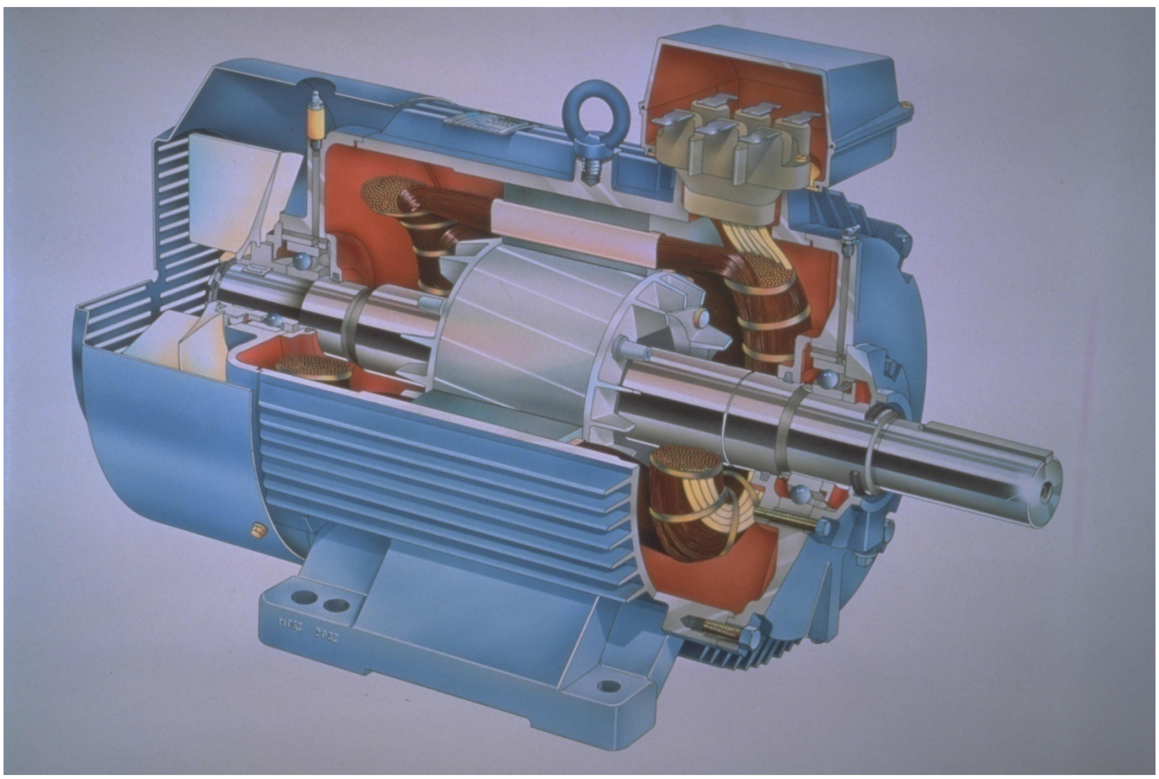
# Open Source 100kW Electric Vehicle Controller/Inverter



