Fast Charging Techniques And Material Specifications Requirement For Lithium Ion batteries Used In Electrical Vehicle: A Review

Suyog S Hirve, Dr. Deepak S Bankar, Parag Choudhari

Abstract: In todays world, the mobility of goods and people is its peak. To make this happen there are numerous vehicles which can deliver this service. In most recent trends, to avoid damage to the environment Electric Vehicles are extensively used. Tremendous amount of research is going on the field of Electric Vehicle such as Battery Types for improvement in overall performance, inclusion of other factors such as Ultra capacitors for betterment of overall performance, advancement in Brushless DC motors which will be more suitable to use in E- Vehicles. Many of research units have solved the issues related with the above topics. The more focus is to be given on the charging and discharging time for E Vehicles. In this paper, various charging discharging methods used for Lithium ion batteries are discussed. The methods such as constant current (CC) method, constant voltage (CV) method, constant current constant voltage method(CC-CV), constant temperature constant voltage method(CT-CV).Not only the Fast Charging methods will be sufficient to make real change in the Li-ion Batteries but also the materials that are used in these batteries should have the capacity to handle the fast charging. So, according to material properties and specifications the battery needs to be designed and as per fast charging methods suitable fast charging technique can be implemented to it.

Index Terms: Lithium Ion Batteries, Electric Vehicles, Bat-tery Charging Techniques, constant current (CC) method, con-stant voltage (CV) method, constant current constant voltage method(CC-CV), constant temperature constant voltage method(CT-CV).

1 INTRODUCTION

A lithium-ion battery or Li-ion battery (LIB) is rechargeablebattery. These batteries were first introduced in 1970s byBritish chemist M Stanley Whittingham. Further improvementand modifications in the battery takes place, the reversible andinter-calation into cathode oxide was discovered during 1976by J. O. Besenhard at TU Munich. Decade after invention,these batteries made available and commercialized in a broadway throughout the global. They are now numerously usedin mobile phones, laptops and small electrical & electronicdevices due its advantages like long life, high efficiency,better operating performance etc. Now these batteries are extensively used in Electric Vehicle applications. The lithium-ion chemistry engrosses a lithium cobalt oxide cathode anda graphite anode. This capitulate cell with an impressive 200Wh/kg of specific energy and good specific power and about90% charge/discharge efficiency [1]. The Fig.1 shows the

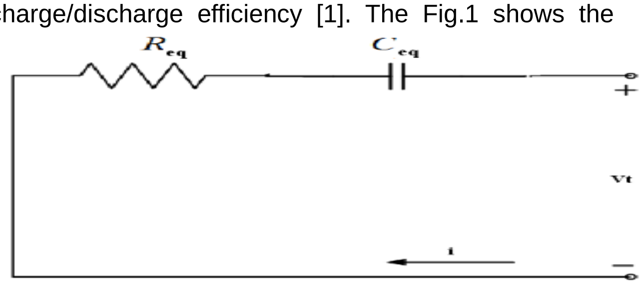

Fig. 1. Equivalent circuit of Li-ion Cel

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equivalent circuit model for lithium -ion cell. In this figure, Vtis the terminal voltage of cell, Ceqand Reqare the EquivalentCapacitance and Equivalent Resistance of the Cell.

$$V_t = V_{Ceq} + V_{Req} \quad (1)$$

$$V_{Ceq} = \frac{1}{C_{eq}}\int_{t_0}^{t} I(\tau)d\tau + V_s, R_{eq} = I \times R_{eq} \quad (2)$$

$$V_t = V_s + \frac{1}{C_{eq}}\int_{t_0}^{t} I(\tau)d\tau + V_{eq} \quad (3)$$

The Performance of Electric Vehicle with Lithium ion batterieshas improved a lot as compared to other batteries, but stillthe issue of battery charging time remains unattended formany years. Now vast research is going on in the field of fast recharging techniques used in Electric vehicle chargingsystems using lithium ion batteries. Some the widely usedbattery charging methods like constant current (CC) method,constant voltage (CV) method, constant current constant volt-age method(CC-CV), constant temperature constant voltagemethod (CT-CV) are discussed in this paper. We will seethese methods in detail in the preceding sections and alsotheir performance conditions as per the conditions of electricvehicles are used. The materials also plays an important role in fast chargingthe Li-ion Batteries. The Li-ion cell consists of various compo-nents. The Li-ion cell consists of Positive Electrode, negativeElectrode, Electrolyte, Salts, Solvents, Separators, Additives.To build the most suitable Li-ion cell as per the requiredapplications, crucial selections and combinations of materialsare required to form a particular Li-ion Cell. This combinationand selection of materials also helps increasing the specificenergy density, power density and reduces charging time ofthe cell as well[2].

