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SPECIAL REPORT FOR SC A1: POWER GENERATION AND ELECTROMECHANICAL ENERGY CONVERSION

Special Reporters

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INTRODUCTION

In 2024 the SC changed its name from “Rotating Electrical Machines” to “Power generation and electromechanical energy conversion” to better serve the evolving landscape driven by the energy transition.

The SC covers the full equipment lifecycle from research, development, design, manufacture and testing of power generation and electromechanical energy conversion equipment and their associated auxiliaries, through to commissioning, operation, condition assessment, maintenance, life extension, refurbishment, upgrades, efficiency improvement, conversion (e.g. from power generation duty to synchronous condenser/compensator duty), storage, and de-commissioning.

Within these fields, SCA1 promotes the international exchange of information, knowledge, practice, and experience, and adds value by synthesizing state-of-the-art practices to develop guidelines and recommendations.

For the 2024 Group Discussion Session, three preferential subjects were proposed to stimulate discussion considering the strategic directions:

• PS1 - Rotating Electrical Machines and the Energy Transition

• PS2 - Evolution and Development

• PS3 - Keeping the Lights On

A total of 29 papers have been accepted and published; the content of each is summarised below.

The Special Reporters have compiled 25 questions synthesised from common issues and trends identified in the accepted papers. This provides the basis for a broader discussion and participation in the SC A1 Group Discussion Meeting (GDM) to be held during the CIGRE Paris Session on Wednesday 28th August in the Palais de Congress.

We encourage you to share your views and experiences in this unique CIGRE environment.

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1. Preferential Subject 1: Rotating Electrical Machines and the Energy Transition

The preferential subject covers:

- Impact of the energy transition on the role, duty, and flexible operation of rotating electrical machines,
- Changing requirements on rotating machines to support the evolution of smart grids,
- Update of international standards for electrical machine requirements to reflect future applications.

Nine papers were accepted under PS1, but for the purposes of continuity within the Special Report, some were reassigned to a more appropriate PS. Therefore, **six papers** are summarised and discussed below related to the theme of PS1.

1.1 PS1 Paper Summaries

Paper 10306 (France): The benefits of nuclear turbogenerators for grids of the future

This paper states that, while wind and solar power play an important role in the global strategy to de-carbonise electricity production, a minimum amount of electricity generated from conventional thermal and nuclear power generation remains necessary to ensure grid stability, security of supply and prevent power failures and blackouts.

The contribution of nuclear power in the future energy mix for France is highlighted as a key asset to ensure the feasibility of targets related to CO2 emission reductions involving a significant increase in renewable generation. The featured benefits are flexible and dispatchable energy with strong grid frequency support capabilities, high reactive power capability, high inertia required to ensure grid frequency stability, and high short-circuit power needed to ensure grid voltage stability and strong capacity for grid restoration.

The main performance parameters related to grid support are presented for a typical nuclear turbogenerator and compared with those of other technologies providing grid services such as smaller turbogenerators, synchronous condensers with flywheel, and battery storage systems (BESS).

Paper 10542 (Spain): Damping local and inter-area oscillations with synchronous compensators: a fundamental study

Recent events in the European power system has shown that there is a concern with power system security with the risk of poorly damped inter-area oscillations.as a result of increased penetration of inverter-based generation in power systems.

This paper describes a fundamental study on the contributions of synchronous compensators (SC) with or without a Power System Stabilizer (PSS) to the damping of local and inter-area oscillations using eigenvalue analysis of three simplified small signal power system models:

(1) SC connected to an infinite bus; shows that the electromechanical oscillation of the synchronous compensator cannot be affected by a PSS,

(2) SC, in parallel with a generator, connected to an infinite bus; confirms that, although the joint electromechanical oscillation of both synchronous machines against the infinite grid can be damped by installing a PSS in the synchronous compensator, the most effective location of the PSS is in the synchronous generator,

(3) SC in the presence of inverter-based generation; shows that the impact of SCs in the damping of inter-area oscillations in the presence of inverter-based generation is improved when equipped with a PSS.

<u>Paper 10692 (Brazil):</u> Insights to the new IEC 60034-33 – The Standard for Hydro-Generators and Motor-Generators for Pumped Storage

This paper introduces the new standard IEC60034-33 "Synchronous hydro-generators including motor-generators – Specific requirements" which has been developed to fill an important gap in the scope of the IEC standards, namely, the absence of a specific international standard for hydro-generators and motor generators used in pumped storage power plants.

The paper addresses the main aspects contained in this standard with regard to specification requirements, design, and operational limits, as well as some tests and quality parameters for the stator and rotor windings.

