SEVENTH FRAMEWORK PROGRAMME

DeepWind Deliverable

Grant Agreement number: 256769

Project title: Future Deep Sea Wind Turbine Technologies

Deliverable No.: D3.1

Deliverable title: Development tool for generator design

Deliverable status: Closed

Name of lead beneficiary: AAU Ewen Ritchie

Nature of deliverable: R

Dissemination level: PU

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Quality check approval by: John Kim Pedersen date: 12/10 - 2012

Institute Leader

Description of Deliverable

The following is the text from Annex 1 of the Deep Wind project agreement:

Development tool for generator design: Study the mechanical coupling between generator and wind turbine rotor, the mechanical geometry, steady state and dynamic model, the electro-magnetic concept to obtain very high torque, cooling method, and insulation system, As part of the generator concept previously proposed methods for the improvement of torque density will be evaluated. The result will be a method for improved torque density that is adopted. Use the results of task 3.1 to determine design rules and develop tools to design the generator. Build dynamic simulation models for the generator system from input shaft to the gear to the network point of connection. A steady state, analytical model will provide rapid calculations yielding operating characteristics and material usage. This will be used to design the proposed generators. The result will be refined using finite element analysis to optimise the geometry which will subsequently be inserted in the analytic program to obtain the final performance and material usage. The analytic program will be an adaptation of existing in-house software. The FEM program will be commercial software. Dynamic models will be provided to the control system design and operation, and to the work package dimensioning the mechanical system.

Work Completed

Taking the phrases from the above description, comments are added. Where appropriate, Deep Wind reports are referred to. These reports are available to the consortium on the Deep Wind Team site Homepage.

Study the mechanical coupling between generator and wind turbine rotor,

Information is available from Risø DTU, giving estimates of the anticipated torque and speed at the input of the generator. Information giving details of the sideways thrust and axial thrust for the kW size generator was determined based on the values given by WP1 for the 5 MW baseline design.

Study the mechanical geometry

For the 1 kW demonstrator

For the 1 kW demonstrator, the mechanical geometry has been discussed and is agreed. The demonstrator generator assembly was delivered to WP7 at the end of June 2012. This work was originally included in D3.2, but it was requested by the coordinator to bring it forward, into D3.1. This means that other aspects have been delayed. A set of mechanical and electrical drawings of the demonstrator, together with the watertight enclosure containing the generator and main bearing, and an electrical cabinet for the raft and the converter with control PC has been delivered to the workshop and WP7, and is available to the consortium on the DeepWind teamsite web page.

For the 5 MW design proposal

A 5MW direct drive wind generator is a production item for a horizontal axis wind turbine, but to in the Deep Wind vertical axis case, deliver full power at 5.26 rpm requires 9.1 MNm, this is a new challenge (Compare with Siemens horizontal axis, 6 MW at 11 rpm, 5.2 MNm). Submersible is a new challenge, requiring consideration of sealing and radial and axial bearings. In this deliverable, initial selection of suitable types of generator is made. Other considerations are the subject of later deliverables.
Many different constructional types of electrical generators for direct drive have been studied. These are reported in Appendix I Deep Wind - WP3 Generator Concepts_A .pdf'. As a result, a synchronous type of electrical machine is considered to be best candidate. There are many sub types of synchronous machine.

Main sub types are categorised according to the means of excitation, electrically excited and excited by means of Permanent Magnets. Both of these are still under consideration for Deep Wind. Two main constructional types of the Permanent Magnet excited generators that have been selected for further consideration are 'Radial Flux Permanent Magnet Generator' and 'Transverse Flux Permanent Magnet Generator'. Examples of a single version of each of these are illustrated diagrammatically in Figure 1 and Figure 2.

