Model Predictive Control for Hybrid Diesel-Electric Marine Propulsion ⋆

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Abstract: In this work, the problem of energy management strategies in hybrid diesel-electric marine propulsion systems is investigated with the implementation of two types of Model Predictive Controllers. The system behavior is described by models based on system identification as well as on first-principles. These models were used for the design of linear and adaptive predictive controllers respectively. The controllers were successfully tested at HIPPO-1 testbed, at the Laboratory of Marine Engineering, evaluating diverse strategies for disturbance rejection, system stability, and operation of the plant within desirable limits.

Keywords: hybrid marine engine, predictive control, λ control, transient operation

1. INTRODUCTION

Strict emission regulations imposed by legislation authorities (e.g. International Maritime Organization-IMO) make marine engine manufacturers to look for new opportunities for emissions reduction. One promising technology for emissions reduction and fuel efficiency enhancement is hybridization, i.e. usage and coordination of more than one energy sources used for propulsion.

This research work tackles the problem of energy management strategies (EMS) in hybrid diesel-electric marine propulsion systems, without any battery storage capacity. Such a system decides in real time the amount of power delivered at each time constant by the energy sources present in the experimental marine power train. Objectives are to investigate a) the interaction between the power sources and b) the feasibility of the hybrid configuration to achieve reduced exhaust emissions and improved fuel consumption during transient loading operation. This could lead to diesel engine downsizing as is the case in the "modern" point of view in marine propulsion.

Usually, the engine control units contain a certain amount of single closed-loops, with many look up tables in order to achieve closed-loop control of the multi-parametric and strongly non-linear engine behavior, Ripaccioli et al. [2009]. Today, a more sophisticated and complicated control method is needed: one that continuously decides the operation point of the plant, while enforcing the operating constraints and optimizing the energy consumption, in terms of fuel and electric energy consumption.

Several strategies for power management have been applied so far, including dynamic programming, stochastic dynamic programming, equivalent fuel consumption minimization and model predictive control (MPC). Of the many advanced control design methodologies, MPC seems to be the most capable to handle multi-variable processes, satisfy constraints, deal with long time delays and utilize plant response disturbance knowledge. MPC has been used in a broad range of applications, such as diesel engine control, del Re et al. [2009], Ortner and del Re [2007], Adachi et al. [2009], Hybrid Electric Vehicles, Ripaccioli et al. [2009], etc.

Usually the objective of the EMS is to minimize fuel consumption. In the work presented here, the control problem is recast in an alternate way so as to track λ reference while ensuring that certain constraints, like NOx and fuel consumption are met.

2. SYSTEM DESCRIPTION AND MODELING

2.1 Experimental Facility

The hybrid propulsion powertrain HIPPO-1 test bed at Laboratory of Marine Engineering, NTUA (LME) (seen in Fig. 1) consists of an internal combustion engine (ICE) in parallel connection to an electric machine (EM). As such, the rotational speeds of ICE and EM are identical, whereas the supplied torques add together. The desired

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