Design, Build and Test of a Motor Controller for a Single Seat Electric Race Car

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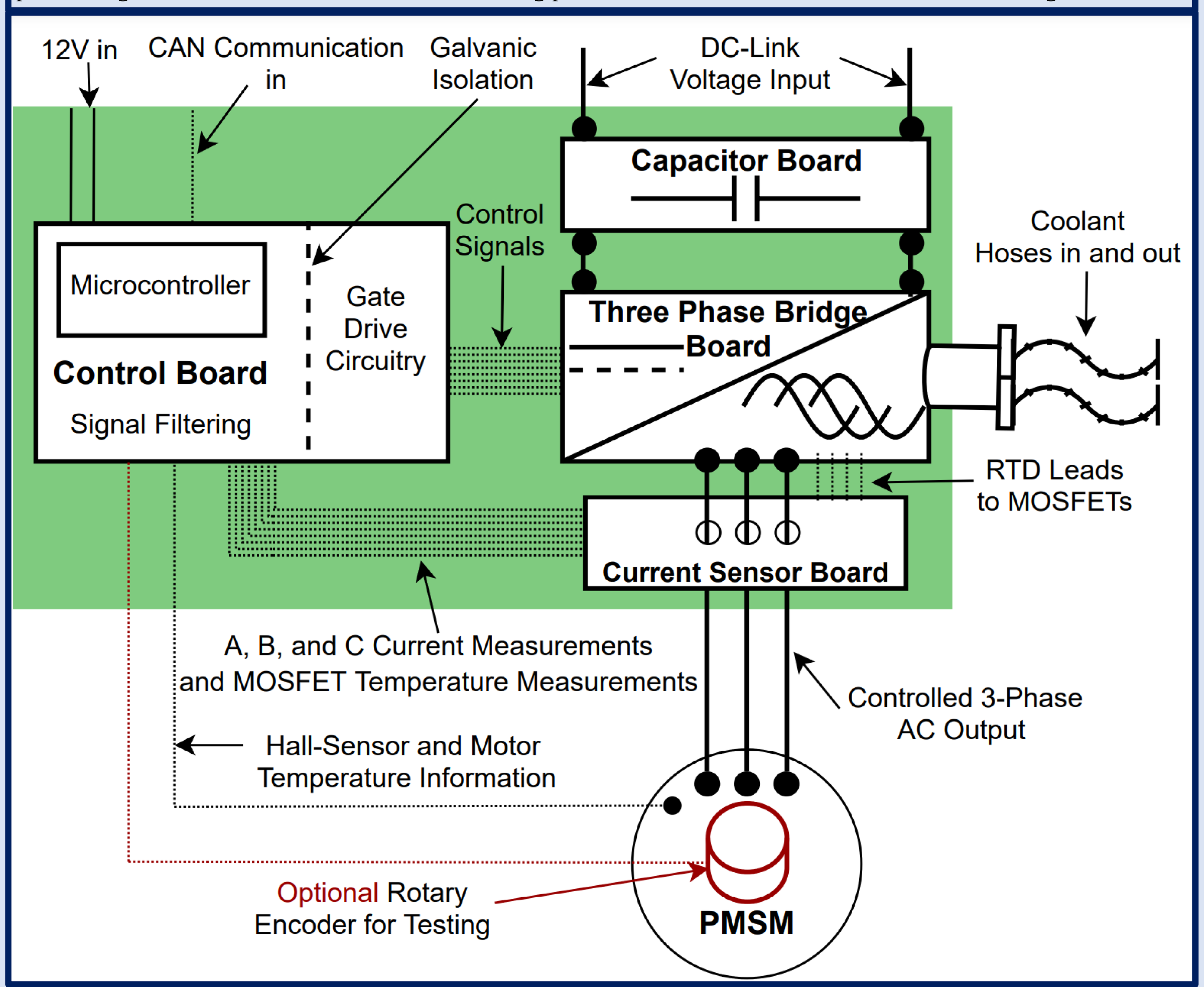
Overview

