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SPECIAL REPORT FOR SC A3: TRANSMISSION AND DISTRIBUTION EQUIPMENT

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Special Reporters

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SC A3 studies Transmission and Distribution (T&D) Equipment. For the CIGRE 2024 conference a call for reports was issued covering the following preferential subjects:

PS 1: Energy transition involving T&D equipment
- Innovative technologies to reduce total cost of ownership and to foster the energy transition.
- Novel applications especially DC and increased duties on equipment due to DER.
- Improvement of grid resilience due to climate change: the impact on equipment requirements.

PS 2: Lowering the carbon footprint of T&D equipment:
- Performance & maturity of SF_6 alternatives – report on industry experience.
- Life cycle assessment of T&D Equipment.
- Life cycle management and life extension of existing equipment.

PS 3: Maintaining and management T&D assets:
- Smart sensors, low power instrument transformers, monitoring, condition assessment and application of IoT.
- Digital twin and equipment reliability modelling also covering new / higher load profiles.
- Big data management and data ownership, with respect to equipment condition assessment.

A good number (66) of specialists were invited to review the submitted draft reports. Each report was reviewed by two or more reviewers. The review process led to the acceptance of 78 reports (26 more than in 2022), of which 72 reports were revised by the authors, based on the reviews. Two reports were rejected.
Preferential subject statistics: 13 Reports fall under PS 1, 32 cover PS 2 and 33 deal with PS 3.

For the special report the reports accepted were categorized into four groups, which serve as the main story line in this document (see summary table):
1. SF_6 alternatives and Life Cycle Analysis (LCA) studies (25 reports).
2. Miscellaneous T&D equipment and systems (19 reports).
3. Asset management, monitoring and diagnostic (16 reports).
4. Instrument transformers and digitalization (18 reports).

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Summary Table

1. SF_6 alternatives and Life Cycle Analysis (LCA) studies (25 reports)	10127, 10258, 10323, 10352, 10549, 10569, 10580, 10717, 10718, 10719, 10720, 10721, 10722, 10725, 10917, 10967, 11042, 11251, 11261, 11263, 11265, 11266, 11336, 11638, 11757
2. Miscellaneous T&D equipment and systems (19 reports)	10161, 10162, 10163, 10165, 10188, 10195, 10280, 10319, 10321, 11079, 11259, 11600, 11610, 11719, 11815, 11830, 11851, 11858, 11900
3.Asset management, monitoring and diagnostic (16 reports)	10257, 10324, 10325, 10709, 11015, 11110, 11148, 11150, 11269, 11320, 11337, 11338, 11339, 11369, 11637, 11855
4. Instrument transformers and digitalization (18 reports)	10132, 10552, 10578, 10579, 10581, 10584, 10599, 10711, 10715, 10726, 10727, 11154, 11323, 11331, 11333, 11494, 11682, 11847

In the General Discussing Meeting of August 27 2024, the discussion of the four groups will start with the presentation of a representative report, followed by the prepared contributions and a discussion. Further information is given at the end of this special report.

Group 1. SF_6 alternatives and Life Cycle Analysis (LCA) studies

Decarbonization is a major topic of the reports, submitted to SC A3. This reflects the combined efforts of utilities and manufacturers to shape technology and procedures towards net-zero emission of T&D equipment. The majority of reports is on alternatives of SF_6 as insulating (and current interrupting) gases, where two technologies compete: mixtures of natural origin gases with fluoronitriles (C_4F_7N, or in short C4FN) or without, the latter with vacuum switching.
Another trend is emerging: Life Cycle Analysis (LCA) studies that consider the equipment impact 'from cradle to grave' on environment considering a variety of aspects, not limited to CO_2 equivalent emission.

Reports on C4FN-based mixtures in T&D equipment (ranked according to rated voltage):
10323 presents an accelerated lifetime study to mimic 10 years life of C4FN mixture based 38 kV submersible switchgear. Thermal cycling between +80º C and -40º C during several month allows extrapolation, predicting a minor pressure drop in 25 years.
10720 compares the performance of 72.5 kV GIS and circuit breaker having a C4FN/CO_2/O_2 mixture with an SF_6 filled equivalent. Attention is paid to the modification (of the SF_6-free design) necessary for the high-speed earthing switch and for the breaker operation mechanism, requiring 24% more energy for opening. The SF_6-free product shows strong performance in back-to-back capacitor bank energization. An LCA study shows 41% lower lifetime CO_2 eq emission. Manufacturing and life-time energy use are the main components of CO_2 eq emission.
10258 describes TSO experience with three "smart" C4FN based 132 kV circuit breakers. Focus here is on asset management through a variety of sensors, giving input to a health index. Through computation, the composition of the gas mixture can become available.
10717 is on a 145 kV C4FN mixture selfblast interruption chamber, to be applied in various circuit breaker designs. The authors report on physical details of the current interruption process such as the chopping number in inductive load switching and post-arc current in short-line fault current interruption. Contrary to earlier findings, the authors report post-arc currents of several Amperes. Various simulation methods are demonstrated, for both mechanical as well as computational fluid dynamical approaches in 2D and 3D.
10722 highlights a 145 kV 40 kA circuit breaker operating with a C4FN/CO_2 mixture. The

authors motivate the choice for a puffer interruption strategy, as well as for an oxygen-free gas mixture that shows lower decomposition of the C4FN component. Development of a digital twin to support customers is reported, the data for which are supplied by numerous sensors.

