# Development And Installation Of Battery-Powered Electric Vehicle Wiring System

Nuraida Md Hassan, Najwan Osman Ali, Mohamed Yusof Radzak

**Abstract**: Thevehicles in use around the world have produced serious problems to the environment and the depletion of the earth's petroleum is the motivation to the researchers to develop the alternative way to our daily life. This research paper focuses on development of overall electrical wiring system - low current installation between the controller, high voltage installation and engine compartment installation for Electric Vehicle (EV) conversion. This conversion system used electrical energy stored in rechargeable lead acid batteriesto drive three phase AC Induction electric motor and equipped with controller build by Curtis. The vehicle successfully runs on full electric power but further improvement and modification need to take into action to improve the performance of the vehicle in tern of speed and motor torque by fine tuning of the controller.

**Index Terms**: Electric Vehicle (EV), controller, low current installation, high voltage installation.

## 1 Introduction

The rise of electric vehicles (EV) is beginning to look like slowly developing tsunami [1]. At least 10 EV models have been approved by British government to qualify for special rebate: the Mitsubishi i-MiEV, Peugeot iOn, Citroen C-ZERO, Smart Fortwo electric drive, Nissan Leaf, Tata Vista, Vauxhall Ampera, Chevrolet Volt, Toyota Prius Plug-in hybrid, and Renault Fluence ZE. In Malaysia, the most visible attempt to embark on green car technology comes from national car company, Proton since 2004. Proton has introduced a fleet of trial vehicles in Putrajaya on last September, consisting of three range-extended Exoras (Exora REEV) and five fully-electric Sagas. The test fleet will eventually be enlarged to 200 Exora REEVs and 120 Saga EVs next year, with the intention of commercial production by 2013. Electric vehicles (EVs) use one or more electric motors or traction motors for propulsion. EV has many advantages compared to conventional internal combustion engine vehicle (ICEV) such as absence of emissions, high efficiency, quiet and smooth operation. Previously, the EV was mainly converted from the existing ICEV by replacing the IC engine and fuel tank with an electric motor drive and battery pack while retaining all the other components, as shown in Figure 1. Drawbacks such as its heavy weight, lower flexibility, and performance degradation have caused the use of this type of EV to fade out. In its place, the modern EV is purpose built, based on original body and frame designs. This satisfies the structure requirements unique to EVs and makes use of the greater flexibility of electric propulsion [2] A modern electric drive train consists of three major subsystems: electric motor propulsion, energy source, and auxiliary.


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The electric propulsion subsystem is comprised of the vehicle controller, the power electronic converter, the electric motor, mechanical transmission, and driving wheels. The energy source subsystem involves the energy source, the energy management unit, and the energy refueling unit. The auxiliary subsystem consists of the power steering unit, the climate control unit, and the auxiliary supply unit.

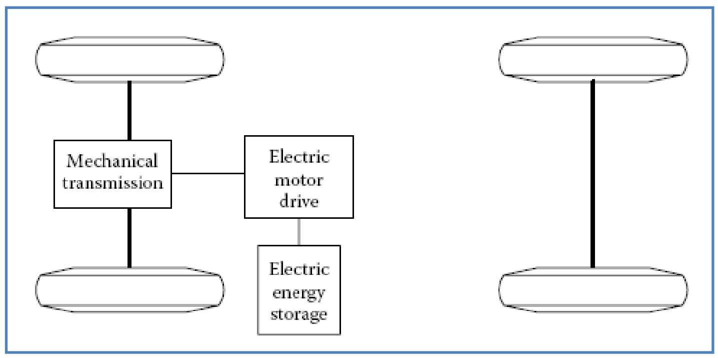


**Figure 1:** Primary EV Power Train [2].

Some challenges facing by EV has stated in [3] which are include as listed below.

- Energy and power density,
- Battery charging,
- Lifetime performance and
- System costs.

These good challenge problems should be put as focus research in future.

## 2 Related Technology and Components

### 2.1 Electric Motor

Electric motor is one of the main and important components which can offer benefits criteria such as robustness, noiseless operation, compactness, almost maintenance-free, low manufacturing cost, and high efficiency for EV to work in various conditions [4]. In this research, the three phase AC50 induction motor is being used because it is only the AC motor that has the most mature technology in EV industry and having several features such as lightweight, small volume, low maintenance, high reliability and efficiency and also offers higher efficiency in the regenerative effect and as shown in Figure 1. The AC50 is Alternating Current (AC) motors which can runs at the range of 72V to 108V. It can draw up until 650 Ampere producing up to 50 Horse-power and 115 ft-lbs of torque. This type of motor work in a medium sized vehicle and remarkably suit for Proton SAGA BLM 1.3 cc engine power.

