LIGHTNING RIDERS

SENIOR DESIGN PROJECT PROPOSAL

Rev	Description	By	Date	Approved
1.0.0	Initial Draft Release	Team	10/4/07	

	Approval Signature	Authority	Date
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Specification Number	**ND00-001**	**Rev** **1.0.0**	**Sheet 1 Of 17**

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1. INTRODUCTION

Electrical engineering seniors at the University of Notre Dame are required to take a year-long course in Senior Design. The course revolves around a project selected by the various 4-6 person student teams and involves a significant amount of in-depth engineering design. As our project, our team elected to design and build a series hybrid motorcycle. This document details the problems we are addressing with this project and how we plan to succeed.

2. PROBLEM DESCRIPTION

The automotive world is feeling the tremors of a technological earthquake that shakes the century-old foundations of the industry and heralds a fundamental shift in automotive technology and design. The conventional automobile model is ill-suited to the challenges of the present day and must evolve to embrace new opportunities for growth and innovation if automotive manufacturers wish to be competitive. 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.

3. PROPOSED SOLUTION

The prevailing wisdom amongst the experts in the field points to the ideal automobile as one that is purely electric and does not directly use fossil fuels for propulsion. Such a vehicle could take full advantage of alternative energy sources such as solar, wind, nuclear, geothermal and other sources provided that the generated energy is converted into a usable form. However, an electric vehicle is not necessarily synonymous with an environmentally perfect vehicle. As long as fossil fuels are burned to generate electricity, some amount of greenhouse gases and pollutants will escape into the atmosphere. In addition, energy storage systems often contain heavy metals and pose a challenge for disposal and/or recycling efforts. Despite the non-ideal environmental impact of an electric vehicle, it is nevertheless a vast improvement over the vehicles of today. Unfortunately, energy storage technology lags somewhat behind the ambitions and dreams of the electric car proponent, which is where the hybrid vehicle enters the picture.

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.
All hybrids currently in production by the world's largest automobile manufacturers follow a parallel model[1] where the electric components serve more as a boost to the internal combustion (IC) engine rather than as the primary traction motor. By contrast, a series hybrid design uses the electric motor as the only traction motor while the IC engine is partnered with another electric motor to serve as a generator. The series hybrid design offers several advantages that we hope to leverage as part of the project. These include the ability to operate in a purely electric mode over a limited range where all power to the traction motor is provided by electrical energy stored in batteries. Furthermore, the series design allows us to use the IC engine at its most efficient operating point at all times, hence resulting in the most efficient possible operation. The series design also allows us to showcase the power and performance of an electric traction motor and to compare it with a similar IC engine. Finally, the series hybrid design is simpler than a parallel design, both from a mechanical and electrical standpoint. 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 of a series hybrid vehicle.

4. PROJECT DELIVERABLES

Upon completion of our project, we will deliver a series hybrid motorcycle that meets or exceeds the following criteria:

4.1. Street-legal motorcycle with the following minimum performance:

- Capable of traveling at least 10 miles in a pure electric mode
- Capable of traveling at least 50 miles in hybrid mode
- Able to sustain a top speed of 50mph

4.2. A user interface with the following features:

- Allow the user to use throttle and brakes as on a conventional motorcycle
- Display current velocity and acceleration
- Current state of charge (SOC) of the batteries
- Current fossil fuel level
- Display efficiency calculations and expected range based on current operating conditions and available on-board energy.
- Display real-time power flow information throughout the hybrid system to inform the user which components are providing and/or consuming energy along with the rates for each.
- Contain a data-logging feature to record critical variables for future analysis
- Enable user to start/stop the vehicle (similar to key ignition switch)

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[1] Series hybrid vehicles are currently in the prototype and research stages and are due to reach markets by 2010, particularly the Chevrolet Volt.

