MOTOR DRIVE & ENERGY MANAGEMENT FOR ELECTRIC VEHICLE USING NATIONAL INSTRUMENTS COMPACT-RIO

By

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12293

FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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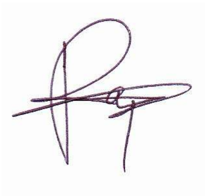
UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2012

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 the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.



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Redhata Gama Ardhian Rangkuti, ID:12293

ABSTRACT

Internal combustion engine vehicle (ICEVs) has been around for more than a century. However, the efficiency of ICEV is considered low, only 30% of the energy formed in the ICE combustion reaction is changed into mechanical power and the majority which is 70% of the energy is vanished into the form of exhaust gases heat. The exhaust gases are consists of mostly of carbon dioxide (CO_2) and a smaller amount of nitrogen oxides (NO_X), hydrocarbons (C_XH_Y), carbon monoxide (CO) and others. Decreasing the dependency on fossil fuels burned in an ICE will directly impact environmental effects and increase the healthiness of human.

Nowadays, pure Electric Vehicle (EV) and hybrid EV are obtainable by world's greatest carmakers because they are significant potential for use in urban areas. Their power consumption ranges from approximately 10% to 70% lower than that of a comparable ICE car, depending on their power, size of battery, control approach, etc. In city traffic, because of their positive effect on environment, electric vehicle are a key factor for improvement of traffic and more particularly for an improved living environment.

A very efficient energy-management system for electric vehicle will be developed and tested. The system minimizes the power requirement of the vehicle and extends the driving range of an electric vehicle. The intention of this project is to develop the energy management system within the electric vehicle to be able to monitor vehicle performance. The energy management system monitors the battery current, battery voltage, temperature, vehicle performance, power consumption, state of charge (SOC) of the battery, and gives feedback in terms of actions that need to do by driver. It will be implemented using National Instruments Compact-RIO hardware and programmed in LabVIEW, graphical application development environment.

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LIST OF ABBREVIATIONS

AC	Alternating Current
BEV	Battery Electric Vehicle
BMS	Battery Management System
CAR	Centre for Automotive Research
DAQ	Data Acquisition
DC	Direct Current
EMS	Energy Management System
EV	Electric Vehicle
FPGA	Field Programmable Gate Array
FTP	File Transfer Protocol
GUI	Graphical User Interface
HEV	Hybrid Electric Vehicle
I	Current
I/O	Input / Output
ICE	Internal Combustion Engine
LAN	Local Area Network
LED	Light Emitting Diode
OEM	Original Equipment Manufacturer
P	Power
PCI	Peripheral Component Interconnect
PGMC	Proton Green Mobility Challenge
PWM	Pulse Width Modulation
NI	National Instruments
PXI	PCI eXtension for Instrumentation
R	Resistance
RPM	Rotation per Minute
SOC	State of Charge
T	Torque
UTP Cat5	Unshielded Twisted Pair Category 5 / LAN Cable
V	Voltage
VCL	Vehicle Control Language

CHAPTER 1
INTRODUCTION

1.1 Background

In the latest decades, internal combustion engine vehicle have experienced continuous improvement in motor performance, vehicle control, passenger comfort and safety measures. However, the efficiency of ICEV is considered low, only 30% of the energy formed in the ICE combustion reaction is changed into mechanical power and the majority which is 70% of the energy is vanished into the form of exhaust gases heat. The exhaust gases are consists of mostly of carbon dioxide (CO_2) and a smaller amount of nitrogen oxides (NO_X), hydrocarbons (C_XH_Y), carbon monoxide (CO) and others. Carbon dioxide is identified to obstruct the earth's radiation emission back into the outer space thus driving worldwide temperature increase, which is called by greenhouse effect. Air pollution in big cities is another serious problem caused by exhaust gases, which leads to numerous diseases such as respiratory system disease and also lung cancer.

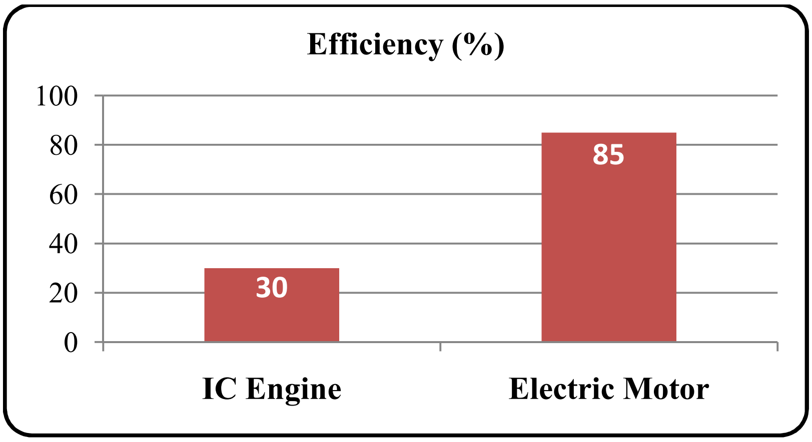


Figure 1 : ICEs efficiency compared to electric motors

It can be seen from Figure 1 above that electric motors is more efficient compared to ICE and can do a superior job in driving force of vehicles and helping to answer the serious environment, air pollution, and healthiness problem produced by ICE vehicle. [1]

The study and improvement actions associated to transportation have emphasized the improvement of high effectiveness, zero pollution, and safe transportation. Electric Vehicle (EV), Hybrid Electric Vehicle (HEV) and fuel cell vehicle have been projected to substitute conventional vehicle in the near future. Electric vehicles have enhanced their performance and made suitable for commercial and domestic use during the recent years. However, pure electric vehicles still have not achieved driving ranges as superior as internal combustion engine vehicles. This problem is as a result of the limited energy storage in the majority electric batteries. The Energy Management System (EMS) lets the vehicle use this limited energy storage wisely.

In this project, driving force of vehicle is converted from an ICE-based to an electric propulsion system. Comprises the motor drive, transmission and wheels. Motor drive itself consists of 3-phase induction motor, motor controller and energy storage device – LiFePO4 battery pack. The electric vehicle has many advantages over the conventional internal combustion engine vehicle, such as a zero emissions, high efficiency, independence from petroleum, silence and smooth operation.

1.2 Problem Statement

To achieve the best performance of the propulsion system, in this project there will be three (3) areas of study that will be implemented:

1. Improvement of the motor drive system
2. Efficiency of the electric propulsion system
3. Power control strategy for the different drive / race objectives

1.3 Objectives

There are some objectives to be accomplished by the end of this project which are:

1. To familiarize with characteristic of Induction AC motor, and motor controller.
2. To install and program the motor controller, Curtis 1238R, inside the electric vehicle.

3. To implement a monitoring, and energy management system for electric vehicle using National Instruments Compact-RIO and LabVIEW, a graphical application development environment.
4. To install and program Battery Management System (BMS) and battery charging system for electric vehicle.

1.4 Scope of Study

The scopes of study in this project are:

1. Understand on how to monitor and perform energy management on the system of the AC Induction Motor.
2. Installing the hardware and setting up the connection for both hardware and software between the AC Induction Motor, motor controller, Battery Management System, and auxiliary systems.
3. Performing field experimentation, testing and analysis of the electric vehicle performance.

CHAPTER 2
LITERATURE REVIEW

2.1 Electric Vehicle Overview

Electric vehicles are propelled with an electric motor(s) power-driven by rechargeable battery packs. Electric motors have numerous benefits compared to internal combustion engines such as:

- Energy efficient
  Electric motors convert 85% of the chemical energy from the batteries to power the wheels. In contrary, internal combustion engines (ICEs) only convert 30% of the energy stored in petrol into mechanical energy.
- Environmentally friendly
  Electric vehicles release zero pollutant, even though the power plant producing the electrical energy may produce them. Electrical energy from nuclear, hydro, solar or wind-power-driven plants causes zero air pollutant.
- Performance advantages
  Electric motors offer silence, smooth operation and stronger acceleration and require less maintenance compared to internal combustion engines.
- Decrease energy dependence
  Electrical energy is a renewable energy resource and by using Electric vehicle the dependence on oil is decreased.

Electric vehicle has major battery-associated challenges which are: [2]

- Driving range
  Most EVs can only go about 160-300 km prior to recharge and petrol vehicle is able to go farther than 450 km prior to refuel.
- Recharge time
  Battery packs need four to eight hour for fully recharging. Even a fast charging to 80% of its capacity needs 30 minutes.

- Battery price

  An expansive big battery packs may required to be replaced one or more times.
- Size and weight

  A significant vehicle space is needed for a heavy battery packs.

2.1.1 Electric Vehicle Classification

Electric Vehicle can be classified into two major classes based on the energy converter types, which are Battery Electric Vehicle (BEVs), also called pure electric vehicle, and Hybrid Electric Vehicle (HEVs). BEVs use batteries to store power that will be changed into mechanical power by electric motor(s) only without the present of Internal Combustion Engine. In HEVs, combination of electric motor and Internal Combustion Engine makes the propulsion system. HEVs also can be classified into four architectures based on the different manners in which the hybridization can happen.[1]

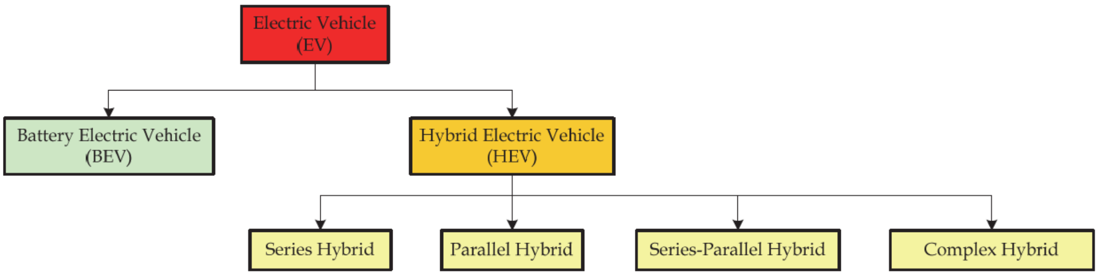


Figure 2 : Classification of Electric Vehicles based on type of energy converters

In this project, Battery Electric Vehicle (BEV) or pure electric vehicle is going to be built for PROTON Green Mobility Challenge 2012 by a team from the Centre for Automotive Research (CAR), namely UTP SAGA-METRO. The author involved in the team as part of Energy Management System and Motor Control.

2.1.2 Proton Green Mobility Challenge (PGMC) 2012

PROTON and Agensi Inovasi Malaysia (AIM) have collaborated to organize the first PGMC 2012 with support from Ministry of Science, Technology and Innovation (MOSTI), the Malaysian Green Tech Corporation, the Malaysia

Automotive Institute and the Society of Automotive Engineers (SAE) International, Malaysia Section.

Figure 3 : Proton Green Mobility Challenge 2012 Event Logo

The focus areas of the PGMC 2012 are: i. Electric vehicle development and strategy, ii. Battery management, iii. Electric motor control technology, and iv Thermal management. The dynamic events of the competition are: i. Farthest distance on a single charge within two hours, ii. Quarter mile acceleration, iii. Fastest time for two laps, and iv. V-Max (maximum velocity at straight sections of Sepang International Circuit). In addition, the selected teams will also be evaluated in the areas of engineering, team identity and promotion. [3]

Figure 4 : Concept of Electric Vehicle from UTP SAGA-METRO Team

2.1.3 General Architecture of Battery Electric Vehicles (BEVs)

According to Samuel E. de Lucena there are several architectures of Battery Electric Vehicles. The fundamental topology for battery-electric vehicle is one-motor BEV as illustrated in Figure 5 below. Energy stored in a battery pack is used by the power converter to drive the electric motor which linked to changeable or fixed gear and a power splitting differential gear to drives the two wheels. The power converter unit may include a dc-dc converter and a motor driver. In order to attain its maximum efficiency, whenever the brake pedal is pressed the vehicle's kinetic energy must be transformed to electrical energy by the motor which can act as a generator and stored in the battery pack via the power converter. [1]

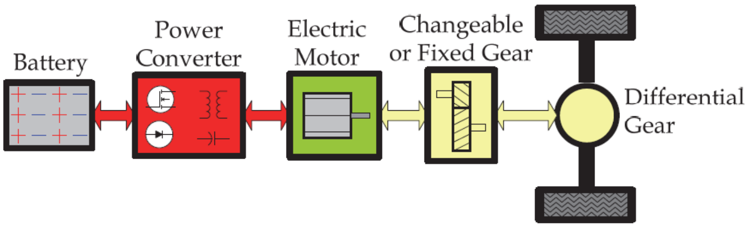


Figure 5 : One-motor BEV

The second architecture of BEV is two-motor BEV which use two in-wheel motors in their power trains, as illustrated in Figure 5 below. Each motor is driven by a dedicated power converter that must control wheel's speed and torque. Importantly, a main electronic controller is required to synchronize speed disparity whenever desired or as an effect of wheel slippage, provided that a differential power splitting device is no more present. The advantages of multiple-motor BEV is that the vehicle can still continue to operate if one of the motors gets out of service, reduced overall power consumption, and of course reduced number of mechanical links compared to one-motor BEV. [1]

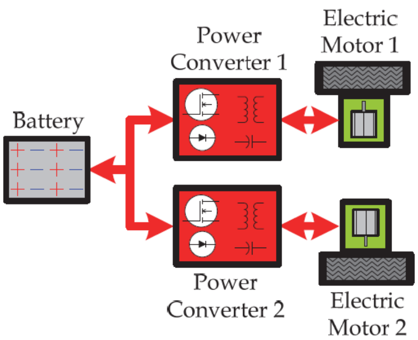


Figure 6 : Two-motor BEV

However, until today BEVs are not as attractive as HEVs because of its limited driving range, and performance due to the battery limitations and relatively low energy stored, and excessive weight of the battery packs itself. Nevertheless, since BEVs are zero-emission vehicles, they should be seen as effective option of transportation to reduce greenhouse gas emission, air pollution, and fossil fuel dependency.

2.2 Electric Motor and Motor Controller

Electric vehicle use an electric motor for traction. However, there are several alternatives of electric motor that can be used for electric vehicle which will be explained in the next part below.

2.2.1 Alternative of Electric Motors for Electric Vehicle

Squirrel cage rotor is an asynchronous induction three phased motors conquered the engineering applications nowadays because of their relative low price, high strength and good dynamic performance which also makes them a good option for driving electric vehicle. Several alternatives of electric motors for EVs are illustrated in Figure 7 below. Asynchronous Induction Motor has low manufacture price, superior toughness, high dynamic performance but a complex control is needed. Switched Reluctance (SR) motor has very low manufacture price but has high variations in torque and quite loud operation. Besides AC Induction Motor, Permanent magnet brushless dc motor is a very promising technology that has been in broad use with EVs since it has high power density, lesser weight, compact size, simplified hardware, but has deprived high-speed performance. Permanent magnet brushless dc motor has been implemented in Toyota Prius and Honda Civic. The rare earths used in the permanent magnets are a significant contemplation for upcoming development of EVs using permanent magnet brushless dc motor. [1]

Hybrid-field excited permanent magnet brushless dc motor offers better performance, as field can be strengthened and weakened, but it has higher manufacture price and the complexity of control is increased.

In this project, AC Induction Motor will be selected for electric propulsion system which is produced by Curtis. The type of motor is Curtis AC50 that has been widely used for electric vehicle applications. [4]

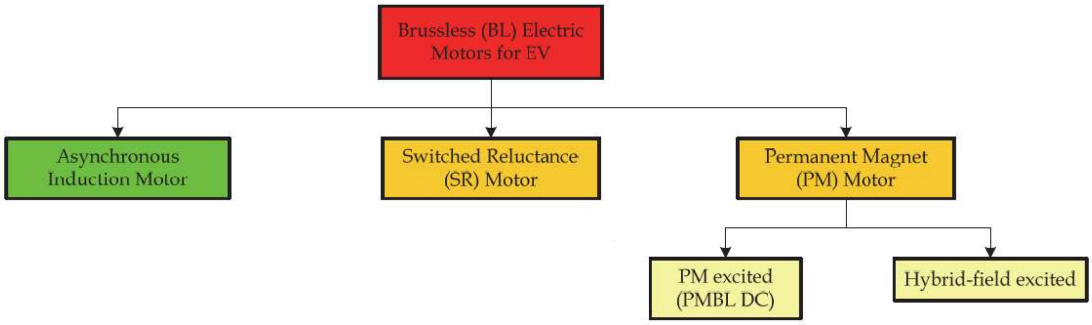


Figure 7 : Alternative of Electric Motors for EVs

2.2.2 AC Induction Motor

AC induction motor is no-commutator motor drives that offer a number of benefits over conventional DC commutator motor drives for the electric driving force of EVs and HEVs. The benefits of AC induction motor compared to DC motor is light heaviness, small dimensions, low price, and high efficiency which are mainly significant for EV and HEV purposes. [5]

There are two categories of induction motors which are wound-rotor and squirrel-cage motors. Wound-rotor induction motors are not as much of attractive as squirrel-cage induction motor because of the high price, need for maintenance, and lack of durability. In this project, induction motor is referring to squirrel-cage induction motor.

