Study Committee A1 – Electrical Rotating Machines

Meeting Report
Wednesday August, 2022
Palais des Congrès
Paris, France

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SC A1: CIGRE 2022 Report including Paris Meeting

Study Committee A1 (Rotating Electrical Machines)

Study Committee A1 covers rotating electrical machines used for power generation. This includes large turbogenerators, hydrogenerators, generators used in wind turbines, and large and high efficiency motors above 1000 kW used extensively throughout power plants for power generation. It also includes synchronous condensers/compensators used for powers system support since these are largely derived from suitably sized generator designs.
SC A1 covers the full equipment lifecycle from research, development, design, manufacture and testing of new machines through to the commissioning, operation, condition assessment, maintenance, refurbishment, upgrades, conversion (e.g. from power generation duty to synchronous condenser duty), storage, and de-commissioning.

In 2022, the Study Committee had 24 Regular Members, 5 Additional Regular Members and 16 Observer Members representing 42 countries across all continents. They are complemented by over 170 experts from utilities, manufacturers, consultants, research centres and universities who have all contributed to SC A1 activities including working groups, committee meetings, symposiums, colloquiums, tutorials, and webinars.

2022 Paris Session
As the impact of the COVID pandemic receded, it was possible to start to return to a more normal CIGRE schedule. Good progress was made on the finalisation and submission of technical brochures (TB) from working groups in the final stages of completion with 5 TBs being submitted/published. There remains some back-log which we will clear in 2023.

2022 saw the return of the full face-to-face Paris Session with an overall attendance of 3369 registered delegates. The Study Committee A1 General Discussion Meeting was held on Tuesday 30th August 2022. The discussion was based on the prepared contributions received in response to the questions raised in the Special Report resulting from the technical papers submitted for the 2022 session.

There were 21 prepared contributions presented, complimented by 1 presentation by the Cigre New Generation Network (NGN). This is fewer contributions compared to previous years prior to COVID, nevertheless there were some very good, open and interesting discussions on various topics without the need to apply strict time limits. SC A1 is reviewing how to bring the level of prepared contributions back to pre-COVID levels for the 2024 Paris Session.

Tutorials

The following tutorial was presented at the 2022 Paris session:

- "*Guide on the Assessment, Specification and Design of Synchronous Condenser for Power System with Predominance of Low or Zero Inertia Generators*" presented by D.K. Chaturvedi (Convener – India), Fabian Spescha (Australia), Dr Fabian Koehler (Scotland), on Wednesday morning 31st August 2022. The tutorial was based on the work of JWG A1/C4.66.

The tutorial was very well attended, excellently presented and fully appreciated by the attendees.

Annual SC Meetings

A review of the status of current working groups was held on Wednesday afternoon 31st August 2022 and continued on Thursday morning 1st September 2022. The meetings were held face-to-face in Paris and also via GoToMeeting for those unable to be present in Paris. The meetings were well attended with active participation from many members both in Paris and online. Four new working groups were proposed and three of these will submitted for approval soon for starting in early 2023.

The Annual General Meeting followed on Thursday afternoon 1st September 2022 with a lively discussion on topics including SC A1 scope and name, New Generation Network and Women in Energy from the perspective of attracting new members to SC A1, and how to improve regular communication within the SC A1 community and promote timely completion of work.

Due to the developments related to the energy transition, there is concern that the existing name of SCA1 is becoming too limited, as there are other kinds of power generating equipment that are currently not covered by CIGRE, but which could add value to both the study committee and the power generation community. Therefore the importance to incorporate the developments that come forward from the energy transition into the CIGRE study committees was discussed.

In a follow-up meeting of the SC A1 Advisory Group, the importance to look further than the main power grid alone was also highlighted – a topic that has also been identified and discussed within the Technical Council as part of the overall CIGRE 2030 strategy review. For example, motors are also present on ships and in other environments where smaller grids are applicable, the use of high speed motors is becoming more prevalent, and combinations of equipment like pump-storage, generator-batteries, generator-flywheel will become increasingly important as the Energy Transition progresses.

This topic will be actively pursued in 2023 in coordination with the CIGRE 2030 Strategic Plan.

Future Activities

The priorities for 2023 will be to finalise the closure of current working groups which are in the final stages of completion. This means submitting the final reports / technical brochures for publication although the actual publishing date will be determined by Central Office according to the Electra content schedule.

The focus is to continue to progress to work of the remaining working groups listed in Table 1. The new working groups proposed during the 2022 Annual General Meeting will be submitted for approval of the Technical Council for start in 2023.

The next Study Committee Meeting will take place in Japan. The details are still being finalised and will be communicated in early 2023 including the call for papers.

