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A Comparative Review on Energy Storage System for E-Transportation

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Abstract: Electric Vehicle is widely used with its technological improvement. It is superior to internal combustion engines in efficiency and simplicity. Energy Storage System (ESS) is a heart of electric vehicle though it faces challenges in storage capability. This paper is about the evaluation of different energy storage options for electric vehicle including the batteries, super-capacitors, and flywheel. This paper conveys a review of the energy storage systems with challenges, opportunities and future guidelines of EVs with energy storage. Suggest some of the options under study to increase storage capacity. The comparison of energy storage system carried out with the help of its parameters such as energy density, specific energy, lifecycle, efficiency.

Index terms- Energy Storage System, batteries, supercapacitors, Electric Vehicle, flywheel

I. INTRODUCTION

Recently, electric vehicles are considered to be part of a new age transport system for of their advantages such as lighter weight, better fuel economy leading to low fuel cost and improved operating efficiency, few refilling and eco-friendly operation. Electric Vehicle is ten thousand times simpler than internal combustion engine and it does not require any gear box. Electric Vehicle is developing in faster rate and becoming a significant part of transportation infrastructure. Electric Vehicle in integration of vehicle body, electric propulsion, energy storage devices, energy management. Here the different storage system is compared by using its various parameters. Fuel cell has high specific energy in Wh/Kg but its cost is very high difficult to store and manage hydrogen. To run an Electric vehicle the required specific power is high for good acceleration.

II. ENERGY STORAGE SYSTEMS FOR ELECTRIC VEHICLES

Energy storage systems (ESSs) are becoming vital in power markets to increase the use of renewable energy, reduce CO_2 emission [3-5], and define the smart grid technology concept [7-10]. Energy Storage system has a major 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 count, an ESS ensures reliable services for consumers during power crises due to natural disasters, as well as lowers the prices of electricity to support the peak demand by storing energy during off-peak periods at low cost [6]. During the earlier decades, renewable energy has been contributing to off-grid power consumers with ESSs. In that logic, EVs are growing technologies with ESS as a substitute for fossil fuels, where energy resources come from renewable energy technologies [7]. EVs are utilized to discourage the use of fossil fuels to reduce CO_2. High-performance ESSs are necessary to power EVs. To meet some essentials of Electric vehicles, ESSs are used in combination so as to provide high discharge time with reliability [6].

In order to devise the options for energy storage, we need to find out the main issues and requirements of the energy storage system. Load requirements such as the prospected driving schedule, the type of vehicle & weight, etc., plays an important role in selecting the storage system. The load profile can be analyzed using available software like ADVISOR [11]. The main problems to be addressed in designing are

1) Rapid charging and discharging
2) Wide operating temperature range
3) High energy density
4) High peak power
5) Long life to reduce maintenance

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The secondary objectives are the cost, size, weight, and volume of the energy storage options. From the design above mentioned, the power storage devices are

a) Batteries
b) Super-capacitors
c) Flywheels

III. BATTERY

Battery is an electrochemical device which converts and stores chemical energy into electricity. It is classified into two types one is non-rechargeable primary batteries and the other is rechargeable secondary batteries. Rechargeable secondary battery is used for vehicular applications. In this paper Lead-acid, Nickel-Metal, Lithium-ion batteries are compared based on their features. Lead-acid batteries are used in earlier stage for electric vehicle Nickel metal provides high energy density than Lead-acid battery but cost is very high which is not satisfactory so, researchers shifted their interest into Lithium-ion batteries because of its higher energy density with low cost and widely used in mobile devices, laptops.

