Special Report - Session 1
NETWORK COMPONENTS

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Introduction

Session 1 covers all aspects related to the components used in 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 optimization of assets from design through installation, operation, maintenance, monitoring, and 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, standardization, 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 provides an opportunity for DSOs and manufacturers to share their objectives.

152 communications were selected for Session 1.

The presentation is structured into four blocks, which are consistent across this special report, the main session, and the poster session.

The structure adopted for these blocks is as follows:

Block 1 "Electrification and Disruptive"

- Transformer and grid compensation systems (10 papers)
- Cable (8 papers)
- Switchgear (3 papers)
- Fault Current protection in AC and DC (7 papers)
- DER and energy storage integration in the grid (9 papers)
- Electrification uses cases and ways to accelerate (6 papers)

Block 2 "Diagnostics, sensors and automation"

- Low Power Instrument Transformers (6 papers)
- Other metering and fault detection solutions (7 papers)
- Condition monitoring (8 papers)
- Digital switchgear and automation (4 papers)
- Experiences in testing and diagnostic (11 papers)

Block 3 "Context and Environment"

- SF6 free developments (12 papers)
- LCA and standardization (6 papers)
- Eco-design optimization (7 papers)
- Circular economy (3 papers)
- Innovations for performance (6 papers)

Block 4 "Models and prediction including ageing"

- Models for cable systems (15 papers)
- Models for transformers and conversion systems (10 papers)
- Models for switchgear (14 papers)

Block 1: "Electrification and Disruptive"

The 43 papers of this block are divided in 6 sub-blocks:

- Transformer and grid compensation systems (10)
- Cable (8)
- Switchgear (3)
- Fault Current protection in AC and DC (7)
- DER and energy storage integration in the grid (9)
- Electrification uses cases and ways to accelerate (6)

Sub block 1: - Transformer and grid compensation systems (10 papers)

The smart transformers aim at improving the stability of the network facing new challenges. Several strategies are deployed through power electronic pack (**paper 54 and 796**), advanced insulation system (**paper 325**) or through highly reliable onload tape changer to adjust the voltage (**paper 247 and 684)** in case of variation of demand.

Fig.6 of paper 54 : On site installation of the first version of smart transformer with power electronic pack (inverters)

The increase of reactive power is also a source of disturbance for the network as it can reduce dramatically the transport capacity to feed the customer demands, especially in presence of DER or EVs . The answer can be active with an association of a transformer with 2 inverters (**paper 54 and 796**), or passive using static compensation controlled by electronic (**papers 606, 721 and 1038**).

Some solutions are combining passive and active systems to compensate voltage and reactive power (**paper 382**).

Electrical grids can show some fluctuation in term of power factor but the datacentres are pure electronic loads and can exhibit harmonics rate of 100%. With massive deployment of datacentres, a new generation of transformer has to be envisaged to mitigate overheating and consequences of overheating (paper **807**).

Sub block 2: Cables systems (8 papers)

The conventional cable technology based on extruded insulation requires adaptations to cope with new grid challenges in term of loads and power generations. Several approaches are presented through dynamic rating (**paper 40**), higher temperature (**paper 445**), reinforced qualification for submarine MVAC systems (**paper 904**) and MVDC for linear solar farms (**paper 342**).

The superconducting cable systems avoid disruptive civil works to bring power in highly constrained urban areas, an example in railway network at 1500 VDC in Paris (**paper 967**) and are envisaged as high power LVDC busbar when PV farm and large-scale datacenter are associated to address sustainable society based on digital and IA solutions (**paper 1159**).

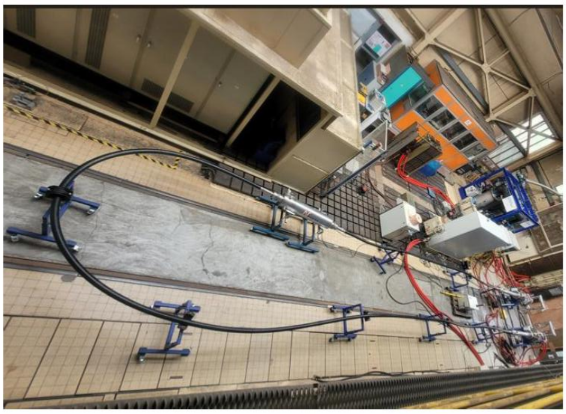

Fig.1 of paper 967: Qualification of 1500 VDC superconducting cable system for railways in Paris

The transmission of GW of power at lower voltage than conventional system is the advantage of superconducting cable systems already in MVAC (**paper 530**) and the technology reaches the full potential with MVDC bulk energy transport to export power from multi-GW renewable farms or as interconnectors between countries (**paper 956**).

Sub block 3: Switchgear (3 papers)

Three papers address the electrification challenges on the switchgear side, though the addition of new features, usages and procedures: as serviceability, life extension and retrofitting in **paper 68**, with an interesting feedback from the US market and IEEE , in **paper 149** with the addition new functionalities though electronification , and in **paper 583**, with the conversion of an AC switchgear for a DC usage, focused on the insulation topic.

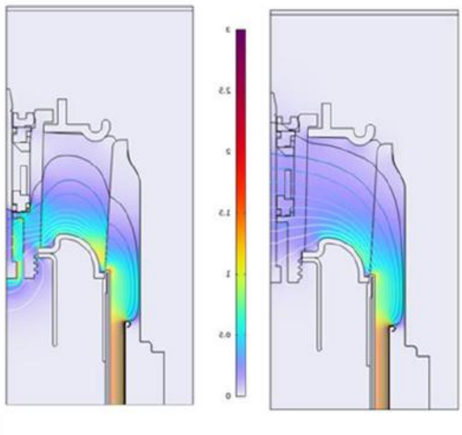

Fig. 6 c and 6 d of paper 583 = Distribution of electric field [kV/mm] of a 10 kV fuse tube cap under DC (left) and AC (right)

Sub block 4: Fault Current protection systems in AC and DC (7 papers)

To address the interest for DC system protection, several comparisons of the behaviour and performance in DC and AC of current interruption systems are carried out through the arcing phenomena (**papers 74 and 737**), the use of fuse (**papers 641 and 732**), the use of semiconductors technology to protect battery storage system (**paper 705**) and an oscillating circuit in MV (**paper 1005**).

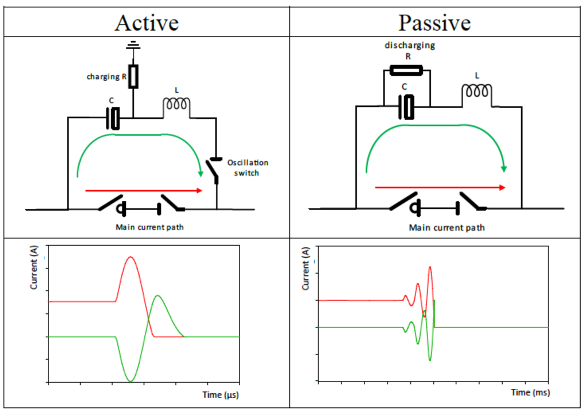

Fig. 6 of paper 1005: Schematics of direct current interruption with oscillating principle

Sub block 5: DER and energy storage integrations in the grid (9 papers)

With the increase of power of PV farms, MVDC systems represents a real potential. The **paper 791** presents the challenges raised by the qualification of DC solid state transformer.

The integration of the electrical energy storage and recovery can be addressed through different technologies like electrical batteries (**papers 437 and 1122**), supercapacitor (**paper 559**) or hydrogen production through electrolysis (**papers 726 and 1044**) associated with fuel cells technologies (**papers 108 and 280).** All this storage technologies have a common points to be natively in DC.