II. BATTERYCHARGINGTECHNIQUES

For charging the Lithium -ion batteries, the most common methods are

A. Trickle Charge Method
B. Constant Current Method
C. Constant Voltage Method

A. Trickle Charge Method

Trickle Charging is charging a full charged battery with arate equal to its self discharge rate. A Li-ion battery are notdischarged below its discharging limit. In most of the lithiumion cell are not discharged below 3V and they are treated asdead cell below this value. To avoid this state the cell needsto be charged up to 10% of its maximum value [4]. To bringthe cell out of dead state the trickle charging method is quietconvincing.

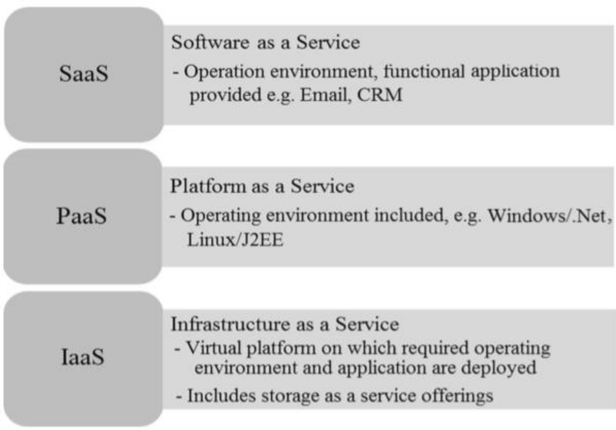

Fig. 2. Charging Curve of Lithium-Ion battery

On the Other hand, if the Lithium Ion cell is not charged up to 3V for 10minutes or so then, the cell is said to permanently damaged.

B. Constant Current Method

The simple and most commonly used method of charging.In this method,the current is maintained constant by keepingcharging voltage same as that of the battery peak voltage.The capacity of battery is given in 'C' while charging andthe charging current is decided by this battery capacity. Thebattery charges faster upto 0.8C by this method. This methodhelps battery to charged till 60-80% and remaining 40-20%can be charged by constant voltage method [5-7]. In the first stage of charging a li-ion battery or cell, the charge current iscontrolled. Typically this will be between 0.5 and 1.0 C. ForExample, a 4000 mAh battery the charge rate would be 4000mA for a charge rate of C).During this stage the voltage acrossthe lithium ion cell increases for the constant current charge.The charge time may be around an hour for this stage[6].

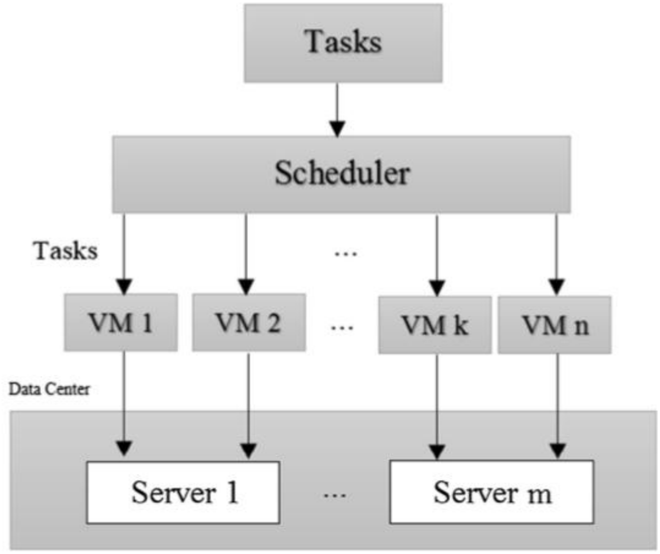

Fig. 3. Constant Current Charging Method

C. Constant Voltage Method

When the battery is charged up to 60-80% of its ratedcapacity, then the battery needs to be charged with this methodof Constant Voltage. In this method the current should beminimised and the constant current method should be termi-nated. To charge the battery fully, the constant voltage shouldbe equal to the maximum voltage of a battery. Such kind ofactivity increases the life of a battery. During this method thecharging time required to charge the battery increases.Moreoften, this method is not suitable for Lithium ion batteries[8].

