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A Review of Hybrid Battery Management System (H-BMS) for EV

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Abstract

Significant to a major pollution contributor in passenger vehicles, electric vehicles are more acceptable to use on the road. Electric Vehicles (EVs) burn energy based on the usage of the battery. The usage of the battery in EVs is monitored and controlled by Battery Management System (BMS). A few factors monitor and control Battery Management System (BMS). This paper reviewed the battery charging technology and Remote Terminal Unit (RTU) development as a Hybrid Battery Management System (H-BMS) for Electric Vehicle (EV).

Keywords: *Electric vehicles, hybrid battery management system, remote terminal unit, charging, discharging*

1. Introduction

Everyday people breathe through the polluted air. Passenger vehicles polluted the air with significant amounts of nitrogen oxides, carbon monoxide, and other pollution. In 2013, transportation contributed more than half of the carbon monoxide and nitrogen oxides, and almost a quarter of the hydrocarbons emitted into our air.Thus, Electric Vehicles (EVs) begin to growth as well as to save earth.The EVs continue life by a designation of the Battery Management System based on battery behaviours and indirectly produced battery charging technology.

Battery charging technology is grown quite quickly nowadays. By referring to the latest article news, the charging process is based on power sources that either come from waste glass bottle and a low-cost chemical process or under sunlight and indoor lighting. This technology is monitored and controlled by Battery Management System (BMS). Battery Management System (BMS) is an advantage to monitor and control for any battery charging technology especially in Electric Vehicles (EVs). A few factors monitored and controlled by battery management systems include: a). main power voltage, b). battery or cell voltage, c). charging and discharge rates, d). temperatures of the batteries or cells, e). battery and cell health, and f). coolant temperature and flow for air or liquid cooling.

BMS in EVs totally monitored and controlled the battery behaviours. The time planning on how the EVs use the battery are monitored and controlled by Remote Terminal Unit (RTU) from distance. In recent years, there has been an increasing amount of literature on RTU development and implementation. The RTU device development is limited only to Power Distribution and Transmission System. Thus, this paper reviewed the development and implementation of RTU for designing the specific purpose RTU in Electric Vehicles.

2. Battery Charging Technology

Battery charging technology in EVs depend on battery type use such as Li-Ion, Li-SO4, Ni-MH, and others. This battery type is proven by their characteristics performance. In [1] cited

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by [2], 18650 Lithium-Ion battery is used to develop Battery Management System (BMS) for 144V 50Ah. As lithium-ion batteries have high value of specific energy, high energy density, high open circuit voltage, and low self-discharge, they are a proper candidate for EVs among other cell chemistries.

Before design BMS, the battery heat is considered during charging and discharging. As described by [3], to determine the heat generated by a Li-ion cell, it is necessary to measure the trend of voltages and currents during different phases of charging and discharging as shown in Figures 1,2,3, and 4. The thermal behavior caused by heat generated give the temperature changes is shown in Figures 5,6,7,8 and 9. The thermal power for each cell in discharge state is shown in Table 1.

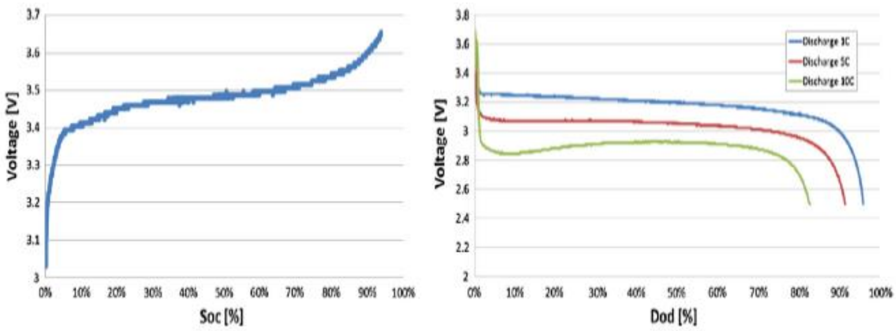

Figure 1. Voltage curves 1C in the charge and 1C, 5C, 10C in the discharge of a soft-pouch cell of 14 Ah