10967 shows reliability operation tests of a 170 kV 50 kA GIS with a mixture of C4FN/CO_2 in a utility test station in S Korea. During four months, 110 load switching operations were performed with up to 2700 A current, while a large number of breaker parameters, including gas composition are monitored. No abnormalities were observed.

10127 focuses on 245 kV (single break) and 420 kV (double break) GIS circuit breakers with C4FN mixture. The 420 kV variant is now ready for a first pilot, early 2025 to be followed by the 245 kV product. Because of the presence of grading capacitors in the double break 420 kV design short-line breaking capacity can be reached of 63 kA. Controlled shunt reactor switching capability with these products is proven. An LCA study shows the impact of various primary energy source mixes on the lifelong CO_2 eq emission.

10719 highlights the progress of a 420 kV double break C4FN-based dead tank circuit breaker for 63 kA with high performance regarding capacitive, electrical and mechanical endurance. Testing was carried out with 75 ms DC time constant and increased fault current making peak. To reach continuous current of 5000 A, simulation studies were carried out and demonstrated.

10718 presents results and data of rate of rise/decrease of dielectric strength of the opening/ closing contact gaps of a 420 kV double break C4FN-based circuit breaker. The data are taken from capacitive switching tests and are necessary to qualify the product for controlled switching. Likewese, data on stability of the operating mechanism are provided.

10725 covers the dielectric testing of 420 kV 63 kA circuit breakers with C4FN mixtures for GIS and dead tank applications. The authors list the dielectric tests carried out in accordance with the IEC and IEEE standards, with in some case higher specifications than standardized. The internal bushing design towards the IEEE chopped wave tests is very critical. Many tests were performed at 440 m altitude, without altitude mitigation factor. It was shown that partial discharge activity remains well below the limit.

Q1: A variety of C4FN based mixtures (with and without oxygen) and composition ratios is reported. With every manufacturer having its "proprietary gas" could "inter-operability" be realized? Can specialist predict whether a "one-gas-fits-all" solution is waiting at the horizon or at what time horizon convergence of various gas-insulation technologies can be expected?

11757 is on the design of C4FN based insulation of GIS instrument transformers. The authors discuss the impact of surface roughness and -coating on breakdown. Partial discharge measurements seem to show similar pattern as in SF_6. Consideration is given to proper sealing.

11251 reports an experimental study of hot gas temperature in a model HV breaker with SF_6 and C4FN/CO_2/O_2 mixture by means of breakdown of micro gaps in the gas exhaust volume during recovery. In the case of the mixture, gas temperature cannot yet be linked to breakdown voltage due to lack of physical data.

10549 is on the impact of moisture on the breakdown voltage of C4FN mixture, after a failure to pass a site acceptance test of a C4FN mixture filled GIL that has been out of service for some time. Laboratory scale tests shows that breakdown voltage decreases with higher humidity, but less so at higher pressure. Inception voltages, waveshape patterns of partial discharges for humid and dry gas are given.

10569 reports results of partial discharge measurements in C4FN mixtures, pure CO_2 and technical air with particle and needle-plain configurations. Due to its electronegativity, partial discharge activity in C4FN mixture is the lowest. Various patterns and distortions are shown.

Q2: SF_6-free gasses are now (going to be) applied in products up to 420 kV. Several reports *are on the lifetime management (material compatibility, composition stability, gas decomposition, gas loss, permeation, moisture ingress etc.). Can specialists shed light on how sufficient confidence can be gained for a lifetime of service? Is there (a need for) a unified approach/ proposal of accelerated ageing testing such as the pre-qualification procedure for XPLE HV cables?*

Reports related to SF_6-free vacuum switchgear:
11266 evaluates in a combined effort of DSOs and manufacturers, long time experience with MV solid state insulated C-GIS 24 kV vacuum switchgear and compares it with SF_6 insulated equivalents. Failure rate was found to be 50% lower, whereas an LCA analysis shows 33% lower CO_2 eq emission. The study includes an extrapolation of vacuum integrity to 60 years.
11263 presents new 72/84 kV GIS with compressed air insulation and vacuum interrupters. In the report, special attention is paid to the lifetime of seals by accelerated ageing at 80º C, oxidation of grease, silver plating etc. There was no detectable gas loss in 5 months operation. New designs of disconnector and earthing switches are demonstrated.
11265 describes 72/84 kV compressed air insulated vacuum switching GIS, in service from 2023. Its size is similar to older generation SF_6 GIS, so it would size wise be suitable to replace. Tests are described with disconnector and earthing switch, including decomposition products due to arcing. Leakage is very small, extrapolating for 30 years lifetime at 0.9 MPa.
11042 highlights the development and testing of disconnector and earthing switches for a 420 kV 63 kA GIS with technical air insulation and fault current switching with vacuum interrupters. The report includes post-arc current measurements in vacuum interrupters, including its interaction with grading capacitors. Also light-weight low-power IT for GIS are described.

