Formula Hybrid Project Proposal

Bridget Taylor, Musodiq Ogunlowo, Neal Smith, William Kuang, Parker Imlay

1. Introduction

We are working with the Notre Dame Formula SAE Hybrid Racing team to improve the legacy electrical system in their hybrid vehicle. The car is a series hybrid powered by a capacitor bank in series with an internal combustion engine (ICE). An alternator converts mechanical energy from the ICE to electrical energy. The capacitor bank serves as an energy buffer between the alternator and the electric hub motors on the two front wheels. Each of these motors is controlled by a Kelly controller.

The electrical system that we are continuing to develop can be broken up roughly into three sections: control, monitoring, and information. The control system involves taking driver pedal and wheel inputs and producing motor outputs or regenerative braking. It also includes control of the ICE to maintain efficient operation. The monitoring section involves measuring voltage, temperature, and current values. If unsafe operation is detected, it shuts down the vehicle. The information system provides the driver and off-track team with live updates of the vehicle diagnostics.

2. Problem Description

Our project is different from the other Senior Design groups in that we are continuing the work of a previous team. For this reason, we will be relying heavily on the previous team's documentation and final report. Their specific design can be split up into five sections as follows: Driver Inputs, System Status Interface, Motor Controllers/Motors/Generators, Engine Feedback Loop, Accumulator Management System. Each of these sections contain problems that must be solved.

Driver Inputs

The driver inputs consist of signals from: pedals, absolute rotary encoder and a switch box

Pedals

The pedals are the foundation of driver inputs. The pedals involved are the throttle pedal and the brake pedal. The pedals would be connected to an op-amp circuit and then the motherboard in order to maintain the right level of voltage in the system. The reliability of the system will need to be improved as false errors occur frequently. The brake system by the previous team used an accelerator pedal. However, the actual vehicle will be using a hydraulic pressure transducer for braking. As a result, we will need to make sure the system is compatible with the transducer and adjust the signal thresholds accordingly.

System Status Interface

The current System Status Interface is designed to provide live updates to the driver regarding fuel level, ultracapacitor charge, vehicle speed, engine RPM, and pertinent error messages, which would all be displayed through an LCD screen. It also contains an off-track transmission by an RF transmitter which communicates to an off-track RF receiver that writes to a serial monitor. The transmitter, which communicates in UART, is used to transmit diagnostics of the vehicle to an off-track computer.

Proposed improvements to the LCD system are mainly for clarity, such as using a higher current 3.3V supply to increase brightness settings, high contrast color schemes, and glare-reducing shield. Extra data (motor/controller/engine temperatures) and modifications to the error messages system, such that multiple errors do not overflow the screen, could also be added. Another possible change is error system adjustments to see which controller sent the error messages.

The RF transmission system can be improved by adding a GUI on the receiving computer as an alternative to the separated comma list system that currently exists. An addition of an auto-saving datalog for viewing can also be implemented.

Motor Controllers/Motors/Generators

The motor and generator controllers facilitate the transfer of signals to and from the three Kelly controllers over a CAN bus. The Motherboard then interprets the contents of the signals as RPM, motor and controller temperatures, motor current, controller, switch status and error messages. There are two different types of messages that each controller sends, each with a corresponding extended identifier (EID) and respective data bytes. Although the EID for the messages are separated, there is no segment of the EID that contains information about the specific controller they came from. This is a major problem for implementation of things like torque vectoring that require differentiation of left and right motor.

There is also a problem involving the FIFO. Each of the three Kelly controllers has a USB connector but the signals are interpreted via CAN bus, where the devices are all connected to this same bus and broadcast information can be read by any of the devices connected to this bus. Since the CAN messages are of the broadcast type, there is no way to tell which controller’s message will be read in the FIFO next. This further complicates differentiating the controllers because each message needs an identifier.

Engine Feedback Loop

The current engine feedback loop consists of the ICE, a sensor to measure the motor velocity, a servo to adjust the ICE throttle, and a PID controller implemented in the motherboard. The purpose of the system is to hold the ICE at a set RPM to balance efficiency and output.

The RPM sensor uses an off-the-shelf IC chip along with a low pass RC filter to measure the frequency of the alternator output. This part of the system and the PID controller currently works.

The biggest problem with the system is noise that occurs on the two signals, RPM sensor-to-motherboard and motherboard-to-servo. The system works when the motors are turned off, but the EMI generated by the motors and motor controllers cause erroneous RPM readings and random servo settings.

Because last year’s team wasn’t able to test the system with the motors running, the PID constants could only be set for no-load conditions. In addition, the current algorithm is very simple in that it only holds the engine at a set RPM. This algorithm doesn’t account for current accumulator charge values. It also must be disabled to run the car in idle mode.

Accumulator Management System

The Accumulator Management System (AMS) requires a more versatile active cell balancing scheme. There are 2 sets of 30, 3000 F capacitors connected in series. Manufacturing tolerances on parameters such as capacitance and equivalent series resistance can affect the voltage divide between these capacitors.

The ultimate goal is to maintain an equal voltage drop across each capacitor. The balancing system in place now detects overvoltage of the capacitors and passively drains excess charge through resistors. This wastes energy and lowers the efficiency of the system. The monitor boards ensure that the voltage across each group of ultracapacitors does not fall below a set threshold. When the monitor boards detect that the voltage of a group of cells drops too low, other groups of cells can be damaged by high leakage currents and voltage spiking. To prevent this damage, the current AMS drains the accumulator cells and initiates a board shutdown cutting off the high voltage system.

3. Proposed Solution

Driver Inputs

In order to improve the reliability of the system, error margins would need to be included to set accurate bounds for the minimum and maximum acceptable values from the throttle. This would help reduce the occurrences of false errors like small variations in the supply voltage or electrical noise triggering a false fault condition.

