Battery Monitoring System in Electric Vehicles Based on Internet of Things

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***Abstract*—** Internet of Things (IOT) technology has enormous application potential for smart grid enhancement and development. The increase in distributed generation, the aging of the current network infrastructure, and the attractiveness for network transformation have created interest in the smart grid. Dynamic electrical energy storage system viz., Electric Vehicles (EVs) are relatively standard due to their excellent electrical properties and flexibility, but the possibility of damage to their batteries is there in case of overcharging or deep discharging and their mass penetration profoundly impacts the grid. To circumvent the possibility of damage, EVs' batteries need a precise state of charge estimation to increase their lifespan and to protect the equipment they power. This paper proposes a real-time Battery Monitoring System (BMS) using the coulomb counting method for SOC estimation and messaging-based MQTT as the communication protocol, based on ease of implementation and less overall complexity. The proposed BMS is implemented using sufficient sensing technology, central processor, interfacing devices, and Node-RED environments on the hardware platform. An optimization model aimed at optimizing the commercial revenue of the aggregator of EVs is presented in order to enable smart charging.

Keywords— **Internet of Things,** Battery Monitoring System (BMS), State of Charge (SOC), MQTT.

1. INTRODUCTION

The Internet of Things (IoT) refers to the network-based interconnection of everyday entities for use. It is referred to as a wireless self-organizing link age of devices aimed at interconnecting everyday objects. IoT technology allows contact between man and machine, or machine to machine, to be accomplished. Three main IoT features are: extensive, smart and internet connectivity [1].There are four features in IoT: gathering of data, bilateral communication, handling and response control.

The International Telecommunication Union (ITU) laid onward officially the notion of Internet of Things in year 2005 [2]. The report illustrated a draft for the IoT period: when a driver maneuvers erroneously, the vehicle will spontaneously alarm suitcase will prompt the owner about neglecting something; communication from garments to washer about the colour and temperature desired and so on. Since the implementation of the idea of the smart grid as an integral part of IoT was put forward, utilities have greatly appreciated it. The integrated IoT Smart Grid results in improved energy productivity, decreased environmental impact, improved reliability, decreased vulnerability to external intervention and increased electricity supply consistency [3]. In the coming years, the introduction of Smart Grid tools into utility networks will have an effect on a wonderful transition in grid management and energy use. Together with the increased dispersion of non-conventional energy sources, the methodical shift in load control indicates a new array of challenges in balancing expenditure and output. Increased deployment in the distribution grid of energy storage systems would help speed up this process and boost system performance [4]. For decades, bulk energy storage has been used in the power grid and the need for more distributed storage is now being generated by the integration of renewables. With increasing adoption of non-conventional energy sources and rise in popularity of plugin hybrid electric vehicles (PHEVs) and all electric vehicles (EVs), the need is for a far more vigorous electric infrastructure. Figure 1 shows the key areas where energy storage systems can be applied. Innovations in battery technology have been the key motivation for distributed storage systems. With the increasing penetration of electric mobility, the battery prices are declining which will be of assistance in grid applications. To prolong the life of battery-based energy storage system and ensure their reliability, a proper battery monitoring system needs to be integrated along with.