Q3: Several reports describe the tests on disconnectors and earthing switches in GIS with compressed air insulation. Since the switching of these devices is in the compressed air, what technical adaptations are necessary to make this possible? Is there a limit of high-current load transfer switching in air, or the short-circuit current making duty even at 420 kV and beyond?

Reports containing TSO/DSO considerations and experiences with SF_6-free switchgear (see also reports 10258, 10549, 10967, 11263, 11265, 11266):
10917 lists the needs of 6 European TSOs of station equipment up to 2032. With a need of 2158 new bays of GIS, 5858 live-tank breakers and 2151 instrument transformers this would mean almost 1000 ton of SF_6 gas needed. Requirements are set-up for SF_6-free switchgear before installation and during service, as well as minimum technical requirements. 25 Pilots are running/planned with C4FN-based, vacuum- and CO_2/O_2 circuit breakers 72.5 – 420 kV.
11336 discusses a feasibility analysis of introducing SF_6-free switchgear in India. Weight factors are attached to various aspects of application of three technologies, SF_6, natural origin gas plus vacuum and C4FN-based mixtures.

Q4: TSOs report a huge need of equipment by the ongoing electrification. At the same time, availability of key-components such as C4FN gas and HV vacuum interrupters is limited and in the hand of a few manufacturers. Can TSO specialists explain how they plan the supply of assets and how the societal urgency of energy transition influences technical decisions?

Q5: Can utility specialist elaborate on how they choose SF_6 alternative technologies, given boundary conditions of technology, availability, size, costs, existing/future legal regulations?

Reports with main emphasis on LCA studies:
11261 proposes a common LCA format for 72/84 kV switchgear by 7 Japanese manufacturers.

They conclude that material impact is not large. Extensive sensitivity analyses are given regarding GWP of the gas, leakage rate, current, maintenance, primary energy mix, recycling. Greenhouse gas emissions in 40 years of the non-SF_6 GIS seems 26% of that of SF_6 switchgear.
10721 present a very detailed LCA study comparing the impact on 18 environmental aspects of 72.5 kV SF_6, vacuum plus air and C4FN-based GIS products of their company. Overall, the vacuum product has the highest environmental impact. Data are provided on the LCA results of 145 kV C4FN/CO_2 based GIS during production, use, transportation and end-of-life.
10580 presents an LCA study of instrument transformer design, based on direct interaction with customers. This can reduce costs and overspecification, avoiding unused functionalities in the product. GWP reduction of up to 23% can be achieved in 123 kV voltage transformers.
10352 highlights an LCA of digital MV substation components. Comparison between digital and "basic" solution shows a slightly higher CO_2 equivalent of the digital version, due to its lifetime power consumption. This must be considered against a higher reliability, resilience and more effective asset management.
11638 describes proposals on speeding up energy transition through the digitalization of distribution system planning. The authors recommend the use of digital product passports, LCA based environmental product declarations and an universal data structure for the energy sector to support standardized planning and Internet-of-Things (IoT) integration.

Q6: LCA studies show that the manufacturing and use process is a significant part of the lifetime CO_2 eq emission. Since these depend heavily on the type of primary energy mix used in manufacturing (of even the basic materials) and during use, how can LCA studies deal with the diversity of global energy mixes and their variations over time, extrapolated towards decades?

More information on the application on SF_6-free equipment in stations can be found in the SC B3 reports 10308, 10309, 10738, 10740, 10960, 11029, 11092, 11306, 11334
More information on the material aspects of SF_6-free insulation gases can be found in the SC D1 reports 10755, 11379, 11644.

Group 2. Miscellaneous T&D equipment and systems.

The transmission and distribution industry is currently encountering various technical challenges in response to the "energy transition", which involves the rapid integration of renewable energy and the expansion of direct current transmission networks. To address these issues, there has been a vigorous advancement in the research and development of innovative equipment and systems. In this group, 19 reports will be discussed.

Reports on advanced technologies for specific duties:
Five reports describe advanced technologies to cope with specific duties or severe conditions such as increasing fault current and failures of series capacitors:
10161 introduces the development of high-voltage fast circuit breakers designed to reduce short-circuit currents in power grids by dynamically changing the system topology. It highlights innovations in breaker technology, such as faster tripping and arc extinction, and their successful implementation in reducing fault currents significantly.
10188 discusses the use of fast switches in power grids to mitigate short-circuit currents. It highlights their advantages such as minimal impact on grid reliability, quicker installation and lower costs. It details operational improvements and applications in China, demonstrating their effectiveness and potential for future integration.
11830 evaluates the economic benefits of the implementation of superconducting current limiters (SFCLs) in 220 kV grids in Moscow. By comparing traditional switchgear replacement

with SFCL installation, the authors claim that SFCL provides a more cost-effective solution, although it needs more SFCL to avoid grid splitting.
10280 presents a two-stage detection system for identifying and classifying faults in power transmission lines using machine learning algorithms like 'Random Forest' and 'Naïve Bayes'. The system shows high accuracy and processing efficiency, enhancing fault detection capabilities, and consequently improving power system reliability and safety.
11600 investigates failures in series capacitors in Indian transmission lines, detailing causes such as MOV faults and fire incidents. It presents innovative methods to minimize damage and downtime through equipment adjustments and fire mitigation techniques. The study serves as a practical reference for improving reliability and reducing costs in transmission systems.

