# Monitoring, Control and Energy Management for In-Wheel Motor Hybrid Electric Vehicle

By

Mohammad Firdaus Hadzwan Bin Mohd Noor Beg

A project dissertation submitted to the

Electrical and Electronics Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfillment of the requirement for the

Bachelor of Engineering (Hons)

(Electrical and Electronics Engineering)

May 2011

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

# CERTIFICATION OF APPROVAL

**Monitoring, Control and Energy Management for In-Wheel Motor Hybrid Electric Vehicle**

By

Mohammad Firdaus Hadzwan Bin Mohd Noor Beg

A project dissertation submitted to the

Electrical and Electronics Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfillment of the requirement for the

Bachelor of Engineering (Hons)

(Electrical and Electronics Engineering)

Approved by:

(Mr. Saiful Azrin Bin Mohd Zulkifli)

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2011

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in references and acknowledgements and that the original works contained herein have not been undertaken or done by unspecified sources or person.

(Mohammad Firdaus Hadzwan Bin Mohd Noor Beg)

# ABSTRACT

Hybrid technology has become one of the new technologies to support existing energy supply. In automotive industry, hybrid vehicle is created to support the fuel combustion engine with less fuel consumption. Thus, electric now has become one of the major power supplies to move the vehicle. The purpose of this project is to develop the simplest possible of energy management system inside the hybrid vehicle to make it easy to monitor it. The energy management system consist of battery monitoring system that monitor the voltage, temperature, and the state of charge (SOC) of the battery by using battery monitoring system – PakTrakr. If there is any alerts occurs during driving the vehicle, PakTrakr will inform the user about the alert and actions should be taken by the driver. By programming using LabVIEW software and implementing in NI CompactRIO hardware, the system can become more simple and user friendly. However, due to a lot of problems occurs during the experimentation of the project and time constrain only some of parts of the system has been successfully implemented such as running the brushless DC (BLDC) motor with battery monitoring by PakTrakr. In addition, integration of the battery monitoring system to the overall energy management system is still ongoing.

# ACKNOWLEDGEMENTS

Alhamdulillah, thanks to Allah S.W.T the most merciful and the most compassionate for the guidance and knowledge bestowed upon me, for without it I would not have been able to come this far. Peace is upon him, Muhammad the messenger of god.

I would like to express my gratitude and thanks to my supervising lecturer, Mr. Saiful Azrin Bin Mohd Zulkifli, for his encouragement, endurance and patient guidance during the course of this project. His advices have guided and helped me though various obstacles and difficulties.

I would also like to express my heartfelt appreciation to all individuals who have directly or indirectly offered help, support and suggestions, contributing towards the successful completion of this project.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| HEV | Hybrid Electric Vehicle |
| ICE | Internal Combustion Engine |
| DC | Direct Current |
| BMS | Battery Management System |
| SOC | State of Charge |
| SOH | State of Health |
| EV | Electric Vehicle |
| DOD | Date of Discharge |
| CAN | Controller Area Network |
| BCU | Battery Control Unit |
| UTP | Universiti Teknologi PETRONAS |
| BLDC | Brushless Direct Current |
| NI | National Instruments |
| MOSFET | Metal Oxide Semiconductor Field Effect Transistor |
| PWM | Pulse Width Modulation |
| USB | Universal Serial Bus |
| AC | Alternating Current |
| LCD | Liquid Crystal Display |
| PC | Personal Computer |
| CSV | Comma-separated values |
| ECU | Engine Control Unit |

# CHAPTER 1
# INTRODUCTION

## 1.1 Background of Study

A hybrid vehicle is a vehicle that uses two or more distinct power sources to move the vehicle [2]. Hybrid vehicles offer the best fuel economy of any car on the market by combining an efficient gasoline engine with an electric motor and batteries that are constantly recharged [1]. The vehicle is driven by a combustion engine with the assistance of an electric drive between the engine and the transmission. A battery is able to store energy during deceleration and to spend energy to the electric drive during acceleration. In a Hybrid Electric Vehicle (HEV) parallel drive train basic concept, a fuel tank will supplies gasoline to the engine and a set of batteries will supplies power to the electric motor. Both the engine and the electric motor can turn the transmission at the same time, and the transmission then turns the wheels [6]. The fuel tank and gas engine connect to the transmission. The batteries and electric motor also connect to the transmission separately. As a result, in a parallel hybrid, both the electric motor and the gas engine can provide propulsion power.

## 1.2 Problem Statement

In this world, there are two types of hybrid vehicle which is the parallel and series type. For the parallel type of drive train, the electric motor is connected in parallel together with the Internal Combustion Engine (ICE) on the transmission of the vehicle. However, this system is difficult to install on an ordinary car for conversion into hybrid car. So, a study must be carried to implement a split parallel type hybrid electric vehicle by replacing the rear wheels with in-wheel electric motors to make it easy to convert an ordinary car into a split parallel type hybrid electric vehicle (HEV).

## 1.3 Objective

The main objective of this project is to implement a monitoring, control and energy management system for a hybrid electric vehicle with in-wheel motors

## 1.4 Scope of Study

The scopes of study in this project are:

1) Understand on how to monitor, control and perform energy management on the system of the Brushless DC Motor.

2) Installing the hardware and setting up the connection for both hardware and software between the brushless dc motor, the controller unit and the user interface.

3) Performing field experimentation, testing and analysis the characteristics of the Brushless DC Motor.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Hybrid Electric Vehicle

There are many types of power train that are widely used for the hybrid vehicle. One type is the parallel hybrid drive train. In a parallel hybrid drive train the single electric motor and the internal combustion engine are installed so that they can either individually or together power up the vehicle. In contrast to the power split configuration typically only one electric motor is installed [4]. Usually the internal combustion engine, the electric motor and gear box are coupled by automatically controlled clutches. For electric driving the clutch between the internal combustion engine is open while the clutch to the gear box is engaged [4]. While in the combustion mode the engine and the motor run at the same speed. Parallel drive trains are mechanically more complicated than series drive trains. For one thing, a transmission is required to allow the engine to drive the wheels. Then there must be a means of coupling the engine, motor, and transmission. Finally, the controller necessary to make all these components work together is more complex than in the series drive train.

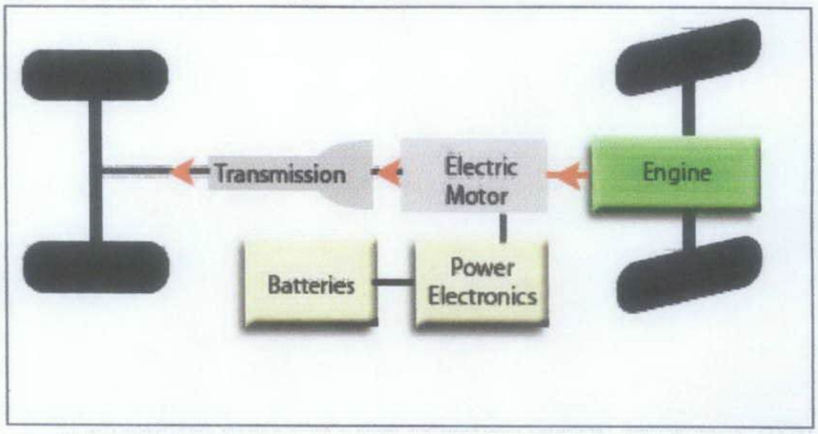



Figure 1 : Parallel Hybrid Electric Vehicle Drive Train

In a series hybrid electric vehicle, an electric motor is the only means of driving the wheels [3]. The motor obtains electricity either from a battery pack or from a generator powered by an engine in much the same way as a portable generator [3]. A controller determines how power is shared between the battery and the engine or generator set.

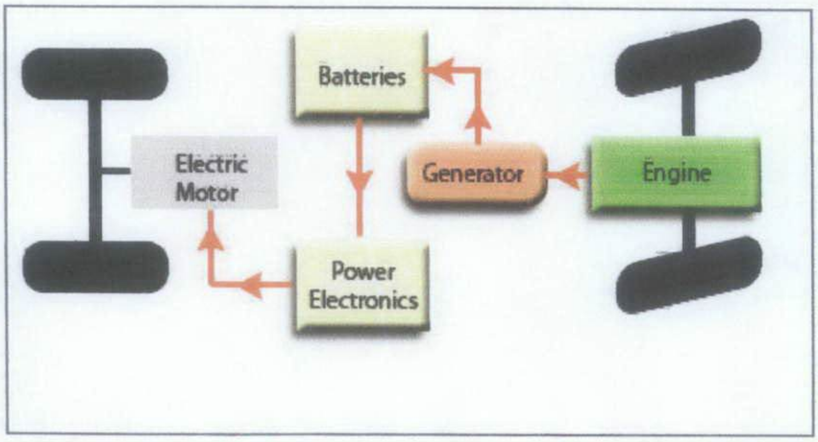



Figure 2 : Series Hybrid Electric Vehicle Drive Train

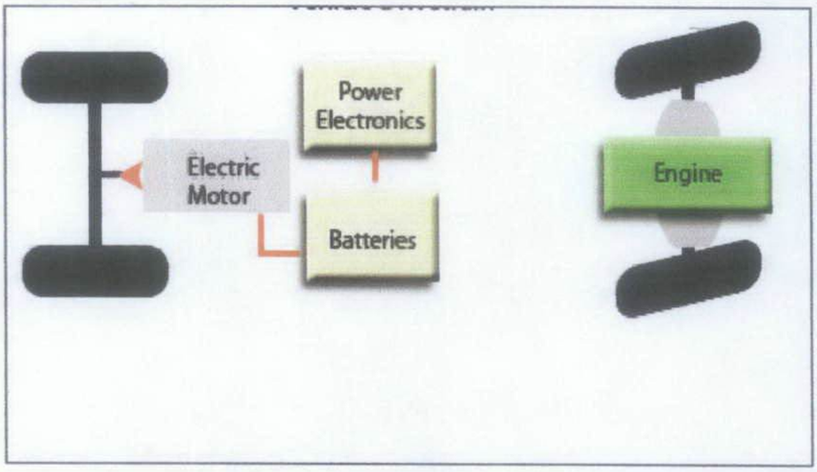



Figure 3 : Split-Parallel Hybrid Electric Vehicle Drive Train

## 2.2 Energy Management System in Hybrid Electric Vehicle

Energy management of the system depends on the objectives of the design process. A vehicle can be designed to either optimize the speed, efficiency or comfort. The drive train configuration, the specifications and characteristic of the components play another role in the energy management. Goals, component specifications and configuration determine the energy management. [10]

The energy management depends on the driver, as it was the case many years ago or it can be implemented to higher levels like in some modern cars. However, the driver is a part of the system in every case and takes over some management work. Hence, the interface between vehicle, implemented management and driver needs to be specified. [10] The goals are to reduce environmental impacts while maintaining the requirements for individual mobility such as range, acceleration and speed.

