LIGHTNING RIDERS

HIGH LEVEL DESIGN

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Prepared By	Lightning Riders Team	EE Seniors	10/4/07
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1. INTRODUCTION

Electrical engineering seniors at the University of Notre Dame are privileged to undertake a year-long course in Senior Design. The students form 4-6 person teams and select a project based on their interests that involves a significant amount of in-depth engineering design. As our project, our team elected to design and build a series hybrid motorcycle. We have written a proposal document outlining the basic scope of our project, the project deliverables and various technologies that we may be able to leverage in our design. Our proposal was approved by the course professor with minor changes, which have been addressed. This document is the next stage of the design process and details the high level design for our system.

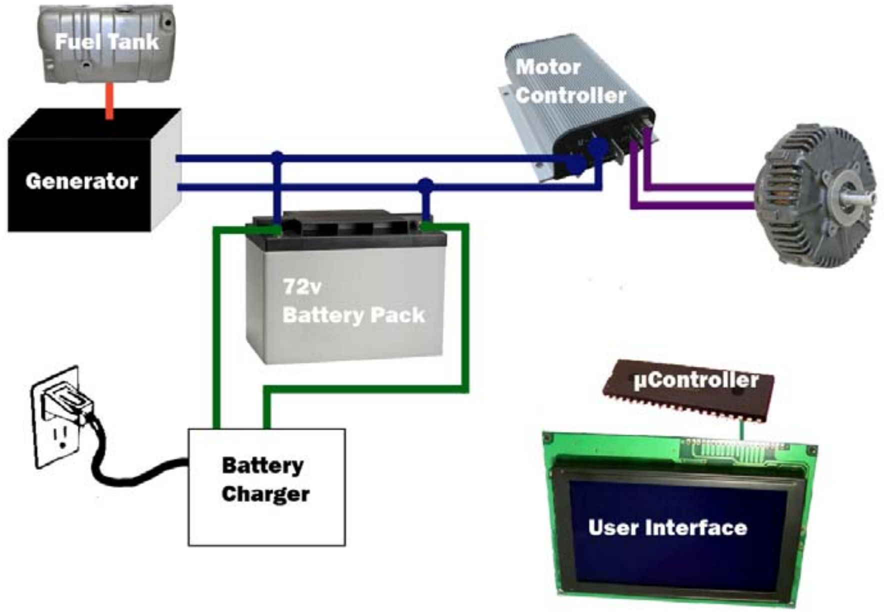
2. PROBLEM STATEMENT & PROPOSED SOLUTION

As we become more aware of our potential to impact the environment, new vehicles must reflect the common desire to protect the planet by having a smaller environmental impact than their predecessors and generate less pollution and greenhouse gases. As fossil fuels are consumed and the laws of supply and demand drive fuel prices up, the next generation of vehicles must take advantage of alternative energy sources and use the limited fossil fuel sources in the most efficient way possible. Presently, hybrid vehicles are at the forefront of automotive research by commercial companies, though they have been somewhat neglected in academic environments. Few people fully appreciate the advantages and disadvantages of hybrid vehicles relative to their mature cousins, the conventional gasoline powered automobile.

Hybrid vehicle technology serves as a bridge between the old world of fossil fuel powered vehicles and a new era of electric vehicles. Current energy storage technology does not allow for the long range travel and rapid charging necessary to compete with conventional designs. However, the combination of fossil fuel and electric based technologies in a hybrid design serves as a compromise to take advantage of the best of both technological worlds. For our project, we will design and build a functional prototype of a series hybrid vehicle that combines the range of a fossil fuel vehicle with the efficiency and performance of an electric vehicle. Due to constraints imposed by funding, time and mechanical complexity, we have chosen to use a motorcycle as the base vehicle for our functional prototype.

3. SYSTEM DESCRIPTION & BLOCK DIAGRAM

3.1. Block Diagram



3.2. Generator

The Generator provides power to supplement and/or recharge the Battery Pack. Ideally, the Generator will have electric start functionality so that it can be started either by the embedded control system or through a push-button interface. In the end, we may not implement the electric start but at the very least, we will implement a kill switch for the generator sub-system.

3.3. Battery Charger

The Battery Charger monitors the State of Charge (SOC) of the battery pack, as well as the temperature of each battery and the voltage across each battery. It is responsible for controlling the flow of input power to the batter pack from the generator. In addition, it communicates the SOC to the User Interface/Hybrid Controller.

3.4. Battery Pack

The battery pack is the primary energy storage device on the motorcycle. To sustain the necessary voltages and currents into the motor controller we will use a 72V pack of 6 12V motorcycle batteries.

