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An adaptive model predictive controller for a novel battery-powered anti-idling system of service vehicles

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ABSTRACT

This paper presents an anti-idling regenerative auxiliary power system for service vehicles. The energy storage system in the regenerative auxiliary power system is able to electrify the auxiliary systems so as to achieve anti-idling. Service vehicles (e.g. delivery trucks or public buses) generally have pre-determined routes, thus it is feasible and profitable to utilize a model predictive control strategy to improve the fuel economy of the new powertrain. However, the mass/load of such service vehicles is time-varying during a drive cycle. Therefore, an adaptive model predictive controller should be designed to account for this variation. Although the drive cycle is preset, it would experience uncertainties or disturbances caused by traffic or weather conditions in real situations. To deal with this problem, a large step size prediction method is used in the adaptive model predictive algorithm to enhance its robustness. The proposed algorithm is compared to a prescient model predictive controller in different scenarios to demonstrate its applicability and optimality (more than 7% fuel savings). The proposed approach is independent of the powertrain topology such that it is able to be directly extended to other types of hybrid electric vehicles.

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1. Introduction

The auxiliary devices (e.g. air-conditioning or refrigeration (A/C-R) systems) of the service vehicles account for a considerable portion of the engine load and hence fuel consumption (FC). For example, the A/C-R system in a delivery truck takes up to 25% of the total fuel or even more in heavy-duty trucks [1]. Diesel engines have efficiencies of 40%, however, when idling their efficiencies drop to 1–11% and discharge more pollutants [2]. That is why new regulations ban the engine idling in many countries.

This study presents a novel optimized regenerative auxiliary power system (RAPS) to reduce idling and improve the fuel economy of service vehicles. As the primary component of RAPS, ESS is integrated into the original powertrain as shown in Fig. 1. The ESS (e.g. a battery) is able to power the auxiliary devices such as an A/C-R system. Using the alternator connected to the engine by a serpentine belt or the gearbox via a power take off (PTO), the RAPS is capable of recapturing a portion of the kinematic energy during vehicle braking. It is also able to efficiently charge the battery by the engine, which is guaranteed by the power management strategy (PMS) [3]. Thus, the feature that it can use the recovered energy or the engine power in an optimal way to power the auxiliary systems differentiates it from the existing APUs and ABPs. The literature in two aspects will be studied to differentiate the proposed system and method from the existing counterparts.

1.1. Anti-idling technologies

Idling is one of the main contributors to poor air quality, extreme noise pollution, and serious health issues. Therefore, it is imperative to eliminate vehicle idling. There are many quantitative studies [4] to demonstrate the negative impacts brought by idling and many corresponding bylaws. To pursue the low level of pollution and high level of fuel economy in the automotive industry [5], many types of anti-idling technologies have emerged over the last several years.

Auxiliary power units (APUs), or fuel-fired APUs, are the most conventional anti-idling solutions. They consist of a small engine and a generator, which are assembled into the existing HVAC system. However, due to the additional engine, vehicles will become noisier and maintenance intensive. Significantly, this extra engine

