Semester I Final Report

Team 2

Electric Vehicle Range Extension

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ABSTRACT

Team 2 is working with sponsor Dr. Michael Hays from Cummins, Inc. and faculty advisor Dr. Seungyong Hahn in order to improve the range of an electric vehicle using alternative power adders while not increasing the onboard fuel supply. The sponsor specifically asked Team 2 to research solar panels and regenerative braking as external power sources to extend the range by at least 15% without having a significant decrease in vehicle performance. Upon doing so, Team 2 has decided to implement a solar panel to continuously charge the batteries while in motion. The current generator system will also be altered to operate more efficiently than before by reducing power usage and directly charging the batteries while the cart is not in motion. Team 2 has begun testing to determine the current range of the cart as a benchmark. This measurement will act as a reference to obtain our overall increase goal. So far, Team 2 has been able to make major improvements to the circuitry of the vehicle from the state that it was received. Moving forward, the specific solar panel selection has to be finalized and ordered for implementation and further testing.

1. Introduction

The purpose of this project is to improve the overall range of the electric vehicle by at least 15% of what was achieved by last year's team. Team 2 is focusing on adding additional power sources, finding ways to generate power while in motion, improving the efficiency of the electric system, and reducing the weight in order to ensure that all aspects of the vehicle attribute to the range improvement. The sponsor has instructed that we begin by ensuring the vehicle is functioning properly, in order to begin testing its current range. Currently, the team has been working on solving issues encountered by last year's team, which mainly consists of the ability of the generator and battery systems to work in tandem. Last year's plan was to have the generator automatically turn on as the batteries fully depleted, continuing to power the vehicle off of the generator alone, causing a sufficient reduction in performance. This year, Team 2 has changed this concept in that the generator will be constantly running, supplying power to the motor along with the batteries, allowing for increased efficiency and slower power drainage. In order to begin benchmark testing of the current vehicle range, Team 2 had to completely redesign the electric system.

2. Project Definition

2.1 Background Research

2.1.1 Photovoltaics

There has always been a great effort in using new methods to generate renewable energy; one of the most significant and widely used methods is the use of photovoltaics. Solar energy is an important renewable source for heat and energy. The sun generates energy from a process called nuclear fusion, and this energy can be captured, converted, and stored as electrical energy using solar panels. Currently, solar roofs are manufactured for installation on small electric vehicles similar to the one given to Team 2. Solar companies claim these solar roofs generate anywhere from 100 to 360 watts of power, depending on cost and size. Large solar roofs are approximately 6ft by 4ft and weigh about 80lbs, which could cause an issue in performance of our vehicle due to increased weight. There is a maximum theoretical efficiency of solar panels based on the amount of solar radiation that hits the earth's surface. On a sunny day at the equator there is a solar radiation density of about 1000W/m^2. It is assumed that actual power generation will be less than the solar companies claim; however, an accredited source noted a noticeable increase in a vehicle's range could be up to 15 miles due to the addition of an external photovoltaic source.

2.1.2 Regenerative Braking

Regenerative braking is a system that converts the vehicle's kinetic energy back into electrical energy. This energy is stored in the batteries when the operator decides to slow the vehicle down and is most commonly known due to the Toyota Prius. This power conversion is ideal for stop-and-go driving environments due to the system only contributing to minimizing the loss of energy while braking. Many new high-end electric vehicles come with regenerative braking systems installed. Our vehicle does not have this system, however, complete regenerative braking kits can be purchased for installation. A new motor may also need to be purchased to incorporate this option due to the compatibility of the electric components. The amount of energy converted by a regenerative braking kit can be calculated through the change in kinetic energy, although mainly depending on the amount of braking the vehicle experiences.

2.1.3 Geographic Regeneration

Based on the main goal for this project, the team is expected to be as creative as possible. That includes thinking outside of the box when trying to supply the vehicle with additional power to meet the 15% increase in range. During one of the brainstorming sessions with our advisor Dr. Hahn, he introduced the idea of saving some energy as the vehicle is driving downhill. Based on an angle between the body of the vehicle and the surface it is being driven on, for any angle that is determined to be a sufficient downhill slope, the electric system would temporarily cut off power flow to the motor.