The transducer would need to be coupled with the rest of the system and adjusted to make sure for seamless integration. The signal from the transducer would also need a gain factor since the pressure transducer outputs its maximum signal at a pressure far higher than normal driving conditions. This gain would be obtained from tuning according to physical testing.

System Status Interface

The LCD problems can be solved through implementing the Eagle file which was revised by the previous team. The high contrast color scheme, additional real-time data values, and error overflow prevention, can all be added through coding modifications. A glare-reducing shield can be purchased and installed onto the LCD. Error-controller mapping would also require coding changes.

Problems with the RF transmission system can be solved through coding adjustments which implement a GUI, datalog, and auto-saving features. Auto-saving implementation would probably be the most complicated problem within the RF transmission system.

Motor Controllers/Motors/Generators

The lack of address in the Kelly controller CAN messages was never completely verified last year. To verify, an oscilloscope with a CAN interpreting function can be used while the various parameters in the Kelly controller are changed. If it is determined that no usable address information is sent, a different method will need to be used. Other methods involve using the status bits of unused switches.

Engine Feedback Loop

The signal noise problem can be solved by simply using shielded cables. In addition, to increase robustness a dedicated pcb should be built for the RPM sensor circuit. Currently, this circuit is realized on a prototyping board. This pcb should be separate from the motherboard to help reduce noise from the high-voltage signals that are inputs to the RPM sensor.

Once the system is able to operate while the motors are running. The PID constants can be set. After that, the system can be improved by taking into account the accumulator charge values. If the accumulators are nearing full charge, the ICE can operate at a lower setpoint. If the accumulators are near empty, it should operate at maximum power. An idle-state should also be implemented to allow for warmup. Finally, if the larger team completes the car in time for race, the algorithm can be modified to optimize the charging based on the track layout.

Accumulator Management System

Active cell balancing can solve the problems presented by the current AMS implementation. This management scheme can transfer current between a pair of capacitor cells if there are uneven charge levels. This setup would take advantage of the ability of the battery monitor IC card to power an external transistor. A special auto-balancing MOSFET circuitry can balance the uneven voltage levels of accumulator cells.

4. Demonstrated Features

Driver Inputs

- A clear mitigation in the amount of false fault conditions resulting into the improvement of the error reporting of the control system.
- Successful utilization of the hydraulic pressure transducer for the braking of the system.

Engine Feedback Loop

- Successful operation of the system while the motors are running
  - RPM will be stable through a range of loads
  - Large overshoot and stalling will not be acceptable
- Multiple control states based on accumulator values
  - RPM setpoint should increase when accumulators are low and decrease when accumulators are nearly full

Motor Controllers/Motors/Generators

- Successful communication of identifying information from the Kelly Controllers via CAN messages. This would allow for information to be reliably identified as coming from a particular controller.
- Implementation of torque vectoring on turns.
- LCD speedometer provides accurate speed even when the wheels are turning at different rpms.

System Status Interface

- Successfully operational LCD screen with modifications for clarity while vehicle parts are running
  - Real-time data values
  - Real-time error management and controller mapping
- RF transmission system changes
  - Easy to navigate GUI and datalog for car data sent through the RF transmission system
  - Hopefully, working auto-save for the RF transmission system

Accumulator Management System

- Active cell balancing scheme
- Minimization of low voltage induced board shutdown events

5. Available Technologies

- Quad/Dual Supercapacitor Auto Balancing (SAB™) MOSFET Array
    - http://www.aldinc.com/pdf/ALD810025.pdf
- 5 A Fuses
    - https://www.mouser.com/datasheet/2/240/Littelfuse_Smart_Glow_MINI_Blade_datasheet-1291256.pdf

Because this project is a continuation of a previous project, we don't foresee implementation of many new/expensive technologies. Much of our work will be in understanding the technology that was implemented last year in enough depth to allow for improvement. One example is isolated SPI. Otherwise, our other costs should be rather minor, such as new circuit boards.

6. Engineering Content

This project will draw on our knowledge from classes such as Power Systems, Electric Vehicles, Control Systems, and Embedded Systems.

Hardware:
Most of the sensors have already been selected and tested. There is still some work that must be completed to integrate all of the subsystems into a working car. We will need to create an updated version of the motherboard, as well as design a board for the RPM sensor. In addition, we will need to either purchase or design a better balancing board for the ultracapacitors.

Software:
There is a lot of software work that needs to be completed. The control algorithms for the engine feedback loop need to be updated to allow for more control states as well as to take inputs from the accumulator charge values. The communication problem with the Kelly controller CAN bus also needs to be solved. There are also many improvements that can be made to both the onboard user interface and the offtrack interface.

7. Conclusions

Beyond the technical aspects, this project is interesting for a few reasons. First, it is a legacy project that is being designed for a real customer. This gives us the opportunity to understand and improve upon the work of a previous engineering team, which is a more realistic experience than building a product from scratch. We must also work with the Formula Hybrid team to develop project expectations as well as work within the guidelines and rules of the Formula

Hybrid organization. Teaming up with the Formula team further gives us the opportunity to work within a larger engineering context. Part of the expectations of the Team is that we keep them updated on our progress and give them the necessary knowledge to operate and improve upon the system in the future.

This project also give us in-depth experience in working with other engineers to create a final product. Although our work is isolated within the electrical side, the overall working vehicle will require cooperation with other engineering disciplines, most notably mechanical engineers. By the time we complete this project, we may find new problems and possible improvements for future groups. While we do not expect a qualified race-ready vehicle, our goal is to help the hybrid team develop a drivable vehicle by the end of the year.