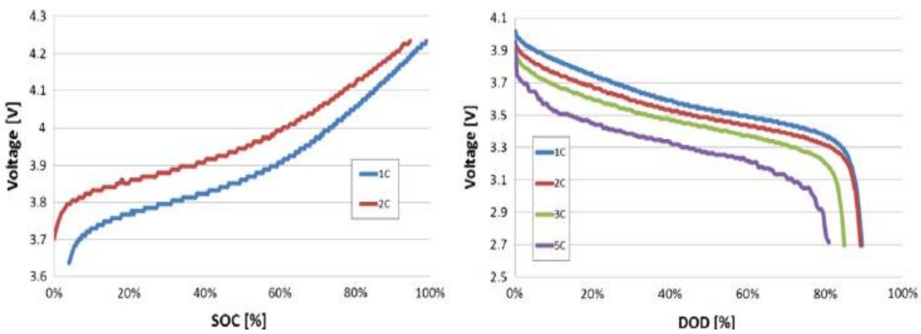

Figure 2. Different profiles of charge at 1C, and 2C and 1, 2, 3, 5C in the discharge of a soft-pouch cell 20 Ah

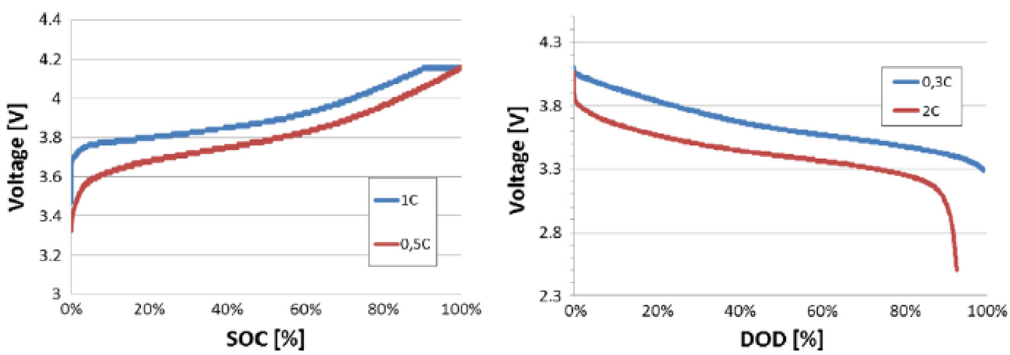

Figure 3. Voltage curves (0.5C and 1C) in the charge and 0, 3C and 2C in the discharge of a soft-pouch cell of 150 Ah

