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Low-Level Design
EE Senior Design 2010
Professor Schafer

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1 Introduction

The search for sustainable energy in a world where we are depleting natural resources has led to the development of systems that have made automobiles run on less, or no gasoline at all. Hybrid cars have the capability of combining the power of internal combustion engines and electric motors to substantially increase the efficiency of the vehicle, and electric cars are able to run entirely off of batteries and eliminate the need for any other fuel. However, both systems involve batteries that have finite and fairly short life times. A hybrid electric vehicle that is capable of powering an electric motor using a bank of ultra-capacitors would avoid the problems of short lifetimes and recharging batteries.

2 Problem Statement and Proposed Solution

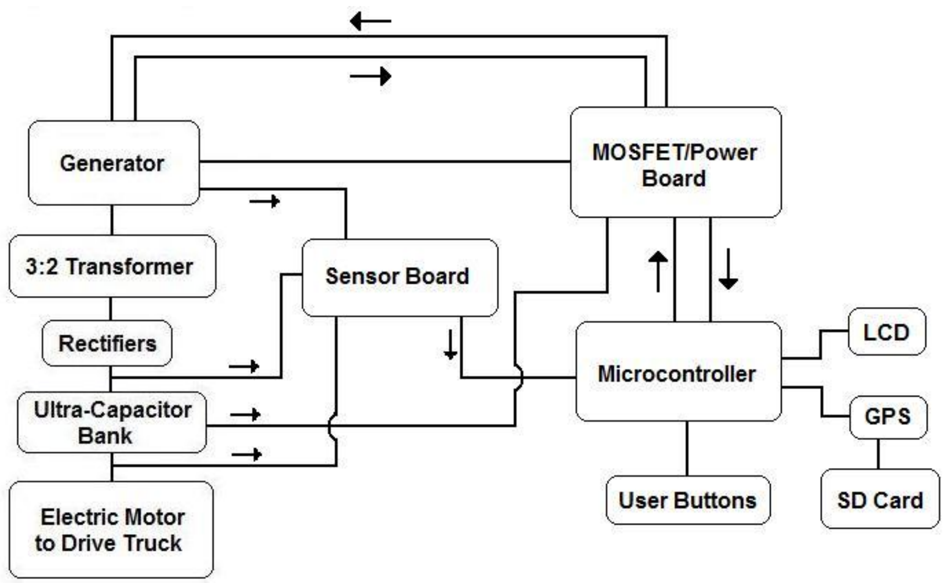
Dr. Bauer is currently working on and researching a hybrid electric vehicle. The vehicle is a truck that runs an electric motor off a bank of ultracapacitors. A crude system is currently in place to charge the ultracapacitors using a diesel generator. Our task is to develop a more robust and intelligent charging system for the ultracapacitors that aids research activities, has a human-to-charging system interface, and uses the current charging system as a starting point.

The new charging system will utilize the current generator system, bank of ultracapacitors, transformer, and bridge rectifier circuitry that is already in place. Power MOSFET and MOSFET driver circuitry will be used to take a 3.3 V signal from the logic of the microcontroller and turn it into a 25 V signal that can electrically stimulate the necessary components on the generator in order to start and stop charging cycles. Current, temperature, and voltage sensors will be used where appropriate to aid in decision-making for turning on and off key system components.

A key differentiation between this charging system and the old charging system are the additions of a global positioning system (GPS), display screen (LCD), button toggle, and SD card. The SD card will allow for data storage of the satellite information received by the GPS, while the LCD will display real-time pertinent system values, such as ultracapacitor charging time, the current drawn by the truck's motor at different points in time and under different driving conditions, as well as ultracapacitor voltage levels at different points in time and under different driving conditions. The button will allow the user to scroll through a variety of parameters such as the amount of miles expected to be available in normal driving conditions and the current voltage on the ultracapacitors.

The GPS, in combination with the SD card, will allow us to later compute the velocity and acceleration of the vehicle, with the hope of a future application in predicting energy needs for the vehicle. The addition of these features to the charging system will not only make it more robust than the old system, but will make hardware problems easier to debug and the system more user- and researcher-friendly.

3 System Description and Block Diagram



Overall System Block Diagram

On the left side of the block diagram, the components of the power system for charging the ultracapacitor stack and driving the truck can be seen. These blocks consist of the diesel generator which passes through transformer and rectifier circuitry which will convert the generated 120 V AC signal to a DC signal that is able to charge the ultracapacitors. The output of the ultracapacitors is then used as the power source for the electric motor.

In the middle of the block diagram is a sensor board. This board contains two current sensors and a temperature sensor. The temperature sensor is connected to the cylinder head of the generator, and eventually interfaces with the microcontroller to decide whether the glow plug needs to turn on or not, based on the current temperature. The two current sensors read the current going into the ultra capacitor stack and the current being consumed by the electric motor. These current sensors will interface with the microcontroller to aid in power calculations.