1) *Lead Acid:* Lead acid battery belongs to rechargeable batteries commonly used in stand-alone power systems. They comes in different types: deep or shallow cycling, gelled batteries, batteries with capacitive or inductive electrolyte, sealed or open battery. Sealed batteries allow evolution of excess hydrogen gas. they are called sealed because we cannot add electrolyte. It requires less maintenance as compared to open batteries. Open batteries also called flooded electrolyte contain an excess of electrolyte and to reduce electrolyte stratification gassing is used. The specific energy (35-40Wh/Kg) energy density (80-90 Wh/L) specific power (180W/Kg)
2) *Lithium Iron:* Research areas for lithium iron batteries include extending lifetime, increasing energy capacity, safety improvement, low cost, high charging speed life cycle is 80% of rated battery capacity. The specific energy (100-265 Wh/Kg) energy density (250-693 Wh/L) specific power (~340W/Kg)
3) *Nickel Metal Hydride:* Nickel metal hydride batteries of bipolar design and it rely on absorption and desorption of hydrogen in metal alloy during charging and discharging. Nominal voltage is 1.2 V. The specific energy (60-120 Wh/Kg) energy density (140-300 Wh/L) specific power (250-1000W/Kg) lithium iron batteries have higher specific energy than nickel metal hydride.

Table1: Comparison of various types of batteries

Types	Energy density(Wh/L)	Lifecycle	Efficiency(%)
Lead-acid	80-90	1000	80
Nickel metal	140-300	2000	75
Lithium-ion	250-693	2000	95

From the above table it is very clear that among all batteries Lithium-ion is preferred by considering its capability of high energy storing capacity and efficiency which helps in mass production of electric vehicles.

IV. SUPERCAPACITOR

Another energy storage device is the super capacitor is an electrochemical capacitor introduced in the 1970s to provide backup power for computer memory. It varies from conventional capacitors in both the electrolyte and electrode design. Traditional capacitors have two electrodes separated with a dielectric material while in supercapacitor it is constructed with porous carbon electrodes which gives high surface area with electrolyte. In super capacitor electric energy storage is achieved by the electrostatic double- layer capacitance or electrochemical pseudo capacitance. Supercapacitor offers advantage of relatively high power density than batteries but low energy storage because of this supercapacitor cannot be replaced by battery in electric vehicle. Energy density, lifecycle of various electrode material is shown in table 2

Table2: Comparison of various types of supercapacitor

Electrode material	Specific energy(Wh/Kg)	Lifecycle	Efficiency(%)
Pseduo-capacitor(Metal oxide)	10-15	40	>95
Hybrid capacitor(carbon/Metal oxide)	10-15	40	>95
Hybrid-capacitor(carbon/lead oxide)	10-12	40	>95

From the table 2,3 it is clear that the battery energy density (8 to 600 Wh/Kg) is higher than supercapacitors energy density(1 to 5 Wh/Kg) so batteries cannot be replaced by supercapacitors.

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V. FLYWHEELS

Flywheel is a energy conversion and storage device also known as electro-mechanical battery. It contains a wheel made of high strength carbon fiber, supporting device, motor/generator and power electronic control device. Flywheel is maintained by magnet floating bear in vacuum and converts electric energy into kinetic energy and also kinetic energy into electric energy through the same motor/generator [12]. Flywheels have the characteristics such as, Specific energy of around 40 Wh/kg, a number similar to lead acid battery, Specific power significantly higher than that of ordinary chemical battery because it can reach more than 3,000 W/kg, Pure mechanical device without pollution, No chemical reaction like the chemical batteries, no gas emission and waste materials, Long cycle life, Fast charge due to high specific power. High efficiency of around 90%. self-discharge rate is low, flexibility in design and operation. The precise energy of flywheels rises proportionally as the weight of rotating material is reduced, when compared in terms of equal mechanical strength of the flywheel. Magnetic flywheels has various features such as high-speed charging ability, high energy density, and low losses.