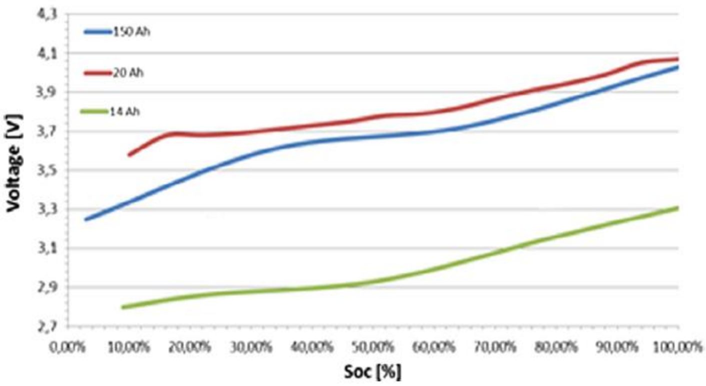

Figure 4. Comparison between OCV curves

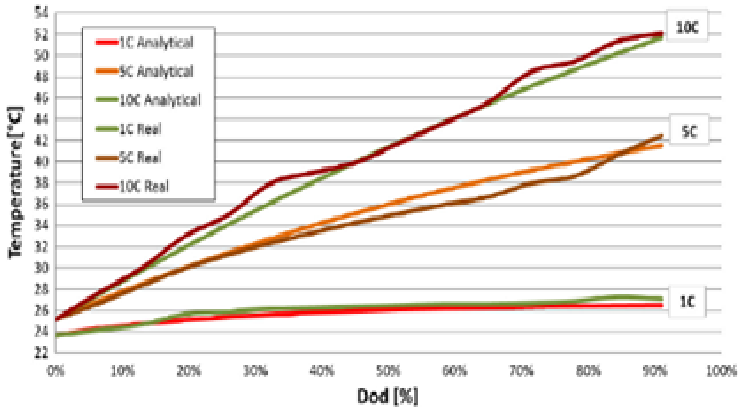

Figure 5. The comparison between the real temperature profiles and the analytical ones for different discharge rates (1C, 5C and 10C) applied to a 14-Ah cell

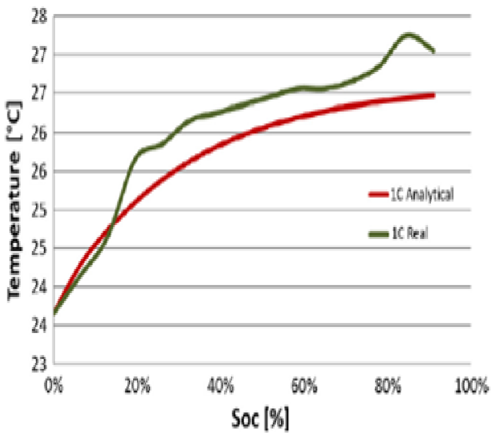

Figure 6. A comparison between the real temperature range for a 1C charge and the analytical values calculated for the 14 Ah cell model

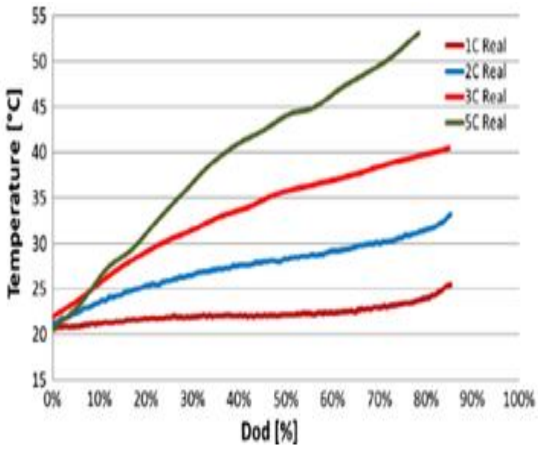

Figure 7. Temperature behavior for different discharge rates (1C, 2C, 3C and 5C) of the 20-Ah battery

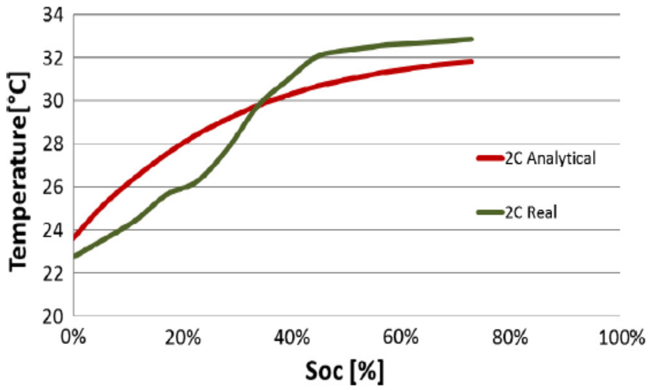

Figure 8. A comparison between the real temperature range for a 2C charge (acquired by an IR camera) and the analytical values (calculated) for the 20-Ah cell model