Q7:10161 and 10188 discuss the fast circuit breakers which change the grid topology dynamically before the fault current rises, and 10183 presents superconducting current limiters. In traditional systems, all equipment in the grid is required to meet the most stringent duties reasonably possible. Do experts have any experience with methods which mitigate severe stresses by non-conventional technologies or can they give suggestions on such solutions?

Reports on switching equipment with intelligence:
Four reports deal with circuit breakers with novel sensors and controllers, where three present controlled switching technologies and one introduces a generator circuit breaker:
11079 provides a detailed analysis of the application of Point-on-Wave (POW) controlled switching of power transformers, particularly in the context of handling inrush currents during transformer energization. The study takes into consideration the growing demand for electricity and the integration of renewable energy sources.
11610 discusses the optimization of controlled switching for transmission lines to mitigate Switching Overvoltage (SOVs). It presents controlled switching as a superior alternative to Pre-Insertion Resistors (PIRs), providing effective overvoltage mitigation and addressing operational challenges through extensive simulation studies.
11719 discusses PoW controlled switching, highlighting its application in reducing switching transients in electrical equipment like transformers and circuit breakers. It outlines the technology's integration into multifunction devices to enhance power quality and extend equipment life, offering both technical descriptions and practical guidance.
11815 covers the benefits of smart Generator Circuit Breakers (GCB) installed at a power plant in Thailand, emphasizing the importance of collaboration between the manufacturer and utility. It highlights technological advancements, unforeseen applications and the integration of digital features for predictive maintenance and asset performance management.

Q8: The reports describe how intelligence enhances the functionality of switching equipment through applications such as controlled switching and diagnostic sensor technologies. Can utility experts provide their experience and knowledge of operating switchgear equipped with such devices in an actual power grid?

Reports on vacuum interruption phenomena:
Two reports deal with relevant interruption phenomena in vacuum circuit breakers:
10165 presents the findings of a diagnostic study conducted on the distribution of plasma in vacuum switching arcs using an optical fibre array. The study reveals that copper and chromium ions tend to accumulate near the cathode, which improves our understanding of arc behaviour and helps in designing more effective vacuum circuit breakers.
11858 examines how molecular dynamics simulations can be used to analyse the formation of cathode spots and erosion of contacts in Vacuum Circuit Breakers (VCBs). The research aims

to improve VCBs for high-voltage applications by investigating the impact of different contact materials and contact microstructures on arc erosion.

Q9: Vacuum circuit breakers are being considered as an alternative to SF_6 circuit breakers. There is an interest in the current development status of new products and future trends for practical applications in high-voltage and high-current duties, and detailed analysis of interruption and insulation is crucial to achieve the targets. Can experts share information on the methods and results of analysis of phenomena required to improve the performance of vacuum circuit breakers further, as well as their future outlook on the development?

Reports on DC switching equipment.
Four reports discuss the innovations in switching equipment for DC applications:
10163 details the development and application of a DC 80 kV SF_6/N_2 plasma injection trigger for controlling overvoltages in a 800 kV DC transmission project. It highlights advancements in plasma trigger gap technology, featuring rapid triggering, high through-current capability and enhanced insulation recovery.
10195 introduces a magnetic-controlled oscillating current interruption technique for DC circuit breakers, enhancing current transfer with high-frequency magnetics applied to vacuum arcs. It details the design, simulation, and experimental validation of a new breaker topology, offering cost-effectiveness, reliability and rapid response.
11259 details the development and testing of a high-voltage DC circuit breaker, focusing on the Residual Current Switch (RCS) for rapidly isolating faulted sections in multi-terminal HVDC systems. It highlights the necessity of RCS in preventing system outages, outlines testing methodologies using synthetic air-filled gas circuit breakers and contributes to standardization.
11900 covers a proposed design of a 20 kV / 45 kA hybrid DC breaker for the current interruption and energy absorption of quenching superconducting coils in an experimental nuclear fusion facility. The simulation study shows an operation speed of 200-300 ms (by a mechanical switch) and an energy absorption capability (by a soft-steel resistor) of 220 MJ.

Q10: The development of DC switching equipment has made significant progress over the past decade, and discussions on their standardization have entered their final phase internationally. Can experts highlight the remaining challenges to expand the application of the equipment in the DC grid and their prospects, or advise on the next step of the development?

