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SPECIAL REPORT FOR SC A1
(Rotating Electrical Machines)

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Special Reporters

(with support from Trevor STOKES)

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 2016

The Study Committee invited written contributions to provide discussion material for the Group Meeting in Paris Session 2016. A total of 21 abstracts were accepted from those submitted for approval under three Preferential Subjects. Two papers were subsequently withdrawn. The submitted 19 papers are summarised below under the following three Preferential Subjects chosen for the 2016 Session.

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PS1 Developments of Rotating Electrical Machines and Experience in Service

- Design, manufacture, maintenance and performance improvements in generators, excitation systems and starting methods of pump storage units.
- Influence of customer specifications and grid operator requirements on generator designs and performance. New developments for improving the performance, design, cost and flexibility of operation of large generators.
- Efficiency, operation, control and design of motors for power stations and dispersed generation.

PS2 Asset Management of Electrical Machines

- Experience with refurbishment, replacement, power up-rating and efficiency improvement of aged generators and associated project cost benefit analysis.
- State of the Art equipment and experience with Robotic inspections.
- Improvements in monitoring, diagnosis and prognosis systems.

PS3 Rotating Machines for Renewable and Dispersed Generation

- Design, manufacture, generator costs, efficiency, monitoring and diagnosis.
- Effects of faults and system disturbances on design and control strategies.
- Evolution and trends in machines for renewable generation.

3. Preferential Subject 1
Developments of Rotating Electrical Machines and Experience in Service

Sixteen papers were originally accepted under PS1 but one was withdrawn. Of the remaining fifteen papers, one paper (A1-111) has been transferred to PS2 by the Special Reporters as the paper better fits in this subject area. The remaining fourteen papers will be discussed in the following order:

3.1 Design, manufacture, maintenance and performance improvements in generators, excitation systems and starting methods of pump storage units

***<u>Paper A1-104 (Japan):</u>* Upgrade from the fixed speed to adjustable speed (Okutataragi Pumped storage power plant)**

This paper refers to the experience of upgrading the Okutataragi pumped storage power plant. The paper describes the unique known upgrade procedure that transforms a fixed speed to an adjustable speed machine. The main challenge was to preserve the main external dimensions, and to reduce the rotor weight whilst securing the same fly-wheel effect (GD2).

<u>Question 1.1:</u> One of the main constraints faced during the upgrade was to deal with the short circuit ratio (SCR). How is the SCR associated with the stator winding modification?

<u>Question 1.2:</u> The conceptual change in this upgrade was the transformation from a salient pole to a cylindrical rotor. Originally, the air-gap magnetic field was modulated based on the air-gap reluctance; in the proposed solution the magnetic field modulation is based on the

rotor winding magnetomotive force spatial distribution. Therefore, it would be interesting to understand how the stator winding had to be adapted to meet this transformation?

<u>Question 1.3:</u> The cylindrical rotor winding demands the introduction of rotor slots to locate the rotor winding? Are there any constraints in choosing the number of rotor slots?

<u>Paper A1-102 (Brazil):</u> Fatigue Assessment in the Pole Fixation of Hydro-Generators

This paper describes the mechanical assessment of the salient pole fixation of hydro generators, using Finite Element Analysis in conjunction with the FKM-Guideline for static and fatigue strength evaluation based on nominal and local stress fields. The assessment takes into account the load spectrum of operation relevant to fatigue lifetime (start-stops, load rejection, runaway etc.), and is used to determine the remaining lifetime, recommend future maintenance intervals, or aid repair/replacement decisions. Further investigation using NDT methods may be advised to determine the actual condition of the pole fixation before a final recommendation can be proposed.

Question 1.4: How does the number of allowed cycles calculated by the method described in paper A1-102 compare with the number originally recommended by the OEM? Are they generally considered to be conservative, or optimistic?

Question 1.5: What is the experience/preference of other OEMs regarding the fatigue limit assessment guideline (FKM, ASME or other), and typically what is the difference in the calculated number of allowed cycles when adopting one or other of the different guidelines?

Question 1.6: Have catastrophic failures of poles occurred on hydro generators in the past due to fatigue crack growth in the areas of the pole fixation discussed in paper A1-102?

