EcoCAR Project

1. INTRODUCTION

Reports recently indicated that on May 12, 2008 the average cost of gasoline was approximately $3.72 per gallon; this was about 20 percent higher than prices recorded the previous year. There is a present and evident need for some alternative to the overwhelming cost of fuel and there appears to be no end in sight. That is, until the advent of the Hybrid Electric Vehicle.

The idea of the GM hybrid electric vehicle (HEV) was born out of a concern for fuel efficiency and is now being nurtured by the problem of increasing fuel costs. It is hoped that the HEV will revolutionize the automotive industry and its way of handling fuel efficiency. And, hopefully this trend can transcend to the public's general outlook on fuel consumption within the general American society.

The goal of the Eco-Car project is the design, modeling, simulation, and analysis of a functional control strategy; sufficiently test and modify sub-systems out of the vehicle; and then successfully implement and improve the systems in the vehicle. The EcoCar team will use Simulink to design a control system as to how the combustion engine, electric motor, and battery of the vehicle will operate/interact with each other to provide the least amount of carbon emission and fuel consumption, while the greatest amount of power needed for the driver of the car.

With the energy crisis looming and green house gas emissions at an all time high, this project is extremely important as it seeks to meet the demands of improved energy efficiency and dramatically reduce GHGs, as well as to address zero emissions vehicle (ZEV) regulations. Thus, Team REV is extremely excited to be a part of Howard University's installation of the Eco-car project from an engineering and ecological perspective.

2. PROBLEM DEFINITION

Team REV has been tasked to design a matlab/simulink model to simulate a control strategy /algorithm for the real world operation of the Saturn Vue Hybrid Electric Vehicle (HEV) architecture chosen by GM and the Mechanical Engineering Department. The control strategy design must be functional and Software in the Loop tested to meet Department of Energy specifications by end of Fall Semester. Later Hardware in the Loop testing and prototyping must meet DOE specifications and be concluded by end of May of the spring semester.

The Control Strategy Design must also contain safety measures as prescribed by General Motors. These measures must include a Battery Disconnect Module (BDM) to isolate high voltage battery from the rest of the vehicle in specific situations such as: Airbag deployment, Isolation fault detection, High Voltage Interlock Loop (HVIL) open circuit, Diagnostic trouble code, engaging manual disconnect and, ignition off.

In addition, the design must comply with standards set forth by the International Standards Organization (ISO) for high-speed and low-speed applications within a Controller Area Network (CAN) (see See ISO 11898, Section 1-5 and ISO 11519, Section 1-3).

3. CURRENT STATUS OF THE ART

HEVs are propelled by an internal combustion engine (ICE) and an electric motor/generator (EM) in series or parallel configurations. The ICE provides the vehicle with an extended driving range, while the EM increases fuel economy and efficiency through regenerative braking and storing excess energy from the ICE during coasting. The design and control of these power trains involve modeling and simulation of control algorithms and power management strategies, aimed at optimizing the operating parameters in any given driving condition. There are two basic categories of HEV, series hybrids and parallel hybrids. However recently, series–parallel HEVs have been developed to improve the power performance and fuel economy.

In series configured HEVs, the ICE mechanical output is first converted into electricity using a generator. The converted electricity either charges the battery or can bypass the battery to propel the wheels via the same electric motor and mechanical transmission. Theoretically, it is an ICE-assisted EV that aims to extend the driving range comparable with that of conventional vehicle. Due to the decoupling between the engine and the driving wheels, it has the definite advantage of flexibility for locating the ICE generator set. Although it has an added advantage of simplicity of its design, it needs three propulsion devices, the ICE, the generator, and the electric motor. Therefore, the efficiency of series HEV is generally lower. Another disadvantage is that all these propulsion devices need to be sized for the maximum sustained power if the series HEV is designed to climb a long grade, making series HEV expensive. On the other hand, when it is only needed to serve short trips such as commuting to work and shopping, the corresponding ICE generator set can adopt a lower rating. There are six possible different operation modes in a series HEV:

1) Battery alone mode: engine is off, vehicle is powered by the battery only;
2) Engine alone mode: power from ICE/G;
3) Combined mode: both ICE/G set and battery provides power to the traction motor;
4) Power split mode: ICE/G power split to drive the vehicle and charge the battery;
5) Stationary charging mode;
6) Regenerative braking mode.