- Enable user to manually start the IC engine
- Display overall system status information to the user

4.3. Other…

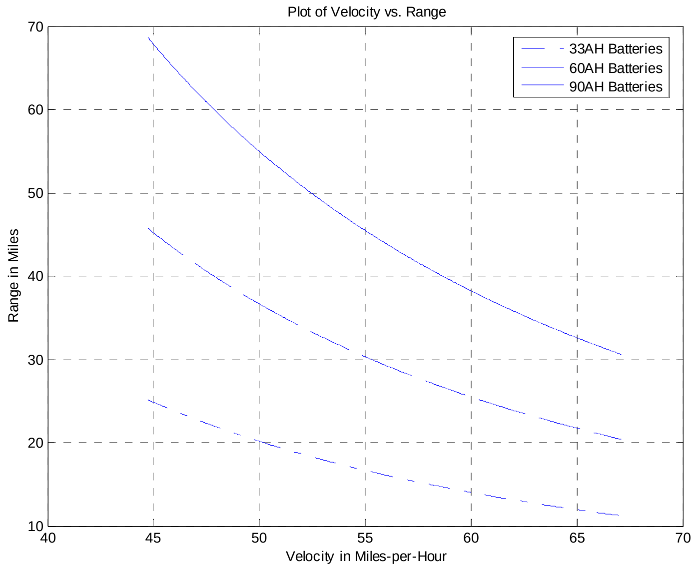
- The battery based energy system will be chargeable both from the on-board generator system and from a standard household wall socket (120 VAC source)
- The IC engine / generator will be capable of providing electrical power to the batteries and/or the traction motor.
- (Optional) It will have a regenerative braking feature to capture and reuse energy normally dissipated as heat during braking.

5. AVAILABLE TECHNOLOGIES

5.1. Batteries

There are many different types of commercial batteries available, ranging from conventional lead-acid to lithium-ion and lithium polymer. From a performance standpoint the lithium based battery technology is ideal for our purposes as they have high energy density, high power density, and low weight. However, all these advantages come at a steep price and these cost restrictions make lithium batteries an unfeasible choice for our design. Due to our financial limitations, a lead-acid battery solution will best meet our needs. The following table presents our research of available batteries. The highlighted rows represent the best battery choices that we have identified thus far.

Technology	Size	AH	Lbs	Vol (in^3)	$/AH	Price
Gel	Motorcycle	31	24	288	2.58	$ 80
Gel	Full	97.6	70	852	1.95	$190
AGM	Full	92	63	867	1.52	$140
AGM	Motorcycle	55	38.5	477	2.18	$120
AGM	Full	105	69	863	1.64	$172
AGM	Elongated	198	129	1940	1.61	$320
AGM	Elongated	245	158	2511	1.55	$380
AGM	Motorcycle	33	24	309	1.92	$ 64
AGM	Motorcycle	45	31.04	343	2.00	$ 90
AGM	Full	55	38.8	530	3.00	$165
AGM	Full	55	42.9	530	3.36	$185



As part of our research we generated the above graph to demonstrate the capabilities of different amp-hour configurations. From the above graph, the motorcycle can travel approximately 17 miles with a 33Ah battery system, which would meet our project goals.

5.2. Electric motors

The electric motor is the component of the motorcycle which will convert the electrical energy provided by the IC engine / generator or the batteries into the mechanical energy needed to move the motorcycle. There are two main categories of electric motors used in vehicles today: alternating current (AC) and direct current (DC). Our initial research indicates that the commercially available DC motors more closely match our specifications than their AC counterparts. Based on our requirements for ideal speed of the motorcycle, distance to travel, and horsepower, we have researched the following DC electric motors which are satisfactory:

5.2.1. Etek Permanent Magnet DC Motor

5.2.1.1. Manufacturer: Briggs & Stratton

5.2.1.2. Pricing

There are two models of the Etek motor with the main difference being the shaft length. Prices are listed below.

Etek 12-48 VDC 2-1/4" Long Shaft: $795.00

Etek 12-48 VDC 1-3/4" Shaft: $750.00

5.2.1.3. Key Features

-light weight and small size

-high efficiency compared to most DC motors

-high power to weight ratio

-lower voltage range, which requires fewer battery packs

5.2.1.4. Specifications

Horsepower: 20 HP peak, 8 HP continuous

Input Voltage: 12-48 V range, 50 V maximum

Maximum current: 300 A for 30 seconds continuous

Weight: 20.8 lbs

Voltage constant: 72 RPM per volt

Motor Diameter: 7.91"

Motor Length: 5.64"

5.2.2. Perm-Motors Permanent Magnet DC Motor[2]

5.2.2.1. Manufacturer: Perm-Motor

5.2.2.2. Pricing

$949.50, $895[3]

5.2.2.3. Key Features

-90% efficiency at 24 V – very competitive for DC motors

-light weight compared to most motors (24 lbs)

-size

5.2.2.4. Specifications

Horsepower: 19.3 HP peak, 9.5 HP continuous at 72 V

Input Voltage: 24-72 V range

Current: 110 A continuous, 200 A for 10 minutes

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[2] Motor information from www.beepscom.com
[3] Price found at http://www.thunderstruck-ev.com/perm132.htm on 10/3/07. Also available at http://www.electricmotorsport.com/PARTS/parts.htm for the same price.