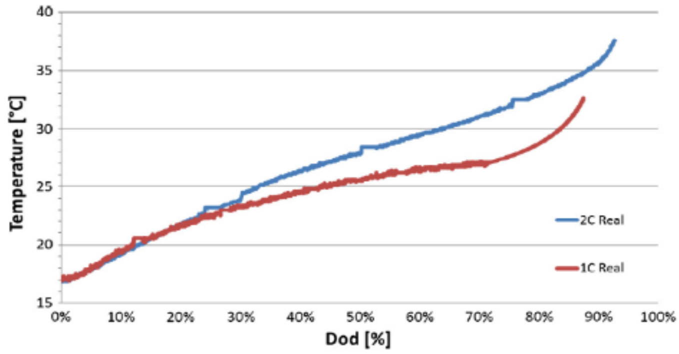

Figure 9. Temperature behavior for different discharge rates (1C and 2C) of the 150-Ah battery

Table 1. Report of thermal power calculated for each cell in a discharge state

	14 Ah	20 Ah	150 Ah
Charge @ 1C	3,0 W	10 W	37 W
Discharge @ 1C	3,5 W	12 W	42 W
Charge @ 2C	4,0 W	23 W	-
Discharge @ 2C	5,0 W	27 W	180 W
Discharge @ 3C	6,5 W	42 W	-
Discharge @ 5C	8,0 W	170 W	-
Discharge @ 10C	21,0 W	-	-

A study [4] provides a simulation framework that models a battery pack and examines the effect of replacing damaged cells with new ones. This simulation framework give a better optimized lithium ion battery pack design in EVs and makes long term deployment of EVs more economically feasible. Thus, car manufacturers will be able to determine how quick the battery pack in an electric vehicle needs to be serviced in order to prolong the pack life.

A hierarchical system model of a network of fast charging stations (FCSs) from the viewpoints of both traffic and service network is proposed [5]. The study focuses on the Li-Ion battery model. The system performance of the proposed model is evaluated based on the Arizona state highway network, the Raleigh city network and the North Dakota state network.

A study [6] adopted the Thevenin model to model the dynamic characteristics of the battery under the variable working mode. The battery parameters will change with time and working conditions. Thus, the diffusion resistance Rp and diffusion capacitance Cp are used for a dynamic response of the battery characteristics.

In general, the electric vehicle use is modelled using a variety of approaches in power systems, energy and environmental analyses as well as in travel demand analysis. Thus, a study [7] provides a systematic review of the diverse approaches using a twofold classification of electric vehicle use representation, based on the time scale and on substantive differences in the modelling techniques. BMS is used for the computation and monitoring of three key indices, namely, state of charge (SOC), state of health (SOH), and state of function (SOF) in EV [8]. The battery performance is analyzed based on the three states mention.

A study [9] found that EV LIB reuse in stationary application has the potential for dual benefit-both from the perspective of offsetting initial manufacturing impacts by extending battery life span as well as avoiding production and use of a less-efficient PbA system. However, technical feasibility of these systems must still be evaluated. This shows that the ability to rapidly analyze the reliability of EV LIB cells, modules, or packs for refurbishment and reuse in secondary applications.

Battery come in a cell, or a pack. A study [10] analyzes the power battery management system (BMS) for LiFePO4 power battery pack to detect the voltage and temperature of each battery at which CAN communication transmit the detection data to the touch screen microprocessor. BMS monitors and controls battery pack charging and discharging processes by setting up the charging parameters and charging mode, and transmitting the voltage and SOC information to motor controller respectively. The development of Battery Management Systems (BMS) is growing at a global level. Therefore, a review on literature that is focusing on the BMS optimization such as MATLAB/SIMULINK for EVs (car) is conducted [11]. This optimization enables model improvement on performance management of EVs.

Pudvay (2014) found that the Battery Management System of an electric vehicle is an alternative energy for a significant focus with the increase in society' s environmental consciousness and also with the impacts of the theory of peak oil and the public's transportation costs associated with this phenomenon [12]. These authors claimed that BMS is useful and safe to monitor and control vehicles in different states of an alternative energy, such as Lithium based energy for the public. The specific characteristics and needs of the smart grid and Electric Vehicles (EVs), such as deep charge/discharge protection and accurate state-of-charge (SOC) and state-of-health (SOH) estimation, intensify the need for a more efficient BMS (Rahimi-Eichi et al., 2013) [13].

