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SPECIAL REPORT FOR SC A1
ROTATING ELECTRICAL MACHINES

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Special Reporters

1. Introduction

Study Committee A1 is responsible for the area of Rotating Electrical Machines within CIGRE and includes in its scope all such machines for power generation and motors for power stations. Also included in the scope are materials technology and superconducting technology relevant to machines.

The range of activities and interests of Study Committee A1 includes research, design and development, manufacture, operation and maintenance, asset management and the de-commissioning of the machines within its scope. The assessment of the current condition of machines and their components, the refurbishment, power upgrade, and long-term health assessment of the machines are all included under the asset management aspect.

In the last decade Study Committee A1 has seen an increasing interest in the use of electrical machines for the newer power generation technologies and in machines for dispersed generation. As part of its commitment to modernisation, and also to try to appeal to the wider machines community, Study Committee A1 has broadened its scope to include these applications.

2. Group Discussion Meeting in Paris Session 2018

The Study Committee invited written contributions to provide discussion material for the Group Meeting in Paris Session 2018. A total of 27 abstracts were accepted from those submitted for approval under three Preferential Subjects. One paper was subsequently withdrawn. The submitted 26 papers are summarised below under the following three Preferential Subjects chosen for the 2018 Session.

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PS1 Generation mix of the future

- Design improvements and technological developments required for machines to withstand cycled operation due to fluctuating feed-in of renewable energy and variable load demand.
- Impact and effect of increasing renewable power mix on existing legacy generators, generator auxiliaries and motors.
- Evolution and trends in designs of machines for renewable generation.

PS2 Asset Management of Electrical Machines

- Experience with refurbishment, replacement, power up-rating and efficiency improvement of aged generators.
- Novel techniques to overcome known operational and design problems.
- Optimised condition monitoring, diagnosis, prognosis and maintenance practices to improve reliability and extend operational life at conventional plant and in new volatile grid conditions.

PS3 Developments of rotating electrical machines and operational experience

- Latest design, specification, materials, manufacture, maintenance and performance and efficiency improvements in generators and motors.
- Operational experience: failures, root cause analysis, recovery options, cost and time reduction initiatives.

3. Preferential Subject 1: Generation mix of the future

Six papers were accepted under PS1, and are summarised below.

3.1 Design improvements and technological developments required for machines to withstand cycled operation due to fluctuating feed-in of renewable energy and variable load demand

Paper A1-101 (USA): Hybridizing Gas Turbine with Battery Energy Storage: Performance and Economics

This paper addresses one of the major issues facing generation utilities faced with the very high, and increasing, levels of renewable energy sources that are penetrating the market. The availability of relatively cheap renewables has resulted in the closure of large fossil fuel-based generation. However, there is still a requirement for traditional energy sources, e.g., gas turbine generators, to provide generation when there is insufficient supply from renewables and/or to stabilize the power system. In the paper, the complexity of this issue is illustrated using the example of the energy market in California. One of the potential solutions proposed in the paper is a gas turbine plant, hybridized with a Battery Energy Storage System. Details of the first installation of such a system and discussion of the economics and performance are given.

Question 1.1: Based on the information provided in paper A1-101, the potential gap between the loads that can be accommodated by renewables and likely peak demand is of the order of several GW. While the solution presented in the paper goes some way to addressing this problem, the present system can only provide support of a few tens of MW. Is the intent to scale up these systems, or what other novel solutions are available?

Paper A1-102 (Switzerland): ***Investigations on ROCOF withstand capability on large synchronous generators***

Paper A1-102 introduces the impact of system inertia reduction on the Rate of Change of Frequency (ROCOF), which can reach a high value (> 6 Hz/s depending on the measurement duration and severity of disturbance) when a system disturbance occurs that involves either a loss of generation, or loss of power export such as a large interconnector. ROCOF withstand capability requirements are now appearing in many grid codes, typically requiring generators to stay connected during high gradients of grid frequency. However, such requirements are not harmonized amongst the various national grid codes, even though frequency is shared within a synchronous area. Usually only the maximum gradients (e.g. 1 Hz/s) are defined, but the boundary conditions (such as duration and frequency profile), methodology and principle in most cases remain unclear and do not allow a detailed evaluation from a generator capability point of view. The paper describes the authors' experiences on performing ROCOF withstand capability investigations for existing power plants in Europe as mandated by one transmission system operator.

Question 1.2: The authors have presented an almost complete assessment; however, nothing was presented regarding the impact on the damper winding of both hydro and turbo generators. Is there any expected increase in the damper winding parasitic current due to a fast rate of frequency change?