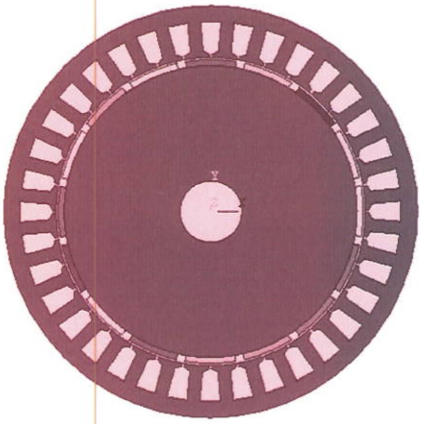

Figure 1 Radial Flux Permanent Magnet Generator

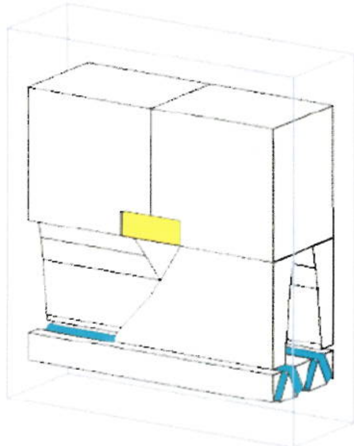

Figure 2 Transverse Flux Permanent Magnet Generator

This work is reported in detail in the reports 'Deep Wind - WP3 Generator Concepts _A', 'DIRECT DRIVE TRANSVERSAL FLUX GENERATOR FOR WIND TURBINE-Alin Argeseanu_A', 'DeepWind - WP3 Finit Element Analysis of PM Electrical Machines-Trifu Ion_A', 'DeepWind - WP3 Remarks about the electrical machine design process-Ewen Ritchie_A', and 'Deep Wind - WP3 Generator Design Rules-KLE_A', available to the members of the consortium on the consortium teamsite Web page. More detailed studies and a design proposal will be the subject of D3.4.

For the 20 MW concept proposal

This presents the real challenge of the Deep Wind project.
Preliminary work is in hand on this concept. The work done is reported in detail in the reports 'Deep Wind - WP3 Generator Concepts_A', 'DIRECT DRIVE TRANSVERSAL FLUX GENERATOR FOR WIND TURBINE-Alin Argeseanu_A', 'DeepWind - WP3 Finite Element Analysis of PM Electrical Machines-Trifu Ion_A', 'DeepWind - WP3 Remarks about the electrical machine design process-Ewen Ritchie_A', and 'Deep Wind - WP3 Generator Design Rules-KLE_A', available to the members of the consortium on the consortium teamsite Web page. More detailed studies of the 20 MW case, and a proposal for a design concept will be the subject of D3.4.

Study steady state and dynamic model

A steady state model is available for estimation of the main dimensions and characteristics of the generator. This has been implemented as a program for two types of generators that are considered to be the main candidates for DeepWind, the Permanent Magnet Synchronous Generators (Radial Flux electrically excited and permanent magnet excited) and the Transverse Flux Permanent Magnet Synchronous generator. Additionally a Genetic Algorithm optimisation program has been implemented to improve steady state performance. The dynamic model of the generator system is available, and will be discussed below.

Study the electro-magnetic concept to obtain very high torque, Study and evaluate previously proposed methods for the improvement of torque density the result will be a method for improved torque density that is adopted.

Methods proposed in the literature for increasing the torque density in electrical machines have been studied and evaluated for the use in the DeepWind concept. Methods such as the use of superconducting coils and ironless machines have been rejected on the grounds that the required cryogenic equipment will be expensive and the complexity may be expected to reduce the reliability of the wind turbine generator.
It was decided to study further the proposal to manipulate the relative permeability of the air-gap by filling it with ferro-fluid. It was further decided to work on parallel consideration of several types of generator, namely permanent magnet excited synchronous generator, electric current excited synchronous generator and transverse flux permanent magnet excited generator. These are all synchronous generators. The methods adopted will use analytic and numerical steady-state and dynamic modelling. Models will be verified by making small scale prototypes and bench testing them in the laboratory. The results of this will be used to enhance the reliability of the design tools, and to determine some of the design rules for the 5 MW and 20 MW design proposals.

Study cooling method, and insulation system

The cooling method relies on transferring heat loss to the surrounding sea-water. This may be by direct or indirect heat transfer. Because of the low ambient temperature of the sea water and the high heat capacity of water compared to air, this is expected to allow the use of increased current density in the windings, and increased flux density of the iron cores. Optimisation of these increases, balanced against the loss of output due to expected reduced efficiency will be the subject of further work, and will be used to determine some of the design rules for the Deep Wind application. The recommendation of direct or indirect heat transfer depends on the resistance of the materials to attack by sea water, and the expected growth of life in the elevated temperatures local to the generator.
Suppliers of insulation materials Nomex and Polyamide-imide have been asked about the effects of sea water on the material. The answer was that there is no reaction with sea-water. This should be confirmed by testing at the elevated temperatures expected.

Determine design rules and develop tools to design the generator.

Design rules for the generator have been defined and provision made to include and study the effects of changing the design rules to increase the torque available on a given machine size is included in the Design Tool.

Steady state, analytic model will provide rapid calculations yielding operating characteristics and material usage. This will be used to design the proposed generators. The analytic program will be an adaptation of existing in-house software.

First version is ready in Matlab script form for two different types of electric generator PMSG and TFPMSG, and a genetic algorithm optimisation program, C++ program and Matlab. These have been used for the first estimate of dimensions for the 5MW design and will be used to help determine some of the design rules. This is in continuous development and will be adapted to apply design rules determined in the DeepWind project.

The result will be refined using finite element analysis to optimise the geometry which will subsequently be inserted in the analytic program to obtain the final performance and material usage. The FEM program will be commercial software.

