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Development of Integrated Monitoring System for Re-Electric Vehicle

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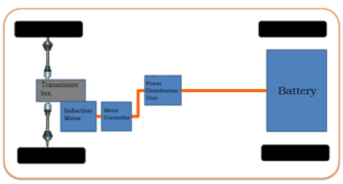
Graphical abstract



Abstract

Awareness of technological development of an electric vehicle (EV) has increased from year to year, particularly with commercialization of the electric vehicles in the consumer market. In contrast to the internal combustion engine (ICE) vehicles based on gasoline, electric vehicles rely on the batteries as the sole energy source. Although the electric vehicles have a relatively simple structure and their operations are more environmentally friendly, the battery energy capacity is limited, high in price and requires long charging time which as a result will limit the driving distance. Therefore, to tackle these issues a dedicated monitoring system for the battery is designed and developed. The developed integrated monitoring system consists of graphical display, measuring circuitries, speedometer, GPS, gyro and the controller module that monitors the batteries' status as well as other parameters that are important for the safe operation of electric vehicles. In addition the data was recorded during the driving for research purpose and future references, and the safety aspects are embedded in the controller module. The development of the system and its algorithm is described in this paper. The integrated monitoring system was tested in a real driving conditions to verify the functionality. The results show that the system is capable to measure and record all key parameter values, especially related to individual batteries along the journey. It also provides the user with a high degree of reliability through interactive and informative graphical display. As a conclusion, the use of the integrated monitoring system is not only able to ensure the efficient use of the battery and prolong its life span but also the safety aspect is considered in the design. For further system improvement, the battery characteristic, regenerative braking and traffic conditionswas incorporated into the algorithm.

Keywords: Electric Vehicle; Integrated Monitoring; Battery Monitoring; Driving Range

■1.0 INTRODUCTION

The interests on electric vehicle development have significantly increased in this decade. This is due to the awareness of the environmental issue such as zero emission and also due to the significant increasein oil prices. These factors boost the research and development of EV. Typically, there are three types of EV development known as commercial EV, commercial Hybrid EV and re-engineered or conversion EV.

As comparison to internal combustion engine (ICE) equipped vehicle, a fully electric vehicle is solely dependent on the batteries as a source of energy. Even though, there is a lot of improvement on battery technologies, the limitations in terms of storage capacity, size and weight, and also lifetime issues affect the performance and driving range of EVs [1]. For that reason, the battery monitoring system is important to monitor key parameters in real time to ensure efficient operation and prolong the battery lifetime [2, 3]. The reliability of monitoring system is affected by a number of factors such as road profile, traffic condition, battery characteristics and availability of charging stations [4]. The effective monitoring system often utilizes available modern technologies in term of power electronics devices, sensors and transducers, interface unit and also communication modules. The monitoring system for the driver can be integrated with an infotainment system for the passengers can also be implemented into a commercial EV.

The developed integrated monitoring system consists of graphical interface unit, measuring circuit for voltage, current and temperature, speedometer, GPS, gyro and the controller module. Its main function is to closely monitor the batteries status as well as other parameters that are important for the safe operation of electric vehicles. The monitoring system is fitted on the re-engineered vehicles and the actual test run are performedon F1 Sepang circuit to verify its functionality.

In this paper, the design and realization of multifunction and integrated monitoring system is explained. The remainder of this paper is structured as follows. Section 2 introduces the basic components of the EV. In Section 3, the development of a monitoring system is presented which covers controller unit, rules-based algorithm, charging module and cells balancing. Section 4, shows experimental results from test drives for the evaluation of the system proposed. Section 5 concludes the paper and suggests future works for improvement.

2.0 COMPONENTS OF THE DEVELOPED EV

This developed electric car consists of 13 units module of Lithium Ion Polymer (LiPo) battery with nominal voltage of 7.5V with total up of 97.5V when connected in series, an induction motor with 50hp rated power and is able to deliver 110Nm torque during its operation, a controller that converts DC voltage from the battery to 3-phase AC system to drive the induction motor, the throttle unit to input speed demand to the controller and a unit of 12V gel cell battery to power up all the relays and the vacuum pump. The relay unit provides safety features by enabling the low current side to switch on and off the high current side of the system. The vacuum pump is necessary to provide the adequate pressure to the braking system in order to stop the car when needed. The concept of the interconnection between the components in the electric car is shown in Figure 1 [5]. The EV working principle is shown in Figure 2.

