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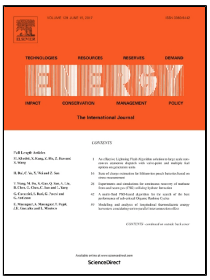

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ACCEPTED MANUSCRIPT

A Novel Energy Management for Hybrid Off-road Vehicles without Future Driving cycles as *A Priori*

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***Abstract*—Hybrid electric tracked bulldozers use engine and ultracapacitor as the power sources for propulsion, and the fuel economy performance highly depend on the coordination of all subsystems. In this paper, a model predictive controller is developed to reduce the fuel consumption of hybrid electric tracked bulldozers. As an optimization-based approach, the model predictive controller usually requires the drive profile to be known a priori. However, in this study, an average concept based model predictive controller is proposed without such knowledge. Simulation results show that a prescient model predictive controller saves approximately 21% more fuel compared to the conventional bulldozer and the average concept based model predictive controller performs similarly to the prescient model predictive controller. Meanwhile, the results of the two model predictive controllers are compared with dynamic programming and rule-based energy management strategy to show the benefit of model predictive controllers. In addition, the robustness of this average concept based model predictive controller is also verified under several disturbed drive cycles. The proposed model predictive controller is independent of powertrain topology such that it can be directly extended to other types of hybrid electric tracked bulldozers, and it provides a way to apply the model predictive controller even though future driving information is unavailable.**

***Index Terms*—Hybrid Electric Tracked Bulldozer, Energy Management, Model Predictive Control, Dynamic Programming, Rule-based, Robustness**

I. INTRODUCTION

Off-road applications include equipment used for e.g. for construction, earthmoving, agriculture, forestry, material handling, recreation, marine purposes, etc. The use of diesel engines in off-road applications is a significant source of nitrogen oxides (NOx) and particulate matter (PM10) [1]. The exhaust emission factors are compared in [2] that, the NOx in on-road transport is 42g/kg while in off-road (construction and mining) vehicles is 46g/kg, and the PM10 in road transport is 2.5g/kg while in off-road (construction and mining) vehicles is 5.5g/kg. Above all, off-road diesel equipment was responsible for 10% of mobile source NOx emissions nationally, whereas on-road diesel vehicles contributed 33%. In order to prevent global warming, conserve natural resources and adjust to the even more stringent emission regulations, manufacturers of earthmoving equipment are more than ever aware of the importance of producing environmentally friendly machines with significant improvement of fuel economy. Though traditional methods have played an important role in energy saving of hydraulic construction machinery, they are still working with low fuel efficiency and bad exhaust. New technologies are needed to further reduce fuel consumption and pollutant emissions. With the successful application in road vehicles, the electrified system is applied to traditional construction machineries recently. The applications of hybrid systems in construction machinery are presented in [3]. Truong. et.al [4] researched the method to regenerate potential energy on the boom system of the hybrid hydraulic excavator. Over the past decade, various major manufacturers and research institutions worldwide have undertook several projects in developing hybrid construction vehicles, including hybrid electric bulldozer, hybrid excavator, and hybrid wheel loader. In May 2007, the world's first hybrid electric forklift truck was developed by Komatsu, and the world's first hybrid excavator was also manufactured by the same company in May 2008. When compared to the traditional PC200-8 hydraulic excavator, 25% to 41% fuel savings were achieved by the hybrid excavator [5]. Whilst, a 6-ton class prototype series hybrid excavator was presented by Kobelco Construction Machinery in July 2008, and the experimental data demonstrated a more than 40% fuel economy improvement[6]. L220F hybrid wheel loader was unveiled for the first time by Volvo Construction Equipment in the ConExpo-CON/AGG exhibition, in March 2008, offering fuel economy improvement by 10%. Meanwhile, Caterpillar produced its first D7E hybrid electric tracked bulldozer (HETB). When compared to traditional models, D7E can reduce fuel consumption by 25%. In this paper, a new HETB composed of an engine-generator, ultracapacitor, and two driving motors is presented to enhance its fuel economy. This HETB uses an integrated controller to manipulate two motors on the both sides independently. The novel hybrid powertrain provides more flexibility to meet driver demand and improve the fuel economy. The layout of this HETB is shown in Fig. 1.

The performance or fuel economy of the HETB heavily depends on the power management strategy, which is a supervisory controller that can coordinate the energy flow between different energy sources and enhance the overall efficiency of the

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