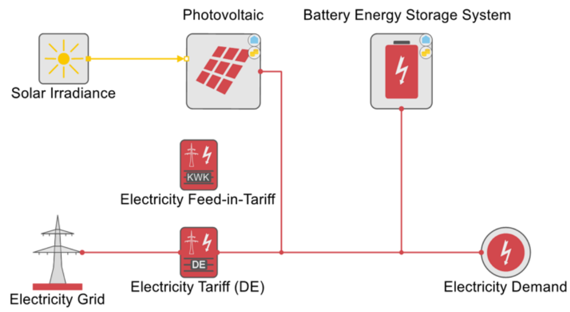

Fig. 1 of paper 437 ; Integration of DER and BESS in the grid

The **paper 680** shows the accuracy of nonlinear model to simulate typical cases of integration of storage and DERs.

Sub block 6: Electrification uses cases and ways to accelerate (6 papers)

The **papers 746 and 452** are focused on the sustainable deployment of microgrids in remote areas by securing the local sourcing of equipment and local availability to spare parts and know-how for the maintenance.

The electrification can be accelerated through optimised civil work process for underground cable system (**paper 835**) and overhead lines (**paper 891**) but also by developing prefabricated substation modules (**paper 838**) and by improving the interoperability of equipment through standardisation (**paper 278**).

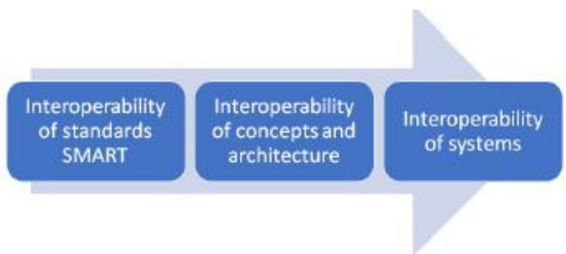

Fig. 1 of paper 278: Interoperability practices

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Table 1: Papers of Block 1 assigned to the Session

Paper No. Title	MS a.m	MS p.m.	RIF	PS
40. Cost and technical optimized use of cables at volatile energy transfer				X
54. Design, manufacture, testing, installation and operation of a “smart” transformer				X
68. Power Switchgear Retrofitting What We Can Learn From Our American Cousins				X
74. Comparative Investigation at AC-Arcing vs. DC-Arcing			X	X
108. Grid-Connected Solid Oxide Fuel Cell and its Ability to Fulfil Fault-Ride Through Capability Requirements				X
149. Electronics in distribution systems- Redefining traditional product solution architectures, installations, retrofits and sustainability dimensions				X
247. Increased reliability of smart distribution transformers for efficient operation of LV distribution electric grids				X
278. Semantic interoperability : a real challenge for international standardization				X
280. Comparison of Fuel Cells through Dynamic Simulations in the Context of Green Hydrogen				X
325. Modern transformer concepts for improved resilience of power distribution systems	X			X
342. Qualification of a 10kV MVDC Cable & Accessories for Solar Application				X
382. D-Suite: a suite of partially rated modular power electronics to increase low voltage network capacity				X
437. Advantages of using high dc voltage in large scale battery energy storage systems operated in various market driven scenarios				X
445. Medium voltage joint design options for higher conductor temperature (110 °C)				X
452. Design for localisation parameters for sustainable energy access in remote areas: a real-time hardware-in-the-loop approach				X
530. High voltage testing of insulators for a medium voltage superconducting cable				X
559. Energy Storage Technology for Power Automation Equipment: Progress and Prospects of Supercapacitor				X
583. Considerations on dielectric design of MVDC gas insulated switchgear	X			X
606. E-REDES Assessing the Value of STATCOM as an Investment Solution to Improve Low Voltage Network Stability				X
641. The use of ultra-fast LVAC fuses in DC grids: state of art, testing and recommendations				X
680. Incorporating Inverters with Volt-Var/Watt Control in Distribution Network Constrained Optimisation				X
684. Voltage regulating distribution transformer (VRDT) – utility’s solution to optimise the hosting capacity of distribution system for the future energy landscape				X
705. Semiconductor-Based Fault Protection for Battery Short-Circuit Currents				X
721. Low Voltage Grid Resilience: Innovations in Active Control Strategies based on Power Electronics				X
726. Experimental assessment of cooling concepts for extending the current carrying capacity for future MW-rectifier systems				X
732. Interruption of MVDC currents with HV fuses				X

737. Study on the arc extinction structure of the low voltage DC switch disconnector				X
746. An ex post facto comparison between the initial concept design and the constructed infrastructure for Noenieput Microgrid in the Kalahari Desert of South Africa				X
791. Definition of standard tests for medium voltage DC-SST in PV application				X
796. Hybrid-Transformer for Advanced Management of Distribution Grids	X			X
807. Improving reliability and performance of transformers for power distribution units in data centers				X
835. EDP Inovação/E-Redes/EDP Redes/Viesgo: SUUG - Speed Up Underground Grid construction through new construction methodology	X			X
838. Prefabricated Modular Substations: development pilot experiences				X
891. EDP Inovação/E-Redes/EDP Redes/Viesgo/EDP Brasil: SUAG Speeding-up aerial grids construction leveraging on new technologies and processes.				X
904. Design selection of MV submarine cables for a more resilient distribution network				X
956. High-Power Medium-Voltage Superconducting Cables for Europe's Energy Transition				X
967. Qualification of SuperRail HTS cable: the first superconducting cable system in the world to be operated on railway grid	X			X
1005. Medium voltage direct current interruption principles and testing methods in DC and AC circuits				X
1038. Grid Forming and Variable Shunt Reactor for State-of-the-Art Dynamic Reactive Power Compensation				X
1044. A novel multi-pulse rectifier system with fractional converters configuration for hydrogen electrolyzer	X			X
1122. Transportable multifunction energy storage system using first and second-life batteries for supporting outages and seasonal demand peaks in the distribution network				X
1159. Superconducting microgrid to support synergy between solar energy and datacentres				X

Block 2: "Diagnostics, sensors and automation"

The 36 papers of this block are divided in 5 sub-blocks:
- Low Power Instrument Transformers (6 papers)
- Other metering and fault detection solutions (7 papers)
- Condition monitoring (8 papers)
- Digital switchgear and automation (4 papers)
- Experiences in testing and diagnostic (11 papers)

Sub block 1: Low Power Instrument Transformers (6 papers)

The Low Power Instrument Transformers (LPIT) topic coupled to the adoption of IEC 61850-based communication is seen as a driver to enhance the grid reliability and efficiency, allowing to multiply metering points. Environmental benefits are highlighted in **paper 770.** Practical applications and challenges to deploy LPITs are discussed. **Paper 289** gives the perspective of an instrument transformer manufacturer that recommends standardized integration pathways. **Paper 860** shows the LPIT integration in existing MV cable accessory T-bodies.

Fig.2 of paper 860: IEC and IEEE sensor for T-bodies.

The need for LPIT accuracy in all operating conditions is of primary importance and is discussed in numerous papers. **Paper 57** emphasizes on linearity verification to enable on-site testing at lower magnitudes using mobile meters.