Reports on insulators and conductors.
The topics of the four reports are related to insulators and conductors for AC and DC systems:
10321 describes dry-type insulation technologies for high-voltage substations, emphasizing their safety, eco-friendliness, and maintenance-free advantages over traditional oil and gas insulation. These technologies meet or exceed industry standards and offer enhanced durability with reduced environmental impact and operational costs.
10319 discusses the modernisation of urban substations using Solid Insulated Busbars (SIB) and plug-in bushings, emphasizing space efficiency and safety. It highlights SIB's compact design, ease of installation, and suitability for constrained environments, enabling effective grid upgrades.
11851 discusses the transition from porcelain to composite insulators in the power industry to address failures such as explosions and flashovers. It highlights the successful adoption of composite insulators in UHV projects in China and 800 kV substations in India and notes their environmental benefits, cost-effectiveness, and operational reliability.
10162 investigates replacing epoxy resin insulators with advanced ceramic materials in HVDC gas-insulated equipment to enhance insulation reliability. Through testing and simulation,

ceramic materials demonstrated superior electrical and mechanical properties, leading to successful application in a converter station in China.

Q11: The reports introduce advanced insulators and conductors that offer technical and economic advantages over traditional components. These components are expected to deliver greater reliability, reduced sizes, and lower costs. What technical challenges does the industry encounter in further expansion of these applications?

Group 3. Asset management, monitoring and diagnostic.

Sixteen reports are summarised under this category. The dominant topic is asset management strategy deployed by Transmission System Operators (TSO). Maintenance interventions are coordinated by centralized asset management centres making use of condition monitoring to achieve health index assessment more and more based on outcomes from digital twin modelling and input collected from IoT data. An homologation of failure modes is proposed.
Diagnostic practice based on monitoring data is another interesting topic where the authors share their approach and experience. From one of those emerges that technical competence can still make a difference for effective identification of anomalous faults. Regarding development, it is worth highlighting the completely non-intrusive circuit breaker monitoring system that can be installed without the need for service interruption.

Q12: From the number of reports received is evident TSOs are quite active in implementing a centralized approach for asset management and maintenance, while Distribution System Operators (DSOs) seem to pay less attention to this topic. If this is really the case, what are the main reasons?

10257 proposes an example of application of the health index defined in the CIGRE Technical Brochure 858 highlighting the advantages of asset management. Integration in IEC 61850 is also discussed proposing a new data point reflecting the health index of the asset.
10324 analyses four cases of condition monitoring interpretation and subsequent diagnostic processes highlighting the importance of competence and experience of the engineers, moving from simple straight forward to a more advanced case. Symbolic is the last case where advanced interpretation of bushing monitoring was able to detect symptoms from a quite different part of the transformer; bringing in contextual data and design expertise allowed for a scenario to be identified and checked, and the asset risk managed successfully to the next planned outage.
10325 is a summary of the implementation of asset performance centre by a TSO to collect all the data of monitored assets and plan for investment and maintenance globally. The management system described allows to deal with 28000 transmission assets. Examples of savings and advantages are given together with challenges and lessons learnt along the project definition and its deployment.
10709 shows an application of ‘additive manufacturing’ to produce spares parts of a breaker mechanism not available any longer. The use of this innovative maintenance practice can become particularly crucial in case of discontinued equipment in the grid, where spare parts may become a challenge, offering the opportunity to extend the life of equipment that should otherwise be replaced.
11015 presents the implementation of an asset performance management system in a TSO to achieve optimal management of assets. This is through the control and evaluation of their condition, assessment of risks related to asset criticality and evaluation of the point of failure, as well as through timely actions to increase the transmission system's efficiency and reliability through the formulation of novel maintenance strategies.

11110 offers another example of an asset management system for TSO. It starts with the data structure and different databases used to store measured and calculated raw data. Examples of asset identification is provided as well as different system modules: Maintenance, inspection, measurement, work orders, measure assessment, risk analysis, criticality management. The improvement of maintenance efficiency of the centralized method is estimated 40% and the number of failures per 100 km/yr are expected to go from 1.06 down to 0.7 in the next 10 years.
11148 illustrates the journey towards the homologation of a failure catalogue across different companies and different countries of the same TSO. The reported methodology has been specifically applied to shunt reactors, but is applicable to other assets providing advantages in terms of effective communication between companies by sharing knowledge and experiences among experts and improved operational effectiveness.

Q13: 11148 provides an example of a homologated failure catalogue applied to a single company distributed across different countries. Is it feasible to extend this concept to a higher scale covering assets of the same typology across different companies? Is it thinkable to get a sort of global database for different asset technologies and designs collecting service experience and failure types?

11150 illustrates the construction of a digital twin by a TSO to manage the risks associated with failure to maintain a safe distance from the ground to a transmission line. A 3D terrain model was generated with Laser Imaging, Detection, and Ranging (LIDAR) technology, and then integrated with the CAD representation of the transmission lines in Power Line Systems - Computer Aided Design and Drafting (PLS-CADD). The 3D model made it possible to quantify the volume of soil to be removed by excavation of the non-compliant areas along the route of the line, estimating the associated costs and effort. For the remaining non-compliant areas, the risk was mitigated by implementing coverage of the conductors with insulating material.
11269 presents the development of a Reliability-Centred Maintenance (RCM) practice to optimize maintenance schemes based on engineering and design knowledge. Specifically, RCM analysis guidelines have been defined and applied to aging GIS equipment. The result was a new maintenance plan that extensively uses a condition monitoring system ensuring the same confidence of fault detection as in the traditional human approach. Comparison between the manufacturer's current maintenance recommendations and the proposed maintenance plan highlights both increased reliability and leads to greater cost reduction.
11320 proposes the experience gathered in a pilot project for the development of a prototype automated mechanism for racking in and out circuit breakers in 22 kV and 33 kV air-insulated switchgear. The main motivations were to avoid this manual operation, reported as a critical maintenance activity with high safety risk. The robot prototype uses artificial intelligence and augmented reality technology, which allows manuals, operational history, and technical data sheets of the switchgear to be immediately available.