<u>Paper A1-112 (Croatia):</u> Loss Reduction Methods of Salient Pole Synchronous Generator Damper Winding by means of Slot Skew

Paper A1-112 presents a numerical assessment using finite element methods of the calculation of voltage waveform harmonics and pole damper bar losses as a function of stator slot skew and damper bar pitch. The paper reviews the advantages and disadvantages of the various FE computational methods available, and proposes the multi-slice 2D procedure as an alternative to 3D analysis. Using the adopted method, an assessment of damper bar loss sensitivity to stator slot skew, and the impact of both slot skew and damper bar pitch on the quality of the stator voltage waveform, is presented. The paper proposes that by a combination of stator slot skew and damper bar pitch, a compromise can be achieved whereby the slot skew can be reduced, thus easing manufacturing aspects, whilst the damper bar pitch can be chosen to achieve the required voltage waveform quality with acceptable steady state bar losses and pole heating.

<u>Question 1.7:</u> The no-load voltage wave shape at the generator terminals is greatly influenced by damper bar currents on salient pole generators, mainly when the number of slots per pole and per phase (q) is an integer number. Currently, this effect is more dramatic when q=3. Sometimes damper shifting or pole shoe shifting is not enough to mitigate this influence. Some authors have defended the idea that the second harmonic of the stator slot permeance requires strict control to avoid undesirable surprises. Have some delegates faced a similar experience, or have observed the influence of this second harmonic effect?

Question 1.8: Paper A1-112 presents the sensitivity of pole damper bar losses to varying stator slot skew for the standard, evenly pitched damper bar arrangement matching that of the stator slot pitch. The paper subsequently shows how damper bar pitch can drastically improve the voltage waveform even with zero stator slot skew, but with increased levels of bar loss. Could the authors please indicate the relative level of the damper bar losses for the shorter pitched arrangement compared to the standard, and if the sensitivity of the losses to slot skew is the same for the short pitched damper bar arrangement placement as for the standard placement?

Question 1.9: In paper A1-112, what would be the influence of the stator slot opening on steady state damper bar currents?

Question 1.10: The generator design considered in paper A1-112 appears not to need either slot skew or a short pitched damper bar placement to meet the THD specified in IEC60034-1. Have delegates experience of a generator with rated power above 50 MVA, with skewed stator slots? Would it be possible to share their experience with us, including the aspect of maintenance?

***Paper A1-114 (Algeria):* Analytical and Numerical Computation of Wound Field Synchronous Generators**

Paper A1-114 presents an analytical procedure based on Laplace and Poisson equations to calculate the magnetic field, the flux linkage, the electromotive force and synchronous reactance in synchronous generators with a single layer stator winding. The proposed methodology considers the slot opening both in the stator and in the rotor. Salient pole synchronous machines are solved as a particular solution of the proposed method. The results are compared with finite element analysis and it has shown a good correlation.

Question 1.11: Have other delegates developed similar analytical procedures to calculate the air-gap magnetic induction on slotted synchronous machines? Would you share that experience with us?

Question 1.12: Has the author or other delegates ever evaluated the analytical procedure when applied to an actual machine? How would this analytical method perform when applied to an actual hydro-generator with a fractional number of slots per pole and phase?

***Paper A1-115 (China):* Calculation and Analysis of Dynamic Damper Bars Currents and Electromagnetic Force for a Generator-Motor Working as Synchronous Condenser**

Paper A1-115 deals with the calculation process involving the damper bars of a salient pole pumped storage generator/motor operating as a synchronous condenser. The general observation and comments are based on finite element analysis of the quasi-static magnetic field.

Question 1.13: The transition from 1600A to 1000A loading will reflect different damper bar current distributions. How is this change in current associated with the operating voltage, apparent power and power factor?

Question 1.14: For a salient pole synchronous machine operating as a synchronous condenser at steady state (cosφ=0 capacitive), the pole and the armature reaction magnetic lines of flux will be concentrated over the direct axis (at the centre of the pole). At the transition from 1600A to 1000A a transient current is expected to flow in the damper bars. Considering this condition, would it be possible for the authors to elaborate an explanation of the flux, or damper current, shifting to bar one?

