Wireless Approach on Battery Management System of Electrical Vehicles

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ABSTRACT:

Battery management systems that monitor individual cells are typically hard wired. In addition, the battery packs of an electric vehicle (EV) contain a daisy-chain of wiring, long copper cabling interlinked by a lot of connectors. Wiring and connectors have a high common risk of failure and sometimes it is not simple to locate the point of failure which would lead to a higher cost of replacing the battery system. With OEMs seeking lighter, less complex, and more cost-efficient battery packs, a new development of a wireless BMS in a form of a system-on-a-chip architecture. The system forms a cell supervisor unit (CSU) where the CSU wirelessly communicates with the overall battery control unit.

I. INTRODUCTION

The monitoring and control function tasks within the lithium-ion batteries employed in electric and hybrid vehicles are carried out by the so-called Battery Management System (BMS). This system is responsible for ensuring the proper and continuous operation of the battery with the highest possible performance. Among its essential tasks are the measurement and control of the state-of-charge (SoC) and state-of-health (SoH) of the individual cells, the charge balance, and the detection of failures (e.g., cell short circuits, temperatures too high, etc.) [10].

In a battery pack, several lithium-ion cells are connected in series and grouped in modules, as shown in figure 1. Then these modules are

Figure 1: Representation of a Battery Pack

connected either in series or in parallel to obtain the desired voltage and current. As an example, a typical battery pack from a hybrid car has between 8 and 12 modules, each of them equipped with 10 or 12 cells. In the current commercial BMS, the data transmission is realized by means of standard bus protocols, e.g., CAN-Bus. This requires the installation of a very large and complicated amount of extra wiring to interconnect the large number of communication nodes [10]. Consequently, this leads to an increase of cost, weight, and construction complexity, as well as complications regarding the galvanic isolation of the cells. Additionally, the CAN-Bus limits the maximum data rate to 1 Mbps, which could turn into a bottle neck for the development of future generations of battery sensor systems. Fig. 1. Representation of a battery pack (source: SB Linotile) The Antlion ("Intelligent data bus concepts for lithium-ion batteries in electric and hybrid vehicles") project aims to develop novel and smart data transmission techniques for the BMS. The focus of this research is on innovative communications systems capable of efficiently controlling and monitoring each individual cell in a battery pack. Our group is currently studying two different alternatives as new physical layers: Power Line Communications (PLC) and Wireless. We are treating the Wireless alternative in this paper. There are only a few studies of wireless data transmission inside the battery pack. In [11] and [12] the authors employed protocols based on IEEE 802.15.4 in the 2.4 GHz band with a maximum data rate of 250 kbps. The work carried out in the BATSEN project [13] deals with the development of wireless sensors for BMS [14].

II. HISTORY ON BMS CONCEPT & FOUNDATION

Current Battery management systems are found in portable electronics such as laptops and cell phones but have not yet been fully deployed onto electric or hybrid-electric vehicles. This is a result of the number of cells in a vehicle's battery is hundreds of times greater than that in portable electronics. Also, a vehicle's battery is not only designed to be a long-lasting energy system. It is also required to be a high-power energy system. This requires electric vehicles and hybrid-electric vehicles to provide high voltage and high current making batteries for EVs and HEVs much more sophisticated than that of portable electronics. The following diagram shows how current battery management systems preform basic functions differently from each other. Some drawbacks of the battery management units include limited data logging function, lack of state of health and state of life estimations and are not interchangeable between current BMSs.