## 2.3 Battery Management System (BMS)

Battery Management System is a component of a much more complex fast acting Energy Management System and must interface with other on board systems such as engine management, climate controls, communications and safety systems.

### *2.3.1 Automotive BMS*

Automotive battery management has to interface with a number of other on board systems, it has to work in real time in rapidly changing charging and discharging conditions as the vehicle accelerates and brakes also it has to work in a harsh and uncontrolled environment.

The functions of a BMS suitable for a hybrid electric vehicle are as follows:

1. Monitoring the conditions of individual cells which make up the battery
2. Maintaining all the cells within their operating limits
3. Isolating the battery in cases of emergency
4. Providing information on the State of Charge (SOC) of the battery. This function is often referred to as the "Fuel Gauge" or "Gas Gauge "
5. Providing information for driver displays and alarms
6. Responding to changes in the vehicle operating mode

In practical systems the BMS can thus incorporate more vehicle functions than simply managing the battery. It can determine the vehicle's desired operating mode, whether it is accelerating, braking, idling or stopping, and implement the corresponding electrical power management actions.

### *2.3.2 Cell Protection*

One of the prime functions of the Battery Management System is to provide the necessary monitoring and controlling so as to protect the cells from out of tolerance ambient or operating conditions. This is of particular importance in automotive applications because of the harsh working environment. In addition to individual cell protection, the automotive system must be designed to respond to external fault conditions by isolating the battery. This is to address the cause of the fault.

### *2.3.3 Battery State of Charge*

Determining the State of Charge (SOC) of the battery is the second major function of the BMS. The SOC is needed not just for providing the Fuel Gauge indication. The BMS monitors and calculates the SOC of each individual cell in the battery to check for uniform charge in all of the cells in order to verify that individual cells do not become overstressed.

The SOC indication is also used to determine the end of the charging and discharging cycles. Over-charging and over-discharging are two of the prime causes of battery failure and the BMS must maintain the cells within the desired date of discharge (DOD) operating limits.[9]

Hybrid vehicle batteries require both high power charge capabilities for regenerative braking and high power discharge capabilities for launch assist or boost. For this reason, their batteries must be maintained at a SOC that can discharge the required power but still have enough headroom to accept the necessary regenerative power without risking overcharging the cells. To fully charge the HEV battery for cell balancing would diminish charge acceptance capability for regenerative braking and hence braking efficiency. The lower limit is set to optimize fuel economy and also to prevent over discharge which could shorten the life of the battery. Accurate SOC information is therefore needed for HEVs to keep the battery operating within the required, safe limits.[9]

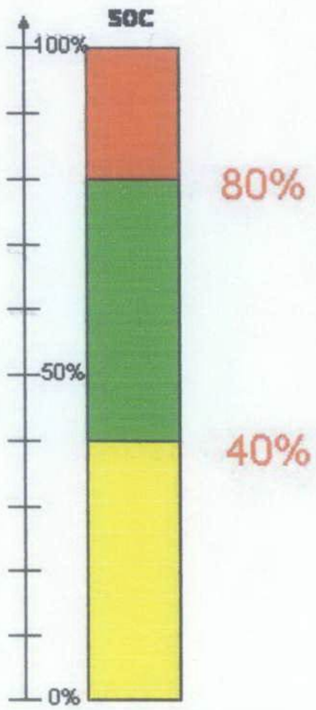


Figure 4 : HEV Battery Operating Range

Figure 4 above show the level of the operating range of any HEV battery. The green area is the working range of the battery. The red area is the headroom for regeneration charge in case of battery overcharge. And for the yellow area is where the battery is on weak level. If the battery continuously working on this range, it may harm the battery and shorten its life.

### *2.3.4 The Battery Management System*

The diagram below is a conceptual representation of the primary BMS functions. It shows the three main BMS building blocks, the Battery Monitoring Unit (BMU), the Battery Control Unit (BCU) and the CAN bus vehicle communications network and how they interface with the rest of the vehicle energy management systems. Other configurations are possible with distributed BMS embedded in the battery cell to cell interconnections.[9]

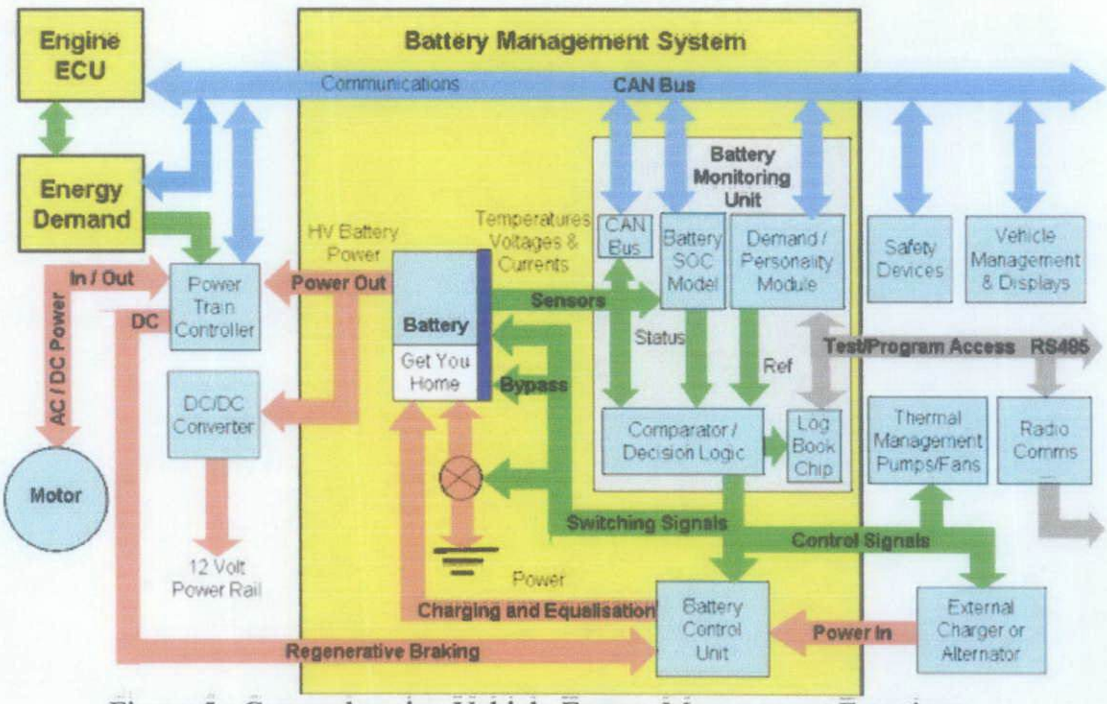



Figure 5 : Comprehensive Vehicle Energy Management Functions

For this project, author looking forward on how much from this comprehensive EMS can be implemented in the project.

## 2.4 PakTrakr Battery Monitor

PakTrakr is a device to monitor the uses of the battery. Unlike simple pack meters, PakTrakr monitors every battery, automatically, all the time, to detect common battery problems before they become pack problems. And with early detection, most battery issues are easily remedied. Figures below show on how is the PakTrakr look alike.

### *2.4.1 PakTrakr LCD Display*

PakTrakr 2-line LCD Display is the main of the system. It display all the data from the remote signal to make use by the user.

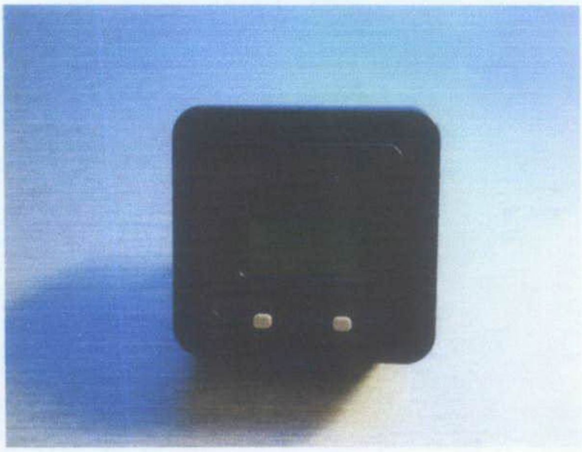


Figure 6 : PakTrakr LCD Display

### *2.4.2 PakTrakr 6-Battery Remote*

Monitor 6 additional lead-acid batteries by adding this 6-battery Remote to the PakTrakr System. Use up to 6 Remotes per system, to monitor up to 36 batteries. PakTrakr remote convert analog output from the battery and convert it to digital signal before send to LCD Display.

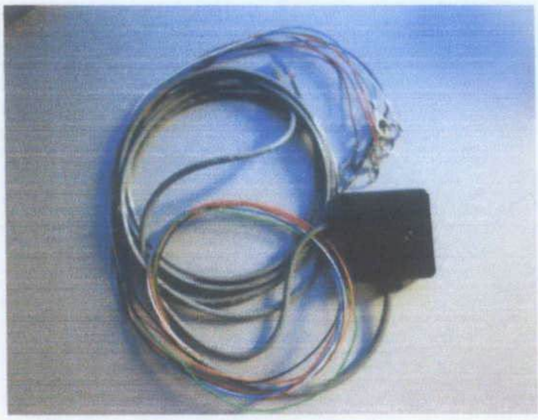


Figure 7 : PakTrakr 6-Battery Remote

### *2.4.3 PakTrakr ES1 Serial Interface*

Monitor and capture data to a PC with this serial interface. ES1 Serial Interface needs to be connected with RS232 cable to connect with the PC. All the data can be read at the PC using Hyper Terminal.

