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Implementation methodology of powertrain for series-hybrid military vehicles applications equipped with hybrid energy storage

Seongjun Lee [a], Jonghoon Kim [b,*]

[a] Power Electronics and Energy Conversion Laboratory, School of Mechanical System & Automotive Engineering, Chosun University, Gwangju, 61452, Republic of Korea

[b] Energy Storage and Conversion Laboratory, Department of Electrical Engineering, Chungnam National University, Daejeon, 34134, Republic of Korea

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ABSTRACT

This paper investigates a component-sizing method and a power-control algorithm for series-hybrid military vehicles equipped with hybrid energy storages that comprise batteries and super-capacitors. Component sizing of the powertrain is determined by the performance specification that is related to mission profiles and power-flow control methods. In order to minimize the effects of mission profiles and power-flow control methods, the linear programming (LP) technique is employed. The LP problem for minimizing the output energy from the engine under different conditions of driving cycles and capacities of the energy storage system (ESS) is solved to eliminate the effect of the power distribution. Through analyzing the effects of different power and energy ratings of the ESS, the optimal values of power and energy capacities of the ESS are determined. The design approaches are extensively verified with simulations and experimental results of a reduced-scale per-unit equivalent system of the 10-ton series-hybrid electric vehicle (SHEV).

1. Introduction

Environmentally, friendly electric vehicles are classified into the hybrid electric vehicles (HEVs), battery-only electric vehicles (BEVs), and fuel-cell electric vehicles (FCEVs) depending on the energy source of the vehicle powertrain as shown in Table 1 [1]. Nowadays these are increasingly studied and manufactured at present to minimize environmental impacts and to increase the fuel economy.

The propulsion sources of the HEVs are the engine and the electric motor and configured as the series hybrid electric vehicle (SHEV), parallel HEV and series-parallel HEV as shown in Fig. 1. The main energy of the vehicle comes from the internal combustion engine (ICE) and the battery and the super-capacitor are utilized as an auxiliary energy sources. The propulsion source of the SHEV is only the traction electric motors and the generated energy from the ICE is utilized to charge the high voltage battery and to supply the power of traction motor. The FCEV which uses a fuel cell instead of an engine is a type of SHEV. On the other hand, the parallel hybrid has two power sources such as the engine and traction motor. These are connected through the transmission, to the drive wheels. Each power source may supply some or all of power needed by the vehicle. The series-parallel HEV is known as a combined hybrid electric vehicle or a power-split HEV. This configuration is investigated and developed to overcome the drawbacks of series and parallel architectures. The powers of the engine and the electric motor are coupled to drive the vehicle in parallel operation. While the power generated from the ICE flows into the battery and the traction motor in series operation.

The one of the main research field in the electric vehicle is the development of components of the vehicle and the energy management algorithm in order to increase the fuel consumption. Among them, the studies of the energy management algorithm in the FCEV application [2–5] are carried out. The power distribution method between the fuel cell and the battery is studied considering the driving cycle, and the manufactured vehicle has been empirically tested. And in order to increase the efficiency and to reduce the cost of the component, the researches of the electric motor type [6,7] and the active suspension have been progressed [8]. As in the previous researches, the studies about the energy management algorithm and more efficient component are important in the existing electric vehicle, and especially in the case of designing of the new type of the electric vehicle, the component sizing considering the driving profile and the power distribution

* Corresponding author.
E-mail address: qwzxas@hanmail.net (J. Kim).

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Nomenclature

HEV	Hybrid electric vehicle
BEV	Battery-only electric vehicle
FCEV	Fuel-cell electric vehicle
SHEV	Series-hybrid electric vehicle
ICE	Internal Combustion Engine
ESS	Energy storage system
IPM	Interior permanent-magnet
LP	Linear programming
CPSR	Constant-power speed ratio
GVW	Gross vehicle weight
PI	Proportional and integral (controller)
AP	Accelerator pedal
BP	Brake pedal
HPF	High-pass filter
LPF	Low-pass filter
EMU	Engine management unit
OOL	Optimal operating line
HILS	Hardware-in-the-loop system
DC	Direct current
AC	Alternating current
UDDS	Urban Dynamometer Driving Schedule
SOC	State of Charge

Table 1
Characteristics of the HEV, BEV and FCEV.