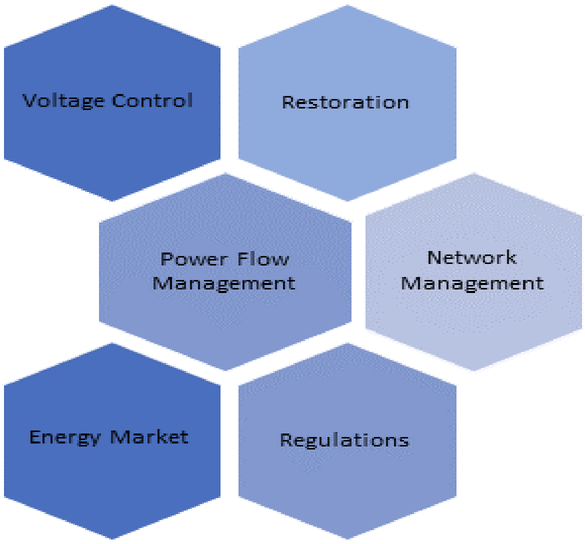

Fig. 1: Areas of application of energy storage in smart grid

This paper proposes a lightweight communication protocol based EV's battery monitoring system aimed at prolonging the battery pack's useful life. The paper is organised as follows. Section II sheds light on EVs impact on grid and how bilateral flow of power can improve grid functionality. Section III tells key features of a typical battery monitoring system. Section IV gives background information on battery capacity estimation technique used. Section V provides the framework of proposed hardware setup. Results are shown in Section VI. To reduce the impact of uncontrolled charging of EVs on grid, an optimization model intended to maximize the EV's aggregator revenue is formulated in Section VII.

2. ELECTRIC VEHICLES AND SMART GRID

As per reports of National Renewable Energy Laboratory (NREL), mass production of EVs has limited adverse effect on the electricity generation need. For example in USA, for EVs constituting the 50% of the total vehicles in use by year 2050 will entail only 8% increment in electricity generation and an increment of 4% in generation capacity meanwhile also considerably reducing the emissions from conventional vehicles and lowering the fuel usage in transportation sector [5]. Other effect of mass adoption of EVs on power grid are-

- Increase in the working temperature of transformers due to the extra load of charging EVs. This reduces the operating life, thereby incurring additional expenditure.
- The energy storage system ought to store electricity from the minimum carbon producing sources, e.g., nuclear energy and renewable energy. However, coinciding the demand and supply load curves is a big challenge.
- Shortage in electric power supply, if the accumulated EV charging profile constitutes the peak demand period.

However, charging of EVs at off peak hours augments the load curve for electric utilities. So, the usage of large no of EVs must be accurately optimized for various charging setups and technologies. A sample optimization model for smart charging is presented in section VII in this paper.

Demand Response (DR) is additional advantage to the grid by disrupting the EVs charging demand at peak hours. In parked condition, EVs generate or store electricity which can be fed back to grid using appropriate connections- this is known as vehicle-to-grid power or V2G power. The batteries of EVs plugged into charging infrastructure can act as distributed energy storage systems for the electrical grid. The electrical energy delivered backed to the grid must be priced such that the additional cost incurred must be recovered back as the battery's lifecycle is reduced due to frequent charging-discharging. The distributed storage provides advantages such as making the grid more steady, secure and resilient by regulating frequency and the spinning reserve as backup power in the distribution system. Large scale integration of intermittent sources of energy e.g., wind and solar sources into the grid is facilitated by V2G system. For the world-wide shift to the emerging green and sustainable energy economy, V2G is an important enabler.

3 BATTERY MONITORING SYSTEM

Battery Monitoring System (BMS) is a smart system whose function is to monitor the vigor of a battery pack. BMS computes the battery's capacity, depreciation of battery while the charging/discharging and correct productivity of the battery and provides this information in real time to users. This mitigates the sense of incorrect safety of periodic battery assessment as it is vigilant to emerging issues before hand the occurrence of a possible malfunction. As every cell is observed separately, so any damage can be checked and appropriate warnings against the values pre-set by consumers and protective measures can be employed, safeguarding the other cells against cumulative damage thereby extending battery life. BMS logs history data of all measured parameters for further analysis and future reference.