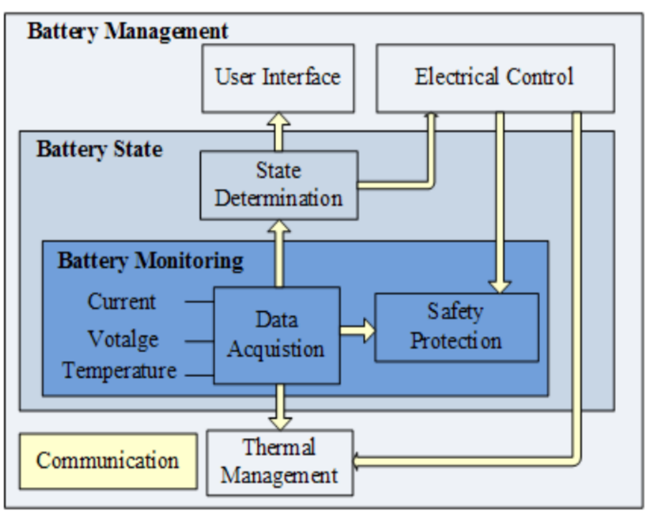


Figure 2: BMS Design

With the rising developments in the battery technologies and increasing gasoline prices, EVs and HEVs were emerging in the 1990s. They eventually became more popular in the 2000s. As a result of promising properties such as high energy density, long life cycle and low self-discharge, lithium-ion battery technology has been becoming very developed and applied a lot more frequently in the past decade because of the slow and insufficient developments of BMSs for EVs. This decline has been the result of battery state evaluation, battery modeling, and cell balancing. Since BMS is critical for e-mobility, evolving it to be wireless makes it more convenient resulting in the system to require additional care. WBMS improves design flexibility and simplifies production without compromising the battery itself.

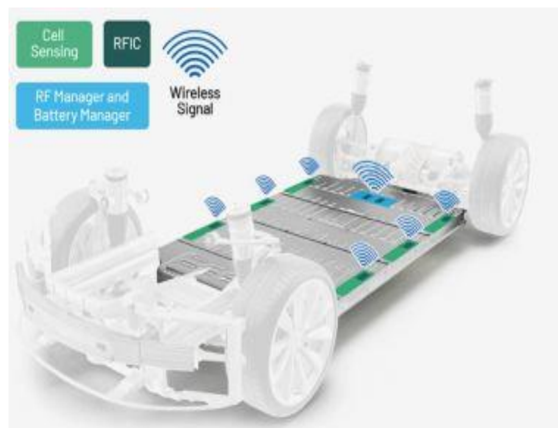


Figure 3: Wireless Management System

On a single chip, ADI's BMS contains all necessary hardware and software for power, battery management, RF communication, and ASIL-D and module-level safety operations. The method allows for optimal power consumption per cell for greatest vehicle range, as well as safe and long-lasting zero cobalt battery chemistry like lithium iron phosphate (LFP).

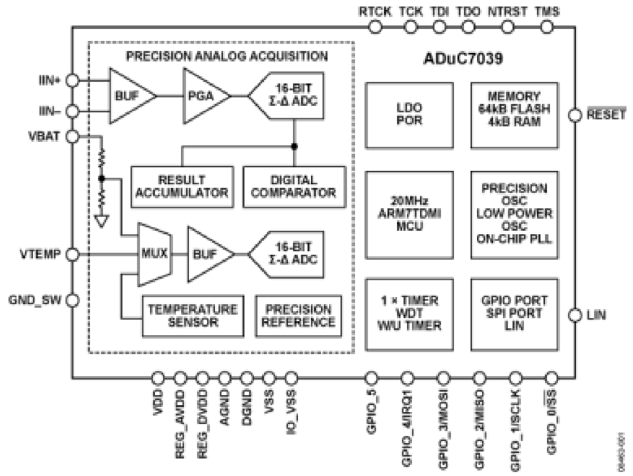


Figure 4: Battery Monitor System

The figure above ADuC7039 is a battery monitoring solution for a complete system in 12 V automotive applications.

III. CHALLENGES AND FUTURE OPPORTUNITIES OF BATTERY MANAGEMENT SYSTEMS

Unlike smartphones, electric vehicles cannot afford a short battery lifespan, especially between life cycle of a car. The lifespan of a battery between recharge is not long enough. The challenging design is to have car batteries that can last the entire lifespan of vehicles. One way of doing that is keeping close tabs on every battery in electric vehicles, and design longer live successors. The challenge in realizing such a goal in high energy Lithium-Ion batteries with graphite anodes and transition metals oxide cathodes in liquid electrolytes that are unable to achieve rapid charge without compromising safety and performance.

The opportunity to curb and possibly eradicate greenhouse gas emission and adopt renewable energy of electric vehicles can change the global trend of environmental pollution and provide energy security for the future. With significant advantage of wireless battery management system in electric vehicles today represents a significant breakthrough that offers enormous reliability, lowers cost, and reduce the complexities associated with wiring of multiple battery stacks for electric vehicles.