Table 3: Summary of the ESS

Characteristics	Battery		Ultra capacitor	Flywheel
	Lithium ion	Lead acid		
Discharge time	10 min to 1 hr	15 min to 4 hr	1 s to 1 min	1 s to 1 hr
Response time (ms)	30-100	30-100	5-10	5-10
Typical nominal power (KW to MW)	10 kW 10 MW	50 kW to 30 MW	10 kW to 1 MW	10 kW to 20 MW
Efficiency (%)	85-95	75-90	85-95	85-95

Flywheel has the highest nominal power capacity, than supercapacitors but supercapacitors have the fastest response and discharge time.

VI. CHALLENGES, OPPORTUNITIES

Automotive sector with a few technological up gradation places in the market every day a model electric car. Until now electric vehicles have to prove a viable alternative to internal combustion engine based vehicles, still their volume on road is frequently increasing. The EV industries have to address many techno-economic challenges to make EV popular and successful in design and its widespread employment. The challenges are mentioned below:

1) Limited dynamic performance due to usages of a single energy source.
2) Higher cost of the EVs.
3) ESS occupies a substantial space.
4) Availability of limited number of plug-in charging station/ hydrogen refueling station in FCHEV.
5) System reliability issue due to consistency issues of the components of power converter, batteries, storage devices, EM, and FC stacks.

From the above challenges, the opportunities given in terms of:

a) Research opportunities in battery technology for much higher specific power and energy giving higher driving range.
b) Improvement in technologies of batteries, storage devices with increased reliability and reduced cost.
c) Merging of renewable energy sources for example photovoltaic for enhanced dynamic performance.
d) Proper education campaigns to attract consumers for enhanced fuel economy with payback periods and diminished air and noise pollution.

The future scope of electric mobility is assessed by Global EV Outlook 2019 through two scenarios: The main thing is that the impact of announced policy ambitions is involved in the New Policies Scenario, and the promises made by Electric Vehicle Initiative's EV30@30 Campaign to influence 30% market share for electric vehicles in all types by 2030 except two-wheelers is taken care by the EV30@30 Scenario. Under the New Policies Scenario, the EV sales are supposed to reach 23 million, and the stock is expected to exceed 130 million vehicles by 2030 (excluding two/three wheelers).

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On the other hand, sales of EVs and stock nearly doubles to 43 million and more than 250 million, correspondingly. The world leader in EV market share with 57% is China (28% excluding two/three-wheelers), subsequently Europe with (26%) and Japan with (21%) in 2030. According to EV30@30 Scenario in 2030 for China, EVs account for 70% (42% excluding two/three-wheelers) out of all vehicle sales, almost 50% In Europe followed by 37% in Japan, 30% in Canada and USA, 29% in India, and 22% cumulative of all remaining countries. With the tremendous penetration of EVs in the global market (particularly for cars), electrification in the car market basically pushes the expansion of battery manufacturing capacity. The global share of EVs is expected to rise as high as 56% for newly manufactured cars by 2040 as per the predictions by Bullish Studies (source: Bloomberg New Energy Finance, 2018). The prediction is heavily based on the assessment that EVs will provide a much cheaper option than ICE vehicles in most countries of the world by 2025-2029 by reducing the overall cost of electricity compared to gasoline (source: Bloomberg New Energy Finance, 2017).

