Predictive Control for a Marine Hybrid Diesel-Electric Plant During Transient Operation*

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***Abstract*— We investigate the implementation of model predictive control to the power split problem of a hybrid diesel-electric marine power plant during transient loading. The modeling procedure, the controller design and the experimental validation of the proposed control scheme are covered. System behavior is described by models based on system identification from experimentally obtained data. These models were used to design predictive controllers that cope with physical and operating constraints of the hybrid power train. Experiments were conducted at HIPPO-1 testbed, at the Laboratory of Marine Engineering. Based on the experimental results it can be concluded that predictive control can be utilized as an efficient energy management strategy in marine power plants for disturbance rejection, and operation of the plant within operator's desirable limits.**

I. INTRODUCTION

Modern marine power systems must cope with tight emission standards. Especially during maneuvering or loading operations within port range, diesel engines of the ship face adverse operating conditions due to the continuously transient loading profile of their power supply system, leading to higher fuel consumption and higher emission pollutants formation. Hybridization is one promising technology for emissions reduction and fuel efficiency enhancement and it is getting considerable acceptance amongst marine engine manufacturers.

Although hybrid crafts have been used for military purposes for many decades, only recently hybridization has been considered for use in commercial applications, such as passenger ferries, tugs, offshore support vessels (OSV), inland ferries, yachts, etc. Various hybrid configurations are reviewed in [11]. In such hybrid installations, the main area of interest is their control strategy, i.e. the decision for the power split between the power train components.

To ensure optimal operation, advanced control strategies are required to estimate the amount of energy to be produced by each component of the power system to cope with the transient demand. Usually, the engine control unit contains a certain number of single closed-loops, with many look-up tables and local limiters in order to achieve closed-loop control of the multi-parametric and strongly non-linear engine behavior [16].

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Power management in hybrid marine power plants decides how much power shall be produced by the internal combustion engine and how much should be supplied by the electric motor so as to achieve the total power demand at the driving shaft of the propeller or waterjet. Marine propulsion plants have slow dynamics, due to their size; as a result, transients last longer compared to automotive engines. Rapid load acceptance of diesel engines leads to higher fuel consumption, and consequently production of more CO_2 as well as higher NOx concentration and smoke formation.

Several strategies for the power management of hybrid power trains have been applied, including dynamic programming, stochastic dynamic programming, equivalent fuel consumption minimization and model predictive control (MPC). Dynamic programming generally provides the optimal solution for an optimization problem over a certain driving cycle [6]. However, in marine environment the operation profile for vessels cannot be known a priori and there is no driving cycle for such power plants. As a consequence, the optimization should be short termed, depending on the knowledge of the present state of the power plant. Recently, strategies including a Machine-Learning (ML) framework were introduced [10], in an effort to address the issue of calculation in real time.

Among the advanced control design methodologies, MPC is capable to handle at the same time multi-variable processes, satisfy constraints, deal with long time delays and utilize knowledge for plant disturbance response. MPC has been used in a broad range of applications, such as diesel engine control [7], [8], spark ignition engine control [15], [14], Hybrid Electric Vehicles [16], [17], Plug-in Hybrid Electric Vehicles (PHEV) [9], etc. In [12] a multilevel predictive control approach is used for the energy calculation and optimal power split control of an OSV during maneuvering under the presence of environmental disturbance.

This work focuses on power split strategies during transient operation of a marine power plant with the use of MPC. This is achieved by tracking λ (air to fuel ratio) reference while ensuring that certain constraints, like NOx and fuel consumption are met.

The paper is organized as follows: in Section II the experimental setup is presented and the identification process is explained. In Section III the control system is formulated and analyzed. The experimental results are presented in Section IV. Section V contains the concluding remarks.