International Journal of Pure and Applied Mathematics
Volume 118 No. 20 2018, 265-276
ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue

ijpam.eu

BMS: Efficient Handling of Battery using Battery Management System and Optimization technique of Battery Charging System in Electric Vehicles

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Abstract **- Electric vehicles are used for high energy efficiency, whereas charging the battery for electric vehicle is cumbersome. Most of the electric vehicles use lithium-ion batteries which contain high energy per unit mass, increasing high temperature and primarily low self discharge. By considering anomalies by handing battery charge and efficient usage of EV, here there two approaches were proposed, redundant battery management scheme and effective battery charging optimization. Here battery management unit consists of two batteries and it is handled by the help of controller called adjudicator. Based on the selected battery, the controller (electrical vehicle) runs. The dry change over between the batteries is dealt by different safe levels identified apriori. There are three safe levels are identified with predefined safe limits. When battery reaches each SoC (State-of-Charge) limits set of events related to battery charge will identify. In case selected battery reaches end of state called dead state, adjudicator controls and change over the battery to redundant or main based on the selected battery. The other one deals with effective optimization of battery charging using approximation technique. It deals with optimization of battery charging in an effective methodology when considering other approximation techniques.**

Keywords: Electric Vehicle (EV); Battery Management; Redundant Battery; Adjudicator.

I. INTRODUCTION

An electrical vehicle increase the customer satisfaction in terms of fast charging, less time charging and more distance travelling. The charging system of each electrical vehicle depends on the battery specifications and charging methodology. In order to provide efficient charging system it is necessary to focus on the charger control function. In order to do that this paper focused on designing a charger control system with a predefined control function in the electronic control unit (ECU) available in the EV. The supply unit of the ECU is concentrated more because to increase the incorporation among the supply unit and ECU. Means it is aimed to create a Client-Server relationship on the charging system [Client-Quick Charge, Server-EV]. The battery control unit of EV is used to determine the original current required in the system according to the battery voltage, temperature, current and so forth. ECU of EV provides optimized charging current need with respect to the battery control unit information.

The digital communication protocol (DCP) is used to control the charger via charging cables in control area network. DCP is also a communication protocol make efficient communication among components on the board and signal noise. Hence this protocol is used in this scenario.

Particular of the EV has developed with renewable energy system for growing the energy security and diminishing the discharges in various localities. Though, for photo voltaic (PV) and other intermittent renewable energy sources with output volatility, large-scale renewable energy connected to the power grid still has many barriers to overcome. Moreover, it is difficult to maintain stable operation of the power grid and optimize scheduling for large populations of EVs with uncertain charging characteristics [1-3]. In addition, if the charging power is generated by coal-fired power plants, the emissions advantage for EV is not obvious [4, 5]. The direct integration of PV with EV charging devices is an effective way to reduce EV emissions and the impact of EV charging on the power grid [6, 7].

There are three types of EV charging modes: conventional charging, fast charging and battery swapping [8, 9]. The battery swapping mode replaces depleted batteries with fully charged batteries and charges the depleted batteries on a charging platform. The battery swapping mode is mainly applied in public transport, such as for electric buses and electric taxis. As an important charging mode, the State Grid Corporation of China has invested in and constructed dozens of battery swapping stations (BSSs) in large cities in China [10, 11]. The centralized charging strategy in the BSS is constructive for the integration of renewable energy generation.

Most of the scholarship on EV charging and renewable energy generation has focused on design, operation and optimal charging strategies [12-16]. A conceptual architecture and an assessment framework were proposed to explore integration scenarios of EVs and renewable energy generation in distribution networks [17]. The combination of PV energy and EVs in uncontrolled charging and smart charging strategies has been studied [18], as was a two-stage framework for the economic operation of an EV parking deck with renewable energy generation [19]. Heuristic optimization algorithms, such as particle swarm optimization (PSO) and genetic algorithm (GA), have been used to solve the multi-objective and nonlinear optimization problems associated with the management of EV charging involved with renewable energy generation. A PSO algorithm was utilized to allocate charging stations of plug-in electric vehicles [20] and to provide a coordinated charging/discharging scheme to increase revenues and incentives [21]. An optimization algorithm was developed based on the well-established PSO and interior point method for the optimal dispatch of EVs and wind power [22]. Two approaches based on the fuzzy genetic algorithm and fuzzy discrete PSO were proposed to minimize energy cost and grid losses by coordinating EV charging [23]. A PSO algorithm can randomly search to achieve satisfactory solutions by using a population of particles and is a practical algorithm for solving EV charging optimization problems involved with renewable energy generation. But in this paper it is mainly focused on battery management system based electrical charging.