The parallel HEV allows both the ICE and electric motor to deliver power in parallel to drive the wheels, unlike its series counterpart. Since both the ICE and EM are generally coupled to the drive shaft of the wheels via two clutches, the propulsion power may be supplied by the ICE alone, by the electric motor, or by both. Conceptually, it is inherently an electric-assisted ICEV for achieving both lower emissions and fuel consumption. The electric motor can be used as a generator to charge the battery by regenerative braking or by absorbing power from the ICE when its output is greater than that required to drive the wheels. A noticeable advantage of the parallel hybrid is that it needs only two propulsion devices, the ICE and the electric motor. Another clear advantage over the series case is that a smaller ICE and a smaller electric motor can be used to get the same output until the battery is depleted. Even for long-trip operation, only the ICE needs to be rated for the maximum sustained power while the electric motor may still be about a half. The following are the possible different operation modes of parallel hybrid:

1) Motor alone mode: engine is off, vehicle is powered by the motor only;
2) Engine alone mode: vehicle is propelled by the engine only;
3) Combined mode: both ICE and motor provides power to the drive the vehicle;
4) Power split mode: ICE power is split to drive the vehicle and charge the battery (motor becomes generator);
5) Stationary charging mode;
6) Regenerative braking mode (include hybrid braking mode).

In the series–parallel hybrid, the configuration incorporates the features of both the series and parallel HEVs, but involving an additional mechanical link compared with the series hybrid and also an additional generator compared with the parallel hybrid. Although possessing the advantageous features of both the series and parallel HEVs, the series–parallel HEV is relatively more complicated and costly. Nevertheless, with the advances in control and manufacturing technologies, some modern HEVs prefer to adopt this system.

Existing products and technologies

1. **Toyota Prius**
    - The world's first commercially mass-produced and marketed HEV.
    - The 2000 to 2003 model Prius was certified as a Super Ultra Low Emission Vehicle (SULEV) by the California Air Resources Board (CARB).
    - The Prius uses a planetary gear set as a power splitting device. There are two permanent magnet motors, one primarily used as a motor and the other primarily used as a generator.
    - The 6.5-Ah 21-kW nickel-metal hydride battery is charged by the generator during coasting and by the motor during regenerative braking.
    - The four-cylinder engine is shut off during low vehicle speed. The vehicle has significant fuel improvement over the conventional vehicles.
2. **Honda Civic**
    - The electric motor is mounted between the ICE and the transmission. The 12-kW PM motor either provides assistance to the engine in high vehicle power demand or splits the power of the engine during low vehicle power demand.
    - The hybrid offers 66% and 24% fuel efficiency improvement in city and highway driving over its counterpart, respectively. Honda also has adopted this technology in its Accord hybrid.
3. **Ford Escape**
    - Ford produced the first SUV hybrid in the world, the Escape. The Escape hybrid also adopted the planetary gear concept as its power splitting device.
    - With a significantly reduced sized engine, this full size SUV hybrid provides the same performance as its counterpart. The second generation hybrid SUV at Ford, the Mercury Mariner, has an improved power train design which offers exceptional drivability and dynamic performance.

4. **Saturn Vue**

- The Saturn Vue simply added a 4-kW electric motor through a belt to its existing power train. The small electric motor is powered by a 36-V 10-kW nickel-metal hydride battery.
- The motor provides 5 kW of electricity in a generating mode either from the engine during opportunity charging or from the vehicle braking.
- The surprising 20% fuel economy improvement justifies the small investment into the hybrid. The drawback is that due to the small size motor, the engine cannot be shut off at low vehicle speed.
- The air conditioning is operated by the engine, therefore, there will be no A/C even though the engine can be turned off during idle.

5. **ISE Transient Bus**

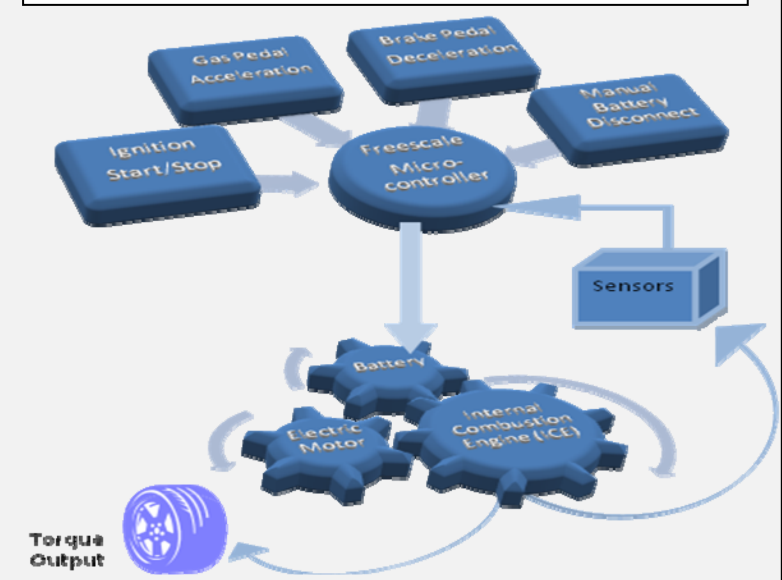
- The transient buses are usually considered ideal candidates for hybridization.
- They have fixed routes and are almost driven in the stop-and-go pattern. It is shown that an average 50% or more of fuel can be saved with either parallel or series hybrids.