**Figure 2: 3** Phase Induction Motor

Furthermore, this motor equipped with the regenerative braking, idle function features and encoder integrated sensor. The details specifications of the motor are listed in Table 2.

**TABLE 2: 3 Phase Induction Motor parameters**

| NO. | PARAMETERS | VALUE |
|---|---|---|
| 1. | Rated power | 37KW (50HP) |
| 2. | Rated torque | 90 Lb ft |
| 3. | Maximum voltage input | 130V |
| 4. | Maximum efficiency | 88% |
| 5. | Maximum speed | 10 000 rpm |
| 6. | Maximum temperature | $180^{o}$ C |
| 7. | Weight | 52kg |

### 2.2 Motor Controller

The controller is the brain for an electric vehicle. Similar function as the ECU, the controller monitors all essential inputs from sensors and regulates the movement of the motors instead of an internal combustion engine (ICE). There are various types of controller in the market. Each controller varies in the type of motor that it can control such as DC or an AC motor. Some controllers are even equipped with its own control system which will be used to tune the EV to our desired performance. This paper presents an EV that is equipped with controller build by Curtis. Curtis is renowned for a large range of EV controller. Most of the popular DC or AC motors are compatible with their controller which is very important to ensure the smoothness of the EV and reducing the hassle of trying to tune the motor with the controller [5]. Below is a specification for the motor used in this research.

- Model: Curtis 1238R-76XX 650 AMP controller
- Max current: 650 A
- Rated power: 73.6 kW
- Maximum working temperature : $80^{o}$C
- Optimal working temperature: $40\text{-}50^{o}$C
- PWM operating frequency 10 kHz
- Maximum encoder frequency 10 kHz
- Maximum controller output frequency 300 Hz
- Electrical isolation to heatsink 500V ac (minimum)
- Storage ambient temperature range -40°C to 95°C (-40°F to 203°F)
- Operating ambient temp. range -40°C to 50°C
- (-40°F to 122°F)
- Internal heatsink operating temp. range -40°C to 95°C (-40°F to 203°F)

### 2.3 Battery

EV used electrical energy stored in rechargeable batteries for electric motor propulsion and also to drive the overall system. Therefore, the selection of storage devices is important. There are many types of batteries in the market and every type of the batteries has its own advantages and limitations. This system used 8 unit lead acid sealed batteries connected in series to power up the controller and 96V 3 phase induction motor as shows in Figure 3.

**Figure 3:** 8 unit 12V sealed lead acid battery connected in series to produced total of 96V

Rechargeable lead acid battery has a good energy density and power density ratio. It has about 80% of charge and discharge efficiency [6]. This type of battery is the most economical for larger power applications where weight is of little concern. The selections of using lead acid batteries are listed for the following reasons:

i. High specific energy
ii. Low cost
iii. Low maintenance
iv. Robust
v. Reliable – oldest type of rechargeable battery

## 3 VEHICLE SPECIFICATION

The selection of type of car, transmission either auto (A.T) or manual (M.T) is a very important step during modifying and converting from internal combustion engine vehicle (ICEV) to fully electric vehicle (EVs) and need a special attention. Almost any traditional fuel vehicle which using petroleum fuel can be converted as a battery-operated vehicle. A small and light vehicle will be more efficient, aerodynamic and can maximize distance travelled per battery charge but this size cannot hold the batteries compared to the larger vehicle. There must be a sufficient space and load capacity for batteries since the vehicle used 8 units of series connected lead acid batteries which are total of 96 Volt powered dc. In this research, we used second generation of Proton SAGA which is Proton SAGA Base-Line-Model (BLM) Facelift (FL) manual transmission combustion engine to convert it into electric vehicle. Proton SAGA BLM is a 1.3 cc of engine powered and is a 4-door subcompact sedan car and the details parameters are listed in Table 1.