II. ELECTRIC VEHICLE MODEL

Here lithium-ion based batteries are mostly considered for EV's which has high energy in nature, increasing high temperature and low self discharge. Lithium-ion battery has a characteristic of high energy density. Charging system where it includes isolating transformer and internal control unit to be given as power supply to connector. From this battery control unit coordinates for charging. Charging system of battery schematic diagram is given in Fig. 1.

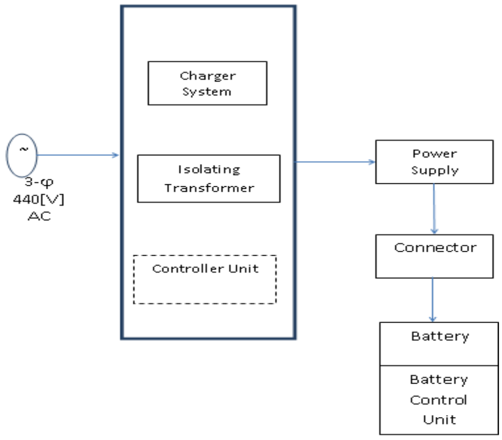

Fig. 1. Charger System of Battery Schematic Diagram

Battery parameters fully depend on cell features and battery size. Charging of battery depends on all of the cell characteristics. The battery current is obtained as follows,

It constitutes of Input function, SoC function and Output power.

$$I_b(\varepsilon, P_b) = \frac{V_{oc}(\varepsilon) - \sqrt{V_{oc}(\varepsilon)^2 + 4R_{init}(\varepsilon)P_b}}{2R_{init}(\varepsilon)}$$

Output voltage function given as,

$$V_b(\varepsilon, P_b) = V_{oc}(\varepsilon) - I_b(\varepsilon, P_b)R_{init}(\varepsilon)$$

Output voltage remains in minimum and maximum limitations, threshold remains between the battery voltages,

$$V_b(\varepsilon, P_b) \in [V_{min}, V_{max}]$$

State of Charge is derived based on the minimum and maximum voltage limits, and it is given as,

$$I_b(\varepsilon, P_b) \in \left[\frac{V_{oc}(\varepsilon) - V_{max}}{R_{init}(\varepsilon)}, \frac{V_{oc}(\varepsilon) - V_{min}}{R_{init}(\varepsilon)}\right]$$

SoC and maximum energy is the function of internal power and efficiency function that comes with increase in current and battery limits. Energy function is directly proportion with battery drain limit with maximum deviation.

$$I_b(\varepsilon, P_b) \in [-I_{max}, I_{max}]$$

$$\dot{\boldsymbol{\varepsilon}} = \boldsymbol{f}(\varepsilon, P_b) = \frac{P_{int}(\varepsilon, P_b)}{E_{int0}}$$

$$E_{int0} = \int_0^1 V_{oc}(\varepsilon)Q_0 d\varepsilon$$

$$P_{int}(\varepsilon, P_b) = \begin{cases} -\eta I_b(\varepsilon, P_b)V_{oc}(\varepsilon)\,, P_b \geq 0 \\ -\dfrac{1}{\eta} I_b(\varepsilon, P_b)V_{oc}(\varepsilon)\,, P_b < 0 \end{cases}$$

The function with respect to battery current is defined as,

$$\eta = 1 + \frac{\partial n}{\partial c}\frac{I_b(\varepsilon, P_b)}{Q_0}$$

Here, EV comprised with both commuter and taxi vehicles. The circuit model of SAFT system cell is given in Fig. 2. Capacitances are connected serial with three bodies and parallel to resistance input to obtain output current.

