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A predictive power management controller for service vehicle anti-idling systems without a priori information

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HIGHLIGHTS

- A novel anti-idling system (RAPS) is proposed for services vehicles.
- A model predictive power management controller is designed for RAPS.
- The MPC is designed based on an average power concept without future information.
- The variable power consumption of the auxiliary device is integrated in the MPC.
- The presented anti-idling system saves up to 9% fuel for light service vehicles.

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ABSTRACT

This paper presents a model predictive power management strategy for a novel anti-idling system, regenerative auxiliary power system (RAPS), designed for service vehicles. RAPS is able to utilize recovered braking energy for electrified auxiliary systems; this feature distinguishes it from its counterparts - auxiliary power unit (APU) and auxiliary battery powered unit (ABP). To efficiently operate the RAPS, a power management strategy is required to coordinate power flow between different energy sources. Thus, a model predictive controller (MPC) is developed to improve the overall efficiency of the RAPS. As an optimization-based approach, the MPC-based power management strategy usually requires the drive cycle or the drivers' command to be known a priori. However, in this study, an average concept based MPC is developed without such knowledge. MPC parameters are tuned over an urban drive cycle; whereas, the robustness of this MPC is tested under different drive cycles (e.g. highway and combined). Analysis shows that, the presented MPC has a comparable performance as the prescient MPC regarding fuel consumption, which assumes knows the drive cycle beforehand. Meanwhile, with the help of the proposed MPC and RAPS, the service vehicle saves up to 9% of the total fuel consumption. The proposed MPC is independent of powertrain topology such that it can be directly extended to other types of hybrid electric vehicles (HEVs), and it provides a way to apply the MPC even though future driving information is unavailable.

1. Introduction

The auxiliary devices (e.g. air-conditioning or refrigeration (A/C-R) systems) of service vehicles, such as delivery trucks, public buses and long-haul trucks, account for a portion of the engine load and hence, fuel consumption. Consider delivery trucks as an example, A/C-R systems, as their main auxiliary loads, can account for 25% of the truck's total fuel consumption; this number increases in long-haul trucks [1]. Specifically, engines sometimes have to idle to power their auxiliary devices during stops. Diesel engines have maximum efficiencies at over 40%, but their efficiencies will drop below 10% resulting in more pollutants when idling [2]. This explains why many countries have implemented regulations and standards sometimes requiring a complete ban on engine idling. Therefore, it is beneficial to electrify the auxiliary systems to reduce idling. In this paper, a novel optimized RAPS is presented to reduce idling and enhance the fuel economy of service vehicles. After integrating the RAPS into a conventional powertrain, its powertrain turns into a parallel hybrid system due to the addition of an energy storage system (ESS). The new configuration is shown in Fig. 1.

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Nomenclature

ABP	auxiliary battery powered unit
A/C-R	air-conditioning and refrigeration
APU	auxiliary power unit
ESS	energy storage system
GISs	geographical information systems
GPSs	global positioning systems
HEVs	hybrid electric vehicles
HVAC	Heating Ventilation Air Conditioning
ITSs	intelligent transportation systems
MPC	model predictive control
NN	neural network
RAPS	regenerative auxiliary power system
SOC	state of charge
TES	Thermal Energy Storage
TSE	truck stop electrification
A_f	vehicle front area
a	vehicle acceleration
C_D	coefficient of aerodynamic resistance
C_r	coefficient of rolling resistance
F_a	aerodynamics resistance
F_g	grade resistance
F_r	tire rolling resistance
M	vehicle mass
$(MC)_{goods}$	thermal inertial of the goods
$\dot{m}_F$	fuel mass flow
$\dot{Q}_{door}$	HL due to the door open
$\dot{Q}_{temp}$	heating load (HL) due to the ambient temperature
$\dot{Q}_{vcc}$	cooling capacity
P_{veh}	vehicle power
P_{alt}	alternator power
P_{reg}	regenerative power
P_{eng}	engine power
$P_{eng\to veh}$	engine power portion going to vehicle
$P_{eng\to alt}$	engine power portion going to alternator
P_{aux}	auxiliary power
T_{eng}	engine torque
T_{cargo}	temperature of cargo
V_{veh}	vehicle velocity
α	road grade angle
ρ	air density
η_{alt}	alternator efficiency
η_{char}	battery charging efficiency
η_{dis}	battery discharging efficiency
η_{eng}	engine efficiency
η_{tran}	powertrain efficiency
η_{reg}	regenerative efficiency
ω_{eng}	engine speed

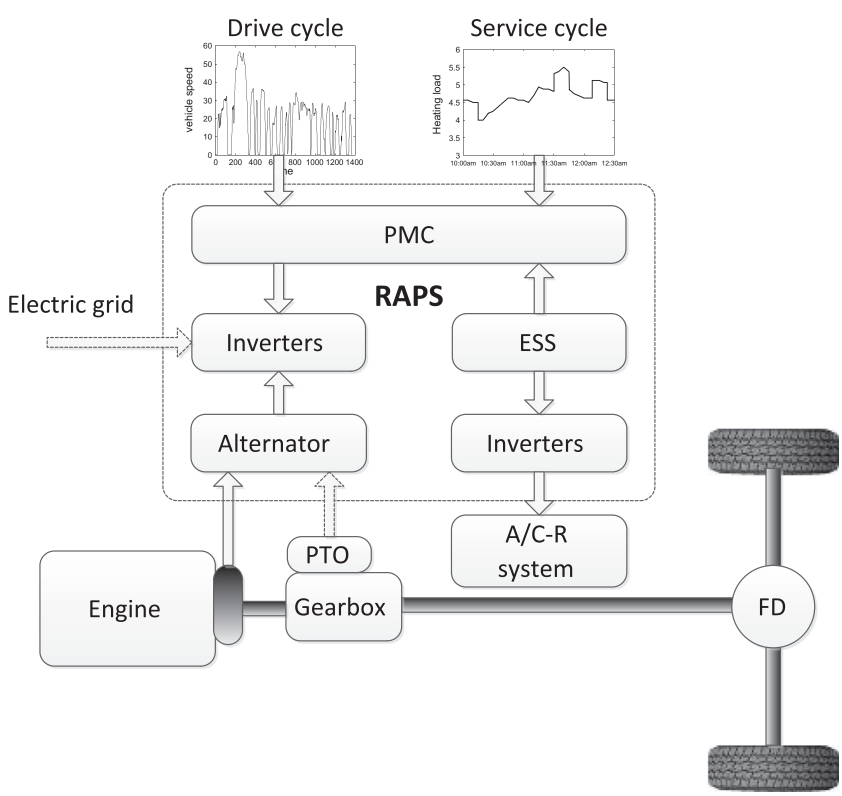

Fig. 1. The structure of the RAPS and the conventional powertrain.

The only difference from a standard parallel hybrid powertrain is that the ESS in RAPS only powers auxiliary devices instead of assisting the engine in driving the vehicle. The ESS is able to power auxiliary devices, such as an A/C-R system, independently so as to achieve the anti-idling purpose. For the sake of overall high efficiency, RAPS requires a power management strategy to determine whether and when the ESS needs to be charged. Using the alternator connected to the engine via the serpentine belt or the gearbox via the power take off (PTO), the RAPS is capable of recapturing a portion of the kinematic energy during vehicle braking. Meanwhile, when the recaptured energy is not enough, the engine can directly charge the battery in an efficient way that is guaranteed