The MOSFET/Power Board block is a board that contains all of the hardware that will encounter high voltage and current. On this board are Power MOSFETS, MOSFET drivers, unity gain buffers, bridge rectifiers, voltage dividers, and screw terminals. This board will interface with the microcontroller through input and output signals. The input signals from the microcontroller will depend on the charging logic in the code. Three 3.3 V signals from the microcontroller will be delivered to the board through connectors and sent to the MOSFET drivers. The MOSFET drivers and the power MOSFETs will amplify and send the appropriate signals to the generator in order to control the charging circuitry. Coming into this block are signals from the ultracapacitor bank and from the generator. From the ultracapacitor bank, the voltage goes through the screw terminals and is dropped across a voltage divider to a level that is suitable for the microcontroller to accept. This signal will encounter an A/D converter that the microcontroller will use to determine when to turn the generator on and off. The signal from the generator will be the 120 V AC signal from the output of the generator. This signal will go through screw terminals, a bridge rectifier, an RC smoothing circuit, and finally a voltage divider which will send the signal to the microcontroller. The microcontroller will take this input and determine whether the generator is on and the signal to the starter can be terminated.

Also connected to the microcontroller block are the various components for the research and user interface. The GPS block interfaces with the microcontroller by sending relevant data such as longitude, lattitude, and altitude, at specified time intervals, which allows the microcontroller to make computations regarding speed, power consumption, etc. This data is also sent to the SD card which stores data for future research purposes to analyze the power consumptions of the vehicle. The data the is acquired by the microcontroller is analyzed and made available to the LCD screen which can output various parameters concerning driving conditions, i.e. velocity, fuel economy, distance traveled, power consumption, etc. The final block connected to the microcontroller block is the User Buttons block which allows for the user to toggle through data on the LCD screen.

4 System Requirements

4.1 Overall System:

Overall System Requirements	
Purpose	Regulate power distribution to the electric motor of the vehicle by maintaining proper energy levels on the ultracapacitor bank using the electric generator
Generator	Supply sufficient power to ultracapacitor bank using a direct current power supply
Ultracapacitor Bank	Must be able to supply continuous power to the electric motor

Driving Data Analysis	Must be able to analyze and adapt system to current driving conditions
User Interface	Must be able to display current driving condition information such as miles per gallon and distance traveled User can change current information displayed on LCD screen

4.2 Subsystem Requirements:

Subsystem Requirements	
Power Control System	
Purpose	Must regulate energy stored in ultracapacitor bank by controlling an electric generator
Generator	Must be able to start and stop diesel generator by determining when the generator is active. Must be able to monitor the diesel engine temperature and activate glow plugs when necessary
Ultracapacitor Bank	Must be able to monitor voltage on the ultracapacitor bank Must be able to prevent undercharging of the capacitor bank as well as prevent low charge on the banks
Sensors	Must be able to monitor various sensors such as current sensors and temperature sensors
Data Processor	
Purpose	Must be able to take GPS data to determine ultracapacitor voltage ranges used by the power control system
GPS	Must be able to read data from onboard GPS and record the data
Power	Must be able to draw power from the on board starter battery near the generator
Communication	Must be able to communicate with the power distribution controller
User Input	Must be able to receive data from a user input device for LCD display options
Display	Must be able to present information about the system on an easy to read display

4.3 Future Enhancement Requirements

In the future we would like our system to allow user-inputted vehicle parameters so that anyone would be able to run a diagnostic on their vehicle's performance. As of right now, however, the hybrid electric truck's parameters will be embedded in the system and a simple button will be used to scroll through the vehicle's outputs. We would also like the vehicle to be able to decide when to turn on and off the diesel generator in response to driving conditions. For example, the truck would hesitate to discharge the ultracapacitors when going downhill, instead saving the energy for an upcoming climb. Ultimately one would have the ability to program a route into the system, and the truck would be able to anticipate driving conditions based on prior data acquisition.

5 Low Level Design

5.1. Power Control System

5.1.1. Generator

A diesel generator rated at 7 kVA with a 3 gallon tank already lies in place in the bed of the hybrid electric truck. The generator will interface with the microcontroller (PIC18F46J50). The microcontroller will control the signals to the generator's starter, fuel valve, and glow plug, as determined by the voltage and temperature levels. The glow plug should be activated if the microcontroller senses that the temperature on the cylinder head is too low for the diesel generator to start. Once the temperature is determined to be sufficient, the generator can be turned on. At this point, depending on the ultracapacitor stack voltage, the starter and fuel valve signals on the generator can be activated and the generator can turn on. The generator has an outlet on it that produces 120 V AC. This outlet will be attached to the MOSFET/Power board through two screw terminals. The terminals are connected to a bridge rectifier (MB2S-TP), then to an RC circuit where the rectified signal is smoothed to make a DC signal. Next a unity gain buffer introduces a high impedance while keeping the voltage the same, and the signal is connected to a 1:45 voltage divider on the board to bring the 120+ V DC down below 3 V where it is safe to be sent to the microcontroller. Through the connector on the end of the board, the microcontroller receives the signal that the generator is producing current through its outlet, by triggering the HLVD (High-Low Voltage Detect) pin. At this point, the starter signal originally sent by the microcontroller can now be turned off.