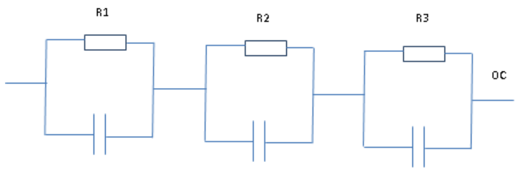

Fig. 2 Circuit Model of SAFT

The Nodal parameters for SAFT considered for evaluation is in Table-1.

Table-1: Model Parameters of SAFT

Variable	SAFT Model	Unit
E_{int0}	590.4	kJ
Q_0	45.0	Ah
V_{max}	4.0	V
V_{min}	2.7	V
I_{max}	100	A
$V_{oc}(\varepsilon)$	Range from 6 to 8	V
$R_{init}(\varepsilon)$	Range from 2 to 4	Ω
$\frac{\partial n}{\partial c}$	-167.2	S

III. Battery Management Model

Electrical vehicles are ease to use, fast and smooth. It is convenient when compare to other techniques. Electric motor is used to power the electric vehicle. Motor receives power from the electric controller. These controllers receive power from re-chargeable batteries. Like other EV's electric motor slows down when battery drains and recharge of battery to be done in nearby charging station. In this model, EV contains of control unit and battery management unit where connector outlet is connected. In this battery management unit consists of two efficient lithium-ion cell re-chargeable batteries called main and redundant is connected parallel and it is connected with the adjudicator. It controls and coordinates the battery change over from selected battery to other battery. It is explained in Fig. 3.

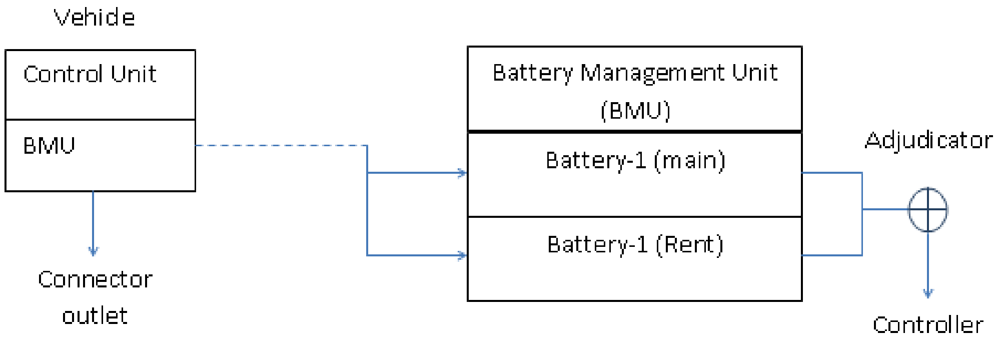

Fig. 3. Battery Management System

Initial battery conditions: condition-1

SoC of each battery is near to Upper threshold point, SoC lies between the Lower threshold point and Upper threshold point or equal to the saturated value. There are three predefined safe levels are identified. Safe level1 is equal to near SoC or saturated value. Here in this point battery is fully charged. When SoC is approximately equal to battery charge value, then no battery related event will triggers. When the battery charge value lies between 50 to 60 % then it hits the safe level-2. In this case, battery around 50% exists, some of the indication levels displays to charge the battery, indication levels has priority, if high priority got triggered means there is no power in redundant battery hence primary or running battery to be recharge in nearby station. If there is a low priority indication, then charging will be done in available time. It is shown in Fig. 4.

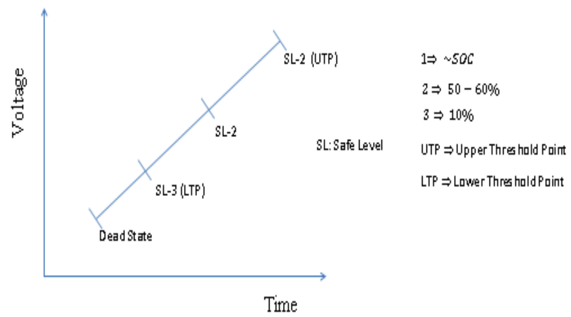

Fig. 4. Safe Level of Battery System

When battery limit reaches safe level3, here almost battery SoC reached lower threshold point; In this case adjudicator waits for continuous three level of event identification from battery management unit states that running battery reaches dead state crossing lower threshold point. Once adjudicator unit receives three event identification, then change over takes place to select other battery to be given to the controller. If main is primarily selected, after change over secondary or redundant battery is selected for controller.