Paper A1-107 (Netherlands): ***Root Cause Analysis of 450 MVA generator stator core fault***

Paper A1-107 gives details of a 450MVA generator core fault and the results of the root cause analysis carried out prior to repair. The unit in focus suffered a severe core fault whereby a portion of the core melted, although damage was also observed in other areas of the core but in a less advanced stage of deterioration. The failure was finally attributed to a combination of circumstances involving potentially weakened core lamination insulation (by inclusions during manufacture which may have resulted in high pressure points on assembly), over-fluxing events on start-up due to a forcing of the excitation to accelerate the start-up process, an increased number of starts due to the generation profile required by the grid, an increased axial flux component at the drive end of the core due to rotor/stator cold offset at start, and finally an extended period of operation at leading power factor which results in higher axial flux loading at the core ends. The critical factors were deemed to be the quality of the lamination insulation and the over-fluxing during start-up. No generic design factors were identified, so the repair was to fit a new stator core, and rewind using the undamaged stator bars, and new bars where necessary. The excitation system was modified to a soft-start scheme, which had already been implemented on the other units at the plant prior to the incident.

Question 1.15: The final core fault described in Paper A1-107 appears to be due to a combination of factors that led to a general deterioration of the core. Why was this not detected by routine testing during outages? Could such deterioration have been detected by e.g. El-Cid testing using robotic equipment, and has this or other techniques been applied to the other units at the plant?

Question 1.16: Have other users recent experience (within the last 10 years) of stator core deterioration that they have needed to address, and how was the situation detected and dealt with? Has the root cause of such situations been adequately established?

Paper A1-116 (Japan): ***Development of Larger Output Indirectly Hydrogen-cooled Turbine Generator with High Heat Transfer Main Insulation***

This paper presents the continuing improvements in large, indirect hydrogen-cooled generators using high thermal conductivity stator bar insulation using conventional fillers, and improved ventilation features, as the main enabling technologies. A generator development up to 870 MVA is described, which has undergone factory running tests to validate the performance. The results presented indicate that significant improvements in thermal conductivity have been achieved while maintaining good electrical endurance characteristics. Additionally further developments in the insulation technology from a VPI (Vacuum Pressure Impregnation) process to a resin rich insulation system is introduced by which a 900 MVA class generator would be feasible, and it is envisaged that future enhancements could even allow indirectly cooled generators up to a rating of 1000 MVA to be achieved, thus replacing the water-cooled solutions traditionally used in this power range.

Paper A1-109 (Brazil/Germany): ***Improved Generator Performance with a Nanocomposite High Voltage Insulation System for Stator Windings – A Status Report***

The authors of this paper presents a progress report on a long term research and development program focussed on exploiting the beneficial properties of nanofillers to improve the electrical endurance characteristics of stator winding insulation. The authors appear to have overcome the difficulty of incorporating a relatively large percentage of filler in the impregnating resin and provide a qualitative description of the mechanism that permits this new insulation system to exhibit superior electrical properties by mitigating the electrical treeing channels that develop at the resin interfaces. The effort of investigating the retardation of the treeing process is also described, and how this understanding may contribute to the extension of the insulation lifetime. Finally, the voltage endurance testing process is discussed, describing the findings of pure electric field testing of bar samples in regard to the influence of the actual bar geometry on the results. Consequently the advantages of the concept of a Voltage Endurance Improvement factor are presented.

One of the stated aims of this work is to address the challenges to the reliability of generators presented by the new highly flexible grid demands that are being imposed in many geographical regions.

Question 1.17: What are users opinions/concerns regarding the use of such highly rated indirectly cooled machines in power plants given the changing nature of the load profile of thermal power plants? How do users take these concerns into account against the commercial aspects of first cost and operating/maintenance costs when considering new/replacement plant purchases?

Question 1.18: The authors of papers A1-109 and A1-116 describe very significant efforts by two OEMs to address major challenges for the future operation of large steam turbine generators. Given the changing electricity supply market in many countries what other issues are envisaged for generator design that would require the implementation of new materials and developments such as those described in papers A1-109 and A-116?

Question 1.19: In paper A1-109 it is mentioned that SiO2 nanoparticles were finally chosen as the main charge to improve the insulation properties related to lifetime expectancy. Would it be possible to describe if other materials were considered at the beginning of this research and which are the main properties of SiO2 nanoparticles that have driven its selection.