3.5. User Interface/Hybrid Controller:

The Hybrid Controller oversees the entire vehicle system and communicates vital information to the user while allowing user feedback and parameter selection. It communicates with the Battery Charger to determine the projected range of the system. It displays system and component status information to the user through an LCD display while also having several buttons to accept user inputs. Mode and screen selector switches will also be implemented.

3.6. Motor Controller:

The Motor Controller is a commercially available component that accepts a simple potentiometer throttle input and uses the energy supplied by the generator and battery pack to drive the traction motor. Most motor controllers have a serial interface that allows the user to program the device for particular performance characteristics.

3.7. Traction Motor:

The traction motor is controlled by the Motor Controller and is directly coupled to the rear tire through the drive shaft and rear gear. It is a commercially available unit that will be purchased.

3.8. Sub-System Interfaces

Due to the close physical proximity of the subsystems, all communications and interfaces between the systems will be wired; we will not use a wireless interface for communications. The motor controller, battery charger, and hybrid controller systems will contain embedded programs. Based on the technology available, these will programmed using a serial interface. Due to the nature of the systems, a more convenient system for reprogramming these devices (such as USB) is unnecessary.

4. SYSTEM REQUIREMENTS

4.1. Overall System

Our hybrid electric motorcycle will be designed to work as both a pure electric vehicle capable of traveling 10 miles and a hybrid electric/gas vehicle capable of 50 miles of travel. The vehicle will also be capable of sustaining a top speed of 50mph. The system will have a display that will provide the user with information concerning speed, remaining energy for travel, and rudimentary power flow of the system. The user will be able to manually start the gas generator and run the vehicle by key ignition. The lead-acid battery pack will be rechargeable via the gas generator, or by plugging the battery charging circuit into a regular household wall socket. The electric motor will be controlled by a motor controller, and our own proprietary hybrid controller will oversee the system, providing a user interface to the battery charger and energy monitor. For safety, the system will have an appropriately placed kill switch to shut off components in case of emergency. We will also have to design and physically assemble in addition to making any modifications to the frame to hold all the components in place.

4.2. Motorcycle

The bike will need to have enough space to contain all of the equipment associated with our hybrid drive system. Although the electric motor will be much smaller than the IC engine originally associated with the motorcycle, the extra components will require comparable space. The bike should also be relatively light to ease the load on the motor. In choosing a bike we will need a vehicle with sturdy wheels and tires as well as brakes, a sound frame and overall good condition.

4.3. Mechanical Systems

The bike will need to be modified to hold the components of the hybrid system in place. These brackets must provide a solid mounting frame as well as keep the rider safe and the bike balanced. We will also need to attach the electric motor to the drive shaft of the rear wheel.

4.4. Hybrid Controller

The hybrid controller will be a microcontroller based device that will interface with other sub-systems to meet the requirements set forth in the proposal. The controller has the following requirements:

- Communicate with the Battery Charger sub-system to obtain the battery SOC
- Communicate with the Battery Charger sub-system to obtain voltage and temperature for each battery in the battery pack.
- Calculates projected range based on available fuel.
- Monitor the power flow in vehicle system (to/from generator, motor, and batteries)
- Calculates current efficiency since last reset
- Drive the User Interface display
- Accept inputs from the user through switches and buttons
- Monitor vehicle speed and display it to the user.
- Generate warning messages for user as necessary

4.5. User Interface

The user interface will both display information to the user and receive inputs from the user. It must have the following capabilities.

- Interface with the hybrid controller to receive vital information
- Display current fuel levels, both battery SOC and fossil fuel
- Display efficiency calculations and expected range
- Display real-time power flow information
- Display warnings to user as appropriate
- Enable user to interact with the system through simple button interface
- Enable user to select operating modes for the vehicle
- Enable user to change what is currently being displayed on the screen.
- Display overall system status information to the user

4.6. Hybrid Controller Software

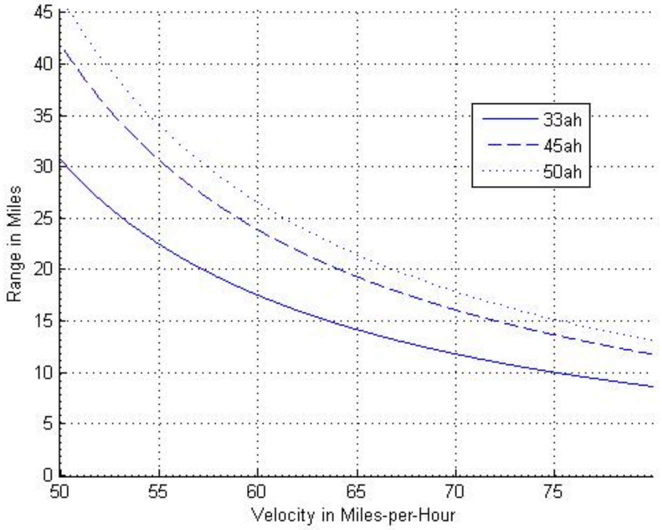
The hybrid controller software is responsible for collecting and presenting vital information to the user while accepting user inputs. As such, the microcontroller will communicate with the battery charger microcontroller to exchange information, which will require a software component for communication. It will communicate with two separate LCD displays. And it will allow user inputs via buttons and switches. A draft version of the software flow is given in a later section.

