupt fault current for a large range of values from 100 A up to 20 kA with low losses in closed position and with neglectable changes of breaking time. **Paper 10730** shows that it is necessary to combine a capacitor based damper circuit with an IGBT to handle switching surge in DC.

Even if regulation and standards around DC networks are still under construction, **papers 10467** and **10335** give some guidance to keep voltage stability in case of fault. In **paper 10467**, the presence of severe DC faults drives the authors to recommend dimensioning of the LVDC converters to withstand faults of at least 15 times the rated current to ensure compatibility with grid selectivity requirements. In case of MVDC side voltage dip from a PV farm collection, **paper 10335** gives the characteristics of DC solid state transformers to keep impact below 6% on the LVDC side voltage.

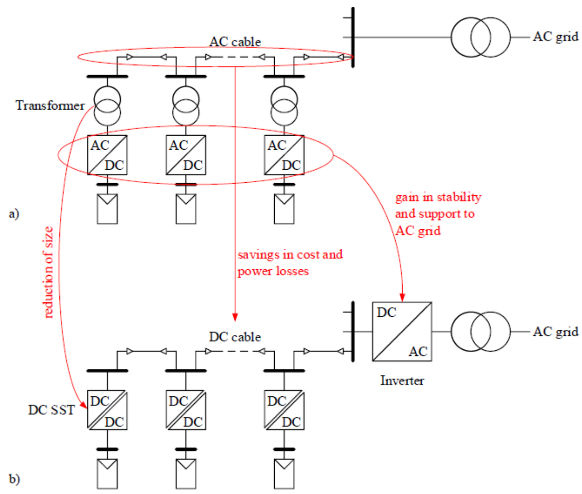


Fig. 1 of paper 10335 : MVAC (a) and MVDC (b) collection network for PV power plant highlighting the structural differences and benefits of MVDC

Going a step further, **paper 10784** proposes a network improvement to tackle future challenges by adding MVDC branches combining PV farm, battery storage and EV charging stations (see Fig. below). A voltage of 54 kVDC is proposed to bypass the 33/11 kV voltage step and simplify the network with a direct conversion from 33kVAC to 54 kVDC and a step-down to 800 VDC for the LV side.

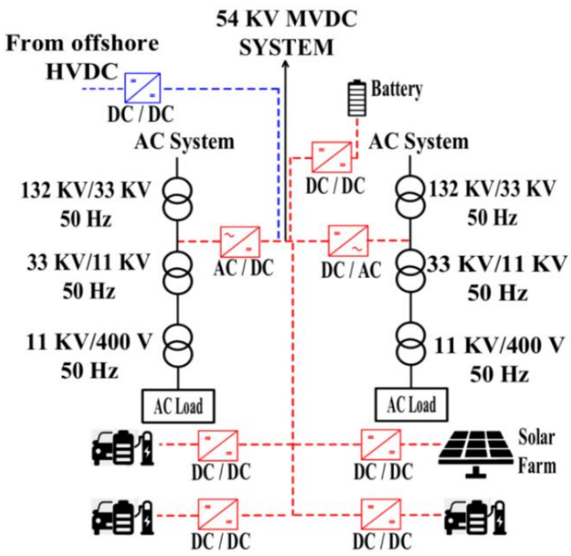


Fig. 1 of paper 10784 : Proposed MVDC Transmission in red colour

Sub block 2 : Power Electronics (5 papers)
In order for DSOs to keep power flow capabilities together with a good level of protection, power electronics gives a set of solutions on a wide range of power from 0,1 to several MVA in LV (**11469, 11251, 11317**) and MV networks (**10364, 11317**).

In **paper 11469**, the efficiency on network protection, capability and stability of distributed power electronic devices in a LV network is assessed, in particular by the modelling of distributed soft open points (D-SOP). **Paper 10364** presents Static Synchronous Series Capacitors (D-SSSC) as a patented solution to mesh MV networks (see Fig. below).

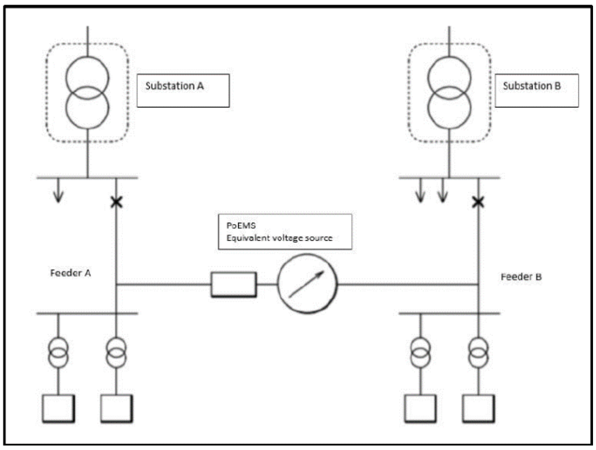


Fig. 2 of paper 10364 : PoEMS - Interconnection of two distribution grids

Taking the opportunities of the replacement of buried transformer, **paper 11251** proposes to use soft open points based of LV back to back AC/DC/AC power electronic devices to better mesh and enhance the utilization of urban networks. The lessons learned from the commissioning and operation of a SOP in LV is shared in **paper 11317**, highlighting criteria to select the best place to install such a device and the recommended change to improved maintenance and operability. An insight for future soft power bridge for MV network is also presented with the challenges linked to the weight, the size and the coolant pipework.

Power electronics is particularly adapted to manage networks with PV and battery system. **Paper 11145** presents the development of a dynamic model able to drastically reduce the need for time-consuming and expensive tests on real hybrid system.

Sub block 3 : Superconductivity (2 papers)
The reduction of available space in urban areas pushes conventional technologies to their limits, especially when always higher electrical power is required to support decarbonization through the development of e-mobility (**11045**) or to increase resiliency of critical assets (**11059**).

The key advantage of superconducting cable solutions is to carry very large current and power in a fraction of size of what is possible with conventional technologies.

In **paper 11045**, the difficulty to install new HV transmission lines in city center substations and the risk of outage on transmission links due to climate change have lead to propose to increase redundancy from N-2 to N-3 by connecting primary substations with 60 MVA MV superconducting cables, with the agreement of the federal regulator to qualify this link as a transmission link. The first phase of project was commissioned in 2021 (see Fig. below).

Fig. 4 of paper 11045: Photo of vertical Termination of superconducting 12kV cable - 62 MVA installed in Chicago in 2021 to increase the network

In **paper 11059**, the required increase of power supply for a major railways station is blocked by the impossibility to create new rights of way. Only the compactness of DC superconducting cables allows to use the available ducts to carry the required power.

Sub block 4 : Storage (5 papers)
Each cell of a second life batteries energy storage system has a different behavior: **paper 10502** proposes an active balancing algorithm to optimize the power delivery, taking in account the characteristics of each cell. The practical reuse of heavily used EVs batteries to support the deployment of renewable production is studied in paper **11504**.

Paper 11050 presents guidance to implement large scale battery systems based on lessons learned from DSOs, with key indicators to anticipate the return on investment, as well as requirements based on good practices for civil works and construction regulations.

To pursue decarbonization, **paper 10395** demonstrates in the case of outage that mobile battery units can replace actual diesel generators with additional benefits in term of power quality and nuisance mitigation.

Sub block 5 : Charging station (4 papers)
The rapid and massive deployment of EV charging stations fleet now requires to anticipate their maintenance (**10322**) and to optimize their business model and ease to use (**11282**).

E-mobility and renewable production have the common goal to decarbonize. **Paper 10998** presents possible synergies in a smart grid with renewable productions and bi-directional EV charging stations (see Fig. below).

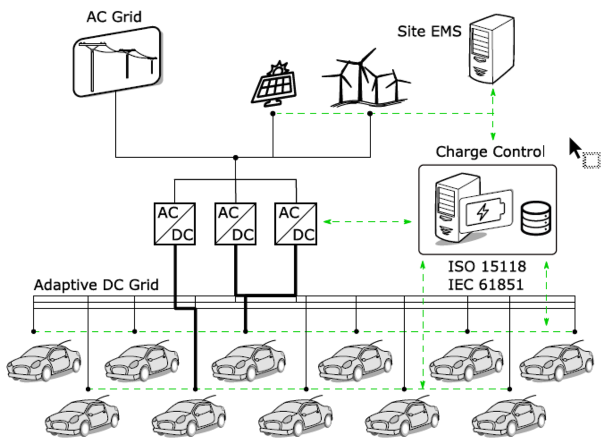


Fig. 1 of paper 10998 : Simplified system architecture with adaptative DC grid of charging stations

Sub block 6 : Prospective (7 papers)
With the deployment of distributed generation and the trends to mesh the LV and MV network several components have been tested from active systems, like automated switchboard (**10713, 11029, 10763**) and controlled switching (**11029, 10586, 10763**), to passive solutions (**10865, 11291**).

The automated LV switch board (see Fig. below) presented in **paper 10713** can improve the quality of power delivery to consumers, insuring fast and adaptative reaction and increasing the power distribution with given assets in rated or peak conditions. However it requires a robust and reliable communication system.

Fig 3 of paper 10713 : Automated LV switchboard

In addition to switchboard, **paper 11029** shows that OLTC and in general advanced on line voltage control system are key components to keep a high level of power quality with highly variable situations.

For MV networks, **paper 10586** draws a parallel with the well proven Controlled Switching in HV grid. Controlled switching in MV network becomes possible thanks to the combination of technologies like power electronics and vacuum interrupters.

A summary of all the latter technologies is presented in **paper 10763** through the European project "FLEXIGRID" aiming at improving both MV grid stability and flexibility.