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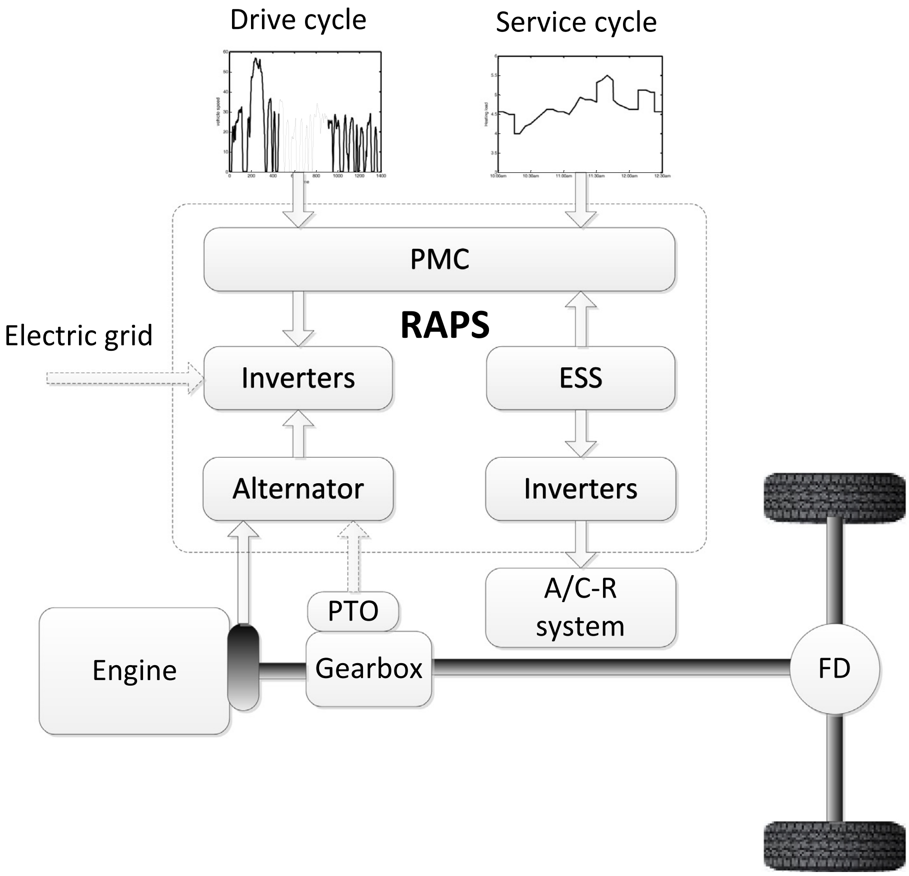

Fig. 1. The overall structure of the RAPS in a powertrain.

probably discharges more pollution than the main engine without properly being regulated. Recently, the Auxiliary Battery Powered units (ABPs) have appeared as an alternative to the APUs [6]. The battery is charged either by the main engine or the stationary anti-idling devices (e.g. Shorepower) and discharged during the truck stops. The additional engine in the APUs is replaced by a package of batteries, offering the same functionalities without the extra drawbacks (e.g. emissions or noise). Although the fuel-cell [7] and solar ABPs also appear, they are however in their early development phase and many factors impeding their development should be properly dealt with before putting into the market.

1.2. Power management strategy

The primary objective of PMS is to meet the driver's demands for drivability and optimize drivetrain efficiency and system costs [8]. The existing PMSs have been categorized into rule-based and optimization-based according to research [9]. A summary of the reported PMSs is shown in Ref. [10].

It should be noted that these strategies are not mutually exclusive and can be used alone or in combinations. The rule-based strategies are capable of real-time applications but are not optimal; whereas, optimization-based ones are capable of acquiring optimal solutions but suffer from real-time implementations. The reason is that optimization algorithms are computationally expensive and require partial or entire future information, such as the vehicle speed. This problem can be alleviated to some extent by recent advances in intelligent transportation systems (ITSs) using onboard global positioning systems (GPSs), geographical information systems (GISs), and advanced traffic flow modeling techniques [11]. Recently, different MPCs (e.g. conventional, adaptive and robust) are being used because of their capability to deal with the multi-variable constrained problems and their potential in the real-world application as a receding horizon control strategy. For instance, MPC technologies for efficient and flexible power consumption in refrigeration systems were proposed in Ref. [12]. An MPC was designed in Ref. [13] to optimize the fuel consumption of the automotive A/C-R system. Authors used MPC technique to solve the path-tracking problem of an autonomous vehicle [14]. The MPC-based power management control strategy was also developed for the off-road hybrid vehicle in Ref. [15] to improve the powertrain efficiency.

Literature [16] assessed two finite-horizon stochastic dynamic programming (DP) algorithms with different degrees of access to the drive route from a GPS combined with a traffic flow information system. The discrete time Markov chain technique was employed to model vehicle's states in each of strategy. The results were compared with those of a prescient MPC with a complete known drive route to demonstrate that a predictive controller is possible to be designed by using information received from the vehicle navigation system and traffic-flow-information. A stochastic MPC was designed in Ref. [17] for a series HEV, where the future power demand from the driver was simulated as a Markov chain. Its performance was compared with that of a prescient MPC with fully known power demand and a frozen-time MPC using a constant power demand in the prediction horizon. The authors showed that the proposed MPC provided a fuel economy similar to the prescient MPC. In order to alleviate the computational efforts of the MPC

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