Motorcycle Project Final Report

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College of Engineering and Computing

Department of Electrical and Computer Engineering

ECE 497: EV Technology

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Introduction

The main objective of this project is to design the powertrain of an electric motorcycle that is able to repeatedly and reliably achieve a fast quarter mile time. We are providing the necessary technical information for future classes/ECE students to buy and build the physical motorcycle. The motivation behind this project is to form an electric motorcycle team within the ECE department to draw prospective students into the program and provide a way to practically use the knowledge we have gained in our education.

Mechanical Design

Mass:

We calculated the mass of our electric motorcycle by starting with the original mass of our selected motorcycle, the CBR500 (194.183 kg). In order to build an electric bike we need to remove the following components:

1. Engine mass (29.84638 kg)
2. Fuel tank (6.80389 kg)
3. Transmission (4.9 kg)
4. Clutch (3.9 kg)

We contacted manufacturers and researched how much each of these components weigh so we could subtract this from the total mass. As we progressed through the project, we added the weight of the electric machine (52.2 kg), weight of the battery pack (22.68 kg), and the estimated weight of the rider (60 kg). Since the power electronics were not discussed in this project, the weight of it was left out. With all of the necessary weights we were then able to find an accurate total mass as shown below and then use this in our MATLAB script to calculate a ¼ mile time.

$$M_{Total} = 194.183 - 29.84638 - 6.80389 - 4.9 - 3.9 + 52.2 + 22.68 + 60 = 283.56\ kg \qquad (1)$$

Opposing Forces:

The opposing forces calculated to simulate a quarter mile race of a CBR500 were the drag force and the force of rolling resistance.

The drag force is calculated by using equation 2 below:

$$F_D = \frac{1}{2} * \rho * C_D * A_F * (v + v_{air})^2 \quad (2)$$

Where $\rho = 1.16$ is the density of air, $C_D = 0.270$ is the drag coefficient, $A_F = 0.438$ is the frontal surface area, v is velocity of the vehicle, and $v_{air} = 0$ is the velocity of air that may be propelling or inhibiting the vehicle's motion. The velocity vector was calculated in only constant torque mode, as our vehicle is accelerating throughout the entire duration of the quarter mile race, never reaching constant power mode. This process can be referenced in the MATLAB script on Github. While ρ is a common constant value for all vehicles, C_D and A_F are vehicle specific. C_D was found by referencing an article about the drag force on Honda CBR's [2]. This value is actually for the CBR1000RR, the original bike we chose. However, after looking at similarity in dimensions and characteristics of both bikes, the value was assumed for the CBR500. A_F was found by referencing a motorcycle discussion thread for the CBR1000F [3]. For the same reasoning as C_D, A_F was assumed to also work for the CBR500. This yielded our drag force, which varies with the velocity calculated and can be referenced in the MATLAB script on Github.

The force of rolling resistance is traditionally found using the equation 3 below:

$$F_R = C_R * M_{eq} * g * cos(\theta_g) \quad (3)$$

Where C_R is the coefficient of rolling resistance, M_{eq} is the equivalent mass, g is the gravitational constant of $9.8\ m/s^2$, and θ_g is the angle of the gravitational constant. However, the force of rolling resistance was found from an excel file for EPA characterization of different motorcycles [1], with a value of F_R **= 135.4 N**.

MATLAB:

We have a MATLAB file that determines how fast our bike will reach the ¼ mile given the parameters of our selected motor. All of our parameters for the bike are included in this calculation such as the total mass, wheel radius, EPA parameters, gearbox parameters, and the rated power and torque of our motor. The quarter mile time is dependent on the rated power and rated torque found from the chosen AC-51 electric machine.

This code produces a plot that shows the rotor power and torque as a function of vehicle speed as shown below.