In **paper 10865**, the active switching of MV shunt reactor, depending on the network compensation needs, gives some interesting prospective to stabilize the voltage.

Novel type of cables, called CTS for Capacitive Transfer System, acting as series capacitances presented in **paper 11291** gives some new way to distribute and manage compensation in MV networks (see Fig. below).

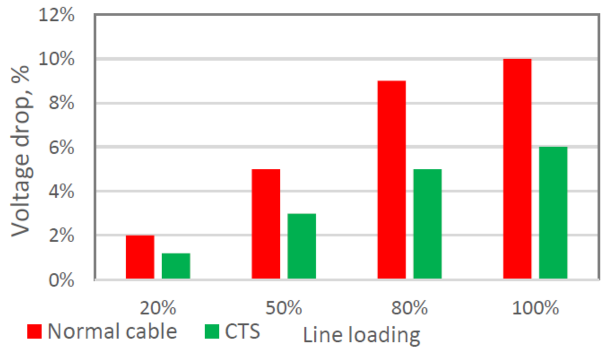


Fig. 14 of paper 11291: Voltage drop of CTS compared to normal cable

Sub block 7 : Performance upgrade (5 papers)
In order to optimize the design and the cost for given specifications, dynamic rating approaches are carried out with more efficient heat exchanger, for transformers in **paper 10648** (see Fig. below), and for breakers in **paper 10369**.

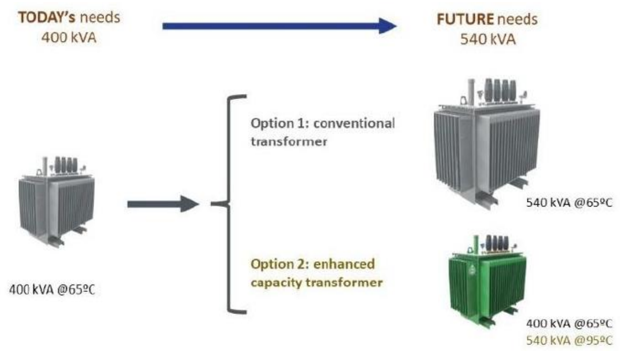


Fig. 1 of paper 10648: The enhanced capacity transformer

The mitigation of faults and lightning impacts on networks requires continuous development with evolving constraints due to the increase of power density of the network, the degradation of soils and the increased occurrence of violent atmospheric phenomena. The aim is to provide adequate path for surge currents to the ground.

In **paper 10954**, the grounding improvement of pole transformers divided by two the number of casualties. For distribution overhead lines in general, **paper 10641** proposes to distribute along the line Arching Horn attached insulators at least every 150 m to cover the full line, mitigate overvoltage and evacuate excess current.

To be as close as possible to the severe environmental conditions **paper 11435** presents a way to test resistance to corrosion including installation and long term thermal life cycles.

Table 1: Papers of Block 1 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
10322: DC Electric Vehicle Charging Infrastructure – Methods for Periodic Verification				X
10335: Fault Ride Through Of DC Solid State Transformer In Medium Voltage DC Systems			X	X
10364: A Novel Power Electronic Meshing Solution for Radial Medium Voltage Distribution Networks				X
10369: Improvement Of Thermal Performance Of Medium Voltage Circuit Breakers By The Implementation Of Heat Pipes				X
10395: Validation Tests of Battery Based Mobile Generators for Islanding Operation During Works on the Distribution Grid				X
10403: Numerical Estimation Of The Parameters Of A LVAC Cable For Use In An LVDC Power Grid				X
10466: DC short-circuit Behavior of LVAC Fuses			X	X
10467: Impacts of Low Voltage Distribution Grid Resilience Constraints on AC/DC Converter Sizing			X	X

10502: A Generic and Scalable Dynamic Model for Stationary Battery Energy Storage System				X
10584: Hydrogen Filled DC Circuit Breakers for Electrical Vehicles Batteries				X
10586: Evaluation And Research Trends On Controlled Switching And Transients Mitigation				X
10610: Development of Underground Cable for Low Voltage DC of 1MW Class				X
10641: Improvement of lightning resistance for distribution facilities				X
10648: Sustainable Peak Load Transformers				X
10649: World's First Enhanced-Cooled Dry-Type Transformer For Wind Off-Shore				X
10713: Innovative Distribution Automation for Low Voltage Networks to accomplish the new challenges arising from the energy transition				X
10730: Study of surge protection in MVDC networks using a solid-state breaker/limiter				X
10763: Smart Secondary Substation development and demonstration under FLEXIGRID project	X			X
10784 : Silicon Carbide Enabled Medium Voltage DC Transmission Systems for Rapid Electric Vehicle Charging in the UK	X			X
10865: Automated Shunt Reactors For MV Feeders Upper Voltage Constraints				X
10897: Direct Current Circuit Breaker With Adjustable Current Injection				X
10954: Improving the Earth Electrode of Pole Mounted Transformers_				X
10998: MADELAINE – A Multi-Adaptive and Cost-Efficient DC Charging System for EV Car Parks	X			X
11029: Distribution Smart Transformer with an Innovative OLTC Switching Technology for LV Grid Real Time Operation				X
11045: Recent superconducting cable installation in Chicago paves the way for a Resilient Electric Grid (REG) system	X			X
11050: Requirements For Large Scale Battery Storages In Low Voltage Grids - Lessons Learned From A Smart Grid Project.	X			X
11059: Superconducting Systems, a New Tool for Railway Power Grids				X
11145: Hybrid Power Solution Modelling Based on Artificial Intelligence				X
11251: Innovative Solutions for the Replacement of Underground Transformers				X
11254: Tubular DC Breaker			X	X
11264: Research Of Components For An Increase Of Transmission Capacity In Distribution Grids By Changing Existing AC Links Into DC Links				X
11282: Smart Meter Based Charging System for Public EV Charge Points				X
1291: Capacitive Transfer System Cable for Efficient Power Delivery in a 33kV Distribution System				X
11317: Lessons from the Installation and Commissioning of Novel Power Electronics for Active Response				X
11435: Evaluation Of Novel Corrosion Protected Aluminium Earth Wire For Use In Underground Cable Networks				X
11469: Distributed Smart Soft Open Point	X			X
11504: Battery Energy Storage System with Batteries of Second Life				X

Block 2: "Monitoring and diagnostics"

The 34 papers of this block are divided in 4 sub-blocks:

- Sensors for condition monitoring
- A specific sub-block on Partial Discharge, due to the large number of papers dealing with this topic
- Metering, fault localization and DLR, especially for cables and lines
- Use case experiences in testing and maintenance.

Sub block 1: Sensors for condition monitoring (8 papers)

Sensors are at the heart of monitoring systems, to capture the operating and aging condition of assets. This sub-block reviews various sensors technologies, as well their implementation by manufacturers and DSOs.

Two papers are good reminders of the main drivers behind switchgear sensorization and digitalization. In addition to the existing smart features (RTU's, fault indicators, general alarms…) the main lack concerns condition monitoring. Benefits of sensors relating to environment, temperature, digital pressure gauge, mechanical, partial discharge, DGA,… and their digital integration are presented in a use case for a primary (**paper 10380**) and secondary (**paper 10397**) substations. Both authors emphasize the need of scoring the critical ageing factors vs. the operating conditions for each asset type.

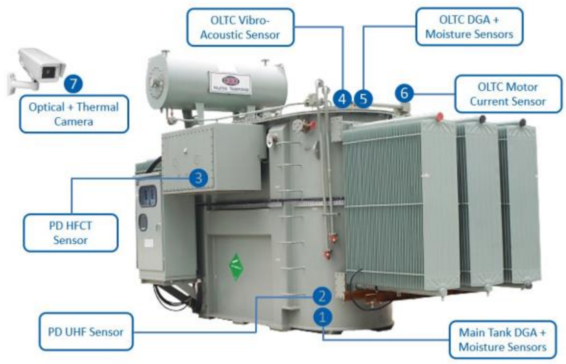


Fig. 3 of paper 10380: Power transformer real-time online condition monitoring technologies

Paper 10120 reveals an important challenge observed during a use-case of mechanical monitoring of 16 circuit breakers in operation: results are impacted by external parameters like ambient temperature and operational frequency (because mechanical measurements in a CB are event-dependent). This induces a bias in the measurements, which needs to be counterbalanced.

Three papers deal with condition monitoring of oil transformer.
On-site implementation of temperature sensors in MV/LV distribution transformers, coupled with a thermal and ageing prediction model (from IEC 60076-7), is described with an emphasis on the right model parameter estimation (**paper 11366**).

Development of resistive nano-sensors capable of detecting H_2 and CO gases dissolved in transformers oil, coupled with ML algorithms for decision making (**paper 11397**).

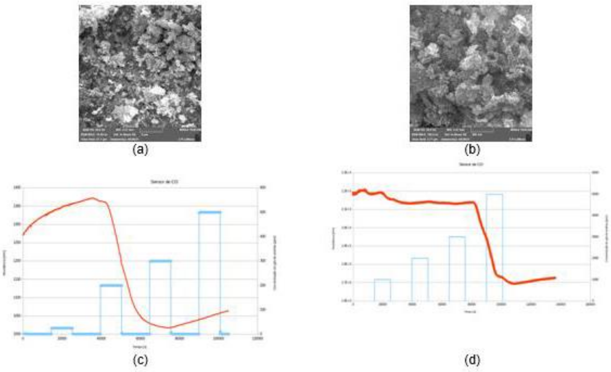


Fig. 3 of paper 11397: (a) and (b) SEM images of SnO2 NPs decorated with Pd NPs; (c) and (d) Graphs of resistance and gas concentration

A two-years surveillance study is presented on 72 OLTCs in **paper 10687.** Health indicators which estimate the degree of deviation vs. "healthy" patterns are extracted from voltage and current measurements of the drive motors.