4.7. Battery Pack & Charger

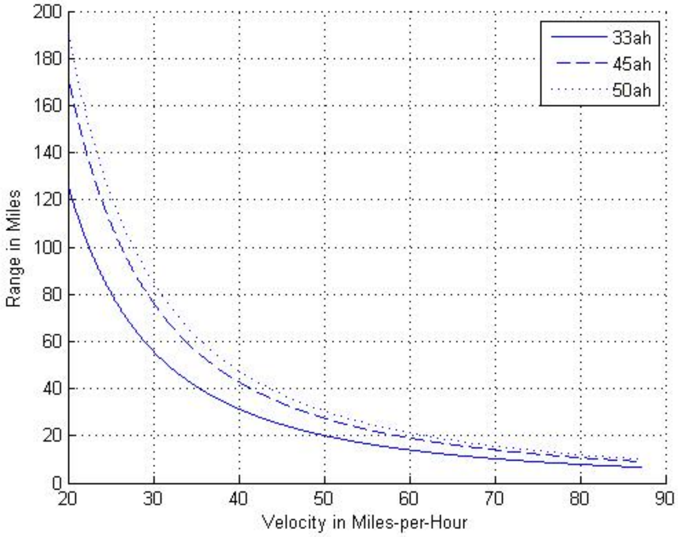
4.7.1. Batteries

After considering our performance requirements and available technologies, we have tentatively selected an electric traction motor and at least a class of motor controllers. In order to achieve the desired performance, the motor controller requires a 72VDC input. We expect to meet the voltage requirement by connecting 6 12V batteries in series.

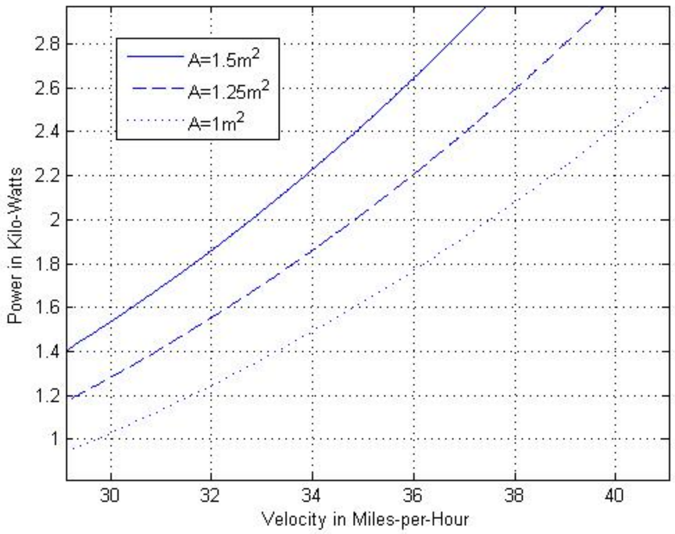
To meet our range requirements, we simulated the bike's range in miles versus velocity in miles per hour for battery packs of varying energy capacity.



We also simulated the bike's range, assuming that the 2kW generator is constantly operating.



To get an idea of a possible generator strategy, we plotted the velocity and power requirements for various cross-sectional areas. The frontal area of the bike is the key parameter for calculating air drag, which is the dominant power sink as velocity increases. The frontal area of the bike is highly dependent on the model we choose for our system.



This graph suggests that the break-even point for the two power supply systems is 35MPH. For constant speeds below 35MPH all the power required for vehicle motion can be supplied by the generator. The further the constant velocity is below 35MPH the more power will be available to charge the batteries.

4.7.2. Battery Charger

The battery charger needs to take power from either a wall socket or the onboard generator, both of which are assumed to be AC voltage sources greater than 100V, and convert it to the appropriate charging voltage for the batteries. It must provide voltage above 72V in order for the batteries to charge; if we assume ~+2V per battery, the charger must supply 84V to the battery pack for charging.