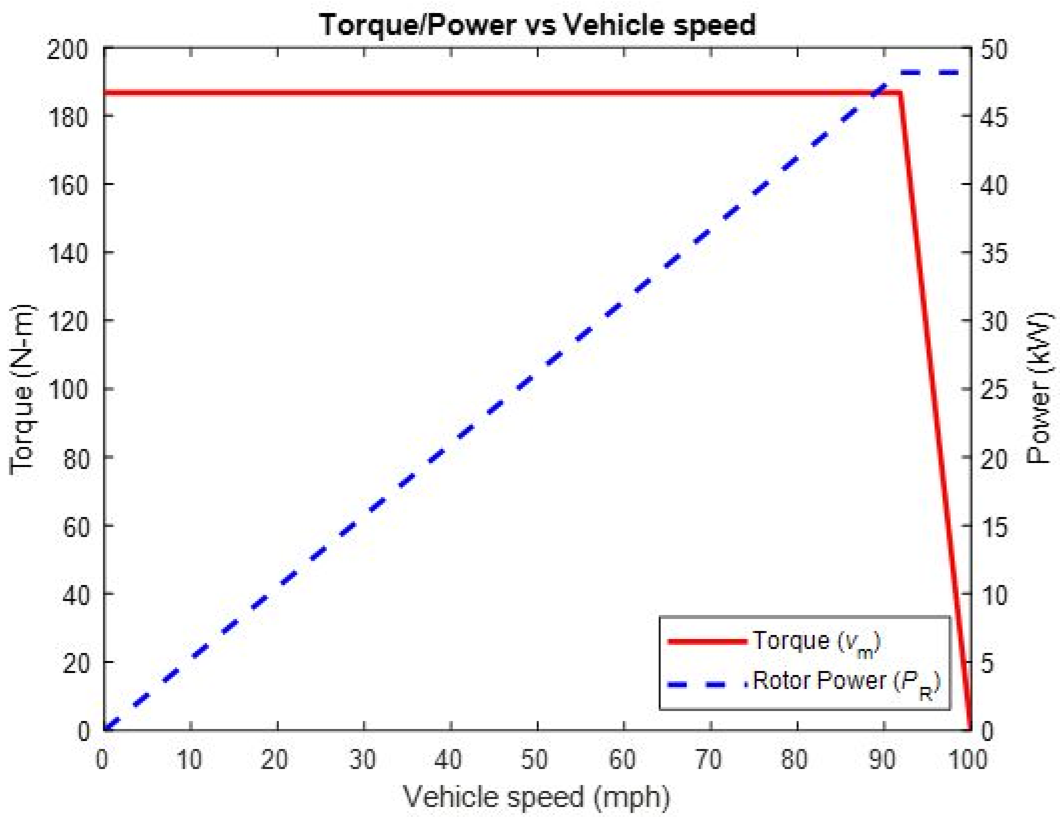

Figure 1: MATLAB Plot of Bike Velocity and Rotor Power for ¼ Mile.

As you can see from the resultant plot in MATLAB, our bike reaches constant power mode at the rated speed of 92 mph. This is also the point where the bike leaves constant torque mode. The top speed of the bike is 116 mph. For the quarter mile our bike does not reach the rated speed before completing the race as the top speed achieved is 82 mph. Results of the quarter mile test can be seen in figures 2, 3, and 4. The lap time using our MATLAB script was 11.30 s.

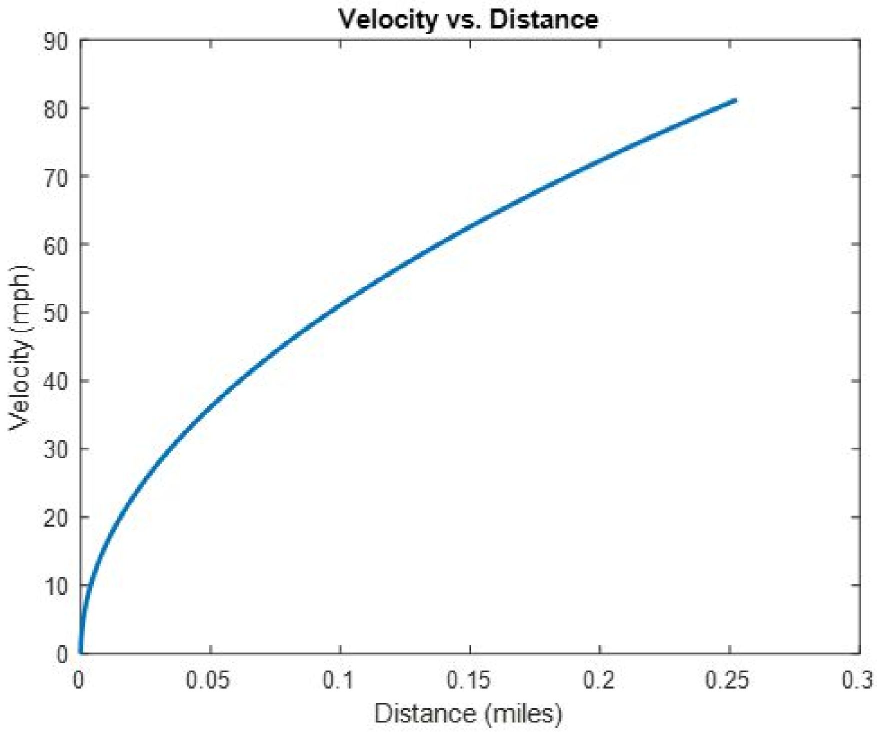

Figure 2: MATLAB Plot of Bike Velocity and Distance for ¼ Mile.

Figure 3: MATLAB Plot of Bike Power and Distance for ¼ Mile.