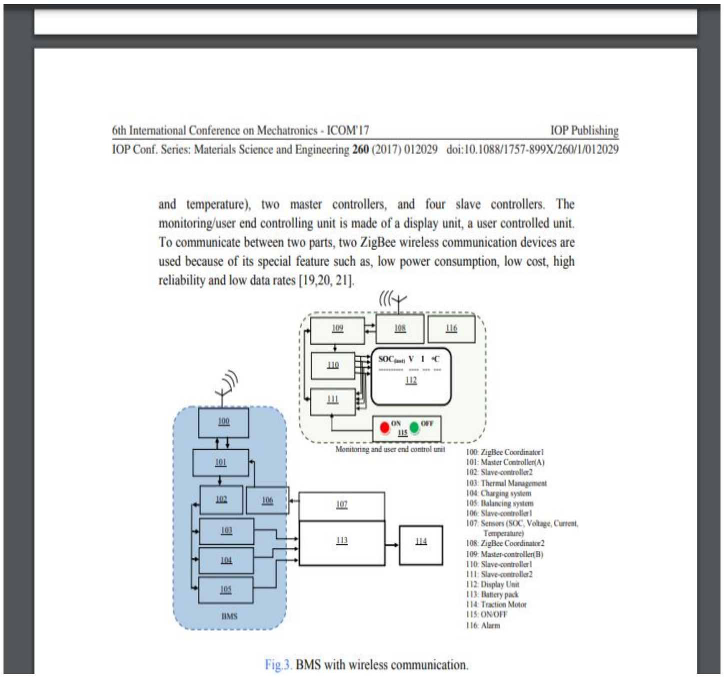
With wireless network of a BMS with Smart Mesh, it has a potential for new functionality not available with wired systems. With the wireless network, there is the flexibility to stack modules more compact that were previously not possible because of the bulkiness in a wired system. Smart Mesh automatically time synchronizes each node to within a few microseconds, and accurately timestamps measurements at each node. The ability to time-correlate measurements taken at different locations in a vehicle is a powerful feature for calculating more accurately the battery state of charge (SOC) and state of health (SOH).

IV. ESTIMATION OF GRAVIMETRIC AND VOLUMETRIC ENERGY POWER DENSITY

A small percentage increase in volumetric energy density and a very high percentage of gravimetric of NiMH battery can compete with majority of available lithium-ion batteries. The fact that high energy density of Nickel Metal hydride batteries is a common and widely used in portable electronic devices and in electric vehicles. The used of fossil fuels can be minimized by the employment of NiMH batteries. As the main purpose of the battery is for storage, maximizing the battery energy density serves a great deal of interest that allows high power application. The maintenance to these batteries can be mitigated by providing a great seal to prevent leakage. It can also operate under a wide range of temperature spectrum. It is also very safe to use as it has negligible toxic composition if any at all.

V. ADVANTAGES OF WIRELESS BATTERY MANAGEMENT SYSTEMS

Wireless communication is preferable because of low cost, reliable, easy implementation. Wireless network deployed in BMS to monitor instantaneous current, voltage, SOC, capacity and temperature of battery cell or module. It provides wireless bidirectional communication between BMS and monitoring (user end control) units where BMS can be controlled from the user end. Figure below shows battery management system with ZigBee wireless communication. The design model is divided into two parts: battery management system (BMS) and monitoring/user end controlling unit.


6th International Conference on Mechatronics - ICOM'17 IOP Publishing
IOP Conf. Series: Materials Science and Engineering **260** (2017) 012029 doi:10.1088/1757-899X/260/1/012029

and temperature), two master controllers, and four slave controllers. The monitoring/user end controlling unit is made of a display unit, a user controlled unit. To communicate between two parts, two ZigBee wireless communication devices are used because of its special feature such as, low power consumption, low cost, high reliability and low data rates [19,20, 21].

Fig.3. BMS with wireless communication.