2.2 Need Statement

Our team has been approached by Dr. Michael Hays of Cummins, Inc, to extend the range of an electric vehicle similar in size to a golf cart. The vehicle's range needs to be improved by 15% above its current capability. Dr. Hays wishes us to do so without increasing the fuel capacity of the vehicle and minimizing the reduction in performance. With this information the following need statement has been created.

"The current range of the cart is unsatisfactory and needs to be extended without adding fuel supply and minimizing the reduction in vehicle performance."

2.3 Goal Statement and Objectives

After thorough discussion with our adviser and sponsor along with a need assessment, our team formulated the following goal statement.

"To increase the range of the electric vehicle by at least 15% through non-traditional power adders while minimizing the reduction in acceleration and top speed."

Objectives:

- Document current vehicle performance
- Research variety of possible power adders
- Procure/incorporate additional sources
- Reconfigure overall vehicle circuitry
- Increase vehicle range by 15%

2.4 Constraints

- Fuel supply cannot be increased
- Vehicle must be able to carry four people
- Top speed cannot be reduced by more than 10%
- Acceleration cannot be reduced by more than 10%

2.5 Current Project Status

As this project is a continuation from last year, the vehicle was given to Team 2 in the exact condition it was left by the last team. The vehicle, which is a 48V Tomberlin Low Speed Vehicle can be seen below in Figure 1. They were unable to finish their overall goals due to encountering issues with the generator and battery charging tandem system. Team 2 has slightly differing project goals and therefore decided to take the system in a different direction by redesigning the overall electrical circuitry and adding external power sources.

Figure 1. 48V Tomberlin Electric Low Speed Vehicle supplied to Team 2.

So far, Team 2 has completely scrapped and rewired the generator-battery system to be in operable condition as intended by last year in order to benchmark the current range of the vehicle before external sources are incorporated. Team 2 has already begun preliminary testing to calculate the vehicle's theoretical range from the stored energy in the batteries as well as the 20lb propane tank for use with the generator. Team 2 is implementing a current sensor to measure the use of energy over a known distance to determine this measurement for both scenarios of the vehicle being powered either by the batteries or the generator alone, the results of which are shown described in detail below in the benchmarking section. Adjustments to the existing Arduino code that works with the system's microcontroller is ongoing, aimed at most efficiently allowing for the electrical and mechanical systems to work together by recording the test data and controlling the output of the electrical components. Currently, the circuitry is now being altered in order to achieve the design plan outlined in introduction and is discussed further below.

2.5.1 Generator-Charger System Control

Last year's team spent a great deal of time and effort developing a new charging system that ran off of an onboard microcontroller to record values for various electrical sensors while controlling the status of the generator. This allowed for the generator, a Cummins QG2800, to turn on automatically as the batteries were fully depleted, powering the vehicle off of the generator alone, which can be seen below in Figure 2. The goals of this year's project vary slightly from that of the previous year in that operating in extreme conditions is no longer a requirement, allowing for the removal of battery warmers that were originally installed. The existing Arduino code was written to control the system as described above and is being changed significantly to make the system perform as Team 2 intends.

Our goal for the generator and battery tandem system is for the generator to always be running, simultaneously providing power to the motor while the vehicle is in use. While the vehicle is not in use, the generator will simply only supply power to the batteries, allowing for them to be charged. If the batteries were to reach a full charge, the generator would be then turned off as to not waste power. This system design insures that the vehicle is always running at maximum performance, while maximizing the efficiency in the power available.

Figure 2. Cummins QG2800 Generator implemented on the electric vehicle.

2.6 Benchmark Testing

In order to physically realize our project goal of an increase in the vehicle's range, the current range based on what was developed from last year needed to be documented. The team selected a track to test the cart that would allow for all possible additional system components on the vehicle to increase its range. The certain track was chosen based on a having the duty cycle of the system to experience multiple periods of acceleration, deceleration, elevation, and complete stops. The chosen route was a loop around the National High Magnetic Field Laboratory on West Paul Dirac Drive and is shown in Figure 3. The track was approximately 1.37 miles in length.