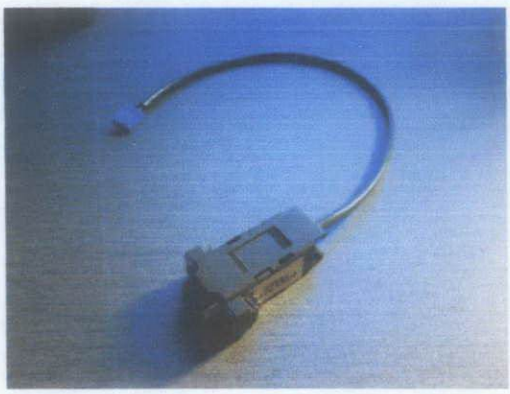


Figure 8 : PakTrakr ES1 Serial Interface

### *2.4.4 PakTrakr Current Sensor*

PakTrakr current sensor is a Hall-effect current sensor. Unlike a shunt resistor system, the PakTrakr current sensor is completely isolated from the pack, wastes no energy, and may be installed anywhere in the pack.

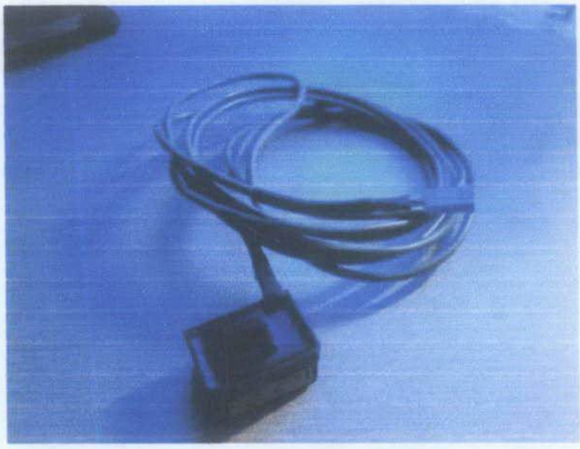


Figure 9 : PakTrakr Current Sensor

### *2.4.5 Copper Bus Bar for Current Sensor*

Solid copper bus bar (.5" x .25" x 3.5" with 5/16" holes) fits through PakTrakr current sensor to make connection of large cables simple and easy. Connect one end to battery terminal, slide the sensor over the bus bar, and connect battery cable to other end.

Figure 10 : Copper Bus Bar for Current Sensor

The PakTrakr package monitors 6 batteries. Four additional 6-battery Remotes may be connected, to monitor up to 30 total batteries. Using 8-battery Remotes, up to 40 (3.2V, 6V, or 8V) batteries may be monitored. The PakTrakr sends out a CSV data stream every second, containing all the battery data. By attaching a PC to the PakTrakr via the optional serial interface, the data may be easily read into a spreadsheet for analysis [8].

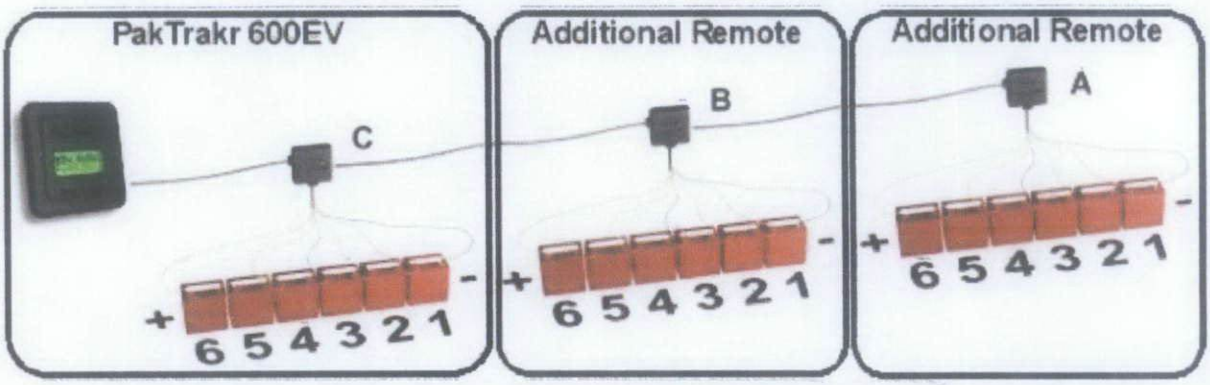
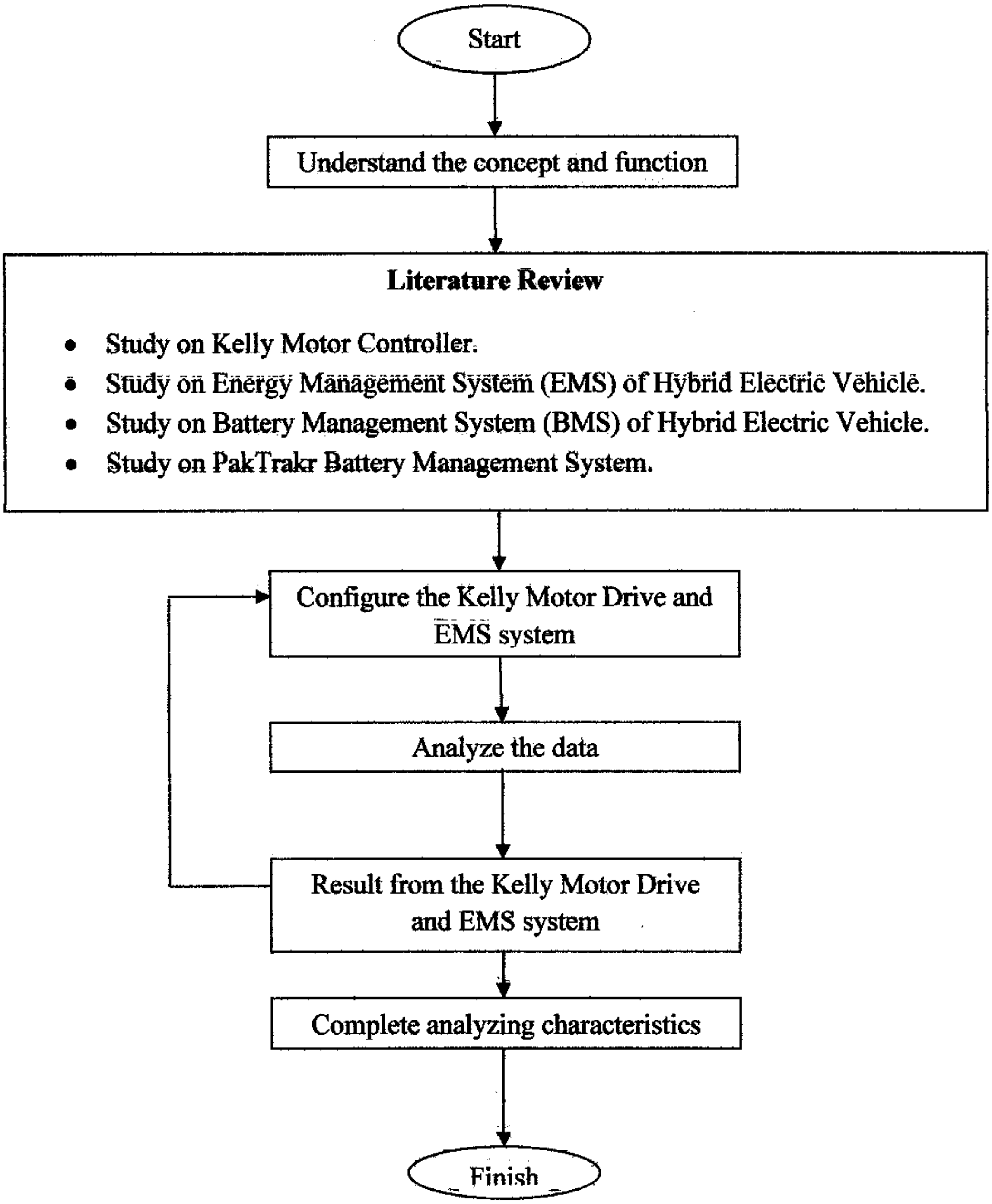



Figure 11 : PakTrakr connection with 3 Remotes

# CHAPTER 3

# METHODOLOGY

## 3.1 Procedure Identification



## 3.2 Method of Research and Investigation

In order to achieve the objectives of the project, research and investigation will be done on the configuration instrumentation for the electrical control and energy management system of the hybrid vehicle, where the main control system is implemented on *National Instruments' Compact RIO* hardware and *LabVIEW* software platform. From the analysis on *National Instruments' Compact RIO* hardware, the energy management can be set up on the user interface and the system will be tested. In order to implement the in-wheel motor to the rear wheel of the car, some modification on the car and the motor itself must be done to make sure it suit together.

## 3.3 Tools and Equipments

Below are the expected tools and equipments needed for completion of the project. These equipments are obtainable at UTP. The software required is also available. The equipments are:

1. 3-phase brushless motor (BLDC) – prototype
2. *Kelly* motor drive
3. LabVIEW 8.5 Software
4. NI Compact RIO (external energy management controller)
5. Oscilloscope
6. Function Generator
7. PakTrakr - Intelligent Battery Monitoring Systems
8. Electrocraft motor drive

# CHAPTER 4
# RESULTS AND DICUSSIONS

## 4.1 Analysation and Characteristic Familiarisation

In order to fully understand and familiarise with all the tools and equipments use in this project, author have done some study on the tools and equipments regarding the circuit diagram, simulation and also how the system works. This is some of the tools and equipment that have been covered by the author. Author also has proposed a concept design in block diagram of connection inside the Hybrid Electric Vehicle (HEV).

## 4.2 Kelly Motor Controller

Kelly's programmable KEB motor controllers provide efficient, smooth and quite controls for electric bicycle, electric motorcycle, scooter, etc. It outputs high taking off current, and strictly limit battery current. It can work with relative small battery, but provide good acceleration and hill climbing. It uses high power MOSFET, PWM to achieve efficiency 99%.

In most cases, Powerful microprocessor brings in comprehensive and precise control to the controllers. It also allows users to set parameters, conduct tests, and obtain diagnostic information quickly and easily. For this project, the model of the Kelly Controller used is KEB72810. Figure 12 below show the controller and its components look alike.