**TABLE 1: SAGA BLM FL parameters**

| NO. | PARAMETERS | VALUE |
|---|---|---|
| 1. | Mass of car | 954kg |
| 2. | Radius of tyre | 0.29m |
| 3. | Gear ratio<br>Gear 1<br>Gear 2<br>Gear 3<br>Gear 4<br>Gear 5 | <br>3.333<br>1.954<br>1.285<br>0.926<br>0.755 |
| 4. | Frontal Area | 2.098m$^2$ |
| 5. | Drag coefficient | 0.358 |
| 6. | Rolling resistance | 0.005 |
| 7. | Gear efficiency | 94% |
| 8. | Auxiliary power usage | 0.1kW |

## 4 ELECTRICAL WIRING INSTALLATION

Electrical wiring for this project can be divided into three categories; low current wiring between controllers and other devices such as transducers and sensors, high voltage wiring between controller and battery management system and lastly engine compartment wiring. Ranges of voltages used in the wiring are 5V DC, 12 V DC and 96V. Most of the wiring are actually connected to each other through the controller. Starting from the main battery that provides up to 96V DC, the controller will convert the high DC voltage into 5V and 12V which will be used to connect to sensors and transducers. The source of AC voltage to power up the motor comes from the controller where in this case the controller converts DC to three phase AC voltage. Electrical wiring for the controller is based on the settings given by Curtis. Figure below displays the connector located on Curtis controller. There are many connections involves in wiring the EV. However, this paper will cover the most essential part of wiring for this type of controller.

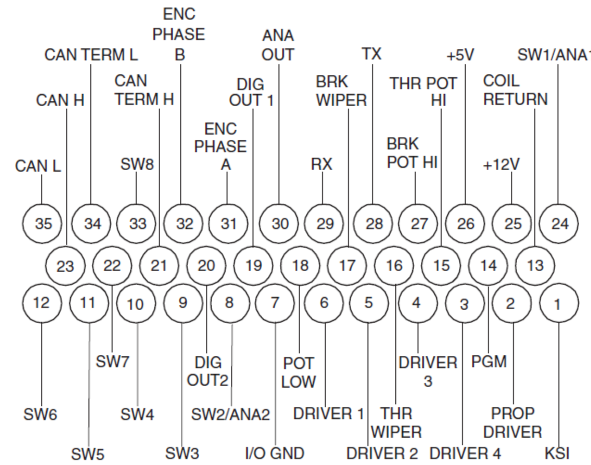


**Figure 4:** Connector wiring for Curtis Model 1238R [5]

### 4.1 Low Current Installation between Controllers

All low power connections are made through a single 35-pin AMPSEAL connector. The mating plug housing is AMP p/n 776164-1 and the contact pins are AMP p/n 770520-3. The connector will accept 20 to 16 AWG wire with 1.7 to 2.7mm diameter thin-wall insulation. AC 50 motor has a build in position encoder that can be used as a feedback to the controllers. The encoder is crucial to ensure precise speed control of the AC motor. Without the encoder the motor can still move but the rotation of the motor will not be smooth. If the motor runs to long without the encoder it can damaged the motor. Due to the nature of the encoder it is important the encoder cables must not be near the motor cables. The high AC voltage inside the motor cables can interfere with the signal send from the encoder to the controller. Placing the encoder cables far from the motor cables is enough but if in extreme application; the cable can be shielded and grounded at pin 7 on the connector. In order to provide power for low power control circuits, power capacitor precharge, power supply outputs and high power output drivers, Keyswitch input (KSI) must be connected to the positive terminal of the main battery/battery management system. Although the voltage is as high as the main battery, the current consumption for KSI is low. Using 16 AWG wire is sufficient. As the KSI precharge the power capacitors, the output from the controller can be used to turn ON the high voltage contactor. There are five high power output from the controller that can be used to drive inductive loads such as contactors. One of the high power output is Driver 1(pin 6). Driver 1 will drive the contactor as soon as the KSI precharge the power capacitor which at the same time connects the positive terminal of the main battery to the positive terminal of the controller. In order for the Drive 1 to work, a connection to Coil Return (pin 13) is required to complete the circuit. Curtis controller has input switches that can be used to configure the controller. The most basic switches that can be considered are Switch 3 and Switch 7. Switch 3 is an interlock switch. It is critical to connect a switch such as a SPST switch to enable and disable the interlock for configuration purpose as an example setting the throttle. Switch 3 is an input for forward configuration, there are four important parameters related to the input voltage of Switch 3; forward deadband, forward map, forward max and forward offset. In order to set the values for these parameters Switch 3 requires input voltage range from 0V to 5V. the range of voltage that can be used are show the figure below. A potentiometer can be used to change the input voltage for Switch 3. Voltage source for the switches can be taken directly from the controller. This project uses 12V DC from pin 25 for easier wiring.