5.1.2 Transformer and Rectifier

The diesel engine drives a generator that produces a 120V alternating current. This output is then connected to a 3:2 autotransformer to take the voltage from 120 to 80 volts. After the signal has been transformed, it is fed in parallel to 3 bridge rectifiers that supply an 80 volt direct current to the bank of ultracapacitors. All of the power requirements have been met during previous work and should not be of concern to us.

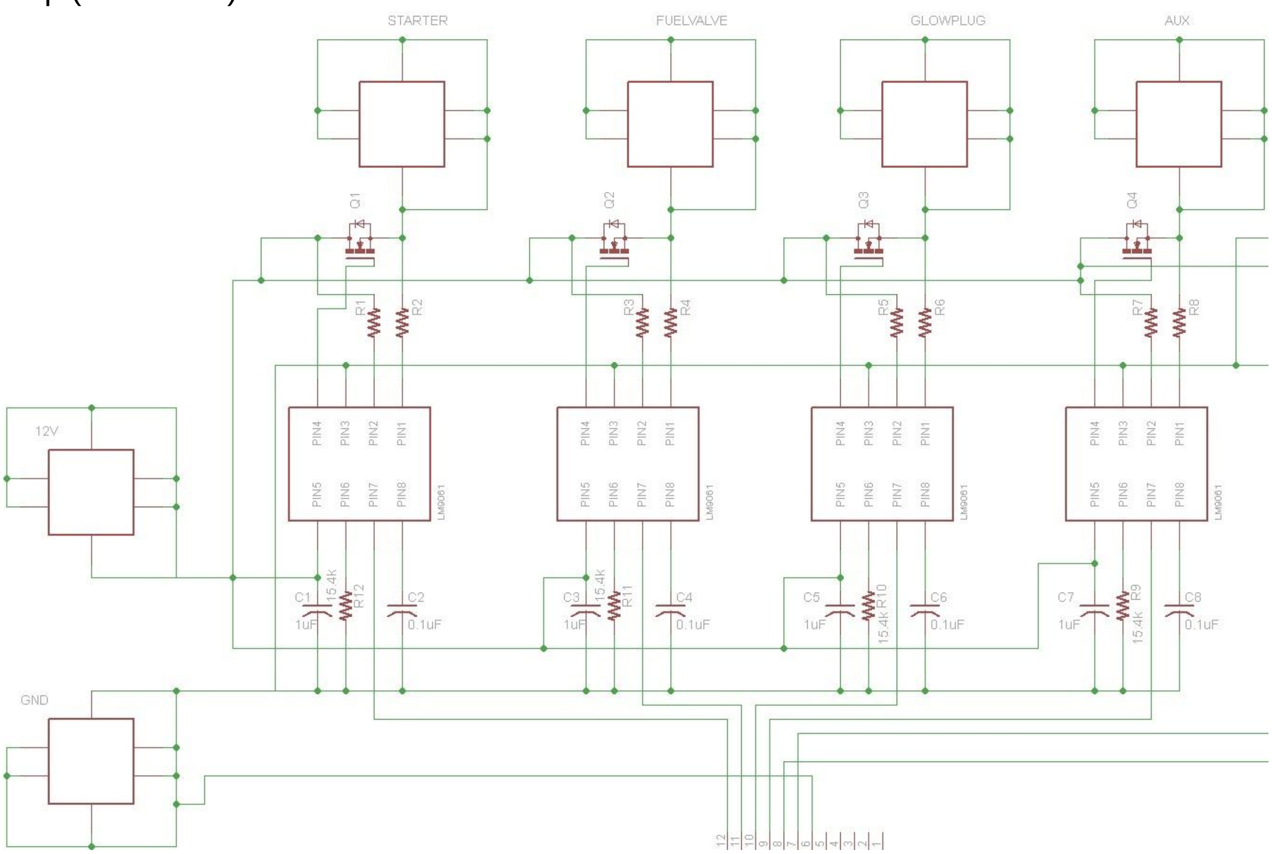
5.1.3. *Ultracapacitor Bank*

A bank of 34 ultracapacitors rated at 2.7 V each are located in a box in the bed of the truck. They are wired in series and have diode circuitry to dissipate current at high voltages. The ultracapacitors each have an extremely low impedance and when fully charged will have a tremendous current going across them, so they have the potential to be very dangerous if overcharged. With 34 ultra-capacitors, the bank can theoretically hold a 91.8 V charge. To power the electric motor of the car, the ultracapacitor bank should have a voltage above 60 volts. On the other end of the spectrum, the ultracapacitors should not exceed an upper range of 80 volts so as to not break the capacitors by overcharging. Attached to the ultracapacitor stack are 22 gauge wires that connect to the MOSFET/Power board through screw terminals. These terminals lead to a unity gain buffer to introduce a large impedance and avoid short circuiting. Next, a voltage divider uses a 1:30 ratio to bring the maximum allowable voltage on the stack of 80 V down to 2.67 V. The voltage divider is tapped in the center and brought to a connector on the edge of the board that interfaces with the microcontroller, where the A/D converter built into the microcontroller will take the analog signal and create a usable digital signal to determine voltage on the bank, and inform the system when thresholds have been met.