Figure 12: Kelly Motor Controller (taken from www.newkellycontroller.com)

### 4.3 Hardware Connection by using Kelly Controller

Figure 13 below show the hardware connection by using Kelly Controller Integrated MOSFET motor drive. For this speed control, this program will be implemented by using a throttle speed. The speed will be control by the user at the Speed Control Panel. The Kelly controller inside itself has 6 transistor switches and will be combine and be control by the Pulse Width Modulation (PWM) by varying the duty cycle to control the speed. The 3 Hall Sensors will give information about the actual speed run by the motor and to be comparing with the speed needed by the user. The speed controller, Kelly Controller will controls the speed of the motor by either increasing or decreasing the applied voltage to the motor depend on the comparison between the actual and needed speed by the user.

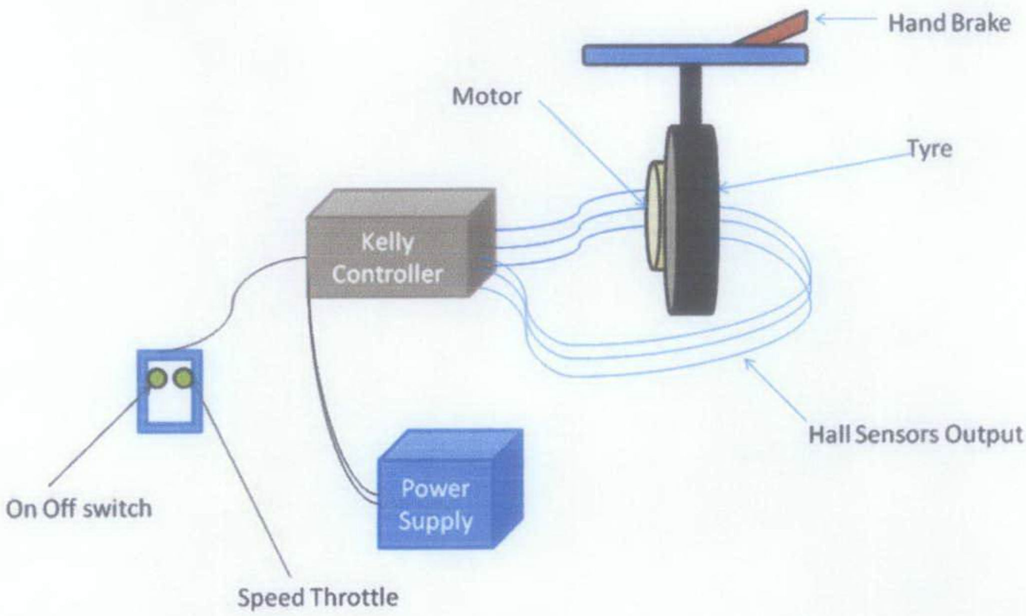



Figure 13 : Hardware Connection by using Kelly Controller

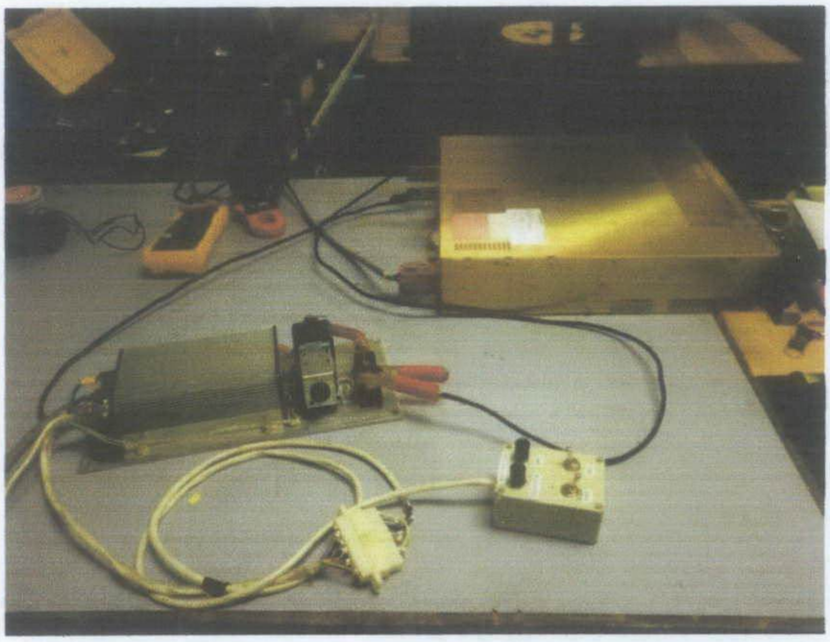


Figure 14 : Connection of Kelly Controller

From the Figure 14 above, it show the connection of the Kelly Controller with the DC Power Supply. The positive terminal from the DC Power Supply need to be connect to the positive terminal of Kelly Controller as shown in Figure 15.

For negative DC Supply, it is connected at the back of the Kelly Controller at the negative terminal as shown in Figure 16. For the external controller, there are 2 knobs (Speed and Brake) and two switches (On/Off and Reverse) that connected to the Kelly Controller.

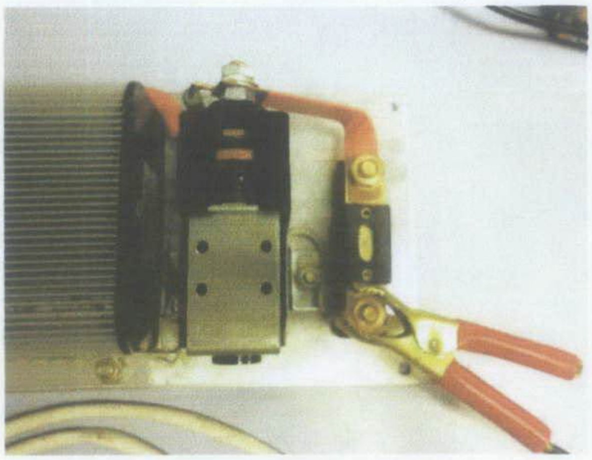


Figure 15 : Connection from power supply to Kelly Controller

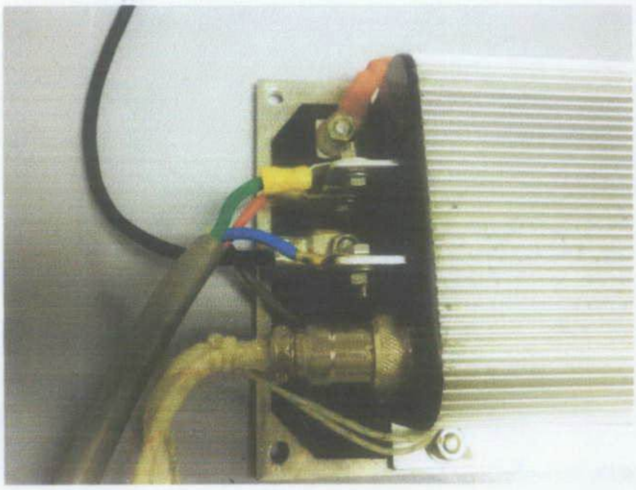


Figure 16 : Connection from Kelly Controller to the BLDC Motor

The Kelly Controller is connected to the computer by using USB to RS232 cable, as in Figure 17. The Kelly Controller need to be configured first before it starts working. It has its own software need to be installing in the computer. By using the Kelly configuration software, there are a lot of elements need to be check and confirmed. The main element need to be check is the hall sensor's degree either 120° or 60°. The setting need to be used is 120° since the hall sensor placed in the motor is 120° apart. Since we were not using battery as the power supply, another element that needs to be changed is to disable the regenerative function because the power doesn't need to be supply back to the power source that is DC power supply.

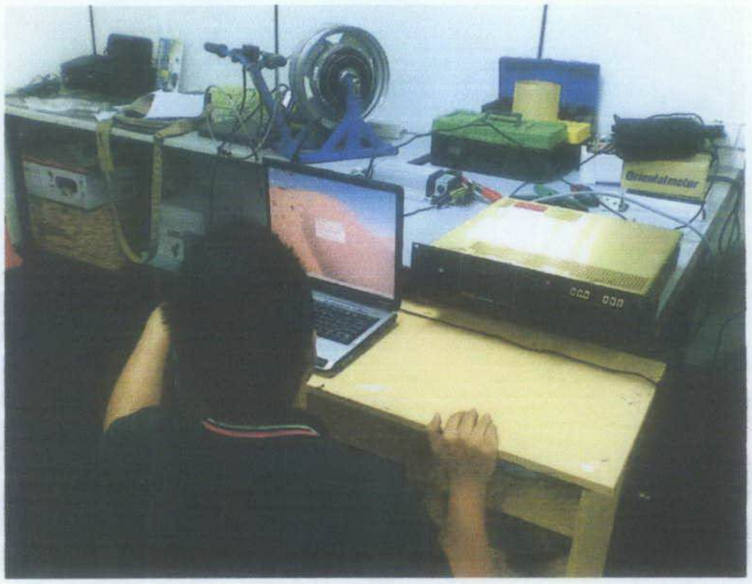


Figure 12 : Kelly configuration by using laptop

Figure 13 : SORENSEN DCS60-50E Power Supply

The SORENSEN DCS60-50 Power supply is capable to supply the voltage until 60V. For the test, DC Supply is set to be 48V (Figure 18). It is to make it the same as 4 car batteries which usually 12V each and connect it in series to get 48V. The current at the meter will start increase when the motor start to move.

A 3 phase BLDC motor (Figure 19) is then connected with the Kelly Controller. There is also a brake attached together at the handle of the motor. The brake acts as the medium to supply the load and can be use as the load to test the current characteristic of the motor. In addition, handle also included with the throttle that can also control the speed of the motor. But for this test, this throttle not connected as the user input to control the speed since an external input controller has been set up.