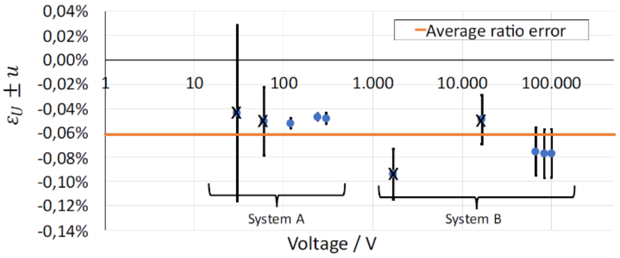

Fig.4 of paper 57: Voltage ratio error of LPVT

Paper 291 underlines the ability of LPIT to address PQ and supra-harmonics monitoring.

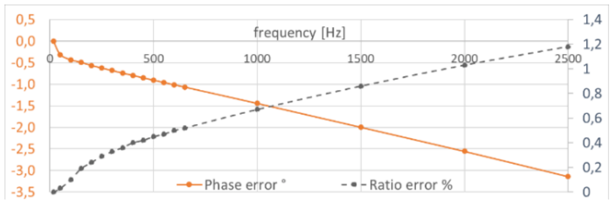

Fig.2 of paper 291: Ratio and Phase error of LPCT.

Additional LPIT applications are currently developed, as revenue metering in **paper 1169**.

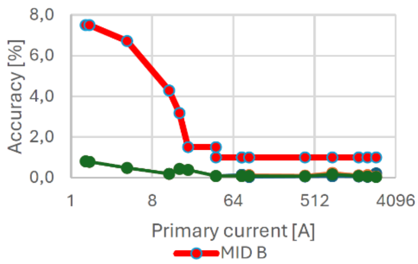

Fig.2 of paper 1169: Current measurement accuracy.

Sub block 2: Other metering and fault detection solutions (7 papers)

Paper 508 discusses the advantages of shunt-based technology for current measurement, providing a wide dynamic range. Phasor Measurement Units (PMU) allow to monitor the flow of electricity with high-speed synchronized measurements, are shown in **paper 978.**

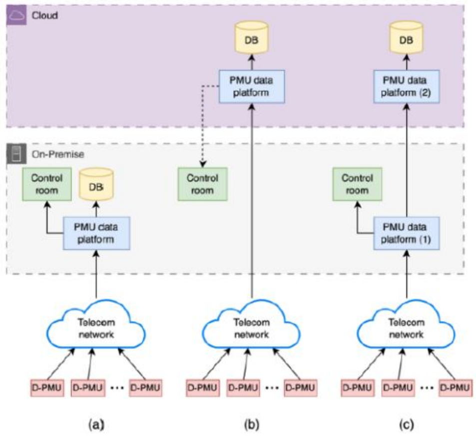

Fig. 2 of paper 978: local, cloud and hybrid PMU.

Measurement transformers being at the interface between MV and LV, **paper 180** introduces a new open circuit protection for CT secondary, to improve safety. **Paper 360** introduces an approach for detecting arc faults, for a better differentiation from normal operations.

On the low voltage side, p**aper 1177** describes use cases of network monitoring, close to real time, to detect network congestion, power quality issues, ageing, faults,...

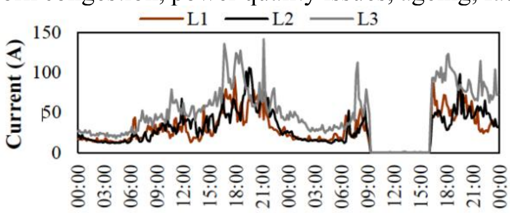

Fig. 4 of paper 1177: Outage registered with an LV monitor.

Papers 308 and 670 deal with smart meters, with fist a retrospective of their deployment in Japan, then a pilot to explore opportunities use them to control local renewable sources and specific charges as eV, storage, heat pumps…

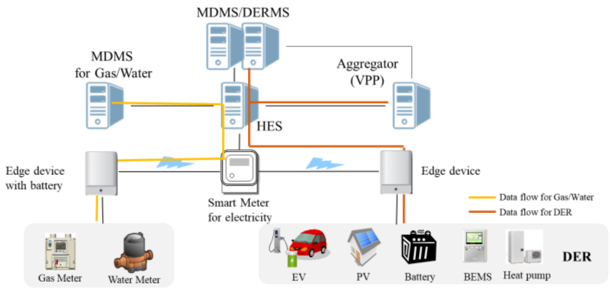

Fig.4 of paper 308: Use case diagram.

Sub block 3: Condition monitoring (8 papers)
This sub-block reviews various sensors technologies, and monitoring experiences from manufacturers and DSOs.
Paper 754 presents a "smart" circuit breaker that assess its mechanical, electrical, and thermal health. This allows a selective replacement of parts affected by ageing, for example erosion or wear.

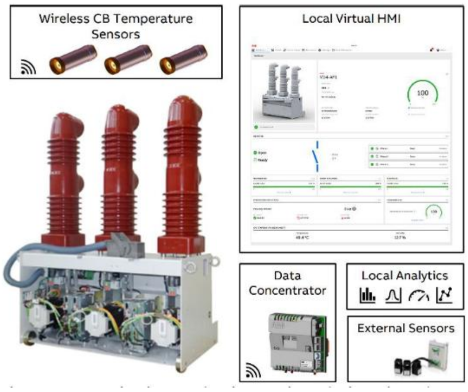

Fig. 2 of paper 754: Monitoring and Virtual HMI.

Paper 689 compares different sensor technologies including SAW, for thermal, environmental, and PD on a primary AIS.

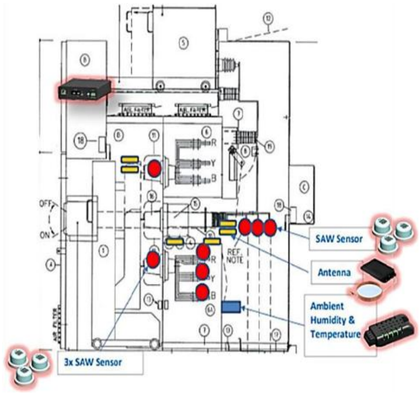

Fig. 1 of paper 689: IoT SAW sensors in MV switchgear.

In **paper 1045,** wireless cost-effective vibration sensors are applied on power transformers. Data are processed through AI analytics to detect mechanical defects.

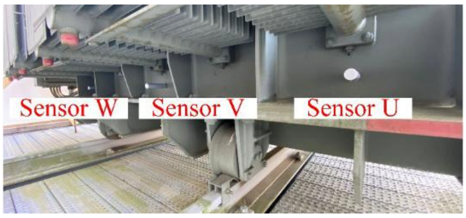

Fig. 1 of paper 1045: Sensors on the transformer.

Paper 660 investigates methods to estimate the plastic elongation of overhead lines using data from clamp-on DLR sensors providing inclination, conductor temperature and current data.

In **paper 14**, ageing monitoring with the 3rd harmonic of leakage current is recommended for MOV surge arrestors,

Fig. 3 of paper 14: 3rd harmonic current monitoring.

Partial Discharge (PD) monitoring enables to detect premature ageing of insulation but can also lead to false alarms. **Paper 1153** explains filtering and mitigation strategies to avoid high frequency signal interferences.