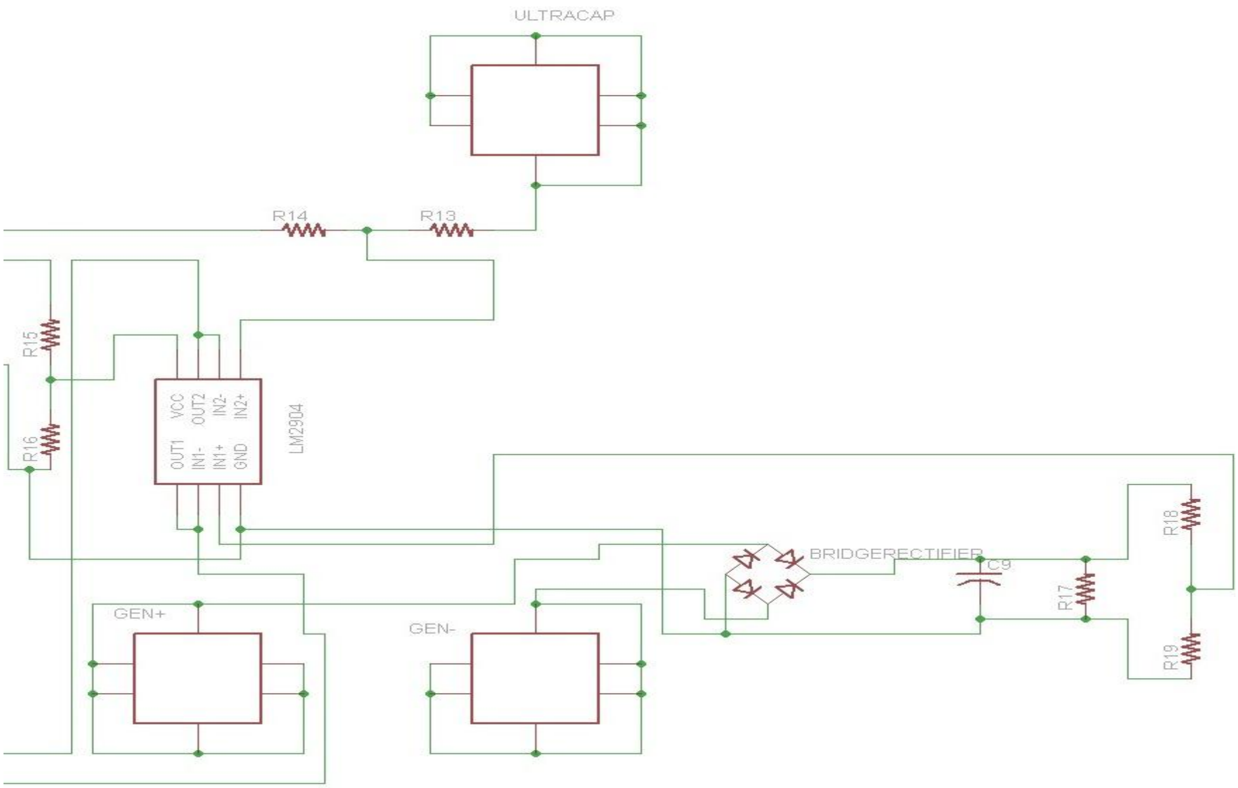
5.1.4. *MOSFET/Power Board*

This board contains the hardware that will encounter high voltages and currents. The board contains power MOSFETs, MOSFET drivers, screw terminals for outside connections, rectifier, unity gain buffers, resistors and capacitors for circuitry, and connectors to interface with the microcontroller board. The drains of each of the power MOSFETs are connected to the 12 V signal coming from the battery on the generator. The MOSFET drivers are also powered by the 12 V from the battery. The inputs to the board come from the microcontroller and include the 3.3 V logic signals for the starter, the fuel valve, and the glow plug. These signals come through the connectors and lead to the MOSFET drivers. The MOSFET driver circuitry amplifies the 12 V supply by minimum Vcc +7 to maximum Vcc +15 and is thus able to turn on the gate of the power MOSFET when presented with the 3.3 V logic input. The MOSFET source is connected to a screw terminal that connects to and activates either the starter, fuel valve, or glow plug on the generator with current sourced through the MOSFET. The screw terminal is capable of handling currents up to 30 A, which is why it was chosen because of the high current that can spike from the starter and fuel valve signals. If the input from the microcontroller is 3.3 V, the screw terminal on the source can expect to be in the 19-27 V range, and if the signal from the microcontroller is 0 V, a 0V signal is expected at the source screw terminal.