Figure 5: Wireless Communication on BMS

- Wireless Battery Management System eliminates the need of cable maintenance, connectors, and harness repair
- Sensors could be added to enhance network reliability
- It can enhance battery lifespan because it can balance the battery cells in a shorted time
- Communication breakdown is eliminated as the common source of failure with wire harnesses and connectors do not exist anymore
- Realtime data can be achieved pertaining to the electric current, voltage, temperature etc.
- Remote access to data is readily available wireless

VI. DATA TRANSMISSION INSIDE THE WIRELESS BMS

The BMS communications system aims to transmit information between the battery control unit (BCU) and the cell sensor units (CSU). There is one CSU on each individual cell for measuring several parameters such as its voltage and temperature. The BCU is designed to compute all these values to determine the soc and soh of the pack and to execute the corresponding actions. This new proposal consists of installing an antenna in each CSU as well as in the BCU to facilitate the wireless communication between them. We provide a schematic of this approach in figure 2, which shows a battery module with 10 cells in series, each of them with its own antenna. The electromagnetic waves will propagate along the free space inside the traction battery, mainly between the upper side of the cell cans and the battery housing [14].

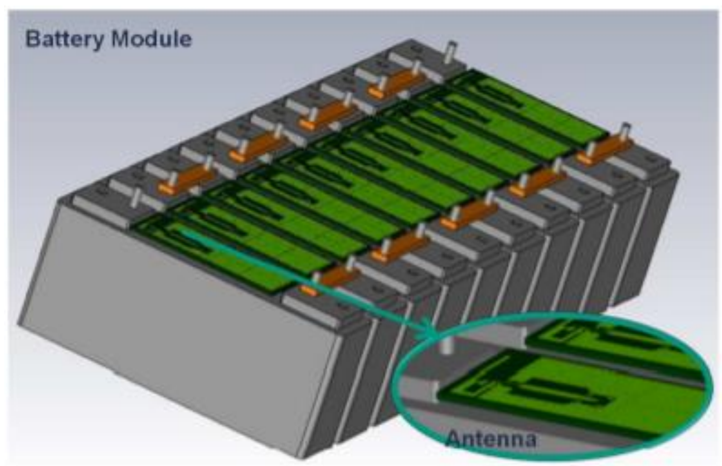


Figure 6: Scheme of Antenna

The wireless approach has many advantages. Among them, the most important are: lower costs, because a piece of PCB (for planar antennas) or a short helical wire (helix antennas) costs much less than a long isolated cable; less space and weight in the battery pack and higher data rate (for this project a minimum data rate of 2 Mbps was specified, which is twice the rate of the high speed CAN-Bus) [14].

The antennas will play a key role in this communication system. Therefore, we carried out a thorough study on them in order to choose suitable devices. In principle, there is no restriction in the frequency range for this application, because no standards or normative restrictions must be observed. Additionally, most batteries have a housing made of metal, which provides strong electromagnetic isolation; hence, we expect no important problems with electromagnetic compatibility (EMC) or external interferences. Therefore, we evaluated a large frequency range between 100 MHz and 3 GHz. We analyzed the performance of various commercial antennas, including different types, such as wired helix, planar, ceramic/chip, etc [14].

Several requirements must be fulfilled by an adequate antenna for this application. Apart from the already mentioned low cost and small size, the antenna must be suitable for every cell position inside the battery, as well as for different battery sizes. The channel capacity between the antennas should be in accordance with the specified data rate.

The battery pack interior is a complicated and completely uncommon medium for wireless transmission. Due to the presence of reflective objects (mainly metallic battery cell cans and housing) in the vicinity of the antennas, their parameters (impedance, resonance frequency, efficiency, antenna factor) are modified with respect to the ones in free space [15]. The environment of an antenna depends not only on the battery pack itself (size, cell distribution, etc.) but also on its position inside the battery pack. Thus, its parameters will be location dependent [15]. Consequently, a matching network seems not to be a proper universal solution, because each antenna would need a particular different one, and that is not feasible. Hence, we expected that some communication nodes will deal with significant antenna mismatching. Another complication of the battery pack as wireless channel is the multipath propagation caused by the multiple reflections. This produces several resonant and notch frequencies, which results in a very strongly frequency-selective fading channel [16]. Additionally, two of the three dimensions of the space where the waves are spread (length and width, the height of this space is always very small) are smaller than the wavelengths for some frequency ranges of interest, the environment of the wireless channel behaves as a microwave resonant cavity [17]

VII. SPECIFICATION OF SYSTEM

The specification of this system can be divided into four main categories. The cost, energy and power requirements, range, and the voltage requirements.