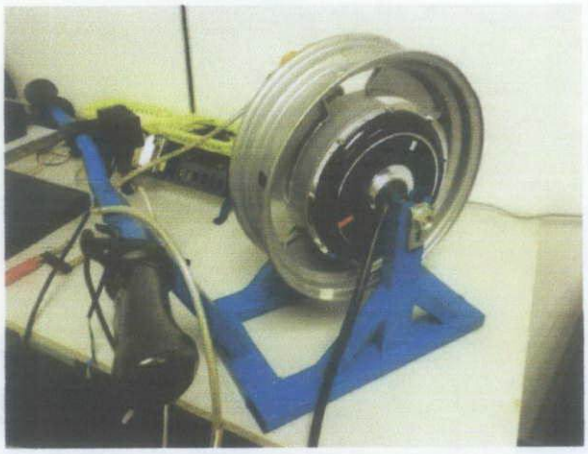


Figure 14 : 3 Phase BLDC Motor

For this project, a 4-channel oscilloscope (Figure 20) is used in order to capture the data and graph of the current and voltage. An AC/DC Current Clamp (Figure 21) is clamped to measure the current value of the supplied and each phase current.

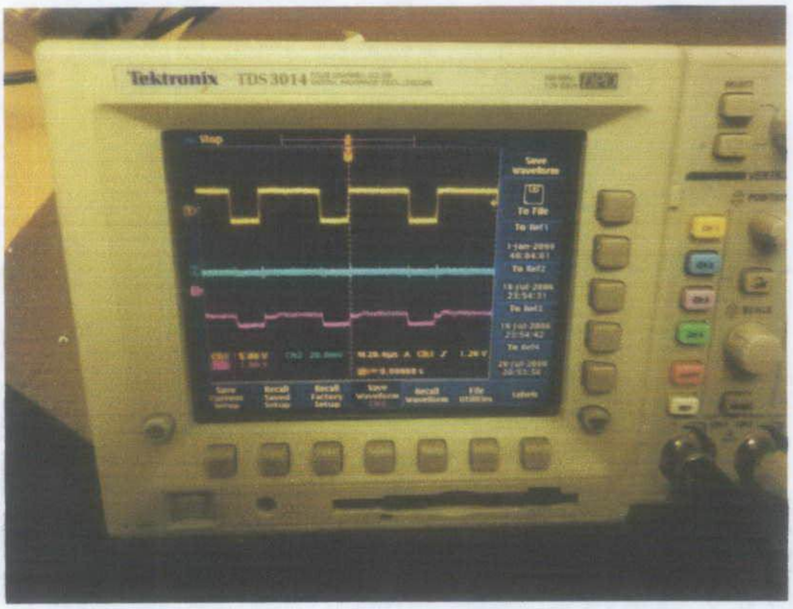



Figure 20 : 4-Channel Oscilloscope

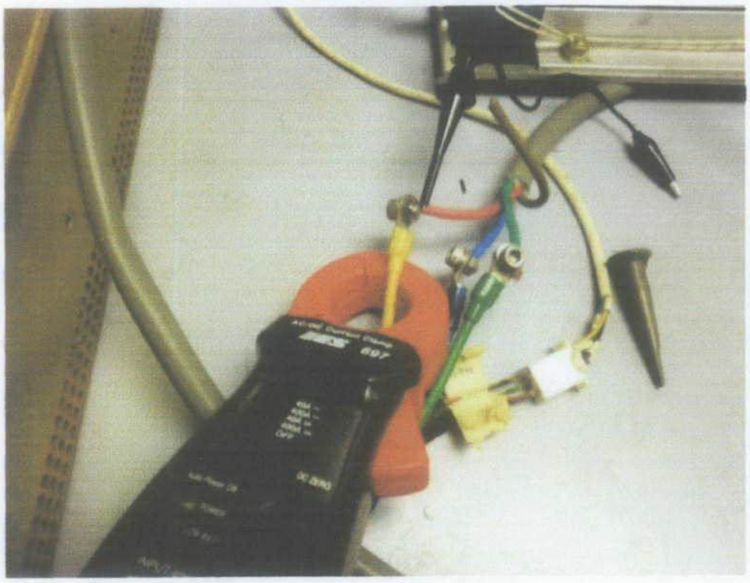


Figure 21 : AC/DC Current Clamp

By using the oscilloscope, a clear interpretation can be achieved. While increasing the throttle knob, mean increase the speed of the motor, the oscilloscope shows that the throttle acts as the switch that controls the PWM Duty Cycle. As increasing the throttle knob, the voltage supply to the motor for each phase also increase accordingly and also increasing duty cycle of the PWM in the Kelly Controller.

## 4.4 No load Test

A no load test has been done to study on the characteristic of the motor, the voltage and the current supplied. The DC Voltage supply is set to be 48V and turns the current knob limit into 50%. While a tachometer will capture the speed for each time the current level increases. An average speed of the motor running without load as stated in the Table 1 below. The throttle knob is turned until the current supply to the Kelly Controller reached 0.5A for each level. The test starts from data of 0A until 5A.

Table 1 : Result for No Load Test

| Current (Amp) | Speed (RPM) |
|---|---|
| 0 | 0 |
| 0.5 | 61.4 |
| 1 | 133.4 |
| 1.5 | 197.2 |
| 2 | 272.6 |
| 2.5 | 341.8 |
| 3 | 409.5 |
| 3.5 | 478.5 |
| 4 | 547.2 |
| 4.5 | 617.6 |
| 5 | 662.2 |

### 4.5 Concept inside the HEV

Figure 22 below shows how basically the system inside a retrofit HEV is connected inside the car. The main objective is to connect the battery management system (BMS) with the brain of the system that is the EMS.

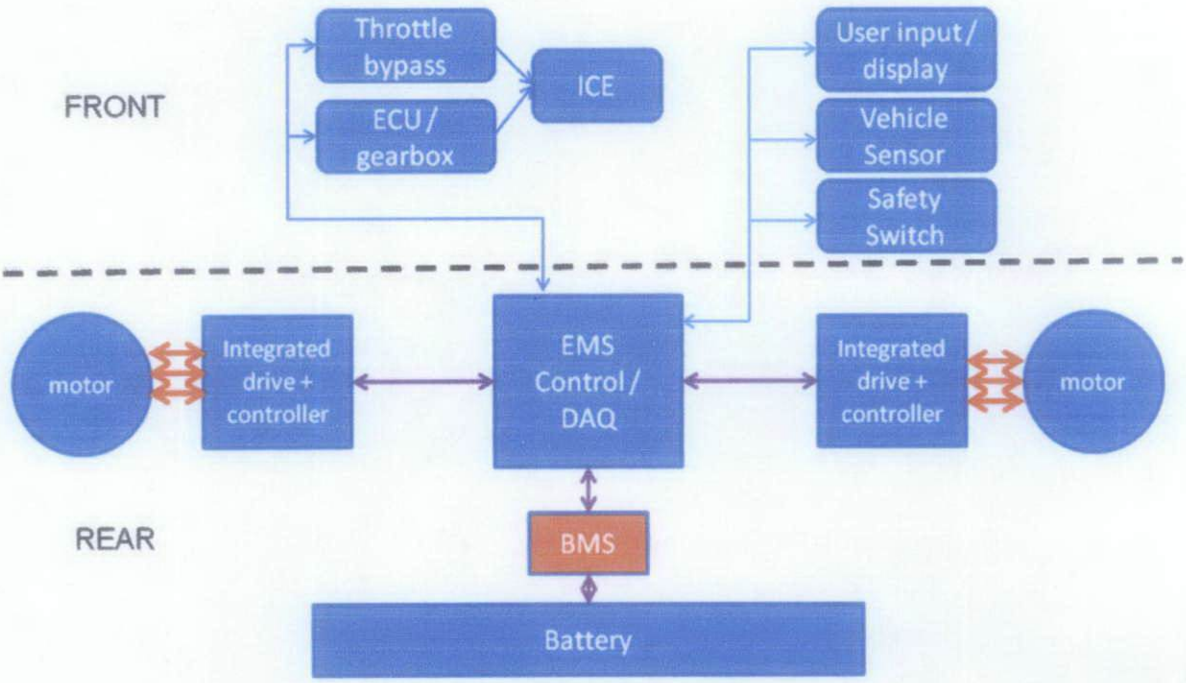



Figure 22: Design Concept inside HEV

Notes:

- The EMS will control the operating modes of the system and will interface with:
  - User inputs – throttle, brake, mode selector, display LCD panel, etc.
  - Data from ECU/gearbox on engine operating points & fuel level.
  - Throttle bypass – in EV mode ICE is still on but idling.
  - Battery Management System – SOC monitoring, cell balancing, thermal control.
  - Vehicle sensors – steering angle, accelerometer, speed, ABS signal, etc.
  - Safety switch – internal and external manual safety switches.

## 4.6 Implementation of the Battery Management System - PakTrakr

The idea of the implementation is based on how to monitor the battery while the car is running. The basic concept of the implementation is the BMS is connected to the NI Compact RIO hardware and then to the tablet PC inside the car as the User Interface. (Figure 23)

