Project Note 75

Energy Management System for Fuel Cell Powered Ships

Project Funded by Department for Transport
(Transport Research and Innovation Grants)

Fuel Cell (FC) powered vessels are one of the promising methods of reducing greenhouse gasses in the maritime industry. A FC powered ship has a power system consisting of a fuel cell, inverters, a battery system, electric machines (propeller motors) and the auxiliary loads of the ship. Depending on the vessel's operation, e.g., docking or sailing, a certain power needs to be provided by combining FC and battery power. The FC represents the main power source to generate power by converting the hydrogen, stored in the FC tank, into water. The battery acts as a buffer, storing and releasing power to satisfy the propellers' power requests. The policy for managing the power flow among different components of the vessels power system is termed the Energy Management System (EMS). This should limit the battery and the FC degradation due to changes in the power delivered over time.

A Rules-based EMS represents the simplest technique to control the power of a FC powered vessel. The control performance that can be achieved is, however, limited and not optimal. Advanced methods suitable for developing advanced control for FC vessel are based on optimisation and the most common are Dynamic Programming (DP), Pontryagin's Minimum Principle (PMP) and Model Predictive Control (MPC). The DP method provides the global optimal control performance, but it cannot be implemented in real-time and is often used for simulation-based assessment of nominal best performance (benchmarking). The PMP and the related Equivalent Consumption Minimisation Strategy (ECMS) and Adaptive ECMS (A-ECMS) provide an optimal solution of the power control problem. They approximate the global optimum with respect to a locally evaluated cost function. Although their performance is limited compared with the DP, the ECMS is less complex and can be implemented on limited capacity micro-computing control boards. The more computationally demanding MPC-based schemes reduce the suboptimality of the ECMS-based schemes by iteratively solving a constrained optimisation problem based on a receding horizon principle.

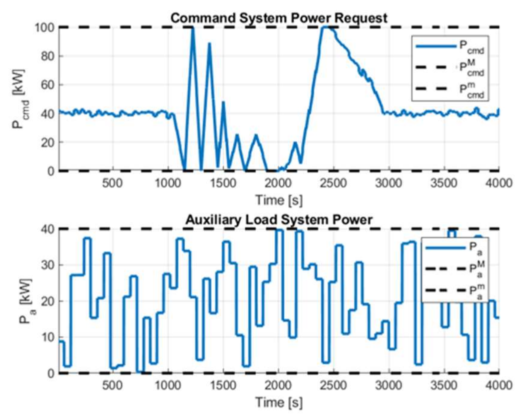
In the TRIG supported project undertaken, the combination of optimisation-based predictive control methods and Machine Learning (ML) was used. ML was needed to improve the prediction of the value of the actual and the future operating conditions affecting the power system performance. This overcame the limits of MPC that are based only on the assumed physical models of the controlled system.

The vessel power system model considered in the project included a set of power sources (fuel cell and battery), systems to be supplied (auxiliary loads and propulsion system), and a command system representing the controller that sets the propulsion power demand. For comparison purposes, a baseline simple control system was first developed according to a rules-based approach. The proposed MPC-based advanced control policy was then designed to adjust the vessels power distribution.

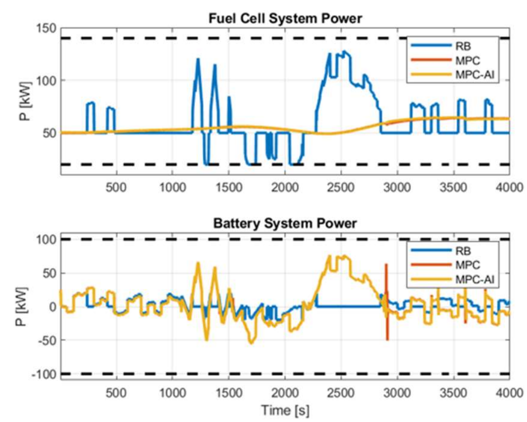
The vessel power system design model was found from a nonlinear model using an approximate Linear Parameter-Varying (LPV) form. Based on the LPV model, an LPV-MPC was developed to optimally manage the power system. The LPV-MPC was combined with a ML module to increase the limited prediction capabilities of the LPV-MPC controller. The

ML module is able to exploit information hidden in the measured data to approximate the future power demand signal to be passed to the MPC. By combining MPC and the ML module, the algorithm improved the control performance and reduced the suboptimality introduced into the controller due to the approximation in using the LPV model based model.

The most interesting solution was that given by the LPV-MPC with ML controller. Compared with the rules-based policy, the LPV-MPC provided an improvement and further benefits were obtained by adding machine learning. The hydrogen consumption was reduced by 15.89%, the FC stress was decreased by 99.97% while the battery degradation index worsened. Note the hydrogen FC degradation is the most important economically. Comparing the different predictive control policies, the LPV-MPC with ML controller gave a reduction in FC degradation of 62.5% with respect to the basic LPV-MPC performance, together with a reduction of battery stress of 2.32% and a reduction of hydrogen consumption of 2.5%. Both battery and FC powers allocated by the different controllers satisfied their constraints on magnitude, and the battery State of Charge remained within its prescribed bounds. This was due to the constraint handling ability of the LPV-MPC based EMS to satisfy the physical and logical limits of the plant.



Power Demand Scenario



Compared FC and Battery Control Signals

ISC Limited is grateful for the support of Department for Transport on the project.

ISC Limited works across industrial sectors and has gained wide experience in various applications. It is this peripheral vision that is valuable for companies. ISC has expertise and experience on areas and methodologies including Physical system modelling and simulation, developing tailored optimal or predictive control solutions for real-world applications, production of bespoke estimation and filtering algorithms for nonlinear control, use of stochastic or robust controls for different industries like wind energy and marine, design of Machine Learning algorithms for industrial and embedded domains, and training courses.

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