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 2026 conference a call for reports was issued covering the following preferential subjects:

PS 1: Transformation of T&D assets for evolving grid conditions:
- Innovative current limiting solutions for T&D networks.
- Innovation and field experience of T&D equipment to enhance system flexibility, resilience, stability and connectivity.
- Application of T&D equipment in meshed DC-grids.

PS 2: Sustainability and circular economy of T&D equipment:
- Use of recycled material and refurbished components in T&D equipment.
- Alternatives to SF_6 and field experience in applications; impact of PFAS regulation on T&D equipment design.
- Impact of low-power instrument transformers and smart sensors.

PS 3: Asset management strategies for T&D equipment:
- Integration of sensors in T&D equipment for enhanced monitoring.
- Efficient data management and information sharing for T&D condition assessment.
- Utilizing digital twins, IoT, and AI for T&D equipment management.

A record number of 135 synopses were received, 121 of which made it to a full report. A good number (56) of specialists were invited to review the submitted draft reports. Each report was reviewed by two reviewers and three in case of doubt or 'weaker' reports. The review process led to the acceptance of 113 reports from 31 countries (35 more reports than in 2024; 61 more than 2022), most of which were revised by the authors, based on the reviews. Eight reports were rejected.
Preferential subject statistics: 25 Reports fall in PS 1, 50 cover PS 2 and 38 deal with PS 3.

At the end of this Special Report, detailed instructions are given on how to participate actively in the SC A3 Group Discussion Meeting and the SC A3 Poster Session.

For this Special Report the reports accepted were categorized into five thematic groups, which serve as the main story line in this document (see summary table showing the ID number of the reports in each group):
1. Equipment using SF_6 alternatives (35 reports).
2. Miscellaneous T&D equipment and systems (21 reports).
3. Monitoring, asset management, reliability and digital technology (43 reports).
4. Instrument transformers (14 reports).

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Summary table

1. Equipment using SF_6 alternatives (35 reports)	10153,10210,10214,10734,10766,10767,10768,10769,10813, 11245,11430,11501,11502,11506,11510,11725,11829,11831, 12000,12002,12244,12245,12250,12252,12253,12255,12257, 12259,12260,12261,12262,12369,12399,12462,12495
2. Miscellaneous T&D equipment and systems (21 reports)	10151,10152,10167,10211,10221,10260,10275,10687,10747, 10765,10770,11056,11057,11360,11460,11504,11509,11597, 11998,12074,12485
3. Monitoring, asset management, reliability and digital technology (43 reports)	10179,10259,10267,10268,10269,10271,10273,10274,10328, 10329,10354,10649,10653,10816,10817,10860,10861,10869, 10941,11149,11246,11626,11664,11720,11736,11832,11956, 11992,12027,12035,12091,12128,12191,12202,12306,12397, 12411,12421,12425,12487,12556,12640,12641
4. Instrument transformers (14 reports)	10212,10265,10867,11155,11361,11417,11497,11975,11999, 12001,12112,12249,12372,12375

Group 1. T&D station equipment using SF_6 alternatives

Decarbonisation 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. A large number of reports is on equipment using alternatives to SF_6 as insulating (and current interrupting) gas.
Three mainstream SF_6-free technologies are reported for switchgear:

1. Gas mixtures of natural origin gases (CO_2, N_2, O_2) with a small percentage of fluoronitriles (C_4F_7N, or in short C4-FN) for insulation and switching;
2. Gas mixtures of natural origin gases for insulation and switching;
3. Gas mixtures of natural origin gases for insulation and switching in vacuum.

In case of 'passive' station equipment (GIB, GIL, instrument transformers) the mainstream technology reported is the use of natural origin gases with or without C4-FN.

1 Reports on C4-FN-based mixtures in T&D equipment (ranked according to rated voltage). Unless mentioned otherwise, all equipment uses a C4-FN/CO_2/O_2 mixture.

a. Products and user experiences

12255 (FR) reports on 7 years' experience with GIS. Over this period, gas samples have been taken from a 50 kV station, every two years, from 59 compartments. Analysers were used from five different brands, that showed relatively large variations in read-out of C4-FN and O_2 content. An average leakage rate of 0.22%/yr is reported, but a lower value (0.17%) during the last 3.5 years despite not having yet optimised sealing. After two 17 kA fault current interruptions the CO level was established at 1633 ppm (< 50 ppm in non-switched compartments), labelled as 'normally arced'. The report contains a detailed analysis of C4-FN, O_2 and humidity ingress over the reported period.
12257 (CH) is on the successful type-testing of 145 kV/63 kA dead-tank type single-phase enclosed and 145 kV/40 kA GIS three-phase enclosed switchgear, designed with a common philosophy. Short-line fault and terminal fault test-duties for 50, 60 Hz are covered. Testing includes shunt-reactor switching in accordance with IEC 62271-110. For both products, information is provided on the chopping number as a function of arcing time. For the dead-tank product, single bank capacitive current switching tests are performed with success.
12000 (KR) describes climate chamber tests of a 170 kV/50 kA spring-operated GIS from

minus 30º C to plus 50º C. During the tests, gas density was monitored and mechanical operation checks were performed, and well as the integrity of the sealings was confirmed. Additionally, LI and AC dielectric tests and short-circuit T100s and T100a tests are described and passed successfully. Hot gas flow details of CFD simulations are included in the report.

12260 (CH) covers a multi-objective design methodology for 245/300 kV/63 kA 50/60 Hz circuit breaker chambers, both for dead-tank and GIS applications. Results from tests and simulations provide a large number of parameters as input of an automated design process. As an example, two geometries are compared regarding current-zero pressure as a function of arcing time. Other studies highlighted include dielectric shielding and arc zone optimization for capacitive and inductive switching.

12261 (CH) presents development and testing of dead-tank and GIS switchgear for 245/300 kV/63 kA with a single chamber, including fast earthing switch for the GIS design. The authors illustrate the design for combined ratings for 245 and 300 kV to cater for the global market and its varying requirements (e.g. slightly higher than standardized rated voltage, chopped wave dielectric stress, higher induced current ratings for earthing switches but also improved service continuity). Possibilities for combined testing are highlighted in order to reduce costs. Development tests (SLF, TF, transformer-limited faults) are described, as well as inductive load switching test showing current chopping behaviour and re-ignition free window similar to a 550 kV SF_6 breaker. The design target includes controlled closing capability, and details of the mechanical making characteristics are given.

10210 (FR) deals with development of similar chambers for 245 kV (single chamber) and 362, 420 kV (double chamber) GIS. Testing of the 245 kV/50 kA design has finished, including shunt reactor switching. The design is prepared for controlled switching and to be extended to 63 kA @ 60 Hz using non-linear springs in the drives. The 362 kV/63 kA product is designed for minus 30º C (with an adapted gas mixture) and 60 Hz, is capable for capacitive switching and prepared for controlled closing for capacitor bank switching. The 420 kV 63 kA GIS is now in serial production, and meets extended electrical endurance, back-to-back capacitor bank (C2 class) and shunt reactor requirements.

12252 (CH) reports on efforts to qualify a modified 420 kV/63 kA live-tank and GIS switchgear design for 80 kA application, as per customer requirement. The report lists the adaptations necessary to achieve this: larger grading/line-to-earth capacitors to facilitate SLF, increase minimum clearing time to satisfy T100a and increased recovery voltage to 440 kV as per customer requirement. Short-time current requirements for 80 kA are covered with longer current duration at 63 kA. The earthing switch needs redesign for 80 kA making capability. A system study shows that the impact of larger grading capacitances may lead to ferroresonance overvoltages requiring mitigation.

12245 (CH) is related to type-testing of 420 kV/80 kA live-tank, dead-tank breaker and GIS. The emphasis is on the proper design and application of test-circuits for the very large current, especially the evaluation (by arc modelling) of current suppression by the arc-circuit interaction and the application of constant AC voltage in synthetic testing. High-speed earthing making tests at 420 kV/80 kA are described. Attention is paid to the establishment of two accuracy testing methods for C4-FN analysers and traceable reference gas mixtures.