### *4.6.1 Diagram for implementation*

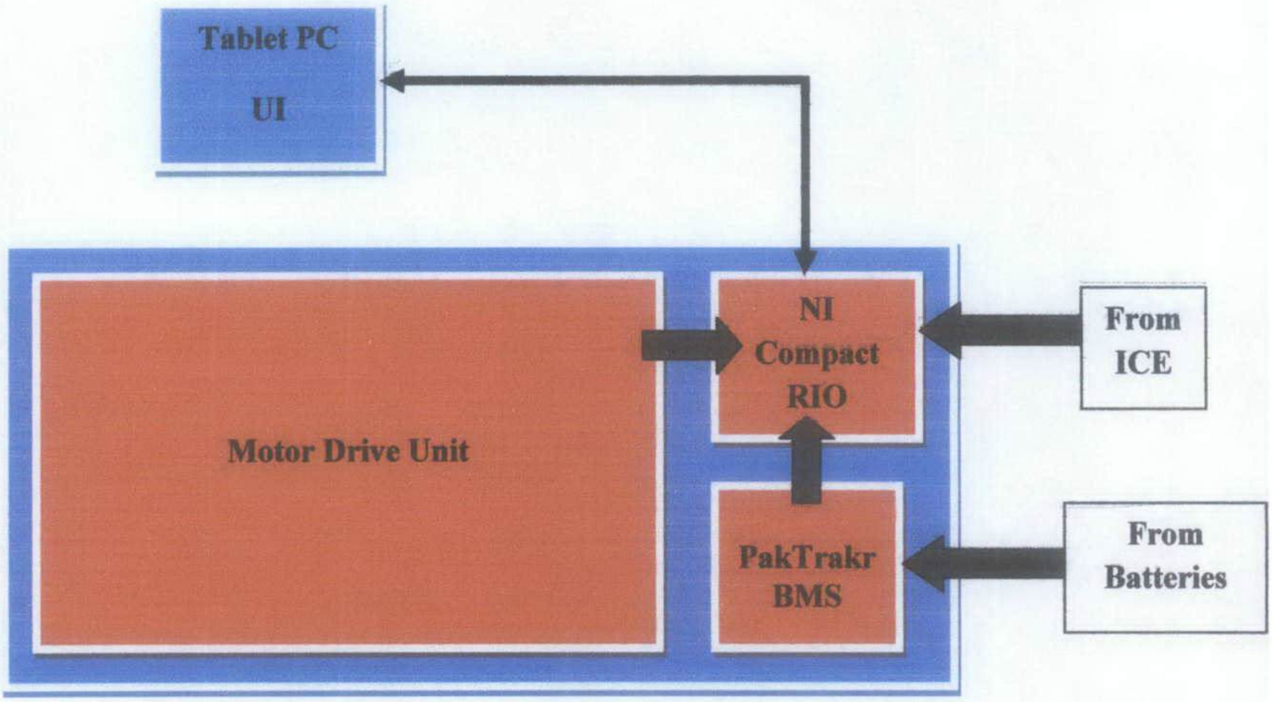



Figure 23 : Diagram of implementation inside the EMS

## 4.7 Design idea of the functionality of NI Compact RIO hardware

As for the system to work, the NI Compact RIO hardware needs to be programmed by using LabVIEW software. The software programmed touch on several points that will be using the tablet PC as User Interface (UI).

### *4.7.1 Output from the ICE*

The system will read the output from the ICE such as output from the throttle bypass, ECU and also gear position. So when the hardware is connected with the UI, users can easily know the vehicle speed, engine RPM and the gear position that has been selected by the driver.

### *4.7.2 Output from the BMS*

As for the BMS, the hardware will get the output from the batteries such as the State of Charge (SOC), failure and also battery damage. So the user will know the condition of the batteries when they are driving the vehicle.

### *4.7.3 Regeneration*

This part is the most important while driving a Hybrid Vehicle. Regeneration button will be programmed inside the hardware and connected to the PC. So the user can easily put on the Regeneration mode when they need it.

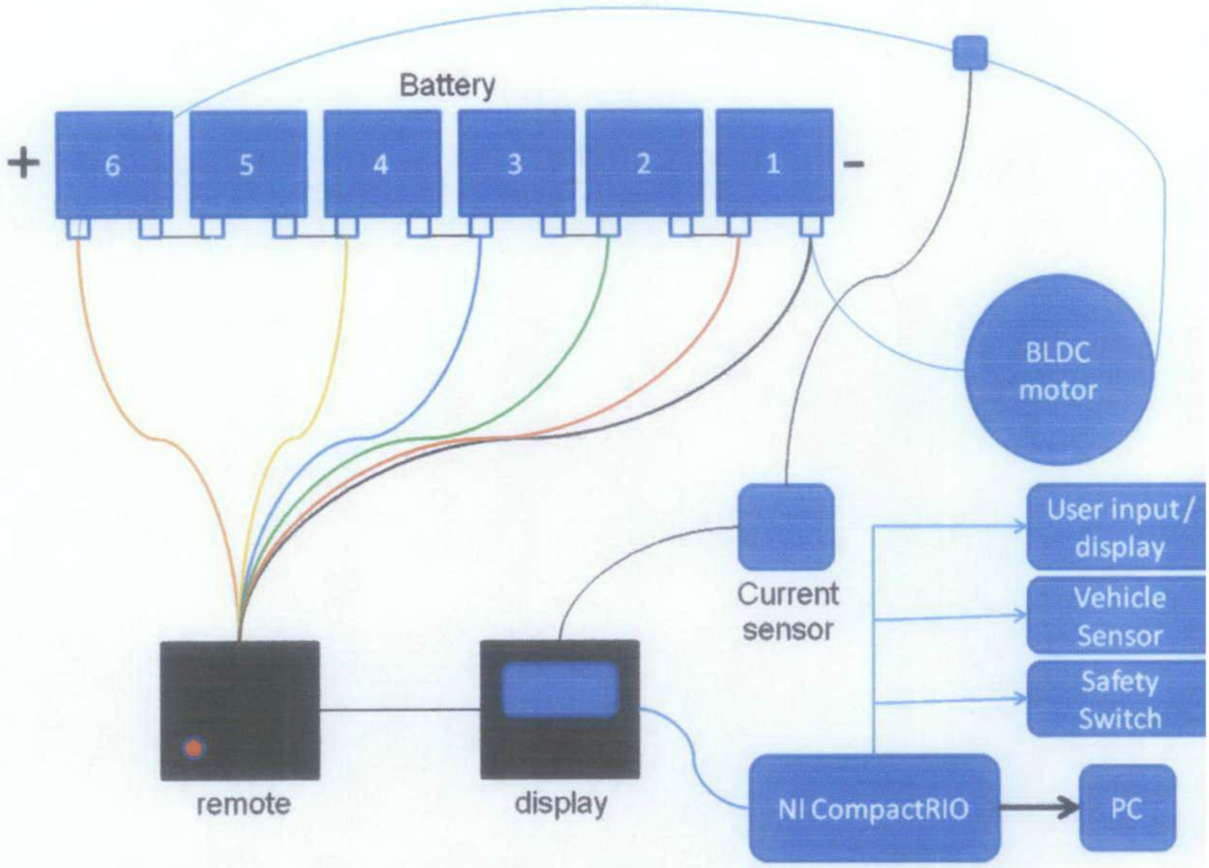



Figure 24 : Configuration of PakTrakr with NI CompactRIO hardware

Figure 24 above shows how the battery management system is configured together with the NI CompactRIO hardware. The hardware is also connected with other inputs such as vehicle gear position, sensors and other safety switches.

Figure 25 belows show the workbench that has been setup with the BLDC motor, motor drive and the PakTrakr battery monitoring system. For this configuration, Kelly Motor Drive has been changed with the Electrocraft Motor Drive due to many problems that occurred during the experiment using Kelly Motor Drive.