For GIS application, a combined "gas pressure & two temperature" sensors system **(paper 10447)** reduces drastically the influence of temperature on the measurement. This "densitometer" allows to detect low leakage rates in advance and anticipate maintenance long time before reaching the alarm level.

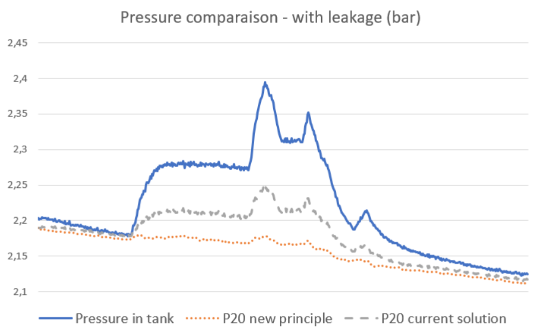


Fig. 5 of paper 10447: Pressure comparison with leakage - raw pressure (blue), corrected P20 pressure with 1 temperature (dotted), corrected P20 pressure with 2 temperatures + model (orange)

To detect extreme events as snowfall on overhead line in severe environmental regions (mountains, etc…) **paper 10231** proposes a multi-technologies sensor including MEMS + GPS (for vibration, torsion, and inclination analysis) and environmental data. It's worth noting the challenges of batteries life optimization for such complex sensors (by triggering only on active wake-up), and reduction of the huge dataset generated locally (which topic also enters in block 4's discussion).

Sub block 2: Partial discharge (11 papers)

Partial Discharge (PD) testing and monitoring is particularly important to detect premature ageing of insulation, such as discharge activity in voids, delamination, developing cracks in solid materials, as well corona and surface discharge induced by a severe climatic environment.

Several papers compare different coupling techniques: mainly capacitive and HFCT (High Frequency Current Transformer). Sensibility tests on capacitive coupling are presented in **paper 11171** using a smart bushing in a GIS. 5 scenarios are considered depending on the sensor position vs. PD source, and additional capacitance in the circuit.

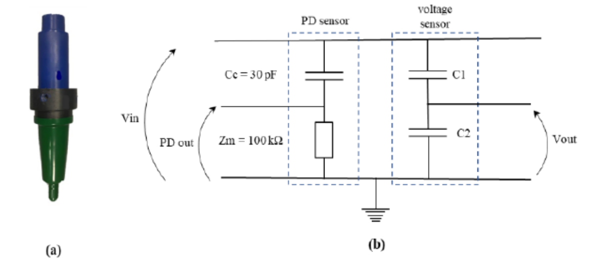


Fig. 1 of paper 11171: (a): the smart bushing, (b): electrical model of the smart bushing

Use of an extended frequency range in **paper 10400** improves PD detection in cables, through the VDS (Voltage Detector System) port installed on numerous switchgears.

With a similar principle, **paper 11331** presents PD capacitive monitoring device (PMPD) for MV switchgear. Its sensitivity, as well its simplified cloud-compatible phase resolved dataset are compared in lab with a standardized IEC capacitive measurement on specific PD sources.

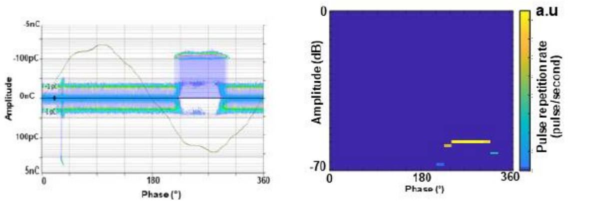


Fig. 5 of paper 11331: PRPD from a laboratory IEC Device (left) vs. simplified from PDMD (right)

One of the challenges of PD diagnostic and monitoring in real installations, is to separate a combination of signals from multiple PD sources, including also noise and interferences. The two last ones need to be filtered, to prevent false alarms for end users.

Appropriate bandwidth and high-pass filter selection are discussed in **paper 10470**, to remove the “synchronous noise” during test campaigns on cable termination

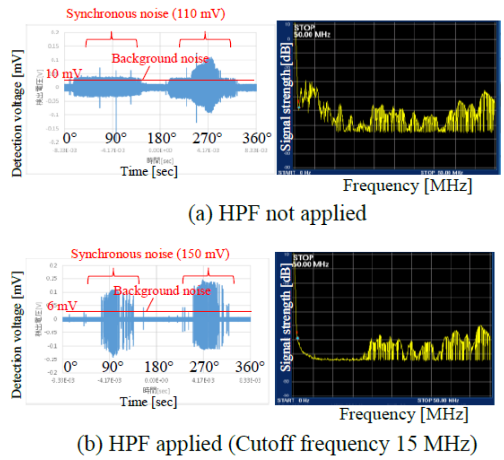


Fig. 8 of paper 10470: Noise waveforms and frequency characteristics (capacitive method)

A combination of different-frequencies sensors in **paper 10434,** helps to distinguish between noise and PD. Among other parameters to identify insulation failure types, the pulse repetition rate is investigated as an easy statistical feature for default classification.

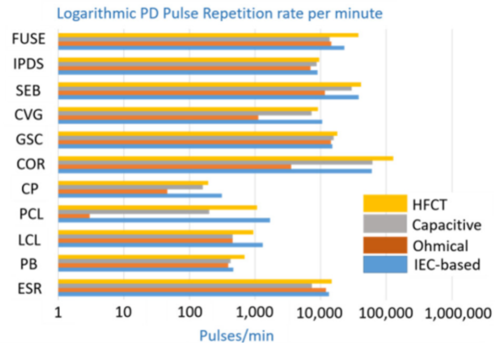


Fig. 4 of paper 10434: PD pulse repetition rate per minute for different failure

Thanks to PD data acquired during a field test, **paper 11338** presents a correlation study with environmental and operating factors.

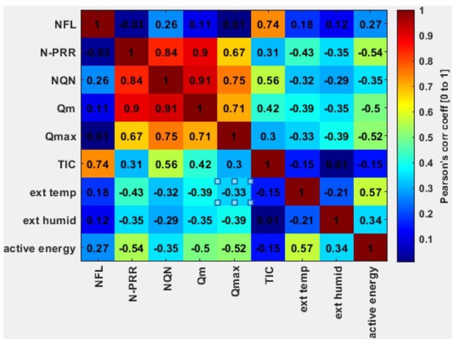


Fig. 7 of paper 11338: Correlation matrix among PDMD indicators, environmental and network operating features

Advanced signal clusterization based on T-F map in **paper 10723**. allows to follow and assess the severity of single PD source trends, and not of the whole acquisition signal.

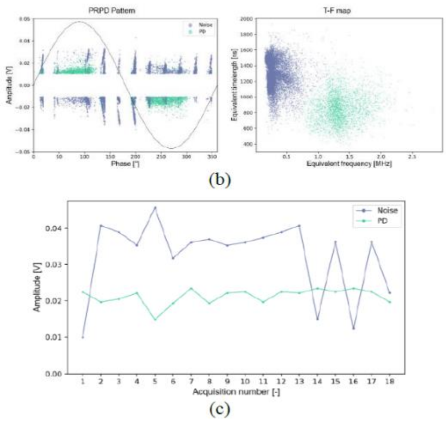


Fig. 8 of paper 10723 (extract): (b) PRPD pattern and T-F map containing PD and noise signals, (c): two separated amplitude trends of the two detected phenomena

In case of air insulated switchgear (AIS), the ideal localization of ultrasonic PD sensors is discussed in **paper 11486**. PD measurements on artificially polluted insulators in a test laboratory are reported in **paper 11014**.

Paper 10235 introduces an original approach for interpreting on-line partial discharge measurements: a dual-model combining a discharge pulse model (based on plasma physics) and a HF signal propagation model aims to simulate the PD signal received by the sensor. It opens new perspectives for calibration and fault localization, possibly using a multi-sensors system coupled with algorithms.

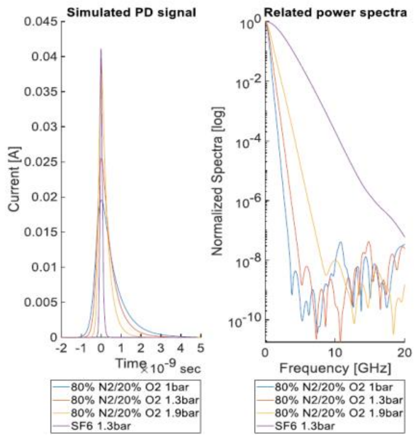


Fig. 6 of paper 10235: Simulated PD signals

To conclude this sub-block on partial discharges, **paper 11140** gives interesting perspectives from a DSO on permanent PD monitoring: 1) cover the largest number of assets with minimum number of sensors. 2) powerful noise elimination 3) use of AI tools to become operator independent for the detection of the most common insulation defects with mixed signals.

Sub block 3: Metering, fault localization, DLR (7 papers)

Current and voltage transformers play a vital role in monitoring network power and energy, as well as providing the necessary inputs for protection relays.

Paper 11000 reviews the advantages provided by the installation of numerous meters at strategic points of a low-voltage network.

Accuracy and calibration are of primary importance, as mentioned in **paper 10867** which presents a live line metrology instrument, based on a high voltage stick equipped with current and voltage sensors, synchronized with a GPS time base.