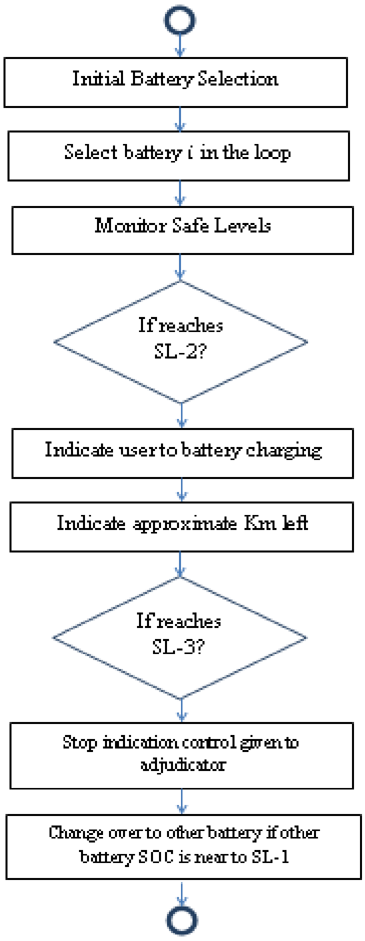

Fig. 5. Flowchart for Battery Management Model

In Battery management model, initialization of batteries to defined SoC then every equal time intervals when EV is moving this SoC is compared with set limits. when SoC touches safe level2 only warning gets initiates and looking for battery charging. In case of safe level3, indication rejects by adjudicator and call for change over to other battery takes place one and only the other battery SoC is above to the Safe level2. The algorithm for battery management is given below:

Algorithm-1_BM_Model ( ) // Battery management Model

```
{
    Initialize battery to SoC
    Check for safe level, SL ∈ {SL-1, SL-2, SL-3}
    loop
        Select Battery-1
        check for  SoC
        if SoC is in SL-2
            Initiate warning and battery charging init
        end if
        if SoC is in SL-3
```

Stop indication

Adjudicator call

Change over to redundant battery if bat_volt> SL-2

end if

}

Efficient technique to minimize the cost of battery charging depends on the constraints with respect to power and battery. It can be denote with number of slots in unit time. Charging power depends on power of the vehicle and time slot. Based on the available charging grid locations, charging power for each vehicle and quantum called time slice defines the charging power. The entire functionality of the proposed EV system is shown in Fig. 5.The main objective of the vehicle industry is to maintain fast and less charging in short period with more power capacity. Most of the EV like Reva-1 is proving in certain levels. In this paper the upper limit of the electrical power is assigned as more than 50kW. The charger in the fundamental system requires more power but it provides good speed and driving capacity for large distance. Here the experimental results obtained from a real time experiment and a simulation based experiment obtained from MATLAB software are given below and discussed.

IV. Experimental Results

As per minimum energy requirement of EV battery current and phase current in different timings is traced. Here both commuter and taxi vehicle is considered for analysis.