Weight: 24.2 lbs

Peak Efficiency:

2.2 KW @ 24 volts, 1080 RPM, 2.94 HP

3.5 KW @ 36 volts, 1700 RPM, 4.69 HP

4.74 KW @ 48 volts, 2300 RPM, 6.35 HP

5.97 KW @ 60 Volts, 2870 RPM, 8 HP

7.22 KW @ 72 Volts, 3480 RPM, 9.7 HP

5.3. IC Engine / Generator

To provide a source of power apart from the batteries we are presented with two choices. Energy from fossil fuels can be provided either through an IC engine that runs a generator to create electric current or through a single piece generator that takes fossil fuels and produces electric power.

We looked at engines from ATVs and pocket bikes and found that most of these had multiple gears, which would not be advantageous to our design. For $480 we could purchase a 4-stroke, 4-speed pocket bike 110cc engine that would produce about 5250 Watt/7 hp[4]. A smaller 50cc 4-stroke pocket bike engine would be a better fit for providing the baseline power of approximately 2250 Watts/3 hp at a cost of $275.[5] Physical dimensions for these engines were not readily available but from the images available they appeared relatively small. For $100-$250 a simple one cylinder engine could be used to provide 2250 Watt/3 hp[6]. It would be a much weaker engine than the pocket bike engines and multiple gears would not be an issue. The size of these motors is approximately a cubic foot.

For both the small engines and the pocket bike engines, a high power alternator would be needed to transform rotational power into electric power. For approximately $200 a 100 Amp alternator could be used in conjunction with an IC engine to make useable electric power[7]. The main issue with these alternators is that they are designed to provide voltage to the standard electronics in a car. The voltage would need to be boosted through a DC/DC converter or, if possible, by taking out the voltage regulator to generate a sufficient voltage level. The weight and belts used to drive these alternators would also need to be dealt with to create a safe connection between the two components.

The use of a complete generator system to provide power to the electric system of the vehicle would require a generator that could provide power in excess of 72 volts while having a small physical size. The generators that could be found were usually rated at 120 volts, more than adequate for our purposes but were both lacking in current and overly large[8]. Most had peak

[4] http://www.pocketbikesunlimited.com/110CCMOTOR.html
[5] http://www.sdscooters.com/4Stroke_Engine_Parts.html
[6] http://www.northerntool.com/webapp/wcs/stores/servlet/category_6970_76
[7] http://cpgenerator.com/highampalternators.html
[8] http://www.electricgeneratorstore.com/

currents less than 25 amps, falling short of the necessary current to run an electric motor. Because of these limitations the use of a gas generator does not seem to be a viable solution to our hybrid motorcycle problem.

5.4. Battery Chargers

As part of the hybrid controller we will be integrating the IC engine / generator into the power system so that it can charge the batteries and/or provide power to the traction motor as necessary. An integral part of this hardware will be a battery charging circuit, which we plan to design. However, our design also calls for the motorcycle to be chargeable from a 120VAC wall socket. It may be possible to modify the required design for the generator charging or create a similar circuit to facilitate the wall charging. For completeness sake, we have done preliminary research into commercial battery chargers as well.

5.4.1. Lead Acid Charging Methods

There are several different methods to charge lead acid batteries. The prices for commercially available chargers differ substantially depending on the required speed of the charger. Overnight chargers, as opposed to quick chargers (which take under 4 hours to complete) seem to be the solution that best fits our budget.

There are several types of inexpensive overnight lead acid battery chargers available. One option is to use an unregulated transformer-based charger. These chargers consist of a diode and a wall mount transformer, which is designed to deliver approximately 13-14 volts to the battery. As the battery becomes fully charged, the voltage rises and current decreases; at these voltages, electrolysis begins in the battery, so it is highly recommended that these batteries be disconnected from the charger within 12-24 hours. These chargers are the cheapest on the market. As we plan to use a 72V system, we would either need multiple chargers or some circuitry to switch between the batteries so that they would all be charged.

