WTE'16 - Second Workshop on Wave and Tidal Energy, Valdivia, Chile. 16^{th} to 18^{st} November 2016

E-Drive: Developing an all-electric power take off for Wave Energy Converters

Highlights:

- The E-Drive project aims to tackle a fundamental weakness of Wave Energy Converters (WEC), namely the electro-mechanical Power Take off (PTO).
- Investigating functional requirements within the PTO chain, from the generator to the grid interface to create an optimal all-electric solution.
- Addressing key issues such as reliability and maintainability within the concept.

Keywords: Marine technology, Wave power, Power electronics, Motors, Energy conversion

1. Abstract

One of the main objectives of E-Drive is to develop an integrated low speed direct conversion Power Take-Off (PTO) for a Wave Energy Converter (WEC). This will take the low speed high torque motion from the WEC prime mover and convert it directly to electrical energy for the grid. The advantage of this approach is the potential reduction in mechanical complexity of the PTO, but poses significant additional demands on the Electrical Power Converter (EPC).

This presentation focuses on the direct drive PTO and will start with a review of existing solutions and in particular identifying the strengths and weaknesses within the state of the art. Following on from this, the specific challenges of replacing the electro-mechanical PTO with a direct-drive substitute are further explored. Aspects such as power quality, WEC control and reliability are discussed. Then, focusing on the key components within the direct-drive PTO, a new modular approach is proposed for both the generator and the EPC to improve fault tolerance and maintainability. By incorporating recent developments in power electronics from automotive and elsewhere, the EPC is tailored to the time varying nature of the WEC power output.

Initial evaluations of the proposed EPC will be presented along with an explanation of why the solutions being proposed are valid, in particular for the power electronics converters. This will include preliminary simulation results. A prototype EPC is currently under construction to validate the concept.

2. Introduction

The customary approach in WEC's is to use a mechanical solution such as hydraulics or gearing to extract energy from the incoming waves before converting it to electrical energy via a rotary generator. This simplifies the Electrical Power Conversion (EPC) components as the speed of the generator can be optimized and the mechanical system's ability to store some energy within springs, compressed air or hydraulic accumulators can be used to reduce the naturally peaky nature of the WEC power flow. In many cases standard industrial variable speed drives are used as the WEC developer is less focused on optimizing this part of the PTO chain. Tuning of the WEC for optimal energy extraction from the oncoming waves is also generally part of the mechanical control [1]. The EPC is required to enable efficient transmission to the nearest electricity network connection point, which may be several kilometers from the WEC. Typically this necessitates a medium voltage solution, i.e 11kV, especially for an array of devices to mitigate against losses in the cables.

The EPC must ensure the quality of power fed to the grid or offshore substation is acceptable in terms of frequency, voltage, harmonics and flicker. Further, fault-ride-through and power factor control will typically be a requirement imposed by the grid operator to support network stability which will be an additional challenge for the EPC [2]. The grid interface is likely to form part of a coordinated network responsible for the collection and onward transmission of power to shore from multiple WECs in an array, so power sharing, protection and fault tolerance are additional features to consider in the EPC design stage.

Direct drive for the PTO is not a new concept and has been investigated by a number of researchers, including collaborators within the E-drive project [3-5]. However, investigating enhancements to the whole EPC chain from the generator through to the grid interface for a direct drive PTO is worthy of further investigation. This holistic approach forms the basis of this work. A brief summary of the rest of the content to be presented is:

3. Generator concept

Linear generators based on the Vernier Hybrid, Transverse Flux and Flux Switching topologies are being further investigated, Fig 1. Two prototypes will be built for full evaluation. These machines generally have the advantage of producing a high force with a high pole number, resulting in an improved electrical output for low speed applications such as the WEC [3]. These machines typically have low power factor which necessitates consideration during converter development.

4. Converter

For this application, a current source converter/inverter (CSI) is considered to have some advantages, especially when combined with newer RBIGBT switching devices which operate at much higher frequency and have low on-state losses. With the CSI, the bulk of the increased reactive energy requirement for the generator will be delivered by the AC filter capacitors rather than necessitating an increased rating in the semiconductor devices. Further flexibility in terms of adapting to the dynamic needs of the WEC is to be investigated by incorporating a Z-source network as illustrated in Fig 2. [6]

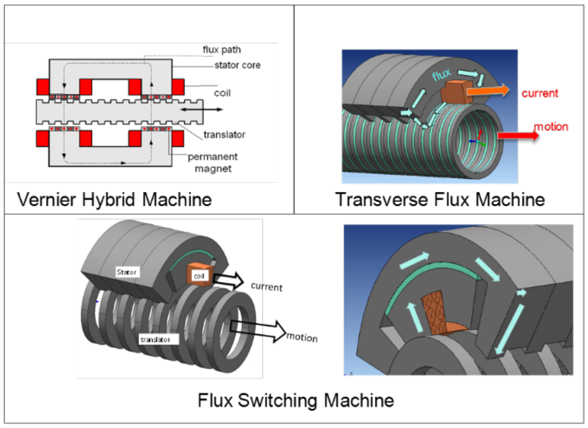

Fig 1. Machine topologies under investigation

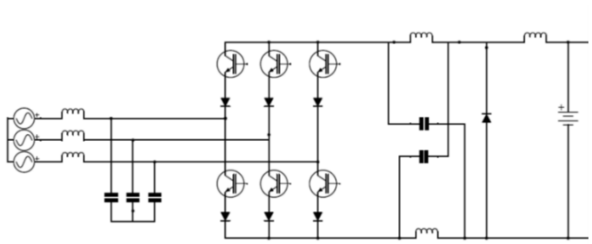

Fig 2. CSI with Z-source network

5. Energy storage

A fully electric PTO cannot realistically operate without energy storage to replace the mechanical storage used for device tuning and to smooth the real power flow for onward transmission. A number of investigators have already suggested that supercapacitor ESS could be applied to WEC's [7]. The advantage of the supercapacitor is the relatively high power capability and cycle life, but the energy density is quite low [8]. The EPC development will involve optimizing this element to meet the needs of the active and reactive power flows within the system.