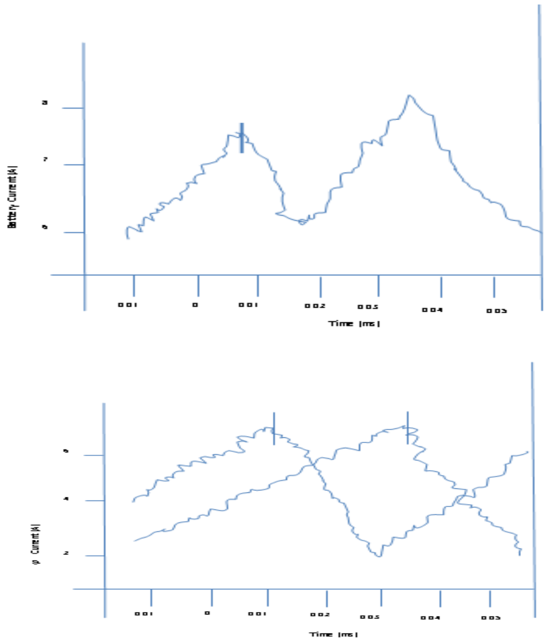

Fig. 6. Phase and Battery Current

V. Discussion

Based on different versions of input given in different time, the battery current flows is in different values. It is given in Fig. 5. Phase current is given in different time slots. Here, SAFT circuit model is considered therefore voltage ranges from 6 to 8 volts and resistance ranges from 2 to 4 ohms. In Fig. 6. Battery1 value is given with respect to time and kilometer. If beyond the time derives catastrophic struck of battery event. Maximum of higher range kilometer is based on the battery characteristics. Here 60 kilometer is considered as a maximum value beyond that battery drains and leads to permanent struck of battery usage. Same model is analyzed for Battery-2 and based on the cell characteristics; maximum usage of battery is given in Fig. 7.

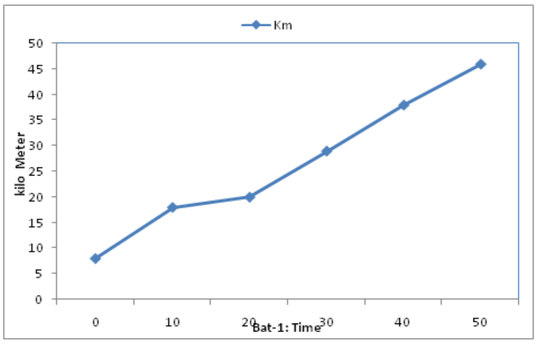

Fig. 7. Battery1 versus Kilometer

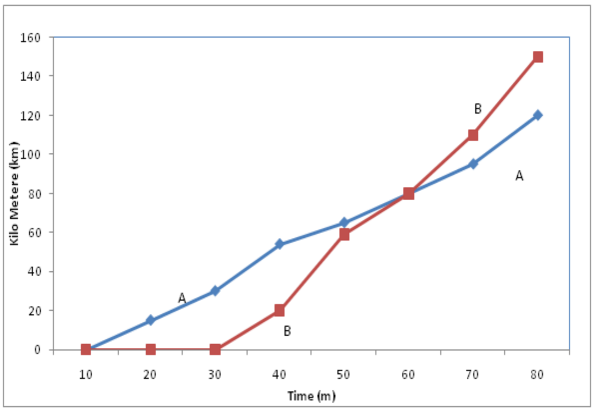

Fig. 8. Battery-2 versus Kilometer

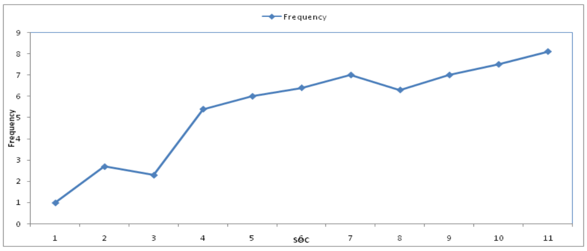

Fig. 9. Frequency Distribution of SOC

The change over between the batteries when battery drains and touched the final safe limit, adjudicator call will happen and change over between the batteries happen if the other battery is in available with near SoC battery limit. It is given in Fig. 8. Frequency difference between two periods in each time slice is analyzed. Here SoC and equivalent frequency is taken into consideration and given in Fig. 9. It ranges from dead level lesser than lower threshold point to battery full charge where SoC is 100%. Here SoC limits are in the scale of 10. The plot discusses the difference between two periods P1 and P2. The charging current with different limits are taken into consideration, predefined limits were analyzed and maximum limit reaches upto 130 in different period of time intervals. It is given in Fig. 10. Charge current and battery current in different voltages and current in milliamps is analyzed, battery consists of lithium-ion rechargeable cells will keep track of battery current in raising and falling range and given in Fig. 1.-11. In case of choosing a proposed architecture based test vehicle for investigating the performance, the goal of the charging system is, the time taken for charging should be same for all the criteria of EV. Goal of the charging time is 50km driving range for 4 to 5 minutes charge whereas 70km of driving range is below 10 minutes of charging. The charging current and energy obtained from charging is shown in Fig. 12. From the result it is obtained that5 minutes of charging gives more than 40km whereas 10 minutes of charging gives more than 65km.