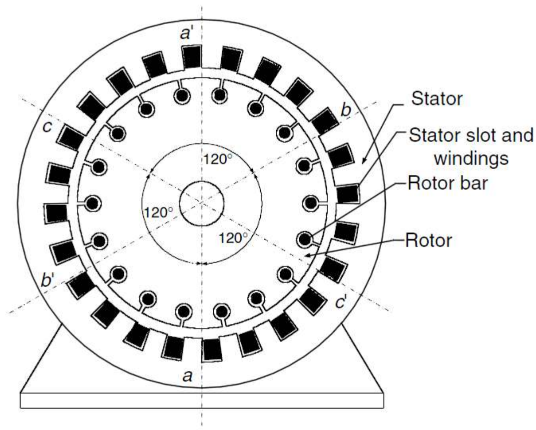


Figure 8 : Cross-section of an induction motor

Figure 8 above shows a cross-section of an induction motor. Slots in the inner periphery of the stator are inserted with three phase windings, a-a’, b-b’, and c-c’. The turns of each winding are distributed such that the current in the winding produces a fairly accurate sinusoidal distributed flux density in the region of the edge of the air gap. The three windings are spatially set by 120 degree.

The majority general types of induction motor rotors are the squirrel cage in which aluminum slabs are cast into slots in the external periphery of the rotor. The aluminum slabs are connected together at both ends of the rotor by cast aluminum end rings, which can also be formed into fans.

Curtis AC50 induction motor will be used in this project as selected by the PROTON Green Mobility Challenge 2012 committee. This custom-wound AC induction motors can generate a better amount of power and torque at exceptional levels of efficiency. It includes with Curtis Controller 1238R, Main Contactor, key switch relay, AMPSEAL connector and Molex Mini 840 Display. Specifications of Curtis AC50 induction motor is summarized in this table below. [4]

Curtis AC50 induction motor	
Diameter	8 inches
Weight	122 lb
Voltage	72-108 Volt
Ampere Rating	550 Amp
Motor Efficiency	89%
Peak Power	52 HP
Torque	115 ft/lbs
RPM	6500

Table 1 : Curtis AC50 Induction Motor Specifications

The graph of Torque, Battery Voltage, Horsepower and RMS Current versus speed (in RPM) of Curtis AC50 induction motor can be seen in the Figure 9 below.[4]

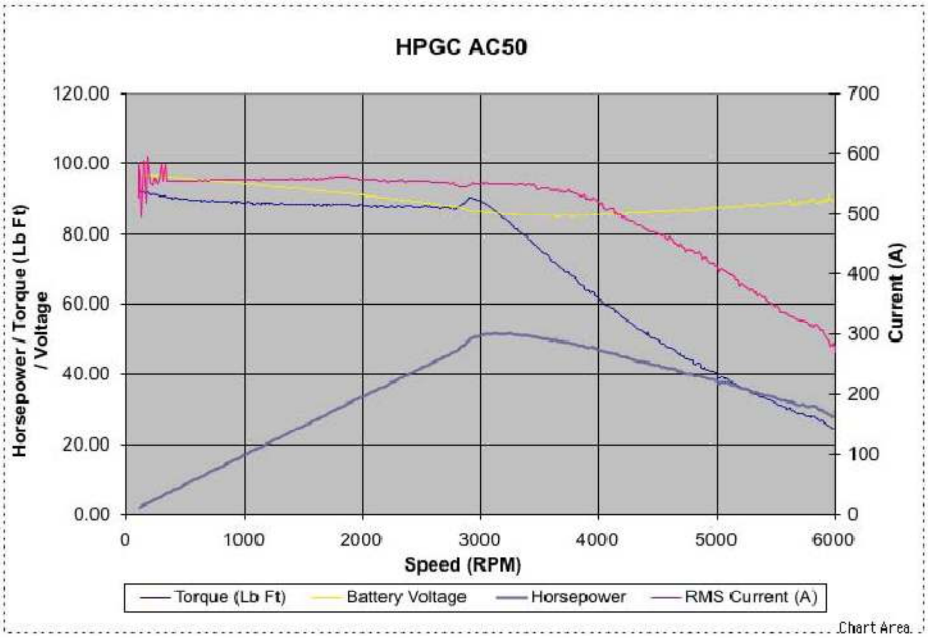


Figure 9 : Performance of Curtis AC50 induction motor

2.2.3 Electric Motor Control Area of Study

The drive train of electric vehicle is consists of three major subsystems: electric motor driving force, power source, and supplementary. The electric driving force subsystem which shown in Figure 10 below consist of motor controller, power electronic converter, induction motor, mechanical transmission unit, and driving wheels. The power source subsystem consists of power source, energy management unit and power recharging unit. The supplementary subsystem consists of the power steering unit, and the supplementary supply unit.

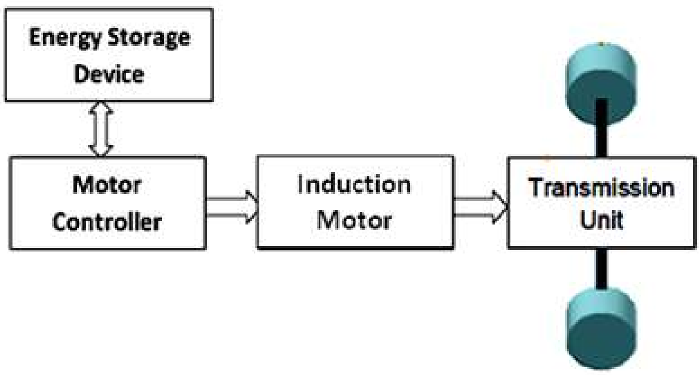


Figure 10 : Electric driving force system of the electric vehicle

The most common and feasible technique that can be used to control the speed of three-phase AC induction motor is by changing the electrical supply frequency to vary the synchronous speed. The control speed algorithm used in this paper is based on this characteristic. [13]

The synchronous speed of induction motor is given by following equation:

$$Nsync = 120\ x\ Fe/P$$

where,

Fe = electrical frequency (Hertz)

P = number of poles in the motor

Synchronous speed is the speed at which the stator flux rotates. Rotor flux rotates slower than synchronous speed by the slip speed. This slip speed effect means that the rotor speeds can never exactly reach the synchronous speed [12]. The rotor speed can be explained by the following equation:

$$Nr = Nsync\ (1 - s)$$

where,

Nr = rotor speed

S = slip

The algorithm to control the speed of three-phase AC induction motor should include varying electrical frequency instead of the applied voltage.

In order to achieve the best performance of the propulsion system, in this project there will be two areas of study which are:

- Enhancement of the motor drive system – increase start-up current limit and thermal limit.

  The motor controller consists of power converter and electronic controller. The power converter that can handle high voltage and current levels for motor operations consists of semiconductor switching devices. The electronic controller is turning on or off the transistor switches based on information of rotor position given by hall sensors as illustrated in figure below.

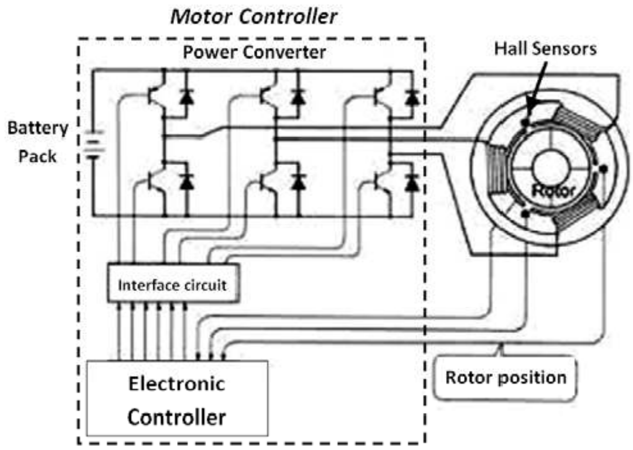


Figure 11 : AC Induction Motor Drive

With the implementation of a higher resolution encoder the controller is able to apply phase advanced control to increase the operating speed of the motor which will results in higher speed and acceleration rate of vehicle.

Increase in motor maximum torque will increase the maximum continuous current limit which increases the heat of motor. To overcome this problem, the liquid cooling system over the motor and the controller will be implemented as illustrated in figure below.

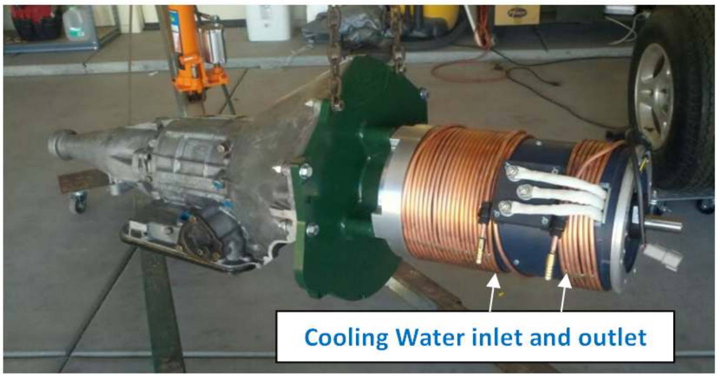


Figure 12 : Concept of Motor Cooling System

With the usage of liquid cooling and phase advanced, it is possible to extend the maximum speed of motor as illustrated in figure below.

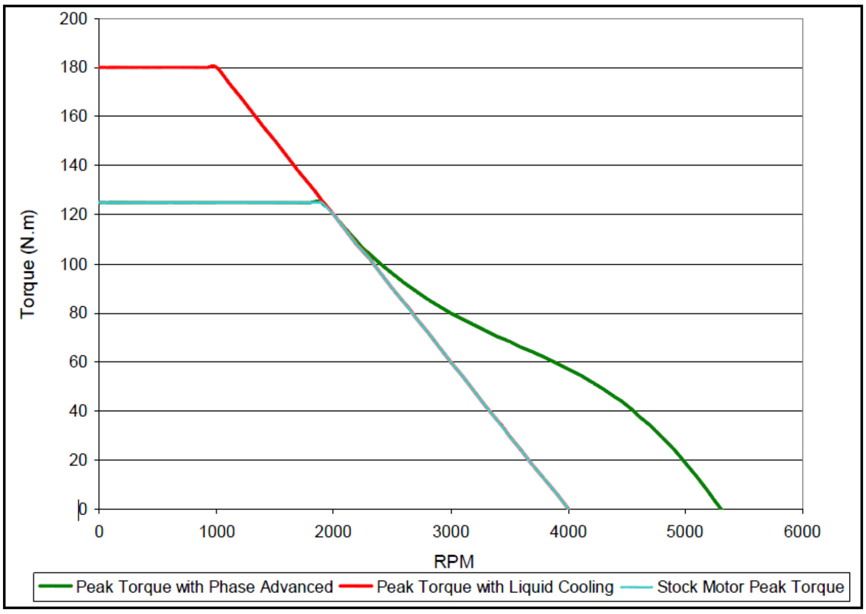


Figure 13 : Motor Peak Torque with Stock, Liquid Cooling and Phase Advanced

- Efficiency of the electric driving force system.

The efficiency of electric driving force system is affecting the vehicle performance. More efficient system will reduce the power consumption and prolong the battery life. Therefore efficiency of driving force system is an important factor to extend the driving range of electric vehicle.

It is important for the motor control strategy to ensure that the motor operates most of the time in the high-efficiency regions of the efficiency map as shown in Figure 14 below. Due to the limitation functionalities of motor controller, this additional supervisory control will be implemented by a separate controller – an Energy Management System (EMS) using National Instruments Compact-RIO.

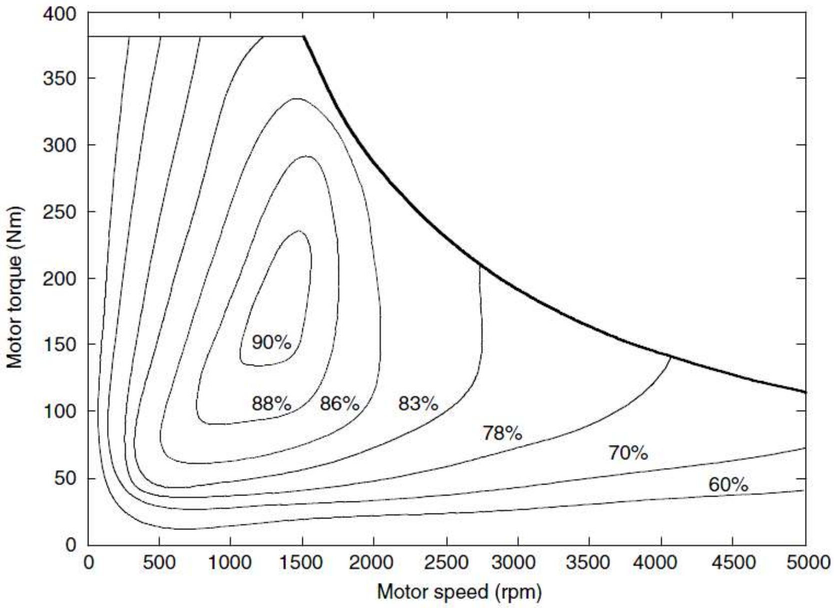


Figure 14 : Typical Electric Motor Efficiency Map

2.2.4 Motor Controller

The Curtis 1238R motor controller will be used to control the induction motor for this project that able to deliver smooth power. It provides flexibility and power through inclusion of a field-programmable logic controller embedded in a state-of-the-art motor controller. [6]

The embedded logic controller runs a fully functional field-oriented AC motor control operating system (OS) that can be user-tailored via parameter modification. The OS also contains logic to execute OEM-developed software, called VCL, which can be used to enhance the controller capabilities beyond the basics. [6]

VCL (Vehicle Control Language) is an innovative software programming language developed by Curtis. Several electric vehicle tasks are distinctively built into the VCL code. [6]

Figure 15 : Curtis 1238R Motor Controller

Features of Curtis 1238R motor controller are listed as follow. [6]

- Having algorithm for field oriented motor control for creating high efficient system.
- Technology of advanced Pulse Width Modulation (PWM) for efficient usage of battery, low harmonics of motor, low ripple of torque, and reduced losses of switching.
- Capable of doing wide torque or speed range and full regeneration.
- Speed control can be done smoothly for zero and low speed.
- Maximum performance can be maintained under varying conditions due to adaptation of control algorithm over motor temperature variation.
- Able to display real-time battery current, motor torque, RPM, and power estimations.
- Consistent performance under varying battery state of charge (SOC) because of power limiting maps.
- Capable of doing parallel processing of vehicle control, motor control, and user configurations tasks because of powerful operating system.
- Maximum distributed system control can be applied because of wide range of input/output.

2.3 Energy Management System in Electric Vehicle

Energy Management System is another controller besides the motor controller used in this electric vehicle. The main function of energy management system is to supervise the driver and monitor vehicle condition to ensure that the electric motor always operates at high efficiency region of efficiency map.

To reduce the development time of the EMS controller, modular instruments Compact-RIO from National Instruments will be used. NI Compact-RIO is a reconfigurable embedded control and data acquisition system. It has rugged hardware architecture which includes I/O modules, reconfigurable FPGA chassis, and real-time controller. Programmed in LabVIEW, user able to develop a variety of embedded control and monitoring applications. NI produces four slot Compact-RIO chassis and eight slot Compact-RIO chassis. For this project, eight slot Compact-RIO will be used as energy management system.