6. Grid interface

Finally, the approach adopted here is to have a number of modular sections of the generator and each would have its own generator converter within any one WEC. The idea is to improve failure tolerance if a section should fail, the whole can keep operating at a reduced power level. Thus, the grid interface has to manage power fluctuations, module failure and yet provide a quality of output that is appropriate for direct connection to the network. Multilevel converters are considered be best suited to this task. [9]

7. Conclusions

A summary of the investigations for each of the system elements will be presented and initial results will be presented.

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3rd page: Short biography

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Dr. Steve McDonald was educated in the North East of England, he was engaged in a number of power engineering and power conversion projects with NEI and Siemens before returning to academia to complete his PhD in 1996. After a period of R&D in various power electronics projects with UMIST and Alstom he took up a role as part of the management team that led the development of the National Renewable Centre in Blyth. He recently joined the Electrical Power group at Newcastle University to continue pursuing research activities in Power electronics and sustainability.

Dr. Nick Baker is an electrical machines lecturer at Newcastle University, with a PhD in Linear Generators for Direct Drive Wave Energy from Durham University, which he continued as postdoc developing a larger scale prototype for the National Renewable Energy Centre 2003-2005. EDRIVE will build upon some of his PhD research. As an academic at Lancaster University (2005-2008) he secured £590k for renewables research from the public and private sector, including carrying out experimental trials in the University's wave tank for Engineering Business and Oleotec. As a senior consultant in renewable energy firm TNEI Services (2008-2010) he won a £240k Carbon Trust grant in power take off for wave energy, conducted research for Ocean Wave Master limited and worked on power systems analysis for windfarms.

Professor Volker Pickert has 20 years of industrial and academic experiences in applied power electronics. In 2003 he joined Newcastle University and is now the Head of the Electrical Power and Professor of Power Electronics. His research expertise is in thermal management, control of electric drives and compact inverter topologies. He is PI on various EPSRC, InnovateUK projects and industrial funded grants (Total values of awards as PI and CI since 2003: £8.56m). He is the recipient of the Denny Medal Award for most worthy paper on power electronics for wave power applications in 2011 published in the Journal of Marine Engineering and Technology. He is the acting Editor-in-Chief for the IET Power Electronics journal. Prof Pickert was also heavily involved in producing the NMI White paper "Power Electronics – The UK Strategy" for Mark Prisk, Minister of State for Business and Enterprise.

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Prof Markus Mueller holds the Chair in Electrical Machines at Edinburgh and is Head of the Institute for Energy Systems. He has published 140 journal and conference papers, 3 patents have been granted and he has co-edited a book with Henk Polinder (TU Delft), "Electrical Drives for Direct Drive Renewable Energy Systems" published by Woodhead Publishing in April 2013. In 2006 along with Baker (NCL) he was awarded the Donald Julius Groen Prize by the IMechE and won best conference paper prizes at the International Conference on Electrical Machines and the IEEE IEMDC conference both in 2010. Previous projects relevant to E-DRIVE include: Supergen Marine Phase 2 WP 5 leader Power Take Off and Conditioning (35 papers were published from this work); Carbon Trust Marine Accelerator project to design, build and test a 50kW linear generator; UPWIND developing structural design and optimisation tools for direct drive generators (FP6); MARINA PLATFORM developing generic design tools for electrical generators in combined floating wind and wave platforms (FP7); SNAPPER design and system modelling of a novel linear generator for wave energy (EU FP7 7 partners), which won the Engineer Magazine Innovation Award Marine Category in 2012, and was a finalist in the IET Innovation Awards in 2012.

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Roberto Cárdenas : was born in Punta Arenas Chile. He received his B.S. degree from the University of Magallanes, Chile, in 1988 and his M.Sc. and Ph.D degrees from the University of Nottingham, UK, in 1992 and 1996, respectively. From 1989 to 1991 and 1996 to 2008, he was a lecturer in the University of Magallanes Chile. From 1991 to 1996, he was with the Power Electronics Machines and Control Group (PEMC group), University of Nottingham, UK. From 2009 to 2011, he was with the Electrical Engineering Department, University of Santiago. He is currently a professor in power electronics and drives with the Electrical Engineering Department, University of Chile, Chile. He received the Best Paper Award from the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS in 2005, the "Ramon Salas Edward" Award from the Chilean Institute of Engineers in 2009 and the best paper award from the Electrical Vehicles and Renewable Energy (EVER2013) conference in Monaco 2013. His main interests are in control of electrical machines, variable speed drives and renewable energy systems. Professor Cárdenas is a senior member of the Institute of Electrical and Electronic Engineers.