Costs:

- Device costs
- Labor costs
- Engineering design costs
- Setup costs
- License and regulation costs

A wireless battery management system specification must take into consideration. The temperature range for wireless detection ranges from 30-40 degrees. A wireless battery management system has been used to maintain the cells SOC variation (0.75 +/- 5%) Ah.
The central control system of BMS communicates with its sub-systems through the Controller Area Network (CAN) bus or serial bus to provide safe and efficient performance. BMS collects the information from the sensors (voltage, current, SOC, impedance, internal and ambient temperature) relate to battery cells or pack, process, controls its sub-systems and send that information to the user end to monitor through communication interface. Two types of communication system are being employed with BMS, which are wired and wireless communication. For wired communication, each battery cell connected to BMS. Since, battery pack consists of many cells, the complex connection causes the correction of the electric contact, which may lead to whole system failure. Instead of wired, wireless communication is preferable because of low cost, reliable, easy implementation.

The initial costs of setting up a wireless battery management system is moderate-high. Although these initial costs are high but the return on investment and potential savings outweigh wired connections and tests.

VIII. WIRELESS DESIGN

The design model is divided into two parts: battery management system, and monitoring/user end-controlled system. The BMS mainly consists of thermal management system, a charging system, balancing system, a battery pack, and different kind of sensors. The sensors detect SOC, voltage, current and temperature. The monitoring/user end controlling unit is made of a display unit and a user-controlled unit. A communication channel is established to communicated between these two unites.

IX. ANALYSIS OF SYSTEM DESIGN

The system developed in the study uses a 14 kwh Litium Iron Phosphate battery with a nominal voltage of 140 V and a capacity of 80 Ah. The battery pack in this case is configure to use 80 cells. Each cell has a nominal voltage of 7V and a capacity of 80 Ah. Moreover, to further detail the design of the system, the van is powered with a 48kw motor controlled by a VCO (Voltage controlled oscillator) used to control facets of the input AC signal. In addition, a thermal management system is utilized (two phase) to control the battery temperature from a range of 30-40 degrees Celsius. A wireless battery management system has been used to maintain the cell's SOC variation of (0.75 ± 5%) Ah.

The IIUM system has developed a battery thermal management system to reduce the temperature of the battery pack to an optimal range between the reduction range mentioned earlier. The Heat produced from the battery as a byproduct is then absorbed the refrigerating agent in the system. This allows the temperature in the system to oscillate shortly in and out of the desired range of the system. In conjunction with the battery management system in which the load of the cells is balanced dependent on the dynamic load allocated via varying system constraints, the battery life would be enhanced by about 20% via the use of the system. In this case specifically, the life of the system can be extended from 8 years to approximately 11 years. These values are a projective value based on the field experimental results using the IIUM campus and the Sepang F1 circuit. The modifications done to the system in this case is mainly to the evaporative thermal management system in conjunction with cell load balancing sequence to maintain a reduced internal temperature of 25-25 degrees Celsius.

Figure 7: Thermal BMS

The central control system of the BMS communicated with the system under the code design structure through the CAN (Control Area Network) or serial bus for a more efficient performance. The BMS collects the necessary information from the peripheral sensors. These sensory information include voltage, current, SOC, impedance, internal, and ambient temperature related to the cells in the battery pack, the process in which the load is allocated per cell in a dynamic simulation, and the sub systems that communicate with the user for a more usable user interface. In a BMS, a wireless network is used to monitor the current, voltage, SOC, capacity (AH), and temperature of a battery cell or module in real time. It enables bidirectional wireless connection between BMS and monitoring (user end control) equipment, allowing BMS to be controlled remotely. Charging and discharging functions in this BMS is a common occurrence in this controlling and monitoring in order to create a safe and efficient performance. In the Battery management system, the slave controller 1 which then takes information from the battery pack using the analog sensors and design structure, mapping the subsequent result acquired from the respective sensors into mapped ranges relative to the desired output. Then the slave controller sends the information, processed from the slave controller to the master controller. Upon receiving the information from the periphery sensors on the module, the master controller also makes two decisions: communication with the slave module and the user interface, and control signal generation respective to the current state of the controller system and the constraints place by the feedback loop. The reception of information then triggers the ZigBee coordinator in the system that sends the information to the user interface. With regards to the monitoring and the user-controlled aspects of the system, the master controller 109 receives the information sent from the ZigBee coordinator. The master controller then processes the information and then sends it to the slave controller via the use of the coordinator to both update the slave controller and the user interface on the same clock signal.

