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Review of energy storage systems for electric vehicle applications: Issues and challenges

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ABSTRACT

The electric vehicle (EV) technology addresses the issue of the reduction of carbon and greenhouse gas emissions. The concept of EVs focuses on the utilization of alternative energy resources. However, EV systems currently face challenges in energy storage systems (ESSs) with regard to their safety, size, cost, and overall management issues. In addition, hybridization of ESSs with advanced power electronic technologies has a significant influence on optimal power utilization to lead advanced EV technologies. This paper comprehensively reviews technologies of ESSs, its classifications, characteristics, constructions, electricity conversion, and evaluation processes with advantages and disadvantages for EV applications. Moreover, this paper discusses various classifications of ESS according to their energy formations, composition materials, and techniques on average power delivery over its capacity and overall efficiencies exhibited within their life expectancies. The rigorous review indicates that existing technologies for ESS can be used for EVs, but the optimum use of ESSs for efficient EV energy storage applications has not yet been achieved. This review highlights many factors, challenges, and problems for sustainable development of ESS technologies in next-generation EV applications. Thus, this review will widen the effort toward the development of economic and efficient ESSs with a longer lifetime for future EV uses.

1. Introduction

The world is moving toward development by ensuring proper utilization of advanced technologies. Many developing and underdeveloped countries are competing to achieve the technological advancement of developed countries. Addressing the transportation needs of citizens symbolizes the furtherance of technology and economic growth. Global mobility and development of many cities have significantly increased the number of vehicles on roads. According to Ref [1], approximately 295.57 million vehicle were sold from 1990 to 2014, and 31.70% of the total sales were reported in 2014. An increase of 3% in vehicle sales is anticipated in 2015 [1].

The increase of vehicles on roads has caused two major problems, namely, traffic jams and carbon dioxide (CO_2) emissions. Generally, a conventional vehicle dissipates heat during consumption of approximately 85% of total fuel energy [2,3] in terms of CO_2, carbon monoxide, nitrogen oxide, hydrocarbon, water, and other greenhouse gases (GHGs); 83.7% of total gas emissions are CO_2 [4]. CO_2 emission by transport has increased dramatically from 22.7 billion metric tons in 1990 to 35.27 billion metric tons in 2013 [5], as shown in Fig. 1. While a slow rise of CO_2 emission in 1990 to the next decade is seen in Fig. 1, the growth rate increased faster from 2003 to 2008. In 2013, the emission rate reduced from 3.80–2.00%. Carbon dioxide is one of the GHGs that contribute to global warming, which is a serious global environmental problem.

Decarbonization plays an important role in reducing the CO_2 emissions of the transport sector. Improvement of internal combustion engines for fossil fuel-driven vehicles is still far from achieving CO_2 emission targets. Thus, advanced technologies are required to reach long-term and higher emission targets. Reduction of CO_2 and other GHG emissions is a vital concern of many countries and researchers. Many action plans have been approved by governments individually and collectively to reduce CO_2 emission by replacing the conventional internal combustion engine-run vehicle with electric vehicle (EV) [6,7]. Hence, a significant reduction of GHG emissions is projected in the next few decades [4]. Electric-driven vehicles are attracting attention because of their low emission and efficient reduction of CO_2 emission. The EV is a system with higher engine efficiency and does not emit pollutants through tailpipe emission, fuel evaporation, or fuel refining. Thus, it is known as a zero-emission vehicle [8].

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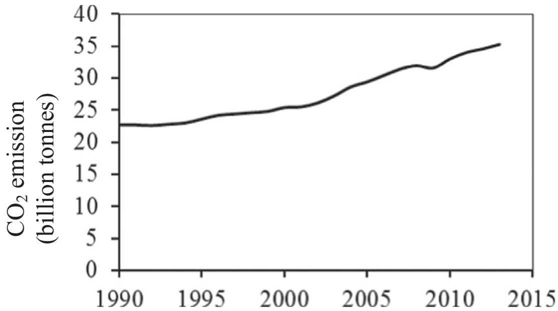

Fig. 1. Carbon dioxide (CO_2) emission by transport [5].

The EV operates with electricity stored in batteries, fuel cells (FCs), and ultracapacitors (UCs), where the ultimate source of electricity includes generating plants and renewable energy resources, which means that a plug-in charged storage is used. Depending on the source of power, EVs are of several types, such as hybrid electric vehicles (HEVs), battery-powered electric vehicles (BEVs), plug-in hybrid electric vehicles, photovoltaic electric vehicles, and fuel cell electric vehicles [9,10]. Unlike conventional vehicles, EV uses a more efficient power source and electrical motor than the powertrain of power combustion engines [10,11]. Regenerative braking and thermoelectric generators are used in EVs to reduce energy waste. The braking process of the vehicle absorbs its energy, converts it back to electrical energy, and returns the energy to the batteries, while the thermoelectric generator converts heat from the engine and machine systems to electricity automatically [3,11,12]. EVs normally do not need a gearbox as used by electric motors and have high torque at a wide range of speed. Moreover, the EV does not consume any power when it is stationary [13] and consumes more than 75% of energy during run time. At present, EVs could cross a mean of 4–8 miles using only a kWh capacity [3].