12259 (CH) reports development experience of a 420 kV/63 kA/6300 A double break single-pole spring-hydraulic operated puffer-type circuit breaker with a C4-FN/CO_2 mixture. The design is kept free of oxygen to limit toxic by-products by arcing. The design includes pre-insertion resistors across each of the chambers. A study on the sizing of grading capacitors is added, as well as an analysis of required clearing pressure under various 60 Hz impedance stress conditions and gas blow temperatures. Proper grading capacitors not only favour adequate voltage sharing between the chambers, but also add to thermal interruption performance. An LCA (life cycle assessment) study has been added showing 82% reduction

of life-time CO_2-eq emission compared to an SF_6 equivalent.
10214 (FR) is on a retro-fill project of an existing 420 kV GIL (gas-insulated line) with an SF_6-free gas mixture. Attention is paid to the leakage and permeation of the SF_6-free gas mixture through the existing EPDM (ethylene propylene diene monomer) sealings. From research, it is reported that a mixture of C4-FN/N_2/O_2 has acceptable loss rate (2.3 times higher than SF_6). Oxygen is accepted, in spite of oxidation, because it enables earthing and disconnecting switches to be installed later in GIS. However, the presence of oxygen lowers the temperature rise limit. The report contains a study on dielectric performance of various N_2 based gas mixtures; the ratio 5/85/10% (C4-FN/N_2/O_2) is reported as optimum. Accelerated thermal ageing tests confirm compatibility of existing materials with the new gas mixture.

Q1-1: In this (and past) CIGRE sessions, various projects have been reported on retro-fill of SF_6-designed gas insulated busbars and GIS sections with SF_6-free gas mixtures. Apart from the compatibility of sealings with the SF_6-free medium, as described in report 10214, the pressure of the SF_6-free mixture shall be well above the rated pressure in the SF_6 case in order to fulfil dielectric requirements. Can specialist explain how to overcome this seemingly contradictory pressure-difference issue? Doesn't the SF_6-rated pressure make the alternative gas dielectrically 'weaker'?

11501 (CN) reports delivery of a 550 kV/63 kA dead-tank breaker, based on double break technology with pre-insertion resistor unit in the same enclosure. Tests based on IEC, IEEE and GB (Chinese) standard were passed for 50 and 60 Hz. Test duties applied included terminal fault tests (with asymmetrical current T100a tests having 45 and 75 ms DC time constant), out-of-phase (OP2), short-line fault, capacitive line/cable (C2 class), extended electrical endurance (E2 class), shunt reactor switching, seismic and extended mechanical endurance (M2) requirements. In addition, chopped wave tests at 2320 kV were carried out. Regarding size, the SF_6-free product is 38 cm longer and 27 cm higher than its SF_6 counterpart. An 800 kV product is announced for 2027.
11829 (NO) deals with qualification of a 420 kV cable connector for a C4-FN/CO_2/O_2 GIS. A qualification program is designed for four stations, including dielectrical, mechanical, thermal, material compatibility and environmental performance. The 'outside' cable box lay-out eliminates the need of a cable basement. Tests were for rated voltage 420 kV but repeated for 550 kV rating. The impact of insulation gas loss was studied by dielectric tests at 252 kV.
10813 (IN) summarizes steps taken in India to switch over to SF_6-free equipment. Huge steps in SF_6 emission reduction have been made, with at present a level of SF_6-loss reached of 0.04%/yr. The planned SF_6 replacement steps culminate in the formulation of requirements for SF_6-free 145 kV circuit breakers and gas detection systems.

Q1-2: The authors of report 10813 mention an actual SF_6 emission of 0.04% per year. Can they explain what they did to achieve such a remarkably low value? Can other grid operating specialists give insight in how they realize reduction of SF_6 emission from T&D equipment, even when facing a large extension of their existing fleet, as report 11831 predicts?

b. Modelling and research
11510 (CN) is a research-oriented report on the design of a 145 kV 40 kA circuit breaker with C4-FN/CO_2 mixture. The report focuses on the gas flow, in particular on the avoidance of restrike after longer arcing times as a result of the faster (compared to SF_6) pressure drop, necessary for arc extinction, at longer arcing times in the mixture used. Detailed pressure and gas mass flow dynamics based on CFD (computational fluid dynamics) simulations are outlined.

11506 (CN) reports studies on the interruption performance of C4-FN/CO2/O_2 and CO_2/O_2 mixtures in a model breaking chamber. The study was largely experimental, aimed to study current interruption performance and dielectric recovery by applying high-voltage pulses at very short intervals. It was observed that C4-FN and O_2 content have a low impact on interruption performance, but that C4-FN has a strong impact on recovery.
12253 (CH) gives insight in how machine learning modelling is used in the design of puffer circuit breakers with C4-FN/CO_2 mixtures. The input data are on the one hand geometry and material parameters, and on the other hand data collected from test results of near-zero arc resistance, arc voltage extinction peak, extinction pressure from 61 short-line fault tests with various designs at current 54-60 kA. A visualization is presented of a 'decision boundary' relating near-zero arc resistance with arcing time. The impact of various nozzle material composition is analysed. Various stages in an iterative methodology are outlined.
12262 (CH) provides the mathematical framework behind the automated component optimization discussed in report 12253. The machine learning (AI) optimization is of higher fidelity than the classical physical and CFD modelling. Examples are shown of diffuser design optimization, the validity of which is verified in wind tunnel experiments.
11725 (KR) presents the application of an alternative gas mixture, PMVE (perfluoro methyl vinyl ether, C_3F_6O) mixed with CO_2 (PMVE/CO_2 10/90%), for insulation and interruption in a 145 kV circuit breaker, designed for SF_6. PMVE is not an F-gas. The study presents plasma and thermodynamic modelling, including radiative heat transfer and nozzle ablation. Calculations of near zero arc conductance are in agreement with interruption performance experiments. A prototype passed short-line fault tests based on rating 145 kV/40 kA/50 Hz.

Q1-3: A multitude of reports covers products that are designed for shunt reactor switching. Can utilities report on application examples or expectations of this switching duty with SF_6 free switchgear? What mitigation technology is preferred in order to reduce the impact of (multiple) re-ignitions, controlled switching, snubber circuits or other?

2 Reports on switchgear having CO_2/O_2 mixtures for insulation and interruption (ranked according to rated voltage).

10153 (FR) reports on achievements in development of CO_2/O_2 live-tank circuit breakers. Rating 145 kV/40 kA/3150 A is available for application from minus 50º C to plus 40º C, capable of shunt reactor switching including controlled switching. A live-tank circuit breaker rated 420 kV/50 kA/4000 A is demonstrated as double break, having terminal faults, C2, M2, OP2, L90 and VCC (voltage condition check) testing passed. Rating 170 kV/40/50 kA in single break design is in development, same as rating 362 kV/50 kA/60 Hz (derived from the 420 kV design) for the Canadian market. Filling is with separate CO_2 and O_2 cylinders; O_2 top-up requirement after 25 years. The CO concentration after 2200 kJ of electrical wear resulted in 'not classified'.
10768 (JP) highlights development of F-gas free 420 kV GIS for application from minus 25º C to plus 55º C. The development of non-switching components such as GIB (gas insulated bus), MOSA (metal oxide surge arrester), and switches has been finalized. The bus sections passed dielectric, temperature rise, short-circuit and internal arc tests. Disconnector switch capability has been confirmed for bus transfer of 4000 A @ 300 V. Design modification was necessary, whereas the earthing switch was tested for electromagnetically induced switching in accordance with Japanese requirements. A GIS puffer circuit breaker 300 kV/63 kA/6000 A in a single-break design is in development; a prototype passed the T100a current test.
12250 (CH) reports on a 420 kV/63 kA/5000 A CO_2/O_2 live-tank double-break circuit breaker, designed from a 420 kV C4-FN/CO_2/O_2 dead-tank breaker with necessary

adaptations. The product discussed has extended electrical and mechanical endurance, capacitor bank switching capability (class C2). Inductive load switching (including controlled switching). Asymmetrical fault current test duty T100a is passed with 75 ms DC time constant. Further tests reported are dielectric performance with power frequency, lightning and switching impulse test, including wet tests, and seismic stress verification.
12244 (CH) is on the verification of a 420 kV CO_2/O_2 live-tank circuit breaker design being suitable for controlled switching. Technical specification IEC 62271-319 is followed in confirming adequate rate-of-decay of dielectrical strength (RDDS) during closing as well as mechanical consistency with very low scatter. Relevant data on both quantities, from a large number of low-current making and breaking tests are shared in the report. Very low prestrike duration is reported favouring capacitor bank switching. A re-ignition window is determined for shunt reactor switching, for avoiding (multiple) re-ignition at controlled switching.

Q1-4: As several reports testify, the availability of products using only natural origin gases for insulation and switching in HV circuit breakers has rapidly reached the EHV level. These, however, are all live-tank designs (except the development described in report 10768). Can specialists elaborate when metal enclosed (GIS, dead-tank) switchgear will emerge on the market based on natural origin gases only? What are the technical obstacles? After having reached that point, what would be the technical/applicational pros and cons of natural origin gas circuit breakers versus C4-FN based gas circuit breakers?