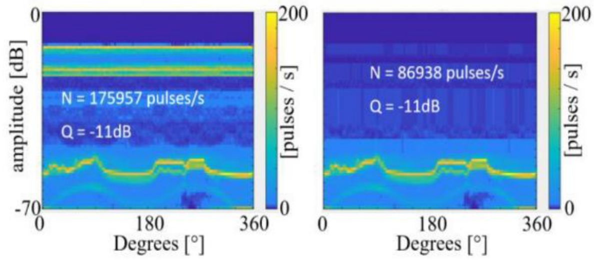

Fig. 8 of paper 1153: Example of noise filtering

A multilevel network PD monitoring system, combining local embedded intelligence and cloud advanced treatment is presented in **Paper 1289**,

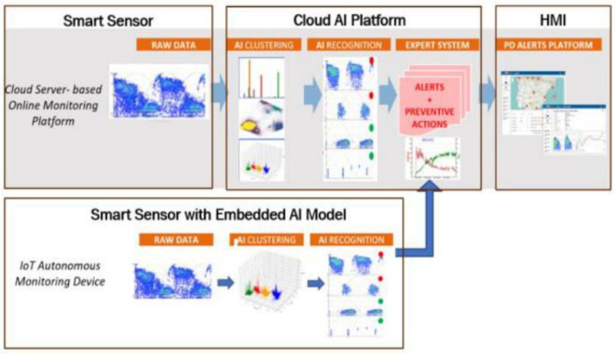

Fig.4 of paper 1289: IoT PD device in cloud AI platform.

To conclude, in the end, the economic viability and ROI will rule the installation of condition monitoring solutions. This crucial point is discussed in **paper 499**, in the case of primary transformers.

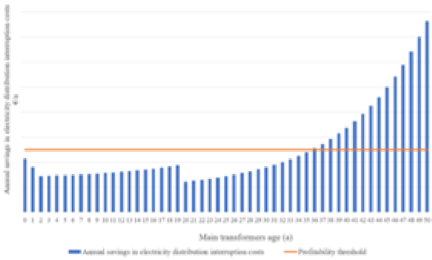

Fig. 3 of paper 499: Economic viability of the gas analyzers (red line=positive threshold).

Sub block 4: Digital switchgear and automation (4 papers)

The next step after the sensorization is the "full" digital switchgear, with new functionalities thanks to the combination of smart sensors, analytics, communication, and automation.

In this direction, **paper 575** discusses transformation of medium voltage RMU due to the combination of SF6-free requirements and digitalization.

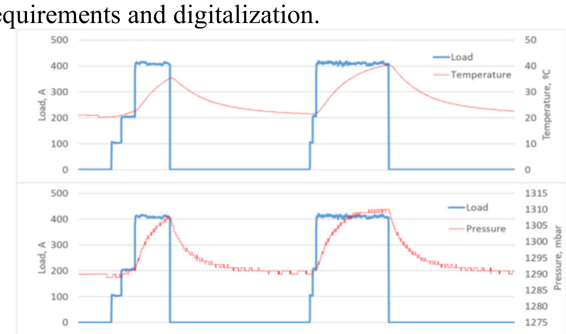

Fig. 8 of paper 575: Historical data available for analysis, modelling, and subsequent predictive analysis.

Paper 766 explores applications with smart switchgear in primary distribution applications, as revenue metering, busbar differential protection.

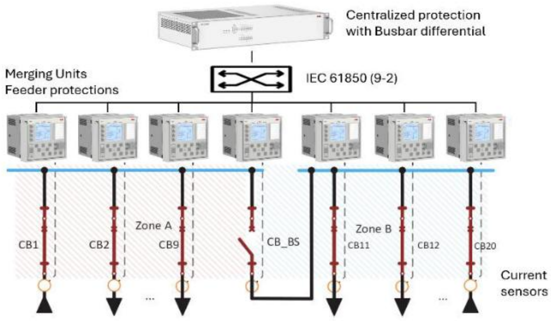

Fig.4 of paper 766: Busbar differential protection.

In **paper 836** the self-adapting switching sequence optimization is realized with a reduced measurement dataset and predefined strategies.

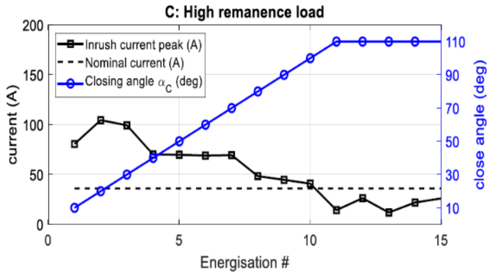

Fig. 6c of paper 836: Adapting search for closing angles.

Virtualized protection and control will surely be the ultimate stage of the digital switchboard: **paper 379** presents the process bus validation of a centralized protection automation and control system (PACS), that aims to simplify the system integration engineering.

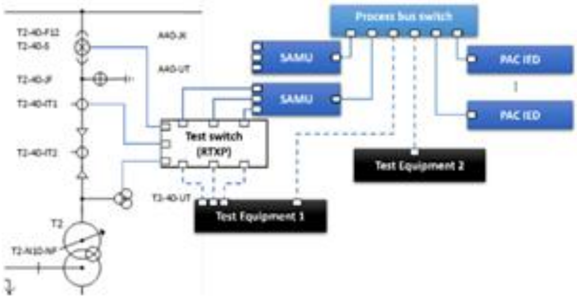

Fig. 2 of paper 379: Conceptual test system architecture.

Sub block 5: Experiences in testing and diagnostics (11 papers)

Power cable handling must be improved to reduce negative effects on installers' health as presented in **paper 133**

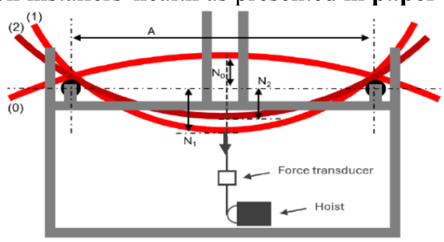

Fig. 2 of paper 133: Cable bending test setup.

Concerning dielectric, the qualification of the interfacial adhesion of polymers is detailed in **paper 1201**. Detection of potential failures during the installation phase of long cable infrastructures is the aim of **paper 511** with the development of modular resonant test and PD measurement techniques.

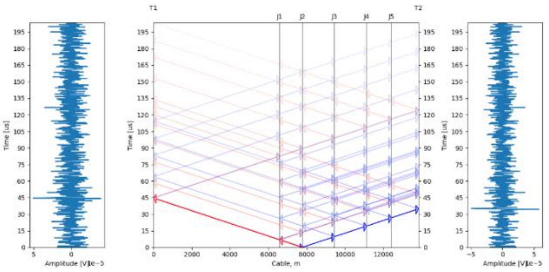

Fig. 14 of paper 511: Wave propagation diagram.

A retrospective of partial discharge diagnostics in Canada is given in **paper 71**, with interesting feedback on the difficulties solved.

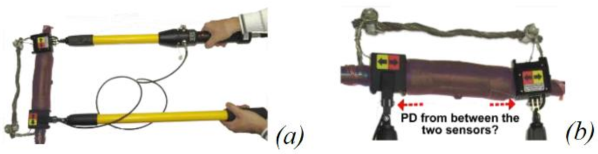

Fig.7 of paper 71: PD sniffer measurement.

Paper 1062 recommends combining DCR (U-I plot with DC ramp test) together with partial discharge to assess insulation condition of stator bars.

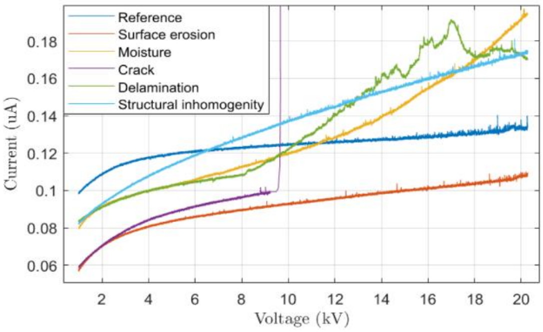

Fig. 9 of paper 1062: U-I plots of the simulated defects,

Methods for estimating low quantiles of voltage percentiles (typically 2%) in dielectric breakdown are depicted in **paper 778**.

