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Hybrid electric vehicles and their challenges: A review

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ABSTRACT

There are numbers of alternative energy resources being studied for hybrid vehicles as preparation to replace the exhausted supply of petroleum worldwide. The use of fossil fuel in the vehicles is a rising concern due to its harmful environmental effects. Among other sources battery, fuel cell (FC), super capacitors (SC) and photovoltaic cell i.e. solar are studied for vehicle application. Combinations of these sources of renewable energies can be applied for hybrid electric vehicle (HEV) for next generation of transportation. Various aspects and techniques of HEV from energy management system (EMS), power conditioning and propulsion system are explored in this paper. Other related fields of HEV such as DC machine and vehicle system are also included. Various type models and algorithms derived from simulation and experiment are explained in details. The performances of the various combination of HEV system are summarized in the table along with relevant references. This paper provides comprehensive survey of hybrid electric vehicle on their source combination, models, energy management system (EMS) etc. developed by various researchers. From the rigorous review, it is observed that the existing technologies more or less can capable to perform HEV well; however, the reliability and the intelligent systems are still not up to the mark. Accordingly, this review have been lighted many factors, challenges and problems sustainable next generation hybrid vehicle.

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1. Introduction

An emphasis on green technology is greatly demanded of modern cities. The significant growth of today's cities has led to an increased use of transportation, resulting in increased pollution and other serious environmental problems. Gases produced by vehicle should be controlled and proactive measures should be taken to minimize these emissions. The automotive industry has introduced hybrid cars, such as the Honda Insight and the Toyota Prius that minimize the use of combustion engines by integrating them with electric motors [1]. Such technology has a positive effect on the environment by reducing gas emission. The greatest challenge in research activities today is developing near zero-emission powered vehicles. Electric vehicles powered by renewable energies offer a possible solution because they only emit natural byproducts and not exhaust fumes, which improve the air quality in cities and, thus the health of their populations [2].

One potential renewable energy device to power vehicles is the FC. A FC is an electrochemical device that produces DC electrical energy through a chemical reaction [3]. It consists of an anode, an anode catalyst layer, an electrolyte, a cathode and a cathode catalyst layer. Multiple FCs are arranged in series or parallel in a stack to produce the desired voltage and current [4]. FCs can be used for transportation applications from scooters to tramways, for combined heat and power (CHP) systems and in portable power supplies. In fact, the applications of FCs start at the small scale requiring 200 W and can reach the level of small power plants requiring 500 kW [5–7]. FC technology uses hydrogen as the main source of energy that produces the electricity needed to drive an electric vehicle. In comparison to an internal combustion engine (ICE) that emits gases such as NO_x and CO_2, FC emits water as byproduct [8,9]. However, the downside to FCs is their slow dynamic properties, and therefore, they require auxiliary sources, such as batteries and SCs [10]. Batteries, which have high power density but low energy density have problem in longer charging time which can take from 1 h to several hours for full charge. On the positive side, batteries supply voltage more consistently than FCs. Batteries that are typically used with FCs, which are lead–acid, Li-ion and Ni–MH batteries [11]. In the energy management system for hybrid vehicles, batteries can be charged during regenerative braking and from the residual energy of FCs in low and no load power systems. In this case, batteries are implemented for energy storage and can supply energy continuously depending on the charge and discharge time cycle. Unfortunately, batteries have a limited life cycle that depends on the operating temperature (approximately 20 °C) and on the depth of discharge and the number of discharge cycles. Typically, lead-acid batteries can sustain1000 cycles while Li-ion batteries are limited to 2000 cycles [11]. In addition, Li-ion and Ni–MH batteries have a higher energy density and are lighter compared with lead–acid batteries. However, lead–acid batteries have an advantage over other batteries in their cost and fast response to current changes [12]. SCs also have the potential for power enhancement in vehicle applications.

SCs are electrochemical capacitors that offer higher power density in comparison with other storage device. They contain an electrical double layer and a separator that separates and holds the electrical charges. The separated charges provide a small amount of potential energy, as low as 2–3 V [13]. The double layer is made of a nano-porous material such as activated carbon that can improve storage density. The capacitance values of SCs can reach 3000 F. Super capacitors or ultra capacitors have a few advantages over batteries such as a longer lifecycle (500,000 cycles), a very high rate of charge/discharge and low internal resistance, which means minimum heat loss and good reversibility [14]. Furthermore, SCs have an efficiency cycle of approximately 90% whereas the efficiency cycle of a battery is approximately 80%. However, SCs are not a source of high energy density. The amount of energy stored per unit weight of SCs is between 3 and 5 W h kg^{-1}, whereas that of a Li-ion battery is approximately 130–140 W h kg^{-1} [15]. Therefore, the combination of SCs with FCs, which have low power density but high energy density, is a practical alternative to improve the efficiency and performance of HEVs. In addition, SCs have a high charging rate, which allows regenerative braking to be used more efficiently. As SCs have the potential to function as an energy storage device in the future, many industries are interested in fabricating SCs with new technology and material design. The lab experiment shows that the energy density of SCs can be reach up to 300–400 W h kg^{-1}, however, future lithium based batteries are projected to achieve densities around 400–600 W h kg^{-1} [13]. The Fig. 1 shows comparison between various energy sources and storage in terms of power and energy density.

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