Yuan (2015) designed a battery management system (BMS) for low voltage electric vehicle by adopting resistance shunt method to avoid over-charging the battery cells [14]. Once one of the faults of low voltage, over current and high temperature occurs, the Micro Control Unit (MCU) will shut down the whole circuit to avoid permanent damages of the battery stack or even explosion events. MCU is a part of BMS or RTU device. These authors also used Extended Kalman filter (EKF) for high precision estimation of State of Charge (SOC), which is very important for remaining the cells working within appropriate State of Charge (SOC) and avoiding overdischarging the cells. The system has been tested so that it can maintain the battery stacks at a good state and improve the reliability and security of the electric vehicle. However, this BMS is limited for low voltage electric vehicles that can be improved to unlimited BMS voltage in advance.

Hu (2015) studied and designed the power battery management system for LiFePO4 power battery pack to ensure the safety of power battery pack and the cycle life extension of the battery pack [15]. Thus, these authors claimed a problem exists when one of the batteries voltage reaches the charging cut-off voltage, other battery voltage rises in stages, even though it has not reached the cut-off voltage, indicating it is not yet fully charged. The data validation process has been validated based on parameters used by validating the battery SOC parameter at different temperature and room temperature [16] for Li-Ion. Li-Ion battery SOC parameters include battery capacity and constant discharge time. This online data validation has been adapted from a study [17].

3. RTU Development for EV

Aamir et al. (2015, 2014) design and implement an optimal Remote Terminal Unit (RTU) for wireless SCADA that is suitable for wide area operation essential for controlling and monitoring oil and gas sector, water and power industries based on FPGA which has resulted in reliable and reconfigurable RTU [18]-[19]. Thus, these authors claimed that extraction would extract from the layout, the devices formed because of junctions of different semiconductor and metal layers and the interconnections. As FGPA is being used as the main processors, this extraction step has little practical value.

Remote Terminal Unit (RTU) is a microprocessor-controlled electronic device that transmits telemetry data to a master system, and uses messages from the master supervisory system to control connected objects such as Battery Management System (BMS) for the electric vehicle (EV). A battery management system (BMS) manages a rechargeable battery (cell or battery pack), by protecting the battery from operating outside its Safe Operating Area, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and / or balancing it. A BMS may monitor the state of the battery as represented by various items, such as voltage, temperature, state of charge (SOC) or depth of discharge (DOD), state of health (SOH), coolant flow and current.

In recent years, there has been much literature on RTU implementation. However, the RTU device development is limited to Power Distribution and Transmission System [20-31]. Thus, this work investigated and analysed the implementation of EV-RTU for the specific purpose in Electric Vehicles based on RTU development literature.

Among the development of EV-RTU, the data speed is widely employed based on hardware designations for PIC, FPGA, and FPGA and FPAA. PIC microcontroller processes the data received and sends them to the Global System for Mobile (GSM) and saves the data in RTU memory. Then, Short Message Service (SMS) and Graphical User Interface (GUI) command [20]-[22] at which the GUI command is developed from Visual Basic (VB) [21]-[24] to take further actions. However, a number of studies show that significant differences do exist in the development of RTU for the data speed. FPGA gives results in reliable and reconfigurable RTU [24]. Moreover, FPGA and FPAA based RTUs are more compact and offer more immunity towards component obsolescence issues for more reliable and reduced power consumption [25].

Electric Vehicles (EVs) production comes in various type. There are Plug-In EVs (PEVs), Hybrid Electric Vehicles (HEVs), e-bike and others. These EVs have a range of distance to go from one destination to another destination based on the reliability battery capacity and battery type. In [32], from the theorithical-based, a larger battery used at less than full discharge can be more economic and last longer than a smaller capacity battery used at full depth of discharge. This factor influences the BMS design in EVs to extend the life cycle of the battery and mileage of the EVs. Besides, users have to ensure the correct assumptions regarding temperature, maximum voltage or full charge, minimum voltage or depth of discharge, and C rate of the battery.