<u>Paper 10904 (Ireland):</u> Moneypoint Synchronous Condenser and Flywheel - A Zero Carbon Solution to Increasing Renewables and Improving Resilience on the Irish Electricity Grid

This paper describes Ireland's first combined synchronous condenser and flywheel plant which, in response to EirGrid's DS3 programme, will be paid for providing two products to the grid that previously would have been provided by conventional thermal plant – synchronous inertia response (SIR) and steady state reactive power (SSRP). This is necessary to address the increasing risk of power system instability at times of elevated levels of system non-synchronous penetration (SNSP) resulting from the significant rise in the installation of intermittent renewable generation such as wind and solar.

The paper discusses synchronous condenser and flywheel technology and explains why the inertia and reactive power values were selected. Specific adaptions of the plant design to meet the existing site constraints and Grid Code compliance requirements for the Irish Grid are detailed. The challenges of a shared grid connection with an existing operational thermal unit are also discussed.

<u>Paper 11031 (Germany):</u> Practical Experience with the Thermal Evaluation and Classification of Type II Machine Insulation Systems according to IEC 60034-18-31

The principal contribution of this paper is to provide input for the ongoing revision of IEC 60034-18-31 that concerns the thermal qualification of rotating machine insulation systems. The points raised by the authors are derived from actual tests on insulation systems conducted as per the current version of 60034-18-31. This IEC standard is quite fundamental for the design and manufacture of rotating machines.

The results of the study are timely and important. A substitute for anhydrides used in insulation production is expected to be needed in the future and the insulation systems with these substitutes will need to be qualified.

<u>Paper 11102 (India):</u> Synchronous Condenser to Ensure Stable, Reliable and Quality Power in Renewable Energy Rich Regions – India Perspective

The paper presents an interesting comparison of different technical solutions that could be applied to improve power system stability in regions of the Indian network operating with a high share of renewable generation.

The main advantages and disadvantages of synchronous condensers, synchronous static compensators (STATCOM) and battery energy storage systems (BESS) are outlined for frequency and voltage events in the power system with the aim of maintaining stability.

1.2 PS1 Discussion

The energy transition from fossil-based power generation sources to renewable energy (RE) sources is well underway with many countries switching to predominantly wind and solar power. Some, but not all, countries are retaining nuclear power generation where necessary, but the overall global trend is to reduce dependence on coal-fired power plant.

Natural gas power plant have not been so dramatically affected since they are seen as potentially less environmentally impacting than coal plant, are better suited to intermittent operation to ensure continuity of power supply, can be easily integrated in hybrid power schemes, and the gas turbines themselves can be adapted to burn various percentages of hydrogen instead of natural gas with the prospect of burning green hydrogen as proposed in some renewable energy production, storage and power generation schemes.

Nuclear power stations are categorised as 'clean' energy since they produce less CO_2 emissions but do have other challenges related to the handling of the fuel, processing, long term storage of spent fuel, and decommissioning of the plant.

The closure of large coal-fired plant, combined with the intermittency and operational capability of RE sources, has led to grid issues related to reduced inertia for frequency stability, Mvar control for voltage stability, short circuit power capability in case of system faults, and continuity of power supply.

The high penetration of RE into country power grids has forced many grid codes to put increased demands on both existing and new power generation equipment and large motors, particularly regarding Rate of Change of Frequency (RoCoF), and wider voltage and frequency ranges for normal and transient operation.

Paper 10306 (France) describes how nuclear power generation plant can be used to address some of these issues, whilst paper 10542 (Spain) explains how synchronous condensers with PSS can be applied to damp grid inter-area oscillations in the presence of inverter-based generation. Paper 11102 (India) gives a broader overview of the advantages and disadvantages of installing synchronous condensers compared to alternative means of controlling reactive power while paper 10904 (Ireland) presents a practical example of the choice and sizing of a synchronous condenser installation with flywheel as an extension to an existing power plant.

The changing operation environment impacts equipment specification, design, and performance. International standards traditionally applied to control the quality and performance of equipment for defined duties need to be adapted to reflect the current and evolving needs resulting from the energy transition. Paper 10692 (Brazil) gives an insight into the new IEC 60034-33 related to hydro-generators and motor-generators for pumped storage. Paper 11031 (Germany) describes practical experience with the thermal evaluation and classification of machine insulation systems according to IEC 60034-18-31 which is presently under revision.

1.3 PS1 Questions

PS1-Q1:
Paper 10306 refers to a revival of nuclear power generation and highlights how large rotating units can complement and support the increased introduction of renewable energy sources. However, the current buzz around nuclear power plant refers to the use of Small Modular Reactors (SMR) which individually contribute less to system support due to their smaller size. In those countries still pursuing nuclear power for electricity generation, what is the policy

regarding new / existing plant (large units or SMR) and what is driving that policy, reduced CO_2 emissions, enhanced grid support capabilities, cost, build-timescale, or other factors?