3 Reports on equipment having N_2/O_2 mixtures (pressurized dry, synthetic air) for insulation and vacuum interrupters for interruption in case of switchgear.

10734 (FR) reports operational experience with 63/90 kV vacuum circuit breakers in hydro power plants. The focus is on laboratory research of inductive load switching, notably transformer magnetizing current. The authors conclude from a three-phase station model that the very steep transients originating from multiple re-ignitions, that normally come with this duty, may lead to premature transformer insulation ageing. Arresters are proposed for mitigation, reducing overvoltages from (up to) 4 to 1.8 pu.
11430 (KR) discusses technology challenges in the development of HV vacuum interrupters (VI). The authors present the history of Korean VI development, before going into back-to-back capacitor bank switching at 170 kV. Details are presented on various contact conditioning processes (with voltage, current) and on test results of a large number of back-to-back switching operations with 20 kA inrush current at 72.5 kV level. For application at 170 kV, multi-layer bellows and contact material adaptations are under study.
12462 (DE) deals with reactive load switching of HV vacuum circuit breakers (VCB). Single bank capacitive switching is confirmed with a 145 kV live-tank and GIS VCB. Regarding capacitor bank back-to-back switching (up to 420 kV designs), research work is reported, focussed on prestrike, contact welding and electron field emission. Shunt reactor switching is discussed: RC snubbers for application at 145/170 kV are available and field tested. Extension to 420 kV application is under study. For ratings >170 kV, resistive dissipation of the snubber may be too high and TRV mitigation and/or controlled switching are recommended. Shunt reactor switching type tests of a 420 kV live-tank double-break VCB are presented.
12002 (DE) highlights the participating in the EU projects 'MISSION' and 'LIFE' in which framework various pressurized dry-air insulated vacuum switchgear is being developed and put into operation in pilot projects (2026-2029): 420 kV/63 kA/4000 A live-tank double-break VCB; 550 kV/5000 A DC GIS (without vacuum switchgear); 420 kV/63 kA/4000 A four-break GIS and 245 kV/63 kA/4000 A live-tank single-break VCB. An overview of the numbers of products contracted and in operation as well as the actual status of testing and

performance verification of these designs are presented.
11831 (NO) is on the EU 'MISSION' project. Apart from the HV switchgear developments, highlighted in report 12002, it highlights the development of a 12 kV DC circuit breaker and fundamental studies on discharge development in natural origin gases. Studies are also included on the resilience of EU grids against the SF_6 ban as laid out in the 2024 EU F-gas regulation. It is concluded that the transition to SF_6-free has low risk, though bottlenecks are identified: vendor availability, limited TSO experience and complexity of HVDC grids. Two scenarios are presented of a future estimate of SF_6 content and emissions in Europe.
10769 (JP) presents insulation design studies for 245 kV dead-tank VCB. F-gas restricting regulations in EU, US and Japan are summarized. Eleven candidate gas mixtures are identified, and research test results of breakdown versus pressure are presented, as well as flash-over characteristics of gas-insulator interfaces. A detailed analysis is presented of the breakdown voltage ratio of AC and LI waveshapes in dry air, and the consequences for the design when chopped wave requirements are to be met. A test program is presented while tests confirm suitability of dry air insulation in dead-tank VCB rated at 245 kV.
12369 (DE) covers the application of non-linear resistors (NLR) in series application of HV vacuum interrupters, such as on a 420 kV live-tank double-break design. The report explains why the large post-arc current in vacuum after very large current interruption makes it necessary to apply NLR across each interrupter, in addition to grading capacitors. Studies, carried out by a system operator, illustrate the benefit of NLRs in the reduction of restrike overvoltages and its positive effect on the damping of traveling waves in case of lightning strike. Plans are described to install high-bandwidth monitoring equipment after installation.
10767 (JP) discusses switching of electromagnetically and electrostatically induced- and bus transfer current switching with earthing and disconnecting switches in dry air. By Japanese practice, requirements are beyond the IEC standards. Data on arc voltage and commutation capability are provided. Bus transfer capability is comparable to that in SF_6, whereas earthing switches need improvement of arc quenching capability with a 'suction type' technology.
10766 (JP) goes into the development of a dry-air insulated 550 kV residual current switching device, that serves to disconnect HVDC circuit breakers by interrupting residual (leakage) current. The report describes dielectric prototype testing including 550 kV DC + super imposed 1425 kV LI voltage and partial discharge measurements. Special attention is paid to metallic particles at negative DC polarity and charge accumulation in insulators, and countermeasures. Interruption tests at 185 A show very low contamination levels of NO, NO_2.

Q1-5: *SF_6-free switchgear is now applied in many high-voltage products, soon in service up to 550 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 'pre-qualification' accelerated ageing testing? Do actual 'lifetime verification' test programs such as (extended) electrical endurance, based on SF_6, still suffice? Can users report on their experiences regarding life time performance of SF_6-free switchgear?*

Non-switching equipment with pressurized dry, synthetic air insulation:
12245 (IT) presents a synthetic air insulated RC voltage divider for HVDC. Two prototypes are covered in the report, one for 60 and one for 200 kV. The capacitors required a dielectric redesign, resistor also a thermal modification. Test are performed in accordance with IEC 61869-15 and passed. There is no need to repeat accuracy tests, given the fact that synthetic air has similar electric permittivity as SF_6. Development towards 600 kV product is ongoing.
12495 (DE) demonstrates a synthetic air insulated test reactor (340 kV) for HV test

equipment for onsite testing of GIS. Details of breakdown voltage as a function of pressure for various gas mixtures are given, along with a finite-element electric field calculation. Heat transfer in air is comparable to that in SF_6, as results from simulation and measurement.
12399 (CH) presents pressurized air cables for 420 kV, as a hybrid between cable (flexibility) and GIL (capacity). Conductor design is optimized to elliptic for 4000 A @ 420 kV (single-phase enclosed) and 145 kV (three-phase enclosed). The boltless flange design enables similar size as an SF_6 equivalent. Reactive power loss is 2-5 times lower than in XLPE cable.
11502 (CN) highlights a dry air insulated 550 kV current transformer. Various geometries are studied regarding dielectric capability; measurement results of AC and LI breakdown voltages are provided. An additional shield is required, given the 75% dielectric performance (compared to SF_6) at rated gas pressure. The higher pressure (0.8 MPa) requires thicker steel, resulting in 33% more material and 3% higher costs. Tests carried out for 550 kV are passed.

Q1-6: Though not in detail discussed by reports (in spite of an explicit call in PS 2), can specialist share some thoughts on the impact of PFAS regulation on T&D equipment design? More in general, how do buyers and globally oriented manufacturers deal with future regulations the details of which are not decided upon yet, vary globally and may be some years in the future, such as SF_6 ban, ecodesign for sustainable products regulation, PFAS regulations etc.? Do manufacturers diversify portfolios in the 'fear of missing out'?

More information on the application on SF_6-free equipment in stations can be found in the SC B3 reports 10686, 10738, 10837, 11739, 11997, 12004, 12281.
More information on material aspects of SF_6-free insulating gases can be found in the SC D1 reports 11549, 12332, 12336, 12448.

Group 2. Switchgear and miscellaneous T&D equipment.

This group covers reports on switchgear and miscellaneous T&D equipment. The main themes are higher fault duties, DC applications, asset renewal, and environmental constraints. These assets remain essential in substations and transmission networks, especially where short-circuit duty, switching stress, or environmental constraints are rising. Utilities need solutions that can withstand higher short-circuit currents and stricter environmental requirements in conventional applications, while still being viable for meshed DC grids and acceptable in cost.
Conventional T&D equipment is being adapted to new grid topologies, higher stress levels, stricter environmental requirements, and tighter cost constraints. The SC A3 reports for the 2026 session cover switchgear technologies, related devices, and system solutions addressing severe operating conditions, protection performance, asset life extension, and sustainable design.
The reports in this group are organized into four topics: 'Advanced interruption and protection devices', 'Insulation, transient and external stress', 'Asset renewal and service experience' and 'Decarbonization, circularity and SF_6-free design'.

Reports on advanced interruption and protection devices.

This topic addresses advanced switching and protection technologies, including their development, testing, optimization, and application. The main themes are improved interruption performance, faster fault current limitation, DC interruption, and optimized vacuum switching devices.