Question 1.20: Paper A1-109 concludes that the aging process of the new composite follows a different, retarded degradation mechanism when compared to the neat epoxy resin. Would the authors present an explanation of this new degradation mechanism, if possible listing its accelerating factors?

Question 1.21: In paper A1-109 the authors expect that the adoption of the nanocomposite insulation will increase the overall generator performance (MVA) between 10-15%. Would it be possible to the authors to explain in more detail how this improvement would be achieved?

Paper A1-113 (France): ***Optimized design of 4-pole Turbo Generator 2235 MVA platform***

Paper A1-113 provides an overview of the efforts of one manufacturer to re-engineer the design of an existing 4-pole generator to take into account a number of challenges such as accommodating various grid codes, power uprate and cost concerns. The approach adopted was to utilize as many of the existing design features as possible in order to leverage previous research and development investment as well as avoiding expenses associated with retooling manufacturing equipment. Among the innovations described in the paper are the reduction in the number of components and interfaces, and continued application of a welded rotor.

Question 1.22: The welded rotor concept was introduced at the previous CIGRE General Session in 2014. Can the authors provide an update on operational experience with this type of rotor? Is this design being investigated by others and, if so, what are the perceived advantages?

3.2 Influence of customer specifications and grid operator requirements on generator designs and performance. New developments for improving the performance, design, cost and flexibility of operation of large generators

Paper A1-103 (Japan): Adjustable speed pumped storage system contributing in stabilization of power system

This paper describes the Kyogoku Hydroelectric power plant that was launched into commercial operation in Hokkaido, the northern island of Japan, in 2015. Adjustable speed pumped storage technology is applied in its 3x200MW units. Therefore, the authors describe the capability of power adjustment in pump mode operation and how it may contribute to power grid stability against the increasing use of renewable energy sources. Most interesting is the introduction of what the authors have called “zero output operation in generation mode and flywheel operation”.

Question 1.23: The paper introduces the concept of a “flywheel operation” function. However, there an illustrative explanation of the background theories that support this operation has not been offered. Have delegates any similar experience with the concept of the flywheel operation function or a theoretical introduction?

Question 1.24: Would the delegates present an idea upon the required time to switch from generator mode to motor operation mode and vice versa? According to each country, are there any special requirements from the grid or is it an independent operation?

Paper A1-108 (Spain): Impact of turbogenerator uprating on its transient response in case of grid events

Paper A1-108 discusses the impact on generator/grid stability when uprating existing power generation plant. A specific example is considered of a 975 MW nuclear generation plant in Spain, which was successively uprated by simple re-powering, and then by re-winding the stator. The changes in the generator parameters are presented, and then the ability of the generator to survive a close in fault at the generator terminals is studied in terms of the critical clearing time. In the example presented the generator is able to stay in synchronism with the grid long enough for the protection to operate for the original and increased ratings, albeit with reduced margins. The results are compared with the requirements of the European grid codes elaborated by ENTSOE for the fault ride through case considered. Although the grid code is mainly focussed on new generating plant, the uprated 1092 MW generator still meets the grid code requirements but is close to the defined limits for leading power factor operation.

The authors highlight the variability in the requirements between, and even within, grid codes/TSO, and the level of expertise and equipment/system data needed to evaluate whether the requirements can be met or not. The question is posed that, given the speed of today's protection systems, whether the onus of meeting fault ride through conditions should be shared by the protection schemes, and not solely by the generator operating characteristics.

Question 1.25: Paper A1-108 raises the question of Low Voltage Ride Through and the contribution of both generation equipment characteristics and protection schemes in ensuring that Grid Code / TSO requirements are met. What are the views of the delegates on the reliance on faster protection schemes specifically related to large thermal plant?

Paper A1-110 (Switzerland): Flexible Generator-Converter System with Enhanced Grid Support Features - Design and Applications

This paper presents a new solution to operate with flexible regimes as imposed by the proliferation of renewable energy sources. This up to date technology introduces a 300MW thermal four pole multi-phase generator able to operate at variable speed directly connected to an AC-AC converter system. Among the innovative operating features are an enhanced grid support for grid frequency and voltage stabilization; active damping of shaft line torsional natural frequencies, virtual inertia and fast frequency response.