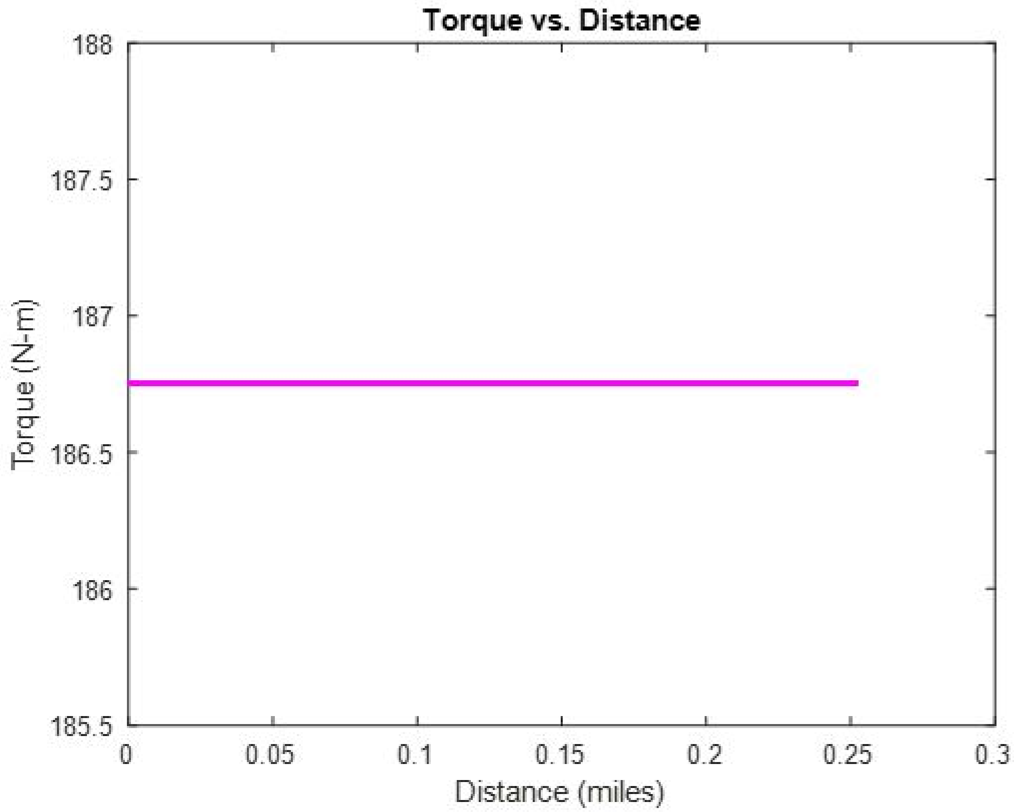

Figure 4: MATLAB Plot of Bike Torque and Distance for ¼ Mile.

Electric Machine

To decide which motor to use for this project, we compared various voltage and current ratings of the AC-50 and AC-51 motors to determine which would have the highest performance in the simulated quarter mile. This was completed by adjusting the mass of the electric engine to 52.5 kg, or approximately 115 lbs, along with adjusting the parameters for rated power and rated torque for each of the electric motors.

These parameters were found from the imperial peak graphs on hpevs.com for each of the respective motor, voltage, and amperage ratings. The imperial peak graph for 96-volts/650 Amps for the AC-51 electric motor is below:

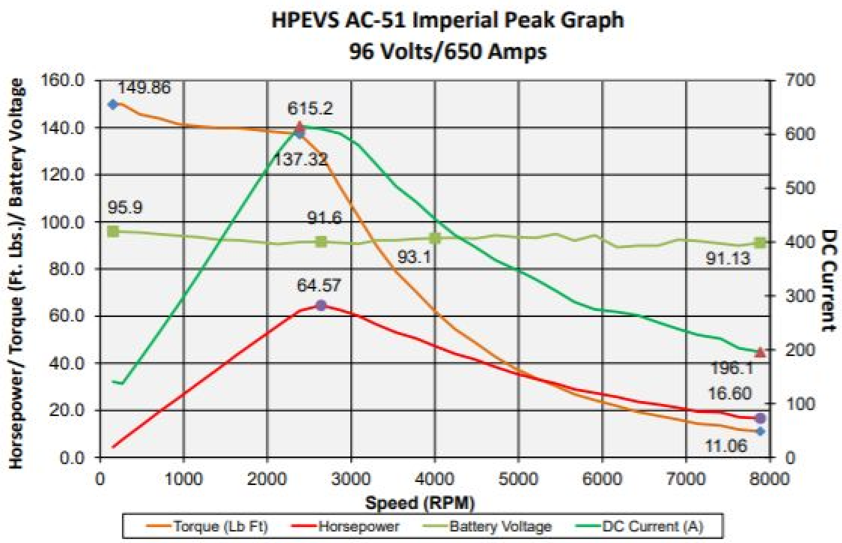

Figure 5: Imperial Peak Graph for AC-51 at 96 Volts/650 Amps from [4].