To be used with an AC Induction Motor

**Description**

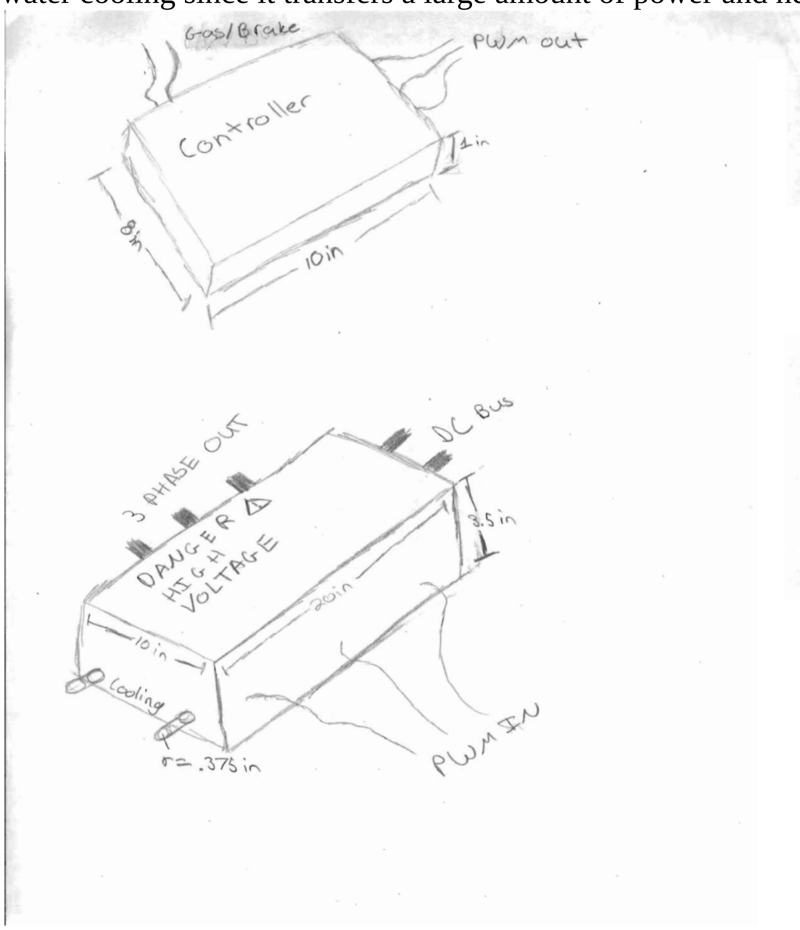
By Tony Ahmann

## Abstract

The Open Source 100kW Electric Vehicle Controller/Inverter acts as the bridge connecting the driver and motor. Interpreting the driver's actions, the controller will take swift action, instructing the inverter to supply appropriate power for the motor.

## Functional Description

This controller/inverter design is open source and originally created by students at Camosun College. This project is intended to be a close replica of the original design and will provide more insight to the open source design. The figure below shows the intended final product. The controller is a microprocessor that interprets the user input (accelerator and brake pedals) and outputs a three phase signal for the inverter. The inverter interprets the phase signal and outputs the same signal with high power for an AC induction motor (AMIC). The DC bus provides high voltage DC for the inverter. The inverter includes water cooling since it transfers a large amount of power and heat.




**Hardware description**

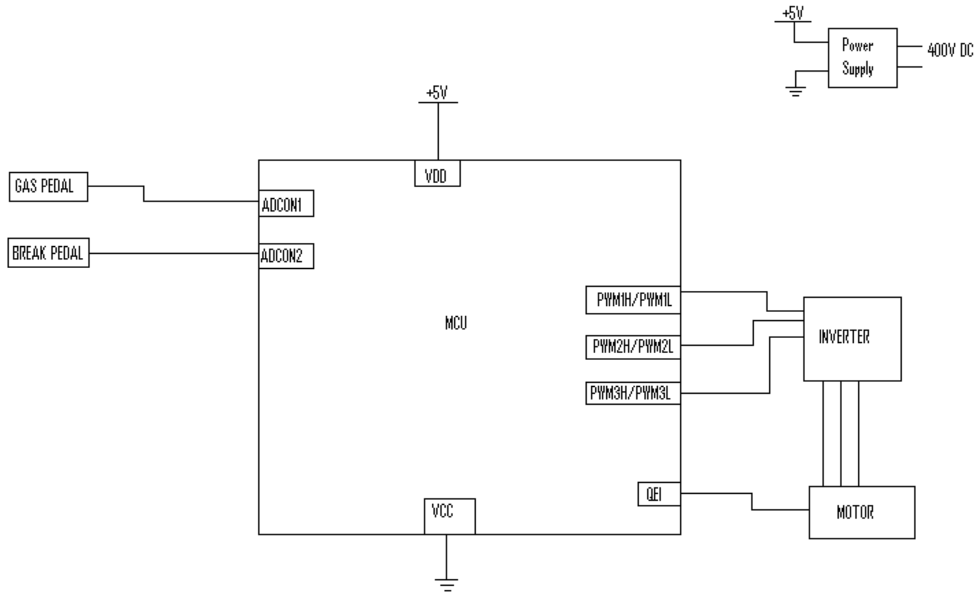
The controller is a Microchip dsPICDEM MC1 Motor Control Development Board. The board contains a dsPIC30F6010, but supports all dsPIC digital signal controller though a custom interface header system. This development board allows the open source design to be modified over a wide range of dsPIC chips. Modules needed for this project include 2 analog to digital (A/D) converter inputs, 3 pulse width modulation (PWM) outputs and a quadrature encoder interface (QEI) which are included with the development board.

