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Analysis and Review of Graphene based Super-Capacitor and its Fast Charging in application of Electric Vehicle

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Abstract: *Electric Vehicles are reflected as a significant solution in developing an ecological and carbon free mode of transportation. However, the major encounters for the EVs smooth performances are its high cost, limited range of process and fast battery dreadful conditions. There are several promising strategy with comprehensive optimization techniques can lead to solve out the above-said issues. This paper represents an overview of effective fast charging techniques of EV in graphene based Super capacitor as an Energy storage system (ESS) concerning prolonging life cycle and high charging efficiency of ESS for EVs instead of Battery as an energy storage system. This paper is also dealing with the comparison analysis between the Li-ion based battery as an energy storage system with the Graphene based Super Capacitor as ESS in application of EVs.*

Keywords: Battery, Graphene based Super Capacitor, Fast Charging, Energy Storage System (ESS)

I. INTRODUCTION

The intact EV Network is standing on the interface between EV charging method with the EV itself. Four phase of Vision in overall charging network – Battery innovation, charging optimization, infrastructure evolution and sustainability which is in consonance with the recent trends in development of EVs [1]. The growth of EV market depends on the advance of efficient battery charging technologies; the efficiency is decided by the enhancement in life and performance of the Battery [2]. So, it is clear that battery considered as the heart of the EV and that is why it accounts at least one third of the total cost associated with EVs. The overall performance of the EV battery has a significant impact on the charging network as well. The commercial EV Battery in the market is mainly based on Lithium-ion. But as the capacity of the battery increased day by day, the charging time of the battery will become longer. This lead to seek the solution towards the battery innovation with different materials along with efficient fast charging techniques. Beside this, EV's fast charging technique for Battery Management System (BMS) can allow the charging of an EV at least 80% within a half of hour from its depletion [3]. By using Graphene based super capacitor replacing the Li-ion battery in EV can be an effective solution to fulfil the requirement. This type of technology may secure its position for developing a new edge of EVs battery management system. This paper is organized as follows. Section-II discusses different types of Battery materials used for EVs. Section-III focuses on fast charging methods for EV. Section-IV gives an overview of graphene based super capacitor and also its charging technique for EV. Section-V provides n comparison analysis between li-ion based battery and Graphene based super capacitor and finally in section-VI in this paper is concluded with some future extended scope of this work.

Section – II

Different types of Battery materials used for EVs

The Battery is most essential part in the EV. The performance of the EV battery has a significant impact on both the EV itself and the whole charging network. The viable EV and HEV batteries consist of the lead-acid batteries, nickel-based batteries such as nickel/iron, nickel-cadmium and nickel metal hydride (NI-MH) batteries and Lithium based batteries

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such as lithium-polymer (Li-P) and Lithium-ion (Li-ion) batteries. It seems that Cadmium based and Lithium based batteries are the major usable batteries for EVs and HEVs [6].

Nickel-Cadmium technology has several advantages like high specific power (over 220 w/kg), long life cycle life (up to 2000 cycle), wide range of discharge current and rapid charge capability (about 40% - 80% in 18 min), availability in a variety of size and design. However, this type of technology is also suffering from some limitations like – high initial cost, low

cell voltage and its carcinogenicity effect on environment due to cadmium. The major manufacturer of nickel-cadmium batteries for EV and HEV applications are SAFT and VARTA. Recent EVs which are using Ni-Cd batteries are Chrysler TE Van, Citron AX, Mazda Roadster, Mitsubishi EV, Pengeot 106 and Renault Cilo [7].Lithium based battery is now a days mostly useful technology for EV application. There are two major technologies of lithium based batteries are used - Li – P and Li – I. Lithium is the lightest among all metals and it allows a very high thermodynamic voltage, which results in a very high specific energy and specific power. The commercial EV battery used by different manufacturer are shown in Table:1 [1].

Table:1 The commercial EV Battery used in the Market

Type (Chemistry Combination)		Cell Characteristics				Battery size and range		Application	
Anode	Cathode	Capacity (Ah)	Voltage (V)	Specific Energy (Wh/kg)	Energy Density (Wh/l)	Energy (kWh)	Range (km)	Manufacture	Model
C	LMO-NMC	16~63	3.65~3.7	109~172	218~312	16~35.5	140	• Li-Energy Japan • Samsung SDI • LG Chem	• Mitsubishi i-MIEV (2008) • Fiat 500e (2013) • Ford Focus EV (2012) • Renault Zoe (2012)
LTO	NMC	20	2.3	89	200	20	130	• Toshiba	• Honda Fit EV (2013)
C	LMO-NCA-NMC	37-94	3.7	122~189	228~357	22~36	130~300	• Samsung SDI	• BMW i3 (2014, 2017) • VW eGolf (2016)
C	NMC	25-59	3.65~3.7	152~241	215~466	17~60	145~400	• Panasonic/Sanyo • Li-Tec • SK Innovation • LG Chem	• VW e-Golf (2015) • Smart Fortwo (2013) • Kia Soul EV (2014) • Chevrolet Bolt (2016) • Renault Zoe (2017)
C	LMO-NCA	33-40	3.75	155~167	309~375	24~30	135~172	• AESC	• Nissan Leaf (2010, 2015)
C	LFP	20	3.3	131	247	21	130	• A123	• Chevrolet Spark EV (2012)
C	NCA	3.2	3.6	236	673	60~100	330~500	• Panasonic	• Tesla S (2012)
Si/ SiOx-C	NCA	3.4~4.75	3.6	236~260	673-683	60~100	330~630	• Panasonic	• Tesla 3 (2017) • Tesla X (2015)