A few interviews have been carried out [33] to answer the question on how long do electric car batteries really last. Bill Wallace (respondent 1) claims that in extreme hot climates such as Phoenix, the Chevy Volt will last at least 10 years, 150,000 miles, and 6,000 cycles. The second respondent asserts that the financial savings of the Volt versus the non-EV vehicle depend on the time an electric battery’s charging period. Each interview most probably focuses on the performance of EV based on th battery use, Li-Ion.

In 2016, a study [34] found how far electric car can travel on one charge for a few model of electric cars in UK. Based on the UK route, Tesla Model S is in the range of 311 miles, BMW i3 is in the range of 125 miles, Volkswagen E-Up is in the range of 93 miles, Nissan Leaf is in the range of 124 miles, Tesla X is in the range of 300 miles, Volkswagen Golf is in the range of 80 miles, Kia Soul is in the range of 131 miles, Renault Zoe is in the range of 100 miles, Ford Focus in the range of 99 miles, and Nissan eNV200 is in the range of 110 miles from the first route of each EVs. It is not quite different in 2017, [35] found the top 10 EVs ranked by total driving range.

How far EVs user can really go depend on a few factors. A study [36] found feedback from user claim on how long the battery charge will last as well as the route taken by users. Other EVs users claim that flat road and hot or cold weather influence the life cycle of the battery. There are many route growth as well as country development. Thus, a study [37] develops a more accurate range prediction for electric vehicles (EVs) resulting in a routing system. This routing system could extend the driving range of EVs through calculating the minimum energy route to a destination, based on topography and traffic conditions of the road network.

Sometimes road users have problem to find charging stations or plug in the car. Therefore, in a study [38] the research team at Korea Advanced Institute of Science and Technology (KAIST) in Daejeon has developed the on-line electric vehicle (OLEV) system. This system also face problem in terms when using wireless scheme that would be improved for further reseach. Electric Vehicles (EVs) give impacts to environment. Through this issue, a study [39] investigated the usefulness of different types of life cycle assessment (LCA) studies of electrified vehicles. This life cycle assessment (LCA) is analyzed to provide robust and relevant stakeholder information.

Overcharging and overdischarging are a quite familiar problem in battery charging. A study [40] developed a network of fast charging facilities and coordinate service. This network of fast charging is used to facilitate the adoption of electric vehicles (EVs) and their plug-in hybrid (PHEVs) counterparts, and there is a strong need to avoid straining the capacity of the power grid. However, when the network has exceeded a critical threshold, the drivers receive and send back the necessary information through the communication infrastructure and the routing. BMS monitors and controls battery characteristics for charging and discharging process in EVs. Therefore, the battery life cycle is extended longer. EVs travel depends on battery life cycle. BMS and EVs need device to plan the destiny, time and cost for maintaining the battery life cycle. Thus, RTU development for an EV is recommended to plan BMS and EVs data.

4. Conclusion

Electric Vehicles (EVs) growth well in abroad. These EVs need energy power to move forward, backward, rightside, and leftside on the road. Li-Ion battery acts as the main power source to place generator during electricity breakdown in EVs. The battery is monitored and controlled by the Battery Management System to perform the EVs movement. This paper reviews the battery technology that supports development of BMS in EVs, battery type in EVs, and RTU development. RTU development is also covered in this paper because the device is analyzed based on the implementation and development of the specific RTU that acts as time planning for the charging and discharging of the battery life cycle in EVs. Thus, the safety and performance in EVs is well-improved.

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References

[1] P Amiribavandpour, W Shen, A Kapoor. *Development of thermal-electrochemical model for lithium ion 18650 battery packs in electric vehicles*. IEEE Veh. Power Propuls. Conf. IEEE VPPC. 2013: 117–121.

[2] M Ikram, M Rashid, JR Anak, J Osman. Design and Implementation of Battery Management System for Electric Bicycle. *ETIC 2016*. 2016: 7.

[3] P Cicconi, D Landi, M Germani. Thermal analysis and simulation of a Li-ion battery pack for a lightweight commercial EV. *Appl. Energy*. 2017; 192: 159–177.