Q14: Regarding 11320, considering the huge amount of medium voltage switchgear installed for a long time, it is surprising that this is the first application of this type available. How high is the perceived safety risk of racking in and out a circuit breaker in medium voltage switchgear? Are there other initiatives underway to mitigate risks of this practice?

11337 reports the results of Reliability-Centred Maintenance (RCM) strategy application by a TSO with one of the world’s largest equipment base. Its implementation requested calculations of health indices, criticality indices, and mitigation plans for AIS, GIS and Flexible AC transmission systems (FACTs). The reported experience showed an increase in reliability, and reduction in equipment downtime and costs with approx. 25% of savings on maintenance

expenditure compared with a conventional time-based maintenance approach.
11338 reports the experience of applying ultra-high frequency partial discharge monitoring in a GIS. Besides an educational part that describes the basic principles of this technology, a couple of specific cases are reported where this technology made it possible to identify dielectric problems in the GIS commissioning phase. The challenges encountered when implementing this monitoring technology are also reported.
11339 concerns single-phase automatic reclosing in the event of single-phase line-to-ground faults in 400 kV transmission lines. Specifically, the role played by the Secondary Arc Current (SAC) flowing in faulty phase in the dead time, although isolated on both sides by open circuit breakers. This current is supplied by the capacitive and inductive coupling with the other healthy phases and can cause a resumption of the fault once the open pole is re-closed too early. The influence of the neutral grounding reactor on the SAC and transient recovery voltage is studied using simulations validated with measurements.

Q15: In 11339 for validating simulated cases, the transient recovery voltage, obtained from the fault detector acquisitions, is used as a reference without specifying anything about the characteristics of the voltage transformer used. Since the bandwidth of industrial instrument transformers is typically very limited, a question arises about the reliability of the transient recovery voltage signal and the measurement of its rate of rise.

11369 calculates and measures power losses due to current and voltage transformers in a medium voltage switchgear comparing traditional inductive technology with alternative technology, specifically a Rogowski coil and a resistive divider. The result is then used to evaluate the potential savings in terms of total power losses and CO_2 eq emissions for a ten-panel MV switchgear over 30 years of service.
11637 presents a completely non-intrusive monitoring system based on measurements from electric field sensors, piezoelectric sensors, radio-frequency antennas and AC clamps for trip/close coil current. The functionality is supported by several tests and real case studies of field installations. There is the possibility of a perfectly functioning system even when electrically completely decoupled from the asset, which gives the possibility of installing it without planning an outage of circuit breakers already in service.
11855 introduces a new online real time system to monitor leakage current of insulators in polluted environments. Separate intervention criteria have been established for porcelain and Hydrophobicity Transfer Material (HTM) type insulators regarding leakage current value and frequency of occurrence. Compact leakage current sensors are tested in the laboratory together with its communication device using the RS-485 standard. Field experience is being collected with 145 and 220 kV air-break disconnectors, to be followed by an 550 kV installation.

Group 4. Instrument transformers and digitalisation.

This group contains 18 reports, all focusing on new technologies and grid topology adaptions, motivated by the grid transition for the integration of green energy semiconductor technology. Six reports focus on Low-Power Instrument Transformers (LPIT), a technology which can offer additional applications besides conventional measurement applications.
Monitoring applications, diagnostics and Artificial Intelligence (AI) concepts are approaches which are discussed in nine reports. Condition monitoring, Power Quality (PQ) monitoring and Partial Discharge (PD) monitoring are the focus. Five of this nine reports consider conventional Instrument Transformers (ITs), the other four provide a global view. Two reports focus on conventional ITs with the priority to improve the technology to the new grid requirements.

10132 gives an overview of LPIT standards, feasible applications and (dis)advantages. By a (holistic) asset management approach, the authors show cost benefits, especially in an environment of new technologies such as HVDC and Fully Digital Protection, Automation and Control Systems (FDPACS), but also when replacing conventional instrument transformers or complete substations and in certain niche applications.
10599 discusses the voltage level impact when testing the extended bandwidth of voltage transformers as required by IEC 61869-1. The report provides and discusses four test methods that use different excitation signals. The “frequency sweep” and “white noise” signals are then used to study the impact of the voltage amplitude on ratio and angular error across a frequency range, measuring the impact on four voltage instrument transformers. The results are discussed highlighting the impact of the voltage amplitude for the different categories.
10726 complements the study results of a 24 kV resistive divider considering the external stray field impact with those of a 36 kV and a 123 kV capacitive-resistive voltage divider. It also provides mathematical calculations and physical relationships considering external electrical stray fields on the measurement performance of voltage dividers.
10727 provides an overview of Low-Power Voltage Transformers (LPVTs) with a focus on RC (parallel) dividers and CR (series) dividers. It shows the different applications where voltage dividers could be used in an AC grid. One of the main purposes is the measurement of PQ parameters, from rated frequency to transient voltages. It also provides a comparison between the mentioned LPVTs and conventional voltage transformers (VTs).
11333 provides detailed information on a Fibre Optical Current Transformer (FOCT) regarding its mechanical and electrical design. The report discusses and presents in detail the high-voltage design aspect and requirements of FOCTs and its implementation, with special reference to the manufacturer’s development. The HV testing requirements and operational experience of the developed and commissioned FOCT at a 400 kV substation are also presented.

