A1 - 00

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 large 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 2014

The Study Committee invited written contributions to provide discussion material for the Group Meeting in Paris Session 2014. A total of 21 papers were accepted from those submitted for approval under three Preferential Subjects. (Two papers were subsequently withdrawn before the final submission deadline.) The three Preferential Subjects for Session 2014 are:

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PS1 Developments of Rotating Electrical Machines

- Improvements in design, manufacture, efficiency, operation and maintenance. Developments in insulation, machine capacity, cooling reliability, bearings and materials
- Influence of customer specifications and grid operator requirements on the operation, design and cost of machines

New developments for extending the power rating of large generators

PS2 Life Management of Generators

- Refurbishment, replacement, power up-rating, efficiency improvement. Economic evaluation and influence of grid codes on refurbishment decisions.
- Effects of torsional oscillations on the shaft fatigue of generators
- Failure analysis: determination of root causes and prevention, including robotic inspections

PS3 Rotating Machines for Dispersed Generation

- Design, manufacture, development, capacity, generation costs and operation problems, efficiency, monitoring and diagnosis
- Effects of faults and system disturbances on design and control strategies of machines
- Evolution and trends in machines for dispersed generation

3. Preferential Subject 1
Developments of Rotating Electrical Machines

Thirteen papers were originally accepted under PS1 but one was cancelled before receipt. Of the remaining twelve papers, two (Papers A1-107 and A1-110) have been transferred to PS2 by the Special Reporters as the papers are a better fit in this subject area. The ten papers will be discussed in the following order:

3.1 Improvements and developments in design and manufacture
3.1.1 The use of models and other simulation techniques

Paper A1-101 (Canada) is an interesting paper that describes research into a new method of estimating the efficiency of refurbished induction motors without the need for dynamometer tests. The method involves taking some basic electrical measurements, both at standstill and during a no-load test, and using these results with some nameplate details as input data to a new algorithm. This algorithm has been developed and tested on a range of small induction motors and has provided the basis for a new software programme. This software has been used to test a total of 192 motors to date.

Paper A1-103 (Argentina) describes how the ventilation system of a hydro-generator was optimised by using Computational Fluid Dynamics (CFD) modelling techniques. The resulting model was validated by comparing the CFD results with the results obtained from tests carried out on a laboratory scale model. The use of scale models in ventilation studies is a recognised technique that, when applied correctly, produces results that compare well with the conditions in the actual machine. The paper concludes that as this is the case, measurements taken on scale models may be used to validate CFD models with some confidence.

Paper A1-105 (Brazil) describes the use of mathematical models to predict the behaviour of windings which are subject to transient voltage surges from the supply system. Typical source of surges are lightning strikes and switching operations. A series of measurements was carried out on installed machines and the results were compared to predictions made using standard transmission line models. These comparisons indicated that the results obtained from the computer simulations were similar to the measurements taken on site, and the paper concludes that such simulations will predict the response obtained on site quite accurately.

Paper A1-111 (Spain) describes a study that examines whether using a modular rotor build for a permanent magnet synchronous machine (PMSM) could adversely affect the machine behaviour. The use of PMSMs is increasing, particularly in offshore applications, mainly because of their reliability and performance. However, conventional PMSMs can cause serious transport difficulties because of their size. The paper examines the effect of using a modular build machine on various electrical and mechanical parameters. The authors found that, in general, the performance and parameters of such a machine are close to those of a normal build machine, the exception being the amplitudes and frequencies of the cogging torque components.

Question 1.1 The method described in Paper A1-101 provides a useful tool particularly for repair workshops. However, the accuracy of the input data is extremely important. Will the algorithm be further refined in the light of the ongoing assessment referred to in the summary section? Have delegates any experience of similar developments in motor repair technology?

Question 1.2 The successful application of Method A in Paper A1-101 requires high accuracy input data. If, on a particular motor, one or more of the key nameplate data items was missing or had been stamped incorrectly, rated speed for example, would the algorithm still be used with a 'best estimate' value, or would a different approach be used?

Question 1.3 Could the authors state how often the ventilation optimisation technique described in Paper A1-103 has been used and over what range of pole numbers? Have other delegates experience in the use of similar, or other, CFD applications on electrical machines?

Question 1.4 Surges and transient voltages from many sources can affect machines on power systems. Do delegates know of other power companies that use a surge modelling technique described in Paper A1-105 (or similar)? If not, do these organisations rely on the machine manufacturers or specialist companies to ensure that their machines are adequately protected against surges?

Question 1.5 Paper A1-111 quotes cogging torque frequencies and amplitudes that could be damaging. Have any such problems been reported with wind farm installations and, if so, how have they been dealt with?