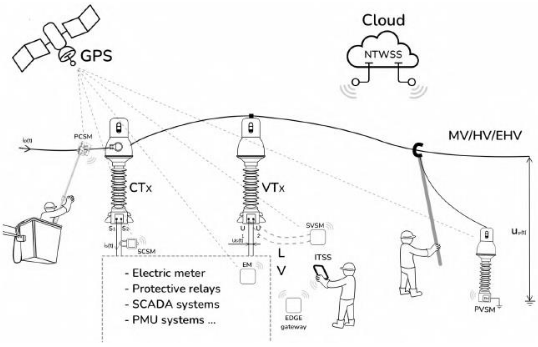


Fig. 1 of paper 10867: Schematic view of developed live line metrology instrument

Low-power voltage transformers (LPVT) can replace classical ferromagnetic transformers, providing compacity and high bandwidth advantages**. Paper 10484** studies the impact of such LPVT on the possibility of carrying out VLF cable diagnostics. Partial discharge and withstand tests are not affected. However, as expected, the measurement of the dissipation factor is significantly impacted by the resistive divider function.

Paper 11433 focusses on a metering retrofit solution for a very compact RMU switchgear where installation of CT and VT is unfeasible due to the lack of available space.

Two papers introduce sensors deployed on overhead lines for Dynamic Line Rating (DLR), to optimize their power load in real time. **Paper 10206** describes a DLR architecture based on fiber optics both for sensing (temperature and wind) and communication (existing OPGW network).

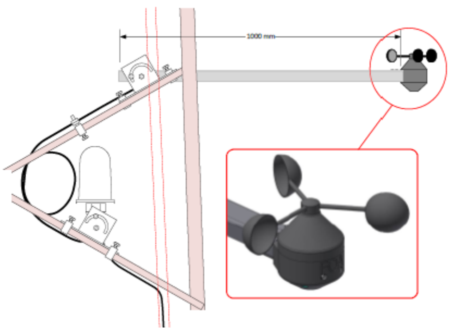


Fig. 1 of paper 10206: Position of Fiber Optics Anemometer (FOA) on a cantilever

A self-harvesting smart sensor is shown in **paper 11289**, which provides real-time measurements, that are used in a model to derive a '10 minute' short-term post-fault rating, thanks to the available thermal capacity of cables (model based on CIGRE TB 601).

The localization of damaged area in underground cable is a tedious task. **Paper 10537** describes an off-line "hard to find" fault localization system for MV underground distribution, based on Traveling Waves (TW). This system requires the full synchronization of the time base with the Global Navigation Satellite Systems (GNSS), and a fast treatment the recorded signals (voltage and current) with FPGA.

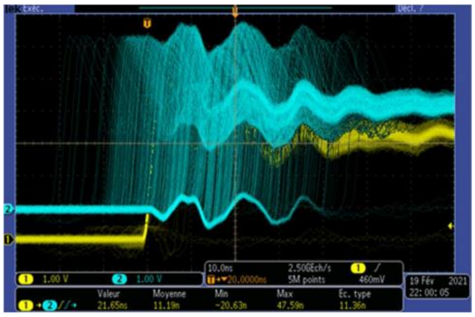


Fig. 6 of paper 10537: GPS synchronization error

Sub block 4: Use cases experience in testing and maintenance (8 papers)

Various use cases of equipment usage and diagnostics are presented in this sub-block

Paper 10186 is an interesting review of field experience on recloser usage and maintenance in emerging countries, including the integration of the latest innovations.

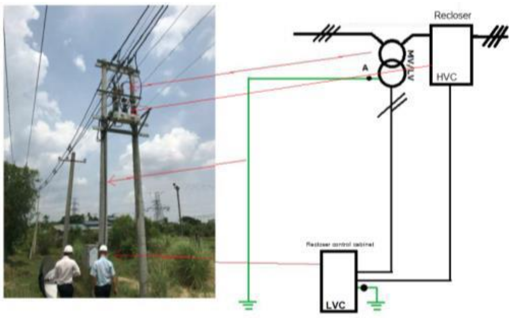


Fig. 4 of paper 10186: Typical recloser installation in rural distribution network by APQ, Yangon, Myanmar

Three papers concern testing of Vacuum Interrupters (VI). Their BIL performance testing is always questionable: it derives from a statistical treatment of several voltage impulses withstand test, thus from the applied procedure. It is also highly depending on the conditioning state of all metallic parts inside the VI. To overcome this problem, **paper 10533** investigates various statistical test procedures that could be used as routine tests in factories, and **paper 10830** proposes a revision of the standards: the number of conditioning impulses should be indicated in the datasheets provided by the manufacturers.

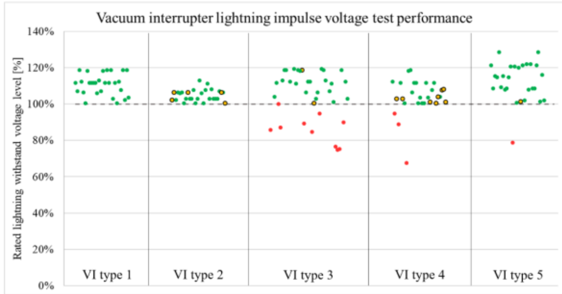


Fig. 4 of paper 10830: Vacuum interrupter BIL test results

Paper 10679 investigates rotative switching arcs in Radial Magnetic Field (RMF) vacuum interrupters, with high-speed camera, and simulations. Measurements are compared to contact erosion level.

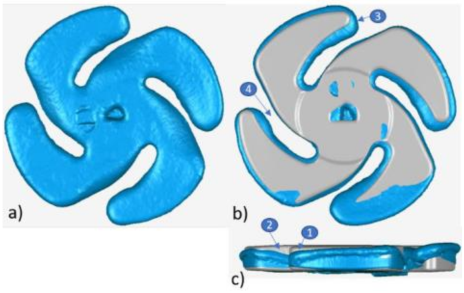


Fig. 8 of paper 10679: top view of 3D reconstitution of a) eroded contact; b) eroded contact superimposed with brand new contact, c) side view of superimposed contacts

Three papers concern cable testing. The operational challenge (conformity with procedures, handling complexity, safety…) of RTS (Resonant Test System) cable testing in offshore windfarm exploitation is reported in **paper 11027**.

Fig. 4 of paper 11027: Setup of RTS at offshore substation

Two papers assess the ageing behavior of cable joints. **Paper 10719** demonstrates the impact of pre-use storage conditions (up to 2 years) by electrical and mechanical tests on cold shrink joints from different manufacturers. In **paper 10699**, the focus is set on ageing behavior of connection joints between very aged oil/paper cables and new XLPE cables. A combined ageing test protocol is proposed to reproduce the riskiest situations.

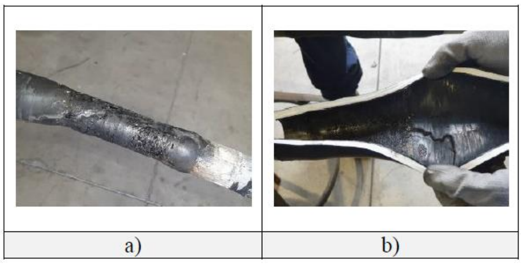


Fig. 13 of paper 10699 a) Discharge from the conductor to the screen; b) signs of discharge inside the main insulating body

In the field of power transformers, **paper 11052** discuss dissolved gas analysis (DGA) to investigate chemical markers as symptoms of thermal faults with high performance aramid insulation.

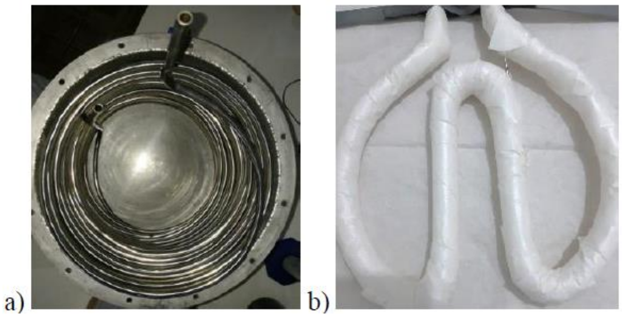


Fig. 6 of paper 11052: Test equipment for thermal fault modelling in liquid immersed system with aramid insulation: a) vessel, b) paper-wrapped heating resistance

Table 2: Papers of Block 2 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
10120: Failure Prediction for Circuit Breakers: Vibration and Trip Coil Current Feature Extraction for Machine Learning Applications	X			X
10186: System Issues & Mitigations - Reclosers Installations Experience From Developing Countries				X
10206: FORM: A Novel Principle for DLR				X
10231: IoT Sensors To Increase Resilience Against Critical Weather Events				X
10235: Improved Partial Discharge Analysis By Applying Specific Digital Twins	X			X
10380: TNB Distribution Network's Asset Management Strategy Future Outlook through Advanced Asset Analytics				X
10400: New Approach for Online Detection of Partial Discharges in Cable Systems via VDS Ports				X
10434: Low Cost, High Performance Monitoring System for Renewable Distribution Systems				X
10447: Innovant Densimeter for GIS Tank, Insensible to Temperature Variation	X			X
10470: Sensitivity Evaluation of Partial Discharge Measurement Method for XLPE Cable Joint				X
10484: Influence of Low Power Transformers (LPVT) on the Results of VLF Diagnostic Tests on Medium Voltage Cables				X
10533: Acquisition And Evaluation Of The Breakdown Voltage As A Result Of The Layout And The Statistical Spread Of Vacuum Gaps				X
10537: Fault Location System for MV Distribution Underground Network				X
10679: Vacuum Interrupter With RMF Contacts: Arc Movement Observation And Modelling To Master Electrical Endurance				X
10687: On-line Monitoring Condition of On-load Tap Changer of Power Transformers	X			X