From this figure, the rated torque is 137.32 ft-lbs, which was converted to 186.76 N-m. The rated power is 64.57 HP, which was converted to 48.169 kW. Please note, these timings do not include the impact of the power electronic mass or the battery pack pass, as this portion of the project was completed prior to these components being selected. Although the power electronics are not included in the project, the weight of the battery did slow down the quarter mile times, but not significantly. The converted torque and power were used in the MATLAB CBR500 quarter mile simulation for each of the motors, as seen below:

HPEVS Motor	Motor Voltage	Motor Amperage	Quarter Mile Time
AC-50	48 Volts	650 Amps	12.2 s
AC-50	72 Volts	550 Amps	13.7 s
AC-50	72 Volts	650 Amps	12.3 s
AC-50	96 Volts	650 Amps	12.4 s
AC-50	108 Volts	650 Amps	12.5 s
AC-50	144 Volts	500 Amps	14.9 s

AC-51	96 Volts	650 Amps	10.9 s
AC-51	108 Volts	650 Amps	10.9 s
AC-51	144 Volts	500 Amps	10.9 s

From these results, the HPEVS AC-51 96V/650A electric motor was selected, as it will give the best performance in a quarter mile race and will be the easiest to build a battery for to fit in our CBR chassis because it has a lower voltage, resulting in less battery cells in series. These motors can be found in sources [5], [6], and [7]

The efficiency of the electric machine can be calculated by the ratio of the output power to the input power. The output power is calculated by looking at the output horsepower of the electric machine at its peak in figure 5, HPEVS AC-51 Imperial peak graph. This is converted to kilowatts by using the conversion factor of 0.746. This results in a value of 48.169 kW, seen in equation 4. The input power is calculated by multiplying the input voltage and current at the peak in figure 5, HPEVS AC-51 Imperial peak graph. The resulting value is 56.352 kW and is seen in equation 5. The final calculation for the efficiency of the electric machine is complete in equation 6, and is 92.45%.

$$P_{EM_O} = P_{EM_{o,HP}} \cdot 0.746 = 64.57 \cdot 0.746 = 48.169\ kW \quad (4)$$

$$P_{EM_I} = V_{Rated} * I_{Rated} = 91.6V \cdot 615.2\ A = 56.352\ kW \quad (5)$$

$$\eta_{EM} = \sqrt{\frac{P_{EM_O}}{P_{EM_I}}} = \frac{48.169}{56.352} = 0.9245 = 92.45\% \quad (6)$$

Battery Design and Selection

We selected a lithium ion battery type for our bike. This decision was made to accommodate the peak performance of the bike in a quarter mile race. These batteries tend to be more stable than other chemical make-ups and have a higher density, voltage capacity, better depth of discharge, and lower self discharge rate. This makes them ideal for high power applications, such as racing.

The design of the cell pack is a crucial step in making our bike practical. We wanted to select a cell that could fit into our chassis while also providing the needed amperage and voltage to our motor. The battery selected for this project was the MOLICEL/NPE INR-21700-P42A 45A 4200MAH FLAT TOP 21700 Battery. We selected this battery cell because it had a high amperage rating of 45 amps per cell. This meant that, compared to other cells, we could get the same performance while using less cells. This gives us more volume within our chassis and maximizes weight savings.

Since our motor requires 96 V and the nominal voltage of our selected Li-ion cell is 3.6V per cell we can calculate that we need, $\frac{96}{3.6} = 27\ cells$ in series. To meet the current requirement of 650 amps, we need 12 batteries in parallel. The calculations for these are done in the MATLAB script posted on Github. The total number of cells needed is the number of cells in series (27) multiplied by the number of cells in parallel (12), which is 324 cells, assuming a 100% depth of discharge. We wanted to be sure these would fit in our chassis, so we calculated the number of cells that would fit in the CB750 frame used in class. We tried contacting OEM Motor parts, but they gave no email address, only a phone number and address in the Netherlands. Additionally, we contacted designers at Honda in hopes that they could give us the dimensions of a CBR500 chassis. However, they said that most of that design work is done in Japan and they didn't know specifically where to go to get those dimensions and that it may be proprietary information. They did suggest we look in the CBR500 user manual, but that yielded nothing but motorcycle maintenance and care. Therefore, we decided to simply use the dimensions of the CB750 frame that was given to us. The CBR750 can hold up to 1,368 of our chosen battery cells, but we only need 324. This shows that it is feasible to use the cell we chose to power our electric machine for the quarter mile race.

The resistance of our battery cell was calculated by using the graph below in figure 6. We took the difference between the voltages and current of the red curve and the pink curve and then divided them as shown below:

$$R = \frac{\Delta V}{\Delta I} = \frac{4-3.5}{|0.84-30|} = 17.15\ m\Omega \tag{7}$$

The efficiency was calculated using the input power to the power electronics divided by the battery power input where the input battery power is the motor voltage times the motor current and the output battery power is the rated power of the motor divided by its efficiency. Alternatively, the efficiency can be calculated by subtracting the voltage drop due to the internal resistance from the total battery voltage, divided by the total battery voltage. These calculations can be seen in equations 8 and 9 below:

$$\eta_{BT} = \frac{P_{BT,O}}{P_{BT,I}} = \frac{P_{PE,I}}{P_{BT,I}} = \frac{53.52\ kW}{62.4\ kW} = 85.8\% \quad (8)$$