III. ADVANCECHARGINGSCHEMES

The above mention charging methods are the basic chargingschemes. Apart from this,there are other methods which aremore reliable and are used extensively as Fast Chargingschemes. Some of them are mention below:

A. Constant Current-Constant Voltage (CC-CV) Method

This method uses the combination of both the methods i.e.CC and CV in combination. This is the most generalisedmethod of charging the Li-ion batteries. If we consider theLi-ion Cell of Rating 4.2V, then the constant current (CC)charging method is used for charging the Li-ion batteries during the initial stages when the battery voltage is 3.0V tillit reaches the to a voltage level of 4.1V. After this stage, theConstant Voltage method is activates which provide constantvoltage and the charging current reduces till the voltagereaches to 4.2V. To initiate the fast charging process, thebattery should be charged more with CC method then CV method.

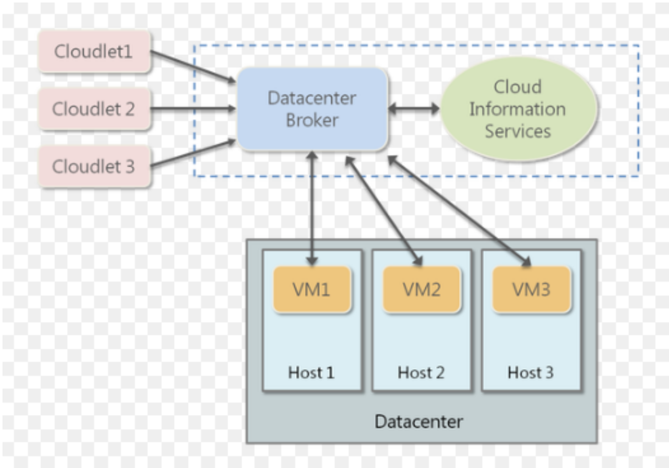

Fig. 4. Constant Current-Constant Voltage Charging Method

B. Five Step Current-Voltage Charging Method

Till now, it is observed that earlier method of chargingmethods has high charging time and has reduced battery lifecycle. To avoid such issues of battery life and charging time,the battery is charged at 5 different levels of voltage andcurrent. In every Step, the battery is charged with 5 differentvalues of voltage and current. The each step is governed by thethreshold voltage level. On every step the voltage is increasedtill its threshold value and and current remains constant for theduration of individual step, but decreases for every precedingstep [9].

System Used

Server Id	Server Name	Speed	Request Type
1	System A(1000)	1000 (MISP)	type1
2	System B(1500)	1500 (MISP)	type1
3	System C(1000)	1000 (MISP)	type1
4	System D(2000)	2000 (MISP)	type2
5	System E(3000)	3000 (MISP)	type2

Simulation Result

Algorithm	ThroughPut	Response Time	Execution Time	Energy Consumption
PSO	100	0.11666666666666667	91.17864285714286	8206.077857142856
CSA	100	1.2142857142857142	58.38571428571428	5254.714285714285
CSO	100	2.3333333333333335	54.89999999999999	4941
BAT	100	0	77.6	6984

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Size: 209 KB
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Fig. 5. Five Step Charging Method

C. Method of Charging using Pulse

In this method, a cascaded voltage and current pulses are applied to the battery. By controlling the rise time, frequency, amplitude and pulse width of a DC pulses, this can be used to any size of battery. With this method, high instantaneous voltage can be used without battery overheating and alsoincreases the battery life cycle. In general, many chargers areused to check the battery's current state. In the beginning,constant current charging is used for fast charging and thenPulse charging technique is used for trickle charging for persevering the charge. Some of the charging uses negativepulse charging. These chargers uses both positive and negativecurrent pulses for charging. Pulse charging method is use for obtaining for equal distri-bution of ions in the electrolyte. It helps in speeding chargingprocess and lowering the battery polarization. It also helpsin improving battery life cycle. Pulse frequency depends onthe battery size, capacity and charging time. It is very muchimportant to find out the best pulse charging frequency for theoptimal utilization of this method. The most common methoduse for this purpose is AC Impedance method [10-14].