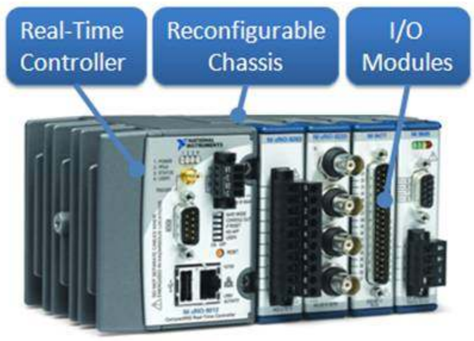


Figure 16 : Four Slot Compact-RIO

2.4 National Instruments LabVIEW

Compact-RIO that are going to be implemented as EMS controller are programmable using NI LabVIEW. LabVIEW is a graphical programming environment used by millions of engineers and scientists to develop advanced measurement, test and control system. Since its introduction in 1986, it offers great integration with thousands of hardware devices and provides hundreds of built-in libraries for advanced analysis and data visualization.

LabVIEW provides a lot of features and tools to create user-defined interfaces, and differentiable by its graphical, general-purpose programming language (known as G) along with an associated integrated compiler, a linker, and debugging tools. LabVIEW differs from most other programming languages in two major ways. First, G programming is done by wiring mutually graphical icons on a block diagram then compiled directly to machine code so the computer processors can execute it. All graphical representation in LabVIEW contains the same programming concepts found in text-based language, such as types of data, looping, handle of event, variables, and object-oriented programming.

NATIONAL INSTRUMENTS LabVIEW™ 2010

Figure 17 : National Instruments LabVIEW 2010

There are several LabVIEW add-ons that the author has been explored and studied which are listed as below:

- NI LabVIEW Real-Time Module
  This module helps user to develop applications that execute reliably and deterministically as autonomous systems on NI real-time devices such as PXI, and Compact-RIO.

- NI LabVIEW FPGA Module
  This module helps user to create field-programmable gate arrays (FPGAs) code on NI hardware without using VHDL or Verilog.

- NI Vision Development Module
  The NI Vision Development Module helps programmer to create an image processing application.

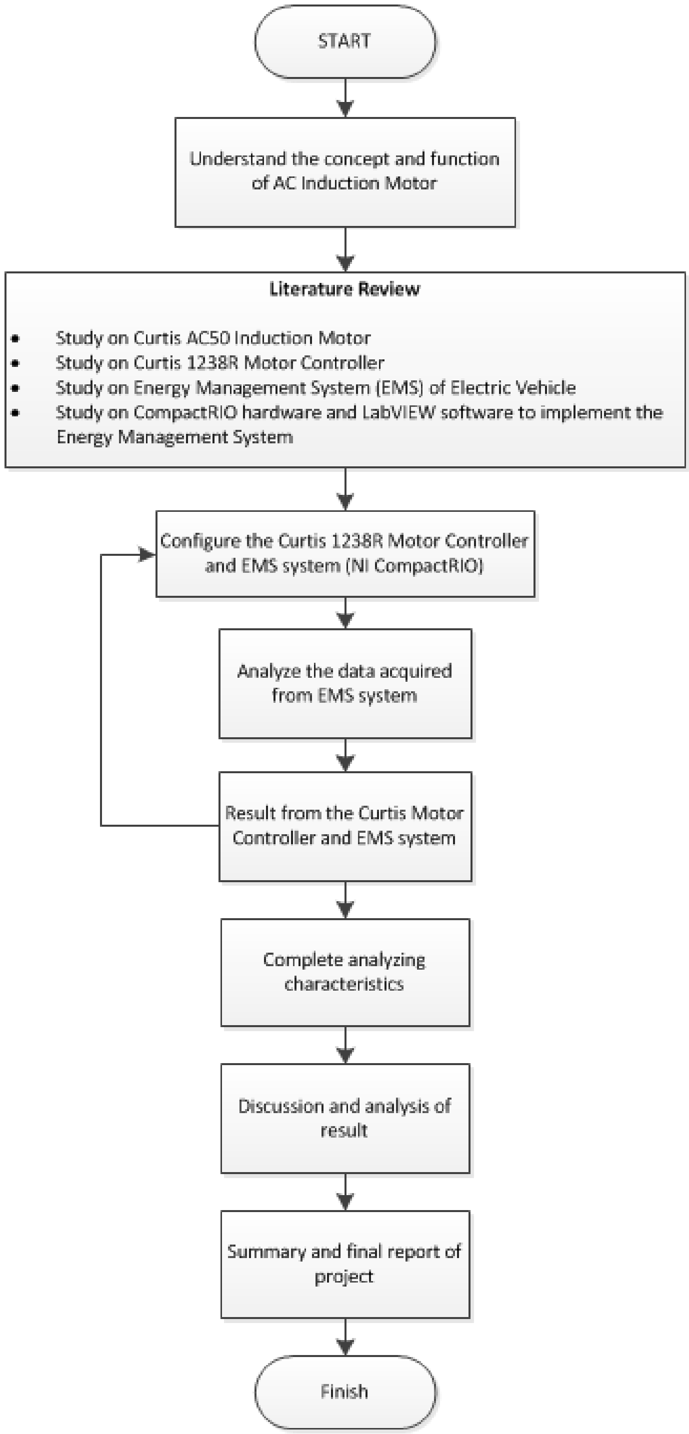
- NI LabVIEW Report Generation Toolkit for Word and Excel
  This module made user able to make and edit Word and Excel report using LabVIEW.

- NI LabVIEW Internet Toolkit
  This module consists of numerous of communication protocol such as FTP transfer in LabVIEW.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification



3.2 Method of Research and Investigation

In order to achieve the objectives of the project, research, implementation, and testing will be done on the configuration instrumentation for electrical control and energy management system of the electric vehicle. The research will be done from some resources such as books, journals, and any technical paper to obtain necessary information that related to this project.

The energy management system will be implemented using National Instrument's Compact-RIO hardware and LabVIEW software. The NI Compact-RIO will be connected to windows tablet PC as a User Interface which will advice driver during race.

3.3 Tools and Equipments

The required tools and equipments for completion of motor drive and energy Management for electric vehicle are listed as below. These equipments are sponsored by PROTON and some of them are obtainable at UTP. The software required is also available. The list of tools and equipments are:

1. Curtis AC50 induction motor
2. Curtis 1238R motor controller
3. Serial cable
4. Throttle and switch box made by Kelly Inc.
5. Main contactor
6. Key switch relay
7. DC Fuse 10A
8. LabVIEW 2010 Software
9. NI Compact-RIO 9104 (Energy Management System)
10. NI Power Supply, PS-15 for Compact-RIO
11. Tablet PC (User Interface)
12. ORION Battery Management System
13. LED indicator bar
14. 144 Volt 11.5kWh battery pack (72 units of 4 V 20 Ah cells)
15. Function Generator
16. Digital Multimeter

Figure 18 : Tools and Equipments required for this project

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Subsystems of Electric Vehicle

The predesigned important subsystems of electric vehicle are listed in the table 2 below.

No	Subsystem Name	Remark
A	Touch-screen driver interface (GUI)	Windows based PC
B	Gear box & differential gear	Manual 5-speed gearbox
C	Curtis AC50 Induction Motor	Curtis AC50 induction motor
D	Curtis 1238R Motor Controller	Curtis 1238R
E	Energy Management System (EMS) Controller	NI Compact-RIO 9004 8-slot
F	Battery pack & ORION Battery Management System	97.5 Volt 86Ah battery pack (13 series of 7.5 Volt 86 Ah unit)
G	LED Indicator Panel for Gear-shift assist	Custom self-made of LEDs array

Table 2 : The Subsystems of Electric Vehicle

The subsystems are connected each other using specific cable. The lists of cable type that connect the major subsystem are illustrated in the figure below.

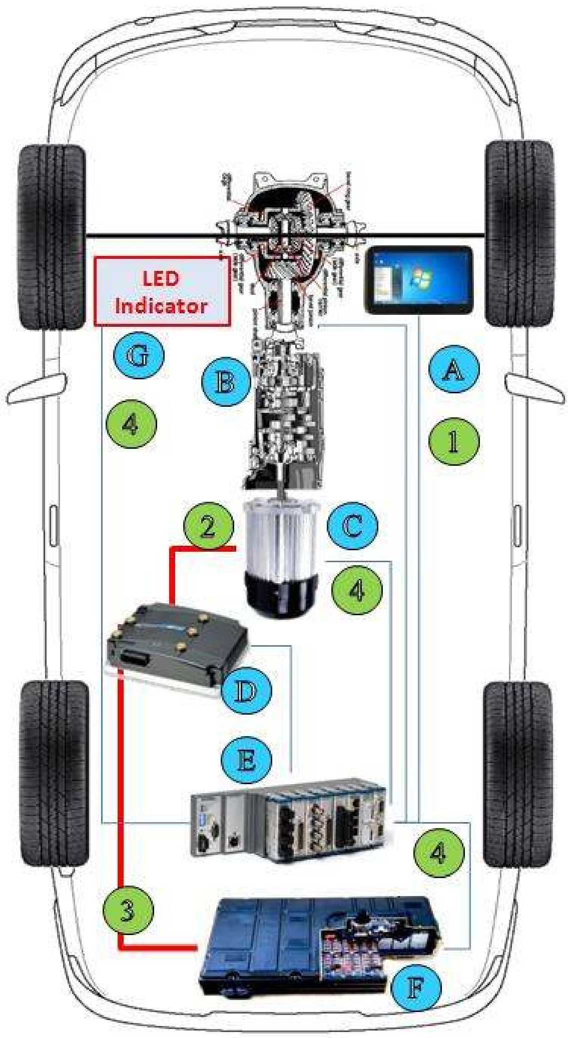


Figure 19 : Subsystems and cable connections of Electric Vehicle

No	Power/Signal Type	Cable Type
1	Ethernet network	UTP Cat-5 Ethernet
2	3-phase motor power	Heavy-gauge power cable
3	DC bus link +/-	Heavy-gauge power cable
4	Various signals	Single-core/multi-core signal cable

Table 3 : The Connections Details of Electric Vehicle's subsystems

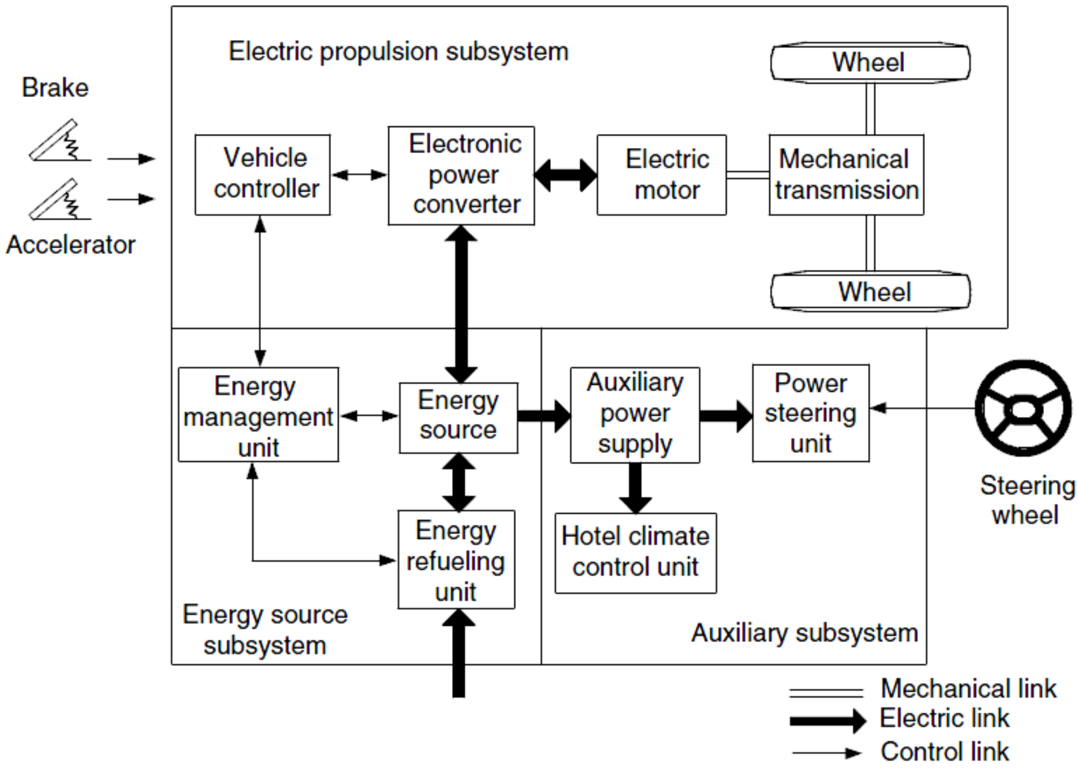


Figure 20 : General EV Configuration [11]

Current electric vehicle subsystems are made of 3 main subsystems which are. [11]

1. Electric motor propulsion

   It comprised of a vehicle controller, power electronic converter, electric motor, mechanical transmission, and driving wheels.

2. Energy source

   It consists of energy source, the energy management unit, and the energy refueling unit.

3. Auxiliary

   It consists of the power steering unit, the hotel climate control unit, and the auxiliary supply unit.

The accelerator and brake pedals give control inputs to the vehicle controller to provide proper control signal for electronic power converter. Due to the regenerative braking of vehicle, the backward power flow may occur and it can be restored to the energy source if the energy source is receptive. The energy management unit and vehicle controller are responsible for controlling the regenerative braking and its energy recovery. The auxiliary power supply provides the necessary power at different voltage levels for all the EV auxiliaries, such as power steering units and the vehicle's climate control.

4.2 EMS and Propulsion System Bench Test

Bench test for Energy Management System, Curtis 1238R motor controller, Curtis AC50 induction motor with general control box has been done. General control box consists of throttle potentiometer, brake potentiometer, key switch power, and forward-reverse toggle switch. The EMS, motor and motor controller bench test is illustrated in figure below.

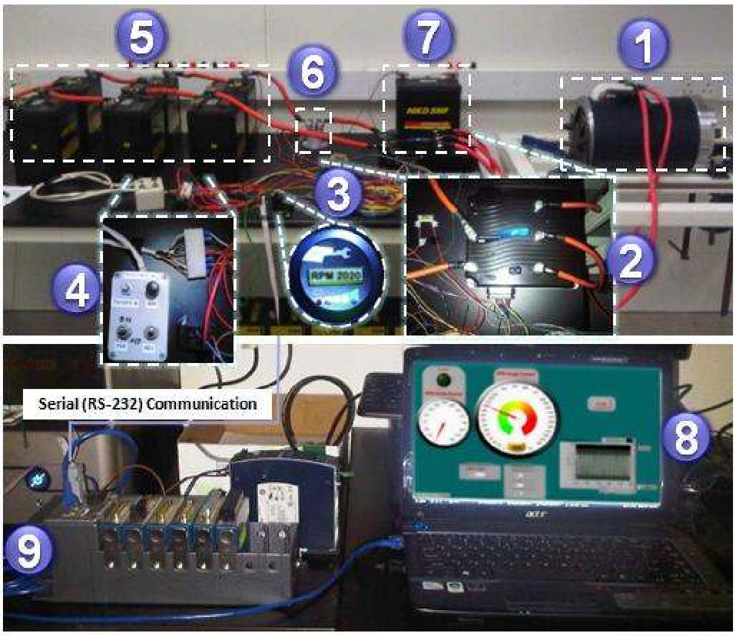


Figure 21 : Bench Test for EMS and Propulsion System

The list of each component of bench test for EMS, motor and motor controller are listed in table below.

No	Component
1	Curtis AC50 Induction Motor
2	Curtis 1238R Motor Controller
3	Molex Display 840
4	General Control Box & Relay
5	Battery Pack 72 Volt
6	Main Contactor
7	Battery 12 Volt
8	LabVIEW GUI
9	Real-Time Controller NI Compact-RIO

Table 4 : Components of EMS and Propulsion System Bench Test

4.3 AC Induction Motor No-load Test

A no-load test for Curtis AC50 induction motor has been performed to study the characteristics of the motor, the voltage and the current applied. The DC voltage supply of battery packs is 72.9 Volt. The battery packs consists of 6 pieces of battery 12 volt as illustrated in figure below.

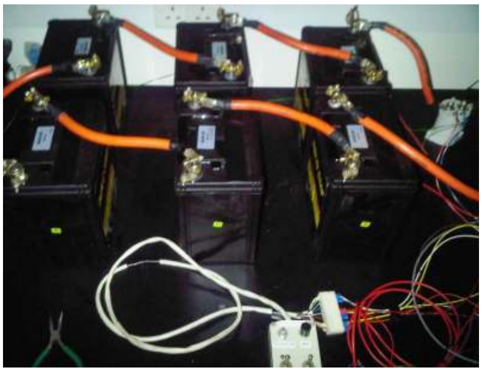


Figure 22 : Battery Packs

Figure 23 : AC Induction Motor for No-Load Test

The molex mini 840 that connected to serial port (Rx and Tx) of Curtis 1238R Motor Controller displays speed of motor in RPM as illustrated in figure below.