Weakness of Current Status of Art

While there are certain advances in technologies and more stringent standards for fuel economy and consumption thus far, the problem remains that the cost of production of fuel efficient and low emission vehicles are relatively high. In addition, these vehicles force compromise such as can be seen with the Saturn Vue, high fuel economy versus no air conditioning.

4. ENGINEERING APPROACH

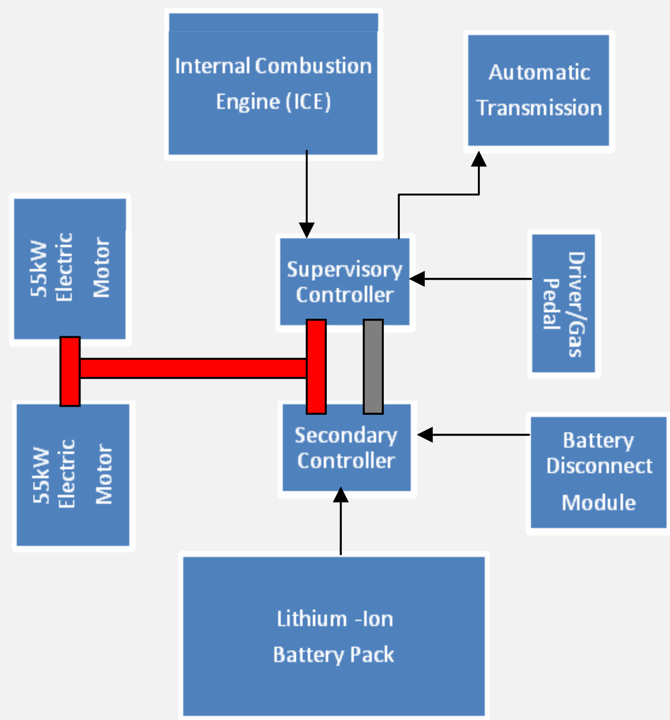
Block Diagram of System Inputs and Outputs



Team REV's ultimate goal is to implement a SimuLink model of a control system for the hybrid Saturn Vue. Our proposed control system would oversee the operation of the hybrid vehicle, lower fuel emissions, fuel consumption and decrease fuel dependency. Team REV has thus far far identified a five step process to achieving the goals of this project. The first phase of this process would include developing a pre-software block diagram of our system. The second phase would be to model our system and control strategy in SimuLink. The third phase would be to conduct software-in-the-loop testing and finally we would conduct a battery of hardware-in-the-loop tests. The team believes that the projects objectives can and will be achieved by strictly adhering to these steps.

In devising an appropriate block diagram model of our system we have identified five key modes of operation for our vehicle: ignition start, acceleration, cruise, braking/deceleration, and engine stop. Identifying these modes play a huge part in developing a control strategy that would allow the vehicle to effectively move through them within the driving process.

In addition, we have identified that the vehicle system with control strategy should essentially function as a feed-back loop. This means that a signal would be sent to the controller from the various input points indicated in the diagram (i.e. Ignition, Accelerator, Brake Pedal etc.). The controller then takes this data and calculates the optimal response from the system. A signal is then sent to the hybrid architecture components (Battery, Electric Motor, Internal Combustion Engine (ICE) etc.). A resulting torque output is then achieved, and signals are fed back to the controller.