AC breakdown tests and DGA results are compared in **paper 414** both for mineral oil and eco-friendly oil.

A diagnostic strategy for evaluating the condition of measurement instrument transformers is described in **paper 561**.

Fig. 3 of paper 561: Condition of the TC primary: burnt paper and epoxy resin.

On the temperature rise topic, **paper 1046**, combines tests and simulation to predict hotspot temperature in distribution transformers, and the gain with nanofluid. A flexible, user-friendly web software tool is developed in **paper 1087** for accurate ampacity calculations of cables. The corrosion of copper, zinc, aluminum, and carbon steel is assessed with sample in real conditions **in paper 120**.

Fig. 2 of paper 120: Outdoor ageing of coupons

Table 2: Papers of Block 2 assigned to the Session

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
14, Active monitoring to improve the condition assessment of existing HV MOV Surge Arresters				X
57, System accuracy test of LPIT-based metering systems				X
71, Innovating for Safety: The Journey of Partial Discharge Measurement Tools at Hydro-Quebec				X
120, Corrosion of primary substation components and distribution pole in tropical marine atmosphere rich in H2S resulting from the decomposition of Sargassum algae.				X
133, Investigating the bending stiffness of polymeric cables				X
180, Novel and efficient, Current Transformer (CT) open circuit protection solution				X
289, From Theory to Practice: LPIT Integration from the Perspective of an Instrument Transformer Manufacturer				X
291, High-accuracy wideband LPCT for advanced grid automation and PQ metering				X
308, Utilization of Smart Meter Systems for IoT Communication Infrastructure				X
360, Arc Fault Detection Using LSTM Autoencoders and Isolation Forest in Electrical Distribution Networks				X
379, Verification of Next Generation of Process Bus based Modular Substations	X			X
414, Dissolved Gas Analysis Associated with Electrical Degradation in MIDEL 7131 and Mineral Oil				X
499, Data-driven condition management in urban distribution system operator				X
508, On shunt-based sensing technologies for current input channels of protection and control IEDs				X
511, On-site testing of critical cable infrastructures	X			X
561, E-REDES Strategy for evaluating the technical condition of measurement instrument transformers				X
575, Challenges and lessons learned towards Digital Native Medium Voltage Switchgears	X			X
660, Estimating the plastic elongation of overhead lines using clamp-on DLR-sensors	X			X
670, General outline about the smart meter system in Japan - Its history, specification, performance, and future prospect -				X
689, Advanced asset analytic via IoT sensors on primary equipment in TNB distribution network				X
754, Monitoring and aging evaluation in MV smart circuit breaker for special applications				X
766, Smart Medium Voltage Switchgear with LPITs and IEC 61850 - Experiences after 10 years and the next evolution	X			X
770, Utilization of smart measurement technologies to improve medium voltage switchgear sustainability				X
778, Sequential designs for efficient estimations of voltage percentiles in breakdown experiments			X	X
836, Minimizing transformer inrush current under variable load conditions by controlled switching with automatic search				X
860, High Performance and High Reliability Low Power Voltage Transformers in Medium Voltage Accessories				X

978, Demystifying Distribution PMUs: A Comprehensive Guide for Distribution System Operators				X
1045, Vibration-measurement-based condition monitoring of power transformers			X	X
1046, Thermal analysis of new generation of distribution transformers: experimental validation				X
1062, Assessment of stator bars by four diagnostic methods				X
1087, User-friendly current capacity rating for power cables based on finite element analysis				X
1153, Interferences mitigation in Partial Discharge continuous monitoring				X
1169, Revenue metering based on LPITs complying with the IEC 61869-10 and IEC 61869-11 standards and its utilization in the medium-voltage applications				X
1177, Low voltage monitors: use cases				X
1201, The Effect of Interface Adhesion of Over-molded Polymer Materials for Electrical Components Used in Power Distribution Equipment.				X
1289, Experience in PD Defect Detection and Location Using Smart Sensors with AI Deployed in Distribution Grid	X			X

Block 3: "Context and Environment"

The 34 papers of this block are divided in 5 sub-blocks:
- SF6 free developments (12 papers)
- LCA, carbon footprint (6 papers)
- Eco-design optimization (7 papers)
- Circularity (3 papers)
- Innovations for performance (6 papers)

Sub block 1: SF_6 free developments (12 papers)
Twenty years after the initial research on SF_6 alternatives, the topic has matured significantly. New SF_6 free products are presented, such as in **paper 996**, with the design of an ultra-compact RMU for the UK market, and **paper 267** with a high-ratings primary GIS at 40.5 kV.

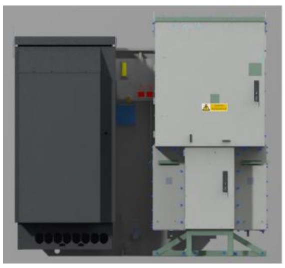

Fig. 4 of paper 996: Direct coupling of RMU with transformer for UK

Technical optimizations are detailed: mechanical interfaces to work with pressurized air in **paper 555**; temperature rise impact in **papers 1281** and **565**, arc fault pressure calculation in buildings in **paper 802**.

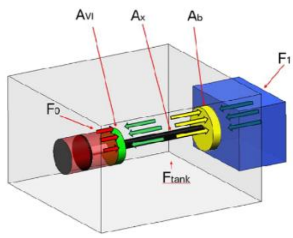

Fig. 3 of paper 555: Forces due to pressure acting on interfaces.

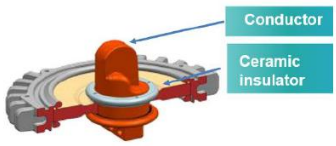

Fig. 4 of paper 267: Ceramic bushing for thermal conduction.

For current interruption, different solutions coexist. vacuum (and the derived shunt vacuum) on one side, and gas interruption in puffer, or with rotary double breaking on the other side. Three **papers 310, 521 and 1132** discuss arcing in gas solutions, with respectively a fundamental study, new materials for nozzle and a puffer switch design for RMU. **Paper 819** focus on the operation and protection of transformers up to 1000 kVA, addressing also voltage escalation avoidance during small inductive current interruptions. **Paper 908** proposes the use of RC snubber to overcome this problem.

Fig. 1 of paper 819: SF_6-free gas insulated switch-fuse protection functional unit.

Paper 38 provides an heuristic comparison of the different technological options for both MV SF_6 free insulation and current interruption, from the authors' perspectives.

Sub block 2: LCA, carbon footprint (6 papers)
Environmental Product Declarations (EDP) and Life cycle Assessment (LCA) aim to improve transparency and promote environmentally conscious decisions. Several environmental comparisons are presented: **paper 104** in the case of indoor and outdoor insulators. **paper 1123** for underground cables and **paper 594** for transformers.

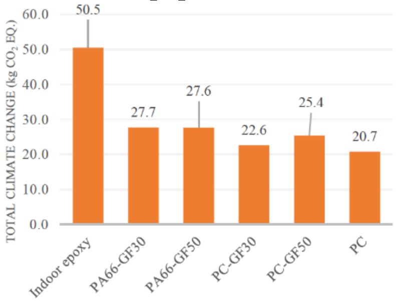

Fig. 5 of paper 1123: Climate impact of indoor insulator.

Reliable and consistent data, simplified tools, and standardization are all required to green the complete value chain. **Paper 81** gives an example with the development of tool to assist B2B decision makers, and **paper 316** with the role of digital transformation to convey environmental performance information.