PS1-Q2:
Environmental concerns regarding power plant CO_2 emissions are the main factors driving the overall energy transition, but studies have and are being conducted to assess and quantify the CO_2 impact of the whole manufacturing, operational and decommissioning lifecycle, including raw material processing (ref. paper 10306 and WG A1.76). As the energy transition and environmental concerns continue to gain momentum, to what extent are these concerns likely to impact equipment specifications, manufacturing processes and material/component sourcing strategies?

PS1-Q3:
Synchronous Compensators/Condensers are being widely applied in many countries to address grid issues resulting from the significant introduction of renewable, invertor based energy sources. Power System Stabilisers (PSS) are not normally considered for such installations, but the study in paper 10542 indicates potential advantages in damping inter-area oscillations. Have PSSs been considered in the many SC equipment installed and, if so, with what outcome? Could the addition of a PSS bring additional benefit?

PS1-Q4:
The high level of invertor-based resources in a grid with conventional machines could directly impact the machine performance due to the additional heating caused by the increased level of time-harmonics. Has this aspect been considered and/or quantified in any of the mixed generation studies carried out so far, and has this required adaptation of machine design?

PS1-Q5:
Two international standards have been the topic of two of the submitted papers, but other international standards define basic rotating machine performance, IEC60034-1, IEC60034-3 and other others. Whilst recent updates have included synchronous compensators to a limited extent, which further topics, and to what depth, need to be included to keep their relevance with the needs of the energy transition? e.g., Rate-of-Change-of-Frequency (RoCoF), voltage and frequency continuous and transient operating bands, load duty definition, inertia, short circuit capability, and greater details reading synchronous condenser design, operation and performance considerations.

2. Preferential Subject 2: Evolution and Development

The preferential subject covers:

- Developments in the design of generators for new applications such as wind turbine, synchronous compensators, and variable speed pump-storage,
- Improvements in design, manufacture, efficiency, insulation, cooling, bearings, and materials,
- Enhancements in the performance, reliability, and control of rotating electrical machines,
- Design evolution of rotating electrical machines based on operational experience.

Eight papers were accepted under PS2, but for the purposes of continuity within the Special Report, some were reassigned to a more appropriate PS. Therefore, **seven papers** are summarised and discussed below related to the theme of PS2.

2.1 PS2 Paper Summaries

Paper 10693 (Brazil): On the Design of Salient Pole Synchronous Machine to Operate Strictly as Synchronous Condensers

This paper discusses the increase in demand and requirement of synchronous condensers for reactive power management on transmission systems globally. The driver being the change in the energy mix with low inertia generation and the construction of HVDC links. The paper presents a number of considerations for such applications and highlights several specific benefits provided by the inclusion of synchronous compensators for grid stabilisation.

The authors have presented design specification requirements for the sizing of salient pole synchronous generators to meet network requirements for reactive capability at the HV side (500 kV) of the transformer. The paper highlights the benefits of utilising negative excitation current to increase the underexcited reactive range of machines without increasing the physical size. This could aid in meeting the ever more competitive transmission requirements globally.

Paper 10864 (Japan): Retrofit to 2 x 303MW Doubly-Fed Asynchronous Machine (DFAM) System at Oku-Tataragi Pumped Hydro Power Plant

The paper presents the conversion to a doubly fed asynchronous excitation machine during the retrofit of a pump storage generating station. The authors work, to improve the performance of low frequency ride-through requirements by incorporating magnetic saturation of the machine and other improvements in mathematical modelling, has been well detailed. The paper discusses their approach, validation by measurement, and the benefits of the various operating modes the machine provides.

The authors highlight that, from their research, it may be more beneficial to use the synchronous mode of the machine at lower speed ranges for pumping or generating modes, subject to improving the low frequency ride-through characteristics and further modelling.

Paper 11020 (Germany): Development and design of an air-cooled 944.5 MVA hydro-generator

The paper describes the electromagnetic, mechanical and thermal calculation for the 944.5 MVA air-cooled generators, which were the largest ever commissioned in the world in terms

of unit capacity at the time. The design of large machines takes careful consideration of the design aspects and requirements set by the project. The paper takes the reader through the design process and presents the type test results as validation of the design.

Paper 11022 (Germany): Qualification of a HV-Insulation System according IEC 60034-18-42 for a Hydro-generator Operating with Inverter Technology

The paper describes the qualification of insulation systems following IEC 60034-18-42 of the stator subject to impulse high voltage transients associated with inverters. The authors discuss two options, inverted stator output or doubly fed induction machines. It is highlighted that the electrical stresses that these technologies place on the stator winding slot armour and stress grading is significantly different compared to synchronous machines, in particular to hot spot temperatures. It is highlighted that sufficient investigations are required when performing qualification testing. The stress grading of machines with inverters behaves in a different manner to synchronous machines under sinusoidal voltage, such that it requires consideration at the design and manufacturing stage.

