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WIND ENERGY SCIENCE DISCUSSIONS

Interactive comment on "Demonstration of Offshore Wind Integration with an MMC Test Bench featuring Power-Hardware-in-the-Loop Simulation" *by* Fisnik Loku et al.

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Dear Referee, Initially we would like to thank you for taking the time to revise our manuscript. The points mentioned by your side are very valid and helpful points which we are also considering in further investigations and development of our further research.

General Comments: Referee comment: The articles topic is relevant to the journal, however, lack scientific rigours. The HiL implementation of MMC has been studied in many previous articles, with details about the challenges on HiL implementation and connection. As a discussion paper this doesn't goes beyond that level of technicality

and in reviewer's opinion the contribution is not clear. Author's comment: While it is true that the HiL implementation of MMC has been studied in previous articles, according to the research conducted by the author a (P)HiL implementation of MMCs including the DC grid as a hardware, which is represented by Pi-sections has not been conducted yet. Additionally, in this article, the controllability of the hardware MMC stations as hardware components is demonstrated including a connected OWF. Furthermore, several studies have shown that depending on the configuration, Pi-sections can emulate a DC cable up to a certain frequency range especially for steady state cases. In this article this is investigated and is shown that for a complete hardware DC grid, additional parasitic resistances have to be included if the same dynamic response to a set-point change of the simulated full-scale model and the PHiL system is desired. Thereby, this paper shows that it may not be sufficient to derive the Pi-section parameters from an EMT cable model but further parasitic resistances must be considered as well. Technical comments Referee comment: Another issue is the lack of demonstration with respect to dynamic cases (fault cases), which is of interest from the connection or operational point of view. Whether the current state of the PHiL is sufficient enough to reflect the transient studies is not addressed. This is a short coming. Author's comment: Fault scenarios are out not part of the scope of the paper as initially it has to be made sure that the steady state behaviour of a system is identical to a respective simulation model. In order to properly reflect the transient studies with the described PHiL system, phenomena such as the parasitic resistances have to be addressed, such that they do not represent unrealistic losses for the simulated full-scale models. An approach to solve this would be to partially reduce the parasitic resistances in the PHiL setup and partially consider them when defining a DC grid configuration. Referee comment: PHiL interface is touched upon with emphasis on used approach, however, the design criterion for filters, scaling methods etc could have been discussed in more detail. This could facilitate a clear discussion and understanding on the issues related HiL implementation when connecting devices operating at two voltage levels through a power amplifier. Author's comment: The filters and scaling methods are explained in more detail in section 4 after the reviewer's comments. Referee comment: Another question is related to the AC system implementation, it is not clear how the AC system is modelled in the RTS. Is it a source behind impedance or is it with multiple buses, please elaborate? Author's comment: The AC system is modelled as a single voltage source with a grid impedance in series. As it is modelled as a strong grid, from our view there was no need to represent it as multiple buses.

Referee comment: The schematic shown is Fig.3-5 are confusing, for instance, where is the DC network implemented hardware or RTS, similarly what is it inside the RTS which represents a wind turbine, what are the details of the WT test system inside RTS. A high-level hardware implementation with components representation could help the readers. Author's comment: The text explaining Fig 3 has been modified to emphasise that the DC grid is hardware, as well as the details describing the WT have been added to section 2 and 1 respectively. Referee comment: The authors also discuss on the ITM interface and its suitability for facilitating hardware connection to RTS, for strong grid from a stability point of view. The question will be how this interface performs for weak grid connection and what adjustments are needed to be considered to facilitate a stable PHiL connection. Author's comment: As for the transient studies, the weak grids in a PHiL setup are considered a topic on its own as detailed stability analysis and filter design methods would be required. This is unfortunately out of the paper's scope. However, this is a very valid point and an important research topic that will be investigated in the very near future. Referee comment: The design of filters and associated delays in Interface algorithms is an important aspect to ensure stable HiL operation, as shown in Fig 6. However, detailed filter design for the demo experiment has been not taken into consideration. Author's comment: For the used ITM method on the paper, a filter is used only for the voltage measurements, as the OWF is simulated as full scale model for the MMC Test Bench as well. The ripples present in the AC voltage that is provided by the islanded controlling MMC Station would otherwise be scaled up and lead to an unstable system. As the OWF is in full-scale, the ripples on the measurement current are not significant as well as their scaling down is not

considered significant. Therefore a filter is not needed for the measured current. A detailed filter design would definitely be of a great interest when weak grids are investigated as the effects of the filter on the stability of the interface algorithm for a weak grid are be of great importance. Referee comment: The results for steady-state power flow models does not sufficiently demonstrates the HiL operation in reviewer's opinion. This is particularly interesting when the power flow is not reaching the full capacity, currently reaching inly at 0.3 p.u. 1/3 of the capacity of the device (see Fig 10). The comparison needs to be performed at 1 p.u. to see the differences between simulation and experiment and measurement errors. Author's comment: A comparison between the simulation and the PHiL system at 1 p.u. power flow is definitely of great interest. However, this would mean that the interface algorithm has to be adjusted for a weak grid and this is out of the paper's scope. According to our view, a power rating of 1 p.u. is not unconditionally needed for this paper, as this paper' aim is to demonstrate the challenges when designing a PHiL system with real hardware MMC stations and with real hardware DC grid, such as the additional parasitic resistances in real hardware components, which influence the dynamic response of the system. These effects must be studied prior implementing weak grids or fault scenarios. Weak grids as well as the fault scenarios would be topics on their own and need detailed investigations and further studies regarding the stability of the interface algorithms. Referee comment: The references to prior work are not sufficient for a topic of such interest. More academic papers should be included to identify the issues and solutions related to PHiL implementation (only one journal paper out of 16 is not sufficient enough. Author's comment: The references are updated to include additional work done on P(HiL) systems.

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