The controller converts the battery DC power to 3-phase AC by utilizing Pulse Width Modulation (PWM) technique. The controller is connected to the induction motor using three high current cables and in order to achieve precision control, the rotor position of the motor is captured using two quadrature encoders for phase A and phase B mounted on the motor shaft.

The controller serves as the heart and brain of the electric car system which is connected to the LiPo battery pack through a series of safety devices as shown in Figure 3. The automotive grade fuse rated 400A with complete transparent cover is to confine the sparking in case the fuse blowsdue to over current. The high current relay provides the isolation switching to the low current side. The emergency push button is installed within the reach of the driver to allow the relay to be cut off at any necessary time. Since the controller has internal protection, soft start circuit to avoid or minimize high inrush current are not required. In addition, due to wiring requirement for the EV, the cable itself is automotive grade such that it would be able to withstand high temperature and high current up to 500A.

The controller converts the battery DC power to 3-phase AC by utilizing Pulse Width Modulation (PWM) technique. The controller is connected to the induction motor using three high current cables. In order to achieve precision control, the rotor position of the motor is captured using two quadrature encoders for phase A and phase B mounted on the motor shaft. Motor speed and direction that are simultaneously sensed by the quadrature encoder are the primary feedback signal used in the motor control algorithm. The controller drives the induction motor up to the demand speed based on the generated low voltage input created by pressing the foot throttle. The maximum throttle voltage and the throttle resistance must be compatible with the controller specification [6]. Typically, the maximum throttle voltage is 5VDC with a maximum resistance of 5kOhm.

The motor-transmission coupling required precision mechanical works, starting from the design process to the mating jobs. Since the ready-made coupling plate is not available on the market for this kind of donor car, the coupling plate is designed and fabricated from scratch. The coupling plate consists of two parts: adapter plate and shaft coupler. The chosen material is aluminium due to its lightweight nature and its ability to withstand high starting torque produced by the electric motor.

The shaft coupler is used to mount the clutch and flywheel to the shaft of the induction motor. The adapter plate will then house the motor to the transmission bell housing. One side of the adapter plate will follow the profile of transmission bell housing and the other side will follow the profile of the induction motor. The balancing and the alignment are an important factor thus it was done as accurately as possible to eliminate any wobble due to unbalanced forces during rotation.

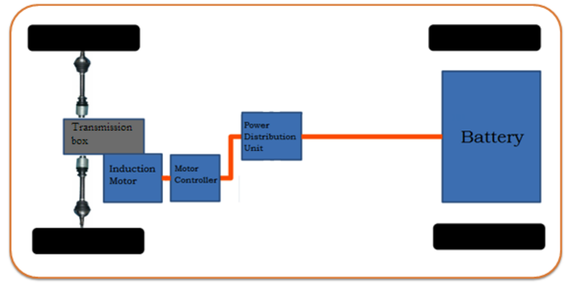


Figure 1 Components interconnection diagram

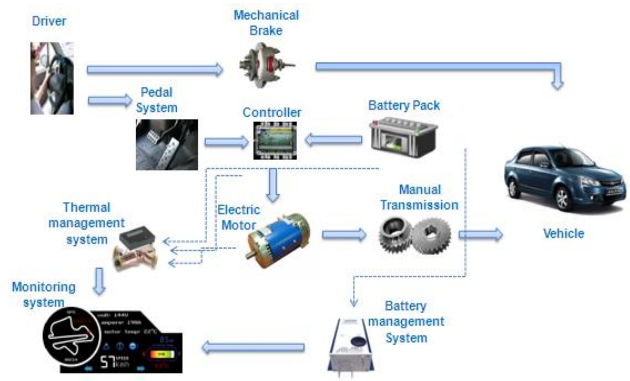


Figure 2 Electric car working principle

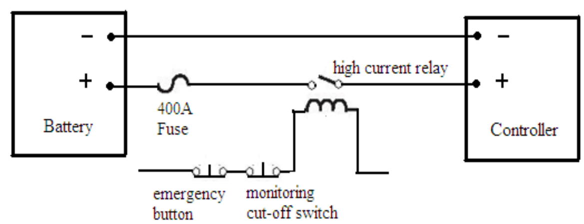


Figure 3 The controller to LiPo battery pack wiring diagram

3.0 MONITORING SYSTEM DEVELOPMENT

The integrated monitoring system consists of the monitoring centre unit closely linked together with battery management unit and all sensing units.