Paper 11171 (Austria): Design Aspects of Synchronous Condensers

The authors have evaluated a range of design aspects of synchronous condensers and have presented practical information for the benefit of the reader. The paper discusses a number of design and specification areas in detail and highlights differences between salient pole and cylindrical rotor machines regarding leading Mvar capability and stability limits for similarly sized units. It also highlights the different method of presenting the reactive power capability against the voltage at the point of common connection (Q-V diagram) compared to the traditional P-Q diagram used for machines with significant active power output.

Paper 11362 (Hungary): Development of Engine Mounted Generators for Eco-Friendly Onboard Power Generation in Marine Applications

The paper describes the development of a generator mounted directly to a large marine diesel engine. The paper discuss the benefits this presents and describes the development of this generator. The inertia of the rotor was matched to replace the flywheel which would have normally been included on the engine. Apart from the more compact design, it is claimed that the solution developed provides 4-5% emissions savings compared to separate diesel generator sets, which has been the more typical set up, as well as reducing fuel consumption.

Paper 11394 (Germany): Design individualization of an air-cooled synchronous condenser with directly water-cooled stator winding due to varying market requirements for grid stabilization services

The paper describes the considerations required under various market requirements globally for grid stabilisation services. Depending on the required services, short circuit power, inertia or reactive power, the configuring of the synchronous condenser can be adjusted which can result in less auxiliaries providing cost optimisation for the project. The technical impacts of the highlighted services is discussed, and the optimisation of the synchronous condenser is presented for each required service.

2.2 PS2 Discussion

The papers this year provide detailed technical analysis of their chosen submissions. The knowledge and the depth of the papers is commendable and each one warrants thorough

reading, which can be used by the community to inform their decisions on these topics in the future.

The transition towards low and carbon-free energy systems is in focus for most transmission system operators and power producers worldwide. The evolution of synchronous condensers to meet the demand of transmission networks with higher renewables penetration and lower inertia presents a number of challenges for operators and manufacturers. There are underlying themes throughout the presentations:

- Enabling and facilitating low carbon solutions to penetrate power generation networks. Efficiency savings (and associated carbon emissions) for existing solutions
- Varying requirements across the global transmission systems for ancillary services. This presents challenges as one standard offering of machine may not be suitable in certain markets and/or for specific ancillary services.
- The change in operation of machines or upgrades, such as retrofitting machines with non-synchronous inverter systems has been described in multiple submissions. Not only does this present challenges for the manufacturer, but the operator and the transmission system operator requires sufficient and detailed modelling to validate the stability of such systems.
- The use of salient pole generators for synchronous condensers has been raised in a number of contributions. These papers present their technical analysis and describes the benefits these machines provide for this application
- Negative excitation current to increase the under excited reactive range has been raised within the community in recent years at the Paris sessions. This presents potential cost saving in that the physical dimensions (and cost) of the machine do not necessarily need to be increased to achieve the wider reactive power range.

2.3 PS2 Questions

PS2-Q1:
Machines equipped with negative excitation on synchronous compensators and generators have been presented and enable the increase in the underexcited reactive range of machines, without physically increasing the size of the machines. To what extent have the wider community experience with such systems?

PS2-Q2:
Is there a perceived need for excitation systems to be enabled to provide negative excitation, and to what extent is the supply market ready? Are solutions readily available?

PS2-Q3:
Doubly fed induction machines are well established and utilised in wind turbine installations worldwide. Stator failure rates at some utilities are high on such wind turbine machines.
With respect to the thorough qualification of stator windings, what is the communities experience with the reliability of doubly fed induction machines in such installations?

PS2-Q4:
Considering the findings reported in paper 11022, what is the experience of others with the qualification/testing requirements for windings of doubly fed induction machines and inverter fed stators?

PS2-Q5:
In the use of synchronous condensers paper 11171, it discusses the reactive power capability chart (Q-V diagram). To what extent is this chart used by the community and do the Transmission Operators accept these in all countries? Are there other methods in use?

PS2-Q6
Papers 11171 and 10693 highlight benefits in leading Mvar operation when choosing salient pole synchronous machines over cylindrical rotor machines for synchronous condenser applications for a specific unit sizing. Have these factors ever been the differentiator when choosing synchronous condenser types in a power range where both would be available, or do other factors dominate the final choice? Which other factors are usually the main drivers of design choice of synchronous condensers?