Figure 24 : Molex Mini 840 Display

An average current of U, V, and W in various speeds is shown in table below. Throttle knob is used to adjust the current supply to the Curtis 1238R Motor Controller start from 0 RPM.

Speed (RPM)	Current at U (Amp)	Current at V (Amp)	Current at W (Amp)
0	-6.50	-0.70	0.80
50	11.30	11.70	11.10
100	12.32	12.47	12.56
150	13.25	13.89	13.76
200	14.27	14.75	14.55
250	15.10	15.12	15.01
300	15.20	16.10	16.27
350	14.96	15.98	16.46
400	15.66	15.74	16.17
450	15.73	16.74	16.62
498	15.72	16.22	16.60

Table 5 : Results for No-Load Test

From the no-load test result, the graph of Current (Amp) versus Speed (RPM) has been obtained as illustrated in figure below. It shows that if more current applied to the motor, the speed of the motor will be higher. Speed of motor increases directly proportional to the current applied to it.

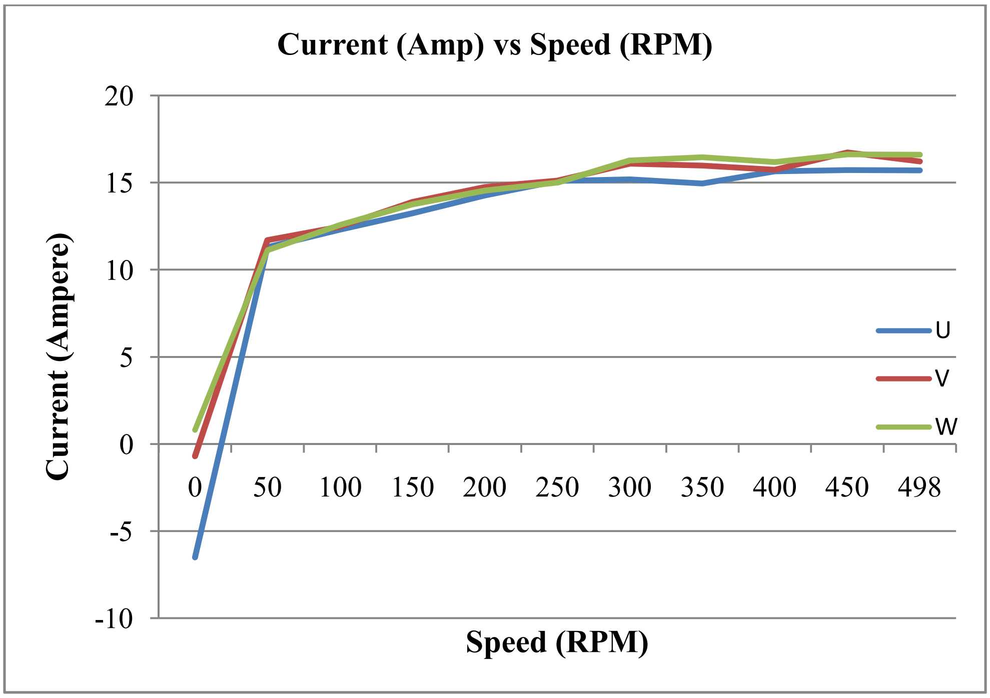


Figure 25 : Graph of Current versus Speed

4.4 Wiring Schematic of Electric Vehicle

Author with his supervisor have designed the major wiring schematic of electric vehicle as illustrated in the Figure 20. The 97.5 Volt battery pack is connected to manual contactor (for safety purpose) and 400A Fuse before connected to Curtis 1238R motor controller, Curtis AC50 induction motor, and DC-DC converter. The DC-DC converter will produce lower voltage to charge the 12 Volt batteries and to power up the Energy Management System (NI Compact-RIO), power steering motor, and brake vacuum pump. The detail of electric vehicle schematic given by Proton that has been implemented in this project is attached in the Appendix B.

There are five high-current ports, located on the controller housing as **B+**, **B-**, **U**, **V**, and **W**.

High Current Connections	
Terminal	**Function**
B+	Positive battery to controller
B-	Negative battery to controller
U	Motor phase U
V	Motor phase V
W	Motor phase W

Table 6 : High Current Connections of Motor Controller

Based on the Curtis 1238R motor controller manual, there are several high current wiring recommendations that need to consider.[6]

- Battery cables (**B+**, **B-**)

  These two cables must be run close to each other between the controller and the battery. High quality copper cables are recommended to use. To avoid noise in the controller the high power cable must not run across the middle of the controller.

- Motor wiring (**U**, **V**, **W**)

  The three phase cables should have approximately the same length and bundled together since they run between the controller and the motor. In applications that seek for the lowest possible emissions, a shield can be positioned around the bundled motor cables and connected to the **B-** terminal at the controller. Typical installations will readily pass the emissions standards without a shield. Low power signal cable should not be located near high power cables. When required, low power signal cable should cross the motor cables at a right angle to reduce noise combination.

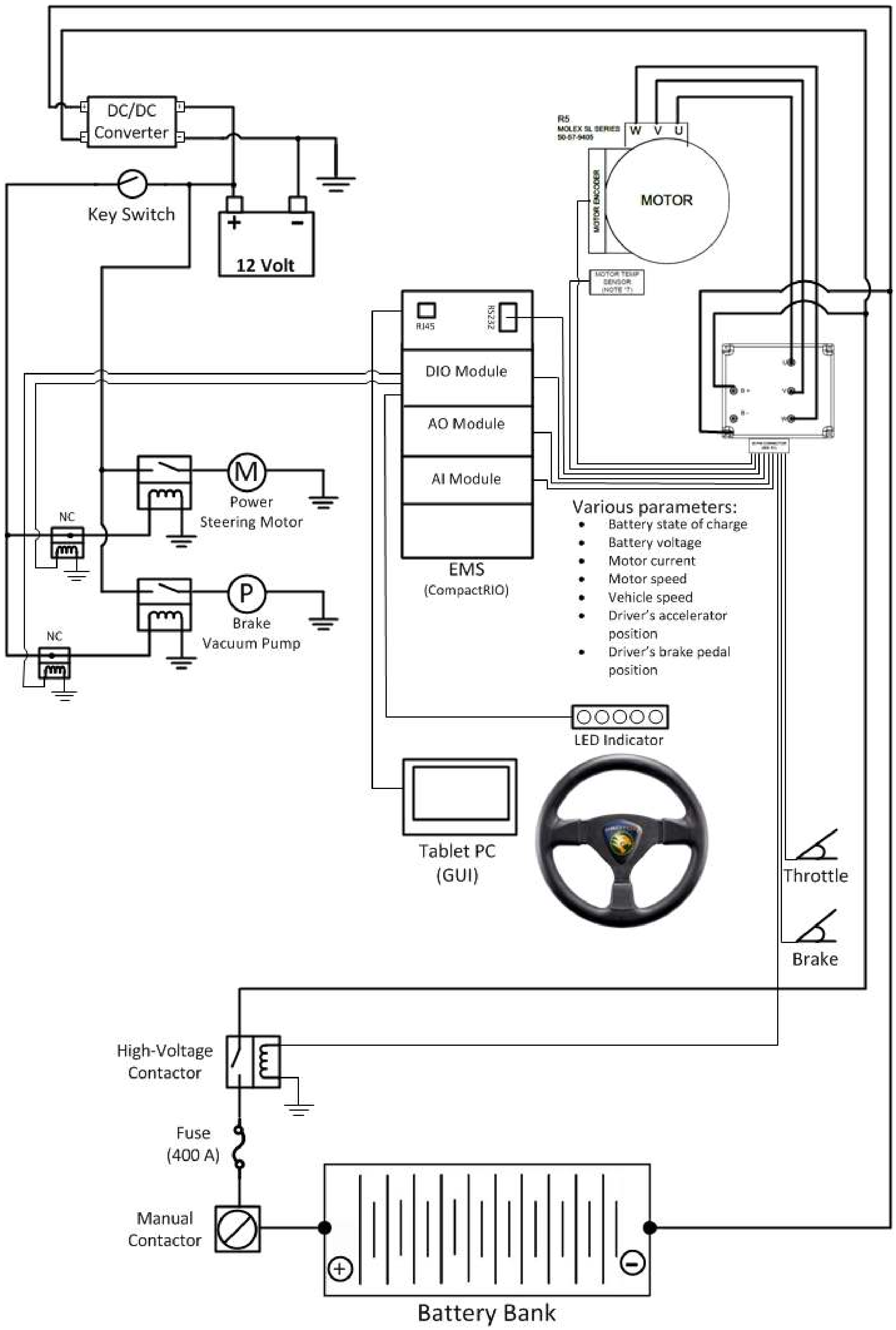


Figure 26 : Wiring Schematic of Electric Vehicle

4.4.1 Motor Controller Wiring

The basic wiring diagram of motor controller Curtis 1238R is shown below. The main contactor coil must be wired directly to the controller as shown in Figure 20 to meet EEC safety requirements. The motor controller can be programmed to check for welded or missing contactor faults and uses the main contactor coil driver output to remove power from the controller and motor in the event of various other faults. This feature will be implemented at electric vehicle for safety issues.

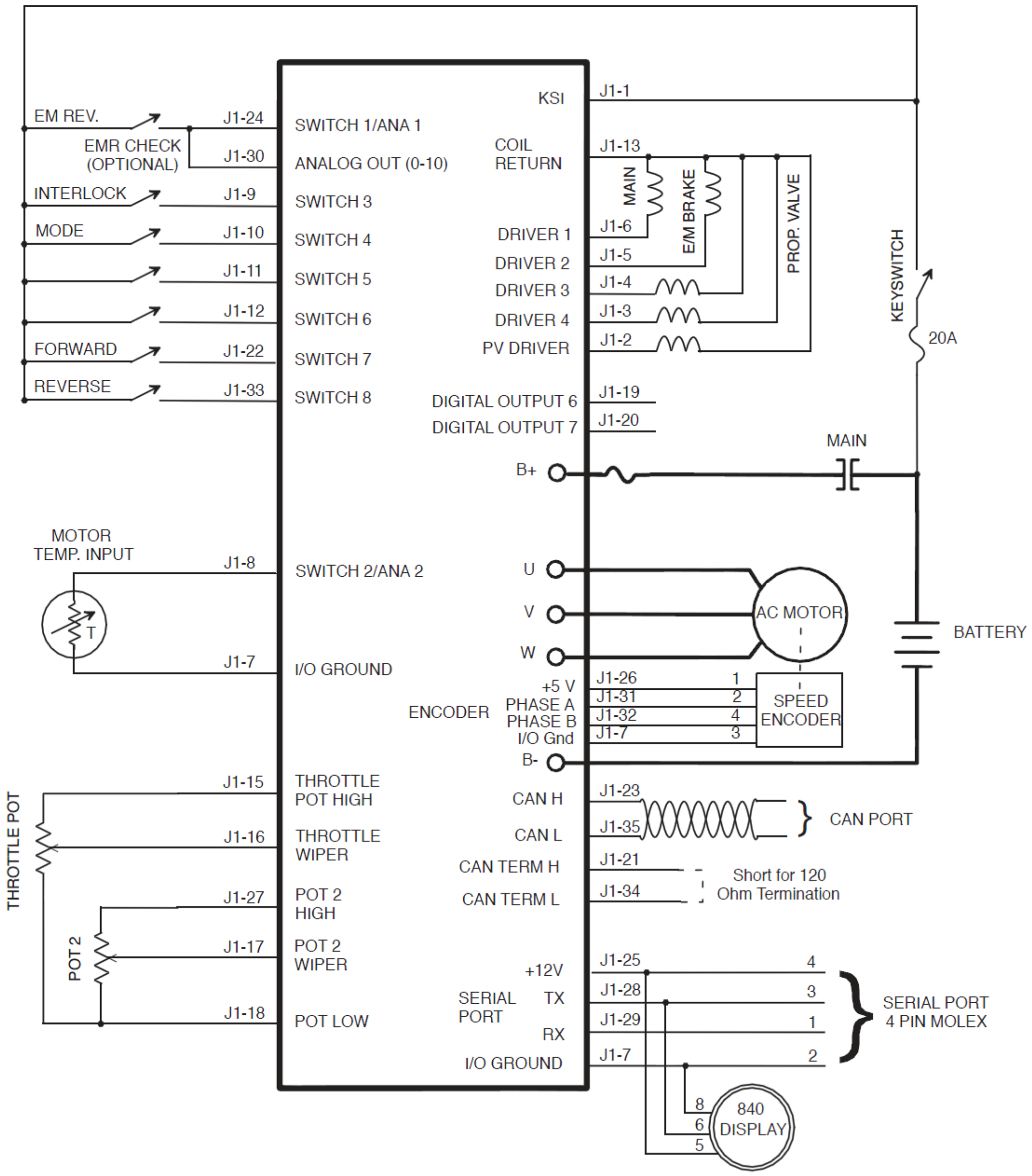


Figure 27 : Basic Wiring Diagram for Curtis 1238R Motor Controller [6]

4.5 Energy Management System Controller I/O

The detailed lists of input/output of Energy Management System (EMS) Controller can be found at the appendix A.

4.6 RPM Reading from Motor Controller

The wiring of motor controller, throttle box, serial data display model 840 and battery packs has been completed. After turn ON the main contactor the current will flow from battery packs to the motor controller and the controller will turn ON. After initialization finished, model 840 will display the battery packs state of charge. The LED service indicator will turn ON whenever the motor controller needs maintenance. The speed (RPM) of motor can be manually set by adjusting the knob of throttle box.

The pinout configuration and the details view of model 840 is illustrated in figure and table below.[6] It shows possibility to tap in the serial data from motor as an input of Energy Management System (EMS).

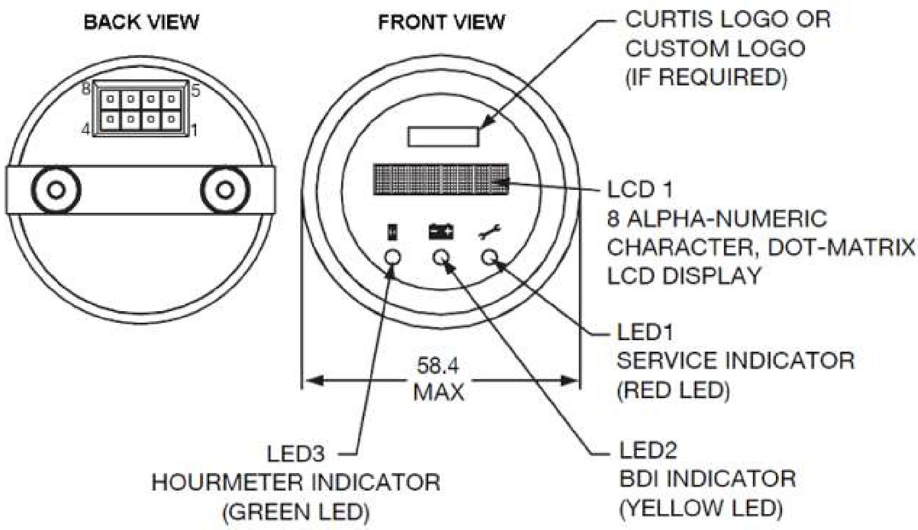


Figure 28 : Serial Data Display Model 840

Pin No.	Function	Remark
1,2,3,4,7	N.C.	Not Used
5	Power Input +	+12V/15V From Motor Controller
6	Receive Communication Input	Tx port of Motor Controller
8	Power Input -	Common / Gnd From Motor Controller

Table 7 : Pin out Configuration of Model 840

The throttle and switch box is illustrated in figure below. After the PWR switch is ON, the speed of motor (RPM) can be manually set by adjusting the throttle potentiometer. If the REV (reverse) switch is ON, motor will spin reversed given a throttle is set.

