Energy Conversion and Management 171 (2018) 1273–1291

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

A comprehensive review on hybrid power system for PEMFC-HEV: Issues and strategies

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ARTICLE INFO

Keywords:
Hybrid electric vehicles
Proton exchange membrane fuel cell
Energy management strategy
Energy storage system
Issues and strategies

ABSTRACT

Nowadays, there is a great shortage of non-renewable energy, and the environmental problems such as air pollution caused by automobile exhaust are very serious. The traditional fuel vehicle has been unable to meet the current human needs, so more and more people are concerned about the development of the hybrid electric vehicles (HEVs). Based on proton exchange membrane fuel cell (PEMFC) is a new clean energy without pollution, PEMFC-HEV has a great potential for development. In this review, we have made a comprehensive research on energy management strategy (EMS) of the hybrid power system (HPS) for PEMFC-HEV in recent years. This paper focuses on the EMS of PEMFC as the main power source, the battery and the supercapacitor (SC) as the auxiliary energy in HEV. In this research, the classification of PEMFC-HEV is introduced in detail, and the advantages and disadvantages of various combinations of HPS are summarized. In addition, according to the different requirements and optimization targets of PEMFC-HEV, this paper makes a deep study of the current PEMFC-HEV hybrid system model, and the EMS developed by the researchers. Besides, the simulation and experimental results are compared with each other. From the perspective of strict evaluation, the existing technology can perform more or less. However, high efficiency and optimization performance still fail to achieve high goals. Therefore, the current problems and main control strategies of PEMFC-HEV are discussed and summarized, which is helpful for the development of PEMFC-HEV research in the future. The review will be expected to bring more efforts to the future development of PEMFC-HEV, including faster dynamic response, longer service lifetime, economic optimization, and high efficiency for the PEMFC system.

1. Introduction

Electric vehicles (EVs) seem to be one of the ideal solutions to the energy crisis and global warming in today society, because they have the advantages of zero fuel consumption and zero emissions [1]. The International Energy Agency released the “2017 Global Electric Vehicle Outlook Report” in June 2017, which disclosed that in 2016, the cumulative sales of EVs worldwide had exceeded 2 million. According to China Electric Vehicle Industry Analysis and Forecast Research Report, sales of EVs in China have increased year by year in 2011–2013. In 2013, the output of EVs was approximately 14,243 vehicles, accounting for 81.39% of the total new energy vehicles, and the sales volume was 14,604 vehicles, accounting for approximately 82.98%. As shown in Fig. 1 (Data from Web of Science search results), the growing appeal of this research area can be observed from the steady increase in the number of scientific papers published in Web of Science academic journals and magazines since 2007. We can see from the chart that EVs are a hot topic, which scholars have studied much in the past decade. At the same time, research on fuel cell – hybrid electric vehicles (FC-HEVs) is also deepening, but it is still relatively immature.

There are three types of power energy for EVs, battery, FC and supercapacitor (SC). The battery is divided into a lead-acid battery, a nickel-cadmium battery, a nickel-metal hydride battery or a lithium ion battery. The most widely used power source at present is a lead-acid battery. The main power sources for development are sodium-sulfur batteries, nickel-cadmium batteries and lithium batteries. FCs are classified into alkaline fuel cells, proton exchange membrane fuel cells (PEMFCs), phosphoric acid fuel cells, molten carbonate fuel cells and solid oxide fuel cells. However, most of the current applications in the automotive field are PEMFCs. SC refers to a new type of energy storage device between the traditional capacitor and the rechargeable battery, with a capacity of several hundred to thousands of degrees. Compared with conventional capacitors, it has a larger capacity, specific energy or capacity density, a wider operating temperature range and an extremely long service life. And compared with a battery, it has a higher specific power and is more environmentally friendly.

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https://doi.org/10.1016/j.enconman.2018.06.065
Received 26 April 2018; Received in revised form 15 June 2018; Accepted 18 June 2018
0196-8904/

Nomenclature

HEV	hybrid electric vehicle
PEMFC	proton exchange membrane fuel cell
EMS	energy management strategy
HPS	hybrid power system
SC	supercapacitor
EVs	electric vehicles
BEVs	battery-powered electric vehicles
FCEVs	fuel cell electric vehicles
ESS	energy storage system
DC	direct current
AC	alternating current
PCH	port controlled Hamiltonian
PDCS	power distribution control strategy
AER	all electric range
SOC	state of charge
FLC	fuzzy logic controller
RB	rule-based
DTC	direct torque control
BBs	battery banks
RTO	real-time optimization
DP	dynamic programming
PMP	Pontryagin's minimal principle
ECMS	equivalent fuel consumption minimization strategy
Haar-WT	Haar wavelet transform
RBF-NN	radial basis function neural network
IDA-PBC	interconnection and damping assignment passivity based controller
PSO	particle swarm optimization