PS2-Q7:
Paper 11362 declares 4-5% reduction in emissions and 1-2% fuel reduction when applying an engine mounted generator on a marine power plant resulting from the optimised overall generation configuration. How have these savings been evaluated, and do other OEMs in this field see similar potential for this configuration? What are the drawbacks of mounting the generator on the engine, e.g. maintenance access and outage time?

3. Preferential Subject 3: Keeping the Lights On

The preferential subject covers:

- Condition monitoring, diagnosis, prognosis of rotating electrical machines including the use of artificial intelligence, deep learning techniques and digital twin concepts,
- Ensuring power supply reliability by asset management of installed base and maintenance practices,
- Improving performance and extending operational service life of installed base through refurbishment, replacement, and power up-rating, and methodologies to establish the sequence of machines to be refurbished/replaced.

Twelve papers were accepted under PS3, but for the purposes of continuity within the Special Report, some were reassigned to a more appropriate PS. Therefore, **sixteen papers** are summarised and discussed below related to the theme of PS3.

3.1 PS3 Paper Summaries

Paper 10123 (France): Rotating diode rectifier, machine, diode failure, frequency, digital signal processor

The paper describes rectifier diode fault detection in rotating brushless exciters for hydrogenerators using FFT analysis. More sophisticated methods are available; however, the cost of these systems is not compatible with hydrogenator operations. The method proposed can detect both short-circuited and open-circuited diodes. Actual field data is used to demonstrate the functionality of the method.

Paper 10125 (France): Fatigue breaking mechanism study at the coils connections of a stator winding and at the magnetic core fasteners

This paper presents an interesting analysis to identify the root cause of failures in the stator winding connection of an HV induction motor used in the water cooling pumps in a nuclear power plant in France. As these are large low speed induction motors it is likely that the designers did not have many reference units to select the best combination of the number of stator and rotor slots. The selected combination - for the given number of poles – resulted in a resonance issue with a natural frequency (eigenfrequency) of the stator core and thus to high vibrations also in the endwinding which degraded the insulation of the connections and finally lead to the failure. Measurement campaigns and finite element analysis (electromagnetic and mechanical) were performed to confirm the root cause.

Paper 10350 (Italy): Use of Non-Destructive Tests (NDT) for synchronous condensers flywheel inspection

Paper 10350 details the on-site inspection of flywheel rotors used with turbo-type synchronous compensators to check for flaws/cracks in critically stressed zones where the main body transitions to the shaft end portion of the integral forging.
These flywheel rotors are derived from turbogenerator rotors but without winding slots, wedges or retaining rings. In this configuration they are simply rotating masses. As such, the forging should be subject to intensive ultrasonic inspection to check for flaws during manufacture.
In this case, the customer has developed an inspection regime using phase array ultrasonic techniques to check for flaws in specifically critical areas of the rotor body during service outages.

Paper 10658 (South Africa): Detection of Generator Earth-brush Fault Types from Shaft Voltage and Currents Measurements to monitor the performance of Earthing Brushes

In this paper description of shaft voltages and currents phenomena in rotating electrical machines is presented. Furthermore, the newly developed prototype for shaft voltages and currents is described. It is based on the monitoring of shaft voltage and current and further analysis (voltage and current waveform, FFT analysis etc.) of the recorded quantities. Experimental test results are presented, and they successfully demonstrate that this detection system can identify the following problems: floating of the voltage brush, floating of the current brush, a worn current brush, a current brush exposed to oil and dust, and a voltage brush exposed to oil and dust, all of which can occur during the operation of large generators.

Paper 10700 (Brazil): Deep learning applied to bearing anomaly detection using advanced signal processing techniques

This paper investigates the efficiency of deep learning in bearing anomaly detection compared to conventional expert systems. It proposes to use a deep autoencoder architecture, trained on extensive vibration data from a healthy turbine. This model extracts salient features from complex signals, enabling the identification of subtle deviations from an established baseline, which can be indicative of potential bearing anomalies.

The obtained results demonstrate that the deep learning models have a potential advantage in anomaly detection accuracy. While the existing expert system exhibited limitations, potentially leading to false positives, and overlooking incipient anomalies, nevertheless the deep learning model may be able to pinpoint anomalies sooner and minimize false alarms, offering potentially valuable opportunities for proactive maintenance interventions and avoiding catastrophic failures.

Paper 10701 (Brazil): Reconfiguration of the Corona Prevention System and Application to a Practical Case

This paper describes the causes of degradation of the semicon OCP (Outer Corona Protection) /stress grading system interface of a hydrogenerator stator winding. In addition to elucidating the deterioration mechanism, the issues associated with developing an effective repair method are discussed. The paper describes in detail the repair procedure that was conducted on-site and provides test results to demonstrate the efficacy of the maintenance.