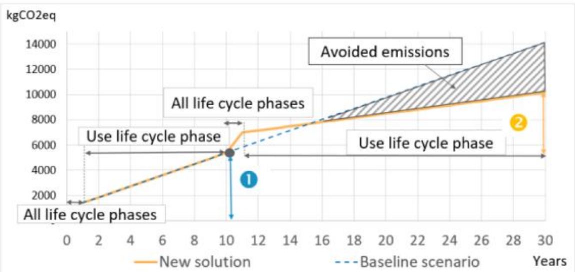

Fig.6 of paper 316: Impact of a new product vs. a new situation on carbon footprint.

The Digital Product Passport (DPP) described in **paper 1188** compiles all information about a product throughout its entire lifecycle and supports the implementation of digital twins.

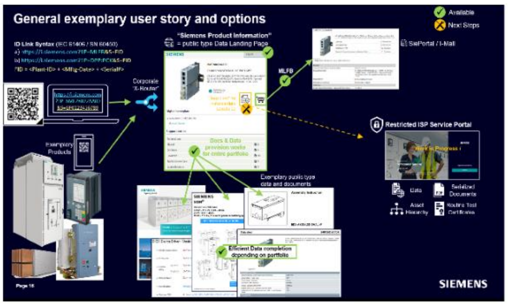

Fig. 1 of paper 1188: Example of DPP

Sub block 3: Eco-design optimization (7 papers)
Paper 432 show how manufacturers can include "eco-design" in their environmental policy through the 4R concept: Rethink, Reduce, Recycle, Reuse. Heuristic design optimizations combining environmental impact, material selection, and performance target are now possible, as in **paper 784** for switchgear design, and in **paper 955** to improve the climate neutrality of the external insulation of vacuum interrupters.

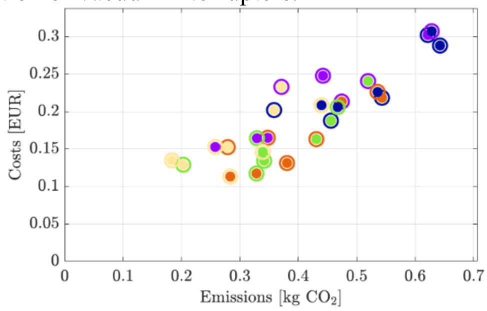

Fig. 5 of paper 784: Joint material/design optimization regarding performance, environment and cost.

Papers 230 and 960 discuss energy losses and cooling architectures optimization of transformers regarding the sustainability aspects, but also the impact on the substation.

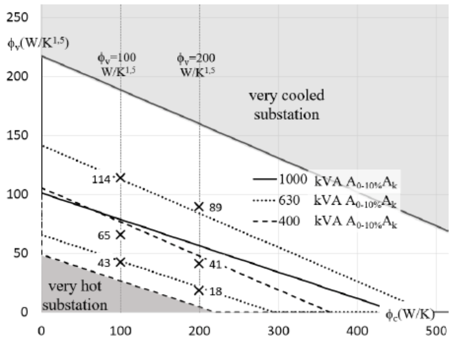

Fig. 4 of paper 230: Impact of transformer eco-design on substation qualification.

Paper 504 studies polypropylene (PP) as a potential eco-friendly alternative to crosslinked polyethylene (XLPE) for overhead cable insulation.

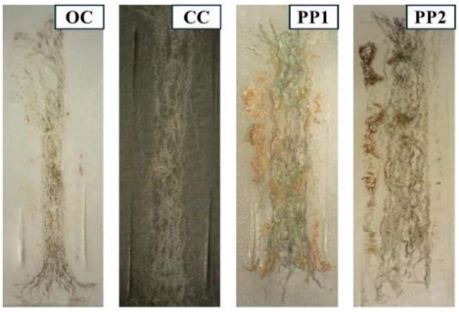

Fig.3 (extract) of paper 504: Specimen after tracking test.4

Sub block 4: Circularity (3 papers)
Circularity involves designing and managing network components to maximize their durability, reusability, and recyclability.

Paper 946 reports a circularity project at DSO level in Spain and Portugal for selected network components. It raises the difficulty to involve the full value chain towards this objective, especially the manufacturers to provide spare parts, tools, and repair manuals, as well to guarantee the quality, safety, and reliability of the repaired product.

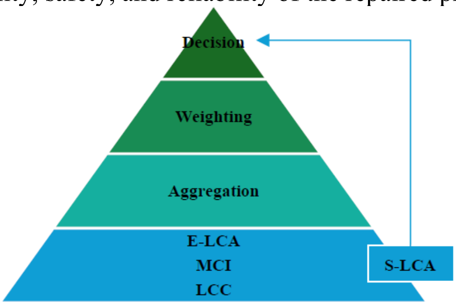

Fig. 1 of paper 946: Circularity Assessment Methodology.

Two other papers present uses cases of recyclability. A transformer oil reclaiming process is described in **paper 820**, claiming the advantage to improve the oil properties compared to the initial one, **paper 977** discuss the PCBs Management Strategy of Pole Mounted Transformers in UK, with a statistical model to prioritize their decommissioning process.

Sub block 5: Innovations for performance (6 papers)
Studies to improve the technical performance of networks components (to reach higher ratings, a better endurance, or a better robustness for example) belong also to the contextual innovation block.
Three papers deal with vacuum interrupters (VI) technology. **Paper 251** discusses the development of a new nominal current interruption endurance test bench, that can perform thousands of operations. In **paper 863**, the local charge distribution on the electrode's surface, obtained with a complex optical setup, serves as a contact erosion indicator. **Paper 752** presents the development of new range of optimized VI.

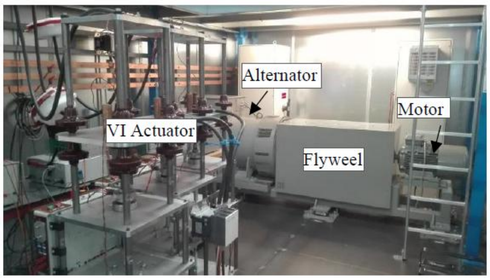

Fig. 1(b) of paper 251: Picture of the test bench.

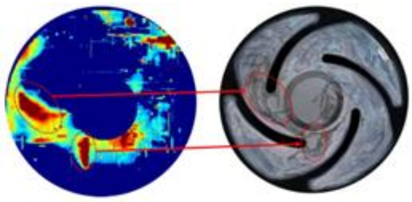

Fig. 11 of paper 863: High-stress area of charge distribution.

Concerning outdoor components, **paper 217** describe the design methodology with multi-physics simulations, applied to a recloser. **Paper 9** aims to improve pole arc diverters device endurance against repeated lightning strikes.

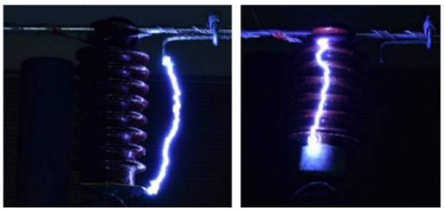

Fig. 7 of paper 9: Flashovers from the arc diverter.

Paper 546 presents a pilot study to evaluate the performance of zinc flake coating on low voltage tension clamps used in coastal areas of Portugal, where corrosion is a significant issue.