The charger needs to monitor the battery pack and determine when the batteries have reached the point at which the cells have reached 2.3V each. At this point, the current applied to the battery must decrease to prevent excessive heating and damage to the battery. We anticipate that the battery charger control will reside in microcontroller driven circuitry. It will be capable of interacting with the hybrid controller microcontroller to provide update information on the battery system status.

4.7.3. Battery Charger Software

The Battery Charger Software is responsible for monitoring, protecting and charging the battery pack properly. To do so, the microcontroller must control the current inflow into the battery pack, as well as measuring that current into the pack, the voltages across the batteries, and their temperatures.

4.8. Generator

The generator will provide power to charge the battery pack, or provide supplemental power to the traction motor. It must provide enough power to the system to have a measurable impact on the power flow, while also being small and compact. A 100 Watt generator, while small, is not really useful when the bike requires 1kW to travel at 28MPH.

4.9. Electric Motor & Motor Controller

In our proposal, one of the project deliverable goals was to have a motorcycle which can sustain a top speed of 50 mph. In order to do so, the electric motor must be able to achieve such a speed within the design constraints of the motor. Using a MATLAB simulation for horsepower vs. speed for motorcycles, we determined that the motor should be able to output about 9 HP to maintain a speed of 50 mph. This translates to roughly 7 kW of power. Given that our battery pack will provide 72 V to the system, this means the motor and motor controller should be able to handle 100 A of current at this speed. Therefore, the electric motor and motor controller must be able to take an input of 100 A at 72 V sustained in order to output 7 kW of power to the wheels.

5. HIGH LEVEL DESIGN DECISIONS

5.1. Motorcycle

We chose to use a 1983 Yamaha Seca bike because of its size and availability. It has a good sized frame which previously held a 750cc 4 Cylinder engine. The vehicle is a direct-drive configuration, with a measured gear ration between 2.6:1 and 3:1. This provides a theoretical top

speed of 80-100 MPH based on the diameter of the rear wheel, and top RPM of the motor. This relatively high gearing could potentially be an issue, but the favorable torque characteristics of the electric motor mitigate this concern. We were lucky enough to find a bike which had no engine. Because of this, the previous owner donated the bike in return for us simply getting it out of his garage.

5.2. Mechanical Systems

The mounting brackets of the different components will be determined by the size of the mounting holes on each individual component. We will weld the mounting brackets to the frame of the bike and then attached the various components with bolts. For connecting the drive shaft of the electric motor and the motorcycle rear wheel we will leave the gear ratio as is. It would be nice from a torque standpoint to tweak the gearing very slightly, but initial testing should show us if this is indeed necessary.

5.2.1. Future enhancements:

We would like to create a cowling to conceal the components from the rider for safety and aesthetic reasons, as well as improving the coefficient of drag of the bike.

5.3. Hybrid Controller & User Interface

The hybrid controller will be a microcontroller based sub-system to accomplish the requirements for it. We intend to use two separate microcontrollers in our design, one for the hybrid controller and one for the battery charging subsystem. These units will communicate with one another through an SPI or other similar interface. This will allow the hybrid controller to obtain information gathered by the battery charger related to the battery status. The hybrid controller will be connected to at least one current transducer to capture the power flow. From the information gathered from the battery charger and the current sensors, the hybrid controller will calculate a projected range for the vehicle and calculate the current efficiency. The controller will also monitor the current vehicle speed, perhaps will a hall effect sensor, and display it to the user.

The hybrid controller is responsible for driving the user interface displays and accepting inputs from the user. We selected an monochromatic LCD display with and LED backlight as the primary display for our system. The monochromatic feature provides a high contrast ratio which should help in situations involving bright sunlight while the backlight will provide illumination in low-light environments. After cost and size considerations, we believe that a 4x20 character display will be adequate for our needs. Several sample screens are given below in tabular form.

MAIN SCREEN

R	P	M	:							X	X	X	X			
S	O	C	%	:								X	X			
S	O	C		R	A	N	G	E	:	X	X	.	X		m	i
F	U	E	L	%	:							X	X			

				P	O	W	E	R	F	L	O	W				
B	A	T	T	:		+-	X	X	X	.	X		a	m	p	s
G	N	T	R	:		+-	X	X	X	.	X		a	m	p	s
M	O	T	R	:		+-	X	X	X	.	X		a	m	p	s

Due to the importance of always knowing the vehicle speed, we envision using a smaller sized LCD display that is solely dedicated to providing the current velocity; even a 1x8 display would be more than adequate for our needs.