3.1 Monitoring Centre Unit

The purpose of the monitoring centre is to continuously monitor and capture the important data to be analysed later. The monitoring system is also used to assist the driver on the safety aspects and has the ability to cut off the main power supply in case of emergency. The concept of the monitoring system is shown in Figure 4.The monitoring system Graphical User Interface (GUI) displays all the necessary information in real time to the driver as in Figure 5. Any error that occurs will be illuminated to the driver with a pre-programmed suggested solution through rule-based algorithm. Some of the critical parameters that are closely monitored are DC current from the battery, battery voltage level, the temperature of the electric motor, individual battery voltage and the motor controller. This detail monitoring system is not necessary for common users but is significant for research and development of the electric vehicle. Furthermore, the nice looking GUI exhibits the future trend of the digital technology and marketing strategies.

3.1.1 Torque Estimation

The power consumption of EVattracts interestsof many researchers. Based on the current and voltage measurement on the controller side, the generated torque is estimated based on (1) and later used to calculate the power requirement [7]. The structure of the torque estimator is shown in Figure 6.

$$T_e = \frac{3}{2}P(\varphi_d I_q - \varphi_q I_d) \quad (1)$$

3.1.2 Communication

For simplicity, almost all the communications between monitoring centres and the components are done using RS232 serial protocol. The data logger is also utilized as a signal conditioning for an analog data obtained from sensors and converted to digital form before being processed and displayed. The XBee wireless module communication module is one additional feature that allows the technical team to monitor real time data of the EV from an acceptable distance.

3.1 Thermal Management

The thermal management is not discussed in this paper since the surrounding air is used and utilized as a cooling system.However the temperature status is one of the critical parameter in a rule-based algorithm. The battery temperature must be maintained below 40 degree Celsius for safe operation as stated by manufacturer.

3.1.4 Rule-Based Algorithm

The predetermined rule-based algorithm is applied in decision making, by referring to several key parameters such as temperature, voltage, current and power [8,9]. The example of the rule-based algorithm is shown in Table 1 (not in priority order). The monitoring system is always active.