Overview of Dual Controller Approach

Safety has been highlighted as a key consideration in the teams control strategy design. For this reason we have decided to use a dual-controller approach in handling our hybrid system. The supervisory controller would oversee the safe operation of the main components such as the engine, transmission, and electric motors. The vehicle components that we would be using have built-in fail safe features that are engaged when errors are detected. Once the fail safes in these components are activated the supervisory controller would take the necessary action to ensure vehicle and driver safety. The secondary controller would supervise the Battery State (i.e. in terms of temperature, pressure etc.). This would ensure the device's longevity and also detect critical malfunctions and disconnect the battery from the rest of the vehicle to protect anyone in the vicinity of the car. The two controllers would also be able to perform error checks against each other as well as the Controller Area Network (CAN) that connects them and the devices they manage.

Team REV also understands that in dealing with our proposed feed-back loop system we would require some knowledge of Linear Controls. We have not taken this class as of yet, but are confident that a working knowledge of this field can be garnered through research. This strategy should get us through the initial phases of the project. Faculty such as Howard University Professor Ahmed Rubaii has been identified as an additional advisor who could provide a wealth of expertise in this field.

5. Tasks and Deliverables

At the close of this venture Howard University's team REV will deliver a hardware tested model of our control strategy for the series-parallel hybrid-electric architecture designed for the Saturn Vue. The strategy would initially be modeled in SimuLink to be later converted to C++ code, downloaded and housed in a control box. It is our goal that this control strategy would promote a higher level of fuel efficiency to the tune of 48/50 mpg (city/highway) for our hybrid vehicle.

To achieve the goals of this project it is necessary to adhere to a strict path of success. Team REV believes that this path involves six major components which when combined would give the desired results:

1. Choose Power Train Architecture

2. Develop block diagram for Control Logic

3. Develop SimuLink model of Control Strategy

4. Software in the Loop Testing

5. Rapid Prototyping

6. Hardware in the Loop Testing

<u>Choosing Power Train Architecture</u>

Team REV decided that the best power train architecture for the hybrid vehicle is a series-parallel type. With the Series Parallel Hybrid System, it is possible to drive the wheels using the dual sources of power (electric motors and/or gas/petrol engine), as well as to generate electricity while running on the electric motors. The system runs the car on power from the electric motors only, or by using both the gas/petrol engine and the electric motors together, depending on the driving conditions. Since the generator is integrated into the system, the battery can be charged while the car is running.

The basic components of the system are the electric motors, the gas/petrol engine, the generator, the power split device and the power control unit (inverter/converter). The power split device transfers part of the power produced by the gas/petrol engine to drive the wheels, and the rest to the generator to either provide electric power for the electric motors or to recharge the battery.

This system takes advantage of the energy-efficient electric motors when the car runs in the low speed range, and calls on the gas/petrol engine when the car runs in the higher speed range. In other words, the system can control the dual sources of power for optimum energy-efficient operation under any driving conditions.

Block Diagram for Control Logic

Team REV believes that a well developed block diagram for our control logic is major step toward a successful project. During this process we would look at the theoretical aspects of the project. This would include the basic components that the system would require, such as the internal combustion engine (ICE), electric motor, battery and energy storage box (ESB). For this step we understand that the real-world function of these components could differ from our theoretical expectations, however, this is still optimal in estimating how our hybrid vehicle and its components would work together.

Team REV has thus far identified five key areas of vehicle operation that our control logic would oversee. For each area the logic would take into consideration inputs from various components such as gas pedal, brake and wheel. These modes of operation for the hybrid vehicle are:

1. Engine start
2. Acceleration
3. Cruise
4. Deceleration
5. Engine Shut-down.

SimuLink Model of Control Strategy

SimuLink is a very effective tool in giving an approximation as to how well our control strategy will perform. Team REV understands that before we can implement the final product we need to grasp how it would perform under ideal conditions. SimuLink makes this possible.

In implementing the software model the project moves from the basic considerations for the vehicle’s components to more realistic concerns that may affect the real-life parts. For instance, when dealing with the battery the state of charge becomes a key factor in how the control strategy functions. Periodic evaluation of the battery's remaining charge ensures extended performance and battery life, as does control of the battery current that goes to the load. A battery's residual charge comprises its previously calculated charge plus the amount of newly accumulated charge or minus the amount of charge it expends. Hence, our control strategy has to constantly account for the state charge of our power source.

Software in the Loop (SiL) Testing

This is a very important feature of SimuLink that allows for the entire system including vehicle components and control strategy module to be integrated into a closed-loop circuit for the sole purposes of testing how the strategy functions without real-time considerations. This is very important because it saves time in allowing components as well as the strategy itself to be fine-tuned without having to start from scratch with each failed attempt. As a result, valuable resources such as time and money can be saved.