OR

$$\eta_{BT} = \frac{96-(650*0.01715)}{96} = 88.4\%$$

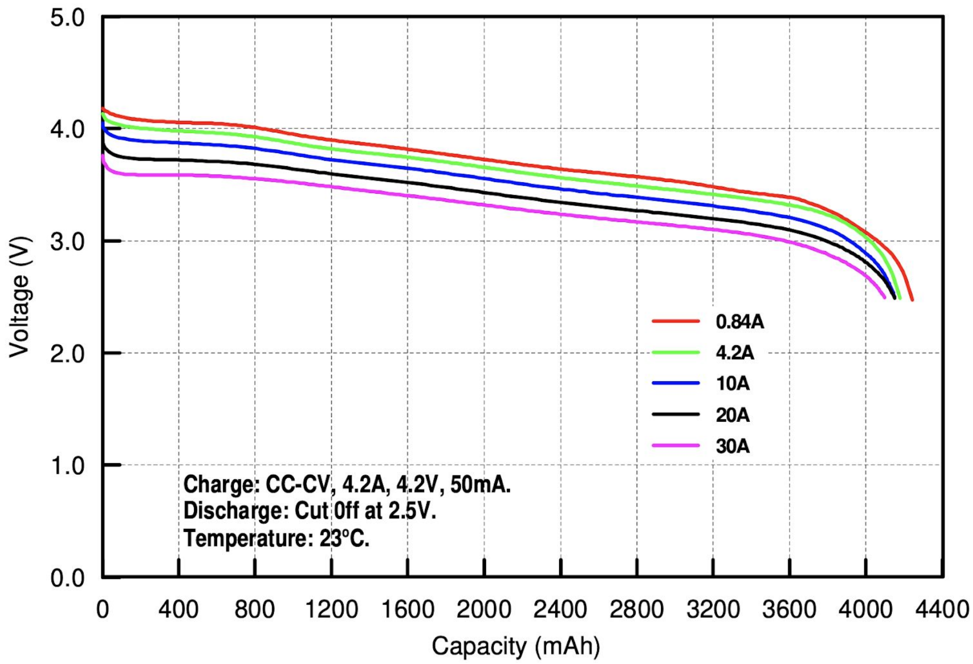

Figure 6: Discharge Rate of our Battery Cell

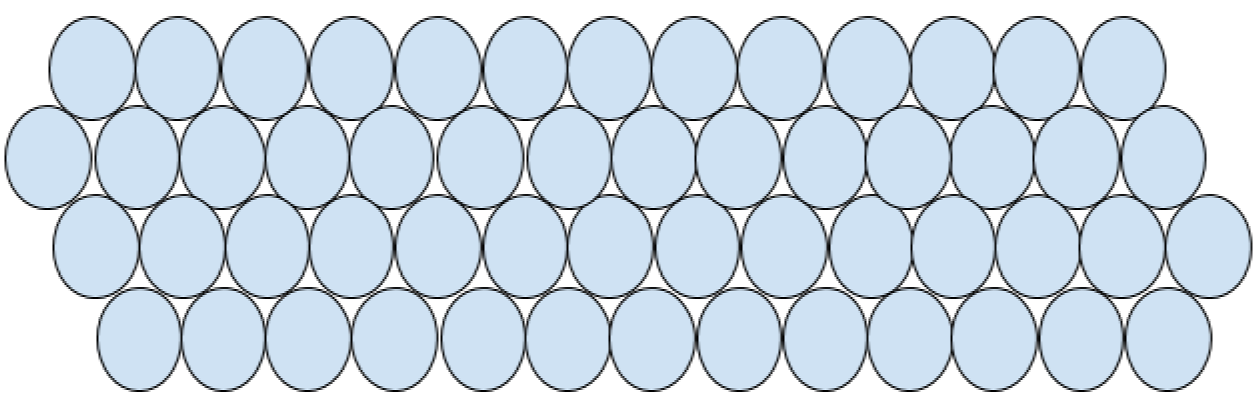

Figure 7: Potential Design of Battery Alignment

Simulation of the Design

The specific power is as follows:

$$\frac{V_{nom}*A_{max}}{Mass} = \frac{(3.6\ V)(45\ A)}{.070\ kg} = 2314.28\ W/kg$$

The specific energy is as follows:

$$\frac{V_{nom} * C_{rated}}{Mass} = \frac{(3.6\ V)(4200\ mAh)}{.070\ kg} = 216\ Wh/kg$$

Specific energy calculated: $216\ \frac{Wh}{kg}$

Gravimetric value in datasheet: $230\ \frac{Wh}{kg}$

Percent error: $\frac{216-230}{230} * 100 = 6.09\%$

Average Power: $P = V * i = 96 * 650 = 62.4\ kW$

Average Power for Singular Cell: $P = V * i = 3.6 * 45.0 = 162\ W$

Resistance of Singular Cell: $R_{Cell} = \frac{V^2_{Cell}}{P_{cell}} = \frac{3.6^2}{162} = 0.08\ \Omega$

Resistance of Battery: $R_{Batt} = R_{Cell} * \#_{Cells} = 0.08 * 324 = 25.92\Omega$