The next Paris Session will be in 2024. The call-for-papers has just been released based on the Preferential Subjects for SC A1 as listed below. The Group Discussion will be based on the Special Report to be released in 2024 based on the new papers submitted for this session.

The preferential subjects have been adapted to reflect the challenges of the energy transition and the increasing prominence of renewable generation as follow:

PS 1: Rotating electrical machines and the energy transition

- 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.

PS 2: Evolution and development

- 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.

PS 3: Keeping the lights on

- 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.

Organisation and Strategic Directions of SC A1

SC A1 is organized into 4 technology groups based on the application of rotating electrical machines. The group renaming and strategic directions were refined in 2022 to better reflect the scope:

- Turbogenerators
- Hydro-Generators
- Large and High Efficiency Motors
- Wind Generators and New Technologies

Since synchronous condensers/compensators are often adaptations of large or small, turbo- or hydro- generators, or large motors, it was decided that these would be covered under the appropriate existing technology groups.

Each of these groups is concerned with the international exchange of information, knowledge, practice, and experience on rotating electrical machines.

Key focus areas within Study Committee A1 are embodied in the updated strategic directions:

- SD 1: Asset management
- SD 2: Machine/Grid interaction and support
- SD 3: Renewable Generation
- SD 4: Machine Monitoring, Diagnosis and Prognosis
- SD 5: High efficiency and efficiency improvement of electrical machines

There are specific activities, mostly in the form of working groups, addressing these strategic directions and forward-looking opportunities within the 4 technology groups. The full list of current working groups is given in Tables 1 to 3 at the end of this report.

The strategic directions are explained individually below.

SD 1: Asset Management

Asset management covers a broad range of aspects relating to the ownership, operation, condition assessment, maintenance and repair, upgrade, conversion, replacement, and storage of rotating electrical machines including strategic spares.
There are currently 9 active working groups associated with this Strategic Direction:

- WG A1.42 seeks to achieve consensus between customer and supplier so that the requirements contained in the technical specification are not a mere continuation of practices originated in the past or even impractical requirements due to a lack of equipment knowledge but to incorporate the current state of the art in the field.

- WG A1.55 is carrying out a survey on split core stators: Site access limitations and the significant size of large hydro generators can make it impossible to transport them as integral units and make site installation very difficult. A split core stator is a practical compromise but is more critical than a single continuous stator core as a poor design can result in core vibrations, noise or shaft voltage and can even lead to core and/or winding damage, shortening the stator life.

- WG A1.56 has completed a survey on lap and wave windings and their consequences on maintenance and performance of hydro-generator stator windings. The focus of this WG has been to describe the different characteristics of lap and wave windings and give a guideline for the optimal choice.

- WG A1.59 has evaluated different techniques and solutions for repairing failed stator windings on a hydro-generator when it is not possible to immediately replace the faulted coil due to operational, commercial, or contractual reasons where the generator must be returned to service as soon as possible. In such circumstances the solution is often to cut out the faulted coil and to operate the generator with a voltage unbalance until a scheduled outage period in which the faulted coil can be replaced.

- WG A1.60 is compiling a guide on the economic evaluation for refurbishment or replacement decisions on hydro generators to assist asset management considerations. It will complement the guide for turbogenerators described in Technical Brochure 641.

- WG A1.62 investigates various problems, root cause analysis and operational limits on thrust bearings of hydroelectric units utilising tilting pads. Failures in the design of these complex systems may lead to failures resulting in major, costly outages.

- WG A1.63 will examine user experiences on large generator terminal bushings. Terminal bushings are a vital part of each turbine generator with extremely high energy concentration, and which are assumed to operate for many years without any maintenance.

- WG A1.64 is developing a guide for evaluating the repair/replacement of standard efficiency motors considering the repairability of the original stator and rotor, the root-cause of the failure, repair cost, motor power rating and efficiency, load duty, environmental conditions, load factor, energy efficient motor purchase price, annual operating hours, electricity price, and economic analysis.

- WG A1.67 is tasked with developing a basic guide on the main state-of-the -art methods applied for end winding corona testing, experience regarding the techniques, the devices used and test conditions and, if possible, establish limit values for end winding corona test results.

SD 2: Machine/Grid Interaction and Support

The behaviour of generators directly influences the behaviour of the system to which it is connected and vice versa. It is essential to clearly understand the effect both systems have on each other to enable effective management of a stable grid as well as to ensure prolonged life of generating equipment.
This strategic direction complements the work of study committee C4 ‘Power system technical performance’, the focus of SC-A1 being the impact on such interaction on the rotating machine and the machine properties and behaviour defined by its design which influence the power system response and reliability.