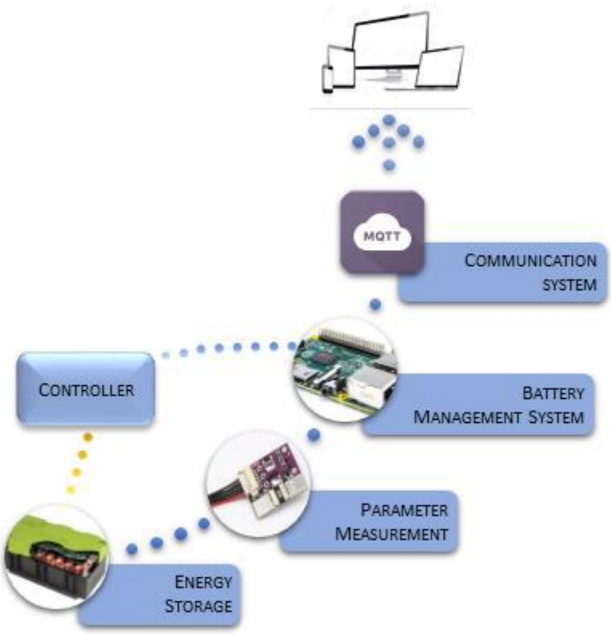

Fig. 2: A BMS Framework

Figure 2 shows a typical BMS framework incorporating the measurement of key battery parameters e.g., current, voltage, temperature etc., and performing necessary calculations/estimations to extract useful information about energy storage system i.e., State of Health (SOH), State of Charge (SOC), operating temperature range. Based on these calculated parameters, controlling actions are taken to maintain the battery's lifecycle and safety against potential hazards. Therefore, the prime objective of monitoring is to gauge various variables, log events, generate warnings, record usage profile and represent this information locally and remotely to the user.

BMS is unable to sense movable connections present in the battery, leakage of cell material, corrosion of connections leading to the development of high resistance and subsequently fire danger. It is also unable to visually monitor developing swelling, potential leakage, cracks in the outer geometry of battery pack etc.

4 SOC ESTIMATION

A. Proper use of the battery includes the awareness of its charge state (SOC). The development of an effective control strategy involves an accurate estimate of the remaining power of the battery, i.e., SOC [6]. As a critical battery performance parameter, accurate estimate extends the battery lifecycle, prevents deep discharges, and helps to design realistic control methods to keep the battery running in the optimal area. A battery, however, is a chemical energy storage source, and this chemical energy is not directly available, which makes it difficult to estimate a battery's SOC [7]. It can be safely charged/discharged at levels suitable for battery lifecycle enhancement by calculating the battery's current capacity. The energy capacity of a battery depends upon its charging current, discharging current, oldness, operating temperature, cut-off voltage, and usage profile.

Various strategies have been recommended for the batteries SoC assessment [3-4]. These strategies can be arranged into three kinds: electrochemical-based, electrical based and versatile ones. The electrochemical strategies albeit profoundly exact are considered hard to execute in programming or equipment as they expect admittance to the compound structure of battery. Versatile procedures [7] include a battery same model and an answer calculation e.g., neural organization [10], Kalman filter [11] and fluffy rationale calculation. The proficiency of the same model decides the precision of these strategies. Be that as it may, electrical procedures request just quantifiable boundaries e.g., terminal voltage, charge/release current and interior obstruction. Because of simplicity of execution and low intricacy, coulomb tallying procedure which depends on the reconciliation of flow over the long haul is quite possibly the most regularly utilized electrical procedure for SoC assessment [10, 11].

In general, battery's SoC is termed as the proportion of its current capacity ($Q(t)$) to the nominal capacity (Qn). The battery manufacturer specifies the nominal capacity which shows the utmost quantity of charge that can be stored in the battery. The SoC can be defined as follows:

$$\mathrm{SOC} = \frac{Q(n)}{Qn} \qquad \text{------------------------------------ (1)}$$

2.1 Coulomb Counting Method

With assumption that initial SoC (at time t_o) is in knowledge, SoC at any instant is usually estimated by integration of the battery current over time, as shown in equation (2)

$$SoC(t) = SoC(t_o) + \frac{\int_{t_o}^{t_o+\Delta} I_{bat}.d\Delta}{Q_n} \times 100\% \qquad \text{---------------------(2)}$$

SOC: State of Charge, I_{bat} : value of battery current, Qn : nominal capacity

The accurateness of Coulomb counting technique depends upon various parameters viz., operating temperature, battery usage history, discharge current, and cycle life [14].

The coulomb counting technique consists of using the equation (2) by enumerating the charge supplied by the battery by sensing its input and output current [10]. Though, few inefficiencies are there in this technique- the initial SOC value is not correctly known, presence of self-discharge phenomena can change the real SOC value after a prolong storage time and battery degradation due to aging should be taken into consideration.