Also on the MOSFET/Power board, as referenced in 5.1.1. and 5.1.3. are the circuitry for rectification, unity gain, and voltage division for the signals to be outputted. The sections mentioned describe in detail these aspects of the board. The Op Amp that is used on the board for a unity gain buffer needs 5 V Vdd. There is another voltage divider on the board that uses a 1:2.4 ratio to get this 5 V as needed to power the Op Amp (LM358MX).



MOSFET Board



Ultracapacitor and Generator Voltage Dividers

<u>Testing</u>: Power Control System

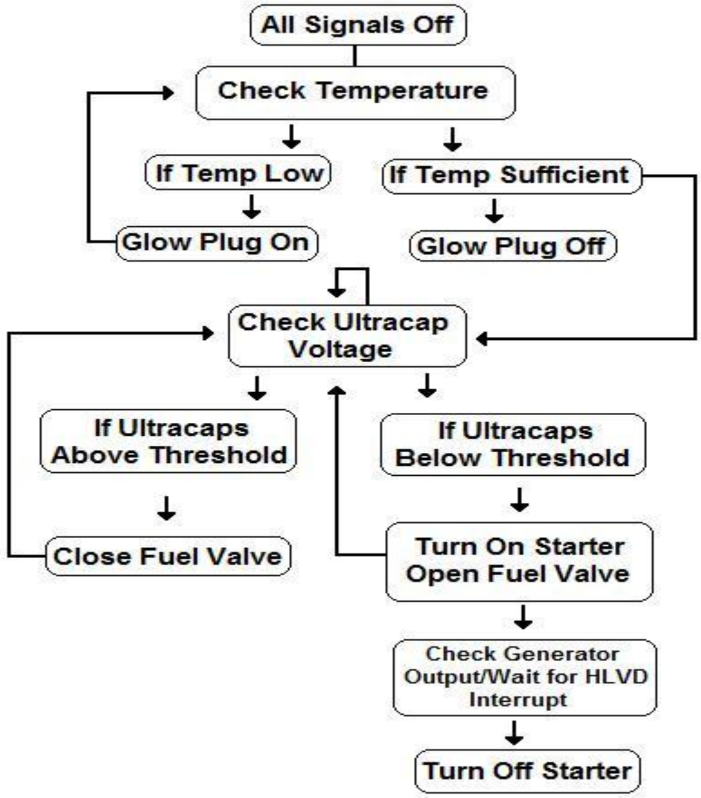
The circuitry between the generator, autotransformer, rectifiers, and ultracapacitor bank is already in place from previous work and has been demonstrated to be satisfactory, so this does not need to be tested. The truck we are going to use has an identical system that is set up in the lab in the basement of Fitzpatrick, so our initial tests will be performed here. For the original subsystem test that was preformed in December, a prototype board was made. This board was similar to the MOSFET/Power board that was described earlier. The recommended circuitry from the data sheet for the MOSFET drivers was soldered onto a prototype board, along with the power MOSFETS. The input power to the board was a 12 V battery that was run through a large 1 ohm resistor, creating a 12 A current. This current did not harm any of the circuitry. The drain of the power MOSFETs each had a constant 12 V signal from the battery, and the gate of each was connected to the output of the MOSFET drivers. On the microcontroller, a program was loaded to simulate a charging cycle. Certain signals were turned on for periods of time, and the 3.3 V output from the microcontroller was connected to the input of the MOSFET driver. When the signal was high, the signal at the gate was read, which successfully revealed about a 25 V signal, which would be more than sufficient for activating the starter, fuel valve, and glow plug on the generator. Also in the program was an low to high voltage detect interrupt that would clear the starter signal. This simulated the generator turning on and outputting a voltage, at which time the starter does not need to be on any longer. Also, LED lights were used to indicate when each signal was on. The test showed accurate results. The code below shows the way this subsystem was tested.

```
volatile bit glowplug@LATA.0;
volatile bit starter@LATA.2;
volatile bit fuelvalve@LATA.4;
volatile bit peie@INTCON.6;
volatile bit gie@INTCON.7;
volatile bit hlvdie@PIE2.2;
volatile bit hlvdip@IPR2.2;
volatile bit hlvdif@PIR2.2;

//low-to-high voltage interrupt to detect when generator is outputting current (PIN
A5)
void interrupt(void){
	if (hlvdif){
		starter = 0;
		late = 11011111b;//LED indicator: glowplug-off;starter-off;fuelvalve-on
		hlvdif = 0;}
}
void main(void){
	trise = 0b;//LED indicator lights
	trisa = 00100000b;//set Port A as outputs except for bit
5(HighLowVoltageDetector)
	hlvdcon = 10111111b;//set bits for HLVD interrupts
	hlvdie=1;//Enable HLVD interrupt
	hlvdip=1;//Enable high priority for hlvd interrupts
	peie=1;  gie=1;  //enable global interrupts
	//initial turn on situation
	glowplug = 1;
	fuelvalve = 0;
	starter = 0;
	late = 01111111b;//LED indicator: glowplug-on;starter-off;fuelvalve-off

	//let glow plug stay on for 5 seconds
	//***Will need to read temperature sensor in future***
	delay_s(5);
	glowplug = 0;
	late = 11111111b;//LED indicator: glowplug-off;starter-off;fuelvalve-off

	//turn on starter motor and open fuel valve
	starter = 1;
	fuelvalve = 1;
	late = 10011111b;//LED indicator: glowplug-off;starter-on;fuelvalve-on

	//let generator run for 20 seconds
	delay_s(20);
	fuelvalve = 0;
	late = 11111111b;//LED indicator: glowplug-off;starter-off;fuelvalve-off
}
```

