Final Report

Enhancing Control Capability of ORE Systems for Stress Management and Grid Support

1. Overview

The fund enabled the Power Electronics Group at the University of Warwick to keep a PDRA researcher for 10 months to work on the concept of integrating phase change material into a power semiconductor module to give the latter a short-term overload capability which could be exploited in offshore renewable energy systems, for the purposes of grid support and stress management.

Through comparison, aided by time-stepping finite element analysis, this research identified a liquid metal material with suitable melting point, specific latent heat (per unit volume) and thermal conductivity to allow acceptable module design geometries. The modified module structure further minimized the side-effects of the integration. A prototype is made and tested to verify simulation models and quantify the performance with respect to the intended applications.

The research shows that with commercially available phase change materials and power semiconductor fabrication technologies, it is feasible to produce IGBT modules with the desired performance. As a result, power electronic converters which interface ORE generation units or farms with the grid can be temporarily overloaded to provide supporting services, including fault current sourcing and voltage recovery, in a similar way to a conventional synchronous generator. This could be necessary for the scaling up of renewable generation which is usually accompanied by the closing of aged coal-fired power plants. Furthermore, the research also evaluated the possibility of making use of this short-term overload capability to alleviate the stresses of the pitching mechanism in wind turbines, using the grid as a pulsating energy storage. Based on a simple on-off control strategy of the overload capability, the effect is shown to be about 10% reduction of fatigue stresses. An evaluation platform is established based on the concept of the digital twin technique. Further control strategies are being evaluated and are likely to be more effective.

2. Research Outcome

The basic design and evaluation of the new power semiconductor module are detailed in [1] as a published IEEE journal paper from the project. The work investigated the positioning of the phase change material to manage the transfer-lag effect but this put constraints on the choice of the melting temperature and the amount of the phase change material that can be accommodated within the power semiconductor module. Design trade-offs are discussed and justified in the paper. It is shown that the module can be overloaded to 240% of its rated current for at least 2.4 seconds without exceeding the maximum allowable junction temperature. For transmission power systems, this is enough for driving protection relays which typically clear a short-circuit fault in 200 ms with possible re-closure in 1-2 seconds in asymmetrical and temporary faults. If the re-closure is unsuccessful, the fault needs to be cleared again.

With the identified amount of phase change material integrated into the power semiconductor module, an Infineon wind turbine power module is simulated to analyse the effect on pitch stress alleviation. A simple control strategy is simulated: the overload capability is activated for 30 seconds provided that the maximum temperature is within the limit and then disabled for 60 seconds for cooling and re-solidification. This fixed pattern control strategy showed about 10% stress reduction but it is clear that improvement of control strategy would produce more effectiveness. The research has not completed but is on-going in this aspect because collaboration with another team on pitch control itself would be beneficial. The Warwick Power Electronics Team instead tried to establish a platform for performance evaluation based on long-term real wind data. In this regard, a digital twin system is proposed as described in [2] as a reviewed and accepted IEEE conference paper. A major breakthrough achieved is data compression using wavelet spectrum techniques. The 1-second sampled data can be compressed to 10%, which are later decompressed to restore the statistic characteristics of the original data. Comparison or evaluation under realistic conditions can then be conducted. The two papers are submitted as appendices of this report.

3. Follow-on Work

The PDRA has now started a new job as a research fellow at Cambridge University.

The work has attracted interest from industry. The Innovation Centre of CRRC and Dynex at Birmingham has signed a £300K contract with the University of Warwick to develop a power module design based on similar solid-liquid phase change material for their products targeting electric vehicles.

The ORE Catapult has also set up a £140K EngDoc scholarship to further address the challenges of fast response and 're-solidification' by extending the concept to liquid-gas phase change materials, making use of the conventional water cooling technology in power electronic converter system for condensation. An able home student has been allocated to the studentship.

Closely related to the project, the Power Electronics Group at Warwick has just secured £1.2M Innovate UK funding to enhance the facilities in power module packaging and reliability testing. This will be used to support research and development work by UK universities and industry.

References

[1] Ren H., Shao W., Ran L., Hao G., Zhou L., Mawby P. and Jiang H., A Phase Change Material Integrated Press Pack Power Module with Enhanced Overcurrent Capability for Grid Support – a Study on FRD, **IEEE Trans. on Industry Applications**, Vol. 57, No. 4, 2021, pp3956-3968

[2] Iosifidis N., Zhong Y., Hu B., Chen B., Ran L., Lakshminarayana S., Jia C., McKeever P. and Ng C., Reliability of Wind Turbine Power Modules Using High-Resolution Wind Data Reconstruction: a Digital Twin Concept, **IEEE ECCE Conference**, October 2021, Vancouver

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