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An energy management strategy based on dynamic power factor for fuel cell/battery hybrid locomotive

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ABSTRACT

In order to efficiently absorb more regenerative braking energy which sustains much longer compared with the conventional vehicle, and guarantee the safety of the hybrid system under the actual driving cycle of locomotive, an energy management control based on dynamic factor strategy is proposed for a scale-down locomotive system which consists of proton exchange membrane fuel cell (PEMFC) and battery pack. The proposed strategy which has self-adaption function for different driving cycles aims to achieve the less consumption of hydrogen and higher efficiency of the hybrid system. The experimental results demonstrate that the proposed strategy is able to maintain the charge state of battery (SOC) better than Equivalent Consumption Minimization Strategy (ECMS), and the proposed strategy could keep the change trend of SOC, which the final SOC is closed to the target value regardless of the initial SOC of battery. Moreover, the hydrogen consumption has been reduced by 0.86g and the efficiency of overall system has been raised of 2% at least than ECMS under the actual driving cycle through the proposed strategy. Therefore, the proposed strategy could improve the efficiency of system by diminishing the conversion process of energy outputted by fuel cell.

Introduction

With the reduction of fossil fuel reserves and the increasingly increasing of environmental pollution problems, developing clean energy has become a popular topic which affects the development of society and economy [1–3]. Fuel cell technology is one representation of numerous clean energy technologies, because it possesses many advantages such as no pollution, high energy density, safety and so on, there is a trend for more and more individuals focusing on the development of fuel cell technology [4–6].

The proton exchange membrane fuel cell (PEMFC) has been widely used in many actual applications, such as vehicles, vessels, aircrafts, and micro-grid and so on [7–12]. Currently, many researches which applied fuel cell to automobile or tramway have been done. However, the research works that involved the fuel cell used in locomotive are less than

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automobile's. Qi Li et al. [13] established the model of fuel cell hybrid locomotive and adopted particle swarm optimization to optimize the model. Y. Karthik et al. [14] designed and set up power model for a fuel cell hybrid locomotive, besides that, the paper proposed an energy management strategy for the fuel cell hybrid locomotive respectively. Qi Li et al. [15] established the model of fuel cell hybrid tramway. Meanwhile, they proposed an energy management strategy based on droop control and state machine strategy, the energy management strategy could decrease hydrogen consumption and improve efficiency of the system. Guorui Zhang et al. [16] have done the locomotive modeling through the Advanced Vehicle Simulator (ADVISOR), and proposed an energy management strategy based on fuzzy logical control, of which purpose is to improve the dynamic and economy performance of the locomotive. The mentioned researches either the energy management way is relatively simple or the performance of energy management strategy has not been verified in hardware experiment platform. However, the researches provided some idea to this paper.

Among the various constituent parts of fuel cell hybrid locomotive, energy management strategy is the core of hybrid system. An appropriate and superior energy management strategy could improve the performance of fuel cell hybrid locomotive, such as less hydrogen consumption, higher system efficiency, and longer life time of power source and so on. Among the previous researches for fuel cell hybrid system, many experts and scholars have done a lot of researches about the energy management strategy of fuel cell hybrid system. For example, Chengshuai Wu et al. [17] proposed a real-time adaptive energy management strategy which could maintain the SOC of battery in addition, the load stress of fuel cell becomes less through employing the strategy, hence, the proposed strategy is beneficial to extend the life time of fuel cell. Chanjun Xie et al. [18] proposed a power management strategy which aims to minimize the hydrogen consumption for the hybrid powertrain. Liangfei Xu et al. [19] proposed an optimal energy management strategy based on Pontryagin's Minimum Principle, the purpose of proposed strategy is to minimize the operation cost of fuel cell bus. Chanjun Xie et al. [20] designed a fuzzy logical energy management approach to stabilize the voltage of direct current bus. Ameen M. Bassam et al. [21] proposed a robust PI control strategy which could decrease the consumption of hydrogen efficiently, in addition, the load stress of fuel cell becomes less through employing the strategy, hence, the proposed strategy is beneficial to extend the life time of fuel cell. Ahmad Fadel et al. [22] proposed an optimization approach which could achieve higher system efficiency than conventional PI control and fuzzy logic control. Ameen M. Bassam et al. [23] proposed a multi-scheme strategy which could minimize the hydrogen consumption of the passenger ship's hybrid system. At present, there are many researches which are similar to the strategies mentioned above, those studies applied different algorithms in hybrid system, such as Pontryagin's Minimum Principle [24–26], fuzzy logic strategy [27,28], convex programming [29], adaptive control [17,30], filtering and decoupling frequency [27,31], equivalent minimum hydrogen consumption [32,33] and so on. Moreover, the purpose of each energy management strategy is different, such as the robustness of control system [34], the performance of maintaining the SOC of auxiliary source [14], improving the efficiency of overall system [35], decreasing load stress of source and extending the life time of source [36] and so on.

Due to the energy management strategies proposed in previous researches did not consider the locomotive's persistent period of recycling regenerative braking energy is longer than the conventional vehicles', and it could affect the performance of sustaining the SOC of battery especially in the fuel cell/battery hybrid system. Therefore, direct applying the energy management strategy mentioned above into actual locomotive application is not advisable, that will cause both the efficiency of system and the performance of maintaining SOC can't arrive at optimum. Moreover, most of previous researches mentioned above did not verify the performance of energy management strategy in actual hardware platform. This paper proposed an energy management strategy which based on a dynamic power factor and the framework of equivalent consumption minimization strategy (EMS_DPF) for fuel cell hybrid locomotive. Although determining the value of dynamic power factor needs to consider the global driving cycle, the energy management strategy based on dynamic power factor belongs to the instantaneous optimization method. The proposed strategy is more suitable for the actual driving cycle of locomotive than traditional energy management strategies. The good performance of strategy proposed in this paper is reflected by maintaining the SOC of auxiliary source, decreasing hydrogen consumption and improving the efficiency of system. In addition that, the energy management strategy was verified through hardware experiment on the scale-down locomotive system set up in this paper.

System description

Due to the power response speed of fuel cell is slow, it is harmful to extend the life time of fuel cell when the output power of fuel cell sharply and frequently vary. Meanwhile, because the fuel cell's direction of energy flowing is unidirectional, fuel cell could not recycle the breaking energy. The power system of fuel cell hybrid system is normally composed of fuel cell and auxiliary source. The auxiliary source is used to supply the load power which varies sharply and frequently, and the auxiliary source is responsible for recycling regenerative breaking energy.

This research set up a scale-down fuel cell hybrid locomotive system according to the actual fuel cell hybrid locomotive, and the whole power of scale-down system is the actual locomotive's 1/1180 time, the structure of system is shown Fig. 1. The main source of scale-down system is composed of an air-cooled fuel cell and a unidirectional DC/DC converter which cascades with fuel cell. The auxiliary source of scale-down system consists of a bidirectional DC/DC converter and a lead-acid battery pack. Moreover, this paper adopts an electronic load and a source to simulate the load of locomotive. In the topological structure adopted by this paper, the voltage of battery pack doesn't need to match with the voltage of DC bus strictly, and the topological structure could much more reasonably control the charge or