10699: Diagnostic Techniques Of MV Cable Joints Under Different Environmental Conditions	X			X
10719: The Impact Of The Joint Pending Time On Its Support Regarding Its Electrical Properties				X
10723: Improvements on the Automatic Assessment of the Reliability of Distribution Grids Through Online Condition Monitoring				X
10830: A Review of Medium Voltage Vacuum Interrupter BIL Performance				X
10867: Real Time Live Line High Voltage Measurement of Instrument Transformer's Ratio and Phase Displacement Errors				X
10937: Asset Management Prepared Smart Secondary Substation				X
11000: Low-Voltage Network Point Measurement And Monitoring				X
11014: Partial Discharge Measurement of Polymer Insulator under Artificial Contamination				X
11027: Field Experience of On-site Cable Testing of 66 kV Offshore Array Cables	X			X
11052: Diagnostic Tools (DGA) for Resilient Transformers with Aramid-Based Insulation Systems				X
11140: Deploying Intelligent PD Monitoring Solutions In Distribution Grid				X
11171: Smart Bushing PD Sensor Testing for Switchgear Application				X
11289: Realising the Benefit of Short-Term Post-Fault Ratings using Smart OHL Sensors for Increased DER Integration				X
11331: Partial Discharge Characterization Through Innovative Continuous Monitoring of Medium Voltage Substation				X
11338: Advanced Switchgear Diagnostics Through PD Monitoring Correlated With Environmental And Operating Parameters				X
11366: TNB Experience in The Use of Smart Meter For Real Time Monitoring on The Thermal Performance of In-Service Distribution Transformer				X
11397: Monitoring of Gas Evolution of Power Transformers Integrating Nanotechnology and Intelligent Techniques				X
11433: Gaining Insight In The MV-grid With Low Effort By Accurate RMU Retrofit Measurement To Accelerate Hosting Capacity And Energy Transition.				X
11486: Improved Condition Monitoring Using Internally Mounted PD Sensors Within Network Components And Switchgear Enclosures				X

<u>Block 3: "Context evolution driving development and studies on components"</u>

Sub block 1 : Environmentally friendly equipment

The study of the impact on health of electrical equipment and installation is of key importance for sustainable development. It should address both human beings (**11234 and 11175**) and animals (**11372 and 11175**).

In **paper 11234**, the limits for electromagnetic field exposure are compiled using different sources based on biophysical and biological considerations (see table below). The measurement and calculation show that no critical situation is identified with actual procedures from 400 V to 35 kV.

Electric field strength		Magnetic flux density	
Low action level	High action level	Low action level	High action level
10 kV/m	20 kV/m	1 mT	6 mT

Table 1 of paper 11234 : Action levels for power frequency (50 Hz) electric field strength and magnetic flux density given by the directive 2013/35/EU

For the common interest of humans and wildlife, a metal-enclosed switching system is proposed in **paper 11175**. It allows to disconnect and to earth separately overhead lines on each side of a pole. It requires to connect the overhead lines to the switchgear with insulated cables. As a result, it reduces the risk for birds and - thanks to a more selective grid protection - to prevent fire in risky area.

Paper 11372, summarizes the lessons learned and the best practices from 20 years of initiatives and experiments to make the grid safer for birdlife. The paper points out that the cornerstone of this program was the cooperation with bird protection association to collect data and to assess the efficiency of the solutions.

Sub block 2 : SF6 alternative (8 papers)

Alternative gases utilizing per or polyfluoro-alkyl mixture are studied from different aspects : global warming potential (GWP) (**10890**), biosafety (**10242, 10890**), leakage rate (**11483**) and long term behaviour (**11483, 10890**)

Paper 10890 reports for these molecules greenhouse effect still much higher than CO2 and with long lifetime by-products having negative impacts on the environment.

After a long series of experiments, **paper 10242** concludes to a low level of toxicity, nevertheless requiring mask, protectives gloves, good ventilation and gas detection to avoid long-term effects on health.

In **paper 11483**, the leakage and decomposition of C4-FN is monitored during dynamic and static operations of MV switchgear and compared to SF6 and CO2 to assist gaskets materials selection.

Instead of trying to develop high performances molecules with some remaining concerns about safety and environment, **paper 10894** gives the way to fulfil the same specifications as SF6 equipment using natural origin gases (NOG) as insulating gas at slightly higher pressure and vacuum as breaking medium. However, **paper 10250** shows that the presence of the surrounding tank in compact GIS can affect the vacuum breaker performance, due to the capacitive coupling of the VI shield with the ground. This requires a proper design. **Paper 10994** presents an in-depth long-term study of fluorine free gas alternative in operation.

Comparison of Long-Term Effects	**SF6**	**Natural Origin Gases (NOG)**	**Alterna-tive F-Gas mixtures**
switching arc impact/partial discharge	++	++	?
permeation	+	+	+
aging of materials	+	+	– –
long term experience of complete GIS	+++	++	+

Table 3 of paper 10994: Comparison of long-term effects of alternative gas solutions and SF6

In order to compensate the lower arc quenching performance of air or CO2, **paper 10557** proposes to assist the arc breaking with a magnetic field induced by the short circuit current inside a polymer pipe coated with Iron. Keeping the same pressure in synthetic air as in SF6, **paper 10868** presents a new type of switchgear with upgraded double effect blowing.

Sub block 3 : Life Cycle Analysis & Carbon Footprint (5 papers)

Based on more and more reliable and consistent data, **paper 10795** has realized an extensive comparison of air and SF6 switchgear impact on environment over their full lifetime. Thanks to recent innovation in the domain of air insulation, the global footprint of air is rated 30% lower than SF6 at equal level of performances. **Paper 11056** confirms the latter conclusion about lower footprint for air and emphasizes that other parameters exist to significantly reduce the impact of MV switchgear from raw materials to the end of life. As shown in **paper 11116** and especially when energy mix is not favorable (see Fig. below).

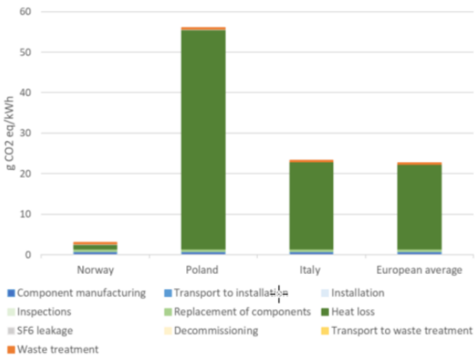


Fig. 3 of paper 11116: The effect of different electricity mixes on the impacts on climate change from the distribution of 1kWh in Norway, Poland, Italy, and Europe

In papers **10469** and **11116**, several areas of progress are identified through new materials sourcing, especially dielectric gas or fluid, and ways to design with lower losses or higher lifespan. However all the process to qualify new technologies with lower environmental footprint is not straightforward. The quality of the assessment of performances and environmental impacts can be degraded by the lack of available data or the time needed to create reliable ad hoc set of data.

In **paper 10332**, a global evaluation of the environmental impact of the sourcing of insulation materials for MV cables is carried out and the main conclusion gives a preference to recycled materials compared to bio-sources polymers.

Sub block 4 : Circular Economy (4 papers)

The progression towards Net zero impacts of electrical grids requires a change of mindset in term of design and specification of grid components. In **paper 10225** the principle of a disassembly manuals, identifying reusable parts, as well as a way to track raw materials all along their life cycles are at the heart of a new sustainable system.

The criticality of metallic raw materials is highlighted for substation equipment in **paper 10745** with the tracking of 60% of the metal mass and a recycling of steel much more developed than for copper.

The use of composite in electrical grid is widespread and **paper 10325** addresses the different options to recycle this materials: for the same initial use (primary recycling) but with proportion of less than 20% or in other components (secondary recycling) with proportion of up to 60%.

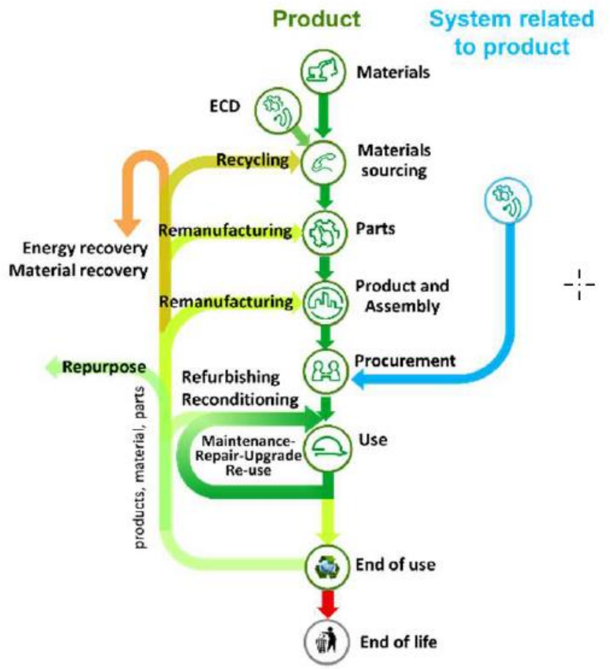


Fig. 8 of paper 10774 : Example of life cycle considered for circular design

In **paper 10774**, an overview is given of all the standards and rules available to support circular economy in order to achieve an environment conscious design of grid components (see Fig. above)

Sub block 5 : New Materials (9 papers)

The evolution of overhead lines towards new environmental challenges are following several paths such as the increase of power per line (**10294**) and the evolution of infrastructures to better protect wild life with new materials (**11350**). The use of composite for High Temperature Low Sag OHL is developed in **paper 10294**. At equal outer diameter the conductors exhibit higher ampacity and much larger peak load providing lower losses for larger rated power and ability to reuse existing poles in some cases. In **paper 11350** metallic and composite arms for overhead lines are compared in terms of global benefits and the composite could be a viable alternative especially as it reduces inherently the risk of electrical accident with birds.