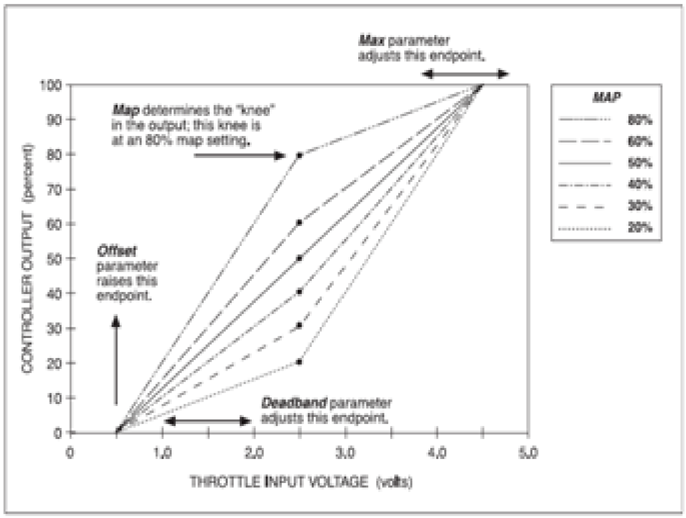


**Figure 5:** Effect of throttle adjustment parameters [5]

Another important low current wiring is the wiring for throttle. There are five types of throttle that can be integrated with the controller as listed in Table 4. Each type has its own advantages and disadvantages. This projects implements Type 4 which is varying the input voltage into pin 16.

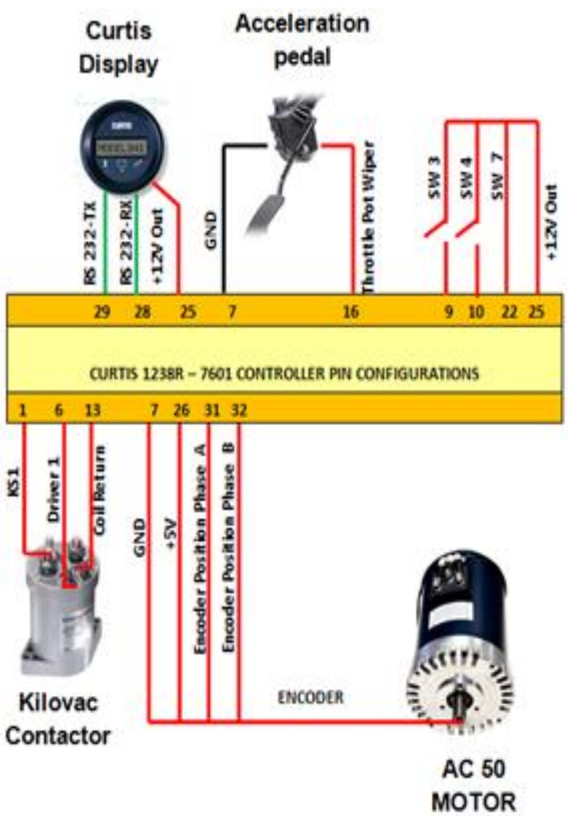


**Figure 6:** Low voltage wiring

**TABLE3: Type of throttle for Curtis controller [6]**

| | |
|---|---|
| Type 1: | 2-wire 5kΩ–0 potentiometers |
| Type 2: | single-ended 0–5V throttles, current source throttles, 3-wire potentiometers, and electronic throttles |
| Type 3: | 2-wire 0–5kΩ potentiometers |
| Type 4: | wigwag 0–5V throttles and 3-wire potentiometers |
| Type 5: | VCL input (VCL_Throttle or VCL_Brake) |

## 4.2High Voltage Installation

High voltage wiring for EV consists of main battery/battery management system, high gauge wire (resistance to heat and moisture), contactor and high voltage fuses. Each high voltage connection requires high quality copper lugs for M8 screws connected to the controller. High quality copper will ensure the maximum current flow inside the wire which will also reduce the heat generated by the high current. Maximum current that can flow from the main battery to the controller is 650A. A suitable wire must be selected to withstand the high current. The wire must not only able to withstand high current but must also withstand heat and also moisture. During the testing of the project the best wire that can be used for high voltage wiring is wire with 70mm2 pure copper multi strands. This wire was able to withstand constant high current and also sudden burst of high current. Another safety element that must be considered in high voltage wiring is using high voltage fuse in the wiring. This is to ensure any current consumption that are higher than the rated current for the controller will cut the connection immediately to protect the controller and other devices.