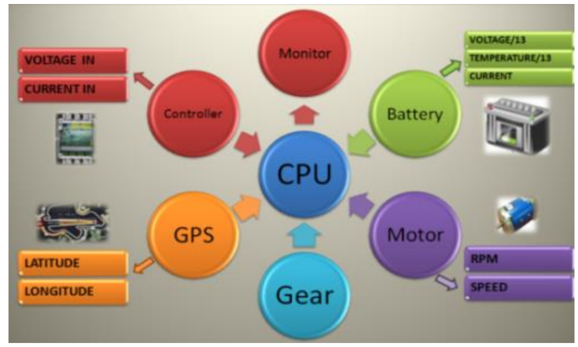


Figure 4 Monitoring system concepts

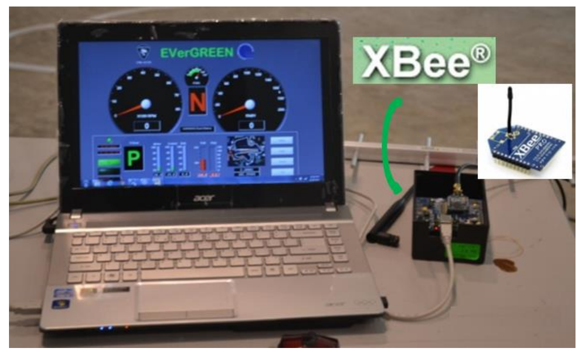


Figure 5 Monitoring center units with graphical display

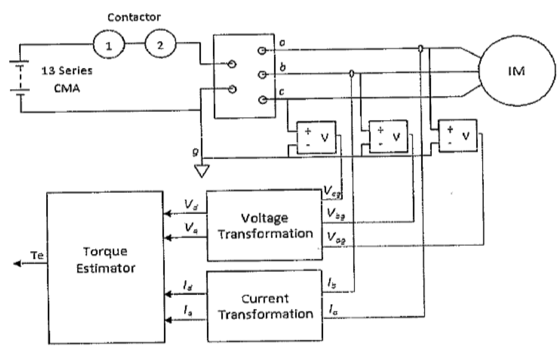


Figure 6 Torque estimator structure

Table 1 Example of Rule-Based Algorithm

Rules	Decision and Action
Controller's temperature near the limit	Turn ON fan to cool down the controller. Beep warns.
Controller's temperature over the limit	Temporarily turn OFF the controller. Required manual switch ON by the driver
Battery's temperature near the limit	Beep warns. Advise driver to drive at efficient speed and avoid acceleration in order to limit the current drain.
Battery's temperature over the limit	Cut-off supply from battery. Monitoring system still active. Required manual switch ON by the driver.
Current reach maximum level	Cut-off supply from battery in case of the 400A fuse is malfunction.
Battery overcharge	Stop charging in case of the battery management unit failed to maintain desired battery voltage
Battery voltage reach minimum level	Disconnect the power to avoid damaging the battery

3.2 Battery Management

The battery provides the energy required to drive the vehicles. Moreover, the battery efficiency will affect the distance range of the EV [10]. Therefore, the battery is the most important technology in an EV. The recent research trend is to minimize the physical size while increasing the storage capacity. The LiPo battery is one of the advanced batteries in battery technology. It has different discharge characteristic compared to lead acid battery.

3.2.1 Charging Module

A simple charging method is implemented to charge 13-units (or cells) of LiPo battery, which is connected in series. This configuration of cell batteries can provide higher current and desired DC voltage of 106.8 V. To ensure the reliability and balanced charging condition, the battery units are grouped into 5 modules, where each module (or set) contains 3 battery units. For a clearer picture, a set of series of 13 units of battery (or 5 modules) in the developed battery charging system is shown in Figure 7. Each module consists of an AC-DC rectifier, an isolated DC-DC converter with high frequency transformer, a low-cost PWM controller and a Charge Controller. It should be noted that the single-phase AC supply for each module is taken from the same power point, i.e. single AC source, 240V/13A.

The AC voltage is rectified by the single-phase rectifier to produce an approximate average DC voltage of 339.4 V. The average DC voltage is then stepped down to 30V using the isolated DC-DC converter, which can provide safety galvanic isolation between the AC supply and the batteries. The Charge Controller is responsible to control the state of charging by supplying the appropriate voltage or/and current depending on the charging characteristic of the batteries. Another advantage offered in the proposed battery charging system is the charging mechanism which allows all batteries to be charged without disconnecting the series connection of the batteries [11].

The motor-transmission coupling required precision mechanical works.Starting from scratch the design process up to the mating jobs, special attentions were accorded to this component.This has to be done as the ready-made coupling plate is not available on the market for this kind of the donor car. The coupling plate consists of two parts: adapter plate and shaft coupler. The chosen material is aluminium due to the lightweight nature of the material and its ability to withstand high starting torque produced by electric motors.

3.2.2 Charging Controller

In this project Infineon XC866 microcontroller as shown in Figure 8 is used to control the charging process. The charging process involves three stages namely pre-charging, constant-current-charging and constant-voltage-charging as illustrated in Figure 9. In the first stage 13 numbers of battery units are charged in series in constant current mode. After a certain level of total voltage, the second stage takes over by charging the module in smaller groups using constant voltage until 100% state of charge (SOC) is reached. This technique ensures that the minimal unbalanced charge between each module can be achieved. On top of that, for safety reason, the temperature andvoltage level of each individual module is measured at every instant. During discharging, the battery line will be cutoff if the voltage level is below the pre-set discharge cut-off voltage as suggested by the manufacturer.