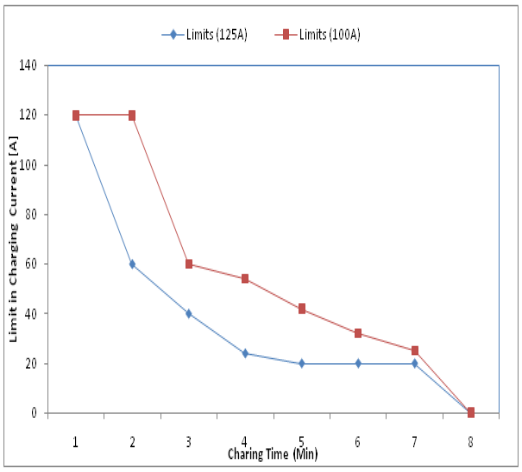

Fig. 10. Charging Current vs. Different Upper Limits

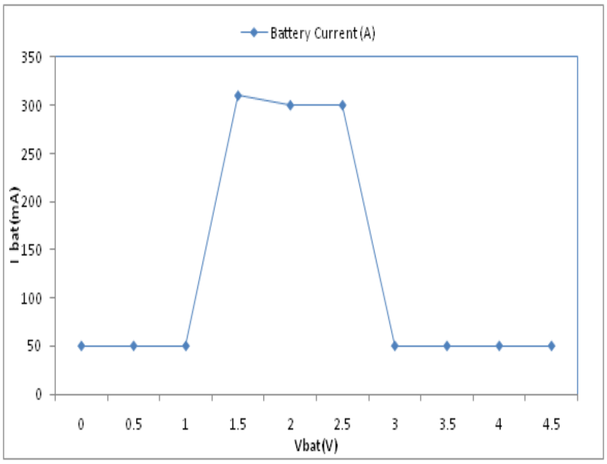

Fig. 11. Charge Current vs. Battery Current

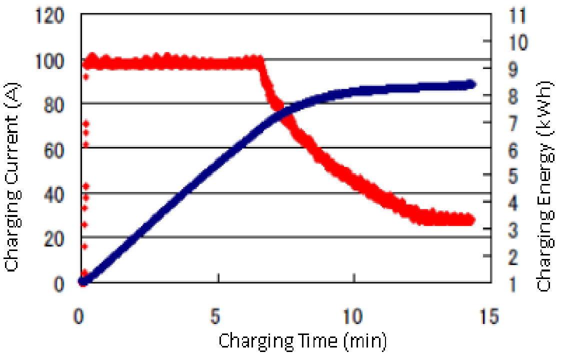

Fig. 12. Quick Charging Results

VI. Conclusion

EV's are efficient in high energy due to rechargeable battery cells, battery used here is low self discharge, hence it supports to maximum usage. The main drawback of electric vehicles lies on size of the battery and its construction. Due to increasing in battery voltage charging is complex. Scarcity of Electric charging stations is one of the demerits. In this paper dual battery management system is focused due to scarcity of charging node stations are available. This battery management supports two batteries called main battery and other one called redundant battery. One of the two battery is selected for control and continues until the SoC limit reaches different pre-defined safe limits. These safe limits coordinates with control unit called adjudicator which helps in change over to other battery when battery safe limit reaches lower threshold value or lesser to the lower threshold point. Based on the indications, other battery recharge will be done in available timeslot using approximation technique which discussed in paper. This is the effective charging approximation technique handles charging of EV in time slot based approach. The main drawback of electric vehicles lies on size of the battery and its construction. Due to increasing in battery voltage charging is complex. Scarcity of Electric charging stations is one of the factors to hold EV performance in road. For analysis commuter vehicle and cabs are taken into consideration and various performance characteristics is given in results and discussion. The main future task from the analysis is, if both batteries are fails then the system is catastrophic, frequent checking of both batteries keep battery health normal and during change over time, smooth transition between the batteries will takes place.

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