Two A/D converter inputs will be used to determine the accelerator and brake pedal positions. Three PWM outputs are used to shape the three phase signal. A QEI rotary shaft is used to measure motor RPM. The controller has 144kB Flash, 8kB RAM, and 4kB EEPROM. The board contains a 16-bit 30 MIPS CPU and a 17-bit x 17-bit single cycle hardware fractional/integer multiplier DSP. The on board oscillator will be used running at 7.3728MHz.

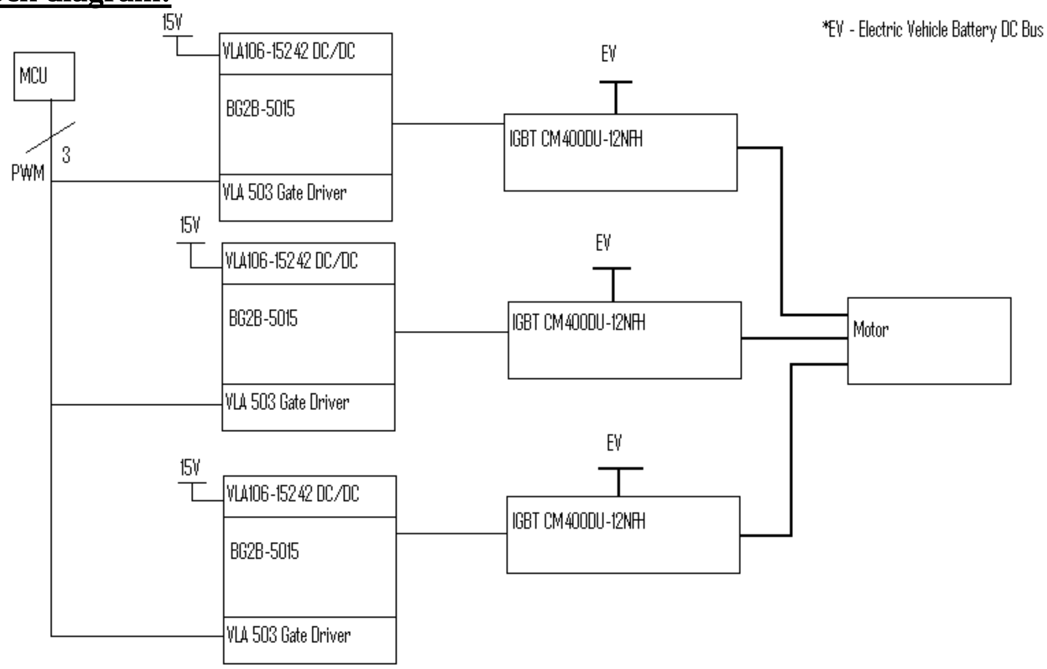
Three Insulated-Gate Bipolar Transistors (IGBT) are used to drive the AC induction motor. The IGBTs are CM400DU-12NFH from Powerex. The BG2B-5015 is a printed circuit board designed to adapt gate drives and power supply to the IGBTs. The VLA503-01 600V, 400A gate drive and VLA106-15242 DC/DC converter are used with the BG2B-5015.