Since system performance is determined by the output and behaviour other generation sources on the same grid, then this strategic direction also has some overlap with SD 3 'Renewable Generation'. Similarly, the operational flexibility required by modern grids can influence the demands put on auxiliary components e.g., large motors (strategic direction 4).

Currently there are 1 activity associated with this strategic direction in the form of a joint working group (JWG) with Study Committee C4.

- JWG A1/C4.52 - As wind generation is becoming a significant component of the generation portfolio in many power systems, provision of frequency-active power control is increasingly required for this technology in many regions. This joint working group between A1 and C4 will document the state-of-art in developing such capabilities for wind turbine generators, as well as the system technical performance aspects of such controls and the impact of such controls on equipment design and performance.

SD 3: Renewable Generation

The retirement of large fossil-fuelled plant as part of decarbonisation initiatives around the world has led to a significant reduction in system inertia which impacts network frequency control capability and the ability to ride through system abnormalities and faults. This has in turn resulted in a resurgence in the installation of synchronous condensers/compensators at strategic locations in power distribution networks and the conversion of existing generators whose MW power output is no longer required.

Currently there are no active working groups on this topic, although 2022 saw the completion of a Joint Working Group (JWG) A1/C4.66 "A guide on the assessment, specification, and design of synchronous condensers for power systems with high levels of renewable generation" and the publication of TB 885.

SD 4: Machine Monitoring, Diagnosis and Prognosis

Condition Monitoring is a vital instrument in any business as it can result in significant cost savings if done correctly and effectively. The long-term goal of any plant owner is to effectively operate machines to achieve maximal performance, reliability, and efficiency and to make intelligent maintenance decisions through understanding the behaviour and signs of deterioration. The system can also be designed to provide diagnosis of machine condition allowing the prediction of problems, optimize operational efficiency and improve plant productivity.
There are currently 7 active SC-A1 groups performing work in this field.

- WG A1.43 has completed an evaluation of state-of-the-art rotor temperature measurement systems. Some rotating machines today are equipped with temperature measurement instrumentation to detect local overheating of rotor windings or, in the case of hydro-generators, rotor structure. This topic is of high importance, not just for machine monitoring and diagnostics purposes, but also for the purposes of machine design and construction improvements.
- WG A1.61, has been tasked with filling the information gap in the predictive diagnosis of winding insulation in large motors (more than 800 kW and 1000 V). The technologies in this field have evolved fast and new measurement and diagnostic tools are now available,

including new kinds of PD sensors and new signal processing tools for noise and disturbance suppression. Simultaneously, the industrial use of converter fed high-voltage machines is steadily growing. Particularly in motors, where the effects of motor drivers on the insulation aging process and in PD monitoring have a significant influence, there is still a lack of information, reference cases and standard procedures.

- The following 4 WGs related to hydro-generators are in the initial phase. WG A1.69 addresses measured v calculated excitation current anomalies, whilst WG A1.71 and A1.72 will carry out surveys on rotor damper winding concepts, and multi-turn stator coil construction respectively. WG A1.73 will assess customer requirements for the qualification of form wound stator insulation systems for hydro-generators.
- WG A1.70 is making good progress and builds on the excellent work done on the use of Dielectric Dissipation Factor (DDF) measurements in relation to the assessment of the condition and quality of stator insulation of new bars and coils of rotating electrical machines (reported in Technical Brochure 769) by focussing on DDF measurement results of complete stator windings. Due to the amount of collected information it is the intention of the working group to publish the results in at least two Technical Brochures (part 1 and part 2).

SD 5: High efficiency and efficiency improvement of electrical machines

Generators and motors are the most efficient components used in the power generation process, with power conversion efficiencies ranging from 98% to 99%.
However, on a large turbo generator of 1000MWe output, a 0.1% improvement in efficiency can result 1MWe extra being available to the national grid, powering an additional 50 to 60 households, without any increase to operational costs.

Motors are used extensively in power plants throughout the many diverse systems to drive compressors, fans and pumps, and many other equipment which are critical to successful and reliable power generation. Use of high efficiency motors also has a large potential for reducing the energy consumed within a power plant (see Technical Brochures 724 and 729).

Rotating machines are generally optimised at the design rating based on the assumption of base load operation, so prolonged operation at part load results in a decrease in the actual mean efficiency that can be achieved.
With a gradual change in the load duties of large power plant in support of the increasing penetration of renewable power sources, machines will operate more and more at part loads for relatively short and variable time frames. Therefore, considerations of efficiency may have to be adapted in future.

There are currently 4 active working groups addressing this strategic direction.