3.1.2 Other improvements in design and manufacturing

Paper A1-102 (Argentina/Brazil) describes tests that have been carried out on standard efficiency, high-efficiency and premium efficiency motors to determine the effect of voltage unbalance, voltage distortion and load level on motor efficiency. The paper concludes that in the case of voltage unbalance, the reduction of efficiency in the premium class motor was significantly more than that of both the high-efficiency class motor and the standard class motor. The authors attribute this to the higher efficiency motors having lower negative sequence impedances than standard class motors. In voltage distortion tests the efficiency of motors in all classes deteriorated at the same rate.

Paper A1-109 (India) reviews the some of the potential problems that must be considered when applying variable frequency drive (VFD) systems to motors, in particular the electrical stresses imposed on the winding by surge voltages. The paper lists the issues that need to be addressed when selecting motors for VFD installations and also considers the additional requirements when retrofitting a VFD to an existing installation.

Paper A1-108 (France/Switzerland) reports on a project to manufacture large welded 4-pole turbo-generator rotor shafts by using existing techniques previously used in the manufacture of reliable steam and gas turbine rotors. The paper reviews the various factors that had to be considered during the project to ensure that the final rotor would be fit for service, with no weaknesses or areas of concern when compared with a conventional rotor. A prototype rotor has been built for use as a spare in a 900 MW nuclear generator and has been in service since November 2013.

Paper A1-113 (Japan) reviews the reasons for and advantages of using adjustable speed units for pumped storage hydro-generation installations. The paper then gives a brief description of the design features and construction of what is, at present, the largest such unit built to date. This unit, rated at 475 MVA/460 MW, has already undergone some site commissioning tests and is expected to be in commercial operation later this year.

Question 1.6 Do the authors of Paper A1-102, or other delegates, have any ideas how the negative impact of poor power supply quality on motor efficiency could possibly be minimised in the future?

Question 1.7 Papers A1-102 and A1-109 share some common ground in that they both cover the effect of supply system harmonics on high-efficiency induction motors. Do delegates have any views on whether the harmonic levels found in VFD systems are significant factor in the choice of motors for use in such systems?

Question 1.8 Although the manufacturing process for turbo-generator rotors described in Paper A1-108 was developed specifically to reduce the lead time of forgings, could the use of this process provide any additional, unforeseen benefits or problems?

Question 1.9 What is the reaction of delegates from utilities to the use of welded rotors in turbo-generators? Do they foresee any future expansion of this technique?

3.2 Influence of customer specifications and grid code requirements

Paper A1-104 (Colombia) outlines the creation of a practical procedure to determine the true reactive power capability range of existing generators on the Colombian power system. This procedure was felt to be necessary following recent problems experienced by the system and has been developed by collaboration between the ISO and the main utilities. The paper describes in some detail the various machine limits and shows that the procedure fulfils the original expectations. The paper recommends that before applying this procedure a detailed system simulation should be carried out.

Paper A1-112 (Italy) explains why the Italian TSO has chosen to install rotating synchronous compensators at an HVDC substation in Sardinia instead of static compensation equipment. The local grid system is unusual in that it has a large amount of generation provided by renewables, with wind and PV generation amounting to a possible 110% of peak load. The TSO believed that this could jeopardise the security of the grid voltage regulation and stability, and undertook a study to determine the best method of reactive power support. The study concluded that rotating machines were the best option with large cylindrical-rotor air-cooled units being the machines of choice.

Question 1.10 System operators throughout the world have long recognised the need for sufficient equipment to provide system voltage support by reactive power control. To ensure this need is met they have created grid codes and appropriate technical requirements similar to those described in Paper A1-104. Do SC A1 members have particular concerns that equipment previously supplied for use on systems not covered by grid codes may in future be covered by codes? How widespread is the use of 'unregulated' systems with equipment already supplied?

Question 1.11 The conclusions drawn in Paper A1-112 are of particular interest to SC A1 members as they describe a specific application in which rotating machines have been chosen in preference to high-speed electronic control devices for compensator duties. Do delegates have other examples where this has been the case?

Question 1.12 Has there been a significant increase in the use of adiabatic cooling systems as described in Paper A1-112 in recent years? Have A1 delegates experience in such systems?