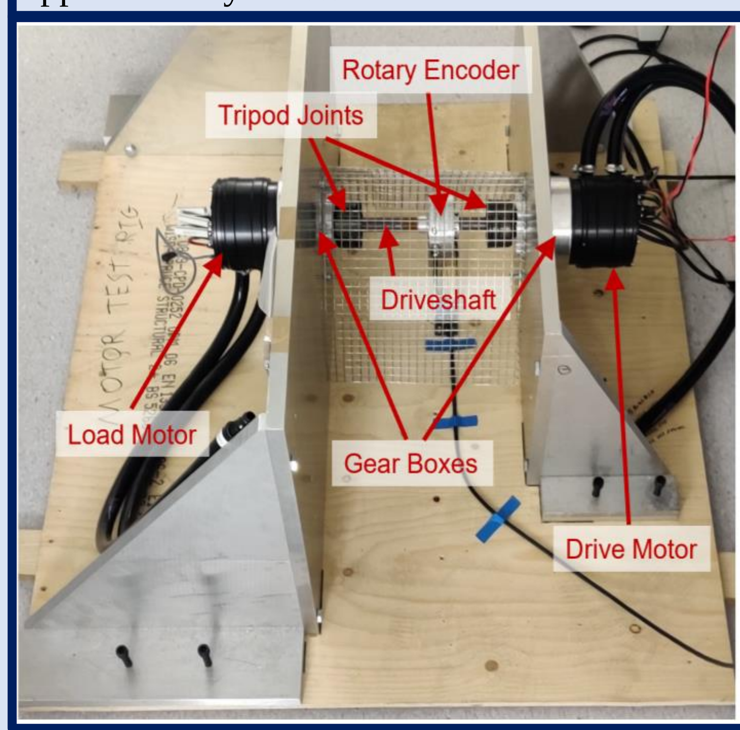
This fourth year project is part of an ongoing project to design, build, test and optimise a 20 kW sensorless motor controller for the Oxford University Racing team. The Oxford University Racing team (OUR) is a group of university students, working to build a single seat electric race car to compete in the IMechE Formula Student competition against other universities. The team currently has a powertrain design revolving around a 112 V battery pack, two Plettenburg Nova-15 permanent magnet synchronous motors (PMSMs), and planetary gears with a gear ratio of 5:1. OUR hopes to implement torque vectoring, tire force estimators and more customised control algorithms to give it an edge in the cepetition. These features require accurate torque control of the motors. This year is the first stage in of developing a high performance motor controllers, tailored to the OUR car.

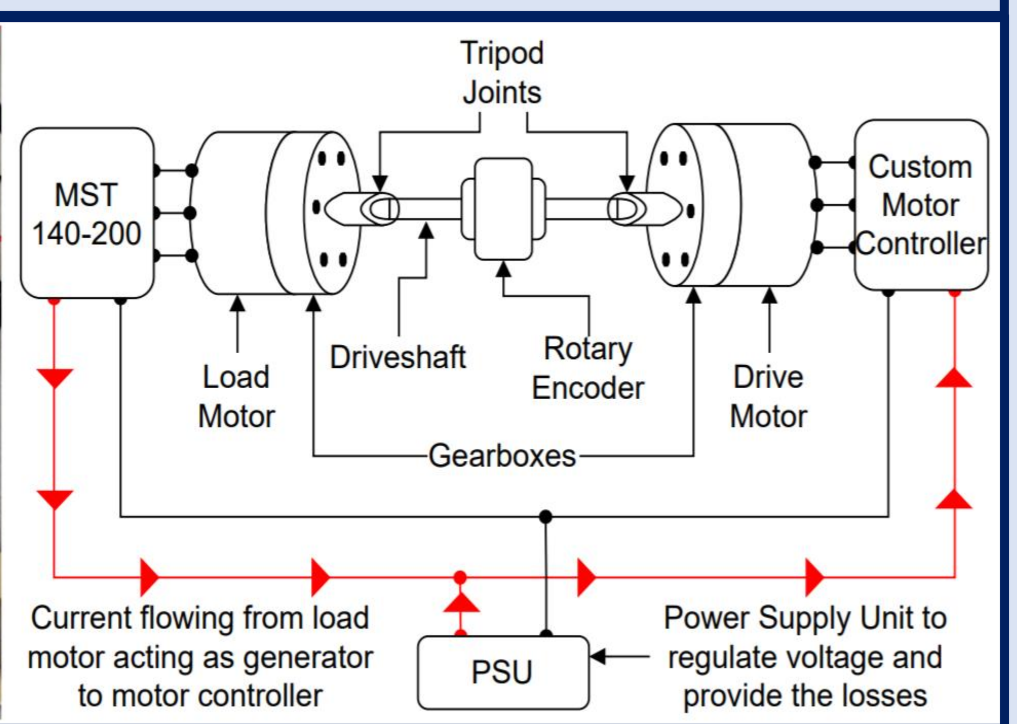
An overview of the design is shown below. A control board was designed to accommodate a microcontroller to run the control algorithms; filter sensor information; and drive the gates of the switching devices in the three phase bridge board. The power stage involves the input from the 112 V battery pack passing through a capacitor board, and being converted to three phase sinusoidal current for the motor, using a PWM topology inverter. The three phase currents are measured by a separate PCB and the information is passed to the control algorithm. The power stage includes a custom made water cooling plate, to cool the MOSFETs chosen as switching devices.