Question 1.26: The application of this new solution brings new and clear expectancies that promise to support modern grids that have an important amount of renewable energy sources. Considering this scenario, have other delegates some insights related to the use of multi-phase AC-AC convertors in such applications to share with us?

Question 1.27: Would it be possible to implement this solution in multiphase hydro units?

3.3 Efficiency, operation, control and design of motors for power stations and dispersed generation

Paper A1-105 (India): Ensuring High Quality Insulation System of Large Motors – Design & Testing Requirements

This paper describes the experience of one utility dealing with a number of generic manufacturing defects on high voltage motors that have led to either failures or increased maintenance activity. Through the implementation of standard test methods, e.g., partial discharge, tan delta, etc., and improvements in manufacturing methods these defects have been identified and mitigated.

Question 1.28: Have similar failure modes (or other defects that are life-limiting), and rates of failure, been observed by others? If so, what measures may be employed to resolve such issues?

Paper A1-106 (Korea): Efficiency and Cost-effectiveness Comparison between Synchronous Reluctance Motor and Induction Motor

This paper compares the performance of workhorse industrial motors; the traditional induction motor (IM), the synchronous reluctance motor (SynRM) and permanent magnet (PM) machines. The chosen comparison environment was the IEC super premium efficiency level (IE4-class & IE3-class). With the aim to fulfil the objectives, a series of SynRM's was designed using an FEA program, manufactured and then tested. The measured results were compared to validate the consistency between calculated and measured values and, finally compared with the results of similar IM and PM machines.

Question 1.29: The importance of power factor varies according to local grid codes. Certainly, workhorse industrial motors have a significant impact on power factor. Therefore, it would be very enlightening if some delegates would share the regulatory norms in their countries and what is the impact on the choice of industrial motors.

Question 1.30: The SynRM is acquiring more and more importance within industries. Would some of the delegates comment about its industrial acceptance?

Question 1.31: How important would the power electronics be in the final solution of a SynRM?

4. Preferential Subject 2
Asset Management of Electrical Machines

Three papers were originally accepted under PS2, and one paper (A1-111) has been transferred from PS1 by the Special Reporters as the paper better fits in this subject area. The four papers will be discussed in the following order:

4.1 Experience with refurbishment, replacement, power up-rating and efficiency improvement of aged generators and associated project cost benefit analysis

***Paper A1-111 (Brazil):* Voith Hydro's experience with the aging of insulation**

Paper A1-111 is a very useful contribution to understanding the long term ageing of stator winding insulation subjected to three different modes of operation. This study on stator bars removed from the subject generators involved accelerated aging and electrical diagnostic tests as well as a novel method to assess the integrity of the bond between the copper conductors and the ground wall insulation. Overall the results of the research program showed that the integrity of the stator winding insulation was not significantly affected by the accelerated ageing tests. However, somewhat surprisingly one of the conclusions of this work was that the insulation system that had been subject to many thousands of start-stop cycles associated with pumped storage generator operation was apparently in better condition than an insulation recovered from an air-cooled generator subject to base load operation.

Question 2.1: The authors of paper A1-111 state that the observation that start-stop operation may not be as problematic as conventionally thought requires further data collection to verify or refute the conclusion. Is any further data available and what is the experience of others (end users or OEMs) with respect to base load vs cyclic operation and its effect on stator winding insulation?

4.2 Improvements in monitoring, diagnosis and prognosis systems

<u>Paper A1-201 (Brazil)</u>*:** ***Brazilian Experience with Development and Deployment of an Online PD Monitoring System on Rotating Machines Based on Virtual Instrumentation

Paper A1-201 presents experience gained with an on-line partial discharge monitoring system that employs virtual instrumentation techniques rather than relying on commercially available equipment. One of the principal advantages cited in paper A1-201 is cost with savings of up to 80% when compared with existing commercial test instruments. A further benefit of this approach is that the end user of this equipment may gain a deeper understanding of the underlying technology.