4. Preferential Subject 2
Life Management of Generators

Seven papers were originally accepted under PS2 but one was cancelled before receipt. Two papers (A1-107 and A1-110) have been transferred from PS1 by the Special Reporters as the papers are a better fit in this subject area. The eight papers will be discussed in the following order:

4.1 Refurbishment, replacement, power up-rating, and improvement

Paper A1-110 (India) looks at the operating experience of a power company with static and brushless excitation systems on generating units in India, and questions the rationale behind the choice of one system over another. They cite problems with the reliability of brushless systems ranging from diode failure to broken flexible connections and cooling fan failure, compounded by difficulties in affecting repairs in a reasonable time frame due to the complexity of the design, which leads to long outage times, and the availability of spare diodes or other replacement parts. Static systems on the other hand are reported to be of a relatively simple and robust construction leading to highly reliable operation. A table is given comparing the advantages and disadvantages of both systems including first cost, technical performance and operating aspects. The paper concludes a strong preference for the static excitation system at least for medium to large power plants.

Paper A1-207 (Ukraine) addresses the problem of axial vibration of large turbogenerator stator cores in service due to electromagnetic effects, and the resulting deterioration in the mechanical and electrical integrity. The experience refers to units in the Ukraine and Russia over the past 60 years rated from 100MW in the 1950's through to recent times with 200-300 MW, and even 1000MW. It is stated that the phenomenon of the internal forces resulting from electromagnetic interactions within the stator core were not fully understood or addressed in the past. The paper presents an explanation, and verification, of the dynamic axial forces that are present in operation compared to the static loading. On machines showing signs of degradation design solutions have been found to improve the core tightness to counter-act these forces, in some cases even allowing an upgrade of the machine output. No details of these specific design measures have however been given.

Question 2.1 The performance of brushgear for static excitation can be sensitive to the ambient conditions (humidity, temperature etc.). Is the view on brushless versus static systems shared by other users in other countries where operating conditions may be different?

Question 2.2 Brushless excitation is used extensively on smaller generators where staff are not always available to check and maintain brushgear performance, and on some very large generator designs for which there are specific advantages. What experience have users had on these generator sizes/types regarding reliability and maintenance?

Question 2.3 Have other manufacturers or users had problems attributed to axial vibration of the stator core? How have these problems been addressed, and is this still perceived as a potential issue on modern generators?

4.2 Effects of torsional oscillations on the shaft fatigue of generators

Paper A1-107 (China) examines the mechanism of sub-synchronous resonance of turbine-generator shaft lines caused by the rapid control of power electronics within transmission systems, e.g. Thyristor Controlled Series Compensation of long distance transmission lines, HVDC systems, and HV convertors for motor control. Apart from the optimisation of the control parameters, the authors analysed additional function blocks in the control schemes of these systems in order to suppress the level of disturbances likely to result in sub-synchronous torsional oscillations and associated loss of life of turbine-generator shaft lines. Such methods still cannot eliminate the problem completely, and therefore additional damping control is proposed on the generator excitation system, or at the generator terminals, using the direct measurement of shaft line speed as the control parameter.

Question 2.4 What practical experience is there in the field of such supplementary control devices to suppress SSO of turbine-generator shaft lines, and is there finally a preference regarding where such additional control features should be implemented?

Question 2.5 Paper A1-107 proposes the use of shaft line speed measurements to detect and control SSO at the generator. Are schemes available to utilise such measurements to also assess sub-synchronous shaft torques and therefore deduce loss of fatigue life?

4.3 Failure analysis and prevention

4.3.1 Generator stator endwinding vibrations

Paper A1-201 (Canada) raises the topic of generator stator endwinding vibration and suggests that there has been an increasing trend of associated problems over the last 10 years or so, predominantly on large air-cooled units typically installed in gas turbine or combined cycle plants. The paper explores the reasons why high endwinding vibrations may occur, and gives some examples of resulting problems in the field. To identify the potential for such problems, the paper proposes offline modal analysis (bump tests) on the stator endwinding, and online monitoring of stator endwinding vibrations. Some guidance values are given regarding natural frequency ranges to be avoided, associated response levels above which high vibration levels may be expected, and alert levels of vibration in operation.
The authors consider why an increasing trend has been observed in recent years, and ask the question if commercial pressures to reduce generator first costs have driven adverse design changes or simplifications.

Paper A1-203 (Canada) considers the same topic as paper A1-201, but with the focus on a specific case study of a hydro generator where fibre-optic vibration sensors were fitted to analyse the vibration behaviour of the stator endwinding after higher noise and vibration had been observed. The paper highlights the importance of sensor location and orientation, and demonstrates the temperature and load dependency of the measured vibration levels. Rather than just relying on vibration amplitudes, the benefit of trending the measurements over time is recommended to detect any worsening of the endwinding support allowing timely intervention to reduce the vibration levels and avoid a major failure.