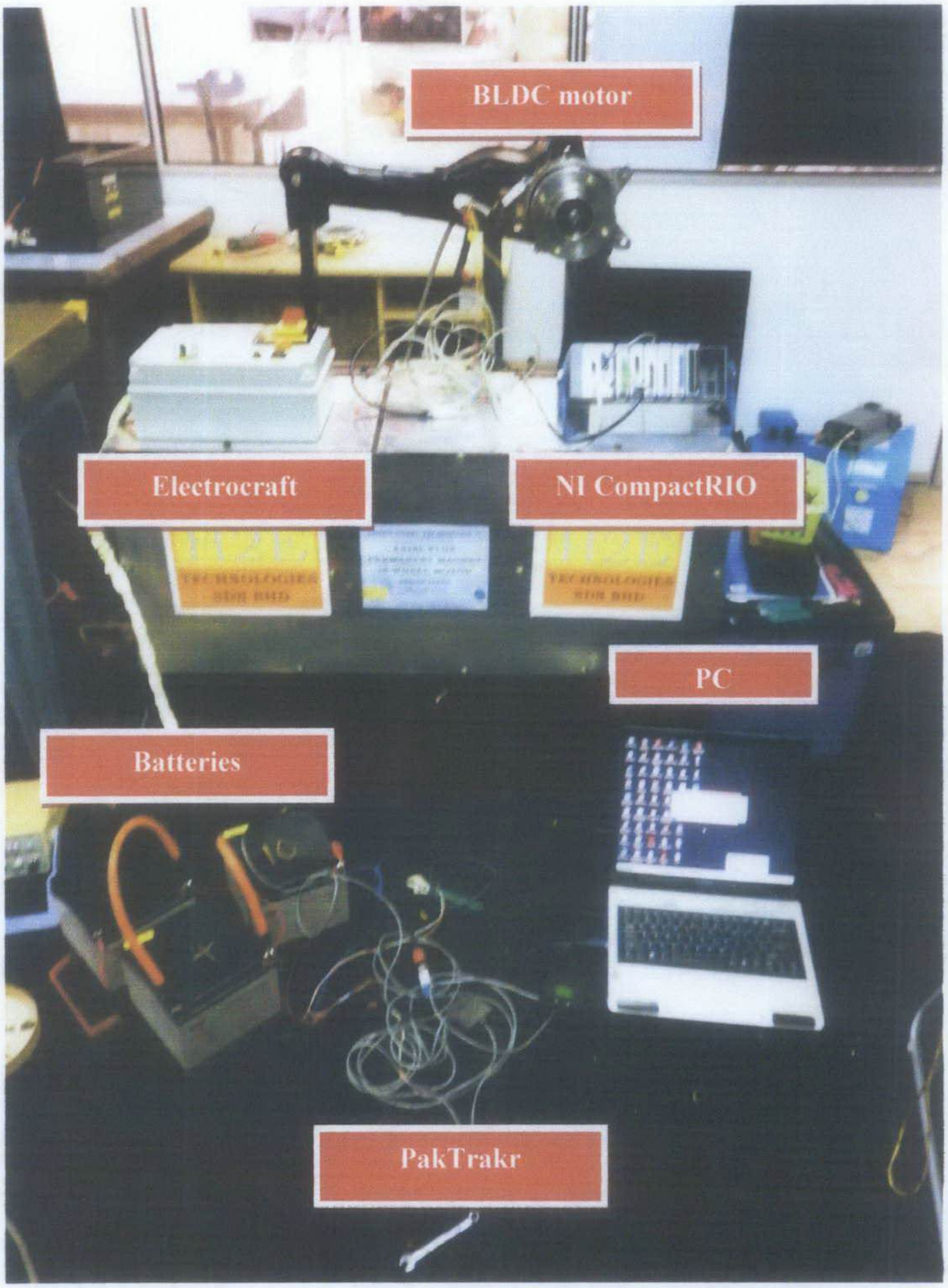



Figure 15 : Configuration of PakTrakr with BLDC motor on a workbench

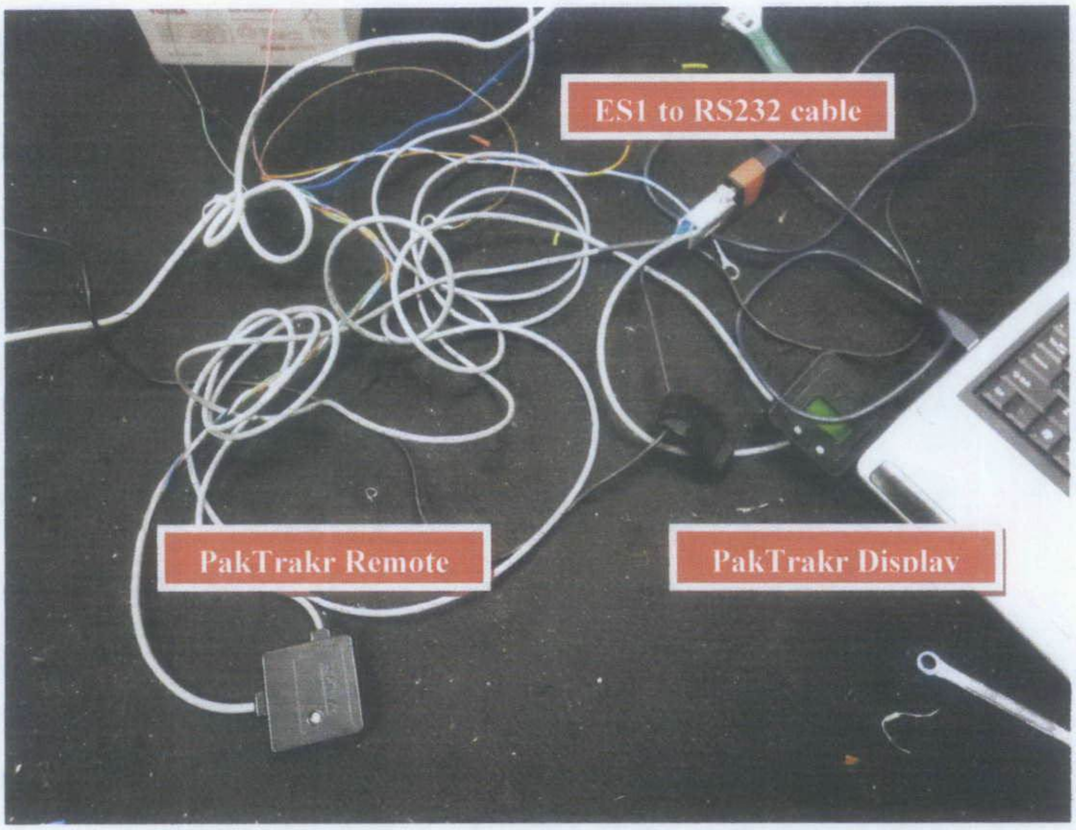



Figure 16 : Battery Management System PakTrakr connnection

Above is the connection of the battery monitoring system, PakTrakr, with the PC. The PakTrakr display is connected with the ES1 cable and then connected with the PC using RS232 cable.

The remote is then connected with the batteries to collect data from them. The battery will send analog signals and the signals are then converted in the remote before the information is shown on the display

There are 2 buttons on the PakTrakr display: The left button is to change the upper screen and the right button is for the lower screen. Figures below show what PakTrakr can inform the user if user pushes the right button.

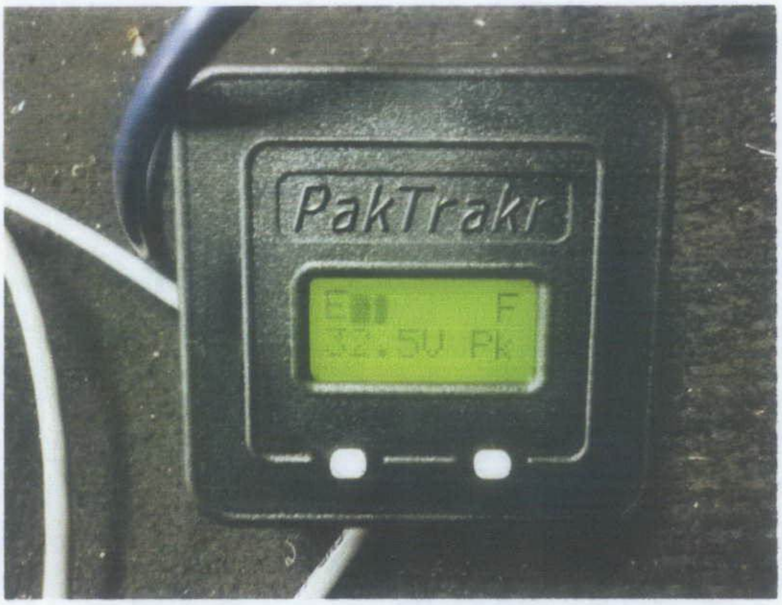



Figure 17 : PakTrakr displaying pack voltage

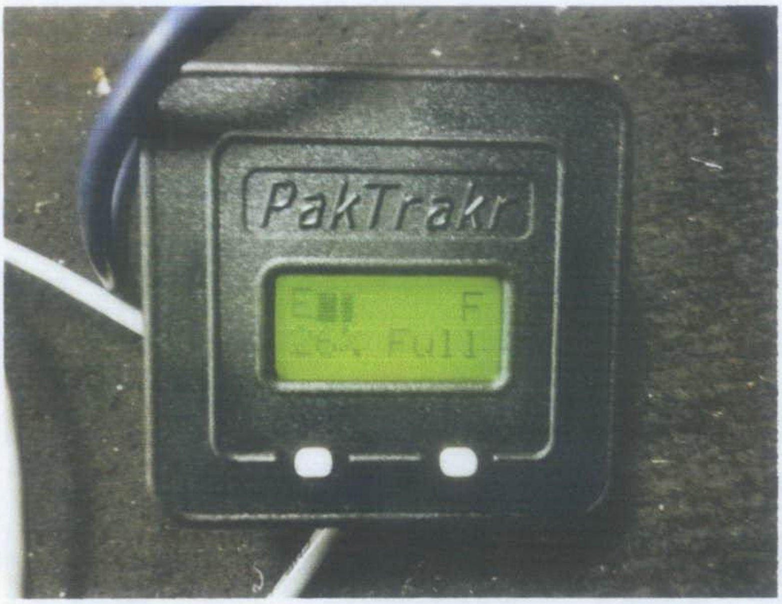



Figure 18 : PakTrakr displaying battery SOC


Figure 19 : PakTrakr displaying battery 1 voltage

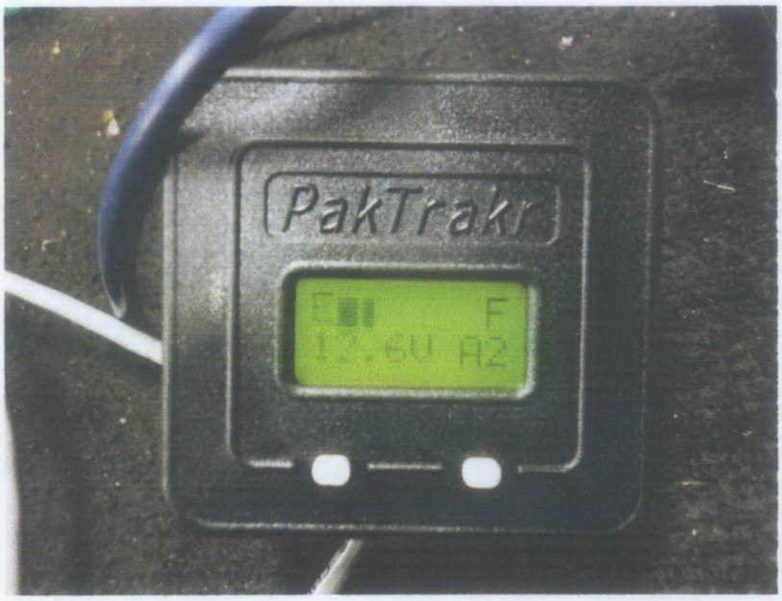



Figure 30 : PakTrakr displaying battery 2 voltage

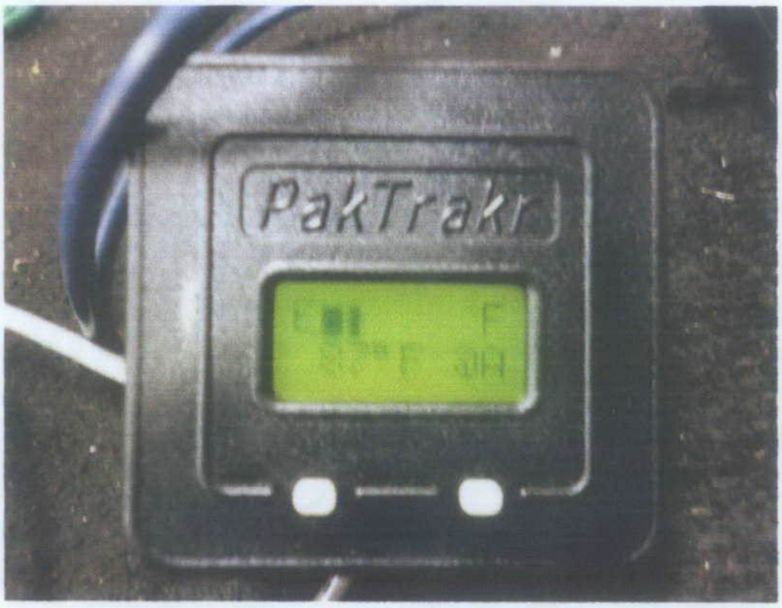



Figure 31 : PakTrakr displaying battery temperature in Fahrenheit

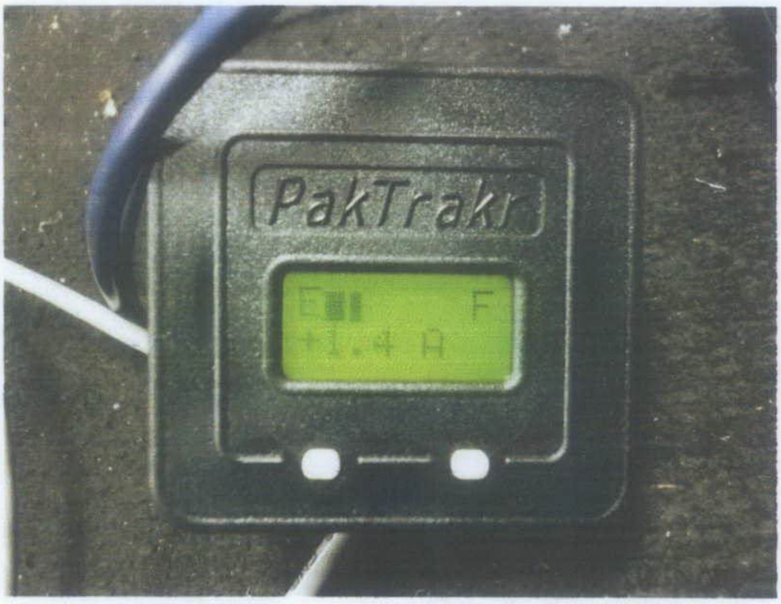



Figure 32 : PakTrakr displaying supplied current

In Figure 27, the PakTrakr show the pack voltage value that is the total voltage of the battery.