Q16: What are the challenges for LPITs to become a significant future measurement system, and what could be the advantages to motivate end users to implement LPITs in their grids?

10578 presents the development and implementation of smart sensors equipped with embedded AI models. These sensors aim to automatically detect PD defects in cables, switchgear, and transformers, offering a novel solution to the limitations of traditional periodic testing. The embedded AI models enable the sensors to function efficiently even under high-noise conditions and to significantly reduce the need for data transfer to central servers, addressing economic viability and communication challenges in PD monitoring.
10584 presents a wireless self-powered monitoring sensor attached to power lines with edge computing capabilities for PQ and grid analysis. It helps real-time PQ monitoring for transmission and distribution systems to improve management and to reduce maintenance costs.
11323 provide the advantages of applying diagnostic methods to MV equipment based on measurement of partial discharges. Applicable methods are discussed; moreover, a case study is presented relevant to a C-GIS, where the location of the PD source is found by analysis of multiple measurement results.
11331 explains the features, benefits, and characteristics of smart circuit breakers as Internet-of-Things (IoT) devices, focusing on Moulded Case Circuit Breakers (MCCB) and Air Circuit Breaker (ACB) technologies for low-voltage applications. The report also provides some background on the communication protocols and mentions a pilot project to monitor the power quality and reliability of power transformers.
11494 presents a signal attenuation simulator designed to optimize the placement of UHF sensors. The simulator is intended for future use in estimating fault locations by comparing on-site measurements of partial discharge signals.

Q17: The approaches presented for utilising AI, online asset monitoring and power quality measurements in principle are becoming increasingly important. What are the challenges to improve the quality of measurement parameters, and what does it need to receive higher quality results for asset condition evaluation?

10552 presents an overview and experimental findings regarding online condition assessment of oil-paper-insulated current transformers. Ageing phenomena were investigated by detecting the deviations of the behaviour of failing CTs, which may lead to explosion, compared to the 'normal' behaviour of CTs by using partial discharge and/or leakage currents in a stress test in a laboratory.
10715 paper focuses on CT failure due to PD. The paper identifies a method for non-invasive measurement and Machine Learning (ML) methods for the identification of PD. The authors use a site-based trial of 31 CTs as sample data to be analysed; they use filtering methods to identify credible data, and then analyse data to extract PD having high levels of energy. Results identify potentially hazardous PD activity in 3 out of 31 CTs.
10581 presents a practical example of using AI to assess the performance of 245 kV IT. It describes hardware layout, data capture and software approach. Some examples compare actual measurements vs. predicted values, underlying the correct function of the model. Because of new assets and rather short operational time no extreme measurements or failures were predicted. The report also outlines future steps to further develop and evaluate the model.
10711 gives deeper information about optical current transformers which belong to the LPCTs. It presents the optical current transformers, considering their operating principles; it addresses the integration of optical CTs with other Intelligent Electronic Devices (IEDs) into IEC 61850 application and shows a comparison of the characteristics and benefits of using optical CTs and conventional ones.
11847 provides information using deep-learning methods to diagnose Capacitive Voltage Transformers (CVTs) with significant measurement errors. A new method has been proposed that employs a deep-learning model to analyse data attributes and provides online error measurement of CVTs. By applying the proposed method, the online measurement error of CVTs will be fully applicable to the power system operators, only acquired by analysing data attributes and employing the proposed deep-learning model.

Q18: What are the asset-specific parameters which are still challenging the AI approach, online condition monitoring, motivated by ageing processes, and PD measurements?

11154 provides detailed modelling of conventional electromagnetic current transformers, with a thorough representation of the saturation characteristic as well as stray inductance, aiming at a more precise modelling response.
10579 focus on conventional instrument transformers, CVTs, and the possibility of measuring PQ parameters in the grid. The correct determination of the Frequency Response (FR) characteristics allows for calculating the behaviour and evaluating the future PQ application, using CVTs. The authors propose a test setup on how the FR could be measured in a test lab. The topic is crucial due to the requirements to integrate green power into the grid with the consequence of having higher harmonics. The need to measure such harmonics is mandatory to evaluate the ageing processes within the installed asset.
11682 provides a study of alternative, biodegradable insulation liquids used in prototypes of a CT and a VT for 420 kV systems. The first aim of the paper is to provide analysis and interpretation of the results of a specific reference testing sequence conducted on prototypes with a focus on dielectric, thermal and simulated dielectric ageing performance. Furthermore,

transformer design, safety and material compatibility shall be observed accompanied by diagnostics and maintenance conclusions and suggestions.