Paper A1-103 (Germany): ***Development, Test and Validation of new Generator Product Line for current and future operational regimes***

Paper A1-103 describes a new generator product line comprising water-cooled stator windings and air-cooled rotor and stator core. This product configuration has been chosen to minimise mechanical wear-and-tear and thermal aging of the generator windings caused by the increased level of load cycling of conventional power plant that results from the current move towards renewable power generation with its inherent intermittency. Water cooling has been chosen for the stator winding to reduce temperature cycles, whilst pressurised air has been chosen for the core and rotor to eliminate the need for hydrogen and its associated shaft sealing systems and safety related requirements, and reduce maintenance. To optimise thermal behaviour and efficiency, the water system is arranged to vary the flow depending on the stator current, whilst the air system adapts the over-pressure used according to the rotor current and power factor.

The paper reports that the first unit has been factory tested, yielding performance data in accordance with expectations, and design standards.

The product range is aimed at the power range currently dominated by fully indirectly air-cooled or hydrogen-cooled designs.

Question 1.3: Could the authors, or other OEMs/users, clarify the trade-off between the benefits of operational flexibility with reduced thermal cycling and no hydrogen, and the reduced specific power output (output to size ratio), compared to conventional indirect hydrogen-cooled designs. User considerations may include overall efficiency over the operational lifetime, and potentially lower transient and subtransient reactances that may affect the choice and size of other equipment, e.g. switchgear, busbars etc.

3.2 Impact and effect of increasing renewable power mix on existing legacy generators, generator auxiliaries and motors

Paper A1-104 (France): ***Impact of grid code evolution on the design of the generators for nuclear plants (Half speed, power above 800 MVA)***

Paper A1-104 presents a very lucid evaluation of the operating challenges and impacts associated with ENTSO-E grid code requirements on large synchronous generators (> 800 MVA). These include general requirements for type D power-generating modules (voltage and frequency ranges), Fault Ride Through (FRT) capability, faster excitation system response, frequency variation withstand capability according to the specified Rate of Change of Frequency (ROCOF), and Low Voltage Ride Through (LVRT).

As the operating point moves away from the rated values of voltage and frequency, the generator core, armature, and field winding temperatures may increase significantly, resulting in damage to the generator stator core, and winding insulation, thus impacting the generator's lifetime. It is normally recommended therefore to limit the extent, duration, and frequency of occurrence of such operating conditions. However, it might be a challenge for generating units to stay within the defined operating limits, and the solution then is to over-dimension the machine, or to use on-load tap changers. The final solution may require some compromise between grid operator, plant owner, and manufacturer.

Question 1.4: The lack of inertia, and intrinsic inability to manage reactive power, associated with the new alternatives of generating electricity, is a demanding reality with which the transmission system operators are learning to deal with. The consequences are to put more burden on the conventional generating units. To what extent do tripartite discussions between grid operator, plant owner, and manufacturer take place in order to find an optimised solution, and have studies been carried out to assess the cost impact of accomplishing the requirements?

Paper A1-105 (Japan): ***Contribution of Kyogoku Power Station, an adjustable speed pumped storage, in actual grid operation***

Paper A1-105 describes the performance of the 2x200 MW adjustable speed pumped storage plant at Kyogoku Power Station under actual grid operation since entering service in 2014. The paper is supported by measured data and simulation results as a follow-up report to a previous paper presented in CIGRE 2016.

These data and simulations are mainly focused on the active power response, which consists of response to the required output command from a power dispatching centre (EDC+AFC), and response to the frequency deviation (Governor Free) measured at Kyogoku Power station. The data shows that the adjustable speed pumped storage system operates successfully as designed with their EDC+AFC functions and Governor free function, both in turbine mode and in pump mode, during normal operating conditions and in case of grid fault condition.

Question 1.5: We would like to thank the authors for presenting the evolution of the adjustable speed technology applied to Kyogoku Power station. Are there any plans to extend this technology on retrofitting power plants?

3.3 Evolution and trends in designs of machines for renewable generation

***Paper A1-106 (UK):* Calculation of Rotor Eddy Current Losses in High-Speed PM Synchronous Generators using Transfer Matrices**

Paper A1-106 describes an analytical method of calculating the eddy current losses in the rotors of high speed permanent magnet synchronous generators using transfer matrices as a quicker, more practical approach during machine design iterations than using a slower but more accurate finite element method. An example is given of a 50kW, 65000 rpm permanent magnet generator demonstrating good correlation between the transfer matrix method and the FE method for rotor eddy current losses both on-load and at no-load.