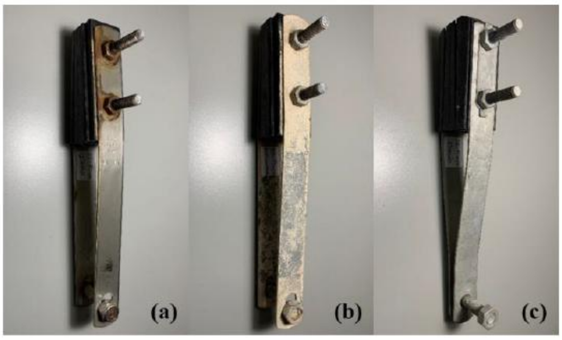

Fig. 3 of paper 546: Photos of different surface treatments.

Table 3: Papers of Block 3 assigned to the Session 1

Paper No. Title	MS a.m.	MS p.m.	RIF	PS
38, Synthesis of the different technologies for removing SF6 from medium voltage switchgear				X
66, Bird mortality mitigation on South Africa's sub-transmission network				X
81, Simple tools are available that assist in visualizing and achieving your network component, targeted CO2 emissions, and circular performance ambitions in a way that is accountable and verifiable.				X
104, Life Cycle Assessment in product development				X
217, Overhead recloser ratings for strengthening the grid under extreme conditions				X
230, How the eco-design of transformers affects temperatures in MV/LV substations		X		X
251, Electrical endurance test at nominal current of vacuum interrupters				X
267, Next generation gas-insulated switchgear with natural origin gases for 40.5 kV level				X
310, Characteristics of arcs in air with axial blowing			X	X
316, New IEC standardization framework of environmental aspects needs to be supported by the digital transformation.				X
432, Is there a sustainable future for electrical equipment through eco-design?				X
504, Tracking Resistance and Breakdown Strength Evaluation of Eco-friendly Insulation Materials for Overhead Line				X
521, Puffer-type load break switch for medium voltage gas insulated switchgear filled with dry air				X
546, E-REDES pilot using innovative and more resilient LV aerial bundled cable accessories				X
555, Optimized Mechanical Interface Solution for GIS Grid Components Applications				X
565, Study on the Temperature Rise Characteristics of a 126kV Porcelain Column Circuit Breaker Using C4F7N/CO2 Mixed Gas				X
594, “Greening” the transformers value chain: Key success factors and recent advancements on environmentally optimized transformer designs with “greener” materials				X
752, Development of New Optimized Range of Medium Voltage Vacuum Interrupters				X
784, Coupled material selection and shape optimization for efficient sustainable switchgear design		X		X

802, Improved Arc Fault Pressure Calculation Methods for Buildings containing MV Switchgear				X
819, Challenges of new technologies non-based in SF6 for operating and protecting MV power transformers of distribution networks				X
820, Oil reclaiming - One sustainable way to extend the lifetime Power Transformer				X
863, Exploring Vacuum Contacts: Analyzing Contact Lifespan for Enhanced Performance in Grids		X		X
908, Dimensioning of protection devices for medium voltage transformers against fast front overvoltages		X		X
946, E-REDES fosters "Circular Economy Action Plan" with E-REDONDO project				X
955, Challenges of Climate Neutrality for the External Insulation of Vacuum Interrupter				X
960, Sustainability aspects of dry-type transformers applied to solar photovoltaic and BESS				X
977, PCBs Management Strategy of Pole Mounted Transformers – A Statistical Model Approach				X
996, Design of an innovative SF6 free RMU with direct connection to transformer				X
1123, Comparison of MV underground cables environmental impacts through a careful use of Life Cycle Analysis (LCA) results disclosed in Environmental Product Declarations (EPD)				X
1132, Alternatives to PFAS for nozzle load break gas switchgear		X		X
1188, Digital Product Passport for T&D enabling IoT Integration and LCA		X		X
1281, Temperature rise test and analysis of various influencing factors of a MV Switchgear.				X

Block 4: "Models and prediction including ageing"

The 36 papers of this block are divided in 3 sub-blocks:
- Models for cable systems (15 papers)
- Models for transformers and conversion systems (10 papers)
- Models for switch gears (14 papers)

Sub block 1: Models for cable systems (15 papers)
The prediction of failures in cable system has a great value for DSOs, as it allows limiting outage and better manage the resources by anticipating needs for materials repair and replacement as well as mobilization of employees.
The analysis if existing data is the first steps to find correlations between assets information, condition monitoring, meteorological data and failure localization (**papers 27, 409 and 1237**).

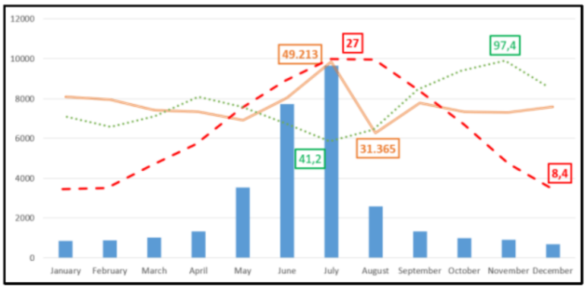

Fig. 1 of paper 1237 : Number of faults by month and corresponding temperatures, precipitations and energy demand in Italian grid.

The second step is to use real time monitoring from sensors or meters together with the prediction models to guide the exploitation teams by scoring the level of risk of failure or assess health (**paper 27**). To get a reasonable fast result, several approaches have been developed to speed up calculation by using neural network (**paper 152**) and two step convolution (**paper 912**).

The correlations of data analytics together with physics laws (**paper 143 and 454**) allow to build models representative of system behavior linked to failures. In general a good understanding of ageing phenomena is not only useful to specify equipment but also can be used to check the limits of installed equipment like for PILC cable

(papers 466 and 950) and in addition for accessories to prepare the specifications of next generations (**papers 235 and 396).**

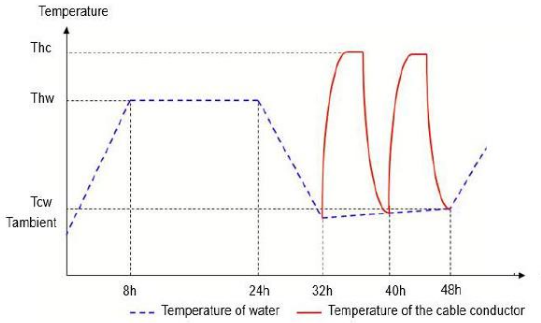

Fig. 1 of paper 235 : heat cycles principle for accelerated ageing of MV cold shrink joint materials

The growing deployment of renewable creates new constraints that have undoubtfully some impacts of the cable system failure (**paper 948**) and on MV or LV fuses ageing (**paper 75**), however a study does not show evidence of heat generation linked to harmonics (**paper 845**).

Sub block 2: Models for transformers and conversion systems (10 papers)

For all equipment the new uses linked to climate change, directly, like temperature, or indirectly, like renewable or EV integrations are potential burdens for the rest of their exploitation life. Thermal modeling with the new types of loads and environment conditions have been carried to check if the equipment are still within their design limits showing that there is still margin for transformers (**paper 213 and 273**), that the models should be improved for oil transformer (**paper 194**) and the life time for inverters can be significantly reduced (**paper 861**).

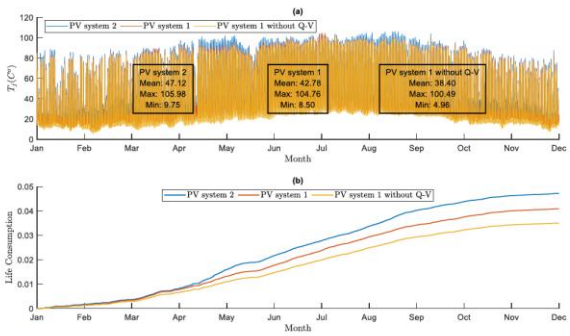

Fig. 7 of paper 861 : Junction temperature and life consumption of PV inverters in different cases**.**

For new generation of transformer, the ageing models are compared to experimental behavior thanks to test bench (**paper 211**). Deeper experimental testing show that for existing transformers even PD of up to 200 are not a sign of near failure (**paper 837**), and that Tan Delta can be an ageing measurement for cast -resin transformers (**paper 261**). However, Dissolved Gas Analysis methods can not be used to detect cellulose overheating (**paper 12**).
Data analyses of the transformation fleets show that the actual situation regarding life time is quite good (**paper 667 and 1171**) but the failure rate is expected to increase within 10 years (**paper 667**).