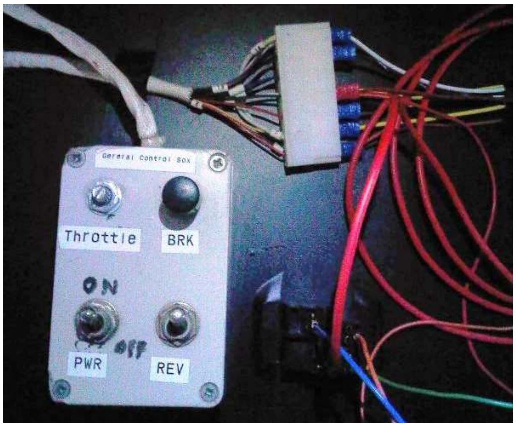


Figure 29 : Throttle and Switch Box

Figure 30 : Model 840 shows the Speed of Motor

In order to get the RPM information from motor controller, the serial connection behind model 840 need to be branched out and connected to Compact-RIO as Energy Management System using serial (RS-232) connection. The branch out of serial connection is illustrated in figure below.

Figure 31 : Serial Branch Out

For testing purpose, the serial connection branch out behind model 840 is connected to EMS/Compact-RIO at serial port as illustrated in figure below.

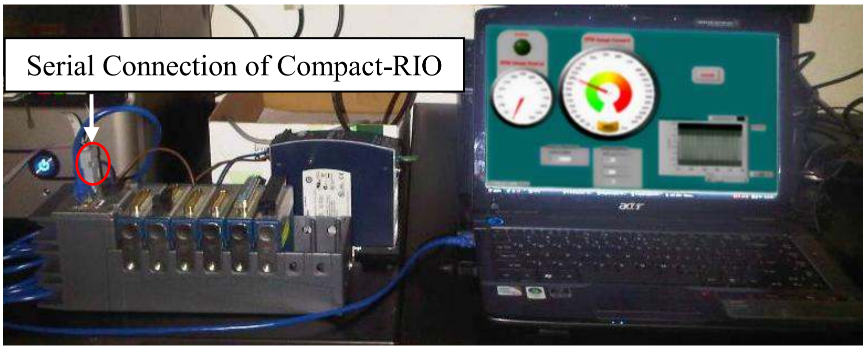


Figure 32 : Serial Connection at EMS

EMS is able to communicate with Curtis 1238R motor controller through serial (RS-232) communication using the following configuration.

Parameter	**Value**
Timeout	10000 mS
Baud Rate	9600 kbps
Data Bits	8
Parity	None
Stop bits	0
Flow control	None

Table 8 : Serial Configuration

Serial reading program has been created using LabVIEW. The user interface and block diagram (code) of the program is illustrated in figure below.

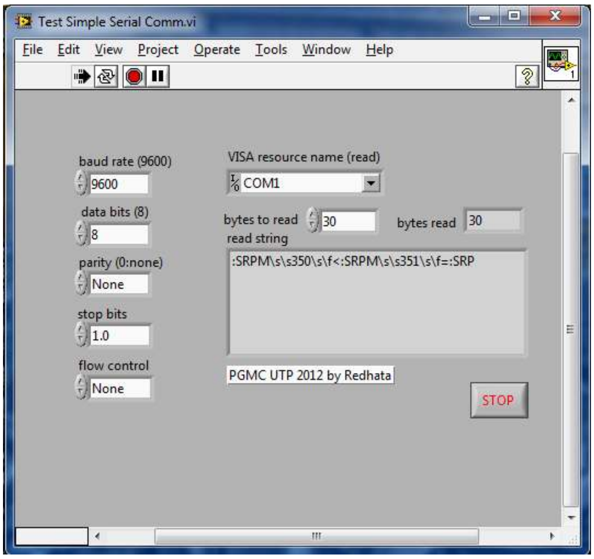


Figure 33 : User Interface of Serial Read Test

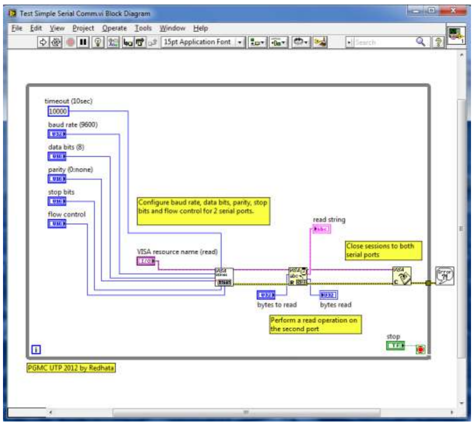


Figure 34 : Block Diagram of Serial Read Test

The data type of serial communication output from motor controller is a string with a characters like “:SRPM\s\s350\s\f<:SRPM\s\s351\s\f=:SRP”. The motor speed information can be obtained by extracting the desired part of that string. The character “\s” is equal with “space” in normal display. Therefore the converter algorithm is needed. First the program will execute “match pattern” of “:SRPM” for input string, if function does not find match is will give -1 and the case structure will go to “False” case which is doing nothing. If the function find match it will not give -1, and the case structure will go to “True” case. In the true case, the output of match pattern will be tunneled into the case. “After substring” output of match pattern will give “\s\s350\s\f<:SRPM\s\s351\s\f=:SRP”. In the true case, the “string subset” function is performed to take 6 character length of “after substring” starting from first character, which means it will take “\s\s350\s”. Character “\s” is considered 1 character length. After that “Fract/Exp String To Number” function is performed to convert string into number with double data type which will convert “\s\s350\s” to 350.

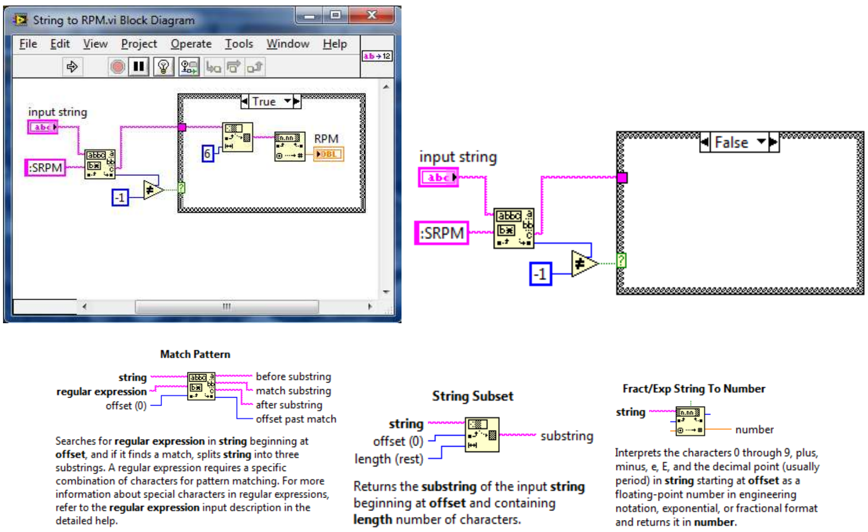


Figure 35 : Block Diagram of String to RPM.vi

The limitation of this algorithm is it only takes the first speed information if a bunch of data coming in input string. For example, if the input string is “:SRPM\s\s350\s\f<:SRPM\s\s351\s\f=:SRPM\s\s349\s\f”, it only take the 350 and ignored the 351 and 349 speed information. Therefore an enhanced algorithm is need. After several testing, author find the best algorithm to obtain all the speed information in input string as illustrated in figure below.

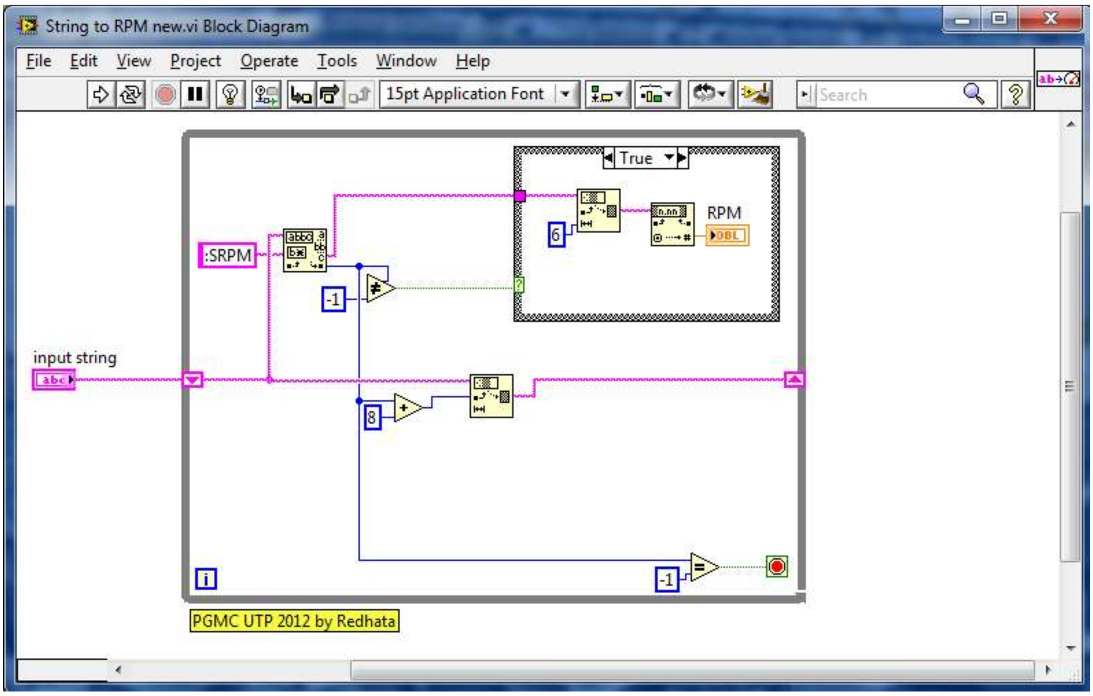


Figure 36 : Block Diagram of String to RPM new.vi

The new algorithm as a while loop and it only stop when “Match Pattern” function give output “-1”. The upper part of algorithm is similar with the previous one, after finding the first speed information it is will not stop as long as “Match Pattern” still find “:SRPM” in the string shift register. Another “String Subset” function is added to take the (offset past match + 8)th character and the rest for the next cycle of while loop. For example, after the first iteration, given the initial input string is “:SRPM\s\s350\s\f<:SRPM\s\s351\s\f=:SRPM\s\s349\s\f”. The offset past match is 6, therefore the “String Subset” function will take starting from (6+8)th character to the rest. At the end of first iteration the string shift register will contain “s\f<:SRPM\s\s351\s\f=:SRPM\s\s349\s\f”. In the second iteration it will give 351 as speed information and continue to iterate until the last speed information is found in string shift register.

After getting the speed information data in double numeric (decimal), another program will display the information in the user interface as illustrated in figure below. The indicator looks responsive whenever the throttle input is changed. If the Reverse switch is ON and the throttle is pressed the motor will spin reverse.

For testing purpose, RPM Gauge Reverse is placed in User Interface. The LED Reverse will turn ON if motor spin in reverse direction. In the final program there will be no RPM Gauge Reverse but the Reverse LED indicator will remain to indicate the parking mode of vehicle.

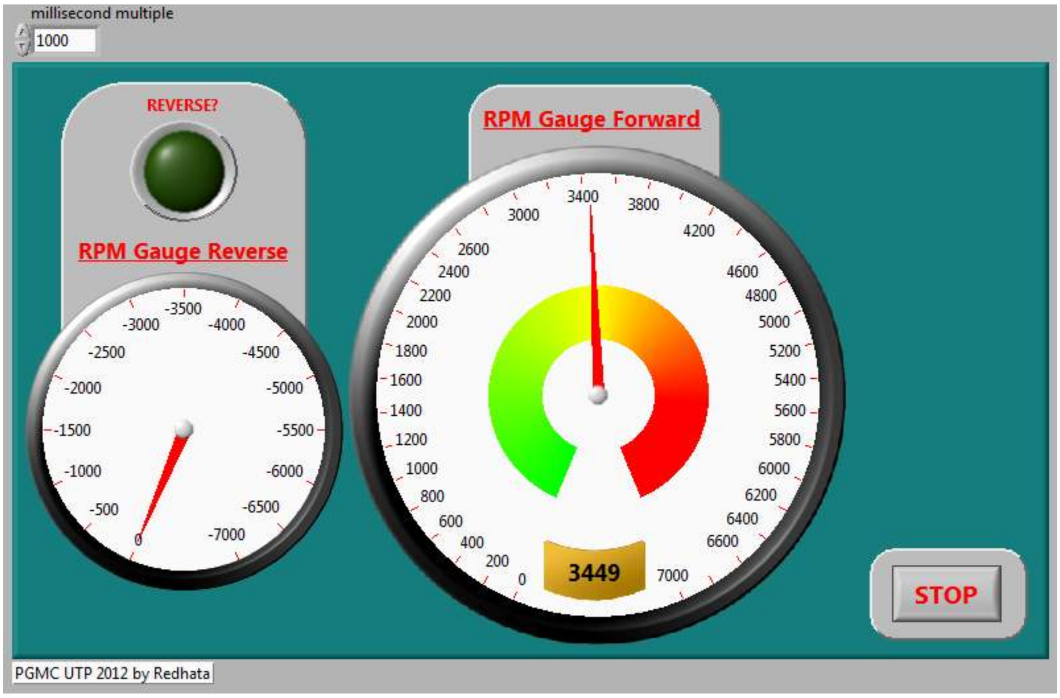


Figure 37 : User Interface of RPM Reading in Forward Direction

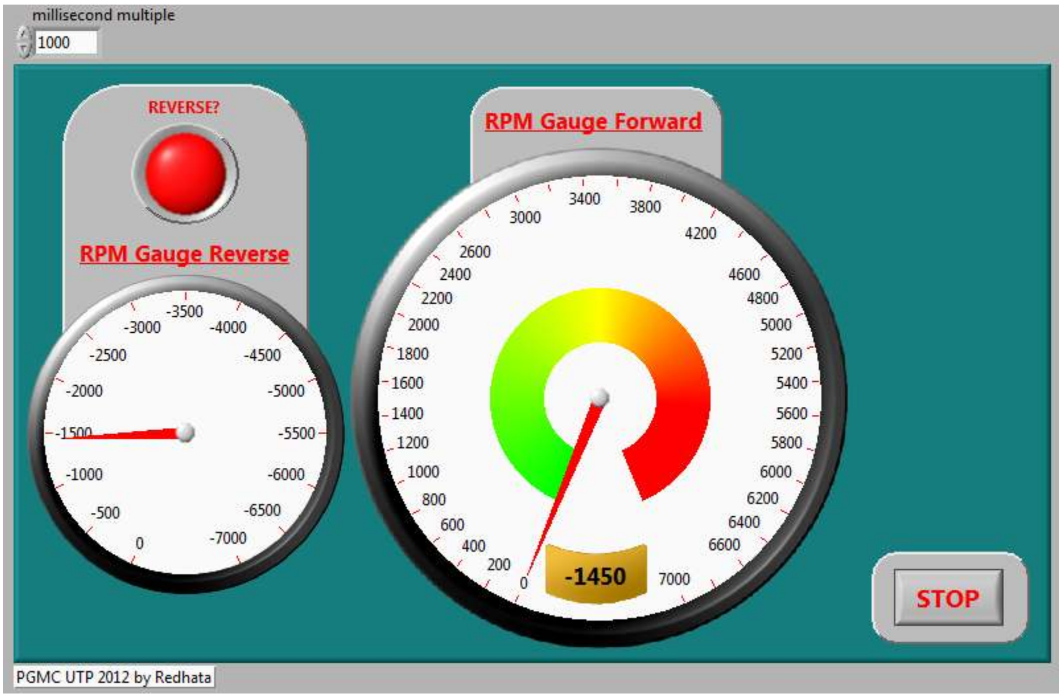


Figure 38 : User Interface of RPM Reading in Reverse Direction

The millisecond multiple is a parameter of delay before reading the serial data. The 1000ms delay is set to ensure the reading rate is almost equal with data rate of serial. If program read serial too fast, the indicator will not show RPM properly. The block diagram of Testing Reading RPM.vi is illustrated in figure below.