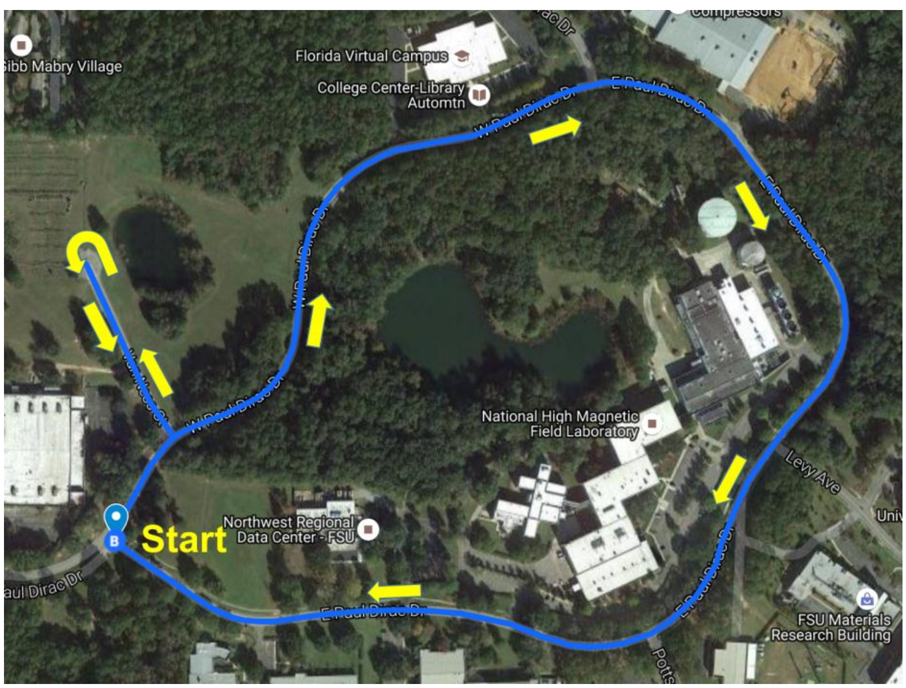
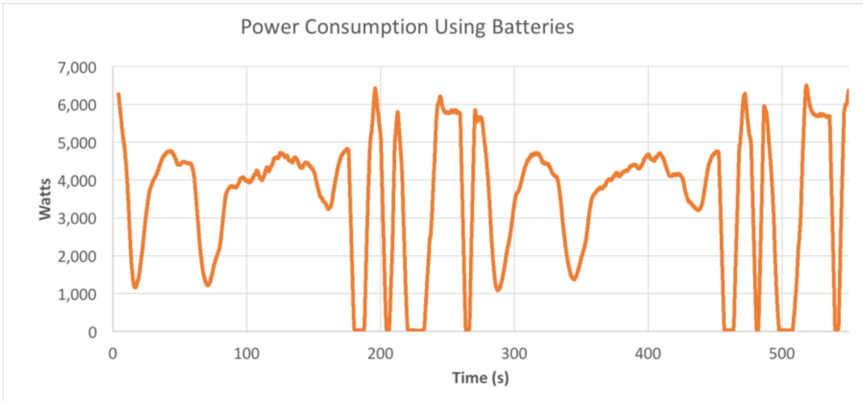
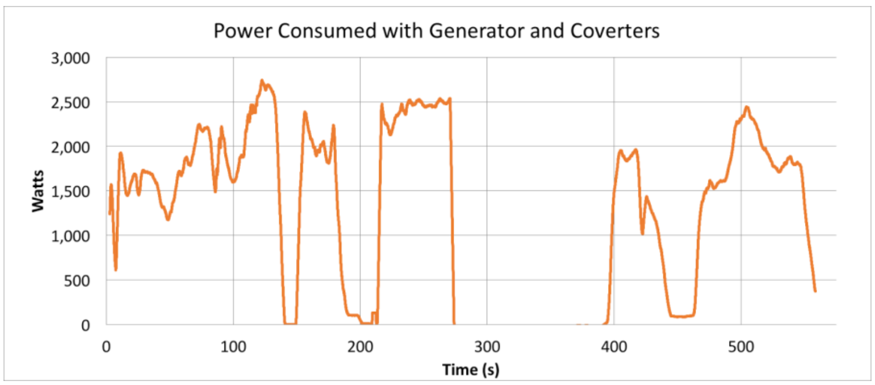


Figure 3. Test track loop chosen around W Paul Dirac Drive.