Future testing for the rest of the power control subsystem will have a few more additions. Already in production is the MOSFET/Power board described above. This board contains all of the parts described in the prototype board above, plus the necessary voltage divider circuits to process the signals from the generator output, and the voltage on the ultracapacitor stack. To test that the system can work properly on the generator, we will have to have a better understanding of corresponding values specified by the AD converter. To perform this task, the kit board will be utilized. A voltage will be sent through a 1:30 voltage divider circuit identical to the one on the MOSFET/Power board. This signal will be sent into the ADC of the kit board microcontroller in order to set boundaries within the microcontroller program. This same type of test will be performed for the current sensors, so that the corresponding current and ADC values can be determined. Likewise, the temperature sensor will undergo a similar test, by varying the temperature, the corresponding temperature and ADC values can be analyzed to determine the temperature that corresponds to the low threshold temperature when the glow plug will need to be activated.

Another test that we will need to perform is to make sure that an acceptable end signal is created from the generator output. This will be done by replicating the circuitry on the MOSFET/Power board on a bread board. A rectifier, op amp, RC circuit, and voltage divider will be placed on a bread board. The input to this circuit will be a wall outlet that outputs the same 120 V 60 Hz signal as the generator. The signal at the end of the circuit will be measured to verify that its voltage is below the maximum allowable 3.3 V that the microcontroller can handle. Also, an oscilloscope reading will be performed to make sure that a smooth DC signal is being created by the RC circuit.

Overall, the final programming flow for the Power Control System that can turn the generator on and off will look like the following.



Programming Flow for Power Control System

5.2. Data Processing

5.2.1. *Microcontroller*

A microcontroller will be used to monitor and control all subsystems. A Microchip PIC18F46J50 will be powered using the 12 volt starter battery attached to the generator. The auxiliary board used to control the generator will be connected to the microcontroller using standard input/output ports. A default starter program will be used to start and stop the generator. Power used by the motor will be monitored by the microcontroller through current sensors attached to both leads of the ultracapacitor bank. Monitoring the power used by the motor will allow the microcontroller to know when to start and stop the generator. A GPS system will also be connected to the microcontroller through a serial SPI interface. The GPS will supply general location information which can then be stored on a Secure Digital (SD) memory device. Also, the microcontroller will use the location information to determine the power needed to accelerate the vehicle. Relevant information to the driver (i.e. power consumption of the motor and miles per gallon) will be presented on an LCD display. What exact information will be displayed on the LCD is determined by user input through push button signal sent to the microcontroller. A push button located in the cab of the vehicle will allow the driver to activate the system.

5.2.2. *Glow Plug and Temperature Sensor*

The diesel generator may only be started if the cylinder-head is heated to a high enough temperature. The temperature sensor will be a K-type thermocouple cable attached to the cylinder head. A thermocouple-to-digital IC (Maxim MAX6675ISA+T) will be used to translate the thermocouple data to a readable digital signal. The digital signal can be translated by the microcontroller and compared to a threshold value using a standard SPI serial interface. If the cylinder head temperature is below the threshold value, then a glow plug sequence will be initiated. The glow plug is already attached to the cylinder head, so a simple 12V signal can be applied to activate the glow plug. The auxiliary board will supply the 12V signal from a power MOSFET. When the temperature exceeds the threshold, then the microcontroller will deactivate the glow plug.