Several reports address fault current limiting and protection coordination in networks with increasing duties.
10151 (FR) discusses resistive superconductive fault current limiters (RSFCLs) for multi-terminal DC (MTDC) grid protection. The report highlights their potential for fast current limitation in meshed DC networks, where selectivity, speed, and robustness are critical. It also compares RSFCL-based protection with classical DC reactor (DCR) schemes and mechanical DC circuit breakers (DCCBs).
11460 (CN) presents the application and optimization of fast fault current limiters in regional grid expansion. The study shows how these devices can reduce system stress and support the integration of new network capacity under changing short-circuit conditions.

Another group of reports is centred on vacuum-based switching technologies.
10167 (EG) analyses the electric and thermal behaviour of a 33 kV DC vacuum circuit breaker with a 3-D model. It offers insight into the internal field distribution, heat generation and thermal behaviour that affect interruption performance in DC applications and design optimization. The results help clarify the main design constraints for compact DC switching devices.
11360 (ES) presents a vacuum generator circuit breaker (VGCB) model for EMT-based sizing and validation. It shows that vacuum technology can be used for generator protection and that the new simulation tool closely matches an established EMT platform across multiple plant cases, supporting equipment selection.
11504 (CN) focuses on the design optimization of a contact structure for vacuum circuit breakers. The study uses numerical and algorithmic methods to improve interruption performance and switching robustness. In addition, the work helps clarify the relationship between contact geometry and switching behaviour.
12485 (DE) examines vacuum current interruption for low-frequency applications, broadening the practical use of vacuum technology and helping clarify its applicability beyond conventional frequency ranges, especially where operating conditions differ from standard power-frequency duties.

The development of HVDC and ultra-fast DC switching equipment is also strongly represented.
10765 (JP) is on the development of an HVDC circuit breaker and associated testing methods, reflecting the growing need for reliable DC interruption solutions, for appropriate verification procedures and for practical paths toward future network deployment. The report emphasizes both device development and the challenges of demonstrating performance in a reproducible way.
11597 (CN) presents sub-millisecond artificial current zero interruption of DC fault current using a 40 kV ultra-fast vacuum interrupter, demonstrating the potential of extremely fast interruption concepts for future DC fault clearing and for reducing the technical barrier to DC protection. The report also underlines the significance of very fast switching for meshed DC grids.

Q2-1: This topic shows a shift from conventional switching solutions toward more advanced interruption technologies for new grid conditions, especially in DC systems and highly stressed AC networks. How much reduction in fault stress has been demonstrated in service or field tests for advanced interruption and fault-current-limiting devices? What design, manufacturing, and testing methods are most promising for vacuum interrupters and DC switching equipment?

Reports on insulation, transient and external stress.

This topic includes reports that analyse insulation behaviour and the impact of transient phenomena, environmental conditions and external stresses on T&D equipment. The main topic is not the equipment itself, but its ability to withstand demanding service conditions.

A number of reports deal with insulation reliability under environmental or mechanical stress.
10152 (FR) evaluates the seismic resilience of composite insulators in HV substations through five representative case studies. Shake-table tests and validated models show strong agreement, no structural damage, and higher safety margins than porcelain. Composite designs offer lower mass, greater damping and improved reliability in earthquake-prone areas.

Other reports focus on surge arresters, switching transients and recovery voltages.
10687 (US) reviews surge arrester application in US 765 kV systems, where rapid grid expansion demands improved insulation coordination and asset protection. It compares IEEE and IEC standards, analyses switching and temporary over-voltages, defines electrical and mechanical selection criteria, and recommends higher-rated, monitored ZnO arresters for reliable EHV operation.
10747 (BR) examines shunt reactor switching in the Brazilian transmission grid, focusing on TRV stress, IEC test requirements, and real network conditions. It shows that neutral-reactor grounding can significantly increase dielectric stress and suggests revised minimum test currents, specification practices, and controlled switching to improve circuit breaker reliability.
11998 (AT) investigates switching tests during transformer inrush with a 123 kV vacuum circuit breaker, with attention to transient recovery voltage, interruption behaviour and associated switching stress, all of which are relevant to performance verification under demanding duty cycles. The report also contributes to a better understanding of test conditions for transformer energization.
12074 (CL) evaluates the effect of form factor, non-uniform contamination and UV radiation on leakage current in high-voltage insulators, showing the combined influence of pollution, weathering and surface condition on insulation performance and on the risk of deterioration in outdoor service. The report provides useful information for understanding ageing under realistic field conditions.

Q2-2: The reports demonstrate that as network stresses increase, equipment qualification must go beyond nominal ratings and address the actual transient and environmental conditions encountered in service. How effectively do current standards and design practices represent transient and environmental stresses in service, such as TRV, inrush switching, and contamination? What progress has been made in improving insulation performance for new gas-insulated, solid-insulated, or composite-insulated equipment under combined electrical, thermal, and mechanical stresses?

Reports on asset renewal and service experience.

This topic covers reports focused on asset renewal and service experience of T&D equipment. These reports are strongly linked to operational reliability and to the management of ageing equipment in modern T&D systems.

A number of reports discuss renewal and service experience.

10275 (IN) is on restoration, installation and commissioning of a 420 kV GIS after prolonged storage, illustrating the importance of careful life-cycle handling, recommissioning procedures and quality assurance before return to service after an extended dormant period. The report also provides lessons for asset recovery and re-energization.
10770 (JP) discusses criteria for renovating circuit breakers of 500 kV mixed technology stations (MTS), based on deterioration assessment, and shows how renewal decisions can be made more objectively using condition information and asset condition evaluation. This helps utilities improve transparency in renovation planning.
11057 (IT) presents a graphene-based dry-lubrication coating for medium-voltage circuit-breaker mechanical actuators. FEM-guided component selection, and tests under IEC 62271-100 showed stable operation through 29,000 cycles, nearly three times the extended mechanical endurance (M2) requirement. The coating reduced friction and wear, extended maintenance intervals, and supported lower-maintenance circuit breaker designs.
10221 (US) reviews four decades of medium voltage switchgear retrofit operations, demonstrating that retrofitting assets while adding online monitoring to the maintenance operations generates less CO_2-equivalent and saves important quantities of raw materials compared to a full asset replacement. The report calls on IEC to develop normative guidance to encourage these sustainability and economic efforts in the global market.
10260 (IN) presents operational experience with current-limiting series reactors in a conventional substation within the Indian grid, providing insight into field operation, system integration and practical performance under service conditions, as well as lessons learned from actual deployment.

Reports on decarbonization, circularity and SF_6-free design.

This topic includes reports dealing with the reduction of carbon footprint, reuse of materials, circular economy approaches and SF_6-free or low-emission design solutions. These reports are central to the environmental transformation of T&D equipment.
10211 (FR) examines recycled aluminium for GIS enclosures, showing that 85% recycled castings are feasible but challenging due to traceability, supply, and quality requirements. LCA results indicate that recycled aluminium can cut enclosure-related CO_2 emissions substantially, yet industrial-scale adoption depends on mass-balance accounting, standards, and supplier collaboration.
11056 (IT) investigates mechanical stresses in SF_6-free GIS circuit breakers using pressurized natural origin gas and vacuum interruption. Experiments and simulations show that front-wall stiffness significantly affects displacement, contact travel, and switching consistency. Optimizing the enclosure reduces deformation and improves reliable operation across pressure and temperature variations.
11509 (CN) describes a flash method for recycling insulator core rods into silicon carbide, demonstrating an advanced circularity concept for insulating materials and the potential for high-value material recovery, reuse and resource efficiency.

Q2-3: The reports in this group show that asset renewal and service experience, together with decarbonization, circularity and SF_6-free design, are key pathways toward longer service life and lower environmental impact in T&D equipment. What barriers still limit wider deployment of such solutions, especially in terms of technical performance, footprint, lifetime behaviour, supply chain availability, and lifecycle cost? How should utilities balance environmental performance against reliability, maintainability, and total cost of ownership when selecting equipment for future substations?

Group 3. Monitoring, asset management, reliability and digital technology.

The reviewed reports highlight the growing role of artificial intelligence and digital technologies in modern power systems, ranging from the design and optimization of high-voltage equipment to advanced monitoring and predictive maintenance applications. A strong focus is placed on condition monitoring solutions that use AI-driven diagnostics, health index evaluation, digital twins, IoT platforms, machine learning, and neural networks to improve equipment reliability, optimize maintenance strategies, and support grid resilience under increasingly demanding operational conditions. Together, the contributions demonstrate a broader transition toward data-driven, digitally integrated asset management approaches that address the technical, operational, and sustainability challenges of future transmission and distribution networks.
The reports in PS1 address failures at ultra-high voltages, digital transformation, gas leakage caused by corrosion, and substation building and commissioning. The reports in PS2 address sustainable asset practices through retrofitting standards, SF_6 lifecycle management, field diagnostics, and asset operational records. The reports in PS3 address the modernization of asset management through ISO 55001 governance, enterprise asset performance management platforms, AI/ML predictive diagnostics, condition assessment frameworks, data infrastructure, and interoperability.