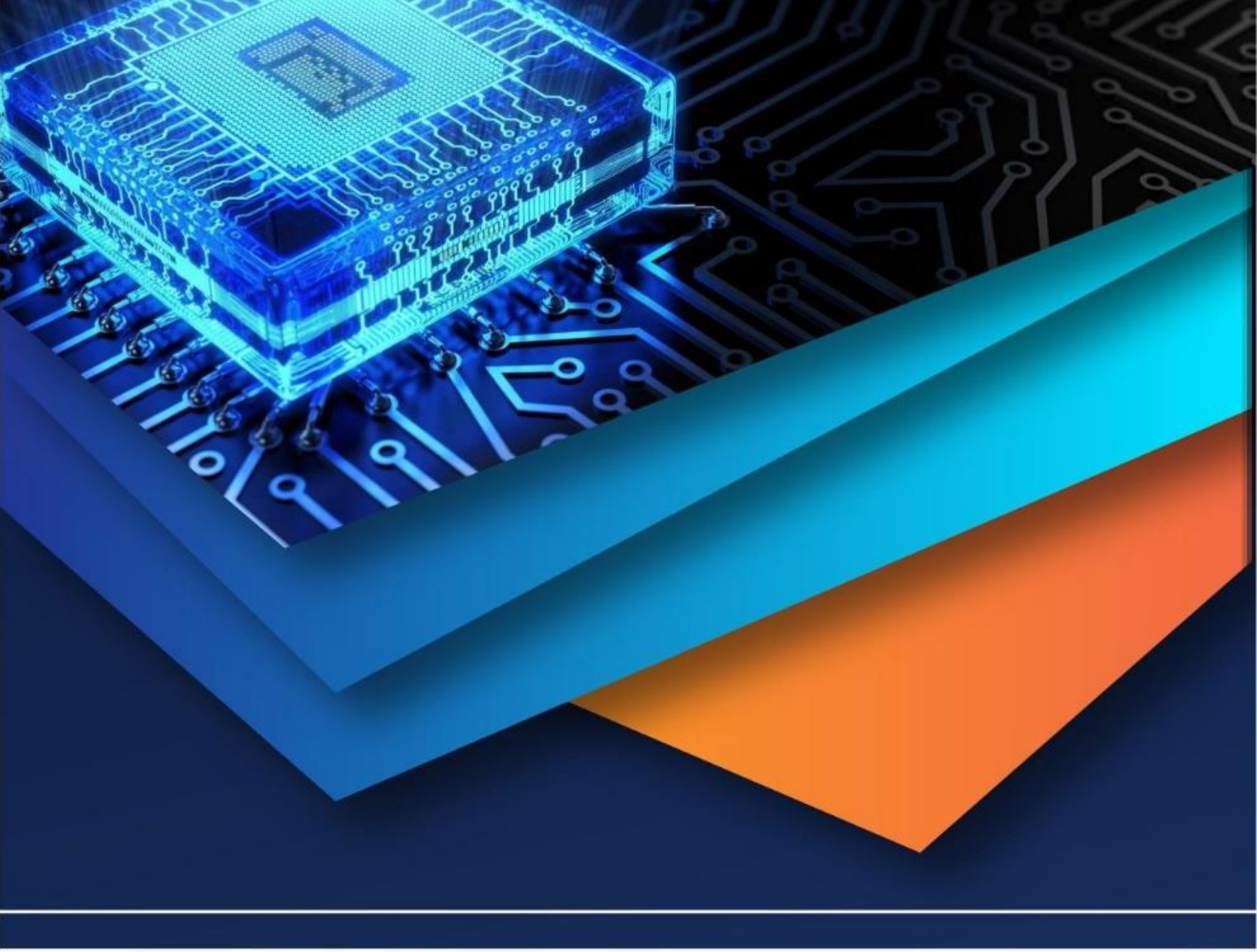
VII. CONCLUSION

A comprehensive review on ESS for electric vehicle is presented in this paper. With the current knowhow, the Li-ion battery is one of the most suitable battery technology in vehicular application. The current trend is to use Li-ion batteries in EVs, so far battery technology is being more explored for improved alternatives, thus still an area of research. The supercapacitor is appropriate for supplying transitory power demand at the time of starting and braking of EVs apart from its possible role as back-up and emergency power supplies. Batteries and super capacitors independently cannot meet all the requirements for EVs, the HESS could complement their drawbacks. Different HESS structures and control strategies. The current trend is to use hybrid capacitors in vehicular application Apart from the battery, the use of FC and solar PV is also gaining importance day by day and one can predict that FCHEV is going to be the future of electric vehicles. Hybrid energy storage system with advanced power electronic technologies has a major influence on optimal power utilization to lead innovative EV technologies

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