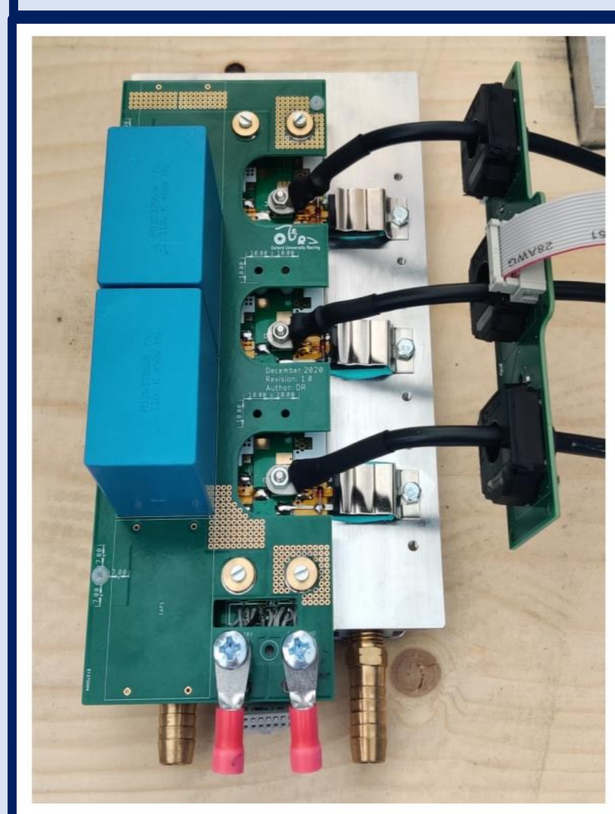
Testing Rig

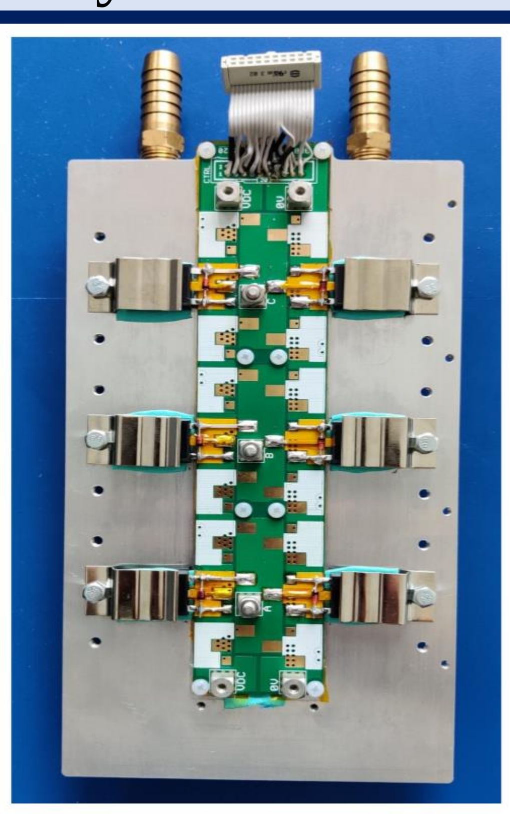
To test the motor controller the rig shown below was designed and built. It uses one motor to connected to the motor controller and another identical one to serve as a load. Each motor mounted to a gearbox and a tripod joint with a driveshaft connected between them. A rotational encoder is mounted onto the rotor, with mesh guard over all moving parts for safety. Higher power tests can be done by using a second motor controller to recover the mechanical energy. The two dc link voltages can be connected in parallel so that one is operating as a generator can provide some of the power to the drive motor. This means that the power supply only has to provide the power for the electrical and friction losses in the system. This setup was tested using two of OURs off-the-shelf motor controllers. The current measured around the loop was around ten times the current being drawn from the power supply. Therefore, for a 300W power supply unit this setup will allow tests up to approximately 3 kW.