5 HARDWARE SETUP

Rechargeable battery frameworks are to be an essential part of energy storage system in smart grids. Monitoring of battery performance is one of the key issue in control and management of a battery management system. The measurement part of BMS records cell voltages, battery current, and converts them into the digital measure. The measurements are done in every specimen period and communicated with a processor through an Analog-Digital (A-D) interface. Using these deliberate battery parameters, the processor's function is to assess the SOC. Although SOC is considered as the "fuel gauge" of the energy storage system, but it actually displays the remaining vitality in the battery.

The coulomb counting technique for SoC estimation was realized on the hardware platform. The battery monitoring system include the measurement of battery parameters viz., voltage, current flow and temperature by appropriate sensing technology and interfaced through an ADC (Analog to Digital Converter) device to microcontroller Broadcom BCM2837 SoC based Raspberry Pi 3 Model B. The SoC estimation technique has been implemented by measuring voltage, current and temperature of two parallel connected 3S Li-Po (Lithium Phosphorus) batteries with total nominal capacity of 4400 mAH. The direction of flow of current determines whether the battery is in charging or discharging condition. When the current ceases to flow, it is assumed that battery is in open circuit condition i.e., idle provided recent SoC monitored is more than 10%.

If so, the last SoC reported is taken as initial SoC for next cycle. If SoC falls down below 5%, it is assumed that batteries are completely discharged and SoC is set to 0% for next cycle. Similarly, algorithm is applied at full charge condition. The estimated SoC along with experimentally obtained parameters by the BMS were shown both on PC and MQTT Broker-DIoTY App for Smartphone. The work can be further extended by integration of database management system to predict the time to charge/discharge the battery.

5.1 Node-Red

The estimation algorithm was implemented in the Node-Red environment. Node-RED is a graphical means for connecting various hardware appliances, Application Programming Interfaces (APIs) and real-time facilities together– to equip the Internet of Things. Using a browser based flow editor, Node-RED offers an extensive range of nodes to simply connect the flows which can be executed to the runtime with minimal effort. The light-weight runtime is built on Node.js, taking maximum benefit of its event-driven, non-blocking model [15].

5.2 MQTT

MQTT (Message Queuing Telemetry Transport) is a messaging based communication protocol that affords the lightweight network with an easy means to deliver data. The protocol is used for machine-to-machine (M2M) communication and plays an imperative part in the IoT. It uses a publish/subscribe communication model.

MQTT is a useful selection for wireless systems which undergo fluctuating levels of latency because of bandwidth restrictions or fickle connections. In publish/subscribe model, communication is straight from client to an endpoint. But the publisher (client sending message) and subscriber (client getting message) have no knowledge about the presence of each another. There exist a third element, known as broker, who is familiar with both the existing parties i.e., publisher and subscriber. The broker categorizes every received message and delivers them suitably. As MQTT delinks the publisher and subscriber, only the information about hostname/IP and port of the broker is sufficient in order to communicate with messages. Delivery success is effortlessly conveyed upon the successful communication of the message [16].

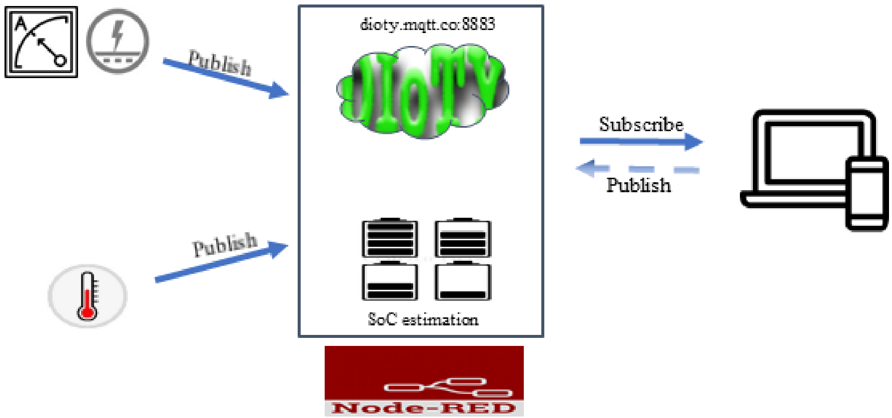

Fig. 3: BMS Hardware Block Diagram

Figure 3 shows the BMS hardware prototype at the block level. The battery packs electrical parameters are measured using Hall Effect current/voltage sensors and after amplification, are communicated with the processor Raspberry Pi 3 B interfaced through an 8-bit ADC. Likewise, the external temperature is measured using sensor DHT 11 and conversed with the processor. The coulomb counting algorithm is implemented in the Node-RED environment and estimated SOC is communicated via MQTT protocol. Users can view the value of SOC and operating temperature in smartphone or PC by subscribing to corresponding topics via the broker DIoTY.