Question 1.6: The paper states that good accuracy is required in the computation of rotor losses due to the generally poor cooling and the possibility of failure. However, the operating temperature depends on the combination of both loss generation and the cooling regime. Whilst the transfer matrix method described gives good correlation with FE calculations, to what extent is the overall accuracy masked by uncertainties in the heat transfer to the cooling medium?

4. Preferential Subject 2: Asset Management of Electrical Machines

Eleven papers were originally accepted under PS2, but one paper (A1-206) was withdrawn. The remaining ten papers will be discussed in the following order:

4.1 Experience with refurbishment, replacement, power up-rating and efficiency improvement of aged generators

***Paper A1-211 (India):* Generators as Synchronous Condensers to meet Dynamic System Requirement by Renewable Mix. – Indian Scenario**

Paper A1-211 considers the use of existing, retired generator installations, or strategic spare generators, as synchronous condensers to alleviate VAr compensation problems in the Indian electricity grid resulting from a rapid build-up of power generation capacity using wind and solar plants. A specific example of three 95 MW hydrogen-cooled generators is described, and the considerations needed when converting a generator to synchronous condenser duty.
The benefits of using rotating machines in VAr compensation over static Var compensators is also discussed.

Question 2.1: The 'Indian Scenario' is currently under consideration, but other countries, have installed many synchronous converters to alleviate VAr compensation and grid stability issues, and/or converted existing plant to such duty. Would other colleagues care to share their experiences of such conversions that may benefit the technical and commercial considerations that are ongoing in India?

4.2 Novel techniques to overcome known operational and design problems

***Paper A1-208 (Egypt):* Torsional Oscillations Mitigation for Interconnected Power System via Novel Fuzzy Control Based Braking Resistor Model**

Paper A1-208 introduces the dynamic braking resistor (BR) to mitigate the devastating effects of unsuccessful reclosure on the fatigue life of shafts due to torsional oscillations. The BR method was initially used to enhance electric power system transient stability. It does this by acting as an extra load capable of dissipating surplus generation in case of severe faults in hydro dominated power systems, thereby preventing generator pole slipping, or out of step conditions. A novel BR model, namely a rectifier controlled braking resistor (RCBR) model, controlled via a fuzzy logic controller (FLC) is proposed in this work for the mitigation of torsional oscillations following reclosure. The RCBR is basically a single BR unit connected to the generator terminals via a six-pulse full wave rectifier bridge.

It is claimed that no similar work is found in the literature regarding the use of RCBR for the mitigation of torsional oscillations in multi-machine interconnected power systems.

The proposed scheme enables the utilization of high speed reclosure (HSR) near power plants safely without jeopardizing the mechanical integrity of the machine. The proposed scheme might resolve the controversial debate between the electric utilities and the turbine-generator manufacturers about utilizing HSR near power plants. Additionally, the utilization of single BR unit for each generator might lead to a reduced system size and cost. The scheme advantages might encourage the electricity producing utilities to implement it for mitigation of turbine-generator shaft torsional oscillations arising from unrestricted HSR.

Question 2.2: Given that the success of the proposed scheme is based on the fuzzy intelligence and that the electric torque response time is quite fast, have the authors assessed if there will be a time delay between the fuzzy logic controller processing the answer and the actual oscillation speeds which may affect the performance of the system?

4.3 Optimised condition monitoring, diagnosis, prognosis and maintenance practices to improve reliability and extend operational life at conventional plant and in new volatile grid conditions

***Paper A1-201 (Brazil):* Variability of PD readings and failure location in high voltage bars**

Paper A1-201 presents results from a study conducted at a number of laboratories into the variation of partial discharge (PD) results obtained from testing the same test objects using the same equipment. This investigation was undertaken in light of the recent trend for end users to require “acceptance” limits on PD magnitudes for individual winding elements (coils and bars) and, in some cases, on the assembled stator winding. Three independent laboratories performed PD testing on a group of six Roebel bars that had been subject to accelerated ageing (thermal cycling and voltage endurance). In addition, the authors of paper A1-201 conducted their own PD testing. The results of the testing revealed significant variability in the PD magnitudes thus raising questions about the prospect of specifying pass/fail criteria based on this parameter. Further, in this study, no correlation could be found between the sources of highest PD magnitude and the failure site when the bars were subjected to electrical breakdown testing.