The joints of MV cable are still a major source of failures. An epoxy resin is used to insure the adhesion and the tightness of joint on the cable sheath and **paper 10309** highlights the differences of performances between cable manufacturers, especially after ageing when the surfaces has not been abraded. For high temperature underground cables, **paper 10271** finds the parameters for MV cable joint design to create a temperature sink and gives the configurations for which the external temperatures of both joint and cable do not exceed 90°C.

The polymeric insulation used for MV cable could be enhanced by additives. The challenges are to bring enough added values to compensate the increase of raw material cost and processing complexity. **Paper 10211** presents a study on the impact of nano and micro alumina powders on the dielectric breakdown of LPDE.

Even if polymeric insulation is now used in most of underground cable, there are still significant fluid filled cables in service in some countries with leaks at country level of several hundred of thousand litres every year. **Paper 11126** presents a new formulation of dielectric fluid that prevent leakage if replacing the actual fluid after flushing to remove antioxidant from the previous formulation.

Dielectric fluids are also present in transformer and in **paper 10596**, the use of natural ester produced from agriculture materials is investigated and shows numerous advantages in term of carbon footprint and performances equal or higher than mineral oils.

A lot of energy infrastructures are exposed to salt and pollution, with the risk to modify the surface properties from insulating to conducting, provoking leakage current with harmful damage through corrosion (**11472**) or fire (**10642**). In **paper 11472**, studies were conducted to identify the adequate alloys and conclude that steel should have contents of Ni and Cr equal or above to 304 grade.

In **paper 10642**, the creation of leakage current due to salt on the insulators was able to ignite the wood pole itself (see Fig. below). Insulators with composite have been developed to prevent this phenomenon.

Fig. 1 of paper 10642 : Pole top burning in an advanced stage due to earth leakage current

Sub block 6 : Resiliency (3 papers)
The context evolution has multi-dimensional impacts on secondary substations and real time units may be useful to control and monitor them. **Paper 10652** describes a methodology to reduce the qualification periods of the new version of real time units taking in account the complexity of the new requirements in term of resiliency, reliability and cybersecurity (see Fig. below).

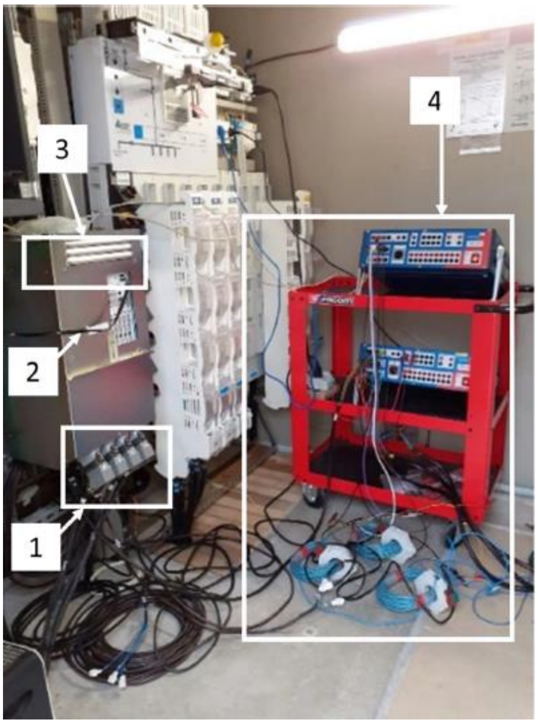


Fig. 2 of paper 10652 : Test setup for fault signal injection in the Modular Equipment for Monitoring and Supervision (EMIS) : 1-switchgear command 2-web connection 3-remote configuration 4-signal injections

In case of major faults, the fast recovery of the maximum of customers is an efficient way to reduce costs and casualties due to long outages. In **paper 10253** a mobile set of equipment intended to be connected directly to the medium voltage has been developed and tested to reenergize rapidly the healthy portions of network. In **paper 11223**, repair kits adapted to MV underground network have been developed and deployed to mitigate outage times.

Table 3: Papers of Block 3 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
10211: Assessment of Breakdown Voltage for Low Density Polyethylene Cables Using Nano Aluminium Dioxide Filler				X
10212: Pro-Active Approach To Mitigating Bird Mortalities On Distribution Networks				X
10225: Enel's Circular by Design Approach for Grid Components		X		X
10242: Biosafety Evaluation of a New Environmentally Friendly Insulating Medium C4F7N Based on Animal Toxicity Experiments				X
10250: Symmetry Breaking Due to Capacitive Ground Coupling in a Vacuum Interrupter				X
10253: Secure Power Supply Of MV Grids - Neutral Isolated - By Means Of GE Directly Connected To Medium Voltage				X
10271: Connection of Medium Voltage Cables with Conductor Temperatures up to 110 °C – Design of a "temperature Sink"				X
10294: Adoption Of High Capacity Low Sag Conductors On High Voltage Power Lines				X

10309: On the Adhesion Efficiency of the PE/resin and PVC/resin Interfaces for Low Voltage Joint Applications				X
10325: Adoption of Recycled Fiberglass Distribution Network Components. Background, Pilot Projects and Future Developments.				X
10332: Adoption Of Recycled and Bio-Based Material For Power Distribution Cables Manufacturing To Achieve A Significant Reduction In CO2 Emissions.				X
10365: Pressurized Air And Vacuum Breaking As Alternative To SF6				X
10469: Alternative Solutions Considered by Enedis to Reduce Electrical Equipment Carbon Footprint Within the Framework of a Global Environmental Approach				X
10557: Influence of Magnetic Fields to the Arc in a Polymer Materials Pipe				X
10596: Sustainable Power Transformers: Enel Grids use of natural ester insulating fluid in large power transformers		X		X
10642: Solving the Problem of Wooden Poles Ignition due to Insulator Contamination - In Theory and Practice		X		X
10652: “End-To-End Testing” of Enedis’ Smart Equipment for Secondary Substations				X
10745: Secondary Material Analysis				X
10774: Standardized Rules For Environmentally Conscious Design And Assessments Of Electrical Equipment				X
10795: Life Cycle Assessment Of SF6 vs. Pure Air Medium Voltage Equipment				X
10868: Avoiding Uncertanties on Safety and Reliability in 24kV SF6 Free Secondary Distribution Switchgear				X
10890: Environmental Issues of SF6-Free Gas Insulated Switchgear				X
10894: Natural Origin Gases & Vacuum Interrupter – A Reliable and Sustainable Alternative to SF6 Medium Voltage Gas Insulated Switchgear				X
10994: Analysis of Long-Term Effects During Development of SF6-free Gas Insulated Switchgears				X
11056: A Simplified Tool For The Life Cycle Analysis Of A Medium Voltage Switchgear		X		X
11116: What Should DSOs Focus On For Reducing The Impacts On Climate Change When Developing And Operating Electricity Networks? A Case Study Of The Power Distribution Network In A Rural Area In Central Norway				X
11126: Non Intrusive Repair Of a Belgrade Fluid Filled Cable With a Self-healing Dielectric Fluid				X
11175: Improve Operator Safety and Protect Wildlife in Overhead Distribution Networks		X		X
11223: Fast-tracking Licencing Of Temporary Lines And The Use Of Mobile Maintenance Kits With MV Aerial Bundled Cables		X		X
11234: Analysis Of The Exposure Of Workers To Electric And Magnetic Fields During Maintenance Works On Distribution Overhead Power Lines				X
11350: Polymeric Composite Crossarms as an Alternative to a Traditional Metallic Solution on E-REDES Medium Voltage Overhead Networks				X
11372: 20 Years Of Birdlife Protection At E-REDES				X
11472: Hardware of Aerial Distribution Networks, for Use on the Seashore, Corrosion Resistant, Corona Discharges and Leakage Current				X
11483: Life-Expectance Evaluation for SF6-free Switchgear using C4-FN Mixtures				X

Block 4: "Data, models and prediction for components"

The 34 papers of this block are divided in 5 sub-blocks:

- Data & models at edge: feature extraction, local algorithms
- Big data for asset management
- Models and tools for components
- Digital twins
- IT/OT infrastructure.

Sub block 1: Data & models at edge: feature extraction, local algorithms (4 papers)

The natural complement of sensors in advanced monitoring systems is the local data treatment with algorithms: simplification, classification, feature extraction, and recognition, possibly with ML. In some applications, the aim is to automatize the process, reducing the subjectivity of human treatment. Another output is to extract the essence of a complex dataset (as for example waveforms) before transmission to the cloud for further computing.

In **paper 10611** large time-series are represented though statistical models of the interesting values, using Gaussian Mixture Models (GMM). **Paper 10743** presents an automated waveform classification system for use as a Distribution Fault Anticipation system (DFA) ie. to be able identify and locate many incipient faults (especially the "low amplitude one"). Two field examples are described based on arcing signatures and current peaks detections.

In **paper 11517**, vibrations measurements associated to feature extraction and ML-changepoint detection algorithm techniques perform extraction of the opening and closing times of a VCB. The authors claim the transferability of the methods to installed base circuit breakers from different vendors.