[4] M Mathew, QH Kong, J McGrory, M Fowler. Simulation of lithium ion battery replacement in a battery pack for application in electric vehicles. *J. Power Sources.* 2017; 349: 94–104.

[5] C Kong, R Jovanovic, I Bayram, M Devetsikiotis. A Hierarchical Optimization Model for a Network of Electric Vehicle Charging Stations. *Energies*. 2017; 10(5): 675.

[6] M Ye, H Guo, B Cao. A model-based adaptive state of charge estimator for a lithium-ion battery using an improved adaptive particle filter. *Applied Energy*. 2017; 190: 740–748.

[7] N Daina, A Sivakumar, JW Polak. Modelling electric vehicles use: a survey on the methods. *Renew. Sustain. Energy Rev*. 2017; 68: 447–460.

[8] Z Hou, P Lou, C Wang, S Member. *State of Charge, State of Health, and State of Function Monitoring.* 2017 IEEE International Conference on Consumer Electronics (ICCE). 2017, 1: 1–2.

[9] K Richa, CW Babbitt, NG Nenadic, G Gaustad. Environmental trade-offs across cascading lithium-ion battery life cycles. *Int. J. Life Cycle Assess*. 2017; 22(1): 66-81.

[10] Y Hu, X Wu, J Tu, Q Fan. Research of Power Battery Management System in Electric Vehicle. *Int. J. Multimed. Ubiquitous Eng*. 2015; 10(2): 187–194.