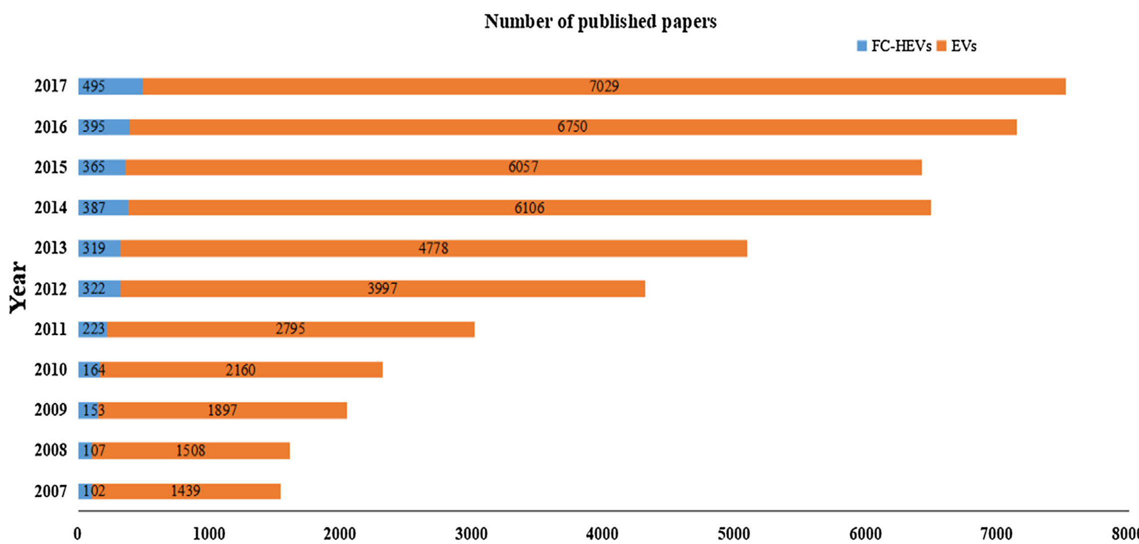

Fig. 1. The growing appeal of this research area since 2007.

All EVs are of three types: battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs) and FC-HEVs. In recent years, Honda, Mercedes-Benz and other auto companies have begun to focus on the development of technology. A summary of the classification, advantages/disadvantages and application cases of EVs is shown in Table 1. BEV only uses the energy storage system (ESS), and FCEV uses only FCs, while FC-HEV uses a combination of FC and battery/SC as ESS to power the vehicle [2]. The advantage of BEVs is that they are the lowest mechanical drivetrain. However, this type of EVs is mainly due to the acceleration of the vehicle high torque traction motor, which greatly reduces the efficiency, and the BEV is suitable for short distance and small vehicles. FCEV is driven by hydrogen and only discharge water and heat. Because there is no exhaust pollutant, FCEV is considered to be zero emission vehicle [3]. And FCEV is suitable for medium-large and long-range vehicles. But the cost of FCEV power system has to be reduced and durability of the power system must be improved for FC to compete with conventional technologies [4]. Compared with BEV and FCEV, FC-HEV, which equipped with not less than two power sources as the energy management system, has a longer driving range than BEV and is more reliable and responses faster when the load changes.

As one of the most potential EVs, FC-HEV uses FC to generate electricity from hydrogen and air. The electricity is either employed to drive the vehicle or stored in an ESS, such as a battery pack or SC. FC-HEVs are not only non-polluting to the environment but also have the potential to be highly efficient. PEMFC has the advantages of high power density, reduced greenhouse gas emission, high efficiency, relatively low operating temperature and pressure, so it is considered to be a candidate for long distance FC-HEV [5]. The increasing attention paid to energy conservation and environmental protection in the world has led to the revival of PEMFC-HEV [6]. However, using only a standalone PEMFC will lead to a short lifetime of the system due to the fact that the PEMFC system will absorb all the dynamic of current [7]. The weakness of PEMFC is the slow dynamic characteristic, and the current slope of PEMFC must be restricted to prevent fuel starvation. Therefore, in PEMFC-HEV, SC or battery as auxiliary power will improve its performance and life [8].

Nevertheless, the limited life cycle of battery [9] and driving range after battery charging become the main obstacle to commercialization of PEMFC-HEV. Furthermore, if SC is used as an auxiliary energy source, the power allocation between PEMFC and SC modules is a basic problem of PEMFC-HEV in order to achieve good performance [10,11]. SC is an electrochemical device and has the advantages of high current discharge capability, high energy conversion efficiency and small process loss. However, the energy density is not high and cannot be discharged for a long time [12–14]. By combining the two energy sources in parallel, it will achieve the benefits of the two as a complete energy source. Therefore, the power allocation between hybrid power sources is a tricky and promising problem.

In addition, it is a complex task to design the hybrid power transmission system and its energy management algorithm, which directly affects the size, cost and efficiency of the whole system [15–17]. The