Reports on asset management of equipment fleets.

12411 (CO) introduces a framework combining a lifetime consumption index and a failure risk index for a circuit breaker fleet. The framework takes uncertainty into account, and diagnostics on 12 equipment in January 2026 enabled targeted OPEX/CAPEX decisions.
12397 (DE) presents an integration of transformer and switchgear asset performance management analytics delivering up to 50% operator productivity gains and highlights the need for standardization for asset performance management models.
12035 (CO) presents a random forest asset fault detection and classification model achieving 99.7% accuracy for 230 kV circuit breakers, using 11 years of operational measurements as knowledge base. SCADA integration is planned within six months.
11720 (CA) proposes a solution to solve circuit breaker tests records regular data losses on a 2,300-circuit breaker fleet by migrating from a legacy proprietary database to a centralized open-source version control system. The report encourages test equipment manufacturers to use open formats like COMTRADE for circuit breaker maintenance records industry-wide.

Q3-1: Digital twins are more and more in use as an asset management tool, for systems but also for equipment. Can experts share examples of predictions based on digital twins or similar models that enabled avoiding critical asset failures?
More general, how do you think artificial intelligence will transform the way fleets of high-voltage equipment will be managed?

Reports on equipment monitoring and diagnostics.

These reports present monitoring solutions for equipment supervision and focuses on using AI-driven diagnostics to support maintenance, health index analysis and reliability.

Monitoring of switchgear:

10869 (BR) presents the development and testing of a prototype system for online monitoring of frequently operated circuit breakers using IED-based sensing and data acquisition on breakers from two different manufacturers. By applying data science techniques and AI models to the collected operational data, the system can identify equipment wear and detect anomalies at an early stage, supporting predictive maintenance strategies. The results demonstrate the solution's potential to enhance maintenance efficiency and improve the operational reliability of circuit breakers.
12421 (DE) proposes vibroacoustic online monitoring as a non-invasive means of detecting circuit breaker failures during normal operation, validating the approach on a field prototype and adding that a gas density sensor should complement the system for holistic monitoring.
11992 (AT) presents a condition monitoring approach for AC-powered solenoids in circuit breakers by analysing their transient current profiles to detect faults that could lead to breaker malfunction. Unlike existing methods focused on DC-powered solenoids, the proposed technique determines the activation voltage phase without direct voltage measurement and uses predictive models with training data to generate expected healthy current curves. By extracting and comparing key mechanical-event features from measured and predicted waveforms, the method enables reliable detection of operational deviations and faults, including verification of whether the solenoid voltage remained within acceptable tolerances.
10273 (IN) presents the 'panel health monitoring system' (PHMS) to enable real-time condition monitoring of medium-voltage switchgear and address the limitations of traditional time-based maintenance practices. PHMS continuously monitors critical breaker components, including interrupters, coils, motors, temperature and humidity, while using I^2T-based thermal stress analysis and high-frequency sampling to predict failures, assess remaining service life and detect abnormal operating conditions. By integrating with SCADA systems and providing early warnings for mechanical and thermal issues, the solution improves switchgear reliability, reduces downtime and maintenance costs, prevents catastrophic failures and supports more efficient and proactive asset management.
12306 (MY) presents the development and field validation of an in-house circuit breaker online monitoring system (CBOMS) to support condition-based and predictive maintenance. The system continuously monitors mechanical, electrical and dielectric parameters of HV circuit breakers using dedicated sensors and intelligent algorithms, overcoming the limitations of traditional maintenance practices based solely on scheduled outages. Field deployments across multiple substations demonstrated reliable performance, vendor-independent compatibility and substantial operational and economic advantages, confirming the potential of CBOMS as a scalable and cost-effective monitoring solution.

Dynamic contacts resistance measurement for switchgear:
10268 (IN) presents a 765 kV interrupter replacement methodology triggered by poor dynamic contact resistance measurement (DCRM) results. It eliminated transportation risks and reduced grid downtime risk.
11664 (TR) presents four case studies in which combined off-service testing such as DCRM, timing, travel, coil current profiles measurements revealed circuit breaker faults such as misaligned gear, mechanical travel gaps, intermittent closing delay, and damaged latch. A complete dismantling of the equipment has been avoided.

Q3-2: Can specialists elaborate on the main remaining obstacles to a broad application of dynamic contacts resistance measurement as a standard maintenance practice? How to remove those obstacles?

Monitoring of other equipment:

10860 (BR) presents an advanced monitoring solution for series capacitor banks (SCBs) designed to detect early-stage capacitor faults and support predictive maintenance, overcoming the limitations of traditional imbalance-current monitoring methods that only identify failures at advanced stages. The project combined testing, numerical simulations, wireless communication validation and the development of dedicated hardware, embedded software, AI algorithms and an online monitoring platform to create a smart sensor system with energy harvesting and wireless communication capabilities. By enabling early anomaly detection, failure forecasting, and optimized maintenance recommendations, the solution reduces SCB downtime, minimizes maintenance shutdowns, improves asset management and enhances the reliability and operational efficiency of transmission networks.

10269 (IN) proposes a real-time condition monitoring solution for current transformers by continuously analysing leakage current at the grounded tan δ terminal to detect insulation degradation that conventional periodic diagnostics may miss. The system uses a precision current transducer integrated with existing SCADA infrastructure to track leakage current trends, establish predictive maintenance alarms, and correlate measurements with indicators such as dissolved gas analysis (DGA) and abnormal tan δ values. By enabling early fault detection, reducing unexpected failures and secondary equipment damage, and supporting reliability-centred maintenance strategies, the approach offers a scalable and cost-effective transition from reactive to predictive asset management.

12641 (RS) presents a two-step defect detection (TSDD) method that uses video recordings and computer vision to improve the inspection of electric distribution systems and overcome the limitations of manual field inspections. The approach first detects larger infrastructure components such as poles and crossarms, then applies a second defect-detection model to the cropped regions, enabling more accurate identification of small or rare defects such as missing animal protection, open cut-outs, and floating primary lines. The study demonstrates that TSDD enhances inspection efficiency, detection accuracy, and worker safety while providing practical insights into the deployment of AI-based defect identification for utility distribution networks.

10861 (BR) develops a coupled electro-thermal model for ZnO surge arresters with porcelain and polymeric housings to support predictive maintenance using infrared thermography. Validated against high-voltage tests, the simulations reproduce non-uniform internal heating, explain housing-dependent temperature differences, and enable deeper condition assessment than surface thermography alone.

10267 (IN) proposes a method for assessing the health of EHV lightning arresters using total harmonic distortion analysis of leakage current, providing a practical indicator for condition-based evaluation and for identifying deterioration before failure develops. The method also supports a more objective approach to field maintenance planning.

11626 (KW) presents a large-scale diagnostic program for Kuwait's 11 kV distribution network using offline partial discharge (PD) testing with Damped AC (DAC) signals to proactively identify insulation degradation and reduce unplanned cable failures. Conducted between 2023 and 2024 across 11 service areas, the program tested 583 cables over 448.5 km, leading to 246 corrective actions, replacement of 133.9 km of cable and significant reductions in joint-related faults through condition-based maintenance decisions driven by PD severity analysis. The results demonstrate that DAC-based PD diagnostics provide an effective, data-driven approach for improving network reliability, optimizing maintenance resources and establishing a scalable and sustainable asset management strategy for MV cable systems.

12640 (RS) presents the advanced battery ground monitoring system (ABGMS), developed to automate the detection and management of DC battery grounds in substations and overcome the limitations of traditional manual inspection methods. The system applies the proprietary Kugler Method hourly using relays and remote terminal units generating real-time local and

SCADA alarms while storing historical resistance-to-ground data for trend analysis and correlation with external factors such as weather conditions. Pilot testing at a substation demonstrated that ABGMS provides accuracy comparable to conventional methods while improving reliability, reducing human error, and enabling faster troubleshooting and enhanced system reliability.

Q3-3 What are the main obstacles for utilities and asset manufacturers to collaborate on building standard asset health models based on product knowledge and in-service data?

Q3-4: What is the current level of using AI or other intelligent solutions for equipment analysis or failure analysis? Are there any experiences gained about the quality results based on AI modules and other intelligent systems?

Report on the use of AI for equipment design.

One report provide insight on how AI could be used to design HV equipment and optimise it for mechanical requirements.