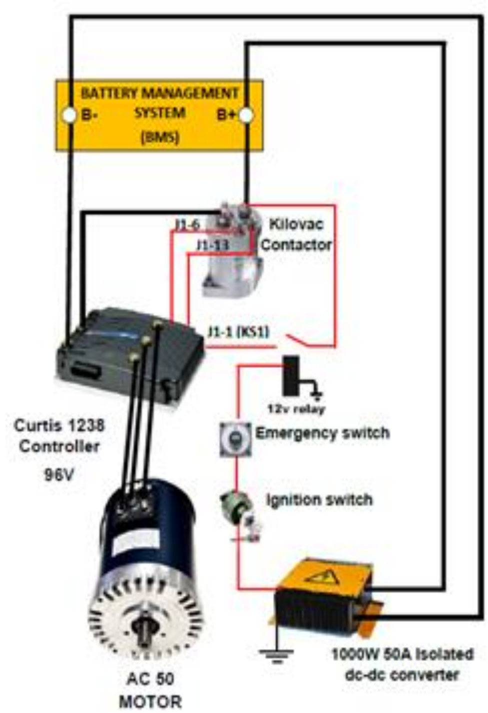


**Figure7:** High voltage wiring

### 4.3 Engine Compartment Installation

With the use of AC motor the alternator connected to the engine is not included in the system. Some would argue that the alternator can still be connected to the AC motor thus generating the 13V required to recharge the Lead Acid Battery in the car but this will only increase the load of the motor which will increase the current consumption. One solution to this problem is by using a DC to DC converter. This converter will convert voltage from the main battery to 12V DC. This voltage will then be used to operate devices in the car and also charge the Lead Acid Battery. Both the Lead Acid battery and DC/DC converter are used together to operates other high current devices such as radiator fan, heat-sink pump and also vacuum pump.

**Figure 8:** Electrical System layout

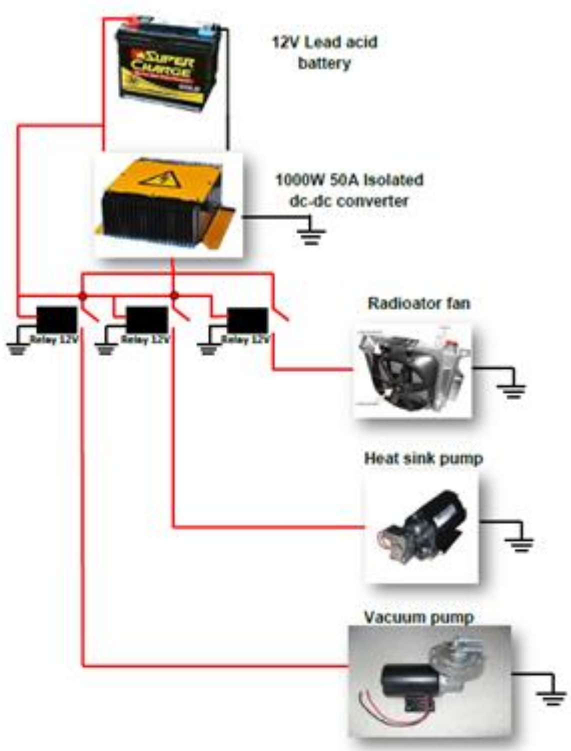


**Figure9:** Wiring for Lead Acid battery and DC/DC converter.

## 5 CONCLUSION

Controller is an important component in Electric Vehicle. The use of suitable and well design controller will enable the EV to be a high performance and energy efficient vehicle. Important aspects such as the layout of high voltage and low voltage wiring and also the battery management system is crucial to ensure the safety of the car and also the devices connected to the system. High voltage cable must be located far from the low voltage cable to prevent reverse current induced in the low voltage cable which will damage the electronic devices. The use of suitable wire and also lug plays are some important aspects of building an EV. The cable used to transfer energy from the main battery to the controller must be able to withstand the high constant current and also high current spike from the battery. It is best to use a pure copper cable that has low internal resistance and also fire and water resistance.

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