D. Constant Temperature - Constant Voltage (CT-CV) Method

Temperature is the crucial factor in deciding the electro-chemical and mechanical deg-ration of Li-ion battery. Thetemperature variation is to be considered for the charging /discharging cycles of Li-ion batteries. The increased tempera-ture has the prolonged effect on the battery capacity and slowand steady increase in the battery impedance. To Avoid suchsituation, the new charging technique of Constant Temperature- Constant Voltage is developed which maintains the sametemperature rise as that of conventional charging methodsbut provides faster charging. This method helps in reducingcharging time and that is too with no loss in the battery life.To some extend this method allows to charge Li-ion batterymore than 1C rate while maintaining the battery temperature.This method basically uses PID controller to keep watch ontemperature rise and accordingly controls the charging current.As compared to others, this method of charging is Close loopmethod [15-17].

System Used

Server Id	Server Name	Speed	Request Type
1	System A(1000)	1000 (MISP)	type1
2	System B(1500)	1500 (MISP)	type1
3	System C(1000)	1000 (MISP)	type1
4	System D(2000)	2000 (MISP)	type2
5	System E(3000)	3000 (MISP)	type2
6	System F(1500)	1500 (MISP)	type1

Simulation Result

Algorithm	ThroughPut	Response Time	Execution Time	Energy Consumption
[illegible]	100	0.11666666666666667	121.5198095238095	10936.782857142856
[illegible]	100	0.8571428571428571	120.59999999999998	10854
CSO	100	2.1904761904761907	66.1652380952381	5954.871428571429
BAT	100	0	83.20038095238094	7488.034285714284

Fig. 6. Constant Temperature - Constant Voltage (CT-CV) Method of charging

E. Maximum-Minimum Optimal Problem Based Technique

The another most efficient technique used for fast charging.In this, the maximum-minimum optimization problem is de-fined which is modelled on nonlinear characteristics of Li-ionbattery and adding it with the practical aspects like charging /discharging current, cut -off voltages and working temperatureetc. The nonlinear equations are solved by using Aronssonoperator. In this method, the nonlinear continuous model ofthe Lithium-ion battery is converted to the discrete model tosimplify the further steps. The Main aspect of irreversible heat produced in the battery is considered, which decreases thebattery life drastically. So, to reduced this irreversible heatis the main objective of this method which further helps inincreasing the charging time [18-19]. The conventional charging methods are time consuming andtakes almost 8-10hours of charging depending upon the batterycapacity. On the other hand Advance charging methods takesvery less time 2-3 hours depending on the battery capacityand type of charging method. In some of the cases the casesthe charging time has dropped down by 20% as compared tothe conventional charging method.

Moreover, the conventionalmethods are open loop, this means they doesn't care aboutthe battery parameters like battery current, battery voltage andbattery temperature. These methods will keep on injecting thecharging current and voltage irrespective of battery conditions.This will affect the battery life and battery cycle. To avoid this,Advanced charging method takes care of this factors and theyare close loop systems [20]. Further the charging time can be more improved by usingcombinations of these advanced methods together to get thebetter results. The CT-CV method can be combined with theSinusoidal Ripple Current (SRC) method or CT-CV methodin combination with Multi-stage Constant Current (MCC)method. These hybrid combination of fast charging techniquescan drastically improve the charging time and also battery life.

IV. MATERIALS SPECIFICATION REQUIRED FOR FAST CHARGING

This section focuses on the material selection and designspecifications required for the different parts of Li-ion batterieswhich will be best suited for the various applications.

A. Material for Positive and Negative Electrode

n general, the Li-ion batteries consist of number of Li-ion cells with inter-calation elements as positive and negativematerials. As the Li-ion batteries are rechargeable lithium ionsare exchanged between these positive and negative electrodes.The positive electrode is made from lithium cobalt oxide($LiCoO_2$), lithium manganese oxide ($LiMn_2O_4$) or lithiumnickel cobalt oxide ($LiMn_2O_4$) in the form of layered structurewith the Aluminium current collector. The negative electrodematerial is of Graphite carbon with layered structure and withcopper current collector. The characteristics required for thepositive electrode materials are like, it should have highlydiffusive towards lithium, good electrical conductivity, easyreversible operation with out change in the lithium structure,incorporation of large amount of lithium and prepared fromlow cost reagents. The selection of negative electrode plays a vital role inthe li-ion cell. The material required for negative electrodeis made from graphite carbon. There are various types ofgraphite carbon like,Synthetic graphite (KS6, 15, 44), Graphitesphere (MCMB 25-28, MCMB 10-28), Graphitized CarbonBlack, Petroleum coke, Needle coke, Hard carbon and CarbonFibre. From above materials, the Graphite Sphere providesgood capacity in between 290-305 mAh/g, and low irreversible capacity in between 19-30 mAh/g. The property of irreversibleis very much important, this property decides the lithiummobility during charging and discharging and it should beas low as possible so that lithium mobility will be high.Practically, a particle size lass than 30micro-meter is requiredfor rate capability to the C rate [2].