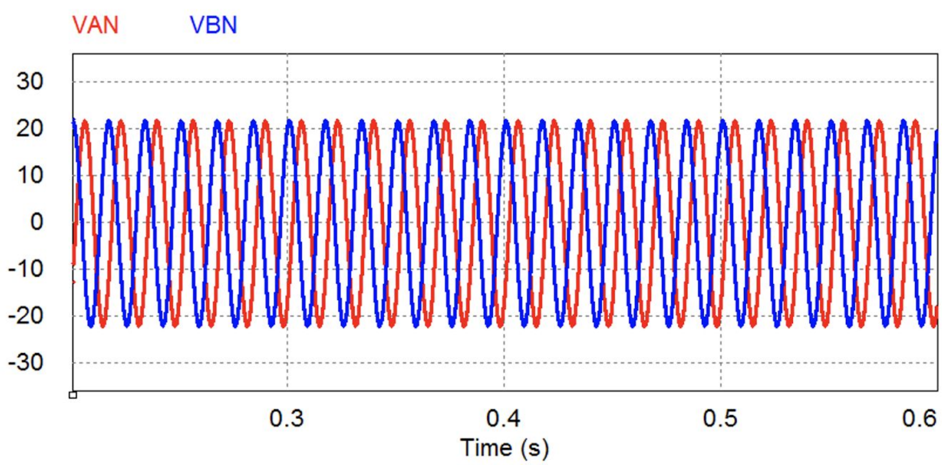

Figure 8: PLot of VAN and VBN for Battery Simulation

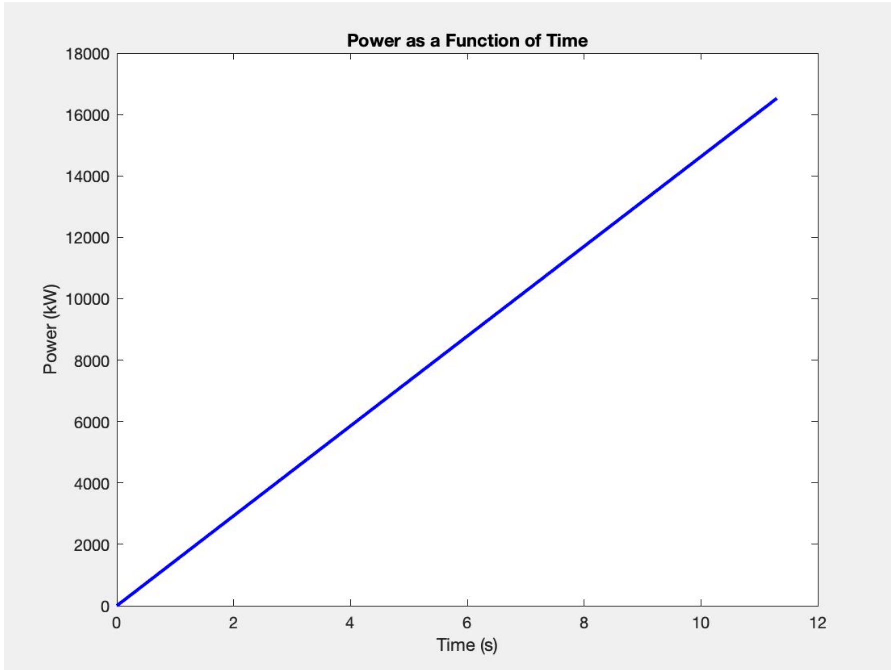

Figure 9: Plot of Power vs Time for Battery Simulation

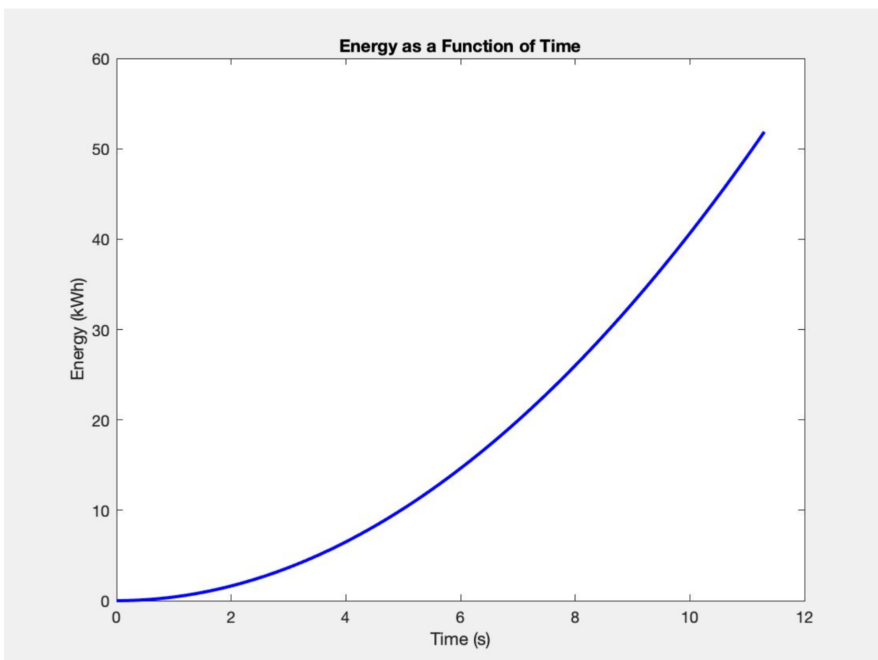