The lifecycle of the battery pack can be augmented overall by the feasible formulation of battery charging, discharging, and sleep practices e.g., in the occurrence of SoC topping 10%, the discharge should be allowed and in the occurrence that it trips down below 10%, the discharge need to be stopped. When the SoC touches 95%, then the battery charging must be stopped. Cyclic full charge/discharge enhances the longevity of the battery pack. The operation should be ensured below the specified temperature to avert the risk of explosion of the battery.

6. RESULTS

During the charging mode of the Lithium polymer batteries, the operation of the SoC estimation technique and real time communication of the battery parameters were checked. The effective capacity measured using the coulomb counting method is represented in Figure 4. Using the MQTT protocol, these values are transmitted to users.

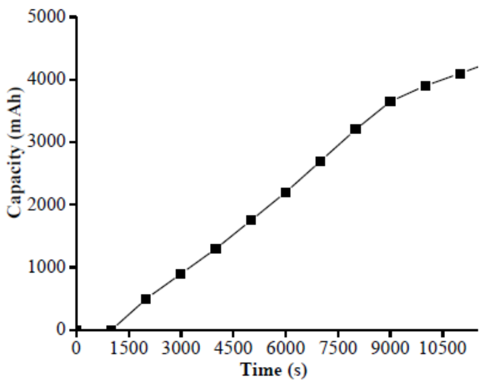

Fig. 4: Estimated capacity of battery packs

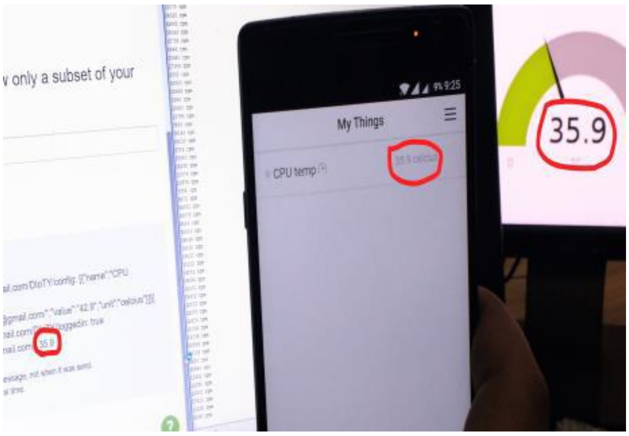

Fig. 5: Battery pack temperature across different platforms

The battery external temperature measured is communicated in real time. Figure 5 shows the temperature displayed on the PC and smartphone App labeled as CPU temp using DIoTY broker.

7 SMART CHARGING

Ideal planning of EVs charging is a need to counter the expanding trouble on matrix. If not done progress of time, it will prompt irregularity of voltage just as recurrence, which at last may prompt network disappointment and power outage. Consistent observing of force framework is vital while charging huge number of EVs, in request to accomplish framework adjusting. An average interest profile for one day regarding 15min offering time blocks, acquired from Indian Power Exchange (IEX) is appeared in Fig. 6 which is a reproduction of the energy interest in Indian situation, where the base load is seen during the night hours and furthermore during the mid of the day.

Low pinnacle hours during night, wherein the heap is at its base, are generally reasonable for locally situated charging, utilizing either Level 1 or Level 2. This time of 6 to 8 hours is likewise excellent for charging batteries at Battery Swapping Stations (BSS). Public charging stations (CSs), where the vast majority of the charging is required to happen during day time, can move their charging burden to low top hours to upgrade the working of framework. This should be possible by conveying appealing charging plans for the buyers during low pinnacle hours or by putting away energy during this period as a reinforcement for top load hours. This kind of booking can end up being gainful for both the utility and shoppers. A compliment load profile with less framework top contrasts can be acquired along these lines, which is attractive. Additionally, from the buyer's view point, this is profitable as obvious from Fig. 6. Cost of buying power is lower during low pinnacle hours when contrasted with that during top hours.