Two tests were run to benchmark the range of the electric vehicle. One test was conducted on battery power alone, while the second was only supplied by generator power. The respective graphs of power drawn from the motor are shown below in Figure 4.



(a)



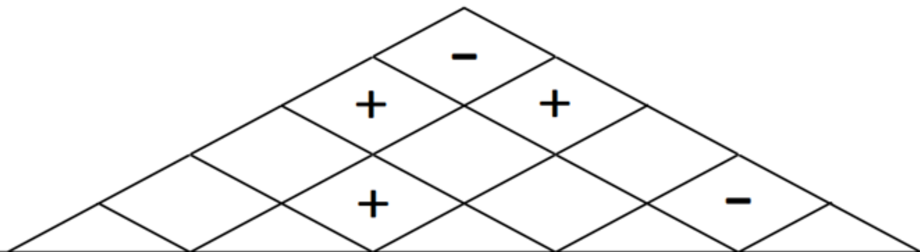
(b)

Figure 4. Power consumption of electric vehicle over two laps on (a) battery power and (b) generator power.

From the battery power test, Team 2 calculated that the cart consumes approximately 710 kJ/mi based on the average power consumption and had a top speed of 25 mph. With the battery bank capacity having an available 15,840kJ of energy, at this rate, the vehicle could theoretically travel up to 22.3 miles on battery power alone. As with the generator test, the theoretical range was calculated in a similar manner by monitoring the consumption of propane over a certain distance. The generator was determined to consume approximately 0.271lb/mile. With a full propane tank having a capacity of 20lbs, the range the vehicle could travel from generator power alone is approximately 73.8 miles. However, the vehicle's top speed on generator power is only around 9 mph, showing a significant decrease in vehicle performance. This leads to a total theoretical range of 96.1 miles that needs to be increased by 15%.

3. Preliminary Design

3.1 House of Quality (HOQ)



CR \ EC	Efficiency	Safety	Durability	Power	Weight
Reliability	2	3	4	1	0
Performance	5	1	2	5	2
Cost	4	2	4	4	0
Capacity	1	1	2	1	2
Range	5	1	3	5	3
Total	17	8	15	16	7
Rank	1	4	3	2	5

Figure 5. House of Quality diagram illustrating the relationships between our customer requirements and engineering characteristics.

This House of Quality was developed using our needs assessment and from earlier discussions Team 2 conducted with both our sponsor and faculty advisor. The customer requirements directly correspond to various constraints of the project such as the range, which must be increased by 15%, and the performance, which must not be decreased by 10% for either top speed or acceleration. As for the engineering characteristics, Team 2 determined efficiency, durability and power were the most important by comparing and contrasting to the customer requirements. Efficiency is key to this project because it is through having an efficient system that the range of an electric vehicle will be increased. Power is the second most important characteristic for the reason that the top speed and acceleration of the electric vehicle may not be decreased by 10%. Durability is also important because the added components need to be able to withstand the operating conditions of an electric vehicle which include but are not limited to bumpy terrain, inclement weather conditions, rain, dirt, and dust. These are basic conditions which may be met by any electric vehicle, especially the cart on which these components will be implemented and tested.

3.2 Concept Generation

The main design aspect for this project deals with the creativity and implementation of an additional power source. For that reason, the following design ideas for this source were developed.

3.2.1 Photovoltaic Method

As mentioned earlier, solar panels are becoming ever popular in a multitude of applications. They have already been put into practice on electric vehicles with great results, some sources claiming as much as a 25% increase in range. There are various solar panels for this application. Figure 6 shows an example of a solar panel roof for an electric vehicle.

Figure 6. Electric Vehicle showing an example of a solar roof installed.

A full solar panel roof can produce between 100 and 360 watts for a standard size electric vehicle which is approximately 1.2 x 0.9 m. It is important to note that this project is based out of Florida, where the solar panel will operate in near optimal conditions with the abundance of sunlight year-round. The system has many advantages including being lightweight and being available in many different formats. Options include having a full roof replacement panel which serves as both a power-adder and the roof of the electric vehicle. There are also flexible solar panel mats which simply secure to the preexisting roof. All versions are simple to install and require no special tools. The greatest drawback of this method is the cost. For durable solar panels for an electric vehicle, the price ranges between $600 for a low end system to upwards of $2500 for a very efficient system. If solar panels are used then some time will need to be spent in determining the best option to achieve maximum power output per dollar spent.