System Used

Server Id	Server Name	Speed	Request Type
1	System A(1000)	1000 (MISP)	type1
2	System B(1500)	1500 (MISP)	type1
3	System C(1000)	1000 (MISP)	type1
4	System D(2000)	2000 (MISP)	type2
5	System E(3000)	3000 (MISP)	type2
6	System E(1500)	1500 (MISP)	type1
7	System E(2500)	2500 (MISP)	type2

Simulation Result

Algorithm	ThroughPut	Response Time	Execution Time	Energy Consumption
PSO	100	0.11666666666666667	218.60680000000002	19674.612
CSA	100	0	79.74242424242424	7176.818181818181
CSO	100	2.3333333333333335	76.83353454545454	6915.018109090908
BAT	100	0	136.1742424242424	12255.681818181818

Fig. 7. Li-ion Cell Reaction

B. Material for Electrolyte

In lithium ion batteries normally, four types of electrolytesare used such as liquid electrolyte, gel electrolyte, polymerelectrolyte and ceramic electrolyte. Liquid electrolytes are gen-erally the solution combinations of different salts and organicsolvents mainly carbonates. The Polymer type electrolytes areliquid based and are solvent free and in them the conductionis formed by the addition of salts. In case of gel electrolytes,salts, solvents are mixed with polymer. Now a days mostcommonly used technique is using gel electrolyte as they havelong life and are free from any kind of maintenance. In electrolyte, there are various types of salts which are usedin this electrolyte such as Lithium hexa-fluorophospahate($LiPF_6$), Lithium tetra-fluoroborate ($LiBF_4$), Lithium Perchlo-rate ($LiClO_4$),Lithium hexa-fluoroarsenate ($LiAsF_6$),Lithiumtriflate ($LiSO_3CF_3$),Lithium bisperfluoroethane-sulfonimide($LiN(SO_2C_2F_5)_2$). From these,Lithium bisperfluoroethane-sulfonimide has the highest molecular weight i.e. of 327g/mol.But, as per the conductivity is concern and the electrolytewhich is mostly used for electric vehicle application is Lithiumhexa-fluorophosphate ($LiPF_6$), which has a conductivity ofabout ¿10-3 S/cm. Most Recently,Lithium bisperfluoroethane-sulfonimide($LiN(SO_2C_2F_5)_2$) is widely used in almost allelectrolytes available in the market today. In Gel electrolyte aremade from these salts and with some carbonate solvents likeEthylene Carbonate (EC), Dimethyl Carbonate (DMC), EthlyMethyl Carbonate (EMC),Methyl Acetate (MA) and DiethylCarbonate (DEC). These are mostly used solvents. Electrolyte formulations in present Li-ion cells typically2-4 solvents are used in combinations to get the betteroperating conditions and for the better performance of the cell.It also helps in higher conductivity and a wide temperaturerange which is not possible only with single solvent. Out ofthese solvents, MA, DMC and EC are suitable as per the Indian environmental conditions. These solvents are havingtemperature range from -40?C to 80?C. Ethylene Carbonate(EC) is most widely used solvent and it is mixed witheach and every solvent for obtaining the better performance.The most suitable combination of solvent as per the IndianSituation is combination of EC:DMC (in the concentrationof 0.75 to 1.50M) where M= siemnes/meter. Also, with thisEC:MA (0.25:3.0M) is suitable as per the Indian scenario. Thecombinations such as EC:PC:DMC (20:20:60) and EC:PC:EA(15:25:60)which are suitable for the temperature range from-40?C to 80?C.