5.3.1. Interface Buttons & Switches

We plan to use 2-3 soft buttons situated close to the display screen to allow the user to provide feedback to the system. In addition, we plan to use a pair of 3 position switches to allow the user easy access to commonly desired features. The first switch will change the operating mode between the three available (all electric, generator always on, automatic). The second switch will change the screen presented on the display between three different options; we believe three screens will contain the data most often needed by the user. Other information could be accessed through the soft keys if necessary. These interface switches can be implemented through hardware interrupts and/or checked pins or a clever combination of these.

5.3.2. User Warnings

It is expected that various conditions will necessitate a special warning to the user. We envision using either hardware or software interrupts to force appropriate messages to be displayed on the primary screen to alert the user of such situations. The message should persist until the user acknowledges the message and the situation has passed.

5.4. Hybrid Controller Software

The following is simple software diagram for the hybrid controller:

```
INFINITE LOOP
    CHECK INPUT PINS FOR PARAMETER CHANGE
    CHANGE STATES AS NECESSARY
    A/D SPEED CONVERSION
    RECEIVE INFORMATION FROM BATTERY CHARGER
    CALCULATE EFFICIENCY AND RANGE
    OUTPUT AS APPROPRIATE TO LCD DISPLAYS
LOOP

INTERRUPTS:
    USER BUTTONS
    WARNING CONDITIONS
```

5.5. Batteries

The battery pack needs to produce 72 Volts for the motor controller. To achieve this with 12 Volt Electric Vehicle (motorcycle-size) batteries, we intend to connect 6 12V batteries in series. We considered a DC-DC converter with a lower battery-pack voltage or a DC to high-frequency AC with step-up transformer and rectifier, but decided against those options due to safety, complexity and robustness. Furthermore, the fundamental power equation (P=VI) states that if the voltage is halved, the current must be doubled so the number of batteries would have to be doubled and the efficiency would be decreased. We would like to use a Lithium-Ion or Lithium-Poly battery but it will not currently fit into the budget. For cost effectiveness, we will use Lead-Acid batteries. For safety reasons, we intend to use a sealed, gel or AGM type battery. Our actual selected batteries will depend upon the highest amp-hour rating with the highest sustainable current and the lowest price.

To interconnect the batteries, we could use 1AWG with lugs, but we do not have the necessary crimping tools and 1AWG is expensive (if we can't get it by the foot). A very attractive and simple alternative is to use aluminum bus bars with heat-shrink insulation. This should simplify the interconnects while providing as good or better current characteristics. We had modeled 7kW as a reasonable power requirement for cruising speed, this translates to 98 Amps being drawn. The bus bars should therefore be designed for at least 160-200 Amps. This necessitates 1AWG or larger (aka smaller numeric AWG). This means the cross sectional area should be >0.0657in^2 (for copper). Aluminum is less expensive then copper and readily available, easily shaped and drilled, and has a very similar (albeit higher) resistivity. To improve the efficiency and safety of the system, the wires should be kept as short as possible, with careful attention paid to insulation. PVC has excellent insulation properties and is readily available for plumbing applications from local hardware stores.

5.6. Battery Charger

The batteries will have to be monitored and recharged. This will be handled by the Battery Charger. It will handle charging from the generator as well as from a wall socket. Generator arrangements we have considered are around 2kW. Assuming 100% efficiency and a charging voltage of 80 volts for the 72 volt system the current would be 25 Amps. If we are charging from a wall socket we need to assume a standard 15-20 Amp breaker, which would deliver 1.8kW and 2.4kW respectively (assuming nominal voltage). These wattages translate to possible charging currents at 80V of up to 30 Amps. The charging system should be designed for 35 Amps, affording a margin of over 15%. In actuality, the charging voltage will probably have to be larger, which would reduce the currents, but the above currents give an idea of the worst case.

The Battery Charger will monitor the State of Charge (SOC) of the battery pack at all time by measuring the current at known time intervals and integrating over time. The current will be measured by relatively non-invasive devices, such as a current transformer or a hall effect device. The Battery Charger's microcontroller may also need to measure the voltages across the batteries and their temperatures periodically to provide the best charging characteristics. This would allow it to detect fault conditions as well as intelligently manage the fully charged state.

We believe that the best point to measure the temperature of the battery is at the terminals. The most obvious technology would seem to be thermocouples because they can be directly soldered to the terminals providing a very solid thermal connection to the terminal. However, they would be floating at the potential of the terminals, necessitating some sort of isolation. There are a few possible strategies for this. One such strategy is to create a floating power supply for the AD converter which uses relays to multiplex the various batteries and a digital optocoupler to communicate the voltage to the micro. Another strategy is to simply use optocouplers for each channel and multiplex that result into the AD converter. If further testing reveals that a sufficient thermal connection can be made through the body of the battery, thermistors would be a much simpler method of testing the temperature. Perhaps isolating a thermal sensor with sil-pad can make optocouplers unnecessary and increase the simplicity of the system. I am concerned that measuring the temperature at the terminals will simply thermally link the batteries through the aluminum bus bars and will return the ambient temperature of the bars, and not the temperature of the battery itself.

