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Comparative study of two different powertrains for a fuel cell hybrid bus

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HIGHLIGHTS

- Buses equipped with two different powertrains have been developed and tested.
- The supply path of fuel cell accessories has an effect on powertrain efficiency.
- A comparative energy analysis of two different powertrains has been conducted.

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ABSTRACT

The powertrain plays an essential role in improving the tractive performance and the fuel consumption of fuel cell hybrid vehicles. This paper presents a comparative study of two different powertrains for fuel cell hybrid buses. The significant difference between the two powertrains lies in the types and arrangements of the electrical motor. One powertrain employs an induction motor to drive the vehicle, while the other powertrain adopts two permanent magnetic synchronous motors for near-wheel propulsion. Besides, the tiny difference between the proposed powertrain is the supply path of the fuel cell accessories, which can have an effect on the powertrain efficiency. The component parameters and energy management strategies for the two powertrain are determined. The fuel cell hybrid buses equipped with the two powertrains are developed, and some road tests are achieved, according to the chosen procedures or driving cycles. The paper focuses on the tractive performance and energy analysis of the powertrains based on the testing results. Finally, the paper summarizes the relative merits of the proposed powertrains.

1. Introduction

Decreasing the dependence on limited reserves of fossil fuels, along with increased concerns for environmental protection, lead to the continuous promotion of and interest in alternative energy vehicles. The proton exchange membrane fuel cell (PEMFC) is an extremely promising green power source for vehicles because it has some advantages, such as low operating temperatures, rapid start-up and high efficiency. However, to reduce the cost and improving the durability of PEMFC, the hybridization of power sources must become a solution with PEMFC and other energy storage systems (ESSs), such as the lithium-ion battery system and the ultra-capacitor system [1–3]. Currently, the fuel cell hybrid bus has become one of the most promising tools to facilitate green public transport in urban areas [4].

With hybridization, the powertrain of fuel cell hybrid bus is complex and has many configurations, which can impact the tractive performances and fuel consumption [5,6]. The powertrain configurations depend on the connecting paths of the powertrain components. Fig. 1 shows the connection diagram of the fuel cell hybrid powertrain, which can be seen as a multi-source, multi-load power system.

“Fuel Cell + Battery”, “Fuel Cell + Ultracapacitor” and “Fuel Cell + Battery + Ultracapacitor” are the typical power sources combinations in the powertrain. Each type of power source can be directly or indirectly connected to the HV DC Bus via a DC/DC converter, depending on the power capacities and the voltage range

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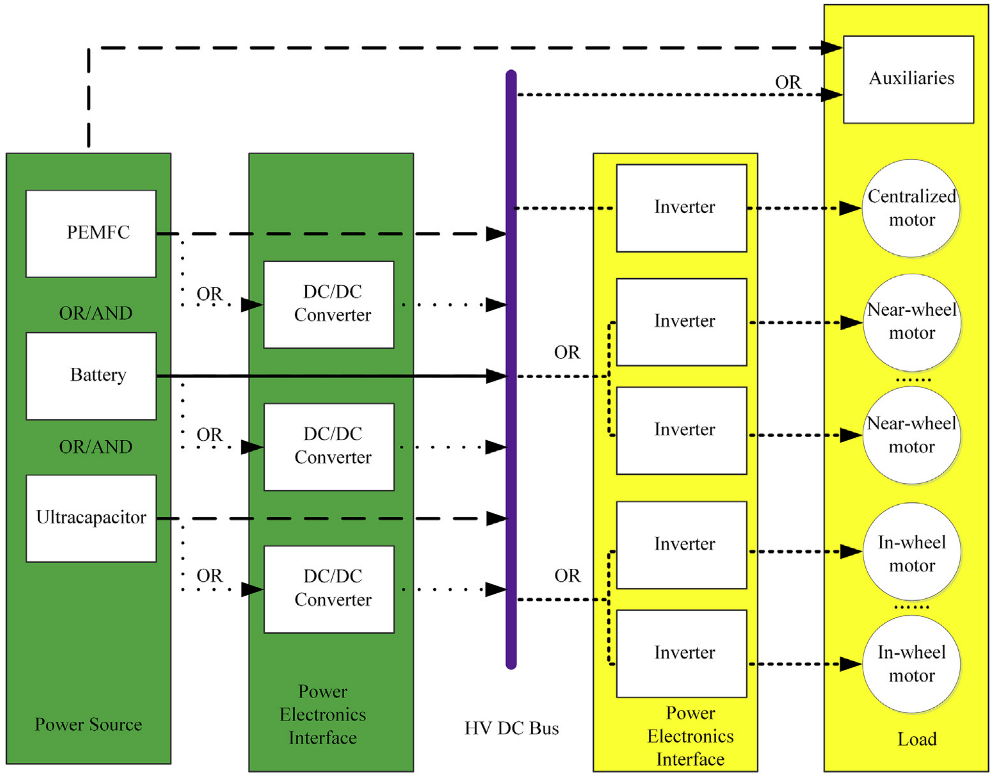