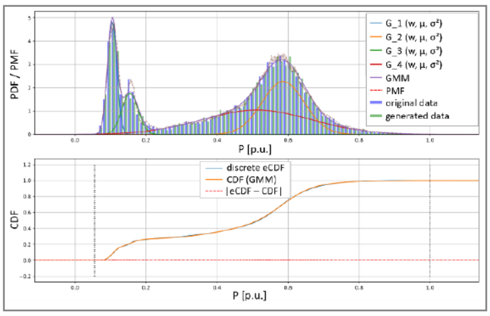


Fig. 4 of paper 10611: GMM example compared with the original dataset

Paper 10316 focuses on deep learning analysis (LSTM-AE) applied to waveforms collected from a non-destructive magnetic diagnosis to detect steel bars breaks inside concrete poles. Performance shows an improved reliability vs. human assessments

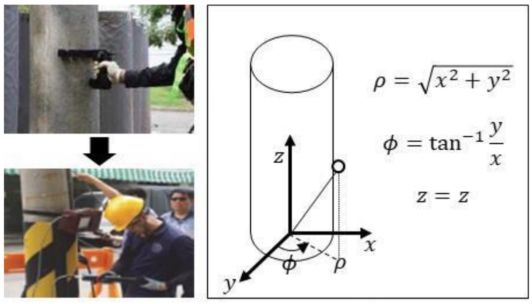


Fig. 1 of paper 10316: Magnetic diagnosis for defective steel bars in a concrete pole

Sub block 2: Big data for asset management (14 papers)

Asset management decisions are more and more data-driven: extraction and cross-analysis from large databases (condition monitoring, network, environmental, etc…) generate new inputs to optimize component integration on the grid, and to predict their future behaviour (as health index, fault prediction, life extension…).

Several papers deal with data model requirements to manage assets. **Paper 10114** discuss the best granularity and stratification for a large portfolio combining different types, manufacturers, models, functions….

On the cable topic, **Paper 10685** is an exhaustive review of data requirements for reliability assessment of MV cables. 3 data families are listed: historical failure (past events on the network), equipment data (design, age, ratings,…), operational data (electrical, climatic including lightning, location: type of soil, past digging, distance of road, railways, etc…). Failure statistics of the Danish MV cable systems are shown in **paper 10834** together with an interesting comparison between PILC and XLPE cable population.

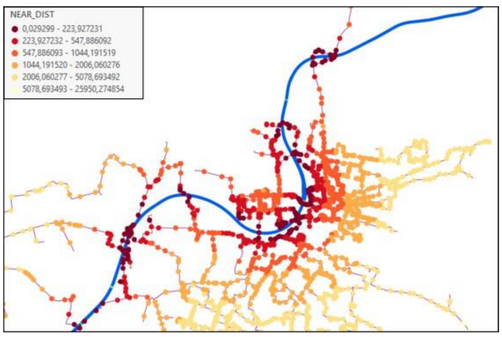


Fig. 2 of paper 10685: Distance to DC railways in [m] as one feature to represent accelerated aging of cables

Correlation from 3 databases (Lightning Overvoltage Detectors (LODs), directional fault detectors, and the "Meteorage" database) is used in **paper 10331** to evaluate advantages and the optimum localization of new Line Lightning Protection Devices (LLPD). A similar dataset combined with an ageing model is used to estimate the cumulative electrical stress on operating surge arresters

(**paper 10339**)

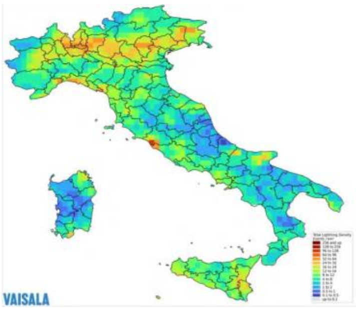


Fig. 3 of paper 10331: Lightning Density in Italy (2021)

Two papers deal with fault prediction: in **paper 10700** pre-fault transient signals from directional fault indicators (FI) are processed and aggregated to localize suspicious area in the distribution network before the occurrence of severe failures.

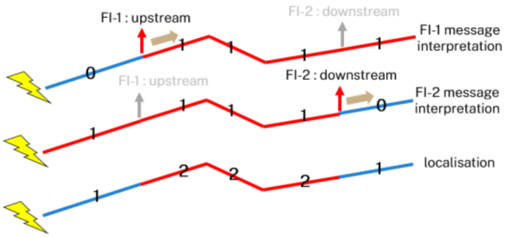


Fig. 1 of paper 10700: Combining message from FIs

A ML based fuse rupture prediction model in **paper 10805** shows a somewhat disappointing result: the best predictor for a fuse rupture is the existence of a past rupture at the same location! However, the influence of fault current and feeder location is also evaluated.

Paper 11246 simulates optimized renovation time at mid-life for transformer, depending on use conditions, to maximize their lifespan extension. Impact of the global warming, as well of electricity demand scenario are estimated in a prospective study concerning the residual lifetime margin of a 400 kVA MV/LV transformer in **paper 10595**.

T_{amb} ↓ fact →	1	1,05	1,1	1,15	1,2	1,25	1,3	1,35	1,4	1,45	1,5	1,55	1,6
10 °C												59,0	39,0
15 °C											48,8	32,7	21,9
20 °C									58,6	39,9	27,1	18,4	12,5
25 °C							67,4	46,7	32,3	22,3	15,3	10,5	7,2
30 °C						52,2	36,8	25,8	18,1	12,6	8,7	6,1	4,2
35 °C				55,4	39,9	28,6	20,4	14,5	10,2	7,2	5,1	3,6	
40 °C		55,6	41,1	30,2	22,0	15,9	11,5	8,2	5,9	4,2			
45 °C	40,0	30,2	22,5	16,7	12,3	9,0	6,6	4,8	3,4				

Table. 4 of paper 10595: Lifetime expectancy (in years), of kraft paper thermal ageing.

Paper 11083 is a system view of thermal cyclic loadability including all distribution network components (cables, cables accessories, switchgear, transformers…), to identify bottleneck components in the network.

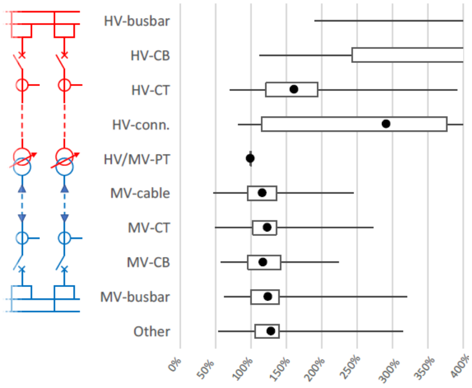


Fig. 5 of paper 11083: Boxplot of the nominal rating of components of typical substation, related to the transformer rated power

Paper 11270 proposes a general architecture and workflow for condition monitoring and predictive maintenance in case of power transformers.

A broad vision of "lifetime extension options" for electrical equipment's is given in **paper 11167**, which is the summary of the CIRED WG 2020-1 report. Good practices, obstacles and/or limitations, for all network components are evaluated. A use-case-study of lifetime extension of HV cables is detailed.

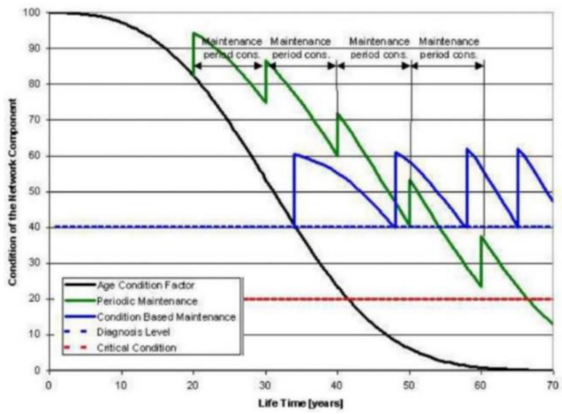


Fig. 4 of paper 11167: Maintenance strategies and their impact on the condition of the network components

To finish with the perspectives on predictive asset management, **paper 10237** estimates the conditions under which predictive maintenance with sensors and data management is profitable versus corrective maintenance. And **paper 11215** gives an historical review on the development and deployment at DSO level of asset management using condition models (HI, PoF, RUL), and the change in mindset needed to capture the benefits.

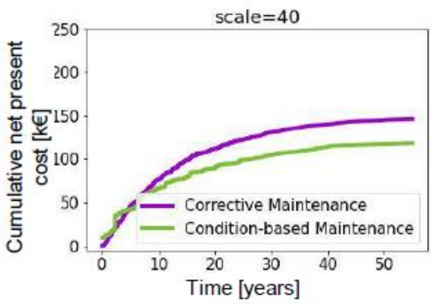


Fig. 4 of paper 10237: Profitability of corrective versus condition based maintenance during time

Sub block 3: Models for components (8 papers)

This sub-block regroups papers dealing with various numerical simulations of component behaviour.

In **paper 10173**, different types of circuit breaker frames are investigated: structural simulations show no significant impact on part strength, mechanical endurance, and travel curves of the system.

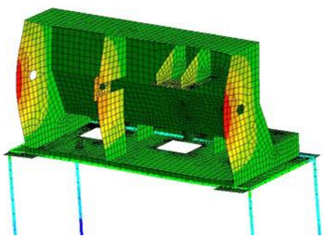


Fig. 5 of paper 10173: Test-bench and CB housing sample deformation results of a modal analysis

3 papers concern thermal and EMAG models to optimize transformer design. **Paper 10939** focuses on high performance transformer with reduction of no-load losses (thus less CO_2 emission) and increased lifetime. In **paper 11108** axially stacked windings are compared to traditional concentric core-form in three-winding transformers. An optimized load split between the two low voltage windings is possible instead of the 50/50 repartition. In **paper 11437,** two architectures of Zero-Sequence Blocking Transformers (ZSBT) are evaluated: single and multi-core design.