Such demand side control will help to operate the power grid smoothly. Fewer disruptions. It is possible to achieve further enhancement of grid service by Power injection back into the grid and also by participation in the reserve sector to maintain the up and down control of the frequency. This can prove to be helpful for In terms of economics, both the EV aggregator and the consumer. The aggregator of EV charging station, as well as BSS, can gain maximum profit by optimizing the cost function of trading revenue mentioned in [17] which includes day ahead (DA) market, reserve market (i.e. regulation up and down) and real time market (unscheduled interchange).

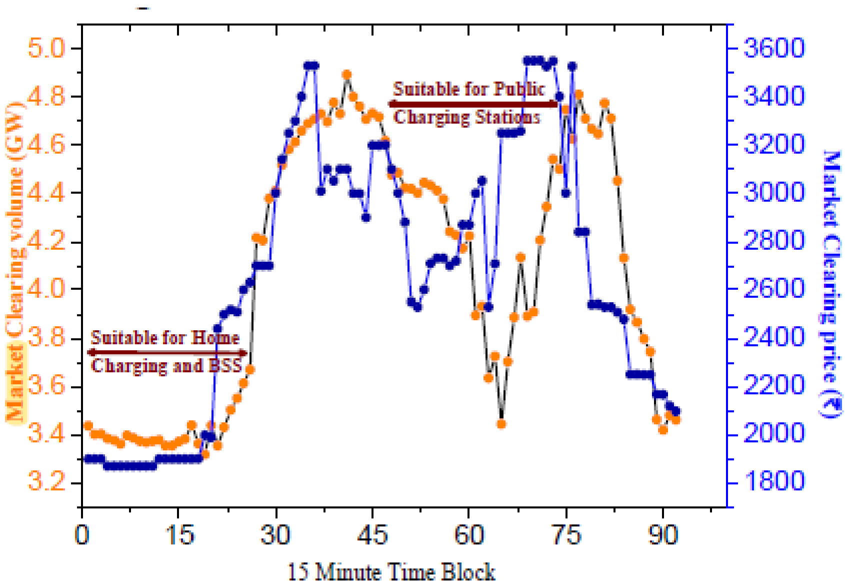

Fig. 6: Demand profile for one day

In order to participate in DA market, proper load forecasting is essential. Numerous techniques have been developed for load forecasting like Simplistic Benchmark methods, Seasonal ARMA modeling, Periodic AR models etc. [18].

The uncertainties involved in the EV fleet characteristics, DA electricity market operations as well as in generation, transmission, and load may be represented by Monte Carlo simulation. Risk involved with the financial as well as economical aspects of the EV aggregator in uncertainty environments can be managed by conditional value added risk analysis (CVaR) as given in [19].

8 CONCLUSION

Internet of Things (IoT) refers to the networked interconnection of everyday objects. IoT has a major role in the rapid development of smart grid. The implementation of Smart Grid devices in the utility grid will influence vast modification in grid management and usage of electric power in upcoming years. The integration of distributed generation necessitates the deployment of energy storage system. Due to better electrical characteristics, the dynamic energy storage system i.e., Electric Vehicles (EVs) is a good prospect although the probability of damage to battery pack in case of overcharging or deep discharging situations is there and uncontrolled charging can severely impact the grid functioning. To mitigate the danger of damage, an accurate real-time capacity determination of a battery pack is desired to increase their lifespan and to protect the equipment they power. A less complex and easy to implement algorithm i.e., coulomb counting technique is implemented in this paper and the estimated SoC along with measured parameters are made available in real time to the user on a remote basis in form of messaging communication. Further an optimization model for maximizing the trade revenue for aggregator of EVs is presented aimed at facilitating smart charging to reduce the impact of increased penetration of EVs on grid.

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