10179 (US) presents an AI-driven approach to seismic design and validation for HV equipment, combining generative design, digital twins, and machine learning to improve seismic performance prediction, optimize designs, and reduce engineering time and costs while complying with standards such as IEEE 693 and IEC regulations. Through case studies on AIS instrument transformers and circuit breakers, it demonstrates how AI tools enhance seismic analysis, enable real-time response evaluation, and integrate into existing engineering and R&D workflows. It also highlights the importance of cross-disciplinary collaboration, digital transformation, data governance, cybersecurity, and regulatory transparency to support sustainable, efficient, and trustworthy adoption of AI in the power industry.

Q3-5: What potential does AI offer in the development of high-voltage equipment to meet the demands of the electricity grid of the future? Is it conceivable that AI could also assist with mechanical design? Can specialist give insights in whether also 'digital' testing and verification can replace physical laboratory testing in the future?

Reports on digital twin, AI, machine learning applied to asset management.

These reports discuss fundamental solutions like digital twin, IoT solutions, AI, neural network, machine learning, digitization and cover the requirements of the future grid. Distinction is made between equipment monitoring and higher-level technologies for system monitoring.

Applications for switchgear:

11956 (PY) presents a machine learning–based methodology to optimize maintenance strategies for switching equipment at the Itaipu Binacional Right Bank substation by supporting the transition from preventive to condition-based maintenance. Using historical operational, corrective, preventive, and component-status data from 500 kV and 220 kV equipment, the study evaluates long short-term memory (LSTM) neural networks and random forest (RF) models to predict failures and calculate asset health indices, with RF performing best for disconnectors and LSTM achieving superior results for circuit breakers. The findings demonstrate that AI-driven health assessment and explainable AI techniques can improve maintenance decision-making, while also highlighting the potential of future hybrid

multimodal architectures for enhanced predictive maintenance applications.
12425 (DE) presents an AI-driven real-time condition monitoring framework for circuit breakers designed to address the reduced maintenance windows caused by increasing renewable energy integration. Using EM-immune fibre-optic sensors together with electrical and environmental measurements, the system captures high-resolution vibration spectra to analyse motor timing, torque dynamics, and switching behaviour for early detection of mechanical and operational anomalies. The proposed multi-layer AI architecture combines convolutional neural network 'you-only-look-once' models, transformer-based self-supervised learning, and 'locally estimated scatterplot smoothing' trend analysis to enable fault classification, millisecond-scale anomaly detection, state-of-health estimation and scalable predictive maintenance for long-term circuit breaker reliability.
10817 (IN) explores the use of Industrial Internet of Things (IIoT) technologies in EHV substations to enable near real-time asset monitoring, predictive maintenance, and improved reliability of transmission systems. By integrating smart sensors, thermal monitoring devices, advanced diagnostics for circuit breakers, AI-driven analytics, and standardized protocols such as IEC 61850 and DNP3, the approach supports condition-based and reliability-centred maintenance strategies while reducing manual inspections, unexpected failures and maintenance costs. The study demonstrates how IIoT-based asset health models and centralized monitoring platforms enhance operational safety, grid resilience and efficiency, contributing to digital transformation toward smarter and more autonomous substations.

Applications for system related digital asset management tools:
10816 (IN) presents a data-driven predictive asset management framework for high-voltage transmission systems that combines digital twins (DTs), IoT-based condition monitoring, and physics-informed AI to address the growing operational stresses caused by decarbonization, electrification, and renewable energy integration. The proposed architecture integrates continuous multi-physics sensing, interoperable communication standards, physics-informed neural networks, and AI-based prognostic models to estimate asset health, predict remaining useful life, and support condition-based maintenance decisions across transformers, overhead lines, switchgear, GIS, and HVDC assets. Through field deployments and simulation studies, the framework demonstrates significant benefits such as increased transmission capacity, highly accurate early fault detection, improved SF_6 leakage prediction, and enhanced system-level resilience and operational planning in modern power networks.
10941 (US) presents a scalable, data-driven approach for underground transmission asset management that uses natural language processing (NLP) and machine learning (ML) to extract valuable insights from large volumes of unstructured historical maintenance and defect work-order records. By processing and classifying 17,605 underground transmission asset records into predefined categories, the developed models enable utilities to better understand asset health, reliability, and performance while supporting risk mitigation and cost-effective asset management. The study achieved strong classification accuracy and outlines future enhancements including broader utility data integration, more detailed defect classification, and incorporation into comprehensive asset management frameworks.
12191 (CO) introduces a risk-scoring system that takes operational events, neighbourhood equipment analysis, keyword extraction with natural language processing, regulatory analysis, and integrates them into a machine-learning model. Adoption of the new system and change management in the company are discussed.
11246 (IT) presents a successful application of digital transformation and collaborative asset management to improve the performance, reliability and lifecycle optimization of T&D assets in support of the global energy transition. Using a wind farm substation in Italy as a case study, the approach combines online monitoring of hybrid switchgear, cloud-based condition

monitoring platforms, and expert-driven analytics to enable predictive maintenance through continuous assessment of dielectric, mechanical, and electrical parameters. The framework demonstrates how shared operational data, remote monitoring, and scalable digital asset management strategies can reduce maintenance costs, improve power supply continuity, enhance safety and sustainability, and preserve valuable operational knowledge over time.

12487 (DE) examines how AI and digitalization are transforming the energy sector by enabling data-driven innovation in grid planning, automation, equipment control and asset management across the transmission and distribution industry. It emphasizes the need for closer collaboration between utilities, EPCs, and T&D providers through seamless data exchange, standardized digital interfaces, and technologies such as digital twins, asset administration shells (AAS), digital product passports (DPP), building information modelling, and Web of Things integration. The report also provides practical recommendations for technical standardization and interoperability, highlighting how unified digital ecosystems and enhanced data accessibility can improve AI applications, lifecycle management, regulatory processes, and cross-sector collaboration in modern power networks.

10329 (IN) follows-up, introducing the resulting unified asset performance management (APM) framework deployed: a four-layers architecture integrating data through a common platform, with structured models computing asset health, risk, and criticality indexes. AI/ML-driven maintenance scheduling has reduced transformer and reactor maintenance hours by 32% at the utility.

10271 (IN) describes the deployment of one of India's first large-scale digital twins for West Delhi integrating geographic information, metering, sensors, drone imagery, and outage data. Field results show a reduction in restoration time and a transformer failure rate reduced to zero over two quarters, with cybersecurity and data governance identified as the principal scaling barriers.

Q3-6: What level of data quality is required to obtain meaningful insights for strategic decisions regarding the network? How can data quality be influenced and ensured? Is the use of AI solutions a sensible approach?

Reports on monitoring SF_6 emissions:

11832 (NO) presents a digital monitoring solution for SF_6 in GIS to reduce greenhouse gas emissions through centralized, near real-time monitoring of SF_6 pressure data from GIS stations. The web-based dashboard replaces manual inspection processes by providing historical and live insights, while the study highlights the importance of user adoption, data quality assurance, proactive support, and dedicated data stewardship to ensure long-term operational success. The report also identifies key maturity factors in product capability, organizational processes, and ownership structures, emphasizing that continuous digital monitoring will become increasingly critical as GIS technologies evolve toward higher operating pressures and SF_6-free alternatives.

12202 (PE) presents a predictive monitoring project for early SF_6 leak detection in GIS substations, focusing on 220 kV substations where leak risks are particularly high. Using hourly measurements of gas pressure, density, and temperature, two predictive models were developed: a production-ready linear regression model that detects sustained negative density trends, and a 'temporal fusion transformer' (TFT)' deep-learning model that forecasts density deviations and identifies persistent anomalies linked to leaks. The approach significantly reduces leak detection time compared to conventional densimeters, minimizes SF_6 emissions caused by delayed detection, and demonstrates the value of AI-driven analytics for improving environmental performance and reliability in GIS substations.

10354 (AU) develops a data-driven business case for SF_6 circuit breaker online gas

monitoring using historical top-up data, Weibull failure modelling, and long-range wide area network communication. It quantifies emission reductions, monetizes environmental benefits with vale of emissions reduction, and shows that early leak detection and shorter repair times improve both sustainability and cost-effectiveness.

Q3-7 What is the tendency to integrate and actively use assistance tools like AI, digital twins, or data digitisation, cloud solutions to be used on the manufacturing side, and also at the utilities? What is missing from the international standardisation point of view?

Reports on reliability and asset failures.