Question 2.3: This paper raises important concerns with the comparability of PD testing between different organizations and the advisability of specifying acceptance limits based solely on PD magnitudes. Have other organizations conducted similar studies and, if so, what is the experience?

Paper A1-202 (Austria): A Study of the Propagation Behaviour of Partial Discharge Pulses in the High-Voltage Winding of Hydro Generators

Paper A1-202 describes a study of PD pulse propagation performed on two stator windings, of different voltages and power ratings, that were due to be rewound. The stated objective of the investigation was to enable reliable identification of PD in different parts of the stator winding. A key element of this contribution is the introduction of an "attenuation matrix" derived from a set of frequency selective measurements. The purpose of this method is to attempt to obviate the well-known attenuation and dispersion of high frequency PD pulses as they propagate through the stator winding. By varying the frequency response of the detector, the authors of paper A1-202 show that this method may be used to identify defect singularities in the winding.

Question 2.4: While the results presented in paper A1-202 are encouraging, successful implementation of the methods appears to require significant expertise in the fields of high frequency measurements and PD theory. Thus, can the authors of paper A1-202, or any others that have experience with PD pulse propagation studies, advise whether such testing can only be considered an "expert" test or whether it can be possible for non-specialist staff to use these techniques and obtain robust measurements, i.e., free of false positives?

Paper A1-203 (UK): Partial Discharge Activity in Isolated Phase Bus (IPB) – Case Studies from UK Power Stations

Paper A1-203 presents case studies based on the use of PD testing to assess the condition and thus the prospects of reliable performance of the IPB. This contribution shows that a number of options are available in order to effect on-line PD measurements on the IPB. While the IPB is not an integral part of a rotating machine, failure of this system has grave consequences given that it functions to connect the generator to the main output transformer or generator circuit breaker. Typically, relatively little attention has been paid to this system given the overall impression that the IPB has exhibited very good reliability. However, a number of end users are recognizing that failure of the IPB will have a very adverse effect on plant availability.

Question 2.5: Paper A1-203 uses on-line PD testing based on pre-installed coupling devices to enable condition assessment of the IPB. Do other operators of large turbine generators have experience with these types of measurements to aid IPB maintenance planning?

Paper A1-204 (Korea): Analysis of Insulation Diagnosis for Generator-Motor Stator Winding and Core in Pumped Storage Power Plants

Paper A1-204 describes efforts to understand the cause of failure of the stator winding insulation of two pumped storage generators and subsequently apply a program of off- and on-line condition monitoring to prevent future occurrences. Analysis of the failures showed that, in one case, the cause was deterioration of the insulation due to the large number of start/stops over 25 years; the second failure resulted from loosening of the stator core. Based on these findings, a program of on-line PD measurements and complementary off-line tests (PD, insulation resistance, polarization index, dissipation factor, low energy stator core flux, UV camera, etc.) was applied. Two case studies are presented in which the results of this testing program were effective in identifying the defect mechanisms and applying corrective maintenance. These tests were also employed to assess the effectiveness of the maintenance actions.

Question 2.6: The authors of paper A1-204 have demonstrated that systematic application of a range of diagnostic tests can be successfully used to guide maintenance planning and effect repairs. This test program is based on well-established test methods. What is the experience of other organizations in the implementation of such methods and are there any alternative techniques available that are not mentioned in this contribution?

Paper A1-205 (Canada): Novel fiber optics technology monitors in-slot vibration and hot spots in an air cooled gas generator

Paper A1-205 presents vibration and temperature results obtained using fibre-optic sensors installed on an air-cooled gas turbine generator. The physical basis for each of these sensors is described in detail in the paper. Measurements are reported of slot and endwinding temperatures as well as vibration data obtained in the slot cell, endwinding leads and the neutral endwinding bus. Good correlation of measured temperatures was observed between the new fibre-optic distributed temperature sensor and the traditional slot RTDs. Following successful testing on this air-cooled generator, further testing on a hydrogen-cooled machine is planned.

Question 2.7: Fibre-optic sensors have been employed in rotating machines over the last 15 – 20 years, however, in some cases there have been questions concerning reliability of the sensor and accuracy of the data. For example, some earlier vibration sensors were prone to measuring artefacts of movement of the leads rather than vibration of the stator winding. Can the authors of this contribution, or any other organization involved in this application, discuss what steps are taken to ensure reliability and quality of the data?