<u>Paper A1-202 (Canada):</u> ***Progress in Interpreting On-line Partial Discharge Test Results from Motor and Generator Stator Windings***

A statistical analysis of Partial Discharge data gathered on many turbine generators and hydro generators over the last 20 years using the same detection methods is presented in Paper A1-202. Although the traditional recommendation of trending PD measurements over time to detect deterioration in the generator insulation is reinforced, the paper presents tables of PD values for air-cooled and hydrogen-cooled generators against which the PD level of a generator can be judged as being within or exceeding typical values measured on other similarly cooled generators in the same voltage range. The values are segregated into defined voltage ranges, and, for hydrogen-cooled machines, also into defined gas pressure ranges. High PD values, when judged against the data-set, would indicate a need for further investigation to assess the cause of the 'high' PD levels – any mitigation action would then be decided according to the observed or derived cause of the PD levels, and not the PD level alone.

<u>Paper A1-203 (Spain)</u>*:** ***Assessment of manufacture quality of stator windings insulation of rotating machines by means of macrographic analysis

This paper describes the long term efforts of a utility to develop a standardized quantitative approach to the analysis of stator coil/bar samples as part of their manufacturing quality assessment program. This contribution describes some of the challenges, e.g., sample preparation, minimizing variances due to human error, etc., as well as attempts to correlate the findings from the microscopic examination of suitably prepared samples with electrical parameters such as partial discharge and breakdown voltage.

<u>Question 2.2:</u> Have the authors of paper A1-201 performed any benchmark studies to compare the performance of the virtual instrument approach with that of any of the other partial discharge monitoring systems on the market?

<u>Question 2.3:</u> What experience do other end users have with the type of approach proposed in paper A1-201?

<u>Question 2.4:</u> Could the authors of paper A1-202 clarify the presented data:

(i) Table IV trend for 16-18 kV hydrogen-cooled machines seems to increase for intermediate gas pressure rather than decrease. Can this be explained?

(ii) Table IV gives data for capacitive sensors. How were the external PD effects accounted for in the analysis?

(iii) Table V gives the data from slot coupler type sensors. How many machines were considered in the statistical analysis?

(iv) The authors refer to 'similar machines'. How should this be interpreted by the reader, i.e. what design features/parameters determine the similarity as considered in the data analysis?

Question 2.5: Could the authors of paper A1-202 give an overview of all potential influencing design factors affecting PD levels, and state whether they have been considered in the statistical analysis, e.g. insulation type (material & impregnation process), electrical stress (kV/mm), number and size of stator bars?

Question 2.6: The conclusions stated in paper A1-202 refer specifically to the tables giving an indication of ground wall deterioration, however in the text of the paper the values are stated as giving guidance for further investigation, before the cause and mitigation can be assessed. Would the authors please clarify this conclusion based on the observations that may have been made on the machines investigated? What were the main causes of the highest of the PD readings given in the tables?

Question 2.7: The authors of paper A1-203 describe a very comprehensive approach to destructive examination of stator winding insulation. A key element of their approach is the quality of sample preparation and identifying what the key elements are when conducting the microscopic examination. Is it possible that this is an area in which some form of guide or standard should be developed?

5. Preferential Subject 3
Rotating Machines for Renewable and Dispersed Generation

Two papers were accepted under PS3, but one has been cancelled before submission. The remaining paper is discussed below.

***Paper A1-301 (Argentina):* Development of a Methodology for the Design of Axial Flux Microgenerators**

A detailed calculation method is presented for modelling small, low speed axial flux generators, based on the theory derived for radial flux machines. The adaptation of the radial flux relationships to the axial flux machine is explained, and a validation of the approach is given based on measurements on an existing generator. Based on the measured data, an adjustment to the equations is made to allow for the edge effects of the permanent magnet poles, which reduces the overall effective flux which should be considered. The final model gives a very good correlation with measured performance. Future improvements to the calculation method are proposed, together with the use of magnetic cores within the stator coils to enhance performance.

Question 3.1: The power output of the axial flux generators is of the order of a few kW, with relatively low rotational speed (600 rpm) for applications in remote areas with relatively low wind speeds. What advantages (technical and commercial) do axial flux generators have over conventional radial flux designs in these applications?

Question 3.2: What maximum power output is envisaged in the future, and what other applications might favour the use of such axial flux machines?