[11] PMW Salehen, MS Su'ait, H Razali, K Sopian. *Development of battery management systems (BMS) for electric vehicles (EVs)* in Malaysia. 2nd Int. Conf. Automot. Innov. Green Veh. (AiGEV 2016). 2017; 90: 1001.
[12] SL Pudvay. Battery Management System for Electric Vehicle. 2014; 1(61).
[13] HR Eichi, U Ojha, F Baronti, M Chow. Battery management system: an overview of its application in the smart grid and electric vehicles. *Ind. Elec- tron. Mag. IEEE*. 2013; 7(2).
[14] X Yuan. Battery Management System for Electric Vehicle and the Study of SOC Estimation. 2015; 19: 152-156.
[15] Y Hu. Research of Power Battery Management System in lectric Vehicle. *International Journal of Multimedia and Ubiquitous Engineering*. 2015; 10(2): 187-194.
[16] V Agarwal, K Uthaichana, RA DeCarlo, LH Tsoukalas. Development and Validation of a Battery Model Useful for Discharging and Charging Power Control and Lifetime Estimation. *IEEE Trans on Energy Conversion*. 2010; 25(3): 821-835.
[17] KN Oo, ZM Naing, HM Tun. Implementation of Distributed Control System In Process Control Management Using MATLAB. *Int. J. Sci. Technol. Res*. 2014; 3(6): 149–154.
[18] M Aamir, MA Uqaili, NA Khan, J Poncela, BS Chowdhry. Implementation and Testing of Optimal Design of RTU Hardware for Wireless SCADA. *Wireless Personal Communications*. 2015; 85(2): 511–528.
[19] M Aamir, MA Uqaili, J Poncela, NA Khan, BS Chowdhry. *Implementation and Testing of Optimal Design of RTU Hardware for Wireless SCADA.* in 2014 4th International Conference on Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronic Systems (VITAE). 2014: 1–5.
[20] WNSEW Jusoh, MAM Hanafiah, SH Raman, MRA Ghani. *Development of a New Modeling Circuit for the Remote Terminal Unit (RTU) with GSM Communication*. in 2013 IEEE Conference on Clean Energy and Technology (CEAT). 2013: 506–509.
[21] WNSEW Jusoh, MAM Hanafiah, MRA Ghani, SH Rahman. *Remote Terminal Unit (RTU) Hardware Design and Implementation Efficient in Different Application.* in 2013 IEEE 7th International Power Engineering and Optimization Conference (PEOCO2013). 2013: 570–573.
[22] WNSEW Jusoh, MRA Ghani, MAM Hanafiah, SH Raman. *Remote Terminal Unit (RTU) Hardware Design and Development for Distribution Automation System*. 2014 IEEE Innov. Smart Grid Technol. – Asia (ISGT ASIA). 2014: 572–576.
[23] RP Behera and N Murali. *Development of Tele-Alarm and Fire Protection System using Remote Terminal Unit for Nuclear Power Plant*. in 2015 International Conference on Robotics, Automation, Control and Embedded Systems – RACE 2015. 2015.
[24] A Gour, R Sanga, RP Behera, P Sahoo, N Murali, S Satyamurty. *Design and Development of FPGA and FPAA based Remote Terminal Units for Nuclear Power Plants.* in 2014 Fifth International Symposium on Electronic System Design. 2014: 44–48.
[25] A Sharma, SC Srivastava, S Member, S Chakrabarti, S Member. Testing and Validation of Power System Dynamic State Estimators Using Real Time Digital Simulator (RTDS). *Ieeexplore.Ieee.Org*.2015; 31(3): 1–10.
[26] A Sharma, SC Srivastava, S Chakrabarti. A Multi-Agent- Based Power System Hybrid Dynamic State Estimator. *IEEE Intell. Syst.* 2015; 30(3): 52–59.
[27] SC Srivastava, S Chakrabarti, A Sharma. Multi-agent-based dynamic state estimator for multi-area power system. *IET Gener. Transm. Distrib*. 2016; 10(1): 131–141.
[28] Y Zhou, X Chen, A Zomaya, L Wang, S Hu. A Dynamic Programming Algorithm for Leveraging Probabilistic Detection of Energy Theft in Smart Home. *IEEE Trans. Emerg. Top. Comput.* 2015; 3(4): 1–1.
[29] Y Guo, CW Ten, P Jirutitijaroen. Online Data Validation for Distribution Operations Against Cybertampering. *IEEE Trans. Power Syst*. 2014; 29(2): 550–560.
[30] D Munandar and D Syamsi. *Data logger Management Software Design for Maintenance and Utility in Remote. in* 2014 1st International Conference on Information Teclmology, Computer and Electrical Engineering (ICITACEE) Data. 2014: 74–78.
[31] Q Ain, M Shah, M Khan, SA Mahmud. *Implementation of SCADA for Multiple Telemetry Units while using GSM for Communicatio.* in Proceedings of 2015 International Conference on Emerging Technologies, ICET 2015. 2015.
[32] C Arcus. Battery Lifetime: How Long Can Electric Vehicle Batteries Last? CleanTechnica. 2016.
[33] C Volt. How Long do Electric Car Batteries Really Last? The Drive. 2016.
[34] W Sussex. How Far Can an Electric Car Travel in One Charge?
[35] E Schaal. 10 Electric Vehicles With the Best Range in 2015. Autos Cheatsheet. 2015.
[36] MK Campbell. How far can you REALLY go in an electric vehicle? Plug In America. 2010: 4–9.
[37] M Neaimeh, GA Hill, Y Hübner, PT Blythe. Routing systems to extend the driving range of electric vehicles. *Intell. Transp. Syst. IET*. 2013; 7: 327–336.
[38] S Ahn, N Suh, DH Cho. Charging up the road. *IEEE Spectrum*. 2013; 50(4): 48–54, 2013.

[39] A Nordelo"f, M Messagie, AM Tillman, M Ljunggren, S derman, JV Mierlo. Environmental impacts of hybrid, plug-in hybrid, and battery electric vehicles???what can we learn from life cycle assessment? *Int. J. Life Cycle Assess*. 2014; 19(11): 1866–1890.
[40] IS Bayram, G Michailidis, I Papapanagiotou, M Devetsikiotis. *Decentralized control of electric vehicles in a network of fast charging stations.* in Proceedings of the IEEE Global Communications Conference (GLOBECOM). 2013; 31(7): 2785–2790.