5.2.3. *Voltage Sensor for Ultracapacitors*

The voltage of the ultracapacitor bank will be monitored using a voltage divider. A voltage divider will allow for the ultracapacictor voltage to be converted to a small signal voltage capable of being read by the microcontroller. The microcontroller will use the voltage signal to determine when to activate and deactivate the generator by comparing a threshold voltage. The microcontroller varies the threshold voltage based on power needs of the motor. It is important to not allow the ultracapacitor bank be below 55V. When the initial start sequence is activated, the priority is to check that the ultracapacitor bank is not below 55V.

5.2.4 *Liquid Crystal Display (LCD) and Push Buttons*

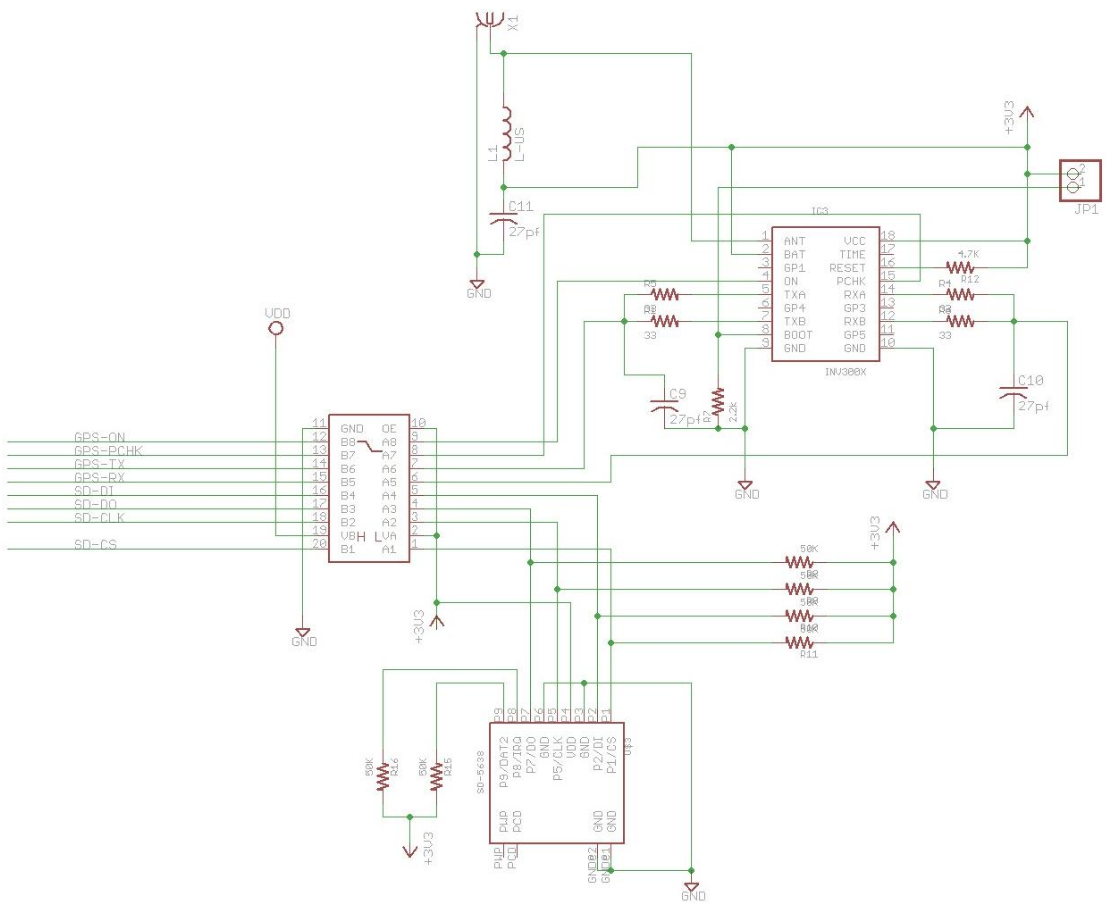
User interface is desired for this project in order to display important and useful information. An LCD display (NDH-0216K3Z-FL-GBW) will interface with the microcontroller and give the user on screen values for velocity, distance traveled, the voltage across the capacitors, and the wait time for the glow plug sequence when needed. These values will be either computed or read from other components in the system such as the temperature sensor on the cylinder-head or the GPS. Various push-buttons located in the cab of the vehicle will allow the user to scroll through the relevant data on the LCD screen.

Testing: *Data Processing*

It will be best to test each subsystem of the microcontroller separately. First, a test of the MOSFET circuits powering the generator will be performed. This testing was described in the testing section of the Power Control System. After these tests have been completed a test of the temperature sensor and glow plug. The temperature IC and glow plug will connect to the microcontroller separately. This will allow the microcontroller to only respond to the temperature data of the IC. The only other output would be the glow plug, which is attached to the MOSFET board. The LCD display can be tested by allowing the microcontroller to output simple text through the serial SPI interface.