EVs are highly dependent on available energy storage technologies, such as battery cell, FC, and UCs [3,14–16] for power. Thus, EVs need to be charged from the power grid. The additional energy demand for EVs is the new challenge to common power grids. To meet the extra demand of electricity, most countries are investing in renewable energies, such as solar and wind energy [16]. Moreover, renewable energy resources contribute to the power grid during peak load demand consumption period. The renewable and stored energy in the vehicles are transferred to the utility power grid as a vehicle-to-grid (V2G) system at peak hours or back to restore energy [17–19]. The electric energy stored in the battery systems and other storage systems is used to operate the electrical motor and accessories, as well as basic systems of the vehicle to function [20]. The driving range and performance of the electric vehicle supplied by the storage cells must be appropriate with sufficient energy and power density without exceeding the limits of their specifications [3,14–16].

Many requirements are considered for electric energy storage in EVs. The management system, power electronics interface, power conversion, safety, and protection are the significant requirements for efficient energy storage and distribution management of EV applications [21–25]. EVs are manufactured with high technology features to assure long and efficient runs. The selection and management of energy resources, energy storage, and storage management system are crucial for future EV technologies [23]. Providing advanced facilities in an EV requires managing energy resources, choosing energy storage systems (ESSs), balancing the charge of the storage cell, and preventing anomalies. The objectives of the review present the current scenario of ESSs, updated features of the ESSs, evaluations, issues, and challenges of existing systems, and recommendations for the future development of ESSs. Moreover, the study highlights hybridization technologies of ESSs in EV application. This study focuses on environmental and safety issues during manufacturing, utilization, recycling, and disposal of ESSs.

In this paper, available energy storage technologies of different types are explained along with their formations, electricity generation process, characteristics, and features concerning EV applications. A tabular comparison is analyzed among the existing electrochemical ESSs and their features. The review focuses on hybridization technologies of the ESSs for their efficient deployments in EV applications. Thus, the contribution of this study is the improvement of future ESSs for sustainable development of the EVs.

2. Energy storage systems for electric vehicles

Energy storage systems (ESSs) are becoming essential in power markets to increase the use of renewable energy, reduce CO_2 emission [4,5,8], and define the smart grid technology concept [26–29]. ESS has an important effect on overall electric systems; it provides continuous and flexible power supply to maintain and to enhance power as a result of congestion and interruption of transmission line for excessive demand. In addition, an ESS ensures reliable services for consumers during power crises due to natural disasters, as well as lessens the prices of electricity to support the peak demand by storing energy during off-peak hours at low cost [30].

During the past decades, renewable energy has been contributing to off-grid power consumers with ESSs. In that sense, EVs are growing technologies with ESS as a substitute for fossil fuels, where energy resources come from renewable energy technologies [26]. EVs are utilized to discourage the use of fossil fuels and reduce CO_2. Hence, high-performance ESSs are necessary to power EVs. To meet some requisites of EVs, ESSs are utilized in combination to provide high discharge time with reliability [30]. Fig. 2 shows the drive train architectures of EVs [3]. Fig. 2(a) and (b) present a BEV drive system and a series-parallel full HEV, respectively.

3. Classification of ESS systems

The classification of ESS systems is determined with the use of energy in a specific form. ESS is classified into mechanical, electrochemical, chemical, electrical, thermal, and hybrid [30]. These systems are classified into various types according to their formations and composition materials [14,30]. Fig. 3 presents the classification of ESS in detail, where the common ESSs for EV application are boxed in gray. Flywheel, secondary electrochemical batteries, FCs, UCs, superconducting magnetic coils, and hybrid ESSs are commonly used in EV powering applications [9,10,14–16,23,30–33].

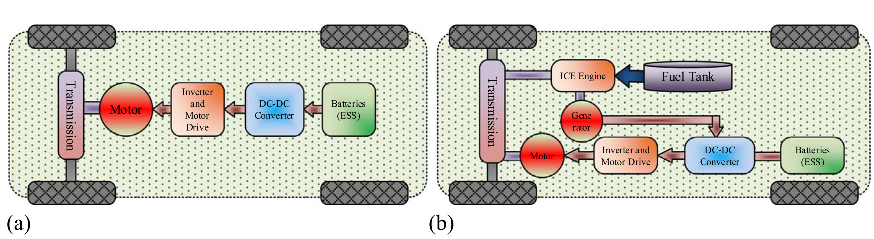

Fig. 2. EV architectures: a) battery powered EV and b) series-parallel full HEV.