Paper A1-207 (Canada): Importance of operating parameters when assessing the condition of machines on-line

Paper A1-207 provides an overview of the parameters that may be measured while the generator is operating that can be used to identify, at an early stage, defects to enable condition based maintenance. Among the parameters covered in the paper are magnetic flux for rotor shorted turns, stator endwinding vibration, shaft and bearing vibration, and rotor to stator air gap (for hydraulic turbine driven generators). This contribution shows that, depending on the technology, different operating parameters will affect the monitored data differently, some with a significant influence. Three case studies are presented that show the sensitivity of monitored parameters (endwinding vibration, air gap and vibration) to changes in operating conditions (stator winding temperature, speed and load respectively).

Question 2.8: The case studies presented in paper A1-207 show the need to understand the relationship between operating conditions and the parameter being monitored in order to provide reliable information to guide maintenance actions. Do the interpretation methods employed in these case studies require an expert or is it possible to automate this process?

Paper A1-209 (Canada): Using an air gap monitoring system during initial commissioning stages of a hydro generator

Paper A1-209 demonstrates through a number of detailed case studies the development of air gap monitoring over the past 30 years from essentially a protection role, i.e., avoidance of rotor to stator contact, into, through proper analysis, a sophisticated tool for commissioning and diagnosing problems during operation, especially when changing operating conditions. In the paper, a web-based platform is presented that enables end users to take advantage of not only the data but the analytical tools needed to fully leverage such systems.

Question 2.9: With respect to the introduction of web-based platforms where the data can not only be archived but be subject to analysis and interpretation, there have been similar systems proposed and utilized in the past to deal with a variety of machine parameters. However, many end users have not adopted such systems due to concerns about the lack of transparency of the outputs, and ownership of the data. Does the author of paper A1-209 (and others involved in this field) see this as a potential problem and what steps can be taken to allay such concerns?

Paper A1-210 (Hungary): Application of Differential Magnetic Field Measurement (DMFM method) in winding fault detection of AC rotating machines as part of expert monitoring systems

Paper A1-210 describes a method for winding fault detection on induction and synchronous machines using two detection coils mounted on the stator teeth, one pole pitch apart, and connected in series such that the induced voltage signals cancel out. A broken rotor bar or interturn short circuit will result in a detectable voltage signal deviation corresponding to the number and location of the faults. Validation of this Differential Magnetic Field Measurement (DMFM) method has included both FE modelling and laboratory testing. The method allows easier signal interpretation than existing single coil methods and is claimed to be more sensitive. Data is presented for induction machines only, but is also applicable to synchronous salient pole and turbo-generators.

Question 2.10: The data presented is for induction machines. For large synchronous turbo machines with distributed rotor windings, the usual method is to detect leakage flux close to the rotor surface. How sensitive is the system to individual shorted turns in rotors with distributed windings, and large air gaps, compared to the traditional leakage flux assessment method?

5. Preferential Subject 3

Developments of rotating electrical machines and operational experience

Ten papers were accepted under PS3, and are summarised below.

5.1 Latest design, specification, materials, manufacture, maintenance and performance and efficiency improvements in generators and motors

Paper A1-305 (China): Analysis on the effect of screen ventilation width on end flux distribution and eddy current losses of Turbo-generator

This paper presents the results of a study of eddy current losses in the stator core clamping flux shield arrangement of a 330MW generator. The study considers a double layer copper

flux shield arrangement in which the spacing between the layers is used as a ventilation duct, and is varied to study the overall impact on the effectiveness of the screening and resulting losses.
A 7% reduction in clamping plate losses is achieved with the larger screen spacing at the expense of a slight increase in flux shield losses.

Question 3.1: Conventional flux shields with radial cooling often use the space between the copper shield and the clamping plate as the ventilation channel. Do the authors consider the double layer shield to have significant advantage over the conventional arrangement of a single, maybe thicker, shield?

Paper A1-306 (China): Influence of total flow rate on complex fluid flow and temperature rise in the rotor region of large Hydrogenerators

Paper A1-306 introduces a novel numerical calculation method for complex fluid flow and temperature in the rotor region of a large hydrogenator. Two-dimensional transient electromagnetic field equations are solved using the finite element method to obtain the losses in the components of the hydrogenerator. Mathematical and physical models of the three-dimensional fluid flow (with heat transfer) in the rotor region are established, taking into account the complex structure of a large hydrogenerator, and including the effect of rotor rotation. The losses obtained from the transient electromagnetic field calculation are applied to the fluid dynamics/thermal model as heat sources. Using the finite volume method, the cooling air flow distribution between the rotor poles of the hydrogenerator are calculated for different total flow rates, and the associated heat transfer from the rotor winding, press plate, damper winding, and end ring are determined. The resulting temperature distribution of rotor excitation winding is then studied for different total flow rates.
The calculated results match well with the measured average rotor winding temperature.