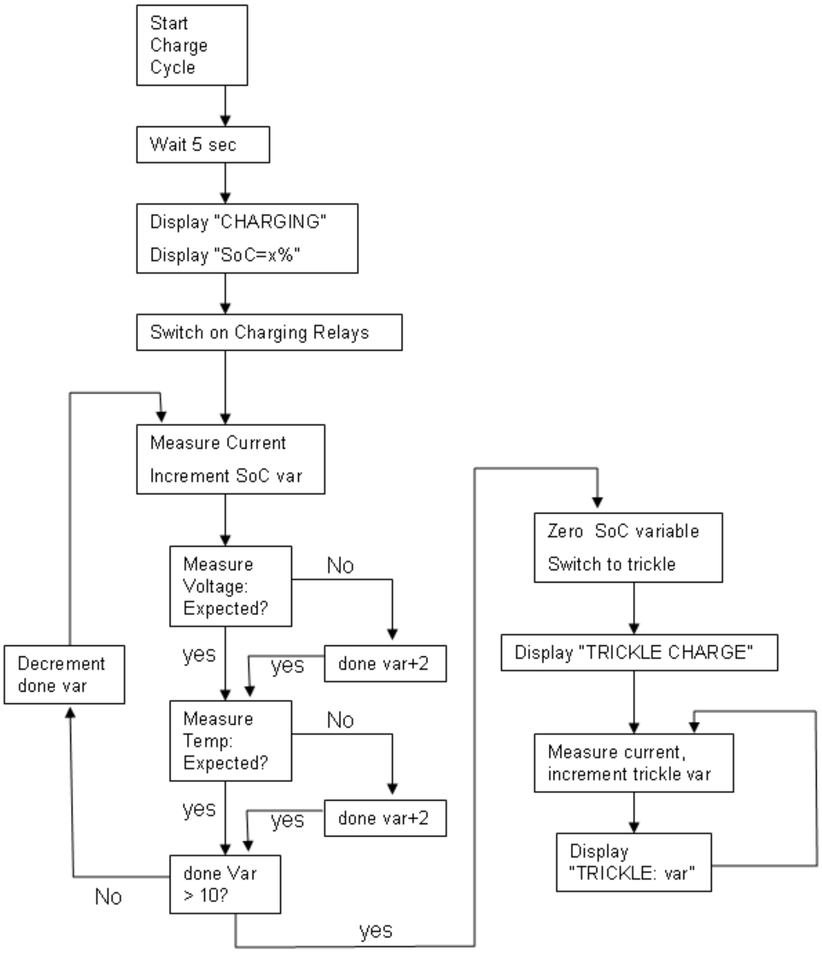
The battery charger for our system is non-trivial. 72 Volts sounds reasonably small when compared to 120VAC, but even an AA size battery can be dangerous if shorted or charged incorrectly. For safety reasons I believe that the wisest course of action is to use our best guess for charging strategies with a single 12 Volt system, and monitor the voltages, currents and temperatures of that battery during charging. From that we can determine if it is indeed strictly necessary to collect the temperature data and the best way to do so.

The basic strategy is to use an appropriately sized transformer (something around 4:3) to get an appropriate open circuit charging voltage, and then use a simple prebuilt high current bridge rectifier (around $3 for a 35 Amp bridge rectifier) and a capacitor to create a very simplistic unregulated power supply. I expect to use a power MOSFET to engage/disengage the charger from the battery pack. I suspect that we will need a voltage and current regulated power supply, but it is worth the effort to test a simpler system for suitability. If we can tune the charger to the battery pack, we might be able to switch in series resistance to give it two operating points, a full charge and a trickle charge, without creating a current source, or regulating the voltage.

I have implied that the 72V pack will be charged in series, but I have not explicitly stated it or defended our reasons for doing it. If all the batteries were in parallel the voltage of the charger would be a more standard 14 volt configuration. However, the current would be much higher. Assuming power delivered is equal to power available, for a 20 Amp breaker at 120VAC, the 14VDC charging current would be 171 Amps. Assuming the transformer would handle that, it translates to 28.57 Amps per battery. If we choose to charge at 80 volts, or 84 Volts (+2 volts/battery) that delivers a current of only 30 Amps or 28.57 Amps. This is the same current delivered to the battery, at much safer currents in the overall system.