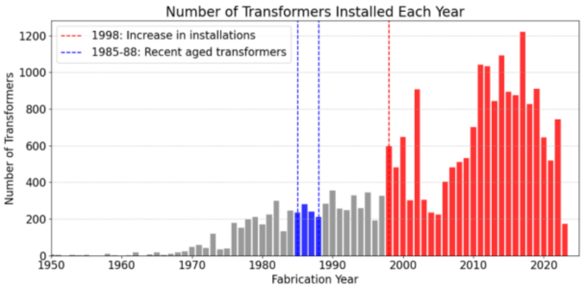

Fig. 6 of paper 667 : Number of transformers installed per year in Brazilian power distribution

Sub block 3 : Models for switchgear (14 papers)

The continuous improvement of switch gears requires the development of models for the equipment itself (**papers 99 and 509**) or network of GIS equipment (**paper 296**), but also to predict the behaviour (**Paper 93**).

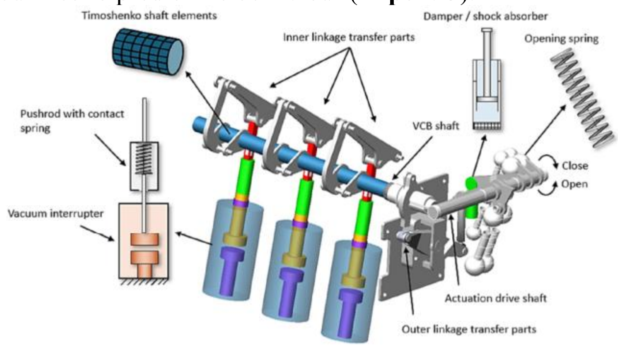

Fig. 4 of paper 509 : Components in the simulation models of the switch gear kinematic drive chain

As a component should survive not only to the grid operation but also to external mechanical solicitations, FEA models has been developed to reproduce the transport (**paper 905**) and seismic conditions (**paper 906**).
The understanding of ageing phenomena is a prerequisite to any predictive approach with iteration between accelerated ageing experimental results and models fitting of MV CB (**paper 1214**) and GIS busbars (**paper 290**).

Fig. 6 of paper 1214 : Disassembled tripping coils after different accelerated ageing conditions

Asset health indexes are very useful to maintain switch gears' fleet and manage resources, they are based on the coupled monitoring of single components (**paper 33**), twin models of full switch gear (**paper 107**) or critical components, like tripping coils (**paper 774**) or behaviour monitoring like CB travel curves (**paper 528**) or PD pattern (**paper 281**). To keep a good reactivity the analyse of data can be partially locally processed (**paper 33**) or can take advantage of IA trained on past data (**papers 107, 528 and 774**).

Table 4: Papers of Block 4 assigned to the Session 1

Paper No. Title	MS a.m	MS p.m.	RIF	PS
12. Shortcomings of dissolved gas in oil analysis in recognizing thermal faults involving cellulosic materials - an example of low accuracy of Duval triangle 5				X
27. Medium voltage cable fault and health assessment through advanced analytics				X
33. Digitalization of medium voltage switchgears for asset management and predictive maintenance.				X
75. Analysis and evaluation of ageing phenomena of high-power LV and HV fuses due to longterm operation				X
93. Improvement of vacuum circuit breaker model based on laboratory results and field testing				X
99. Enhancing Efficiency of Arc Flash Simulation in Metal-Clad Switchgear: Transitioning from 3D to 1D Modeling Using Matlab Simulink/Simscape				X
107. A thermal twin of medium-voltage switchgears for predictive maintenance				X
143. Thermal modelling of the soil to study the impact of climate change on the current rating of underground MV cables		X		X
152. Evaluation of a neural network-assisted thermal model for efficient dynamic cable rating				X
194. Structural Modelling of Hermetically Sealed Transformers under Dynamic Thermal Loading				X
211. An Accelerated Ageing Test Bench for Lifetime Assessment of New Generation of MV/LV Transformers				X
231. CAN DISTRIBUTION TRANSFORMERS IN OPERATION COPE WITH THERMAL CONSTRAINTS NEW USES TOUGHEN? PROOF BY EXAMPLE.				X
235. Accelerated aging of medium voltage cold shrink joint materials under combined stresses			X	X
261. Life Evaluation Method of Cast-resin Transformer by Tan Delta Measurement : A Case Study				X
273. Development of a Thermal Performance Indicator based on a Thermal Model for Oil-Immersed Distribution Transformers with Two-Stage Cooling				X

281. Integrating physics-based twins to enhance partial discharge evaluation – Coupling the thermal and dielectric domains				X
290. Aging and lifespan prediction of busbar connections in GIS: A detailed study on effect of oxygen diffusion in SF6-free dry air atmospheres		X		X
296. Application of Thermal Network Modeling for MV GIS Design Optimization				X
396. Evaluation of Degradation Degree of Artificially Degraded Silicone Rubber Surface				X
409. Predictive analytics for 11kV underground cables: Leveraging advanced analytics and machine learning to reduce breakdowns and operational costs				X
454. Effective Radial Thermal Conductivity for Bundles of Identical Insulated Single Core Cables			X	X
466. Thermo-electrical ageing of paper insulated MVAC cables: experience from laboratory experiments				X
509. MULTIBODY ANALYSIS OF DYNAMIC CHARACTERISTICS IN VACUUM CIRCUIT BREAKERS				X
528. Asset Health Prediction Using Medium Voltage Breaker Travel Curve Data and Artificial Intelligence				X
667. Power transformer aging – large real data analysis of brazilian power distribution system				X
774. Digital Twin of the tripping coils for health monitoring and diagnostics of medium voltage circuit breakers		X		X
822. Towards a digital twin: Operational data evaluation techniques for online monitoring and condition assessment of large rotating equipment				X
837. Evaluation of the Lifetime of Power Transformers Based on Decrease in the Strength of Insulators Supporting the Winding				X
845. Influence of high frequencies and harmonic distorted voltages on refractive field grading for medium voltage cable accessories		X		X
861. Reliability Assessment of Photovoltaic Inverters Considering Volt-Var Control Strategy		X		X
905. Finite Element Analysis (FEA) methodology for transportation-induced stress mitigation in electrical distribution network component.				X
906. Digital seismic assessment for primary electrical distribution device using response spectrum technique.				X
912. Strongly reduced computation time of thermal modelling of load carrying components using a two-step convolution-based approach				X
948. Investigating the Impact of RES Integration on Medium-Voltage Cable Joint Failures Based on Geographical Correlation Methods				X
950. Thermo-electrical ageing of 10kV paper insulated lead covered cables: experience from field experiments				X
1171. Assessing the Temporal and Spatial Impact of Renewable Energy Integration on Medium Voltage Transformer Failures		X		X
1214. Accelerated ageing tests for smart MV circuit breaker predictive maintenance				X
1237. Data driven analysis of underground MV joint failure phenomena in the Italian distribution grid				X