The controller/inverter is intended to be used in various electric vehicles, thus the power supply is dependent on the specific vehicle. The important factors are the 5 volt supply for the microcontroller (4.5-5.5 volt tolerance) and the 15 volt supply for the IGBTs (12-18 volt tolerance). The IGBTs are rated at 600V and 400A (800A peak), but it is more important that the junction temperature does not exceed 150ºC. These parameters are what dictates the battery voltage. A 200V battery would peak at 500A and a 600V battery would peak at 166A. The intended vehicle for this specific project is designed to have a 400V battery, thus a step down from 400V to 5 and 15 volts will be necessary for the vehicle. This is possible using a Vicor DC/DC converter VI-PJ602EZZ which will supply both 5 and 15 volts.

**Controller block diagram:**




**Inverter block diagram:**




**Software**

The code is written in C and is based off of Microchip's motor control software. Understanding assembly is helpful in making changes to the motor software. The Space Vector Modulation software is considered a "black box", meaning there is no need for a complex understating of the code. However, the code can be altered and documentation is provided on Microchip's website. The code is executed using a timed interrupt vector. The code runs a continuous loop scanning the A/D for the pedal positions, then runs the space vector algorithm to create three PWM signals for the inverter. The code is compiled using MPLAB C compiler.

The software is owned by Microchip but supplied to the customer "for solely and exclusively on Microchip dsPIC products." Microchip does not hold themselves accountable for "implied warranties of merchantability and fitness for a particular purpose." Thus the code is available to anyone who legally buys a Microchip dsPIC product.

**User Interface**

The user interface mimics the same interface as operating a vehicle. There are two analog user interfaces, the gas pedal and brake pedal. There are no user interupts however, the user will indircetly turn the contoller on or off by turning the power supply on or off. The user should not notice a difference in operation between an electric vehicle and a gasoline vehicle. The accelerator will accelerate the vehicle and the brake will slow down the vehicle, reguardless of the powertrain type.

## Development Plan

There are two main devices, the controller and the inverter. The controller takes user input and outputs a three phase signal. The inverter takes a high voltage DC source and outputs the controller's three phase signal in high voltage. The high power IGBTs have a 6 week lead time, thus the controller will be focused on first. Although the controller code is provided from the Camosun design, Camosun re-spun their MC1 development board. Interpretation of the code for compatibility to the retail version is necessary. The Camosun design contains a CAN Bus interface while this design has no need for CAN Bus. The code will be altered to use two analog inputs instead of the CAN Bus. For the open source design, it would be useful to have both the CAN Bus interface and A/D inputs and a way for other users to simply choose which style they prefer. No testing will be done of the CAN Bus interface. On the inverter side, there are two major concerns. The snubber may need to be adjusted for noise, and a cold plate will be used to cool the IGBTs.

| **Winter Quarter** | |
|---|---|
| Week 1 | Analyze code for compatibility |
| Week 2 | Programming |
| Week 3 | Program/test controller |
| Week 4 | Controller testing/debugging |
| Week 5 | Continue controller testing/debugging |
| Week 6 | Design snubber |
| Week 7 | Assemble inverter |
| Week 8 | Assemble inverter/test connection to controller |
| Week 9 | Inverter/controller testing/debugging |
| Week 10 | Continue Inverter/controller testing/debugging |

| | |
|---|---|
| Finals Week | Break/write review of the open source design |

| **Spring Quarter** | |
|---|---|
| Week 1 | Begin hardware description |
| Week 2 | Continue hardware description |
| Week 3 | Finish hardware description |
| Week 4 | Hardware reviews |
| Week 5 | Begin software description |
| Week 6 | Testing/debugging |
| Week 7 | Clean up Code |
| Week 8 | Finish software description |
| Week 9 | Code Reviews |
| Week 10 | Demonstration |
| Finals Week | |

MPLAB will be used with C and Assembly languages. The mixed signal oscilloscopes in ET340 will be used for the controller development. When high power testing becomes a reality, the Vehicle Research Institute is able to supply high power and an AC induction motor.

Many precautions should be taken when working with an electric vehicle battery. There are three main UL standards that came about when GM introduced the EV1. UL 2202 pertains to safety standards for charging an electric vehicle, UL 2231 pertains to reducing electrical shock from accessible parts in an electric vehicle, and UL 2251 pertains to plugs, receptors, and couples for high power equipment. UL 698 and 1604 pertains to electrical equipment in hazardous environments which include high power motors and controllers. It is important that the battery of an electric vehicle is insulated from shorting to the vehicle and has an insulated way to be disconnected from the rest of the powertrain.