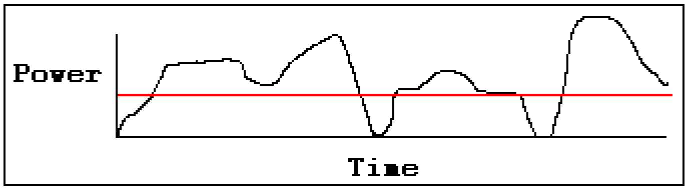
5.7. Battery Charger Software

The following is the flow diagram draft of the software:



5.8. Generator

From an efficiency standpoint, the generator should not provide the maximum power of the bike. Internal combustion engines are relatively efficient while operating at a specific setpoint (such as highway driving). However, when they have to accelerate and decelerate, the momentum of their drive-shaft and gear constellations severely decreases their efficiency. Electric vehicles take advantage of the more dynamic electric motors and do not need as extensive of a drive train. This means that they are much more efficient at city-type driving. A series hybrid system where the generator provides the maximum power would be fundamentally inefficient. The power would essentially be generated mechanically, transferred to electrical power, and then transferred back to mechanical, with the excess being wasted. However, this strategy is efficient when the generator provides the average power necessary while running at a constant setpoint.



The figure illustrates this idea. The horizontal line is the power being provided by the generator. The other peaked line is the power required by the vehicle in traffic. When the required power dips below the constant power, that power is stored in the battery pack. When the required power rises above the constant power, the batteries provide that extra power. This concept is analogous to a large capacitor being used in a car stereo system to provide extra power to a subwoofer.

We calculated that if we set the generator at 2kW it would be able to power the bike at 35MPH. That means that below 35MPH the batteries would be charged. Above 35MPH the batteries would have to provide the extra power. This seemed reasonable for local driving, considering the speed limit is 45MPH-35MPH except in residential areas. The hybrid technology is much better suited to local commutes then it is to cruising to Chicago on the toll road.

In researching available generators in the 2kW range we found all are household type 120VAC systems. This is advantageous to us because we can design one system for wall charging or charging via the generator. Furthermore, it is much simpler to reduce the voltage down to an appropriate charging voltage (probably around 84VDC) then it is to boost a low alternator voltage up to 84VDC from 12VDC. The one issue is appropriately mounting a 2kW generator on the bike frame. The generators we researched are roughly suitcase-sized but that is not a trivial volume relative to a motorcycle. We have discussed a number of strategies from mounting the batteries differently to sidecars and saddle bags. We intend to mount them saddle bag style, but will adjust appropriately.

5.9. Electric Motor

In electric motor technology, there are two general types of motors to choose from: AC and DC. Below is a table listing the advantages and disadvantages of using each technology in a motorcycle application:

	AC Motors	DC Motors
Advantages	-direct input of power from generator to motor -high efficiency at high speeds (~90%) -lower operating currents (20-30 A)	-high efficiency (80-90%) for entire speed range -light weight (~20 lbs) -high torque at low RPM -less expensive ($900-$1,000) -multiple voltages available for operation (12-72 V)
Disadvantages	-higher weight (100-120 lbs) -more expensive (average $1,500) -less efficient at lower speeds -fixed operating voltage (typically 200 or 480 VAC)	-need to develop/provide rectification circuit from AC generator output to DC -high currents (100 A)

Based on these characteristics above and the advice of our faculty advisors (Dr. Bauer and Dr. Sauer), we decided to choose the DC motor technology.

After choosing the DC motors, we researched what DC motors were available and have been used for motorcycle and electric vehicle applications. The two most common motors which we found were the Briggs and Stratton Etek Permanent Magnet Motor and the Perm-Motor Permanent Magnet Motor. Below is a listing of the specifications of each motor for the 48 V and 72 V operating modes:

5.9.1. Briggs and Stratton at 48 V operation:

Voltage Constant: 72 RPM / V

Torque constant: 0.095 lb-ft / Amp

Maximum Motor Current: 330 Amps for 1 min

Weight: 21 lb.

Motor Output: 15 HP Max. (11.18 kW) @ 233 A, 8 HP Continuous (5.96 kW) @ 124 A

5.9.2. Perm-Motor

Weight: 25 lbs	48 V operation	72 V operation
Current	110 A	110 A
Power Output	4.74 kW	7.22 kW
Speed	2,300 RPM	3,480 RPM

From the data above, we can see that although the Briggs and Stratton motor provides relatively similar characteristics to the Perm-Motor at the 48 V operation, the 72 V operation provides much more output power at a lower current and satisfies our 7 kW power requirement for a speed of 50 mph. If we increased the driving current to the 72 V Perm-Motor, we could achieve even higher speeds.