First version of FEM model of RFPMSG and TFPMSG are available and operational. The intention with the first version when completed is to estimate the cogging torque to be expected. Cogging torque appears when the windings are not carrying current and is a parasitic effect that should be kept at an acceptable level. This is in continuous development and will be adapted to apply design rules determined in the DeepWind project.

Dynamic simulation models for the generator system from input shaft to the gear to the network point of connection. Dynamic models will be provided to the control system design and operation, and to the work package dimensioning the mechanical system.

The basic dynamic models are available from a previous project 'Simulation Platform for Wind Turbines (AAU, RISØ, EFP, 2001-2003 (phase I) and 2004-2007 (phase I & II)), funded by the Danish Energy Ministry under their EFP initiative. These are available for WP4. Further work is reported in Dynamic_Simulation_Models_of_the_Generator_System_itr_A which is available to the consortium on the Deep Wind teamsite web page.

Documents detailing the findings reported in this report are to be found in the following files:

Report files available to the consortium on the Deep Wind Teamsite web page

Deep Wind - WP3 Generator Concepts _A.pdf
Deep Wind - WP3 Generator Design Rules-KLE_A.pdf
DeepWind - WP3 Remarks about the electrical machine design process-Ewen Ritchie_A.pdf
DeepWind - WP3 Finit Element Analysis of PM Electrical Machines-Trifu Ion_A.pdf
DIRECT DRIVE TRANSVERSAL FLUX GENERATOR FOR WIND TURBINE-Alin Argeseanu_A.pdf
Dynamic_Simulation_Models_of_the_Generator_System_itr_A.pdf

Published articles arising from the research of the Deep Wind project

[1] *Optimal Design of the Transverse Flux Machine Using a Fitted Genetic Algorithm with Real Parameters.* / Argeseanu, Alin; Ritchie, Ewen; Leban, Krisztina Monika.; Proceedings of the 13th International Conference on Optimization of Electrical and Electronic Equipment. IEEE Press, 2012. Paper [RD-001317]

[2] *Design Preliminaries for Direct Drive under Water Wind Turbine Generator*; Krisztina Leban, Ewen Ritchie, Alin Argeseanu; Proceedings of 20th International Conference on Electrical Machines, ICEM 2012, September 2012, Marseilles, France; IEEE Catalog Number: CFP1290B-USB; ISBN: 978-1-4673-0141-1

[3] *5MW Direct Drive Wind Turbine Generator Design*; Arsalan Zaidi, Lucile Senn, Iratxe Ortega, Przemyslaw Radecki, Ireneusz Szczesny, Mustafa Erkec, Ewen Ritchie, Krisztina Leban; Proceedings of 20th International Conference on Electrical Machines, ICEM 2012, September 2012, Marseilles, France; IEEE Catalog Number: CFP1290B-USB; ISBN: 978-1-4673-0141-1

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Department of
ENERGY TECHNOLOGY
E.T.

Student projects arising from the Deep Wind project

Title	Synopsis	Students
5MW Direct Drive Wind Turbine	Report deals with designing of 5MW direct rive wind turbine. Transverse Flux Machine model was designed in Opera Vector Field and investigated. Steady state analysis of the magnetic and electric fields was prepared.	Mustafa Erkec, Iratxe Ortega , Przemyslaw Radecki, Lucile Senn, Ireneusz Szczesny, Arsalan Zaidi
Design of Transverse Flux Permanent Magnet Wind Generator	In this report a 5 MW permanent magnet transverse flux machine which could meet the requirements for direct drive wind turbines is proposed. The first part of this report presents the project goal. The theoretical basis of permanent magnet transverse flux machine is explained. The advantages of the permanent magnet transverse flux generator as a suitable choice for low speed wind turbines are presented. Two methods of dimensioning the machine are proposed together with the calculations.	Emanuel-Petre Eni; Rakesh Sinha; Shaojun Huang; Viorel Gradea; Zheyuan Hu
Magnetic bearings design and Test	For large machines, magnetic bearings may be a practical solution. In a controlled magnetic journal bearing, the shaft is freely supported in an electro-magnetic field. As this is an unstable equilibrium, it will be necessary to control the magnetic field strength and thus control the forces applied to the shaft by the journal. Bearing loads will be steady state and dynamic, arising from many sources.	Rune Ryberg Thygesen Kristian Sloth og Henning Bjerregaard.
Optimal design of transverse flux generators using genetic algorithms with real parameters	Optimisation of the Design of a Permanent Magnet Transverse Flux Generator using Genetic Algorithm.	Florin Nica
Reduction of Cogging Torque in Permanent Magnet Electrical Machines	Visiting PhD student from TU Bucuresti	Ion Trifu
Iron losses in Permanent Magnet Electrical Machines	Visiting PhD student from TU Bucuresti	Steluta Nedelcu