Another option is to use taper chargers. Taper charges limit the voltage to the trickle charge voltage, so electrolysis will not occur within the battery. Because of this, leaving the battery charging too long will not damage the battery. Taper chargers can either use a transformer and a simple voltage regulation circuit, or they can use a switching power supply in a wall or desk mount. These chargers are also quite inexpensive.

A third option is a constant current battery charger, in which an electric circuit is used to control the charging current. Battery overcharging is possible if the voltage is not limited, thus these chargers are usually limited to slow charging.

Constant voltage chargers, when used with a circuit that limits initial current absorption, are very effective. They can charge at a reasonable rate while giving the added benefit of allowing the battery to charge for extensive time without any damage to the battery.

5.4.2. Commercial Lead-Acid Battery Chargers[9]

[9] Prices from http://www.powerstream.com

36 Volt 2 Amp 83 Watt SLA Charger
5 stage microprocessor charger with charge progress indicator

$117.50

36 Volt 3 Amp 124 Watt switchmode SLA Charger.
5 stage microprocessor charger with charge progress indicator
$142.50

Fast chargers use better technology and can typically charge lead acid batteries in under 4 hours. Since these chargers do not charge at the trickle voltage of the battery, overcharging becomes an issue. Because of this, fast chargers require active charge termination to shut off the charging when the battery becomes fully charged.

24 Volt 4 Amp Switchmode charger

http://www.powerstream.com

$142.50

High Frequency Charger 36V 15A Battery Charger

http://www.atbatt.com/index/SLA_Battery_Charger/Deltran.asp

$332.95

5.5. Electric Motor Controllers

A motor controller is a fundamental element of the hybrid vehicle system as it takes electrical power from the system and generates the appropriate electrical waveform to drive the traction motor as required by the throttle input. In a hybrid vehicle the motor controller is also responsible for handling regenerative braking, which is when the electric motor is used as a generator to capture the kinetic energy of the vehicle rather than dissipate it through heat in conventional brakes. Due to the inherent complexity of the motor control system, we have elected to purchase a commercially available motor controller rather than attempt to design and build one ourselves. We have researched electric motor controllers and assembled a list of controllers suitable for our purposes.

5.5.1. Kelly DC Motor Speed Controller[10]

5.5.1.1. Manufacturer: Kelly Controls, LLC

5.5.1.2. Pricing

Controller price is highly dependent on both the controller input voltage and the maximum current that the controller can handle. Several options are available depending on the number of amps we require for our system.

[10] See Appendix for a detailed product description from the manufacturer

PM Motor Controller with Regeneration
KD72201 24V-72V 200A * $319
KD72301 24V-72V 300A * $369
KD72401 24V-72V 400A * $439

5.5.1.3. Key Features:

- Built-in regenerative braking capability
- Analog brake input for continuous variable regeneration
- Throttle input from 0-5K potentiometer
- Programmable with RS-232 using manufacturer cable

5.5.1.4. Specifications

*Frequency of Operation: 16.6kHz.
*Standby Current: less than 15 mA.
*Full Power Operating Temperature Range:-30C - 90C,100C shutdown (controller temperature).
*Armature Current Limit, 1 minute: 200A / 300A / 400A / 500A / 600A.
*Armature Current Limit, 3 minutes: 150A / 220A / 300A / 360A / 420A.
*Armature Current Limit, Continuous: 120A / 160A / 200A / 250A / 300A.

5.5.2. Alltrax AXE Series or PM Motor Controllers, Programmable

5.5.2.1. Manufacturer: Alltrax

5.5.2.2. Pricing

Model 7234: $549

Model 7245: $645

5.5.2.3. Key Features

Applicable to each model:

- Programmable using RS-232
- Various throttle inputs available
- ½ speed reverse option (series motors only)

5.5.2.4. Specifications

	2 minute current limit	5 minute current limit	1 hour current limit
Model 7234:	300 A	200 A	125 A
Model 7245:	450 A	350 A	200 A

6. ENGINEERING CONTENT

A hallmark of the EE Senior Design course is the emphasis on detailed engineering design of components from an electrical perspective. The desire for team members to gain experience in engineering design must be balanced against realistic ideas of what is practical, both from a time and safety standpoint. For our project in particular, designing a hybrid motorcycle system, it would be possible to oversimplify the project to the point where it becomes a purely mechanical engineering problem of assembling pre-built and tested components. On the other hand, due to the complexity of certain components, we could quickly find ourselves overwhelmed if we tried to construct each component from scratch rather than relying on the proven systems available commercially. We sought to balance experience with practicality in creating the following list of components that we plan to engineer rather than purchase directly.

