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Design of Permanent Magnet Linear Generator for Wave Energy Converters and Methods for Maximizing Power Absorption Using Less Dependent Mathematical Model / Low Computationally Cost Controllers

by

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Room 0046, F1

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Abstract

The study comprises of designing permanent magnet linear generator (PMLG) for wave energy converters (WECs) and method for maximizing power absorption using less dependent mathematical model or low computationally cost controllers. There are three proposed controller methods: the damping control using maximum power point tracking (MPPT), the reactive control using MPPT, and finite control set model predictive control (FCSMPC). The first part of the thesis is started with the design and testing of a laboratory scale test-rig for wave energy converters (WECs). The main element of the test-rig is a double-sided permanent magnet linear generator (PMLG). In this study, detailed design of the PMLG is described. The objective of the design is to find the detailed parameters of the PMLG to meet the targeted electromotive force (EMF) voltage with respect to the designed physical constraints. The design procedure is easy to follow and emphasizes the practical aspects to construct the PMLG. In addition to that, the procedure to find the rating temperature for the generator is explained. Finally, this PMLG is integrated with other components to form the test-rig. The experiment is conducted to show how close the performance of the constructed PMLG is, in term of its EMF voltage and rated thermal, to the designed values.

The second part of the thesis discusses low computationally cost controllers for the WECs. The first two proposed controllers used methods that have less dependent with the mathematical model for WEC systems, namely, damping and reactive controllers using MPPT. The last controller considers the method for reducing the computational cost in model predictive control for WECs. An assessment of damping control using various MPPT methods for heaving WEC was conducted in this study. Various damping controls were implemented using a DC–DC boost converter and an assessment study was conducted to evaluate the effectiveness of the damping controls. The duty cycle for MPPT was determined using a perturb and observes algorithm. This assessment study determines the following for applying MPPT for heaving WECs: best location for the observing parameters; best performance index for the MPPT; and effect of averaging the performance index. Various scenarios using nine MPPT methods were tested using simulated regular and irregular sea states. The test results were validated experimentally using a simple and low-cost hardware-in-the-loop (HIL) scheme. The HIL scheme was developed using off-the-shelf devices that can be used for any topology of WECs. The results showed that the MPPT method has an optimum performance by using the performance index for maximizing power, using observing parameters between the source and the load, and deploying conventional instantaneous values for the observing parameters.

Next, a reactive control using MPPT technique is developed for maximizing of the output electrical power. The perturb and observe algorithm searches for optimum value of damping and stiffness coefficients in order to maximize the converted electrical power (Pe). The running mean value of the Pe is calculated in every MPPT control period and updating of the damping and stiffness coefficients are done as per the direction of the Pe. The proposed MPPT is then compared with the resistive loading and approximate complex conjugate control techniques. The results show significant improvements in Pe using the proposed MPPT using reactive control.

Finally, the thesis discusses a method for minimizing computational cost in model predictive control for WECs by proposing an estimator-based finite control set model predictive control (FCSMPC). The proposed control strategy utilizes an elaborate nonlinear wave-to-wire model of a heaving WEC. The FCS-MPC is formulated such that a control command trajectory is not required; instead, it searches for the optimum control law—in the form of switching functions—that maximizes the WEC converted electrical energy while imposing soft constraints on the states of the power take-off (PTO) mechanism. Current transducers are deployed to measure the PTO three-phase currents and both mechanical and electrical variables required by the FCS-MPC strategy are estimated using an electrical-based extended Kalman filter (E-EKF). Simulations were performed to assess the effectiveness of the proposed control strategy. Results presented herein clearly show that the proposed reference less FCS-MPC managed to produce 10%–23% more energy compared with benchmark resistive loading-based techniques with both fixed and variable wave frequency capabilities while utilizing 18%–45% less PTO resources.

Keywords: Wave Energy Converters, Maximum Power Point Tracking, Power Take Off, Permanent Magnet Linear Generator