5.3 GPS Data Research System

5.3.1 *GPS*



GPS Schematic

The process of analyzing the performance data of the truck will begin with the acquisition of raw positional data with a GPS receiver. In recording the latitude, longitude, and altitude, we will be able to determine velocity and acceleration, which will be incorporated with vehicle paramaters to evaluate the vehicle's performance. While we have yet to finalize the specific model to be used in the final system, we will move forward with a prototype board built previously by Dr. Schafer that uses the Inventek ISM300F2. This module has the necessary input/output for our system, with two serial ports each with a universal asynchronous receiver/transmitter. The microcontroller will provide power to the GPS (3.3V) and tell the it how often to sample the truck's coordinates, which will then be outputted to the SD card.

5.3.2 *SD Card*

A SanDisk SDSDJ SD card will be used to store the GPS data acquired during a vehicle trip. Later on, the data will be uploaded onto a computer and manipulated in a spreadsheet. As with the GPS receiver, the SD card purchased by Dr. Schafer will be used to develop a prototype for the system. The SD card connects to the board via a Kyocera 5638 Series SD Card Connector. We have yet to determine the size of the card to purchase, but it will probably be either 1 or 2 GB to ensure that there is enough room on the card to collect the data from a long trip in the truck. We will utilize the SD card's SPI signaling bus topology to transfer data from the GPS receiver to the card.

5.3.3 *Testing*

Prior to incorporating the GPS and SD card into our entire system, we will test their functionality on a prototype board as mentioned above using one of the kit board microcontrollers. The schematic for the prototype board can be found below.

6 Bill of Materials

Team America Parts						
Total	$159.90					
Quantity	Price Each	Total	Part Name	Manf. #	Dist. #	Distributor
9	$0.88	$7.96	Terminal Screw	8196	8196K-ND	Digi-key
4	$1.40	$5.60	Power MOSFET	IRFS3806TRLPBF	IRFS3806TRLPBFCT-ND	Digi-key
4	$2.08	$8.32	MOSFET Driver	LM9061M/NOPB	LM9061M-ND	Digi-key
1	$0.47	$0.47	OP-Amp	LM358MX	LM358MXFSCT-ND	Digi-key
1	$0.44	$0.44	Bridge Rectifier	MB2S-TP	MB2S-TPMSCT-ND	Digi-key
1	$1.54	$1.54	12 Pos. Header	22-05-3121	WM4310-ND	Digi-key
4	$0.07	$0.26	1uF Capacitor	C2012Y5V1H105Z/0.85	445-3463-1-ND	Digi-key
4	$0.04	$0.18	.1uF Capacitor	08055C104KAT2A	478-1395-1-ND	Digi-key
4	$0.07	$0.28	15.4k Resistor	ERJ-6ENF1542V	P15.4KCCT-ND	Digi-key
8	$0.04	$0.32	1k Resistor	ERJ-6GEYJ102V	P1.0KACT-ND	Digi-key
1	$3.55	$3.55	44-Pin Microcontroller	PIC18F46J50-I/PT	PIC18F46J50-I/PT	Microchip

1	$29.95	$29.95	GPS Module	ISM300F2	ISM300F2	Inventek
1	$9.25	$9.25	GPS Antenna	ACTPAT154-01-IP	ACTPAT154-01-IP	Inventek
1	$2.90	$2.90	SD Card Slot	10067847-001RLF	609-3956-1-ND	Digi-key
2	$26.00	$52.00	Current Sensor	HASS 50-S	398-1062-ND	Digi-key
1	$19.75	$19.75	LCD Display	NHD-0216K3Z-FL-GBW	763-0216K3Z-FL-GBW	Mouser
1	$14.33	$14.33	Thermocouple IC	MAX6675ISA+T	MAX6675ISA+TCT-ND	Digi-key
1	$2.80	$2.80	Voltage-level Trans.	TXB0108PWR	296-21527-1-ND	Digi-key

7 Conclusions

This document highlights the progress we have made thus far in designing and constructing our hybrid-vehicle control system for Dr. Bauer's research project. Many initial low-level design decisions have been made, but implementation of these decisions has yet to attempted. This implies that while much of the design-work is behind us, piecing together the system is a challenge that will continue to keep us occupied. Thus, while details in parts used may change, both the overall system structure and low-level design outlined in this document will remain the same.

8 References

GPS Module: http://inventeksys.com/html/ism300f2-c4.html

GPS Antenna: http://inventeksys.com/html/actpat154-01-ip.html

LCD Display: http://www.mouser.com/ProductDetail/Newhaven-Display/NHD-0216K3Z-FL-GBW/?qs=3vk7fz9CmNwJDkP25WXcsw%3d%3d