Question 2.6 Stator endwinding vibration has become a hotly discussed topic in recent years. Actual values are very machine specific and are highly dependent on where and how the measurements are taken, including the filtering applied to the signals, and the operating conditions at the time. As noted in Paper A1-201, several working groups have been set up recently to provide guidelines on the measurement and assessment of endwinding vibration levels. What is the scope and present status of these working groups?

Question 2.7 The apparent higher incidence of stator endwinding problems highlighted in the papers could be due to many contributing factors. One such factor could be a higher cyclic load pattern than may have been experienced in the past prompted by the higher penetration of intermittent renewable power generation. Since this trend is likely to intensify in the future, what other operational problems may be foreseen, and how can they be addressed on either existing or new machines?

4.3.2 Data collection and analysis

Paper A1-202 (Canada) describes the development of a prognostic model to use as a tool for identifying particular problems with hydro generators as potential root causes of probable failure mechanisms from a set of diagnostic and operational data. The tool could combine analysis of on-line monitored data with the results from other diagnostic tests to help engineers identify maintenance strategies.

Paper A1-204 (China) describes a mathematical method of analysing a set of measured parameters to determine the cause of abnormal readings. The method is a learning based

approach (artificial intelligence), whereby the system is fed typical data associated with defined faults (learning phase), and can thereafter give the likelihood that these defined fault causes are responsible for a given set of measured data where the fault cause is not known.
An example is given of measured vibration data from multiple sensors located on various parts of a hydro generator. 110 sets of data defining known fault conditions are used to prime the algorithm, then 440 sets of 'test' data are used to fine tune it. Then it is applied to a real set of data where the fault is unknown.
The method analyses the frequency spectra of the vibration data at each monitoring location [frequency feature extraction], and the vibration pattern across the whole machine from all locations [spatial feature extraction], to determine which of 11 pre-defined faults are the likely cause of the particular spectra and pattern observed , e.g. rotor unbalance, rotor misalignment, uneven clearance etc.
An example is given where the improved algorithm was applied to data from an operating unit, and gave the same likely cause of the observed behaviour from the two data extractions. The cause was later confirmed by inspection.

Paper A1-205 (Croatia) describes a data monitoring and logging system analogous to the black boxes used on airplanes to help analyse the cause of accidents. The system comprises a combination of measurement sensors and measuring modules connected to a programmable processing unit which analyses and logs specific aspects of machine operation for diagnostic purposes in the event of a failure, but also for assessing preventative maintenance or adaptations to how the machine is operated. The difference between the Electrical Machines Black Box (EMBB) and conventional data monitoring systems is that it detects and logs specific types of machine operation that could lead to problems, e.g. asynchronous operation, incorrect synchronisation, two-phase operation, overload, overheating, vibration etc..
The system is intended to complement existing data collection and monitoring systems, but also to provide a cost effective retrofit to existing plant with limited logging/diagnostic capabilities.

Question 2.8 Learning based systems require a large amount of data to set up the algorithms and tune them to give a reliable diagnosis. This is suited to large utilities with many similar machine types, and facilities to collect and analyse the large amounts of data involved. Can such techniques be cost effectively and reliably applied by smaller operators with a diverse mix of generator types?

Question 2.9 There have been many initiatives in the past to automate the analysis and diagnosis of measured operating data to aid preventative maintenance or repair/replace decisions. Are such systems getting close to being fully autonomous and reliable or will expert knowledge and final assessment always be needed?

5. Preferential Subject 3
Rotating Machines for Dispersed Generation

Only one paper was accepted under PS3 which is discussed below.

Paper A1-301 (United Kingdom) looks at the challenges of asset modelling in the wind energy sector. The research focusses on operational expenditure as one aspect to reduce the cost of electricity and maintain the long-term viability of offshore wind power. The paper considers three main aspects associated with operation costs; modelling of the weather and ocean conditions, analysis of maintenance data, and equipment condition monitoring. Tools are developed to optimise the operation and maintenance of wind farms including such considerations as access for maintenance (weather dependant), hire/purchase of specialist equipment (e.g. floating cranes and barges), and the real need for specific types of maintenance (probabilistic approach to the use of condition monitoring data to avoid false diagnosis). Such approaches to the reduction of operating costs will gain increased importance and focus in future as government subsidies are reduced, and costs of electricity have to become more competitive with alternative onshore energy sources.

Question 3.1 Paper A1-301 addresses the particular challenges faced by UK offshore wind energy operators due to the often adverse weather conditions in the North Sea. Have users/operators in other countries with relatively high wind power penetration (e.g. Germany, Denmark, and Ireland etc.) considered similar approaches to the optimisation of operational costs?

Question 3.2 The size of wind turbines for offshore generation continues to increase. What are the factors that may determine a maximum viable size from the point of view of operational cost?