Question 3.2: When designing pole field coils, it is very common to introduce coil-fins or coils with 'fins' incorporated within its cross-section. Could the authors please comment if such fins were modelled, and the effect on the pole coil temperature?
Additionally, the benefit of such detailed calculation methods is to give a deeper insight into the local temperatures of individual components, thereby allowing a more optimised design in terms of total air flow and efficiency, and the avoidance of local overheating. Have the studies revealed any areas for performance optimisation, and is it intended to use such calculation methods in routine design work?

Paper A1-307 (Japan): Loss Reduction by Large-Scale Electromagnetic Analysis

This paper reports on a large electromagnetic finite element model that has been used to analyse losses in various parts of a 900MVA indirectly hydrogen-cooled generator. The analysis demonstrates loss reduction design features that can be applied to improve the overall efficiency of the generator. Components and design features considered include slitting of the stator core end laminations and laminated flux shield, the use of non-magnetic material in the casing structure close to the stator endwinding and phase connections, endwinding Roebel applied to the stator bars, and improvement of the contact resistances between the rotor wedges and the retaining ring.
The paper gives loss reduction potential in per unit terms of that particular loss component.

Question 3.3: Losses in the core end lamination packets are highly influenced by the saturation of the iron, and eddy current paths in the laminations including keybar structure. Can the authors elaborate on how these effects were modelled in their studies?
Also, can the authors give an indication of the total efficiency improvement resulting from the proposed design features, and whether these have been implemented in running units.

Paper A1-308 (Spain): Reactive power capability of large hydro generators and the European Grid Code requirements with respect to voltage stability

Paper A1-308 reports an investigation on the ability of a 65 MVA hydrogenerator to meet the upper bound of the reactive power requirement of the recently approved European grid code, and the sensitivity with respect to voltage at the point of connection, and transformer tap-changer settings.
The European grid code has introduced requirements with respect to voltage stability formulated as an upper bound of voltage versus Q/P_{max} at the point of connection, and this must be implemented at national level by corresponding TSOs. These requirements deviate from the classical reactive power capability requirements at the generator terminals given in design standards such as IEC 60034-3, IEEE C50.13 and C50.12.
The paper assesses the ability of the hydrogenerator to supply reactive power at the connection point of the step-up transformer as now specified in the new Grid Code requirements. It concludes that, whilst the generator meets the current requirements imposed by the TSO, it cannot meet the full operational envelope now demanded by the European Grid Code.

Question 3.4: Would the authors comment on the generator design requirements that would be needed to fulfil the EU grid code at the step-up transformer connection point? Is there any kind of economic compensation/penalties associated with satisfying the EU grid code?

Paper A1-309 (Japan): Development of Large Indirectly Hydrogen-cooled Turbine Generator and Associated Technologies

This paper describes the application of three key technologies necessary for the development of a 900 MVA generator indirectly cooled by hydrogen, but which can also be applied to generator rewinds/upgrades to improve output, and efficiency. The technologies are High Heat Transmission (HHT) stator bar main wall insulation, optimised Roebel transpositions, and improved stator endwinding bracing. Specifically, HHT and Roebel optimisation have been applied to, and validated on, rewinds of both hydrogen-cooled and air-cooled generators in the power range 160 MVA to 600 MVA. Reductions in stator bar temperature rises of up to 50% are reported to be feasible depending on the generator size and original design.

Question 3.5: To reach the 900 MVA rating for indirectly hydrogen-cooled generators, both High Thermal Conductivity (HTC), and High Heat Transmission (HHT) stator bar insulation systems have been proposed by OEMs. In a similar power range however, Paper 103 describes a return to water-cooled stator bars, but with an air-cooled stator core and rotor winding, citing better suitability to cyclic load variations now being experienced on grids with significant introduction of intermittent, renewable generation. Regarding the issue of load flexibility, what is the service experience, or expectations based on performance tests, of such high-performance insulation systems when subjected to load cycling at operating temperatures?

***Paper A1-310 (Korea):* Analysis of Winding Temperature Characteristic by Dual-frequency Method and Real-load Test for Induction Motors**

Paper A1-310 compares and evaluates the two most common methods used to measure the temperature rise of induction motors under load; the dual-frequency method and a real-load test method.