Paper 10702 (Brazil): The painful (and expensive) experience of having to remedy an avoidable stator failure

This paper explains the root causes of an avoidable failure in a synchronous compensator installed in a substation in the southernmost Brazilian region with high wind energy penetration. The problem started when the stator coil of one of the two synchronous compensators short-circuited, triggering the removal of a screw from the air guide. This event superficially damaged the coil but rendered the synchronous compensator inoperable for 37 days. Root cause analysis revealed maintenance deficiencies, including improper acquisition of the screw and lack of proper visual inspection.

The incident alerts the operations and maintenance team to the importance of following standard procedures and maintenance practices to avoid prolonged breakdowns of rotating machinery.

<u>Paper 10865 (Japan)</u>: Application of Non-contact On-line Partial Discharge Monitoring System to Hydro Generator

The paper presents the development of a partial discharge (PD) detection system for on-line measurements on hydrogenerators in which the sensor does not come into contact with the stator windings. The paper discusses the development, testing, calibration, and installation of the PD sensors including practical results with the measurements taken by the developed sensor being compared with conventional measurement methodology, with satisfactory results.

<u>Paper 11047 (Canada)</u>: EL CID Testing of Rotating Electrical Machines at Elevated Excitation Frequencies

The paper describes in detail how to perform a stator core test with higher frequencies up to 2000 Hz and gives a comparison with a core test of the standard grid frequency. Pros and cons of core tests with elevated frequencies are discussed. In addition, the core integrity tests with high flux and low flux are compared in terms of practicability for new and aged cores and sensitivity to local hot spots. The advantage of lower excitation current at a flux test with 500 Hz is offset by the higher cost of the more complex and expensive variable frequency supply. The influence of the skin effect at frequencies up to 2000 Hz on flux density at the centre of the lamination is calculated and discussed. A model test core for a 50-100 MVA turbogenerator is used to test the influence of test frequency on sensitivity for localization of different lamination shorts with a typical sensor like the Chattock potentiometer for frequencies ranging from 50-2000 Hz. It shows that the potential advantages of using higher frequencies with the low flux test equipment did not point to any improvements in the sensitivity of core hot spot identification.

<u>Paper 11065 (Australia):</u> Incorporating Fibre Optic Arc Flash Detection into a Conventional Generator Protection Scheme

Paper 11065 describes the augmentation of the generator protection scheme to include arc flash protection in the generator stator endwinding zone to improve the detection of faults in the endwinding away from the core end or other earthed components.
The initiative was triggered by a stator endwinding fault that occurred due to fatigue failure of a winding connection resulting in multiple arc events and damage requiring a rewind of the stator. The investigation concluded that, if the initial arc flash had been detected, the later arcing, burning of insulation and extensive melting of the copper connections could have been avoided and a full rewind possibly averted.

<u>Paper 11271 (India):</u> Challenges in Core Flux test of Large Hydro Generators with natural frequency near to Power Frequency

This paper describes a large machine that was found to have a natural frequency (eigen frequency) of the stator close to the 2nd harmonic of the power grid frequency raising concerns that, due to a resonance effect, the stator vibration may be very high during high flux testing (loop test) and could potentially lead to damage on welded joints of the stator core and stator frame.
The paper suggests that the condition of the insulation of stator lamination when the core has a natural frequency near to twice the power grid frequency can be better assessed by performing an ELCID test followed by a loop test at the maximum possible flux density. The maximum flux density is defined by the maximum acceptable vibration limit for the stator core and stator frame. In the particular case presented in the paper, the flux density was limited to approx. 0.5T.

Paper 11661 (Croatia): Mechanical Diagnostic Campaign of a 415 MW Vertical Francis Hydro-Unit

This paper presents the results of a comprehensive mechanical measurement and diagnostic campaign carried out on a 415 MW hydrogenerator. The offline and online measurements are explained in detail and highlighted several deviations from normal acceptance criteria. The paper shows how different types of measurement can reveal more detailed information about the condition of the machine.

Paper 11712 (Germany): Evaluation and Assessment of Operational Data for Condition Based Service Interventions on Synchronous Machines

The paper discusses the benefit of planning individualized maintenance work on synchronous machines/turbogenerators which requires detailed knowledge of the operational history of each individual machine. Methods to evaluate operational history of individual synchronous machines in powerplants and synchronous condenser applications are described using analysis of the machines operational data at different operating points and continuously comparing it with historic baseline data.

It claims that this knowledge-based assessment forms the foundation and validation for possible digital-twin approaches.