Figure 10: Plot of Energy vs Time for Battery Simulation

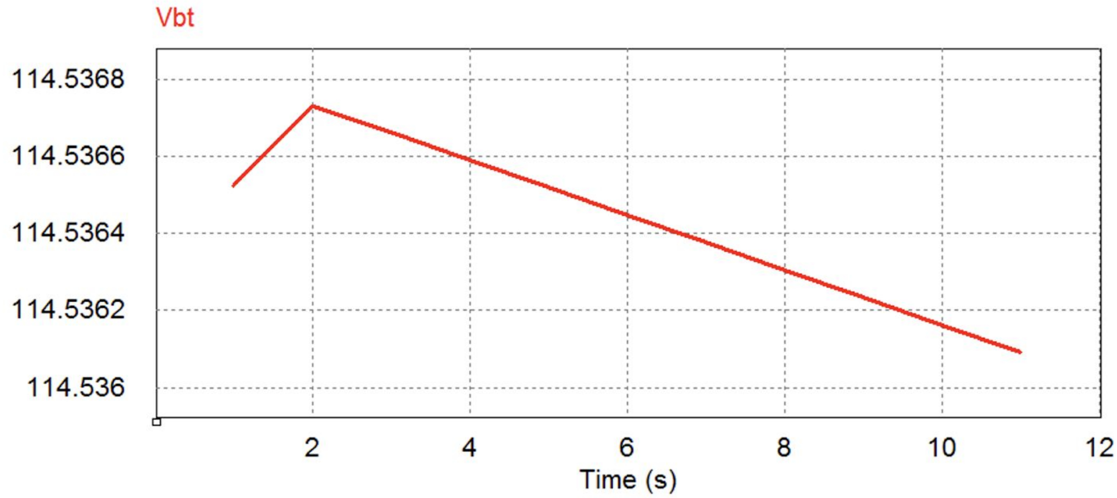

Figure 11: Plot of VBT in Multisim for Battery Simulation.

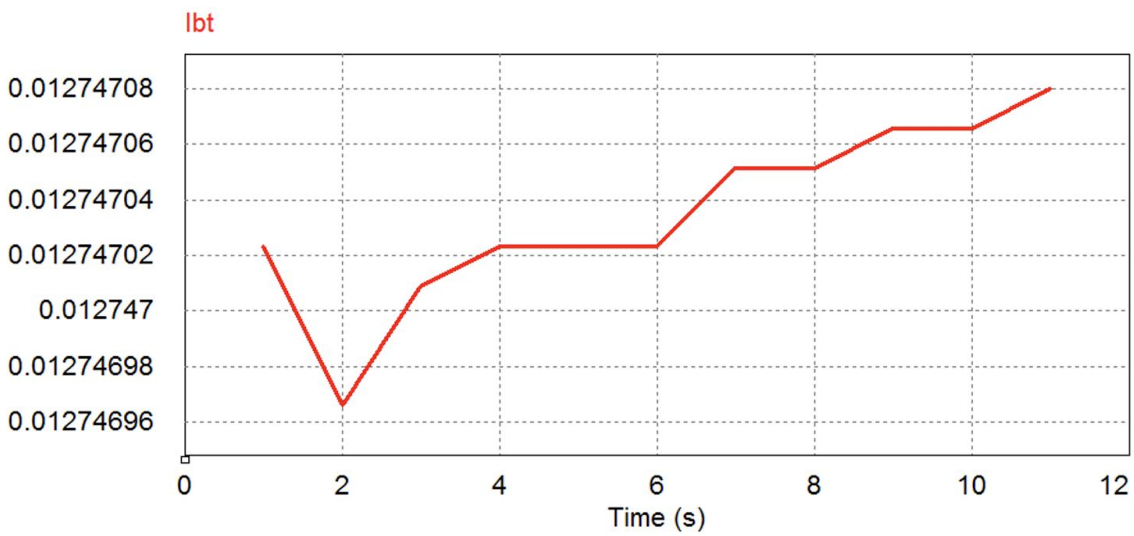

Figure 12: Plot of IBT in Multisim for Battery Simulation.