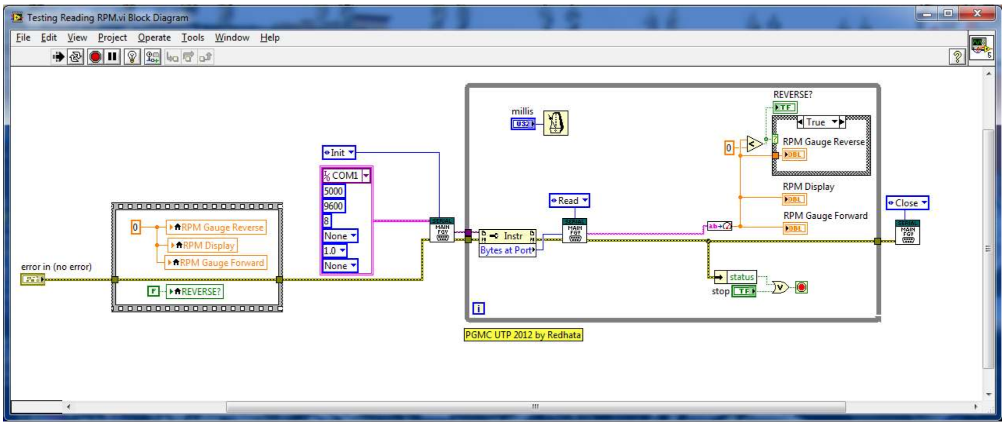


Figure 39 : Block Diagram of RPM Reading using Serial Connection

In the block diagram above there is serial communication program block as illustrated in figure below. The Serial Comm.vi has a task to initialize the serial communication in the initialization part. In the while loop Serial Comm.vi will read serial data continuously as long as error does not occur or stop button is not pressed. The while loop in Testing Reading RPM.vi will stop when an error is occurred or stop button is pressed.

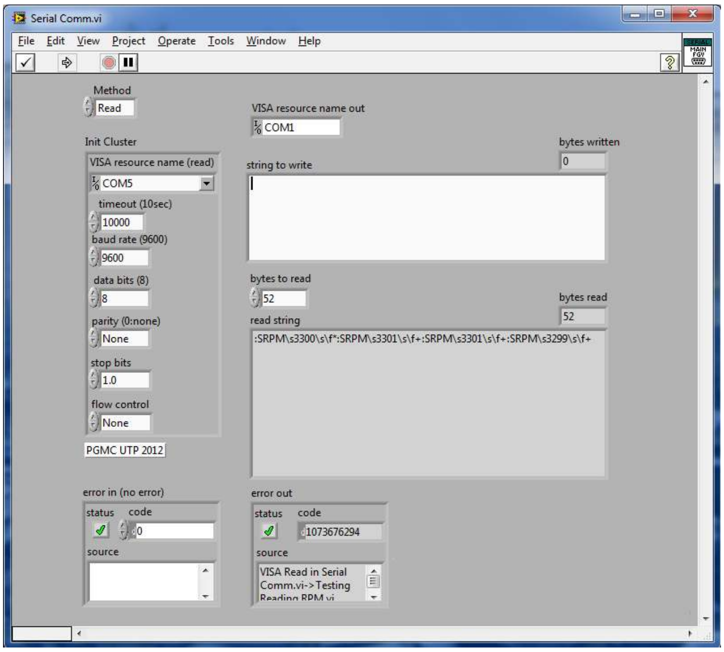


Figure 40 : Front Panel of Serial Comm.vi

The Serial Comm.vi is has a four cases which are Initialization, Read, Write and Close. The architecture of this program is called Functional Global Variable (FGV) in LabVIEW. It is very useful architecture because the program stored the information in the shift registers. When it is called in the other part of main program, the data is still available and accessible at shift registers.

In the initialization case, the parameter of serial communication is being set such as VISA resource name, timeout, baud rate, data bits, parity, and stop bits. The initialization parameters are bundled into an Init Cluster. The reason for bundling all parameters into a cluster is to make the block diagram looks neat.

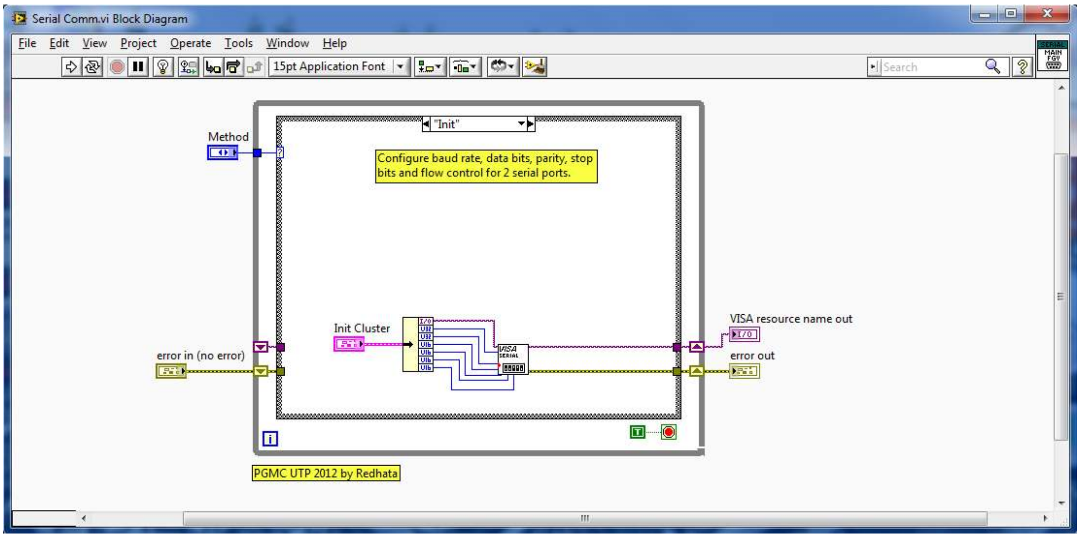


Figure 41 : Block Diagram of Serial Comm.vi Init Case

In the read case, the VISA read function is executed to read all the available data at serial port. If error occurs, it will clear the error and read serial port again.

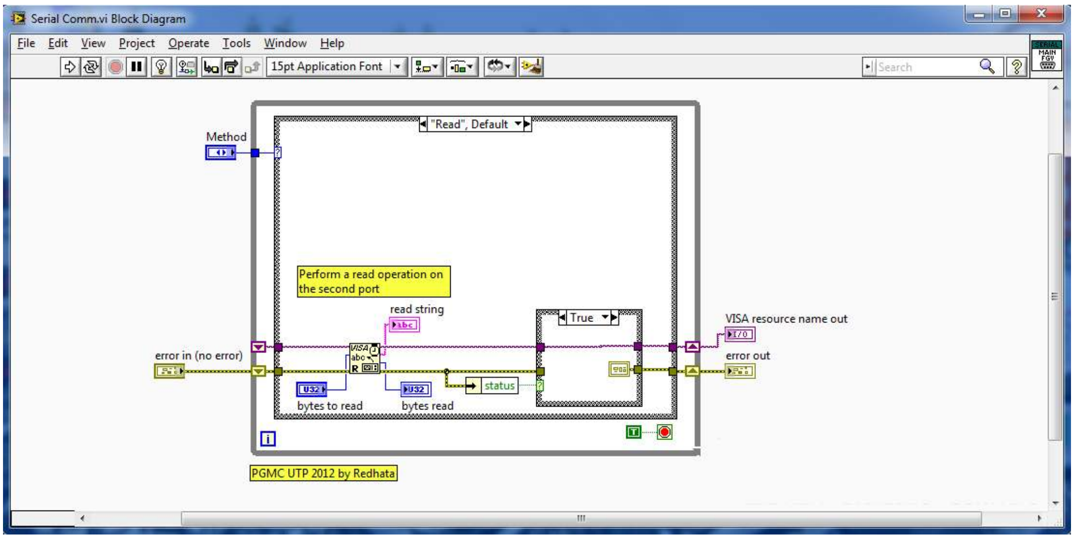


Figure 42 : Block Diagram of Serial Comm.vi Read Case

Until this time, write case of Serial Comm.vi has not been used yet. It would be beneficial after the motor controller is reprogrammed to accept speed set point for closed loop PID speed control using serial (RS-232) connection. We are waiting for the Curtis Programming Software in order to reprogram the motor controller.

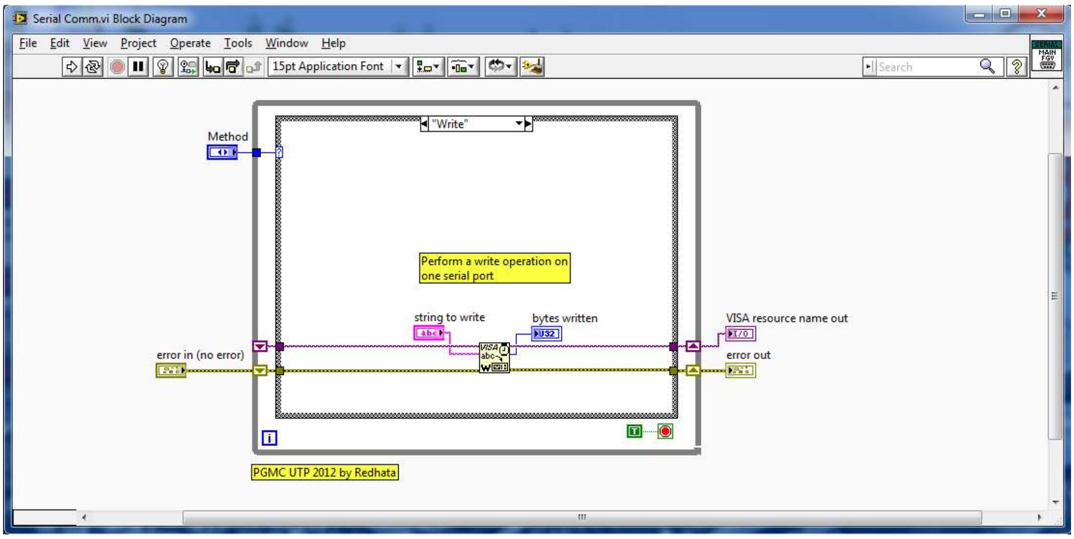


Figure 43 : Block Diagram of Serial Comm.vi Write Case

In close case of Serial Comm.vi, all the sessions and memory of serial related functions will be closed properly to preserve the available memory of Compact-RIO.

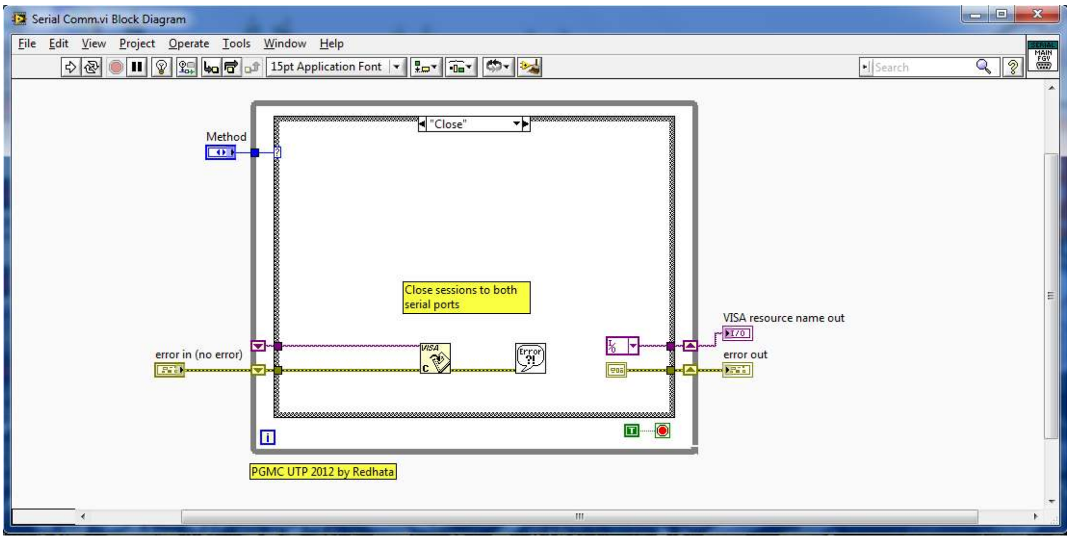


Figure 44 : Block Diagram of Serial Comm.vi Close Case

4.7 Input Reading of Energy Management System Controller

NI Compact-RIO has an ability to reconfigure its input(s)/output(s) by using

LabVIEW FPGA programming. The FPGA code for analog input reading has been deployed inside EMS controller as illustrated in figure below.

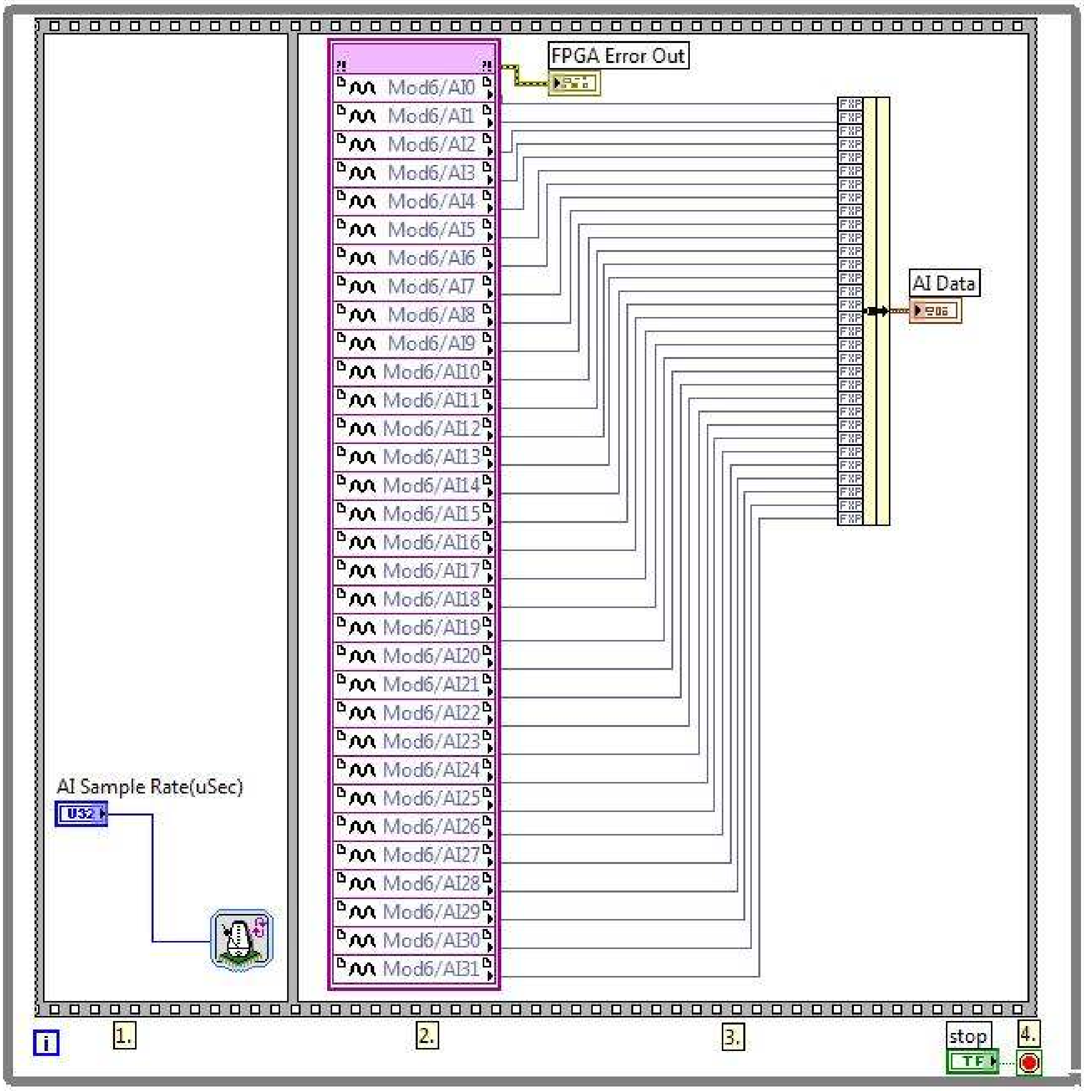


Figure 45 : FPGA Code of Analog Input Reading

The FPGA code has four steps as illustrated in Figure 45 above which are as follow.

1. Set the Analog Input acquisition loop rate. This AI Sample Rate control (uSec) can be customized in the Main Program.
2. Use the FPGA I/O node to read AI channels 0 through 31.
3. Update AI Data control with current data acquired.
4. Stop the loop if the Stop control is true.

The User Interface of Main Program with analog input reading of current is illustrated in figure below. The EMS/Compact-RIO communicates with Curtis 1238R motor controller using serial communication.