10653 (IN) investigates a lightning-induced interrupter failure where a timing discrepancy between two independent double-arc chamber mechanisms amplified dielectric stress under re-strike conditions. Recommendations include tighter type-test specifications for successive fault interruption.
11149 (GB) identifies crevice corrosion at bolted flange interfaces as the primary mechanism causing premature gas seal failure in GIS and AIS equipment a few years after commissioning. A new corrosion protection specification is proposed alongside a meteorological corrosion map developed with the UK Met Office.
12091 (HR) presents a comparative analysis of SF_6 acceptance testing and maintenance strategies across two TSOs, revealing that a 2020 seismic event caused the sudden release of 144 kg of SF_6. A coordinated 20-year SF_6 transition roadmap, from medium-voltage pilots to systematic HV equipment phase out, is presented.
12027 (RU) analyses the reliability and maintenance of gas-insulated switchgear (GIS) and finds that circuit breakers interrupt fault currents well below their rated capacity, meaning neither switching nor mechanical lifetimes will be exhausted over a 30-50-year service life. Two incident investigations revealed that most failures come from installation defects and manufacturing flaws rather than ageing, occurring within the first 2-4 years of operation rather than the expected 15-20-year period. The authors recommend transitioning to condition-based maintenance using partial discharge monitoring and SF_6 decomposition analysis.
10274 (IN) documents five project execution challenges in deploying large HVAC substations: inter-connection transformers installation, electrical clearances on split-level terrain, recovery from a GIS fire in one week using heat-shrink sleeves, a 132 kV disconnector flashover producing a false SCADA earthing-switch position indication, and an ultra-high voltage cable laying under severe space constraints in hydropower underground galleries.
12128 (CO) investigates recurring SF_6 circuit breaker failures, systematically ruling out gas degradation, mechanical wear, and contact erosion as root causes. The confirmed cause was significant current chopping during parallel switching in the breaker-and-a-half configuration, generating excessive transient recovery voltages that triggered restrikes, validated through simulations. Controlled switching and grading capacitors are identified as solutions for future projects.
10259 (IN) investigates premature failures of 765 kV circuit breaker grading capacitors in the Indian power grid, where conventional diagnostic methods based on 50 Hz capacitance and tan δ measurements often fail to detect early dielectric degradation. To overcome these limitations, around 300 grading capacitors underwent advanced diagnostic testing, including variable-voltage analysis, narrow-band frequency testing, and time-dependent measurements, revealing that defective units exhibit clear voltage-, frequency-, and time-dependent anomalies linked to interfacial insulation deterioration. The study demonstrates that

multifactor diagnostic evaluation significantly improves the detection of latent dielectric defects, enabling earlier maintenance intervention and reducing the risk of catastrophic capacitor failures.
10328 (IN) describes a flashover that occurred in a 400 kV GIS compartment because an equalizing pipe valve had been left closed since commissioning, isolating an end compartment that had no independent gas density monitor. An undetected SF_6 leak gradually reduced dielectric strength of the compartment until failure. Damaged components were replaced, and the authors recommend mandatory valve position verification during commissioning and retrofitting gas density monitors on all compartments, including terminal sections, to eliminate blind spots.
11736 (SE) reports 25 years of Nordic utility experience with disconnecting circuit breakers (DCBs), showing improved reliability and lower maintenance compared with conventional disconnectors. DCBs achieved 0.152 major failures per 100 CB-years, improved availability, reduced substation complexity and costs, and supported broader deployment in transmission and distribution substations.
12556 (IE) quantifies how automated reclosers improve supply continuity in Ireland's rural medium-voltage networks. Using customer interruptions (CI) and customer hours lost (CHL) before-and-after analysis, it shows reliability gains on overhead, single-phase feeders exposed to weather, vegetation, wildlife, and phase imbalance. Integrated SCADA/NMS automation reduced outages and costs without expensive undergrounding.
10649 (IN) documents a full ISO55001 transformation, delivering measurable KPI improvements such as improved system availability, reduction of mis-operation rate, reduction of lost time injury frequency rate, and increase of renewables adoption for auxiliaries.

Q3-8: This topic highlights asset life-cycle thinking in SC A3, where monitoring, field experience, deterioration management, and maintenance strategy are used to extend service life and improve reliability and resilience. How are utilities integrating monitoring data, digital twins, and asset performance management into life-cycle decision-making, and what challenges remain in achieving reliable asset-based maintenance? To what extent can condition monitoring and diagnostics be performed without service interruption, and what are the practical limits of non-intrusive sensing and remote assessment?

Group 4. Instrument transformers.

This group contains fourteen reports, all focusing on instrument transformers technologies and relevant technologies, applications and challenges.
In particular, three contributions are relevant to PS1, 9 contributions to PS2 and 2 contributions to PS 3. LPITs (low-power instrument transformers) are considered by 10 contributions, inductive instrument transformers by 7. About field of application, 9 contributions are relevant to transmission and 8 to distribution (3 contributions cover both). Behaviour characterisation and development of advanced models are presented in 6 contributions, on-site calibration and cybersecurity aspects are also considered.

10212 (FR) examines how low-power instrument transformers (LPITs) support the transition toward compact, digital, and more sustainable substations, especially for offshore wind applications. Drawing on nearly 20 years of operational experience with a 245 kV GIS pilot installation, it highlights LPIT advantages in terms of reduced size and weight, improved

safety, digital interoperability, long-term measurement stability, and lower environmental impact compared with conventional instrument transformers.
10265 (IN) describes how LPITs and IEC 61850-9-2 process bus technologies are transforming substations into safer, more efficient, and digitally connected systems. Based on experience in India, it reviews pilot and full-scale deployments, compares LPITs with conventional transformers, and highlights gains in accuracy, reliability, space, weight, and costs. It also discusses implementation challenges, calibration practices, and cybersecurity measures managed by a security operation centre.
11975 (KR) investigates the long-term reliability of a spacer-type LPIT designed for compact GIS digital substations. By integrating Rogowski-coil current sensing and capacitive voltage measurement directly into the GIS spacer, the prototype reduces size, cabling, and material use while supporting maintenance-free operation. Tests confirmed compliance with IEC 61869 and IEC 62271-203, including accuracy, insulation, thermal, vibration, and long-term overvoltage endurance, demonstrating reliable operation over its expected service life.

Q4-1: Can users share other long-term experience of use of LPITs, both at transmission and distribution level? What is the feedback from utilities, in terms of accuracy performance, stability and reliability?

11999 (AT) presents a computationally efficient control-oriented model for ferromagnetic transformer cores, aimed mainly at current transformer (CT) transient analysis and protection-system validation. It combines numerical robustness with reduced computational effort, while still representing saturation, hysteresis, and eddy-current losses. The work also proposes an automated parameter-identification procedure based on standard transformer tests and optimization and shows that the model can accurately reproduce distorted currents, harmonics, and inrush phenomena.
11497 (CN) presents an active on-site calibration method for current transformers based on background current modulation, enabling calibration from 1% to 120% of rated current without interrupting service. Using a reference clamp-on CT, a programmable power source, and real-time digital control, the method adjusts primary current conditions and measures ratio and phase errors in service. Experimental results show close agreement with off-line calibration, with differences below 0.01% in ratio error and 1′ in phase error, satisfying 0.2 class requirements.
11155 (ZA) analyses test signals for determining the frequency response of voltage measurement systems, including conventional VTs and LPVTs, under the new wideband classes of IEC 61869-1:2023. It compares six excitation methods in the time and frequency domains—sinusoidal sweep, superimposed sinusoidal signals, impulse, band-limited white noise, PRBS, and PRIS—highlighting their precision, bandwidth, testing time, and practical suitability. The study provides guidance for selecting the most effective signal according to application, setup, and required accuracy.
12001 (AT) investigates on-site sweep frequency response analysis (SFRA) of medium-voltage LPVTs and VTs for metering applications, with particular focus on the effect of test voltage level. It compares conventional VTs, frequency-optimized VTs, and LPVTs under different excitation voltages and installation conditions. Results show that VTs exhibit some voltage dependency due to iron-core nonlinearity, especially at low frequencies, whereas LPVTs show only minor dependence. The study also highlights the influence of switchgear stray capacitances on LPVT frequency response.

Q4-2: Which impact is expected from the development of more and more advanced models and characterisation methods for instrument transformers? Are practical examples of

tangible benefits available in the users' experience?