3.2.2 Regenerative Braking Method

This method is already implemented in electric vehicles and utilizes the motor and braking system to minimize energy loss. The motor is back-driven instead of using the brakes to slow down, which allows for energy to be returned to the batteries instead of being wasted. The life of the brake pads is extended as a result which reduces overall maintenance costs for the electric vehicle. The drawbacks for this method include price and implementation as some kits are incompatible with certain motors. A typical regenerative braking system can cost well over $2000. It also requires a great deal of work to install and it is not the most efficient means of restoring energy back into the batteries of an electric vehicle as it only replaces a small fraction of the energy that was needed to move the electric vehicle.

3.2.3 Geographic Regeneration Method

This idea involves using the landscape and a gyroscope in order to cut off power to the motor when the electric vehicle is able to coast on its own and use a similar system to regenerative braking in order to store energy by back-driving the motor. The same problem of cost and difficulties that occur with regenerative braking also arise here. This method also has the added difficulty of properly coding and accounting for all circumstances in which power might be needed despite the electric vehicle satisfying the angle which would cut the power to the motor. This option does have the benefit that it can be used without necessarily implementing regeneration such that range can be increased simply by cutting power from the motor whenever necessary, allowing for a small increase in range through power conservation. It is also relatively simple in that case and can be implemented in conjunction with one of the two previously mentioned options. There are very few specifications to consider with this option as the performance varies with each system.

3.2.4 Generator Optimization

Through inspection of the electric vehicle in its original state as given to Team 2, it was found that the generator was not being utilized at its max efficiency. This efficiency is maintained based on the maximum load that the generator can handle without its circuit breaking being activated. Aligning with with Team 2's overall goals and intended use of the generator in tandem with the batteries, this efficiency increase should be easily obtained. By always running the generator at max efficiency, the loss of energy being converted from propane to electricity and then to mechanical motion of the cart is minimized. This efficiency will lead a sizeable but not overwhelming increase in the range of our vehicle if able to be implemented properly.

3.3 Concept Evaluation & Selection

3.3.1 Selection Criteria

At this point in the project, Team 2 has come to a preliminary decision on which method would be most appropriate to achieve the goals outlined in the aforementioned goal statement. The sponsor, Dr. Hays, has asked us to continue researching other, more interesting methods throughout the rest of this year and to consider implementation at a later date. After a great deal of consideration and analysis of the project goals, constraints and customer requirements, Team 2 has determined that the primary selection criteria are cost, performance, reliability, and ease of implementation.

- **Cost:** Although the budget for this project is somewhat flexible and the cost is not considered a constraint, it is still important to consider. It is good practice to choose the most cost effective option that will meet all of the requirements, constraints and goals outlined for the project.
- **Performance:** As previously mentioned, the car needs to operate with as little reduction in performance as possible while still meeting the increase in range. To make this happen, the performance of each new power adder must be considered to ensure that it will not inhibit the performance of the electric vehicle.
- **Reliability:** This criterion is crucial to the project as the components must consistently work together without failing in order for the project to be considered a success. It is essential for design and implementation of the power adders to be robust.

- **Ease of Implementation:** For the time constraints of this project, it is best to keep in mind the simplicity of the solutions.

3.3.2 Pugh Decision Matrix

According to the selection criteria, a Pugh decision matrix was utilized to determine the best design options when compared across each other with weighted values. It was determined that performance and ease of implementation were the most important criteria followed by reliability and finally cost.

Criteria	**Weight**	**Photovoltaic Method**	**Regenerative Braking**	**Geographic Regeneration**	**Generator Optimization**
Cost	1	1	1	2	3
Performance	3	3	1	2	3
Reliability	2	3	3	1	3
Ease of Implementation	3	3	2	2	1
Total		**25**	**16**	**16**	**21**

Figure 7. A Pugh decision matrix was developed to compare design options.