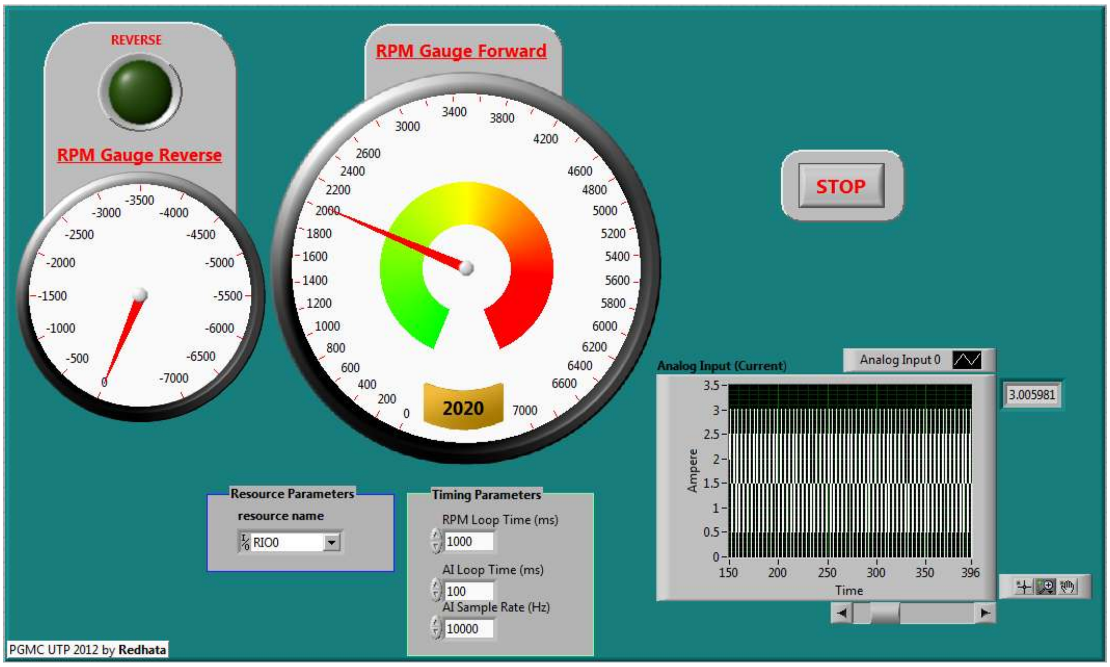


Figure 46 : User Interface with Analog Input Reading

Other features of EMS are still under development until this report is written. Inputs to the energy management controller include:

- Battery state of charge (SOC)
- Battery voltage
- Motor current
- Motor speed
- Vehicle speed
- Gear position
- Relevant Temperature Measurement

4.8 Data Acquisition Program of EMS

The Data Acquisition (DAQ) program also has been developed. It will be deployed in EMS and tested after all the components of electric vehicle installed inside the chassis. Some of parameter that needs to log during vehicle testing is battery pack voltage, battery unit state of charge, motor current, motor speed, vehicle speed, gear position, and battery temperature data. The designed DAQ program is illustrated in figure below which able to log multi digital and analog data.

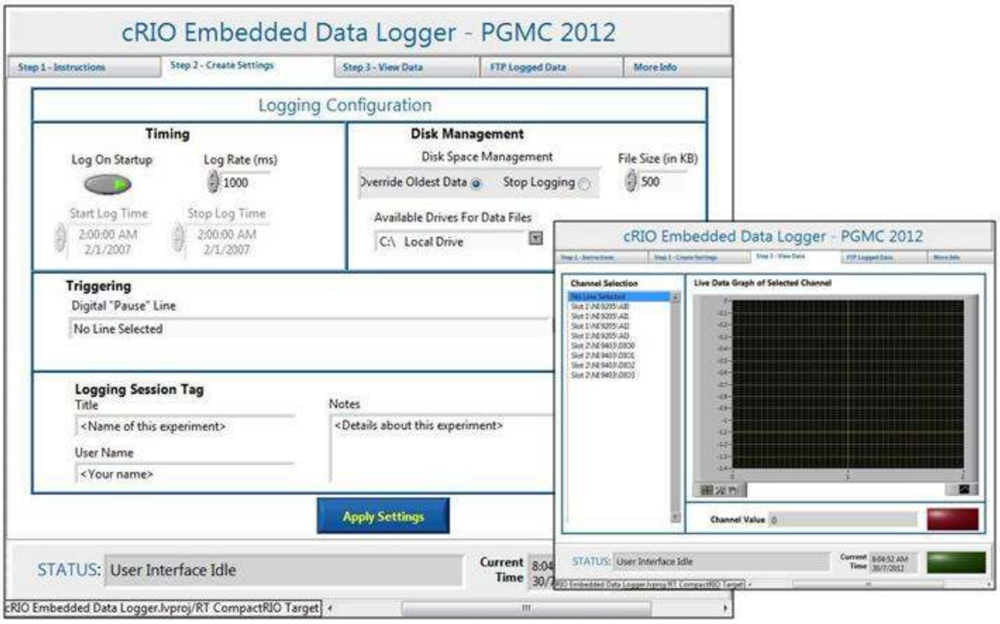


Figure 47   : Data Acquisition Program Deployed inside EMS

4.9 User Interface for Driver

The first design for driver assistance user interface is illustrated in figure below that will be displayed by Tablet PC connected to NI Compact-RIO. The horizontal sliding bar indicates speed of vehicle, if the current speed is perfect the needle position will show perfect 10, and vice versa. When the arrow is going UP above the "Throttle", the driver needs to press the throttle. When the arrow is going DOWN above the "Gear", the driver needs to change the gear position into lower gear as indicated by LED indicator at bottom of window. There are five LEDs that indicating five gear position.

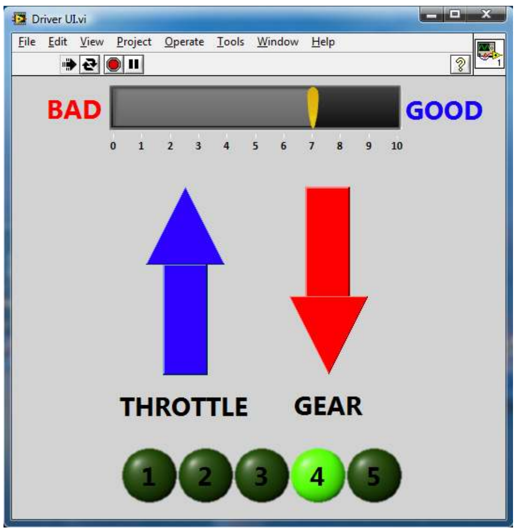


Figure 48   : First Design of User Interface for Driver

The second design for driver assistance user interface is illustrated in figure below. It also will be displayed by Tablet PC connected to NI Compact-RIO. It has more indicators compared to the first design which is important parameters of electric vehicle.

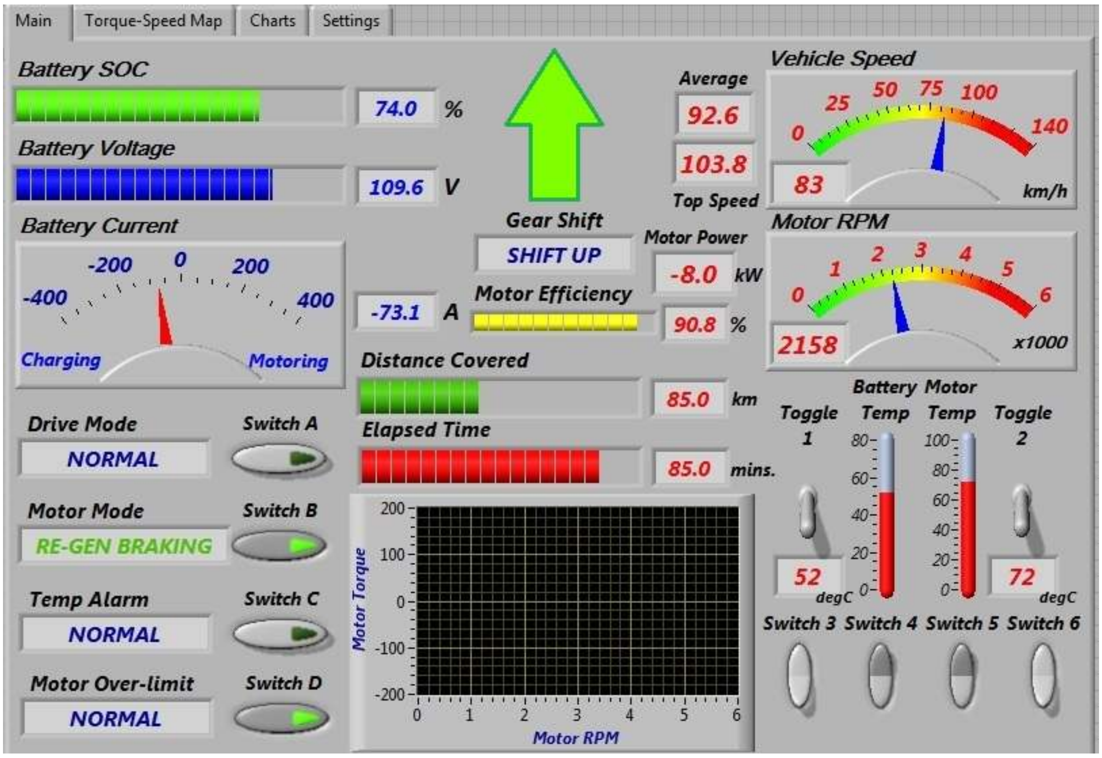


Figure 49 : Second Design of User Interface for Driver

4.10 Battery Charging and BMS Bench Test

Bench test for Battery Charging and BMS communication with programmer has been done. The battery charger used is Manzanita Micro PFC-50. The Battery Management System is produced by ORION. The schematic of battery charging and BMS at electric vehicle is illustrated in Figure 50 below.

During programming mode, the CANbus of ORION BMS connected to Laptop through CANadaptor to convert CAN to USB. The programming software is available at BMS website.

ORION BMS has thermal management system feature which consists of four thermistors for measuring battery temperature, an ON/OFF output, and PWM output designed to control a fan and a voltage monitoring circuit designed to ensure that a fan is operated properly. Currently four themistors has been connected to BMS but fan blower has not been installed.

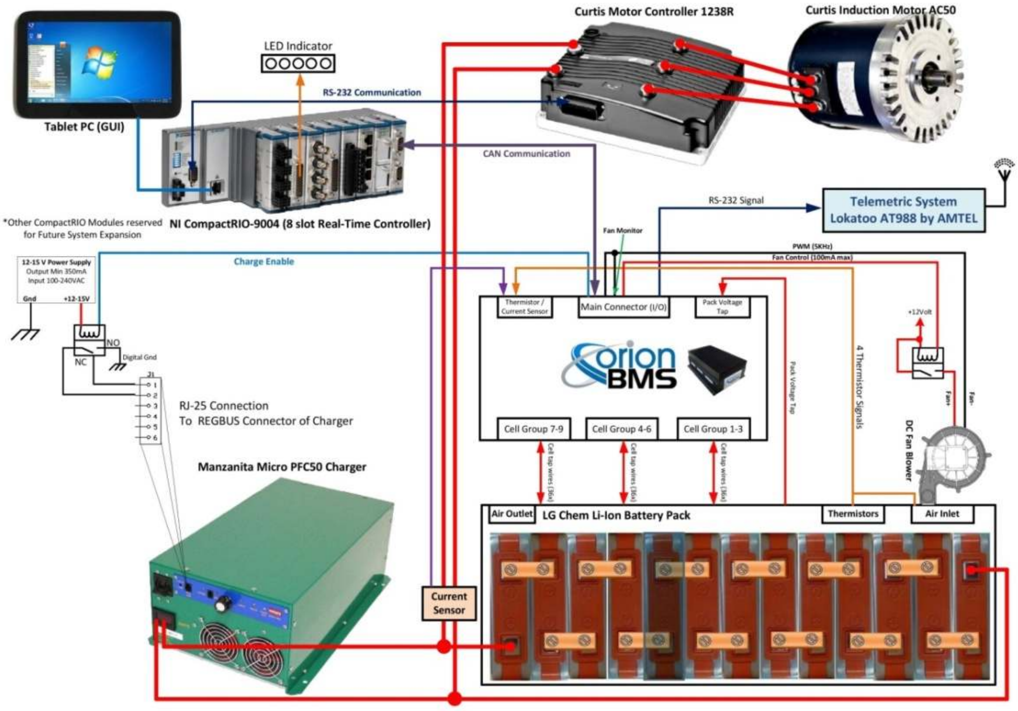


Figure 50 : Schematic of Battery Charging and BMS

Figure 51 : Bench Test of Battery Charging and BMS

The components of battery charging and BMS bench test is listed in table below.

No	Component
1	Power Supply – 12 VDC
2	ORION BMS
3	Laptop to program and monitor BMS in programming mode
4	Battery pack 60V
5	Manzanita Micro PFC50 Charger
6	AC Switch Box

Table 9 : Components of Battery Charging and BMS Bench Test

The temperature reading of sensors can be seen as life graph data as illustrated in figure below.

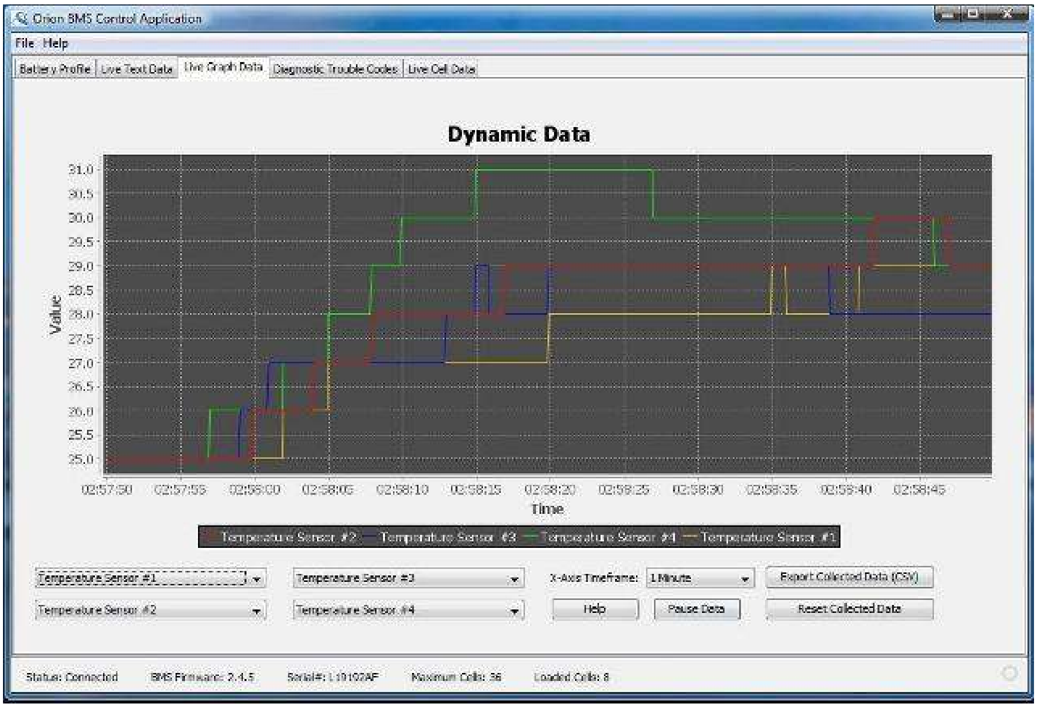


Figure 52 : Live Graph of BMS Temperature Monitoring

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The study and improvement actions associated to transportation have emphasized the improvement of high effectiveness, zero pollution, and safe transportation. Electric Vehicle (EV), Hybrid Electric Vehicle (HEV) and fuel cell vehicle have been projected to substitute conventional vehicle in the near future. Electric vehicles have enhanced their performance and made suitable for commercial and domestic use during the recent years. However, pure electric vehicles still have not achieved driving ranges as superior as internal combustion engine vehicles. This problem is as a result of the limited energy storage in the majority electric batteries. The Energy Management System (EMS) lets the vehicle use this limited energy storage wisely.

AC induction motor is no-commutator motor drives that offer a number of benefits over conventional DC commutator motor drives for the electric driving force of EVs and HEVs. The benefits of AC induction motor compared to DC motor is light heaviness, small dimensions, low price, and high efficiency which are mainly significant for EV and HEV purposes.

Energy Management System is another controller besides the motor controller and Battery Management System controller used in this electric vehicle. The main function of energy management system is to supervise the driver and monitor vehicle condition to ensure that the electric motor always operates at high efficiency region of efficiency map. The energy management system will be implemented using National Instruments Compact-RIO hardware and LabVIEW software. The NI Compact-RIO will be connected to windows tablet PC as a User Interface which will advice driver during race. Hopefully, this project will be able to contribute towards the automotive industry and getting the special prize at Proton Green Mobility Challenge 2012.