It is stated that the real-load test method is more accurate, but its application to large load machines requires a higher investment in test equipment. On the other hand, the dual-frequency method, although very popular and listed in international standards, presents different results when compared with the real-load test, resulting in a large temperature variation between the two testing methods. The deviation in temperature is higher for a low voltage motor than for a high voltage motor of the same capacity (15°C v 5°C for the motor studied).

The paper investigates the cause of this deviation in temperature through actual measurements and simulation via FEA, and concludes that the deviation is due to the different stray load loss associated with the different applied frequencies, and this is more significant for low-voltage, high-power motors with accordingly large input currents. Further study is recommended when carrying out the dual frequency test on this type of motor to assess the impact of current waveform and increased stray load loss on the measured temperature rise.

Question 3.6: An amplitude modulated wave shape current at stator input will impact the hysteresis losses. Can the authors please comment on the hysteresis losses evaluation and on the skin effect in the stator and rotor windings? Would be the authors advise revising the international standards regarding dual-frequency testing based on the reported studies?

5.2 Operational experience: failures, root cause analysis, recovery options, cost and time reduction initiatives

***Paper A1-301 (Brazil):* A Study of the failure and repair rate indicators of the Itaipu generator units**

Paper A1-301 presents the development of a six-state probabilistic model to evaluate the unavailability and failure rates of the generating units at the Itaipu power plant in Brazil. The model considers states of 'Operation', 'Failure', 'Reserve', 'Shutdown failure', 'Start-up failure', and 'Maintenance', and transitions between these states over 29 years of operation.

The resulting analysis of data from 18 units gave a failure rate curve that is well represented by the bathtub curve, with an infant mortality period of 13.2 years and failure rate of 0.74 failures per year per unit in the useful life period. The mean time to repair also evolved, reducing from 28 hours during the first 11 years, to 11 hours during the useful life. The comparison of the unavailability rate with the failure rate shows that the maintenance policy is still evolving, reducing by 48 hours per maintenance per generating unit (from 106 to 58 hours) in 29 years of operation.

Question 3.7: The authors have found that the infant mortality period belonging to Itaipu units is 13.2 years. Would the authors, or other parties who have also carried out such analysis, please clarify how this value relates to experience at other sites, and how the analysed data can be constructively used to improve or optimise plant operational planning, maintenance regimes, or choice of plant for future projects?

***Paper A1-302 (USA):* Forensic Analysis of Gas Turbine-generator Shaft Failures due to Possible Subsynchronous Resonance**

Paper A1-302 presents a case study of a GT power plant that suffered shaft damage due to torsional and system power oscillations at sub-synchronous frequencies. The aim of the study was to confirm the possibility that these oscillations could have been caused by a sub-synchronous resonance (SSR) between the mechanical system of the turbine-generator shaft line, and the combined electrical system to which the plant was connected. The external distribution network comprised several lines having static VAr series compensation to improve the load distribution behaviour.

A full system model was set up using EMTP-RV and a frequency scanning technique applied to various load dispatch configurations to detect potential Torsional Interaction (TI) phenomenon and Induction Generator Effect (IGE).

The analysis confirmed the possibility of TI due to a system resonance frequency coinciding with a torsional natural frequency of the shaft line, resulting in sub-synchronous torsional oscillations and high shaft mechanical stresses at the couplings. No IGE was identified.

Question 3.8: The paper illustrates that SSR phenomenon can be present in gas turbine plant arrangements, and can have a profound effect on both the overall system operation, and the integrity of the turbine-generator shaft line in a relatively short time frame, with costly results. Are there other recent examples of SSR phenomenon, and to what extent are such studies of SSR carried out in the design and configuration of new plant? In today's commercial environment with multiple sources of generation, who takes ultimate responsibility for the avoidance of such phenomenon?

***Paper A1-303 (Montenegro):* Analyses of possible refurbishment of generators in HPP Perucica**

Paper A1-303 presents a general overview of the maintenance and operational problems experienced on the generators of the hydro power plant HPP Perucica in Montenegro, over 50 years of operation, that resulted from oiling and gluing of graphite dust on the surfaces of the rotor and stator windings.

The combination of graphite dust, oil and moisture led to conductive, greasy deposits which needed regular cleaning. Cracking of old insulation on some units exacerbated the problem in that the greasy deposits entered the cracks and could not be easily cleaned. The source of the graphite dust appears to have been the motor-generator sets of the excitation systems as originally installed, and these problems have reduced as they were progressively replaced by static excitation systems. A return to modern brushless excitation systems is proposed to eliminate this problem in future.