<u>Summary of Results</u>

The final quarter mile time for this project was simulated at 11.30 seconds, using a CBR500 skeleton. The quarter mile time was simulated in MATLAB using vehicle kinetics theory learned in class, which included finding the force of rolling resistance and aerodynamic drag for the CBR500. F_C was found to be zero, due to the quarter mile simulation being completed on flat ground. The electric machine was chosen by simulating 9 different motors in the AC-50 and AC-51 motor options for different amperage and voltages. The final electric machine selected was the one that simulated the fastest quarter mile time, which was the 96 Volt 650 Amp AC-51 HPEVS motor. Several motors had the same quarter mile time, but we chose the 96 Volt 650 Amp AC-51 to optimize the space in the chassis by having less battery cells due to the lower voltage requirement. When researching different batteries, our team also looked for a higher amperage cell, to minimize the number of cells needed. This would ensure we would have enough room in the chassis for the battery cell, power electronics, and electric machine. We chose the MOLICEL/NPE INR-21700-P42A 45A 4200MAH FLAT TOP 21700 Battery, which had a nominal voltage of 3.6 V per cell and a peak current of 45 amps. Using theory from class, we were able to find that we would need 27 cells in series and 12 cells in parallel to power our electric machine, ensuring success in the quarter mile race. This yields a required 324 battery cells to power our electric machine, while the chassis can hold a total of 1368 cells. We simulated our battery design, which seems relatively reasonable, but with some hesitation. Before the two second mark, the voltage of the battery is increasing and the current is decreasing. However, we expected the current to increase and the voltage to decrease throughout the entirety of the quarter mile. Therefore this is likely a design flaw and is not realistic because the current draw should increase as we apply torque, and the battery voltage should decrease at the same time. The energy and power curves increase, which make sense because we are summing them over the duration of the quarter mile. The efficiency of our electric machine was estimated to be 92.45%, although when completing the simulation 90% was assumed (as the estimation was calculated at the end of the project after sizing the battery pack). The efficiency of the battery pack was estimated to be 88.4%, which may be a little lower than we would expect. The top speed of 82 mph achieved by the end of our simulated ¼ mile is a little low considering we are completing it in 11.3 seconds. This may be due to not taking into account basic real world physics. For example, fast bikes tend to wheelie, requiring the rider to adjust the throttle accordingly so by not taking factors like these into account in our calculations, the time and speed may not be 100% accurate. Overall, the results seem to match reality, but there were minor discrepancies as mentioned above with the battery current/voltage before two seconds and the efficiencies of the battery and electric machine.

Bonus

The two types of bonus point methods we approached were the testing of ten unique motors and forming the foundation for this project to become a club in future semesters. As shown in our MATLAB code posted in Github, we have a script that is able to take in the differing parameters of each motor and plot their respective power vs velocity graphs over time and calculate a theoretical ¼ mile time. All of our data collection for the motors is shown in the motor selection section.

The team has experience in organizing and leading clubs at Miami University, therefore found it to be fitting to set up everything needed to propose this club to the university in the near future. As shown in the "Student Org Start-Up" document on Github, there are a series of steps that are required to start a club on campus including a list of questions that we have prepared answers for. The second step we completed was the forming of a club constitution with all of the required information needed. This constitution is a sample and can be changed based on the advisor and student preferences but the information written is what has worked for other clubs in the past.

Short Reflection

Overall, this project is a good way to apply the knowledge that was learned in lecture. Through this project, we were able to understand how to choose an effective electric machine that would give us the theoretically fastest quarter mile time and were able to simulate our quarter mile using the rated torque and power output from the electric machine. We also were able to choose a battery cell that would be ideal to power our electric machine and power electronics. One of the coolest things was to be able to actually create a model for the battery pack that would work for our bike by calculating the number of cells in series and parallel. This led to researching how to condense the space needed to store the battery pack, which resulted in researching folding techniques and how to create the physical series-parallel connections of the battery cells. Although this was beyond the scope of the project, it was very neat to research and learn. The bonus portion of the project was a great addition to the project because it allowed groups to go in a different direction, specifically exploring what they were interested in.

The biggest challenge of the project was understanding what we required of us at the beginning of the class. There was a lot of confusion at the start, but as the course went on, the objectives of the project were made to be more clear. Perhaps having a rubric at the beginning of the semester explaining the objectives and overall goals of the project would help this portion of the course to run smoother. Additionally, for the future bonus project (if this really does become an organization at Miami University), it may be beneficial to have students just focus on digging deeper for a technical portion of the project (different battery simulation, power electronics, electric machines) and testing different models of each to see how it impacts the bike's performance in the quarter mile race.

This project was beneficial, as we were able to practically use topics we learned in lecture to a real life application, which does not always happen in our engineering courses. With some minor modifications, this project can really help students apply their knowledge from the course and appreciate how different components of the electric vehicle affect the performance of the bike in hopes to optimize it.

SOURCES

[1] https://19january2017snapshot.epa.gov/sites/production/files/2016-09/2016-mc-ctrr.xls

[2] https://hondanews.eu/eu/lt/motorcycles/media/pressreleases/196422/2020-honda-cbr1000rr-r-fireblade

[3] **http://elmoto.net/showthread.php?t=3400**

[4] https://www.hpevs.com/

[5] https://www.electricmotorsport.com/ac-50-kit.html for $4,684.50.

[6]https://www.electriccarpartscompany.com/ac-50-ev-ac-motor-kit-48-144v-500-650a-34-88-hp-hpevs for $2230.00.

[7] https://electricgt.com/shop/hpevs-ac50-51-systems/ price not listed.

Full Molicel INR-21700-P42A Battery Cell Data Sheet:
https://cdn.shopify.com/s/files/1/0697/3395/files/INR21700P42A-V3-80092.pdf?2425