Since the capacity of the battery increases day by day, charging time of the battery will become longer, which directly affected on the customer's purchase intention. So, for achieving the optimal solution, the combination of both peaking power source and fast charging is the utmost factor.

For the future vision of EV, Battery innovation is one of the aspect, stated in Section – I in this paper. The evolution of new batteries can give the footprint on the EV technology throughout the world. Some researches is going on this prospect like – 1) Magnesium – ion batteries - In this type, Lithium is replacing with magnesium. Theoretically, it is showing 3.2 Kwh/L energy density with 1.7 KWH/ Kg specific energy [8]. 2) Metal air – In the battery chemistry technology, reaction between oxygen and different kind of metals like – Lithium air, aluminium air, sodium air etc. can be used to achieve the higher energy density for the Energy storage system of EVs [9]. 3) Graphene – This technology can be most promising potential for EV batteries for the future. It ensures high thermal conductivity with ultra-fast charging with significant power loss. But still this type of technologies is under developed condition or it is expected yet to be developed in future [10]. 4) Semi- solid Lithium – A new innovation is also under research in battery technology for EV i.e. semi-solid floe cell (SSFC) which offer 10 times the charge storage density of the conventional flow battery solution [11]

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Instead of the above discussion, another energy storage device is also now a burning topic in latest technology, i.e. super capacitor. Due to their potential applications and unique characteristics they offer a promising position in the EV technology by replacing Battery. The driving range of anxiety is also can be reduced by fast charging to the ESS containing super capacitor. In many research it's also showing that, super capacitor made of graphene material offers smooth fast charging with less time comparing to Li – ion battery for EVs.

Section – III

Fast Charging methods for EV

Many Charging methods are available for EV Battery charging. Different charging power levels with respect to various charging standards are given in the following tale. [10]

Table:2 Charging power level [10]

Charging Standards	AC Charging Power Levels		DC Charging Power Levels	
SAE	Level 1 Slow	230V(EU): P=1.4kW(12A) 120V(US): P=1.9kW(20A)	Level 1	200-450V: P=40kW(80A)
	Level 2 Medium	400V(EU): P=4kW(17A) 120V(US): P=8kW(32A)	Level 2	200-450V: P=90kW(200A)
	Level 3 Fast	208-600V: P=50kW	Level 3	200-600V: P=240kW(400A)
IEC	Level 1	P= 4 - 7.5kW (16A)	Rapid	P=1000-2000 kW (400A)
	Level 2	P=8 - 15kW (32A)		
	Level 3	P=60 - 120kW (250A)		
CHAdeMo	---------		Rapid	P=62.5kW (125A)

From the table, it can be depicted that, Level – 3 which is refereed as fast charging method which is useful on highways and mostly in commercial application. Besides that, fast charging stations are also required to reduce the driving range anxiety. A fast charging station (FCS) can allow the charging of an EV at 80% within a half of hour from its degradation. By using fast charging technique, the charging time of EV can be reduced to 7-8 hours to 30 minutes. [3]

Several types of fast charging methods are used for EV charging. Among them Pulse Charge, Combined CC-CV charging, Multi-step constant current (MSCC) methods are famous.

Pulse Charge: - In this technique, EV battery received the charging current in the form of Pulses. The width of the can be adjusted by means of supply voltage before giving to the battery. Although this method results very high efficiency and suitable for LI-ion Battery, its control technique is difficult within limited time. [2]

Combined CC-CV Charging: - In many commercial application this type of charging is preferred. This charging method contains three consecutive stages like – Pre-charging mode, CC mode or Constant current mode and last stage i.e. constant voltage mode. This kind of charging method referred as static fast charging. [11]

Multistep constant current (MSCC): - In constant current charging method Thermal Stress can be seen to develop in the Battery. So, to compensate this stress another process of fast charging is in research, i.e MSCC techniques. [12] This MSCC Technique of charging referred to as dynamic fast charging current method. It's found that for LI-ion battery y applying dynamin fast charging, gives higher state of Health (SOH) and decreased its capacity fading. [13]

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Section – IV

Overview of Graphene based super capacitor and also its fast charging technique for EVs