Types of EV	HEV	BEV	FCEV
Propulsion Source	- Internal combustion engine - Electric motor	- Electric motor	- Electric motor
Energy Source	- Internal combustion engine - Battery - Super-capacitor	- Battery - Super-capacitor	- Fuel cell - Battery - Super-capacitor

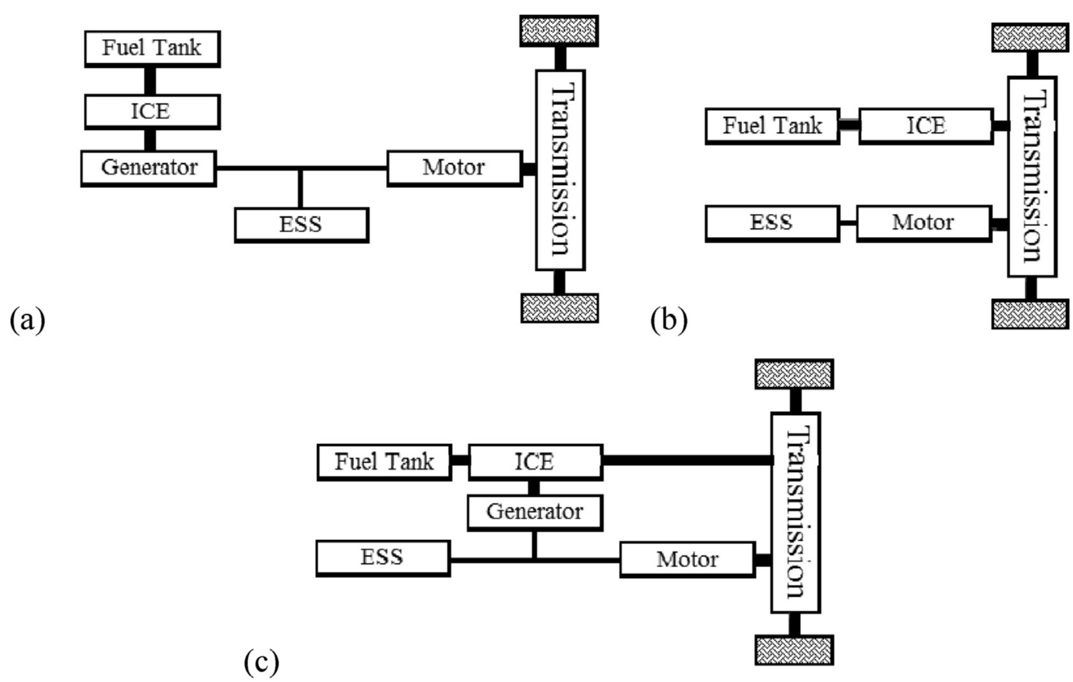

Fig. 1. Configuration of the hybrid electric vehicle.

algorithm is more important to achieving higher fuel economy.

In these days, the HEVs have been extensively developed for military applications to ensure better performance in terms of the maneuver, survivability, and lethality, as well as the fuel economy [9–13]. For achievement of these performance requirements, military HEVs require features such as high grade-ability, fast acceleration, silent watch, and silent mobility. Therefore, various hybrid components, including the electric motor, primary source such as diesel engine and generator, and energy storage element such as battery, super-capacitor, should be appropriately designed considering the performance requirements, fuel economy, as well as mission completeness [12,13].

Several studies [14–19] have been carried out to improve the performance and efficiency of devices used in commercial vehicles to obtain better fuel economy and to reduce emissions. In the case of hybrid military vehicles, because of its specificity, some constraints should be included at the design phase of the vehicles. As military vehicles have high performance requirements and are operated under poor driving conditions, new study that focuses on aspects such as component sizing and power control is important and necessary.

In general, the component sizing of the powertrain is