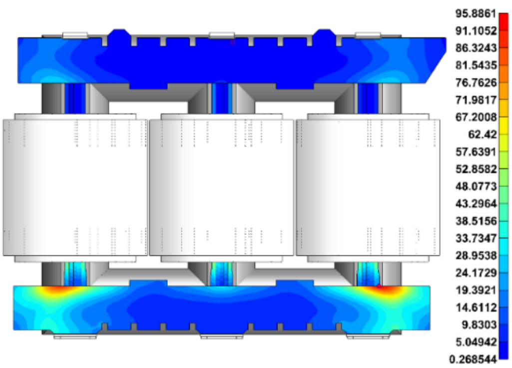


Fig. 6 of paper 11108: LV Frame Hot Spot Gradient

Core and windings vibration models (**paper 11407**) allow analysis of the relative influence of three input voltages: the MV-side terminal voltage, the main-induction voltage and the LV-side terminal voltage. Parametrization of the model is adjusted thanks to a design of experiments.

Reduction of electrical transients (such as inrush current, voltage peak, …) is mentioned in 3 papers. **Paper 11094** presents an electrical (EMT) model to investigate inrush-currents in the case of series combination of in-phase-transformer and phase-shifting-transformer (PST) between transmission and distribution network. **Papers 11182 and 11272** report two use-cases of servo-controlled vacuum circuit breaker: transient suppression in distribution networks during capacitor bank switching, and repetitive switching of arc furnace in steel plants. Measurements are compared to simulation models (PSCAD).

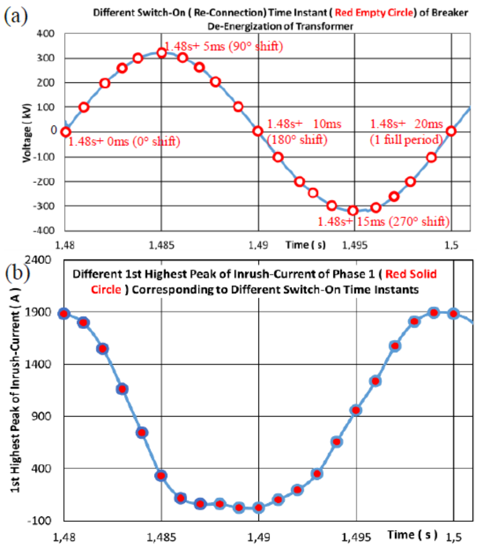


Fig. 8 of paper 11094: (a) Different switch-on time instants of transformer; (b) different 1st highest peak of inrush-current corresponding to switch-on instants

Sub block 4: Digital twins (4 papers)

Digital twins of network components aim to be their digital representations, with the perspective to cover their whole life cycle: from engineering, manufacturing, operating, maintenance, to end of life.

Two papers of this sub-block present component twins with an emphasis on the testing and diagnostic phase. **Paper 10133** shows a digital twin of the "UDEX" network test facility, including all its components (15km of underground cables, 500m of overhead lines, more than 70 automated switchgears, as well as an extensive LV network): it contributes to R&D activity by virtually simulating the behaviour of any part of the electrical grid.

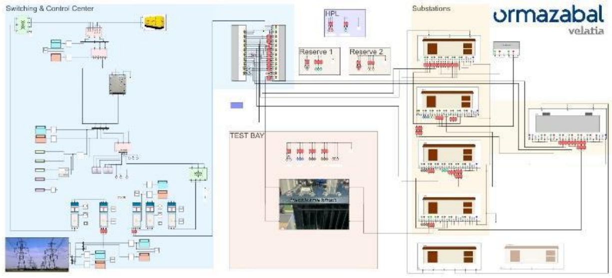


Fig. 3 of paper 10133: MATLAB graphical representation of the UDEX Digital Twin with a Smart Transformer in the test bay

Paper 10660 presents an "overhead network digital twin" from the aerial inspection perspective, including different layers: big data, and a suite of applications.

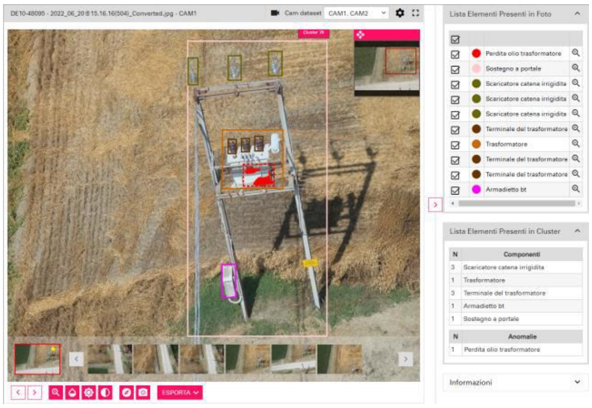


Fig. 13 of paper 10660: the ODIN processing engine: example of Image Recognition of Asset and Anomalies

Two papers give a broader perspective: the different sophistication levels of transformers digital twins are discussed in **paper 10392** (Pre-digital, Digital Twins, Adaptive, and Intelligent). The lack of standards is identified as a limit their adoption in the electric sector.

However ongoing work addresses this issue, as for example the feedback on IEC TC17 WG11 (structure of digital twins' catalogues and properties for high-voltage switchgear) described in **paper 10778**, which emphasise the interdependence between their work and IEC TC57 work (Power systems management and associated information exchange), and the need to be referenced in IEC common data dictionary (IEC CDD).

Sub block 5: IT/OT infrastructure (4 papers)

This sub-block shows various solutions for IT/OT management. At various levels, the papers highlight the need of unification/standardization of the technologies**:** centralization of firmware updates of multiples devices regardless of their manufacturer origin (**paper 10505),** consistent and standardized ICT strategy, compatible with all smart applications (**paper 11341),** virtualization technologies in smart substations with the advantage to utilize plug & play installation, maintenance support, and update rollouts (**paper 11164).** Cybersecurity aspects of an industrial IoT gateway device is also discussed in **paper 11257.**

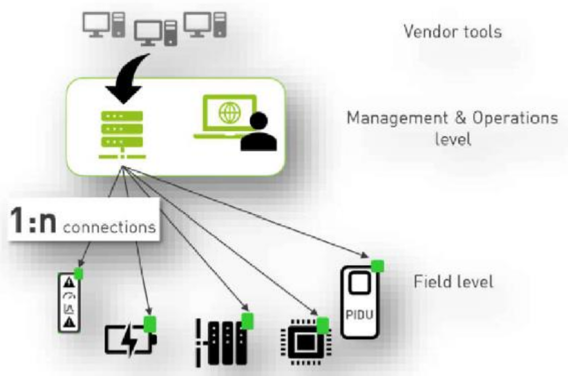


Fig. 2 of paper 10505: Standardized M&O platform for device and patch management across multiple vendor devices in the field

Table 4: Papers of Block 4 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
10114: Statistically Validated Lifetime Assessment and Health Index Using Survival Analysis Stratifications				X
10133: Real And Virtual Testing Of The Future Electrical Power Systems				X
10173: Influence of Circuit Breaker Mounting on its Lifetime				X
10237: Profitability Of Condition Monitoring In The Electric Distribution Grid				X
10316: Deep Learning-Based Automatic Detection of Defective Steel Bars in Concrete Poles			X	
10331: Analysis Of Data Gathered During The Application Of LLPDs On MV Feeder Of E-distribuzione		X		
10339: New Tool For The Improvement Of Maintenance And Expected Life Monitoring Procedures Of Surge Arresters Installed On Overhead MV Lines				X

10392: Digital Twins Used For Condition Assessment Of Transformer Fleets – The challenges of turning Data into Reality				X
10505: Cost Effective Management Of Digital Secondary Substations, On The Example Of The Process Interface And Detection Unit (PIDU)		X		
10595: Distribution Transformer Ageing: Possible Load Increase on an Actual Use Case				X
10611: Monitoring And Rating Of Low Voltage Grid’s Utilization		X		
10660: Enel Grids Network Digital Twin®: The Foundation Layer Of Integrated Suite For Distribution Systems Design				X
10685: Rethinking Data Requirements For The Reliability Assessment Of Medium Voltage Cables				X
10700: Predictive Maintenance On Overhead Medium Voltage Network Using Transient Faults Data			X	
10743: Online Automated System for Incipient Fault and Failure Detection of Distribution Apparatus Using Waveform Disturbances				X
10778: How To Build A Catalogue Data For Digital Twins Of High-Voltage Switchgear				X
10805: Fault Activity Trajectory Estimation – Time To Fuse Blow				X
10834: Failure Statistic for Medium Voltage Cable Systems in Denmark				X
10939: Green Design with Amorphous Metal for Dry Type Distribution Transformers				X
11083: Cyclic Loadability Of Entire HV/MV-Substations		X		
11094: Inrush-Currents of Series Combination of Transformer with in-phase Regulation and Phase Shifting Transformer at the Interface between Transmission and Distribution Networks		X		
11108: Thermal Performance For Three-Windings Transformers With Axially Stacked Windings				X
11164: Virtualization and Management Technologies in IT & OT of Smart Substations				X
11167: Lifetime Extension Options for Electrical Equipment				X
11182: Simulation Study and Field Experience from Switching of Transformer with Minimal Inrush Current				X
11215: Implementation of Asset Condition Models at E-REDES: What Comes Next?				X
11246: Power Transformer Life Extension By An Optimized Mid-life Maintenance				X
11257: Cyber Security Of An Industrial IoT Gateway Device – A Threat Model View And Security Aspects				X
11270: Optimizing the Life-Span of (Smart) Transformers: A Review on Smart Services				X
11272: Synchronous Circuit Breaker For Transient Suppression In Distribution Network: VD4-CS Pilot				X
11341: Standardization of Smart Distribution Substations in Cologne				X
11407: Core Vibration Modelling for Secondary Distribution Transformers				X
11437: Zero-Sequence Blocking Transformers For Use In MV Distribution Networks – Case Study Of Applications				X
11517: Vibration-Based Extraction of Switching Times for Circuit Breaker Monitoring Using Machine Learning		X		