Battery is a device which is able to provide power over a longer period, and battery also have high energy density. But, Battery can't ensure the burst power and rapid charge – discharge capabilities, which is prior to the reason of decreasing driver's range of anxiety. For this reason, Super Capacitor have an ensuring alternative to Li-ion Batteries due to their special features. Capacitors have a high power density which ensure, its ability to release energy rapidly comparing to a battery for an EV. [14] Super Capacitor are generally classified into three class – 1. Electrostatic double layer capacitor (EDLCs) using carbon electrodes. 2. Electrochemical Pseudo Capacitors using conducting polymer electrodes and 3. Hybrid Capacitor such as the Lithium Ion capacitor. [15] The EV containing Ultra Capacitor or super capacitor stores polarized liquid between the electrodes and electrolytes. The energy capacity of this type of storage is increases as surface area of the liquid increases. [16]

The Super Capacitor material as a Graphene used for EV, is a very promising technology for upcoming era. Graphene itself a light weight material, has a comparatively large surface area than that of activated carbon used to coat the plates of conventional Super Capacitor. Graphene also offers better electrostatic charge storage capacity than the Li-Ion batteries. Graphene based Super capacitor can offer better fast charging. For Bulk power applications, it's difficult to havehigh specific capacitance at high current density during fast charging. A unique Hummer's method and tip sonication for graphene synthesis, graphene-based super capacitors offers stable and improved electrical double layer capacitance with high energy density and current density during fast charging and discharging time due to increased ionic electrolyte accessibility in deeper region. Theoretically, it's seen that the discharge capacitance and energy density values are 195 Fg-1 and 83.4Whkg-1, are achieved at a current density of 2.5 Ag-1. The time required to discharge 64.18WhKg-1 at 5A/g is around 25sec. At 7.5A/g current density, the cell can give a specific capacitance of nearly 137Fg-1 and maintain 98% of its primary value after 10,000 cycles, which depicts that optimum performance of Super Capacitors at high current rate is considerable for fast charging discharging application. [17]

Section – V

Comparison analysis between Lithium –ion based battery and Graphene based Super Capacitor.

Any kind of Super capacitor used for EV is characterized by a higher specific power but much lower specific energy compared to batteries. Its specific energy lies in the range of less watt-hours/kg. But in case of specific power it gives more than 3 KW/Kg, which is much better than any kind of Battery. [6] Like this way, in various parameters, comparison analysis can be done between a Lithium-Ion based battery and a Super Capacitor based energy storage system. The following table [15] shows the comparison analysis between them.

Table:3 Comparison Analysis between Battery and Super Capacitor [15]

Function	Typical Lithium-ion battery	Supercapacitor	Comments
Charge time	Minutes (Double digits)	Seconds	Supercapacitors charge and discharge faster
Lifetime	Short	Long	Supercapacitors can be used many times and have a longer life
Reliability	Some maintenance required	Maintenance free and reliable	Supercapacitors are more reliable
Specific Energy (Wh/kg)	Very high	Low	Batteries can hold more charge and energy over a longer period
Specific Power (W/kg)	Low	High	Supercapacitors can provide a lot of power quickly
Current cost per kWh	Low	High	Batteries lower cost at this time
Range of charge/discharge temperatures	Poor/Limited	Good/Wide Range	Supercapacitors will work in a wider range of temperatures, including very cold climates
Over-charging and safety issues	Potential issues	Draws charge only as needed.	Supercapacitors potentially safer with a lower risk of issues such as thermal runaway
Environmental impact	Often contain lithium, cobalt and other materials	Often carbon-based materials and non-toxic	Supercapacitors said to be greener in terms of disposal

Basic comparison of batteries vs supercapacitors

From the above table, it can be said that the Super Capacitor are perfect supplement of Lithium-ion batteries, as they delivering significantly high power density which flexibility to multiple charge/ discharge cycles and short charging times. However, performance of super capacitor sometimes may show delaying productivity due to its limited capacitance of current materials. Graphene based Super capacitors are a highly distinctive options to these technologies. Graphene Based Super Capacitor are of light weight and containing a low range of cost vs performance ratio. Graphene has a larger surface area than the carbon used in traditional Super Capacitor, which ensure more electrostatic charge ability. It can be said Graphene based super capacitor can store equally energy as Li-ion battery, charge – discharge in seconds and maintain these features up to ten, of thousands of charging cycles.

Section - VI

Conclusion

The first part of this paper focussed on the Different types of battery materials are used for EVs in the current scenario followed by various fast charging methods applicable for EVs.Thereafter it has been discussed that instead of Battery as a storage system Graphene based super capacitor offers a better alternative in application of EVs. The Fast Charging method of Graphene based super capacitor has also discussed in this paper and it seems that Graphene based technology offers more efficient performance comparing to any commercial type Batter like Li-ion Battery. Overall it can be assumed that Graphene based Super capacitor in application of EV is the promising and optimized technology of Future based Vehicle Industry.

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