Q19: Is the experience as of today by modelling instrument transformers high enough to use for future applications like AI or digital twin solutions? What are the challenging topics, and what is the possible future application that instrument transformer modelling could be used for grid design and failure analysis?

Guidelines, important dates and activities during the Paris Conference 2024.

Prepared contributions, interview and presentation:
The SC A3 Group Discussion Meeting (GDM) is on Tuesday**, August 27,** 8:45-18:00 in Salle Bordeaux, level 3 of the Palais des Congrès.
Experts, who wish to contribute to the SC A3 GDM are required to send their draft prepared contribution through the registrations portal on https://registrations.cigre.org until **August 10, 2024** at the latest. Prepared contributions in draft, which are received after August 10, will not be considered for presentation at the GDM. Each duly registered delegate will have the possibility to submit and present one (or more) prepared contribution(s).
The prepared contribution is a very short presentation of max. three slides during three to four minutes as an answer or directly related to one the questions (1-19) in this Special Report. A confirmation email will be automatically sent to the delegate once the contribution has been posted. Kindly note that only registered delegates can access the contributions section.
The Special Reporters will check whether and where the contributions fit into the program. The draft presentations will also be checked on readability, technical/scientific content and size of the power point presentation. Commercial information is not allowed. The Special Reporters will give recommendations to the experts and inform them before **August 17, 2024** whether the prepared contribution will be accepted and whether it can be presented.
One day before the GDM all experts with prepared contributions need to contact the Chairman, the Secretary and Special Reporters of SC A3 for a brief interview (on Monday morning, **August 26, 2024**) in Room 234, level 2. Main purpose of the meeting with contributors is to check the contributor's attendance, to finalise the GDM time schedule and learn the timeslots attributed to the contributor.

Spontaneous contributions:
During the GDM the Chairman calls for spontaneous contributions directly from the audience. Attendees, who provide a spontaneous contribution, are allowed to deliver a text for the Proceedings. This text is required to be forwarded within a maximum delay of two weeks after the SC A3 GMD (thus by Wednesday **September 10, 2024**) to the Special Reporter rene.smeets@kema.com and the SC A3 Secretary frank.richter@50hertz.com.

Poster Session:
The authors of the SC A3 Session reports are invited to present the results of their studies during the Poster Session on Monday morning 9:00-12:30, **August 26, 2024**. If the author(s) cannot attend the Poster Session their National Committee is requested to send a substitute. All SC A3 WGs will present the progress and results so far of their investigations.
For each poster (and each SC A3 Working Group) an electronic screen will be available in portrait format. Posters must consist of only one single page, which must be uploaded on the Conftool system between **June 3 and July 31, 2024**. The convenors of the A3 Poster Session will review the draft posters and inform the authors. A3 poster session conveners are Branislav

Pilát (Slovakia) branislav.pilat@sepsas.sk, and Andres Laso (USA), alaso@gwelec.com. Templates, rules for preparation and general information will be announced on: https://session.cigre.org/general-programme.

For more information, contact the special reporter rene.smeets@kema.com or the SC A3 secretary frank.richter@50hertz.com.

Tutorial:
SC A3 organizes a tutorial on "Generator Circuit Breakers", on Monday **August 26**, 10:40-12:30.

Workshop:
SCs A2, A3, B3, C3 and D1 organize the workshop "Driving T&D substations and equipment towards zero emissions" on Monday **August 26, 2024**, Salle Blue, 14:30 – 17:30**.**

General information on SC A3:

Within SC A3, dealing with AC & DC Transmission & Distribution equipment, the following Working Groups have published their Technical Brochures since 2022:

WG A3.41	Current interrupting in SF_6-free switchgear	TB 871
JWG B4/A3.80	Design, test and application of HVDC circuit breakers	TB 873
JWG B3/A3.59	Guidelines for SF_6 end-of-life treatment of T&D equipment (>1 kV) in substations	TB 914
WG A3.40	Technical requirements and testing recommendations for MV DC switching equipment at distribution levels	TB 931

Active working groups in SC A3 are:

WG A3.39	Application and field experience with metal oxide surge arresters.
WG A3.42	Failure analysis of recent incidents of AIS instrument transformers.
WG A3.43	Tools for lifecycle management of T&D switchgear based on data from condition monitoring systems.
WG A3.45	Methods for identification of frequency response characteristic of voltage measurement systems.
WG A3.46	Generator circuit breakers: review of application requirements, practices, in-service experience and future trends.
WG A3.47	Lifetime management of medium-voltage indoor switchgear.
WG A3.48	4th CIGRE reliability survey on transmission and distribution equipment
WG A3.49	Aging effects on accuracy class of instrument transformers.
WG A3.50	On-site calibration and verification of the accuracy of instrument transformers
WG A3.51	Requirements for HV T&D Equipment operating under abnormal weather conditions.
JWG A3/A2/A1/B1.44	Limitations in operation of high-voltage equipment resulting of frequent temporary overvoltages.
JWG B3/A2/A3/C3/D1.66	Guidelines for life cycle assessment in substations considering the carbon footprint evaluation.