**Demonstration**

There are multiple ways to demonstrate the design. The most basic includes a potentiometer to represent an accelerator and the PWM output hooked up to an oscilloscope. This is a simple, compact set up however, requires some technical understand of the audience. The next possibility would include the purchase of MC1H 3 Phase High Power Module. This module connects to the MC1 development board and can run off of a single phase 120V or 208V. Ideally, this would run a .55kW AC induction motor. With this set up, the audience can adjust a potentiometer and visually see how the motor responds without a large technical understanding. It is not likely that a high voltage source and high power motor will be practical for demonstration. Video can be taken of high power testing and then presented using a computer in ET340. Pictures/descriptions of previous and current vehicles in the VRI will show practical applications for the controller/inverter.

**Sustainability**

The implementation of this project on a large scale creates battery consumption. This introduces the topic of sustainability and environmental concerns. For the purpose of this paper, discussion will be limited to batteries and contain no comparison or discussion of the internal combustion engine in current vehicles. There are three current battery types used in electric and hybrid vehicles; Nickel-cadmium (NiCad), Nickel-metal hydride (Ni-MH), and Lithium-ion (Li-ion). The cadmium in NiCad is considered toxic to the environment while Ni-MH and Li-ion are considered only semi-toxic. However, all three batteries can be recycled and is recommended to do so. Although Li-ion batteries are already available, they are still being researched and capable of holding more power with new technology. There are concerns about environment friendly refinement of lithium and of the amount of lithium in the world. However, the future is not just Li-ion batteries. Currently, companies are working on producing sliver-zinc and zinc-air fuel cells. Zinc provides twice as much power to weight as lithium and is the fourth largest metal production in the world. Current refineries are trying to implement solar power in their production. Zinc can also be recycled using solar power. Current research is also being done on aluminum batteries; however there is stability issues that need to be addressed before real implementation can occur. Aluminum batteries potentially hold over 10 times the amount of energy to weight as lithium.

## Electrical Specification

**Project Specification**

- 100kW 3-phase output
- 400V battery
- 5V and 15V power supplies
- 100kW AC induction motor

**Power Requirements**

Controller:

- Source: 400V battery step down to 5V
- Worst-case power dissipation: 300mA

Inverter:

- Source: 400V battery step down to 15V
- Worst-case power dissipation: 1.86A

## Preliminary Parts List

**Controller**

| Part | Part # | Quantity | Price(ea) | Cost | Distributor | Power Dissipation | Lead Time |
|---|---|---|---|---|---|---|---|
| MCU<br>Includes QEI and two potentiometers | DM300020 | 1 | $300.00 | $300.00 | Microchip | 1.5W | Less than 1 Week |
| **Total** | **-** | **-** | **-** | **$300.00** | **-** | **1.5W** | **-** |

**Inverter**

| Part | Part # | Quantity | Price(ea) | Cost | Distributor | Power Dissipation | Lead Time |
|---|---|---|---|---|---|---|---|
| IGBT | CM400DU-12NFH | 3 | $143.00 | $429.00 | Powerex | .24W/.72w | 6 weeks |
| Gate drive board | BG2B-5015 | 3 | $94.09 | $282.27 | Powerex | .25W/.75W | 6 weeks |
| IGBT/Trans modules | VLA503-01 | 3 | $10.24 | $30.72 | Powerex | .36W/1.08W | 6 weeks |
| IGBT Snubber | SCC205K601H7-24 | 3 | Free Sample | Free Samples | Cornell Dubilier | - | 3 weeks |
| DC/DC power supplies | VI-PJ602-EZZ | 1 | $229.00 | $229.00 | Vicor | 1.3W | 10 weeks |
| **Total** | **-** | **-** | **-** | **970.99** | **-** | **3.85W** | **-** |