- WG A1.45 is compiling a guide for Determining the Health Index of Large Electric Motors. The guide will aid utilities in identifying the appropriate measurements that are necessary for statistical quantification of in-service failure risk for effectively planned predictive maintenance interventions.
- WG A1.53: As the penetration of VFDs in industry and in power stations has increased, several motor failures have been reported worldwide and it has become clear that manufacturers do not have common design criteria for inverter grade motors considering

the different stresses imposed on motor insulation by the variety of available VFD technologies. This WG shall elaborate the design requirements of three phase induction motors for variable frequency drive (VFD) applications including a user guide for retrofitting of existing installations.

- WG A1.58 aims to compile a guide for the selection of copper versus aluminium for the rotor cages of squirrel cage induction motors used in power generation plant. The guide seeks to give a clearer understanding of the advantages and disadvantages of these material choices.
- WG A1.68 was established to compile a guide covering the best available practices on evaluating the quality performance of motors.

Currently Active Working Groups

There are currently 21 active working groups:

- Table 1 lists the 17 working groups that will continue their work in 2023
- Table 3 lists the 4 working groups that are in the final stages of TB review and submission which are targeted for completion in 2023, and 1 working group which is expected to complete and issue the first part of its work also in 2023.

Three new working groups, proposed during the 2022 SC A1 Annual Meeting held in Paris, will be launched in 2023 following approval of the Terms of Reference (TOR).

WG #	Title of the Working Group	Convener
A1.45	Guide for Determining the Health Index of Large Electric Motors	Dr. Zhang Pinjia
A1/C4.52	Wind generators and frequency-active power control of power systems	Nicholas Miller
A1.53	Guide on Design Requirements of Motors for Variable Speed Drive Application	AK Gupta
A1.55	Survey on Split Core Stators	Sun Yutian
A1.58	Selection of Copper Versus Aluminium Rotors for Induction Motors	Fredemar Rüncos
A1.60	Guide on economic evaluation for refurbishment or replacement decisions on hydro generators	Mark Bruintjies
A1.61	Survey of Partial Discharge Monitoring in Large Motors	André Tomaz de Carvalho
A1.62	Thrust Bearings for Hydropower - A Survey of Known Problems and Root Causes	Daniel Langmayr
A1.63	Turbo Generator Stator Winding Bushings and Lead Connections – Field Experience, Failures and Design Improvements	Jabulani Bembe
A1.64	Guide for Evaluating the Repair/Replacement of Standard Efficiency Motors	Erli Ferreira Figueiredo
A1.67	State of the Art in methods, experience and limits in end winding corona testing for Hydro Generators	Hélio de Paiva Amorim Junior
A1.68	Evaluating Quality Performance of Electric Motor Manufacturing and Repair Facilities	Kondra Nagesh
A1.69	Hydro-Generator Excitation Current Anomalies	J. Johnny Rocha E.

A1.70	Dielectric Dissipation Factor Measurements on Stator Windings	Monique Krieg-Wezelenburg
A1.71	Title of the Group: Survey on damper-winding Concepts and its operational experience on hydro generators and motor-generators	Thomas Hildinger
A1.72	Survey on multi-turn coils with dedicated turn insulation versus coils without dedicated turn insulation	Yoon Duk Seol
A1.73	Customer Requirements for Qualification of Form Wound Stator Insulation Systems for Hydro Generators	Franz Ramsauer

Table 1: Currently active SC-A1 Working Groups

Publications:

Four Technical Brochures (TB) were published in e-cigre in 2022 and one was submitted for publication. Several other working groups are in the final stages of preparing the submittal documents – these are listed in Table 2 and will be targeted for release in 2023.
Once submitted, the publication in Electra will be coordinated by Central Office.

WG	Title	Type
A1.33	Guide for Cleanliness and Proper Storage of Generators and Components	TB860
A1.44	Guideline on Testing of Turbo and Hydrogenerators	TB879
A1.48	Guidance on High-Speed Testing of Turbo Generator Rotors	TB878
A1.54	Impact of Flexible Operation on Large Motors	TB*
A1/C4.66	Guide on the Assessment, Specification and Design of Synchronous Condensers for Power Systems with Predominance of Low or Zero Inertia Generators	TB885

TB = Technical Brochure, WR = Working Group Report, * = Submitted for publication

Table 2: SC-A1 Publications in 2022

WG	Title	Type
A1.42	Influence of Key Requirements to Optimize the Value of Hydro Generators	TB
A1.43	State of the Art of Rotor Temperature Measurement	TB
A1.56	Survey on Lap and Wave Winding and their Consequences on Maintenance and Performance	TB
A1.59	Survey on Industry Practices and Effects associated with the Cutting Out of Stator Coils in Hydrogenerators	TB
A1.70	Dielectric Dissipation Factor Measurements on Stator Windings: Part 1	TB

TB = Technical Brochure, WR = Working Group Report

Table 3: SC-A1 Publications planned to be submitted in 2023