Separator material of about 10 to 30m micro porous filmsto isolate the positive and negative electrodes are used. Mostcommonly, Polyolefin material is used which is made from thelayers of polythylene and polypropylene laminations, havinga pore size of about 0.03µm to 0.1µm are used. Further, toimprove the battery performance, electrolyte additives havebeen developed like hexa methyldisilazane (HMDS) is mostcommonly used.

V. IMPORTANT INGREDIENTS FOR FAST CHARGING

Along with the material selection, there are five importantparameters which are to be consider for determining fastcharging technique required for lithium ion batteries [19].These includes the following:

A. Diffusion Process of Li-ion and Electrons

This is nothing but a process path for li-ion and electronsthroughout lithium ion battery. This helps in achieving the highperformance. This process includes 1) Solid state diffusion,in which the li-ion and electrons dissociate with anode andmoves towards cathode. 2) li-ion moves through electrolyteand gets diffused in it. 3) The electrons interfaces with thecurrent collector instead of passing through electrolyte andtravels through the external power circuit. 4) The electrons andli-ion enters into the cathode material simultaneously with thehelp of solid state diffusion.

B. Thermodynamics and Kinetics of Electrochemical

The electrochemical reaction is the product of reversible cellvoltage and charge electrons, which is given as

$$\Delta G_r = -eFV, \qquad (4)$$

where, ΔG_r = Gibbs energy change; e = number of electron transfer; F = Faraday's Constant.

In general, battery charging is determined by C-rate, i.e.1C means that the charging current will charge the batteryto its capacity in 1 hour. With increase in C rating, thecharging and discharging time reduces. Due to the result ofKinetic limitations, the open circuit battery voltage is morethan the operating voltage. Kinetic Limitation mainly causeddue to redox reaction, ohmic polarization and concentration polarization.

C. Li-ion Diffusivity in Electrode Material

The li-ion diffusivity is a characteristics with which the li-ion materials moves easily in the electrode material. Normally,the diffusivity dependency on temperature in solids is morethan in liquids. The kinetic diffusion process noramlly followsArrhenius expression:

$$D_i = D_0 exp - \left(\frac{\Delta E}{k_B T}\right) \qquad (5)$$

where,?B is energy barrier; kBis Boltzmann Constant;D0is prefactor. Even though, the increase in the workingtemperature will improve the diffusivity, but it will hamperthe battery safety.

D. Improving the Electrolyte li-ion Conductivity

The objective of electrolytes is to form connection betweenanode and cathode and to isolate the electrons. The electrolyteswith high li-ion conductivity and low electronic conductivityhelps in facilitating the ionic transport and inhibiting electronspassage. The most efficient electrolytes used in the making ofli-ion batteries are already mentioned in the above sections.In many cases, combinations of two or more electrolytes areused to achieved the desired conductivity as the applicationsrequired. In order to achieve higher conductivity from theelectrolyte, the increase in li-ion solubility and decrease inthe viscosity are the important parameters needs to be lookedfor.

E. Improvement of Electronic Conduction in Electrodes

Electronic conductivity helps in solid state diffusion process.Electrically high conductivity is achieved by electron transport.The electronic conductivity is expressed as:

$$\sigma_e = n_i e \mu_e + p_i e \mu_h \qquad (6)$$

where, niand piare the holes and electron concentration; µeandµprepresents the mobility of electrons and holes[21]. The selection of materials for the high performance of the lithiumion batteries plays a very important role. All the necessaryconsiderations has been taken into account for achieving highperformance lithium ion batteries.

VI. CONCLUSION ANDOUTLOOK

As the Electric Vehicles will be the prominent players in theupcoming era. There are various issues which are being han-dled by the experts. This paper specifically deals with the fastcharging techniques and specifications of materials required bythe lithium ion battery for the development of electric vehicles.There are various fast charging techniques available in the themarket and all the techniques are having certain advantagesand disadvantages over each other. Currently, the charging timehas come down drastically from 8hours to 1-2hours and in theupcoming years this time is further going to reduce. The most widely used battery for electric vehicle applicationis lithium - ion battery due to its overall high performanceas compared to other batteries. But the use of any lithium-ion battery for the electric vehicle will not serve the purpose. There are many parameters that needs to be studied beforeimplementing it. Material selection with right specificationplays a vital role in developing lithium-ion battery for electricvehicle applications. These materials are selected in such away that, fast charging techniques can also be applied to it.This will not only improve the charging time but longer batterylife can be achieved.

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