<u>Hardware in the Loop (HiL) Testing</u>

Hardware in the Loop testing allows for the system to be tested with real-time considerations. For example the strategy will, be downloaded to the control-box where it will be inserted back into the closed-loop. While running these tests we can now account for real-time lags that occur within the control box that affect when the control strategy responds to various inputs. As this phase progresses, more real components can be added to the loop until the closest possible approximation of the Hybrid vehicle function is achieved.

6. Project Management

<u>Resources</u>

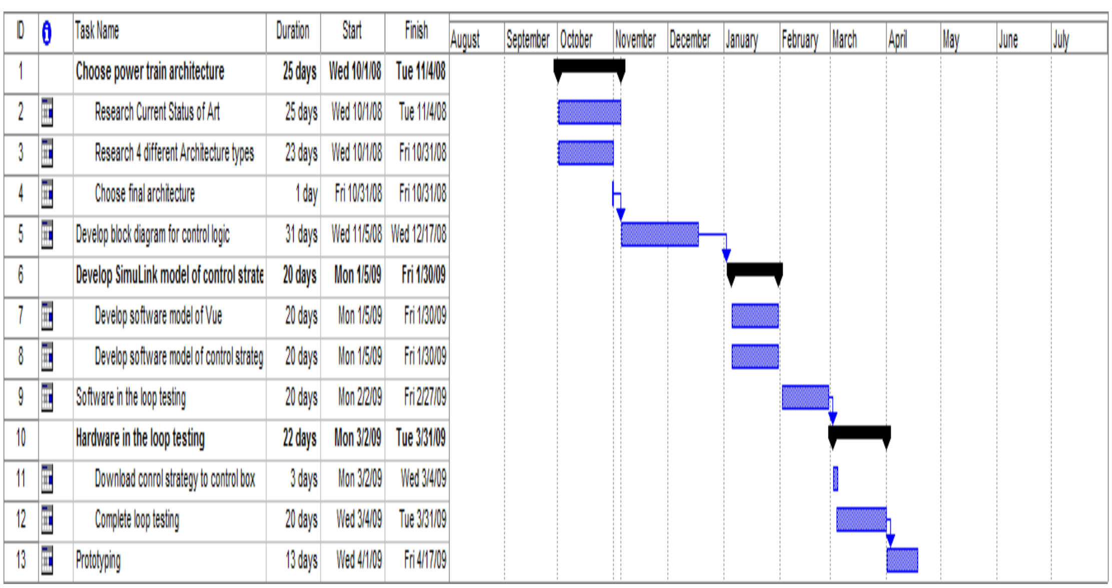
Team Personnel: Derrick Rumbolt –Senior Computer Engineering major

Seitu Brathwaite-Senior Electrical Engineering major

Katrelle Jones-Senior Electrical Engineering major

Tarik Wright-Senior Electrical Engineering major

DeAngelo Woods-Junior Electrical Engineering major



ID	Task Name	Duration	Start	Finish
1	**Choose power train architecture**	**25 days**	**Wed 10/1/08**	**Tue 11/4/08**
2	Research Current Status of Art	25 days	Wed 10/1/08	Tue 11/4/08
3	Research 4 different Architecture types	23 days	Wed 10/1/08	Fri 10/31/08
4	Choose final architecture	1 day	Fri 10/31/08	Fri 10/31/08
5	Develop block diagram for control logic	31 days	Wed 11/5/08	Wed 12/17/08
6	**Develop SimuLink model of control strate**	**20 days**	**Mon 1/5/09**	**Fri 1/30/09**
7	Develop software model of Vue	20 days	Mon 1/5/09	Fri 1/30/09
8	Develop software model of control strateg	20 days	Mon 1/5/09	Fri 1/30/09
9	Software in the loop testing	20 days	Mon 2/2/09	Fri 2/27/09
10	**Hardware in the loop testing**	**22 days**	**Mon 3/2/09**	**Tue 3/31/09**
11	Download conrol strategy to control box	3 days	Mon 3/2/09	Wed 3/4/09
12	Complete loop testing	20 days	Wed 3/4/09	Tue 3/31/09
13	Prototyping	13 days	Wed 4/1/09	Fri 4/17/09

Figure 1: Gant Chart detailing Tasks to be Completed

Team Tasks:

1. Researching Current Status of Art

   Team REV believes that detailed research on the current status of art is a key first component to later success in this endeavor. With this in mind we have assigned Tarik Wright one of our valuable team members to this area of research. Mr. Wright has proven himself to be the strongest researcher on the team and his experience as an Electrical Engineering student at Howard University makes him a viable candidate for this position. The team understands that to improve on the existing technology of today we must know and understand what is already available or currently being implemented. With this knowledge we can make the integral decisions as to the direction of this project; whether that may be improving on existing technology or coming up with a completely revolutionary design.