We solicited the opinion of a senior electrical engineer, Greg Brown, at Northern Electric in South Bend as to comparing the specifications of the two motors. Mr. Brown was very impressed with the Perm-Motor, particularly with the output power and efficiency at 72 V, and recommended that we use this motor for our application. From Mr. Brown's recommendation and our analysis, we are going to order the Perm-Motor model and operate it at 72 V.

5.10. Motor Controller

There are two motor controllers we were able to find on the market that have been used with the Perm-Motor DC motor:

1. Kelly Controls DC Motor Speed Controller
    a. Key Features:
        i. Built-in regenerative braking capability
        ii. Analog brake input for continuous variable regeneration
        iii. Throttle input from 0-5K potentiometer
        iv. Programmable with RS-232 using manufacturer cable
    b. Specifications:
        i. Frequency of Operation: 16.6kHz.
        ii. Standby Current: less than 15 mA.
        iii. Full Power Operating Temperature Range:-30C - 90C,100C shutdown (controller temperature).
        iv. Armature Current Limit, 1 minute: 200A / 300A / 400A / 500A / 600A.
        v. Armature Current Limit, 3 minutes: 150A / 220A / 300A / 360A / 420A.
        vi. Armature Current Limit, Continuous: 120A / 160A / 200A / 250A / 300A.
    c. Models:
        i. KD72201 24V-72V 200A $319
        ii. KD72301 24V-72V 300A $369
        iii. KD72401 24V-72V 400A $439
2. Alltrax AXE Series Motor Controller
    a. Key Features
        i. Programmable using RS-232
        ii. Various throttle inputs available
        iii. ½ speed reverse option (series motors only)
    b. Specifications
        i. 60-90 VDC (90VDC MAX)
        ii. 2 minute current limit / 5 minute current limit / 1 hour current limit
        iii. Model 7234: 300 A / 200 A / 125 A
        iv. Model 7245: 450 A / 350 A / 200 A
    c. Models:
        i. 7234: 24-72 V 300 A peak $549
        ii. 7245: 24-72 V 450 A peak $645

We have found more web sites which mention the use of the Alltrax controller in motorcycle applications with the Perm-Motor motor, which slightly discourages us from using the Kelly Controls controller. We will be contacting Perm-Motor to see if they have tested their motor with the Kelly controller and make a final decision on which controller to use.

6. ESTIMATED COSTS

	Estimated Cost
Electric Motor	$ 1,000.00
IC Engine / Generator	$ 500.00
Motor Controller	$ 500.00
Batteries	$ 800.00
Power Electronics	$ 500.00
Motorcycle Parts	$ 500.00
Expenses Sub-total	**$ 3,800.00**
EE Class Budget	$ (500.00)
ND Energy Center Total	**$ 3,300.00**

7. CONCLUSIONS

Considering the complexity of the system and the number of sub-systems, as design engineers we face a significant engineering challenge. Our high level design is a first step along the path of system design. As we do further research, select particular components and finalize circuit designs our motorcycle will become more of a reality. Our next step is to create a low-level design for the system.

We are designing a system with medium voltage DC and high current capacity. As we move forward, we must always keep safety in mind, both for ourselves and those around us. Particularly for the battery pack and charging systems we should first experiment with our design on a smaller bench top version and slowly increment the voltage and current.

8. REFERENCES

How to construct a lead-acid battery charger:

http://www.powerstream.com/SLA.htm

Building a battery pack

http://www.evadc.org/build_batteries.html

Calculating resistivity

http://www.allmeasures.com/formulae/static/formulae/electrical_resistivity/12.htm

Wire guide and current capacities

http://www.powerstream.com/Wire_Size.htm

Existing Electric Motorcycle

http://www.evdaytona.com/

EV Parts

http://www.beepscom.com/

Really amazing battery technology that we can’t afford

http://ev-battery.com/

SOC Strategies

http://www.mpoweruk.com/soc.htm

How to use a thermocouple

http://www.circuitcellar.com/library/details/1299/c1299cd2.asp

Thermocouple resource

http://zone.ni.com/devzone/cda/tut/p/id/4237

McCullock solid state inverter Generator

http://www.electricgeneratorsdirect.com/catalog/product_info.php?products_id=653

Electronic Circuits Manual by Markus (book purchased from Amazon)

Perm-Motor 132 Motor Specifications
http://www.perm-motor.de/pm_e_htm/products/pmg/daten_pmg_132.htm

Alltrax Controller Specifications
http://www.alltraxinc.com/Products_AXE.html

Briggs and Stratton Etek Motor Specifications
http://www.thunderstruck-ev.com/etek.htm

Kelly Controls DC Motor Speed Controller Specifications
http://dc-permanent-magnet-motor-speed-control.motcontroller.com/