Based off of the weighted design criteria, the photovoltaic method of generating external power was determined to be the optimal choice for Team 2. This method is very easy to implement into the electric vehicle circuitry and hardware and will produce a reliable range increase due to being highly efficient. Generator Optimization placed second and will also be implemented. It is inexpensive to implement and will significantly increase vehicle range. Regenerative braking and the similar geographic regeneration method placed third as both are harder to implement into our platform and won't perform quite as well.

3.3.3 Solar Panel Selection

After extensive research was conducted, a few options of solar panels were considered. The decision of choosing the right solar panel was bounded by multiple factors. The most important aspect of the solar panel is the amount of power generated, based on that the range extension produced by the solar panel could be determined. This would be added onto the overall range of the vehicle.

The size, installation method, price, and control of the solar panel were all taken into consideration when the team was determining which solar panel to purchase for the vehicle. Figure 8 below represents the solar panel kit that will be purchased for the vehicle.

Figure 8. 280W Solar kit selected for our vehicle design.

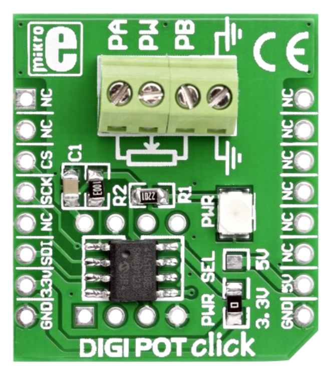
The panel is a 280W solar kit that includes the solar panel itself, a digital MPPT charge controller that will allow simple connection to the frame of the vehicle and the batteries. The kit also includes the necessary cables and electrical connections for installation along with the mounting hardware that will easily be implemented onto our vehicle.

The team has determined that the 280W solar panel is the best choice. However, the default size of the panel is not suitable for the dimensions of our specific vehicle, but the company is able to alter the size of the solar panel to work with our system. The producing company, *Solar Electric Vehicle Systems*, will be provided with the dimensions of the rooftop of our vehicle, allowing them to design a suitably sized panel for our vehicle.

The digital MPPT charge controller will be utilized by the photovoltaic array once connected to begin charging the batteries. The controller gives the user full control on how much power is being delivered from the solar panel to the batteries. The solar panel is predicted to increase the range of the vehicle by at least 10 to 15 miles in overall range. The installation of the solar panel will also reduce the "plug-in" energy use and consumption. This will reduce the cost of operating the vehicle by an average of $400 a year based on average usage.

3.3.4 Generator Optimization Implementation

In order to increase the efficiency of the generator system, two 100A Honeywell current sensors were purchased to prevent the generator from being overdrawn of its power limit of 2,800W and that the batteries are not overcharged/damaged. A Digi-Pot digital potentiometer with 256 settings from 0 to 10kΩ was also purchased to adjust the output voltage of the generator energy converters to prevent overdrawing the generator and to maximize the output and therefore the efficiency. A new Arduino code for the microcontroller will be implemented to make the system work as desired. The selected Honeywell current sensor and Digi-Pot digital potentiometer can be seen below in Figure 9.



(a) **(b)**

Figure 9. Selected 100A Honeywell sensor (a) and Digi-Pot digital potentiometer (b) for generator optimization.

3.5 Overall System Design

After using engineering design methods for decision making, Team 2 was able to produce a preliminary design. First, Team 2 is utilizing a microcontroller similar to last year's team and has made major wiring improvements for the efficient operation of the vehicle. The solar panel option was selected for its ease of implementation, cost, and performance. The solar panel, along with optimizing the generator output should provide enough power to reach the 15% increase in range. However, if time and resources permit, Team 2 would like to consider various aspects of the geographic regeneration idea, such as cutting/limiting power when moving downhill and implementing a regenerative braking system. The completed generic system as it pertains to electric vehicles is shown in Figure 10. The overall system consists of a microcontroller that controls the generator and it's interaction with external power sources and to the electric vehicle itself. The current sensors read the power draw on the generator while also allowing for the level of battery charge to be calculated. The converter then controls the amount of power drawn from the generator, maintaining optimal efficiency. The solar panel is connected directly to the batteries and is constantly supplying power.