6.1. Hybrid controller

The hybrid controller will be a microprocessor based device that provides the 'brains' behind the entire vehicle system, directing the various power components to function together and operate the vehicle. Among the capabilities and responsibilities we must engineer into the controller are:

- Monitors SOC (State of Charge) of batteries
- Enables IC Engine / Generator to charge batteries and/or power the traction motor
- Monitors power flow in system
- Monitors available fuel (electrical and fossil)
- Calculates current efficiency and expected range based on available fuel
- Controls generator power source
- Logs data for future reference

6.2. User interface

The user interface will utilize an LCD display and serve as the primary means for user / system interaction. The screen will display critical information to the user and contain functionality for the user to make changes, either through touch screen buttons or hard wired buttons near the display. The user interface will interact closely with the hybrid controller for its information. Some of the critical variables presented to the user will include:

- Current velocity and acceleration
- Battery SOC and power flow
- Fuel tank level
- Current efficiency and interpolated range based on available fuel
- Overall system status
- IC Generator status and power flow

6.3. IC engine / generator

The internal combustion (IC) engine is a key component of a series hybrid vehicle as it provides the average power required by the user. The IC engine will drive a generator, which is a small electric motor, to convert mechanical energy into the electrical energy required to either charge the batteries or directly power the traction motor. We have not determined whether this system will be microcontroller based or if it will be a complicated circuit design. In either case, our design must solve the following challenges:

- Generate sufficient power to charge batteries
- Charge batteries from IC engine / generator power
- Power the traction motor directly from generator, bypassing the batteries
- Generate sufficient voltage to charge the batteries (voltage converter of some sort)
- Electric start capability
- Electrically detect when the IC engine is running

6.4. Physical design and construction of system

In addition to the design of the electrical components, we will assemble all of the components together into a functional motorcycle. While this portion of the project leans more towards mechanical engineering rather than electrical engineering, it remains a significant engineering challenge and will require electrical engineering knowledge as we wire the power and control systems together.

7. CONCLUSIONS

7.1. Problem & Solution

The ideal vehicle to replace the conventional automobile is a purely electric car, yet current technology cannot support the straight transition to electric cars. Until energy storage technology improves, the hybrid vehicle represents the best opportunity to bridge the gap between conventional and electric vehicles as it takes advantage of the best of both worlds. Therefore, our team will design and build a series hybrid motorcycle to demonstrate the capabilities of hybrid vehicles and hopefully inspire further academic and public interest in the vehicles of the future.

7.2. Project Deliverables

Upon completion of the project we will deliver a fully functional, road worthy motorcycle. It will have a minimum range of 10 miles in electric-only mode and 50 miles in hybrid mode, assuming a full battery charge in both cases. The motorcycle will have a user interface screen to display critical variables along with historical information related to vehicle performance.

7.3. Available Technology

There are a variety of commercially available technologies that we can leverage in our project. A number of these, such as the electric traction motor and motor controller, we plan to purchase outright, while others we will use to create new components, such as the hybrid controller.

7.4. Engineering Content

We will engineer a microcontroller based hybrid controller to control the overall system. In addition, we will design an IC / generator system and a user interface, both of which will interact with the hybrid controller. Finally, we will assemble the components into a working motorcycle.

8. APPENDIX: ND ENERGY CENTER FUNDING PROPOSAL[11]

Project Description:

Current transportation vehicles today are heavily dependent on non-renewable energy sources, especially petroleum-based fuel. This causes two major issues. First, a significant portion of our country's economy is affected by prices of foreign oil. Secondly, burning these hydrocarbon fuels is believed by climatologists to have significant harmful global effects that are almost irreversible. The ideal solution is generally agreed to be a purely electric vehicle. Unfortunately, current technology and infrastructure prohibits such a drastic transition from conventional vehicles. Hybrid vehicles are able to bridge the gap between conventional and electric vehicles. Therefore, as our senior design project, we will design and build a hybrid motorcycle. It will demonstrate the decreased environmental impact and efficiency of hybrid vehicles and generate increased academic and public interest in environmentally conscious transportation.

Estimated Budget:

	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
Donor Motorcycle	$ 250.00
Expenses Sub-total	**$ 4,050.00**
EE Class Budget	$ (500.00)
Team Member's Contribution	$ (250.00)
ND Energy Center Total	**$ 3,300.00**

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