Paper 11744 (Ukraine): Measurement and Practical Applications of Magnetic Flux Sensors by Radial and Tangential Axis in Synchronous Generator-Motors

The paper describes the installation of tangential and radial flux sensors in the air gap of the synchronous generator-motor at the Tashlyk Pump-Storage Power Plant. Measurements taken during different operational modes during generator and synchronous condenser operation are explained and interpreted.
Conclusions are given for the usage of the proposed system for condition monitoring, protection and control of synchronous machines including potential monitoring of the axial flux component.

Paper 11813 (Thailand): Locate Generator Stator Phase-to-ground Fault Point by Burn-out Test

This paper addresses ground faults in large generator stators, which can significantly disrupt power generation operations. It emphasizes the need for precise fault detection methods, especially in large-scale power generation. The paper presents a systematic approach to rapidly and effectively pinpoint fault locations using electrical testing techniques aligned with IEEE standards. The burn-out test method has been explained in this paper.
Two case studies involving a turbogenerator and a hydroelectric generator serve as practical examples to demonstrate the implementation and effectiveness of the proposed diagnostic techniques. An important aspect of the paper is its focus on fault detection and comprehensive assessment of the condition of the stator windings, which it states is important for understanding the overall health of the generator and preventing potential faults. The paper provides insight into locating faults by analysing variations in insulation resistance and identifying indicators such as smoke from burnt insulation.
The paper also discusses different machine insulation tests to verify the overall health after repair work.

<u>Paper 11853 (Brazil)</u>: Case Study: How Pitch Imbalance May Affect Vibration and Performance in a Wind Turbine

This is an NGN paper submission.

This paper demonstrates the effectiveness of an automatic diagnostic system in alerting potential aerodynamic imbalances in the main rotor of a wind turbine based on data from several vibrometers. It also highlights a clear improvement in the vibrational characteristics of the wind turbine after the correction of anomalies in its pitch system.

Since maintenance of wind turbines is a difficult task, this system contributes to selective maintenance planning and reducing maintenance costs.

3.2 PS3 Discussion

The changing composition of the generation mix to accommodate the energy transition has implications for older conventional rotating machines as well as for machines such as wind generators. In both cases, there is always pressure to ensure reliability and availability, and the papers selected for PS 3 cover a wide range of topics.

The potential advantages of machine learning and statistical analysis of large volumes of data to aid maintenance planning of wind generators and hydrogenerators is a feature of a number of papers in PS3. In contrast, older conventional means of diagnosing and locating defects in order to determine the requirements for maintenance ranging from burning in faults to core testing to bump testing are the focus of a number of contributions.

Many of the papers describe the use of various diagnostic tools to maintain and ensure the continued service of older generation equipment. The challenge of keeping these ageing fleets of machines serviceable is further exacerbated by the demands imposed by the transmission system operators that result in more flexible or cyclic operation. Many of these machines were designed and built in an era where the expected mode of operation was baseload. Nonetheless, the innovative diagnostic and prognostic methods described in the papers in PS3 indicate that we may have some confidence in the future service of these older machines.

3.3 PS3 Questions

PS3-Q1:
The authors of paper 10123 indicate that, the concept of using FFT analysis of the excitation current to detect and differentiate between open and short circuit diode faults has been proved. The next step consists in making a real-time embedded device (based on a digital signal processor) to be installed in parallel with the actual analogue protection device and generating only alarms. Do the authors have any progress to report on this device and any results. Do others have experience with developing low cost solutions for diode monitoring?

PS3-Q2:
Paper 10125 careful study to understand the cause of endwinding problems in a group of motors involved the use of on-line vibration monitoring and bump (impact) testing. Based on the authors experience and that of other types of rotating machines, e.g., two-pole turbogenerators, have suffered similar problems albeit from different root causes, is there a need for more widespread application of bump testing and vibration monitoring to avoid these types of issues?

PS3-Q3:
The use of phased array ultrasonic inspection is interesting. Can the authors of paper 10350 comment on why they focus on this method compared to those used for conventional

turbogenerator applications and standard forging inspection practice? Given the proliferation of synchronous compensators, what is the general industry consensus on the integrity of flywheels in this particular application? During the SC A1 GDM at the 2022 Session, a contribution described the design and development of a containment device in the event of a catastrophic failure of the flywheel.

PS3-Q4:
The results of the evaluation of the shaft voltage and current monitoring system described by the authors of paper 10658 were derived from testing of a laboratory scale model. Has this system been implemented on operating generators and, if so, what are the results? There are a number of commercially available shaft voltage and current monitoring systems, and it would be interesting to learn of user experience with them.

PS3-Q5:
While the contributions from papers 10700, 11712 & 11853 take different approaches and concern different types of rotating machines, a common feature is that there is the challenge of sifting through very large amounts of data to detect anomalies that provide diagnostic and prognostic information. Based on these papers and others in the machine learning field, how close is the industry to considering these methods mainstream and thus becoming more widely adopted?