$$V\ (pack) = V\ (battery\ 1) + V\ (battery\ 2) + ... + V\ (battery\ N) \qquad (1)$$

Where N = (1, 2, 3, 4…)

In Figure 28, the PakTrakr shows the state of charge (SOC) of the battery. There are many theories to calculate the SOC of the battery, and for the PakTrakr, the system calculates the SOC by integrating the pack voltage over time.

For display on Figure 29 and Figure 30, the PakTrakr tells the user about the individual battery voltage for each remote. So from here the user will know which battery is in good condition or need to be recharged or need to be changed.

In Figure 31, the display shows the temperature of the battery in degrees Fahrenheit. And in Figure 32, the display shows the value of the input current of the battery. The current is detected using the PakTrakr current sensor attached to the PakTrakr display.

For the data to be displayed on the PC, the PakTrakr should be connecting with the PC using ES1 serial interface and RS232 to USB cable. By using Hyper Terminal software, all the data from the PakTrakr can be seen. Table below is the data from the Hyper Terminal that has been filtered and organized.

Table 2 : Data from PakTrakr using Hyper Terminal

| Battery Voltage 1 (V) | Battery Voltage 2 (V) | Battery Voltage 3 (V) | Pack Voltage (V) | Temp (F) | Time (s) | Time (m) | SOC (%) | I (A) |
|---|---|---|---|---|---|---|---|---|
| 119 | 124 | 60 | 302 | 86 | 1 | 46 | 13 | 14 |
| 119 | 124 | 60 | 303 | 86 | 2 | 46 | 13 | 14 |
| 119 | 124 | 60 | 303 | 86 | 3 | 46 | 13 | 14 |
| 119 | 125 | 60 | 303 | 86 | 4 | 46 | 13 | 14 |
| 119 | 125 | 60 | 303 | 86 | 5 | 46 | 13 | 14 |
| 119 | 125 | 60 | 303 | 86 | 6 | 46 | 13 | 14 |
| 119 | 125 | 60 | 303 | 86 | 7 | 46 | 8 | 14 |
| 119 | 125 | 60 | 303 | 86 | 8 | 46 | 8 | 14 |
| 119 | 125 | 60 | 303 | 86 | 9 | 46 | 8 | 14 |
| 119 | 125 | 60 | 303 | 86 | 10 | 46 | 8 | 14 |
| 119 | 125 | 60 | 303 | 86 | 11 | 46 | 8 | 14 |
| 119 | 125 | 60 | 303 | 86 | 12 | 46 | 8 | 14 |
| 119 | 125 | 60 | 303 | 86 | 13 | 46 | 8 | 14 |
| 119 | 125 | 60 | 303 | 86 | 14 | 46 | 8 | 14 |
| 119 | 125 | 60 | 303 | 86 | 15 | 46 | 8 | 14 |
| 119 | 125 | 59 | 303 | 86 | 16 | 46 | 8 | 14 |
| 119 | 125 | 59 | 303 | 86 | 17 | 46 | 8 | 14 |
| 119 | 125 | 59 | 303 | 86 | 18 | 46 | 8 | 14 |
| 119 | 125 | 59 | 303 | 87 | 19 | 46 | 8 | 14 |
| 119 | 125 | 59 | 303 | 86 | 20 | 46 | 8 | 14 |
| 119 | 125 | 59 | 303 | 86 | 21 | 46 | 8 | 14 |
| 119 | 125 | 59 | 303 | 86 | 22 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 23 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 24 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 25 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 26 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 27 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 28 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 29 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 30 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 31 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 87 | 32 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 33 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 34 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 35 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 36 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 37 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 38 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 39 | 46 | 8 | 14 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 119 | 126 | 59 | 303 | 86 | 40 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 41 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 42 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 43 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 44 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 45 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 46 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 47 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 48 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 49 | 46 | 8 | 14 |
| 119 | 125 | 59 | 303 | 86 | 50 | 46 | 8 | 14 |
| 119 | 126 | 59 | 304 | 86 | 51 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 52 | 46 | 8 | 14 |
| 119 | 126 | 60 | 304 | 86 | 53 | 46 | 8 | 14 |
| 119 | 126 | 59 | 304 | 86 | 54 | 46 | 8 | 14 |
| 119 | 126 | 59 | 304 | 86 | 55 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 56 | 46 | 8 | 14 |
| 119 | 126 | 59 | 303 | 86 | 57 | 46 | 8 | 14 |
| 119 | 126 | 59 | 304 | 86 | 58 | 46 | 8 | 14 |
| 119 | 126 | 60 | 304 | 86 | 59 | 46 | 8 | 14 |

Data from the PakTrakr will be sent to the CompactRIO system via RS232 serial interface. In LabVIEW, a program will be written to extract the various data from the Battery Management System to be used for energy management of the vehicle. However, this work is still ongoing.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

This report presents the work done by the author and also outcome of the project in studying on Monitoring, Control and Energy Management for In-Wheel Motor Hybrid Electric Vehicle project. Most of the objective of this project is to implement a energy management system for a hybrid electric vehicle with in-wheel motors and how to manage it. Energy management system is the main function that every hybrid electric vehicle must have. Without it, the user/driver cannot know the condition of the vehicle while driving it. Therefore, it is very important for the electrical engineers to study and familiarize the characteristic of the system inside the hybrid vehicle especially the battery.

The author also has learned on LabVIEW software and for the future, intends to implement a complete energy management system using it. But due to some problem occur on the middle of project, author lost a lot of time to complete the project. Implementation of energy management is ongoing – hardware configuration and software programming – to achieve successful completion. The author hope the project will be able to contribute towards the development of the green technology industry.

## 5.2 Recommendations

A lot of experimentation needs to be completed in order to make the complete system of the energy management. Therefore, more research must be performed to complete the implementation of an energy management system (EMS). But in the future, author suggests that the programming of the EMS also can be implemented by using other software such as Mat Lab/Simulink. Author also suggests to do a lot more research on the battery monitoring system. Data and results obtained can be compared for improvement of the project.

# REFERENCES


[1] How the Ford Escape Hybrid works, retrieve from http://auto.howstuffworks.com/ford-escape.html

[2] What is a Hybrid Vehicle? - An introduction to hybrid cars and how they are defined, with examples of different hybrid technologies (2007), retrieve from http://what-is-what.com/what_is/hybrid_vehicle.html

[3] Uncle Mark's Alternative Fueling Station, Alternative Drive Trains (2005), retrieve from http://www.altfuels.org/backgrnd/altdrive.html

[4] Hybrid Vehicle, retrieve from http://en.wikipedia.org/wiki/Hybrid_vehicle#Parallel_hybrid

[5] What is a Hybrid Vehicle, retrieve from http://www.mpgmagazine.com/what-is-a-hybrid-vehicle.html

[6] How Hybrid Cars Work, retrieve from http://auto.howstuffworks.com/hybrid-car2.htm

[7] KEB 72V 8KW Regen Kit http://www.newkellycontroller.com/product_info.php?cPath=26&products_id=435

[8] PakTrakr - Intelligent Battery Monitoring Systems
http://www.paktrakr.com/FAQ.html

[9] Battery Management System
http://www.mpoweruk.com/bms.htm

[10] Dennis Dörffel, *"Energy Management of Hybrid Electric Vehicles"*, University of Southampton.

[11] Padmaraja Yedamale, *"Brushless DC Motor Fundamentals"*, Application Notes, AN885, Microchip Technology Inc. (2003)

[12] Ward Brown, *"Brushless DC Motor Control Made Easy"*, Application Notes, AN857, Microchip Technology Inc. (2002)

[13] Dal Y. Ohm, Jae H. Park, *"About Commutation and Current Control Methods for Brushless Motors"*, Application Notes.

[14] Mohd Farizol Fuzmi Bin Mohd Bakhi, *"3-Phase Brushless Permanent-Magnet Motor Control for Hybrid Electric Vehicle In-Wheel Motor"*, Universiti Teknologi PETRONAS.(2010)

## Appendix A : Gantt chart

| NO. | PROJECT ACTIVITIES | WEEK NO/DATE | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| 1 | Project Consultation | X | | | | | | | | | | | | | | |
| 2 | Testing & Project Simulation | | X | X | X | X | X | X | | | | | | | | |
| 3 | Progress Report Submission | | | | | | | | X | | | | | | | |
| 4 | Programming Revision | | | | | | | | | X | X | X | X | | | |
| 5 | Draft Report Submission | | | | | | | | | | | | | X | | |
| 6 | Final Report Submission | | | | | | | | | | | | | | X | |
| 7 | Technical Paper Presentation | | | | | | | | | | | | | | X | |
| 8 | Viva | | | | | | | | | | | | | | | X |

# Appendix B : Kelly Motor Drive Wiring Diagram