Fig. 1. Configuration diagram of fuel cell hybrid powertrain.

of the power sources. If a DC/DC converter is employed by a power source, the output power of this power source can be controlled, and consequently, power distribution can be realized, according to an energy management strategy. From an energy management perspective, every power source that possess a DC/DC converter is not encouraged, although they can be found in some literature [3,7,8] because the accurate demand power of the on-road vehicle is difficult to obtain. A minimum of one power source should be used to make up the power difference between the loads and other power sources, which significantly reduce the complexities of the energy management strategy and the cost of the powertrain.

The powertrain loads can be divided two types, one of which is the driving motor and the other is the accessories. The accessories include FC accessories, a 24-V converter, an air conditioner and so on, all of which can be supplied by a fuel cell or an energy storage system. The motor driving mode can also impact the powertrain configuration. Thus far, three driving modes exist for fuel cell vehicles, namely centralized driving, near-wheel driving and in-wheel driving. Centralized driving is widely used in various types of electric vehicles, in which a single-motor driving system with similar transmission is employed in conventional vehicles by replacing the internal combustion engine (ICE) with an electric motor. The average driving torque is approximately distributed to the left and right half shafts by the differential, and the torque of the individual driving wheel is difficult to adjust independently. Compared with the centralized driving, in-wheel driving and near-wheel driving are also called distributed driving. In-wheel driving is a propulsion mode of directly driving a wheel by incorporating an electric motor into the hub of the wheel. Near-wheel driving is also driving a wheel directly by an electric motor installed near the wheel and connecting it by a shaft or a gearbox. Distributed driving has the advantages of improving driving performance through optimized mass distribution and allowing independent torque control for each wheel with a significantly high accuracy [9]. Moreover, distributed driving can release vehicle space for carrying more passengers or cargo. Considering the technical challenges, such as larger unsprung weight, complicated cooling systems and oversized motors, along with commercial issues, such as cost, maintainability and replaceability, in-wheel driving is less adopted for fuel cell hybrid buses.

Many researchers have been paid significant attention to the combination of different types of power sources for fuel cell vehicles, and relevant results reported can offer references for the design and energy management of the hybrid powertrain [1–7]. This paper aims to analyze the influence of the supply path of the fuel cell accessories and motor driving mode on the performances of fuel cell hybrid bus based on the on-road test results.

First, the paper presents two different hybrid powertrains for the fuel cell hybrid bus, of which the significant difference lies in the types and arrangements of the electric motor. One arrangement employs a centralized induction motor (IM) to drive the vehicle, while the other adopts two permanent magnetic synchronous motors (PMSMs) for near-wheel propulsion. Moreover, the tiny difference between the proposed powertrains is the supply path of the fuel cell accessories. The component parameters and the energy management strategies for the two powertrain are conducted. Second, fuel cell hybrid buses equipped with the two powertrains have been developed, and some road tests have been achieved, according to the chosen procedures or driving cycles. Finally, the paper analyzes and summarizes the relative merits of the proposed powertrains. For the sake of convenience, the two proposed powertrains are called Powertrain A and Powertrain B. In the same manner, the bus equipped with Powertrain A is called Bus A, and the bus equipped with Powertrain B is called Bus B; the fuel cell in Powertrain A is called Fuel cell A or FC A, and the fuel cell in Powertrain B is called Fuel cell B or FC B.