Final Build and Assembly

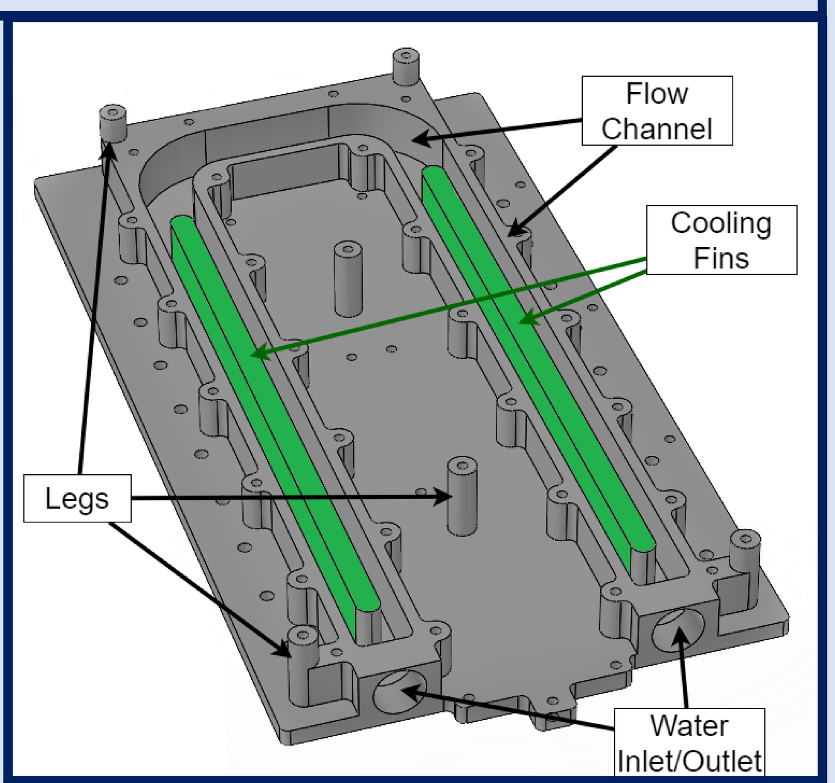


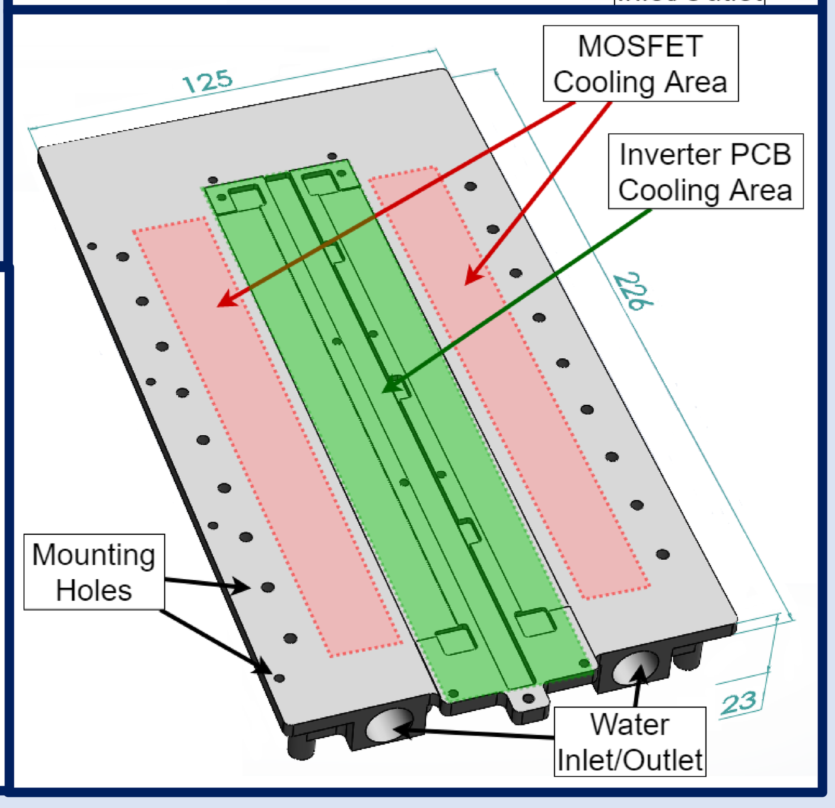


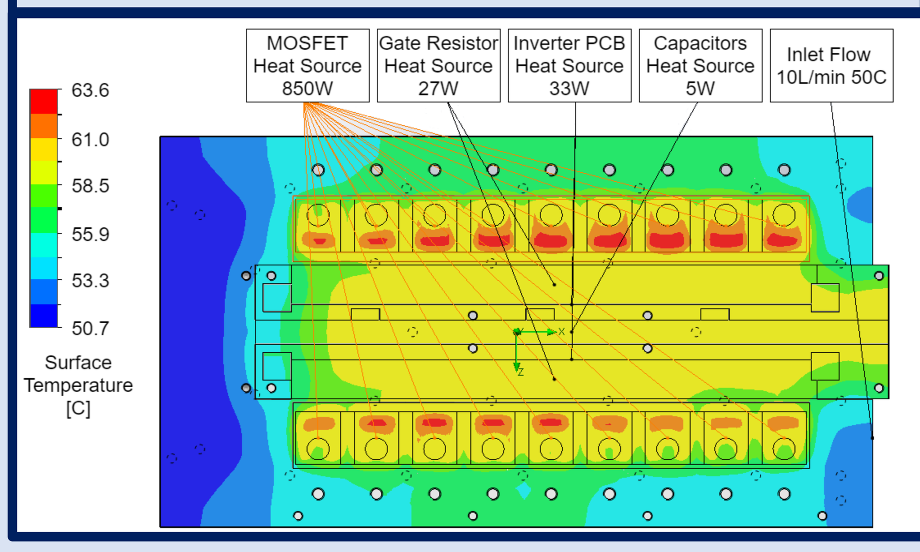
Water Cooling

The cold plate uses a U shaped flow channel that passes under the two rows of MOSFETs. The fins are located under the MOSFETs, as they are the components that generate the most heat. The flow channel connects to the rest of the cooling loop on the front via two barbed fittings (not shown in the picture). The top surface is designed to match the shape of the inverter PCB and its components (resistors, capacitors and terminals) to allow for good thermal contact between the two. It also provides mounting