PS3-Q6:
Remediation of the semicon (OCP)/endwinding stress grading (ECP) interface due to partial discharge attack has been an issue for high voltage rotating machines for many years, if not decades. Due to the difficulties associated with repair, many end users, elect to do nothing with apparently no catastrophic consequences. Conversely, there are many organizations who perform active maintenance on this degradation. Can the authors of paper 10701, and others with experience of performing such a fix, comment on the longevity of the repairs?

PS3-Q7:
The situation described in paper 10702 where the failure of a minor and inexpensive component results in significant damage to the rotating machine with the attendant financial losses is, possibly, familiar to some in the utility industry. What other examples of this scenario have occurred?

PS3-Q8:
The development of non-contact sensors for on-line partial discharge (PD) monitoring of generators has been attempted by other organizations over the past decades. Two of the factors motivating this development, according to the authors of paper 10865, are concerns with making high voltage connections to the PD sensors and the length of time taken to perform coupler installation. Aspects of coupler reliability are dealt with in standards, e.g., IEC 60034-27-2, however, it would be of great interest to learn from the industry what is the view on high voltage coupler integrity and coupler installation duration.

PS3-Q9:
The contributions from papers 11047 & 11271 discuss different aspects of low flux (EL-CID) testing of large stator cores. The authors of paper 11047 concluded, based on low flux measurements at different frequencies, that testing at higher frequencies did not enhance the sensitivity of the measurement. The concerns of the authors of paper 11271 related to the possibility of core damage under the full flux test with a core known to have a resonant

frequency close to that of the flux excitation. What is the experience of other practitioners of this test method when considering the results of these two papers?

PS3-Q10:
Arc flash protection, commonly fitted in switchgear equipment, has not been commonly applied to generator stator endwinding zones although it may have been previously considered. It would be interesting to know other opinions on the value of such protection compared to more traditional schemes, e.g., endwinding vibration sensors.

PS3-Q11:
Paper 11661 provides recommendations for rotor and stator shape, e.g., maximum air gap variations, stator and rotor circularity and concentricity, based on the author's experience. Are these values generally accepted by others in the industry?

PS3-Q12:
The approach proposed by the authors of paper 11744 to use radial and tangential magnetic flux sensors to provide not only condition monitoring functions but also protection and control inputs appears promising. Can the authors comment on whether the use of both types of sensors would provide improvements in differentiating the changes in air gap flux due to shorted turns from that due to the effects of the rotor or stator shape?

PS3-Q13:
While burning out the fault is an effective method to unequivocally locate breakdown sites in stator winding and thus commence the repair process, there are some concerns with respect to any possible collateral damage to the core iron and/or adjacent stator coils or bars. How widely is this fault location method used in the industry and is there any experience of negative consequences for the stator winding or core? Interestingly, burning out the fault for location purposes is featured in papers 10702 and 11813.

4. Important Dates and Instructions

Registered delegates can prepare one or several contributions to the Study Committee Group Discussion Meeting (GDM) related to the questions raised in this report.

Contributors shall upload their contribution in the "Contributions to Group Discussion Meetings" section of the Registration Portal (https://registrations.cigre.org) using their existing account and own credentials. **Note:** Access to upload contributions is given only to duly registered delegates.

A template as well as a guide for contributions are made available to contributors on the Session website (https://session.cigre.org).

In addition to the presentation, a text version should also be prepared. The Special Reporters will review and manage the contributions through the web-based platform.

The draft presentations will be checked for readability, technical/scientific content, and conformance to the CIGRE rules for presented material, and recommendations given for revision/improvement where necessary prior to acceptance for presentation.

During the Session, for each prepared contribution a limited time slot is available for presentation and discussion, so the number of slides needs to be optimised to convey the message and generate discussion.

All contributors with accepted and finalised contributions shall meet the SC Chairman, Secretary and Special Reporters in person as part of the preparatory work for the Group Discussion Meeting. The "Contributors meeting" will be held on Tuesday 27th August in the same location and timeframe as the SC A1 Poster Session. During the meeting the contributors will receive instructions regarding the session and have the opportunity to ask questions.

Main key dates:

Deadline for GDM contribution upload	**10th August 2024**
SC A1 Poster Session GDM Contributors meeting	Tuesday 27th August 2024, 14:30-18:00 (same location and time slot for both)
SC A1 GDM	Wednesday 28th August 2024, 08:45-18:00

During the Session the Chairman may call for spontaneous contributions. Attendees, who provide a spontaneous contribution, are encouraged to summarise their contribution as a short, written response after the GDM which will then be included in the Session Proceedings. This text is required to be forwarded within two weeks after the SC A1 Session (i.e. by Friday 13th September 2024) to the Special Reporters (see title page for e-mail addresses).