Controller Design for Hybrid Diesel Electric Ship Propulsion during Transient Operation

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ABSTRACT

This work investigates the improvement in performance of a combustion engine with the assistance of an electric motor, with appropriate control systems, for transient load uptake, smoke emission reduction, reduced pollutant emissions and lower fuel consumption. For the hybrid diesel electric powertrain, an energy control management strategy dictates the required torque from the electric motor so as to track a reference air-to-fuel ratio/stoichiometric ($\lambda$-value) in the diesel engine.

The feasibility and validity of the proposed control strategy was tested experimentally. A comparison between the hybrid powertrain and the standard engine setup (without the assistance from the electric motor), shows the benefits of a hybrid setup during transient loading conditions.

KEY WORDS: Hybrid diesel electric; hybrid ship; H-infinity control; AFR closed loop; ship exhaust emission reduction.

INTRODUCTION

One promising technology for reduction of gaseous emissions and fuel consumption of ships is the diesel-electric hybrid propulsion, i.e. a diesel engine assisted by an electric motor, with both machines coupled onto a common drive shaft. Various topologies of hybridized power trains have been exhaustively studied from various perspectives in heavy trucks and automotive applications.

A considerable number of publications in this field has been devoted to the development of energy management strategies (EMS) (Fekri and Assadian, 2012). EMS is the supervisory control algorithm which specifies the energy split among the various power sources which make up the propulsion system, (Lin; Peng; Grizzle and Kang, 2003). One main category of EMS consists of optimization techniques, with diverse approaches as found in (Sciaretta and Guzzella, 2003; Ramsbottom and Assadian, 2006; Lin; Kang; Grizzle and Peng, 2001).

This method is not directly applicable in marine power plants due to the requirement of the exact knowledge of the driving cycle by the optimization routine. Another broad category comprises heuristic methods such as fuzzy logic, as adopted in (Salman; Schouten and Kheir, 2000; Baumann; Washington; Glenn and Rizzonni, 2000). The advantages are the easiness to implement and the simplicity to conceive; the drawback is that they neither achieve an optimal solution nor robustness with respect to performance.

The above control strategies have dealt mainly with fuel economy without a particular emphasis on emission reduction. The subject of emission reductions in a quasi-static framework is discussed in (Lin; Peng; Grizzle and Kang, 2003; Lin; Peng and Grizzle, 2004; Tate; Grizzle and Peng, 2010; Johnson; Wipke and Rausen, 2000). However the incorporated quasi-static models for emission formation disregard the substantial rise of pollutant emissions during transient operation of Diesel engines (DE) due to the presence of thermodynamic delays mainly associated with turbocharger (Rakopoulos and Giakoumis, 2006).

A method to calculate the optimal EMS for a diesel hybrid electric power train taking into account the transient pollutant particulate matter emissions is presented in (Nuesch; Wang; Isenegger; Onder; Steiner and Guzzella, 2014).

The reduction of NOx emission in both steady state and transient operating conditions has been examined in (Grondin and Qurel, 2012). Here, the optimal power split in steady state is provided by an EMS while the reduction of transient NOx emissions is achieved through the smoothing of the DE torque demand by utilizing the EM torque as torque compensator. The dynamic control law is not robust with respect to exogenous disturbances and un-modeled dynamics that inevitably exist in real- world hybrid electric powertrains.

The main purpose of the present paper is to examine the feasibility of emission reduction along with fuel consumption reduction, during the transient loading of a diesel hybrid-electric marine propulsion plant, under closed loop control.

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