5.2 Recommendations for Future Work

The next step will be vehicle run testing after all the components installed inside vehicle. Currently the author is waiting for the mechanical mounting of motor controller to be finished. After the basic configuration of vehicle testing the tuning of PID inside motor controller will be done. Therefore a lot of experimentation needs to be completed before the actual date of Proton Green Mobility Challenge 2012. Further investigation on the profiles of current, voltage, and various control inputs is recommended.

Author also suggests doing more research on algorithm for Energy Management System and AC Induction Motor Speed Control. In addition, study and familiarize with motor control, specifically with the PID algorithm. In the future, we should also investigate other control algorithm, such as modified PID and fuzzy logic, and compare the performance between the different algorithms. Data and results obtained during testing can be kept for improvement of the project in the future.

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APPENDICES

APPENDIX A

EMS CONTROLLER I/O SCHEDULE

EMS Controller I/O Schedule

CompactRIO Controller - NI cRIO-9004:

8-slot separeted 195 MHz Real-Time Controller, 64MB DRAM and 3M Gate FPGA Chassis (NI Part Number: 188747D-02)

Note : Under 'Controller Details', NI 9403 B: DI 4 refers to:

1) Module NI 9403 (digital IO module) B - the second digital IO module in the controller

2) Digital Input line/channel 4 - the fourth DI line in the module

DI: Digital Input
DO: Digital Output
CTI: Counter / Timer Input
CTO: Counter / Timer Output
AI: Analog Input (+/- 10 V)
AIH: Analog Input (Higher Voltage)
TC: Thermocouple Input

No	ID	Subsystem	Parameter	Range	I/O Type	I/O	Sensor / Actuator Details	Controller Details
INDUCTION MOTOR (CURTIS AC 50: 72-108V; 550 Amp; 52 HP; 6500 RPM; Efficiency: 89%)								
1	M1	AC Induction Motor	Temperature input	-10 deg C to 200 deg C	Analog voltage (thermocouple)	I	Thermocouple (K-type)	NI 9211: TC 1
2	M2	AC Induction Motor	Rotor position encoder input	0 - 360 deg; 0.5 deg resolution; 0 - ?? pulses/rev	TTL digital pulse train (Quadrature)	I	Rotary encoder (magnetic/optical)	NI 9401 A: CTI 1, CTI 2, CTI 3
3	M3	AC Induction Motor	Hall sensor input	High / Low	Digital TTL: Simple DI	I	Hall sensor	NI 9401 A: CTI 4, CTI 5, CTI 6
4	M4	AC Induction Motor	Motor speed input	0 to 10000 rpm	TTL digital pulse train	I	N/A	Not required
5	M5	AC Induction Motor	Motor direction input	CW or CCW	Digital: Simple DI	I	TBC	NI 9403: DI 1
MOTOR CONTROLLER (CURTIS 1238R: 24 - 36 V; 650 Amp;)								
6	D1	Motor Controller	Phase U current input	Current: -300 to 300 Amps. Actual: -10 to 10 V	Analog voltage	I	Integrated current sensor inside IGBT drive	NI 9205: AI 1
7	D2	Motor Controller	Phase V current input	Current: -300 to 300 Amps. Actual: -10 to 10 V	Analog voltage	I	Integrated current sensor inside IGBT drive	NI 9205: AI 2
8	D3	Motor Controller	Phase W current input	Current: -300 to 300 Amps. Actual: -10 to 10 V	Analog voltage	I	Integrated current sensor inside IGBT drive	NI 9205: AI 3
9	D4	Motor Controller	B+, Positive battery to controller	Current: -300 to 300 Amps. Actual: -10 to 10 V	Analog voltage	I	External shunt resistor on DC bus	NI 9205: AI 4

EMS Controller I/O Schedule (Continue)

CompactRIO Controller - NI cRIO-9004:
8-slot separeted 195 MHz Real-Time Controller, 64MB DRAM and 3M Gate FPGA Chassis (NI Part Number: 188747D-02)

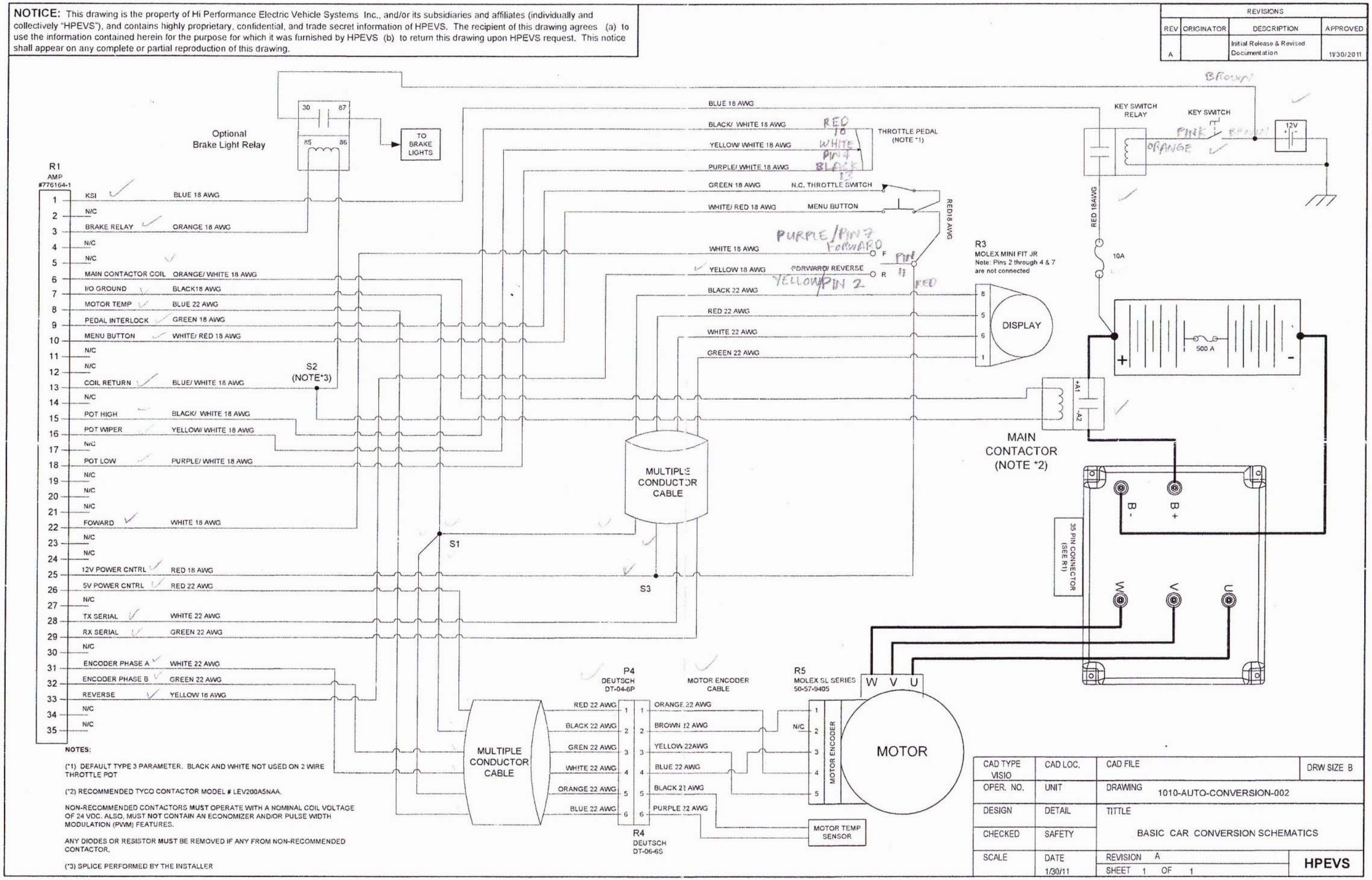
DI: Digital Input
DO: Digital Output
CTI: Counter / Timer Input
CTO: Counter / Timer Output
AI: Analog Input (+/- 10 V)
AIH: Analog Input (Higher Voltage)
TC: Thermocouple Input

Note : Under 'Controller Details', NI 9403 B: DI 4 refers to:
1) **Module NI 9403 (digital IO module) B - the second digital IO module in the controller**
2) **Digital Input line/channel 4 - the fourth DI line in the module**

No	ID	Subsystem	Parameter	Range	I/O Type	I/O	Sensor / Actuator Details	Controller Details
MOTOR CONTROLLER (CURTIS 1238R: 24 - 36 V; 650 Amp;)								
10	D5	Motor Controller	B-, Negative battery to controller	Voltage: 0 to 900 Volts. Actual: 0 to 9 V	Analog voltage	I	Integrated voltage transducer inside IGBT drive	NI 9205: AI 5
11	D6	Motor Controller	IGBT substrate / heat sink temperature input	Current: 0 to 120 deg C. Actual: -10 to 10 V	Analog voltage	I	Integrated temperature sensor inside IGBT drive	NI 9205: AI 6
12	D7	Motor Controller	Trip / fault signal input	Normal or Fault	Switch input (on/off)	I	Integrated error transistor (open-collector) inside IGBT drive	NI 9403: DI 2, DI 3, DI 4, DI 5
13	D8	Motor Controller	Heat sink cooling fan on/off signal output	On / Off	TTL digital output (on/off)	O	Solid-state relay (5V TTL input; 12V output) connected to cooling fan	NI 9403: DO 6
14	D9	Motor Controller	Supply power on/off / emergency stop signal output	On/off 12V supply	TTL digital output (on/off)	O	Solid-state relay (5V TTL input; 12V output) connected to IGBT Drive L	NI 9403: DO 7
DRIVER INPUT/ OUTPUT								
15	UI	Driver Input	Throttle level input	Level: 0 - 100 %. Actual resistance: ?? - ?? Ohms. Final: 0 - 5 V	Analog voltage converted from potentiometer's resistance	I	Potentiometer	NI 9205: AI 2
16	U2	Driver Input	Brake level input	Level: 0 - 100 %. Actual resistance: ?? - ?? Ohms. Final: 0 - 5 V	Analog voltage converted from potentiometer's resistance	I	Potentiometer	NI 9205: AI 3

DRIVER INPUT/ OUTPUT								
17	U3	Driver Input	Emergency manual shut-down signal input - inside and outside vehicle	2 modes (Normal / Shut-down)	Switch input (on/off)	I	Emergency shut-down switch status	NI 9403: DI 5
18	U4	Driver Output	Gear-shift assist LED	5 modes (??)	Switch output (on/off)	I	Dashboard LED indicator panel	NI 9403: DI 1, DI 2, DI 3, DI 4, DI 5
19	U5	Driver Interface (GUI)	Visual display output	Multiple parameters	Multiple functions	I / O	Touch-screen Windows-based Tablet PC	To be determined
GEARBOX								
20	G1	Gearbox	Gear position input	7 modes (R, N, 1, 2, 3, 4, 5)	Hall sensor input (on/off)	I	Gear position switch	NI 9403: DI 9, DI 10, DI 11, DI 12, DI 13, DI 14, DI 15
BATTERY								
21	B1	Battery	Battery stack temperature input	?? - ?? deg C; ?? - ?? mV	Analog voltage (thermocouple)	I	Thermocouple (K-type)	NI 9211: TC 3
22	B2	Battery	Cell 1 voltage input	0 - 52 VDC	Analog voltage	I	Direct voltage measurement	NI 9221: AIH 1
23	B3	Battery	Cell 2 voltage input	0 - 52 VDC	Analog voltage	I	Direct voltage measurement	NI 9221: AIH 2
24	B4	Battery	Ventilation fan signal output	On/off fan	TTL digital output (on/off)	O	Solid-state relay (5V TTL input; 12V output) connected to ventilation fan	NI 9403: DO 16
MISCELLANEOUS								
25	S1	Vehicle Dynamics and Crash Detection	Acceleration (g) input	Charge: ?? - ?? pC. Actual: ?? - ?? V	Analog: charge or voltage?	I	3-axis accelerometer at CG	TBC
26	S2	Steering	Steering angle input	Level: ?? - ?? deg. Actual resistance: ?? - ?? Ohms. Final: 0 - 5 V	Analog voltage converted from potentiometer's resistance	I	Potentiometer	NI 9205: AI 1

APPENDIX B
ELECTRIC VEHICLE WIRING SCHEMATIC



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REVISIONS
REV | ORIGINATOR | DESCRIPTION | APPROVED
A | | Initial Release & Revised Documentation | 1/30/2011
Optional Brake Light Relay
TO BRAKE LIGHTS
R1 AMP #776164-1
1 KSI BLUE 18 AWG
2 N/C
3 BRAKE RELAY ORANGE 18 AWG
4 N/C
5 N/C
6 MAIN CONTACTOR COIL ORANGE/ WHITE 18 AWG
7 I/O GROUND BLACK18 AWG
8 MOTOR TEMP BLUE 22 AWG
9 PEDAL INTERLOCK GREEN 18 AWG
10 MENU BUTTON WHITE/ RED 18 AWG
11 N/C
12 N/C
13 COIL RETURN BLUE/ WHITE 18 AWG
14 N/C
15 POT HIGH BLACK/ WHITE 18 AWG
16 POT WIPER YELLOW/ WHITE 18 AWG
17 N/C
18 POT LOW PURPLE/ WHITE 18 AWG
19 N/C
20 N/C
21 N/C
22 FOWARD WHITE 18 AWG
23 N/C
24 N/C
25 12V POWER CNTRL RED 18 AWG
26 5V POWER CNTRL RED 22 AWG
27 N/C
28 TX SERIAL WHITE 22 AWG
29 RX SERIAL GREEN 22 AWG
30 N/C
31 ENCODER PHASE A WHITE 22 AWG
32 ENCODER PHASE B GREEN 22 AWG
33 REVERSE YELLOW 18 AWG
34 N/C
35 N/C
S2 (NOTE*3)
S1
S3
MULTIPLE CONDUCTOR CABLE
BLUE 18 AWG
BLACK/ WHITE 18 AWG
YELLOW/ WHITE 18 AWG
PURPLE/ WHITE 18 AWG
GREEN 18 AWG
N.C. THROTTLE SWITCH
WHITE/ RED 18 AWG
MENU BUTTON
WHITE 18 AWG
YELLOW 18 AWG
FORWARD/ REVERSE
BLACK 22 AWG
RED 22 AWG
WHITE 22 AWG
GREEN 22 AWG
THROTTLE PEDAL (NOTE *1)
RED18 AWG
R3 MOLEX MINI FIT JR Note: Pins 2 through 4 & 7 are not connected
DISPLAY
KEY SWITCH RELAY
KEY SWITCH
12V
RED 18AWG
10A
500 A
MAIN CONTACTOR (NOTE *2)
B- B+
35 PIN CONNECTOR (SEE R1)
W V U
P4 DEUTSCH DT-04-6P
MOTOR ENCODER CABLE
R5 MOLEX SL SERIES 50-57-9405
RED 22 AWG | ORANGE 22 AWG
BLACK 22 AWG | BROWN 22 AWG
GREN 22 AWG | YELLOW 22AWG
WHITE 22 AWG | BLUE 22 AWG
ORANGE 22 AWG | BLACK 22 AWG
BLUE 22 AWG | PURPLE 22 AWG
R4 DEUTSCH DT-06-6S
MOTOR ENCODER
MOTOR
MOTOR TEMP SENSOR
NOTES:
(*1) DEFAULT TYPE 3 PARAMETER. BLACK AND WHITE NOT USED ON 2 WIRE THROTTLE POT
(*2) RECOMMENDED TYCO CONTACTOR MODEL # LEV200A5NAA.
NON-RECOMMENDED CONTACTORS MUST OPERATE WITH A NOMINAL COIL VOLTAGE OF 24 VDC. ALSO, MUST NOT CONTAIN AN ECONOMIZER AND/OR PULSE WIDTH MODULATION (PWM) FEATURES.
ANY DIODES OR RESISTOR MUST BE REMOVED IF ANY FROM NON-RECOMMENDED CONTACTOR.
(*3) SPLICE PERFORMED BY THE INSTALLER
CAD TYPE VISIO | CAD LOC. | CAD FILE | DRW SIZE B
OPER. NO. | UNIT | DRAWING 1010-AUTO-CONVERSION-002
DESIGN | DETAIL | TITTLE BASIC CAR CONVERSION SCHEMATICS
CHECKED | SAFETY
SCALE | DATE 1/30/11 | REVISION A | SHEET 1 OF 1 | HPEVS