Also presented are the results of diagnostic testing performed in 2014 with a general conclusion about the state of the insulation systems and recommendations for further exploitation of the generators. The paper also explores future plant upgrades options via refurbishment and re-design, including improvements in power output and efficiency.

Question 3.9: The authors must be commended on the detailed report made available to the community. It seems surprising that it was possible to continue operating with visible partial discharges at rated voltage, and with a huge accumulated mixture of condensed oil and graphite dust forming a fatty deposit up to 12 mm thick. Was it considered to fit air treatment equipment to duct and filter the dust laden air at source? Have other users experience of contamination problems with graphite dust from brushes and how was it addressed?

Paper A1-304 (Russia): Operation experience of asynchronized turbo-generators in the Moscow power system

Paper A1-304 provides operational data on 5 Asynchronous Turbo-Generators (ASTG) in the power range 110 MW to 320 MW installed in the Moscow Power System between 2003 and 2009. The ASTGs are fitted with two excitation windings and can be arranged as a symmetrical or asymmetrical configuration, the asymmetrical configuration having advantages in terms of performance on loss of excitation. The data gathered has shown the ability of these generator types to operate at extended leading power factors thereby reducing the leading power factor duty on conventional plant with a lower leading power factor capability. This has had a particular advantage in the dense, local power network in the Moscow region. The paper concludes that despite the VAr absorption capabilities of the ASTG, the additional initial cost has deterred wider commercial applications. Tarif changes benefitting leading VAr capability in the Russia power network, currently being considered, may however make ASTGs more commercially attractive in future.

Question 3.10: The potential advantages of an ASTG design have been promoted for some years, and these are now demonstrated in this paper in relation to the Moscow Power Network. In view of the changing power generation profile and tariff structures in many countries, do users/TSOs see a commercial advantage now in such technology over other options for VAr compensation in power networks, or in the ability to operate asynchronously without excitation?

6. Important dates and instructions

6.1 Contributions:

Experts who wish to contribute to the SC A1 Open Meeting are required to send their draft prepared contribution, on the allocated templates (available here “Contributors”: http://cigre.org/Events/Session/Session-2018), to the Special Reporters before **July 15th, 2018**, in order to allocate a slot into the program. Please email contributions to: Mr. Kevin Mayor kevin.mayor@ge.com, Mr Johnny Rocha johnny.rocha1959@gmail.com and Mr Howard Sedding hsedding@qualitrolcorp.com.

The draft presentations will also be checked for readability and technical/scientific content (no commercial information is allowed). Prepared contributions in draft, which are received after **July 15th**, will not be considered for presentation at the Session. During the Session, for each prepared contribution a time slot of three to four minutes will be available, so that the number of slides essentially has to be less than four. After receiving the draft prepared contributions, the Special Reporters will review the size and readability of the power point presentation. They will give recommendations to the contributors and inform them whether the prepared contribution will be accepted for presentation - before August 15th.

The SC A1 Open Meeting is scheduled for **Tuesday, August 28th**, in the hall Havane, situated on the 3rd level of the Palais des Congrès.

On Monday the 27th of August (the day before the Open Meeting) all Experts with Prepared Contributions need to meet the Chairman, the Secretary and Special Reporters of SC A1 in Rooms 233, 234, 235 and 237 on level 2 mezzanine in the Palais des Congrès (a banner in front of these rooms will indicate the specific meeting room for SC A1). Please note that the Special Reporters will only be available from **9AM to 2PM** for receiving and reviewing of contributions.

During the Open Meeting the Chairman may call for spontaneous contributions. 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 SC A1 Session (thus by Tuesday September 11th, 2018) to kevin.mayor@ge.com.

6.2 Posters:

The authors of the SC A1 Session Papers present the results of their studies during the Poster Session on Monday afternoon, August 27th, 2018 in Hall Terness situated on Level 1 of the Palais des Congrès. If the author(s) cannot attend the Poster Session, the respective National Committee is requested to send a substitute.

Draft Posters need to be sent in digital format, on the allocated templates (available here "Poster Session": http://cigre.org/Events/Session/Session-2018), to Alberto Villarrubia, avillarrubia@iberdrola.es before **15 July 2018**. The received posters will be reviewed by Alberto Villarrubia and Sergio Rodriguez, who will correspond with Authors on any corrections required.