holes for other components such as the MOSFET mounting clips and the DC Distribution PCB. The cold plate stands on six legs, four in the corners and two in the middle and the rest of the body is designed to shave off unnecessary weight. The cold plate was modelled using Solidworks CAD and CNC machined from aluminium for its strength, low thermal resistance and low density.

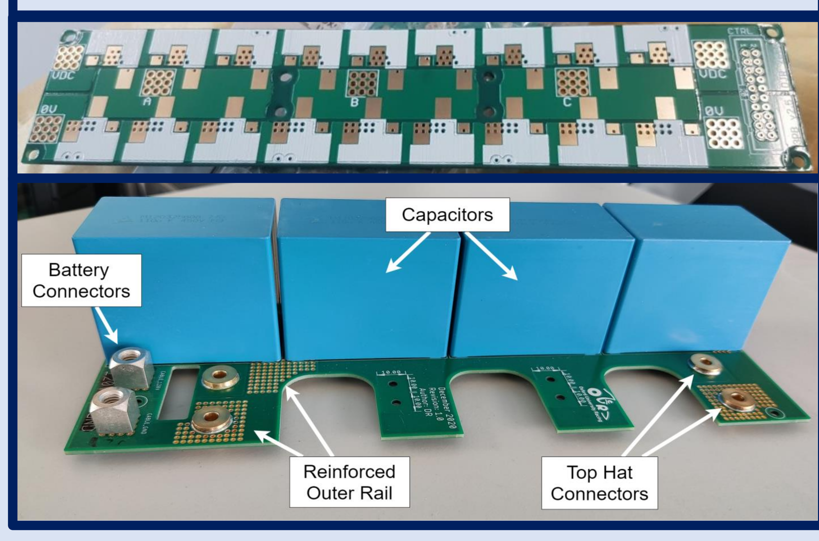
The thermal simulations showed that the system is capable of dissipating 1kW of heat with water flow of 10L/min and 4.5kPa of pressure drop. It maintains the MOSFET junction temperature around 100°C, way below the maximum designed temperature of 120°C.