12112 (CO) examines how digital substations and IEC 61850 process bus architectures affect the specification and connection of instrument transformers. Focusing on conventional CTs and VTs, it shows that digitalization reduces the number of CT cores, copper cabling, and transformer burden, while also improving transient performance and lowering the risk of saturation. The study further highlights reductions in control and protection panels, leading to lower CAPEX/OPEX and more efficient, flexible, and reliable substation operation.
12375 (CZ) reviews a decade of smart medium-voltage switchgear development based on LPITs and IEC 61850 communication. It shows how rogowski coils and voltage dividers, combined with process bus architectures, improve measurement accuracy, reliability, safety, and compactness while reducing wiring, footprint, and energy losses. The report also highlights progress in revenue metering, wider IED compatibility, and busbar differential protection, confirming LPIT-based digital MV switchgear as a mature and sustainable solution for modern power distribution.
11417 (SE) discusses the growing use of rogowski coils as low-power current transformers (LPCTs) in medium-voltage switchgear. It highlights their compactness, low weight, safety, wide linear range, and immunity to saturation compared with conventional CTs. The study focuses on the challenges they introduce for protection relays and relay testing, since the output is proportional to the derivative of current rather than the current itself. It also explains how LPCTs support IEC 61850 process bus architectures and fit within the evolving IEC standardization framework.
10867 (BR) presents the TECO optical current transformer, a self-monitoring optical current transformer for digital substations. By combining Faraday-effect optical sensing, rogowski-coil cross-validation, and IEC 61850/MMS-based diagnostics, it enables continuous condition monitoring, early fault detection, and predictive maintenance. The study shows how this approach improves grid reliability, reduces operational risk and field interventions, extends asset life, and supports sustainability through lower material use, elimination of oil insulation, and better lifecycle management.

Q4-3: Some time ago, digitalisation impact seemed to be mostly limited to transmission applications, a significant number of contributions is now relevant to distribution applications. Which are the present trends in terms of spread of digital applications versus the analogue ones, both at transmission and distribution level? Which are the expectations for the next future? Which are the major constraints and concerns slowing down the digitalisation process, with particular reference to instrument transformers applications?

12249 (CH) reviews the use of LPITs for power quality PQ) metering in transmission grids, with particular focus on digital sampled-value interfaces. It highlights LPIT advantages such as multifunctionality, flexible installation, and bandwidth suitable for PQ applications, but also notes that adoption is limited by the slow emergence of PQ meters with digital inputs. The study identifies key gaps in current standards, especially on sample rates, bandwidth classes, phase-error definitions, and full measurement-chain accuracy, and proposes directions for improvement.
12372 (CZ) evaluates the sustainability impact of low-power instrument transformers (LPITs) in medium-voltage gas-insulated switchgear (MV GIS) through a cradle-to-grave life cycle assessment (LCA). Comparing LPIT-based and conventional instrument-transformer configurations, it shows that LPITs significantly reduce material use, weight, thermal losses, and overall CO_2 emissions, with total global warming potential reduced by about 22–27%. The results confirm LPITs as an effective solution for more sustainable, digitally enabled MV

switchgear.
11361 (ES) evaluates biodegradable insulating fluids for high-voltage current transformers, comparing two new hydrocarbon-based fluids and a synthetic ester with conventional mineral oil. Through material compatibility tests, mock-ups, and full-scale 145 kV and 420 kV prototypes, it shows that the hydrocarbon-based fluid is technically feasible with performance close to mineral oil, while synthetic ester raises concerns over viscosity, dielectric losses, and long-term thermal stability. The study also finds the hydrocarbon-based fluid environmentally preferable in the life cycle assessment.

A few words about Session Papers (or 'reports')

Session papers focussed on a number of subjects – referred to as 'Preferential Subjects' – selected in advance by the 16 study committees of CIGRE and available in the Call for Papers.
Session papers are selected through a two-phase review process – synopses and full papers.
Have a look at the Technical Programme - the list of selected papers for the session, and so have an overview of subjects that will be discussed.

The specificity of CIGRE Sessions

At CIGRE sessions authors are given the opportunity to present their paper during half-day specific meetings – the poster sessions.
Four days are also dedicated to 'Group Discussion Meetings' organised by study committees. Four meetings run simultaneously each day from Tuesday to Friday, under the presidency of the study committee chairs. The purpose of these meetings is the discussion of the session papers on the basis of "special reports" which incorporate the gist of the session papers and raise a number of questions for discussion.
The special reports are available to all on free access – From June 1 - on the CIGRE website, on the Session page.
For fruitful discussions delegates are strongly encouraged to read the papers before the Session.
The set of session papers is made available for downloading to all duly registered delegates before the session through their private account on the registrations portal. Papers are also readable on the session smartphones application on site in Paris.
Follow our session latest news and general programme - by regularly visiting our website

SC A3 Paris session activities summarized (locations to be decided):

Monday	Aug. 24	08:30-12:30	Poster session
Monday	Aug. 24	10:00-15:00	Meeting of prepared contributors, room #235
Tuesday	Aug. 25	08:30-10:30	Workshop on SF_6 replacement and its alternatives
Tuesday	Aug. 25	10:30-12:30	Workshop on digitalisation
Wednesday	Aug. 26	08:45-18:00	Group discussion meeting, salle Bleue
Thursday	Aug. 27	10:40-12:30	Tutorial on instrument transformers

PARTICIPATING IN THE 2026 PARIS GROUP DISCUSSION MEETING AND POSTER SESSION.

You are invited to participate in discussing this Special Report at the SC A3 Group Discussion Meeting (GDM) held on Wednesday August 26 starting at 08:45 in salle Bleue at the Palais des Congrès de Paris.
The reporters have compiled up to 20 questions, these are not specifically aimed at the reports' authors, but are synthesised from common issues and trends identified in across the reports. This provides the opportunity for a broader response and participation in the discussion session.
We encourage you to share your views or experiences in response to the specific questions in this report. During the Group Discussion Meeting, each prepared contribution will be allocated a time slot of three to four minutes for a presentation.

Procedure for contributions in the Group Discussion Meeting.

1. Contributors should upload contributions on the registrations portal – "Contributions to Group Discussion Meetings" section - using your existing account and own credentials before August 7, for a prior screening and a good organization of the Group Discussion Meeting. Important points:
2. Access to contribution uploading is given only to duly registered delegates.
   - Registration to CIGRE Group Discussion Meeting (GDM) should be finalized before uploading contribution(s) online.
   - Register now for the GDM
   - Prepared contributions uploading will be open at start of June.
3. Special reporters will review the prepared contributions (Power point presentation with max 3 slides and a written word file with max 1000 words per contribution). A guide for contributors as well as templates and sample pages will be available on the Paris Session webpage. Important notice: No commercial names are to be included in presentation or the written summary (even TSO/DSO names).
4. Any recommendations or changes to the contributions will be provided to the contributors by the special reporters directly on the registration platform between 7th of August and 14th of August 2026. Contributors are encouraged to visit their account on the registrations portal to see the result of this review.
5. All contributors with accepted/finalised contributions will be contacted by the special reporters between August 7 and August 14, to finalize the presentation and receive the instructions regarding the session.
6. Important note:
   - All contributions must be uploaded prior to the conference in Paris.
   - Last minute changes to the contributions will not be granted.
7. During the GDM the study committee chair may call for spontaneous contributions, which will only be verbal with no slides. All attendees are eligible to make such a contribution. Attendees who provide a spontaneous contribution are allowed to deliver a written contribution which will be included in the session proceedings. This text is required to be forwarded within a maximum delay of two weeks after the study committee GDM Session (i.e. by date) to the SC secretaries (paolo.mazza@rse-web.it or Frank.Richter@50hertz.com).
8. It is expected that the special reporters' questions will attract many prepared

contributions. Therefore, the number of contributions will be limited. The selection will be based on relevance, quality and time of submission of the contribution.

9. Please note that accepted prepared contributors will be required to attend a short pre-session meeting with the special reporters, SC chair and SC secretaries on Monday August 24. You can meet them at 10:00-15:00 in the Palais des Congrès (room #235) to finalise presentation arrangements. The purpose of this short meeting is to confirm presence of the presenter, review final details of their contribution and to receive the latest instructions (such as schedule).

Procedure for poster presentation.

Authors of SC A3 session reports are required to present their work by a poster during the SC A3 poster session scheduled on Monday August 24, 8:30-12:30 in Halle Ternes on level 1. Template and instructions on poster preparation are available on the CIGRE 2026 Session website. Posters will be displayed on digital screens. Poster presentations must be uploaded on the ConfTool platform from May 18 to June 29 for review by the poster session convener (branislav.pilat@sepsas.sk, alaso@gewelec.com, matthew.iles@nationalgrid.com). Poster conveners may ask for a final version, incorporating any requested changes, must be uploaded by August 14 should be noted that authors will not have the possibility to upload their own file on the day of the poster session. If the author(s) cannot attend the Poster Session he/she or the relevant national committee is requested to send a substitute.

Looking forward meeting you in Paris!