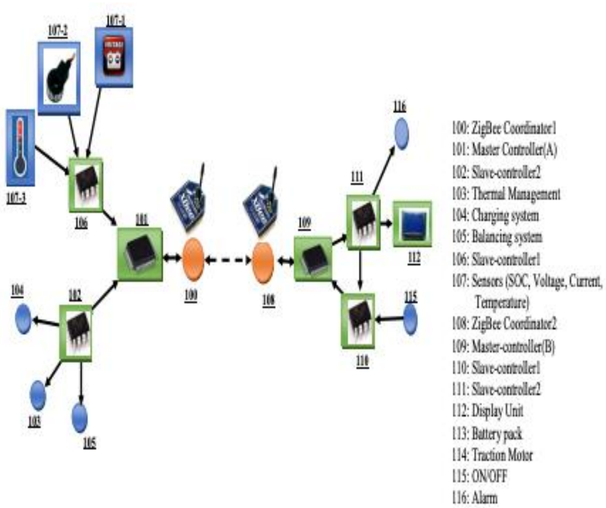


Figure 8: P2P Topology of a BMS Network

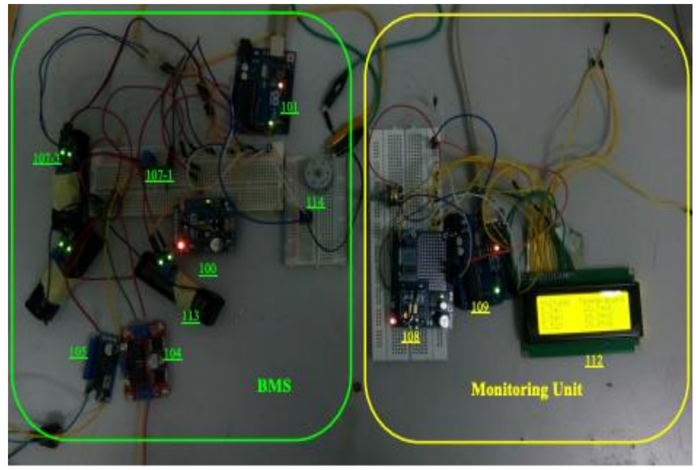


Figure 9: System Design of WBMS

RESULTS AND DISCUSSION

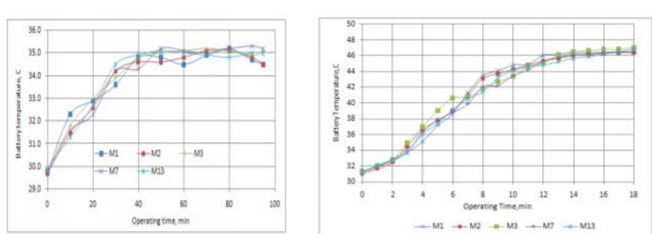
The wireless battery system (WBMS) that had been designed and implemented using an algorithm based on electro chemistry (using lithium iron phosphate ion cells) to maintain and sustain a more accurate state of charge and discharge of the individual Li ion cells. Using this method, the individual cells in conjunction with the battery pack configuration allows the maximum energy of the battery for a given drive cycle to be balanced within its optimal range of function. Moreover, the system designed can prevent overcharging or over-discharging the cells to avoid the cells from losing its overall capacity to charge and discharge repetitively (life of the battery). The battery in this system was made with 22 modules and each with nominal voltage of 7V with a capacity of 80 Ah. Based on the topology, the design structure shown in the figure earlier is representative of the functional design of the system.

The simulation results are carried by networks for serially connected battery cells. These configurations ensured that the connections and simulations were conducted both with and without the internal resistance of the cells. While evaluating and considering the time limits on each simulation, it was important to take into consideration that each individual cell was modelled with a 10F capacitor.

The values networks are 5uH of inductor and 10uF of capacitor.