Power Electronics



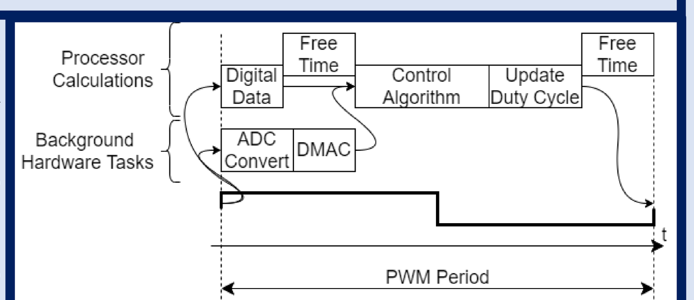
The 3-phase inverter board is shown on the top right. It is a thick copper PCB designed to carry currents in excess of 180A. It houses 18 MOSFETs along the top and bottom, and uses high current press fit terminals.

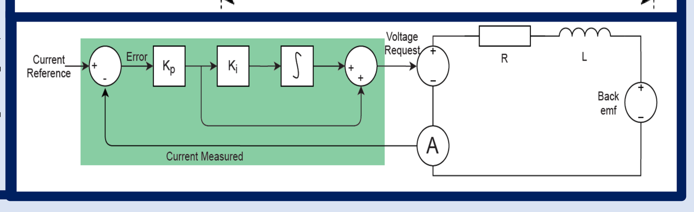
The inverter draws current discontinuously due to the PWM switching technique. The rate of current change creates large voltage spikes in the parasitic inductance of the wires and the battery. To prevent the voltage spikes from damaging the electronics, the switching currents are supplied by a set of high current low impedance film capacitors, capable of delivering 140ARMS. The capacitors are mounted onto a PCB that bolts directly onto the invert board to minimise inductance.

Software and Control

The motor controller uses a Microchip SAME70 32-bit 300MHz microcontroller. Every PWM cycle it gathers information from all analog and digital sensors (current and voltage; hall effect sensors and rotational encoder). Once the sensor data is available the control algorithm is performed and the PWM duty cycle is updated.

The control loops work in the reference frame of the rotor, also known as the DQ-axis. This way the two currents to be controlled independently through standard PI controllers. The motor controller currently uses the positional information from the encoder, however it will be improved to a sensor less design for the final design.





Results and Conclusion

The figure on the left shows a oscilloscope screenshot of two of the three phase currents for the startup procedure, then followed by two step responses. In the first 600 ms the DC currents seen are applied by the controller to align the motor to 0° to start the motor control algorithm. Then it shows the controller not applying any torque to the motor, followed by, a torque of 1 Nm. The motor controller applies sinusoidal currents and steadily picks up speed as can be seen on the detailed picture on the right. After 1.5 seconds, the torque is increased from 1 Nm to 2 Nm, causing the motor to pick up speed. These results show the motor controller is capable of smoothly starting up the motor and increasing the torque.

To conclude, in the first year of this ongoing project to develop motor controllers for Oxford University Racing's single seat electric race car, has successfully developed a working prototype:

- A first revision of the high and low voltage electronics has been designed, built and tested. Some key mistakes were identified and fixed, and noted for future
- The water cooling plate was built and successfully tested for its flow and thermal characteristics.
- A motor controller testing rig was built and tested.
- Control algorithms were simulated and then verified on the hardware and tuned. Initial exploration into the long term aim of sensorless control has been carried out.

The outcome of the project is that for under £700 a prototype of a working motor controller was built. Future projects will improve on the design, with the final goal of racing four high performance motor controllers.