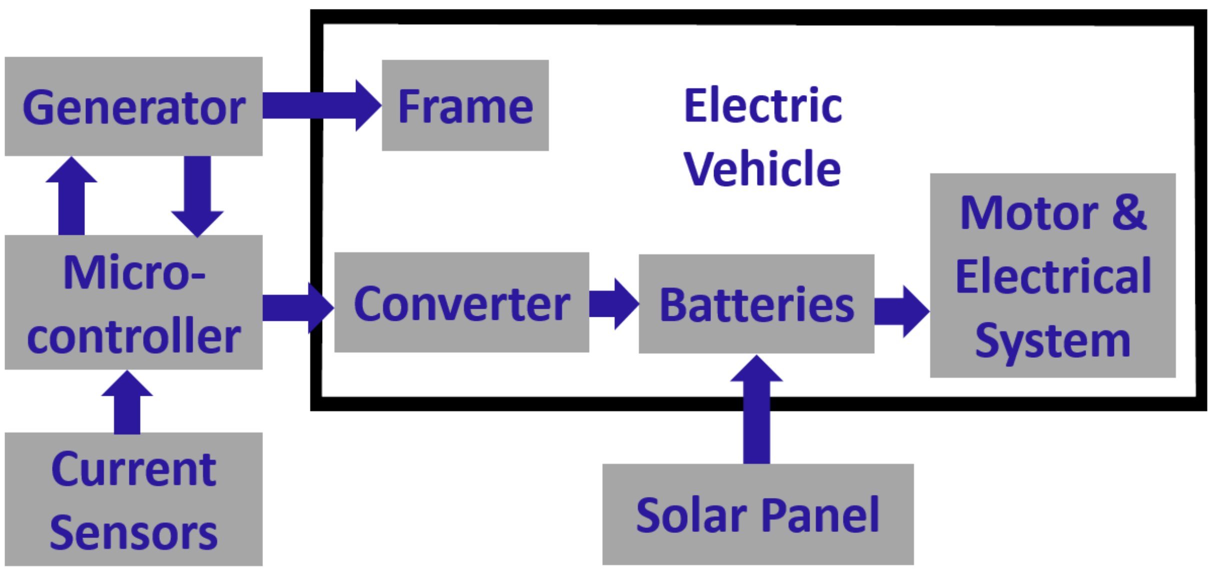


Figure 10. General system schematic showing the various components and their interactions with the electric vehicle.

4. Challenges and Risks

Initially it was expected that the motor on the cart would never draw more than 70A of current and current sensors were selected on this assumption. Upon implementing these current sensors, rated for 100A of DC current, the team noticed that when undergoing increased acceleration, the motor drew more than 150A. The load quickly drops to around 90A during cruising speed, allowing for the collection of useful data. After several tests were conducted, the current sensor stopped working due to the excess amounts of current that had been originally drawn through it. The team then selected a larger current sensor to measure motor draw, capable of measuring currents up to 225A.

Another challenge the team has continually faced is the difference in power ratings of the converters in parallel versus the generator output. The converters are capable of drawing more than 3000W, while the generator is only capable of producing 2500W. When the generator is overdrawn, a circuit breaker is thrown, shutting off the generator. In order to prevent this from happening, the team has purchased a digital potentiometer that will be capable of regulating the voltage output of the converters. The team is working on a code that will control the potentiometer based on the current being drawn from the converters to prevent the generator from being overdrawn.

5. Environmental Safety & Ethics

Safety must always be taken into consideration when dealing with potential environmental hazards along with the safety of the team members themselves. The main power source used for this project is six-8V lead-acid batteries. Lead-acid batteries consist of highly toxic materials that can harm the environment or the team's health if exposed in an improper manner. For those reasons the team will take all safety precautions when dealing, disposing and applying the batteries for use.

Another main potential environmental hazard for this project could be caused by the emissions of the propane powered generator. Generators cause a risk of emitting carbon monoxide, which is a highly dangerous gas when inhaled, therefore is recommended to only be used outdoors to reduce risk of inhalation. However, with newer advancement in technology, certain codes have been implemented on these generators in order to reduce toxic waste. The specific generator selected for this project was approved and meets the U.S EPA standards for emissions.

6. Project Planning

6.1 Schedule

In order to ensure that the project be completed in a timely manner, a schedule had to be developed. This schedule can be seen below in Figure 11 in the form of a Gantt chart. The schedule consists of installation time of components, coding developments, further range tests, and final design iterations.