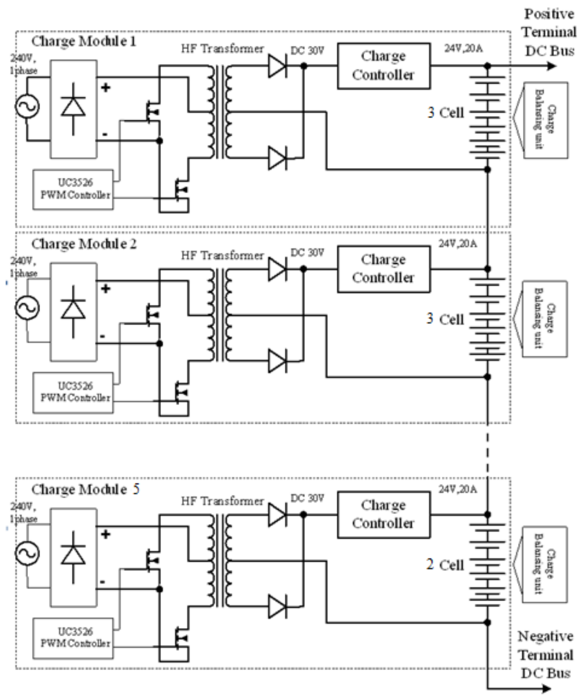


Figure 7A set of series of 13 cells in the proposed battery charging system

3.2.3 Battery Cell Balancing

The conventional battery balancing unit is normally used to have a similar percentage of charging condition for each cell battery. A major drawback of the conventional battery balancing unit is that the high energy wasted when the power is dissipated in the resistor during the discharging operation of the overcharged battery. For example, if the cell is overcharged, the switching devices will turn ON to discharge the battery which consequently causes energy losses in the resistor R1.

The developed battery balancing unit that could avoid the energy loss is implemented in this project. The principal operation of the charge balancing unit is based on the operations of buck-boost converter. In the proposed method, if one of the two adjacent cells is overcharged, its energy will be transferred to the other cell. It is therefore, the two adjacent cells can have a similar percentage of charging [12]. The switching pattern of the switches is fixed, where the duty cycle of gate pulses to drive all switches are set to 50%.

3.2.4 Discharging

For the safe operation during discharge mode, the monitoring system is constantly monitoring both the voltage and current level of the DC line. In case of overcurrent bigger than 400A, the monitoring system will cutoff the supply voltage through a high current relay. This cutoff mechanism is similar when the line voltages are lower than a pre-determined cutoff level. That operation voltage range must be followed to avoid any problem related to the safety and the battery life cycle. Since the current level is considered high during the driving mode, the air gap between modules must be established during battery assembly to allow for air flow path to cool down the batteries.

4.0 RESULTS AND DISCUSSION

The actual test drive is performed to verify the functionality of the developed integrated monitoring system. Figure 10 shows the actual display ofthe monitoring system that allows voltage levels and temperatures of each cell to be closely monitored. With the aid of GPS technology, the journey profile or road elevation as in Figure 11 can be recorded during the trial-run and the data could laterbe analysed for improvement in term of technicalities and strategies.

A sample of data gathered in this test is shown in Figure 12 and Figure 13. It can be seen that the temperature of the battery, the controller and the electric motor are below 40 degrees Celsius through an effective thermal management strategy integrated into the rules-based algorithm. It is interesting to see that in Figure 12, the re-engineered EV is able to reach above and near 100kph in 25 seconds even though the maximum current drawn is limited to 200A.