Battery Temperature in these modules are based on the sensors that are used to measure the evaporative control battery management system during the discharging current for the 60-70A and 220-240 A by the utilization of two different modes (with and without the use of a BMS system). The positive trend in the pattern shown illustrates that the SOC were in the range of 83-84% which illustrates the uniform rate of discharge for the current and the temperature. The current and the temperature also uniformly increase which the negative module has gone below 70% of the state of charge value.

The energy efficiency of the thermal management system developed was compared to other EV using colling technology that utilized an air medium. For these thermal management systems, the fans for circulating air were operative throughout the duration of cells function. The results of the trend of operation for the thermal management system with respect to the BMS is indicated below showing an initial positive trend followed by a plateau with respect to the rising temperatures (in relation to the use of the battery pack). The correlations shown are both between the experimental values and the ideal, simulated values (accounting for the system constraints and patterns of behavior detailed earlier. The mean relative error of the experimental and predicted values from the model for the temperature profile of the system was found to be approximately 9%.



(a) Vehicle operating speed of 60 km/h (b) Vehicle operating speed of 120 km/h

Figure 10: Battery temperature of the electric vehicle with WBMS equipped EC-BThMS

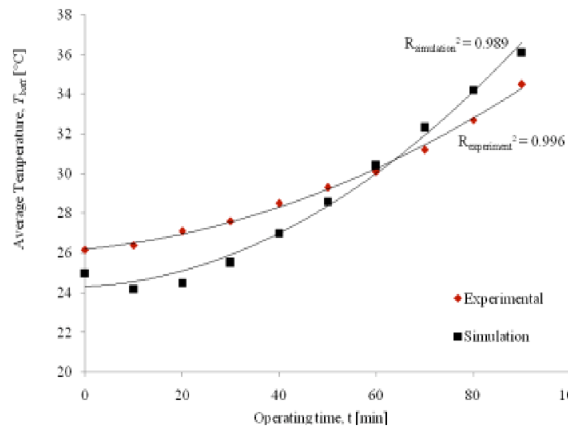


Figure 11: Temperature Validation in Simulation VS. Experimental

X. APROACH ON SMARTMESH NETWORKS

Smartmesh wireless sensor networking products are chips and pre-certified PCB modules complete with mesh networking software, enabling sensors to communicate in tough industrial internet of things (IoT) environments. Smartmesh products are field proven, with over 50,000 customer networks deployed in 120 countries. By delivering > 99.999% data reliability in tough rf environments, Smartmesh wireless sensor networks are entrusted by industrial IoT providers to deliver critical sensor and control data reliably for many years without requiring intervention [4].

Figure 12: SmartMesh IP Wireless Sensor Network

XI. CONCLUSION

In conclusion, this paper highlights the advancement in Battery management Systems (BMS), more so the impact of security on the wireless aspect of it. It analyzes the wireless aspect of a network setup. It also highlights how simplified modules are structurally arranged compared to a wired configuration. This writes up also addresses the security protocol, and how different modules communicate with the onboard Battery management System. In addition, this paper also lay emphasis on battery packs of electric vehicles with bundles of wires and connectors susceptible to failure, and in many cases hard to troubleshoot when problems arise. The essence of a battery network wireless system that can last the entirety of a car's life span with the need for a replacement unlike current use of batteries in cell phones.

The main point is that wireless security over Battery Management Systems can be encrypted just like is done with existing network communication systems or devices as we are already familiar with. The result is that, with key aspect of the system in place, communication could be without external interruption that could affect the overall system operation. As the industry gears towards renewal energy in a more cost-effective approach, wireless battery management systems become a new frontier in electric vehicle architecture.

ACKNOWLEDGMENTS

The authors would like to thank Prof. Gholam-Abbas Nazri, Professor of Electrical and Computer Engineering at Wayne State University for the support and guidance throughout the semester.

APPENDIX A

DEFINITIONS, ACRONYMS, ABBREVIATIONS

BMS	Battery Management System
SAE	Society of Automotive Engineers
IEEE	Institute of Electrical and Electronics Engineers
EV	Electrical Vehicle
SoC	System on a chip
CSU	Cell Supervisor Unit
OEM	Original Equipment Manufacturers
HEV	Hybrid Electrical Vehicle
WBMS	Wireless Battery Management System
LFP	Lithium Iron Phosphate
RF	Radio frequency
CAN	Controller Area Network

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