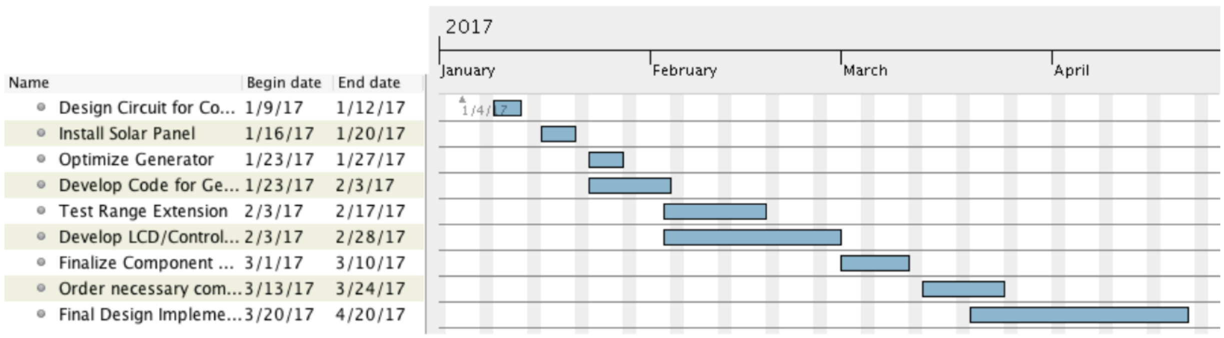


Figure 11. A Gantt chart was developed to easily illustrate and organize our project schedule over the following spring semester.

6.2 Resource Allocation

Team members and their respective project roles have been broken down into the following list.

- **Taofeek Akintola:** Responsible for calculations on theoretical available energy and corresponding range for each external power source option. Taofeek is also the electronics specialist for the team.
- **Khaled Farhat:** Responsible for creating system circuit diagrams and indicating typical current flow at maximum load. Responsible for researching needed circuit components. Khaled is also the lead EE and is in charge of maintaining the overall electrical system of the vehicle.
- **Hafs Sakka:** Responsible for making sure the vehicle is maintained and properly lubricated. Responsible for reducing vehicle’s weight without reducing comfort or

convenience. Hafs is also the team's webmaster, which includes designing the website and uploading/updating all relevant information to it.

- **Seth Rejda:** Responsible for researching the best solar panel option and identifying other cost effective ways to increase the fuel economy. Seth is also the team leader and project manager.
- **Luke Marshall:** Responsible for equipping the vehicle with the proper current sensing hardware and wiring for design implementation. Luke is the lead ME for the team.
- **Sean Casey:** Responsible for coding the controller to display necessary data and have proper operation of the vehicle. Sean is also the team treasurer.

7. Conclusion

Team 2 was tasked with finding creative ways to extend the range of an electric vehicle by 15% without dropping the top speed or acceleration rate by more than 10%. Based on the needs assessment, Team 2 used various design methods to produce engineering characteristics and customer constraints which resulted in design selection criteria, allowing Team 2 to finalize a preliminary system design. The design as discussed above, will use the optimization of the generator and installation of a solar panel to achieve the overall project goal. Team 2 has made significant wiring improvement on the vehicle and has conducted preliminary testing in order to establish a range benchmark. Moving forward, the solar panel kit must be ordered and installed, the generator must be fully optimized, and further testing is to be conducted. Once completed, design iteration can be made to reach maximum efficiency.

References

[1] G. R. I. Productions and L. -Ames, "PowerDrive golf car panels,". [Online]. Available: http://www.powerfilmsolar.com/products/?golf&show=category&productCategoryID=6569&productCategoryIDs=6569.

[2] "Product specs," Solar EV Systems - Solar Golf Carts, Roof, Tops, Solar Panel LSV Cart for EZGO, Club Car, STAR, Yamaha, Bad Boy. [Online]. Available: http://www.solarevsystems.com/product-specs/.

[3] "Regenerative braking motors and controllers for golf carts - GCI," GCI - Golf Course Industry, 2007. [Online]. Available: http://www.golfcourseindustry.com/product/regenerative-braking-motors-and-controllers-for-golf-carts-27212/.

[4] F. Perktold. [Online]. Available: http://www.marshallplan.at/images/PerktoldFabian_580.pdf.