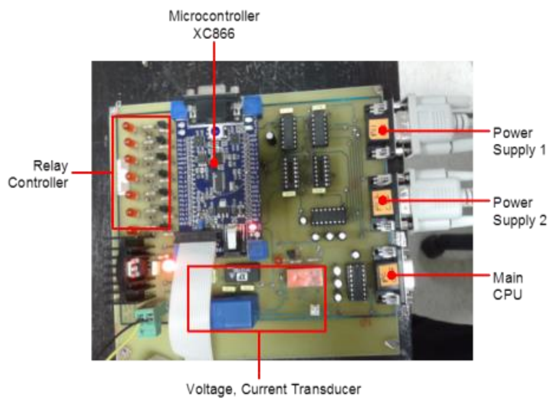


Figure 8 Infineon XC866 microcontroller based charging circuit

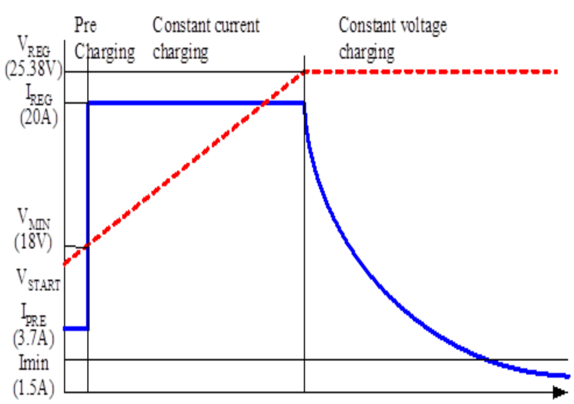


Figure 9 Charging voltage and current characteristics of LiPo battery

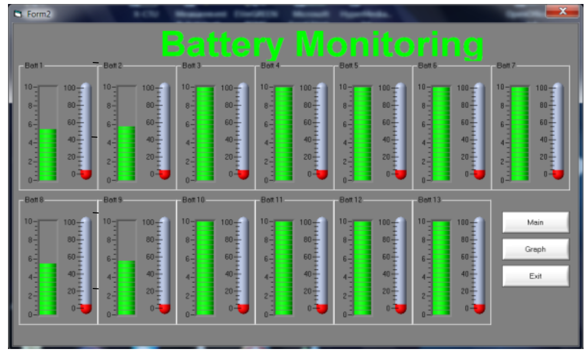


Figure 10 Individual cell voltage levels in monitoring display

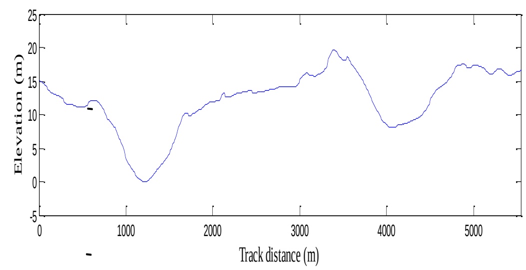


Figure 11 Journey profile for the test drive

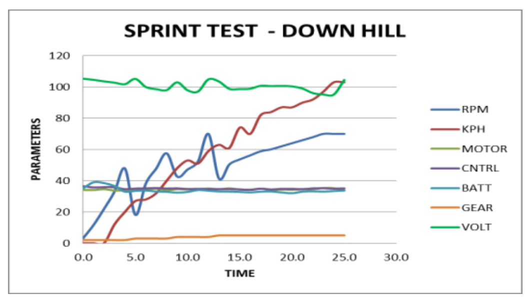


Figure 12 Recorded vehicle performances in monitoring display – downhill

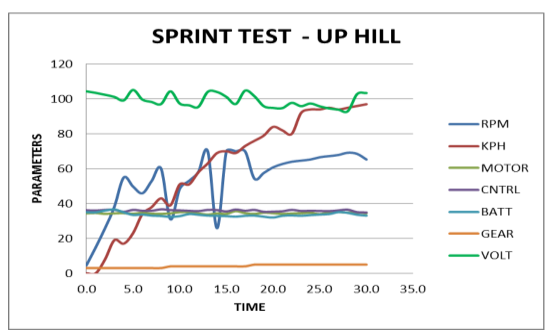


Figure 13 Recorded vehicle performances in monitoring display-uphill

■5.0 CONCLUSION

The design and construction of an integrated monitoring system with the battery management unit is presented. The various key parameters from different circuitry can be measured, integrated and utilized in the decision making process through rule-based algorithm. The rule-based algorithm itself is flexible enough for future modifications and improvements. Because each battery is monitored, it is possible determine a problem cell without the necessity of changing all cells, thus reducing cost of both parts and labor. During the test drive, a lot of information about functions and problems are gathered. These problems were studied, analysed and eliminated in the latest version of the monitoring system. The research on developing robust and marketable monitoring systems for EV is progressing. For further improvement, the battery characteristic, regenerative braking and traffic condition will be incorporated into future algorithm.

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