2. Develop Block Diagram of Control Logic

   It was previously stated earlier in this proposal that a successful project is hinged upon developing a solid block diagram of our control logic. This is still true. Team REV plans to dedicate a considerable degree of time and effort toward ensuring development of a strong block diagram. Seitu Brathwaite, DeAngelo Woods and Funmi Oludaiye have been assigned this task, and the team believes that there tireless efforts would see this task to fruition.

3. Develop SimuLink Model of Control Strategy

   This phase should follow the block diagram phase and for the purpose of continuity it is important that the same team undertake this task. Developing a SimuLink model for the control strategy is important because this is one of the intial requirements outlined by our sponsors. In addition to this, SimuLink provides the latitude to do a variety of testing such as Software in the Loop (SiL), and Hardware in the Loop (HiL) testing.

4. Develop Software model of Vue

   Team REV also believes that for the testing phase of this project to be fruitful a closely approximate software model of the Saturn Vue must be developed. Derrick Rumbolt, the team's senior Computer Engineering major will be heading this part of the design process, and would be working closely with Tarik Wright as and Katrelle Jones. With their efforts, the team plans to have an operable model of the Saturn Vue that reflects the basic factory specifications (shape, size, weight etc.) in addition to the series-parallel hybrid architecture that we have chosen.

Software needed to complete tasks:

The full Matlab/SimuLink suite has been provided by our sponsors and are integral in implementing the control strategy and carrying the testing phases of our design schedule.

Hardware needed to complete tasks:

Once the team reaches the Hardware in the Loop phase it would be necessary to have a control box with a microprocessor to down load, utilize and house the control strategy. General Motors has committed to making these items available before we reach this step in our design.

Requests

1. **Secure location**: throughout the Duration of this project Team REV will be dealing with sensitive proprietary material given to us by our sponsors. It will become necessary that these items be housed in a secure location. Also this same location could serve as a constant meeting place so that the aspects of the project can be discussed discreetly without jeopardizing the security of our sponsor's information.

2. **Matlab/Simulink instruction:** it has already been arranged that instructional classes will be held to provide some tutelage on the use of the SimuLink software package. It would also be necessary to have an expert that the team can seek throughout the duration of the project for further questions in this area.

7. Conclusion

The United States is currently in the midst of a very dire energy crisis. We have long understood that oil is a finite resource and as a nation we have reached a precipice in terms of energy. If the situation is not remedied the nation would be left a wrecked, weakened and fragmented version of its former self. The Eco-car project which is being sponsored by General Motors and the Department of Energy hopes to play a part in providing an alternative to the currently "eco-unfriendly" vehicle industry by creating a more efficient hybrid electric Vehicle. Team REV believes that even though the eco-car may not be the panacea for our energy crisis it is still an integral part of the solution.

Team REV has been tasked to design, Software-in-the Loop test, Hardware-in-the Loop test, and download to a controller box a control strategy for the Saturn Vue HEV. We believe that this can and will be achieved by adhering to our strict six step process which was detailed previously:

1. Choose Power Train Architecture

2. Develop block diagram for Control Logic

3. Develop SimuLink model of Control Strategy

4. Software in the Loop Testing

5. Hardware in the Loop Testing

6. Prototyping.

The Team has also already designed a rudimentary model of our system identifying five basic modes of operation for the vehicle: Ignition Start, Acceleration, Cruise, Braking, and Engine-Off. For increased safety we have proposed a Dual Controller approach to the control strategy design. The supervisory controller would manage the ICE, electric motors, and transmission; while the secondary controller would manage the battery state. The both controllers would error-check each other as well as and the CAN connections between them and their respective devices. Overall, this approach would foster safer vehicle operation, while promoting a more efficient CAN performance.

We expect to have a functioning SimuLink model of our control strategy by January 30th, and then complete Software-in-the Loop testing by February 27th. Hardware-in-the Loop testing would then be done by March 31st and final prototyping done by April 17th. Team REV believes that the work that has been completed thus far has put us on the path to the successful completion of the Eco-car project.

8. REFERENCES

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http://en.wikipedia.org/wiki/Greenhouse_gas