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School of Engineering

Hybrid Powertrain and Control
Module Code: ACEA7007

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1 Introduction

In this Report the Blitzworld buggy used in the first report will have been converted to a series hybrid drive train with an ICE generator charging a battery pack which will send electricity to an electric motor which is directly connected to the wheels. The initial costs, savings, and driving characteristics will be examined to determine if the conversion would be worth it for a larger company or manufacturer.

2 Hybrid Buggy Specifications

2.1 Introduction

A hybrid system was selected for the buggy to reduce fuel consumption. A battery motor and controller were specified to be fitted to the buggy. The hybrid system will add weight to the buggy, but the hope is that the fuel consumption will be lower. The Hybrid system will be in series meaning only the electric motor will be driving the wheels not the electric and ICE engine together. (Ehsani, 2019)

2.2 Motor

The motor that was chosen was the Engiro 159AH_06030 96V. This was chosen for its power output, turning RPM and operating voltage to work with available controllers and motors. Other advantages that come with running this motor include the fact that it is air cooled and has an ingress protection rating of 69k meaning that it is completely sealed from the outside world. This makes it perfect for corporate entertainment buggies that will not get cleaned nor maintained while being used in offroad disciplines. The range of RPMs that this motor runs at mean it can be mounted with a direct drive system. This reduces complexity in the drive system increasing reliability and reduces losses through the driveline. The motors compact size and air cooling will mean that minimal modifications will need to be made to the buggy for installation and no radiator will need to be mounted. The motor weighs 15Kg by itself. This motor will operate at 95% efficiency which is much higher than that of the previous ICE powertrain. (Engiro, 2021)

2.3 Controller

The controller chosen to compliment the motor and the battery pack is a Sevcon gen4 DRAGON8 96V 330A type controller that can handle the 96V that the motor runs on. The controller has an IP rating of IP66 meaning that it is sealed and well suited for the application of an offroad corporate entertainment buggy. The controller weighs 2Kg. (VoltSport, 2021)

2.4 Battery

The battery will best be suited for the application if it is a custom-built battery using Panasonic NCR18650PF cells. Multiple cells need to be wired in parallel and in series to achieve the right voltage output and the right capacity. The 18650 cells have an output voltage of 3.6v this means that 27 of them need to be wired together in series to get the pack to the correct voltage of 96v. A capacity of 9.6 KWh, meaning that the battery will be drained in 1 hour with an output of 9.6 kilowatt each cell has a capacity of 2900mAh, which means that 39 of them would need to be wired in parallel to achieve that

capacity. A total of 1053 cells would be needed; a custom pack allows for the cells to be arranged in such a way that makes it easier to install into the chassis. Each cell weighs 48.9 grams meaning that the weight of all the cells is 51.49Kg. This does not account for all the wiring, case or any other of the components involved in building the battery pack. The real battery pack might weigh around 55Kg. (18650.uk, 2022)

2.5 Cost

The cost of the major components are as follows:

- Engiro 159AH_06030 96V - £875.19
- Sevcon gen4 DRAGON8 96V 330A - £662.00
- 1053 Panasonic NCR18650PF Cells - £7,255.17

There will be additional cost in building the battery pack and fabrication of the chassis and accommodate the new battery, motor, controller, and wiring. The total cost of the system could cost between £9000 and £9500. Additional costs could be incurred if the person of manufacturer need to purchase equipment to build and fabricate the system.

2.6 ICE Generator

The ICE generator will be the original 300cc motor that the buggy is sold with this makes it easy to just install a generator with a proven motor that works and fits nicely into the chassis. This will eliminate the need to find, fit and pay for a new ICE generator. The ICE generator will be directly connected to an alternator which send electricity to the battery for the electric motor to use and it was assumed that the Ice generator would run at a constant RPM at a constant load

Table 1. ICE Generator Specs

Generator	
RPM	5500.00
Torque	22.00
Kw	16.90
Joules/Sec	16900.00
BSFC	475.00
Fuel Flow Rate	2.23
Joules per liter of gasoline	31536000.00
Liters used in one lap	0.04
Joules Produced per lap	1288944.23
Accounting for ICE Efficiency	304.41
Laps Per fuel tank	709.53

2.7 Masses and Gearing

The hybrid system added an additional 72Kg to the mass of the buggy, the buggy initially weighed 545Kg with the driver and passenger. With the addition of the electrical drive system the buggy now weighs 617Kg. (Blitzworld, n.d.)

The hybrid system removes the need for transmission and gear changes so a gear ratio was chosen to make the buggy go the right speeds a 15-tooth sprocket in the front and a 51 tooth sprocket in the rear, both readily available components

Table 2. Buggy Specs

Vehicle Specifications	
Density of Gasoline (KG/L)	0.75
Power (Kw)	6.4
Torque (Nm)	20
Top Speed (mph)	30
Length (mm)	2620
Width (mm)	1650
Height (mm)	1620
Wheelbase (mm)	1440
Ground Clearance (mm)	300
Weight (Car) (kg)	365
Weight battery (kg)	72
Weight Driver and Passenger	180
Weight Combined (kg)	617
Fuel Tank (l)	29
Fuel Weight	21.75
Weight Combined With Fuel (kg)	598.75
Power KW @ 4000 rpm	6.4
Torque Nm @ 0 rpm	20
Front Tyres	24x8x12
Rear Tyres	23x10.5x12
Rear Tire mass (kg)	9
Front Tire mass (kg)	8
Front Rolling Radius (m)	304.8
Rear Rolling Radius (m)	292.1
Front Rim mass (kg)	7
Rear Rim mass (kg)	6
Final Drive	18.0625

2.8 Conclusion

The conversion to a hybrid powertrain is add a total of 72Kg to the overall mass of the buggy. The buggy will retain all the old ICE components for and easy conversion to an ICE generator that charges the battery while the electric system charges it.

3 Calculations

3.1 Repairs of Initial Drive Cycle

Driver inputs were also adjusted to better match the drive cycle with some braking zones increased. Previous calculations did not account for the fact that there was no power demand when the driver was off throttle. Other than these small changes the drive cycle was identical.

3.1.1 Rolling Resistance

The rolling resistance in this report was calculated using **Error! Reference source not found.**

Equation 1. Rolling Resistance

$$\text{Rolling Resistance} = \text{Mass} * \text{Gravity} * \text{Rolling Resistance Coefficient}$$

The initial drive cycle contained several errors which needed to be fixed before converting the drive cycle to a hybrid system. The Rolling resistance used in the ICE only drive cycle was 0.025. This is incredibly incorrect and was changed to 0.25 for the grassy field portion of the drive cycle which it should be according to (Wong, 2001). Using the same reference, the rolling resistance of the sections that are sand were set to 0.4.

3.1.2 BSFC

The BSFC chart was also wrong and needed corrected the photo supplied for this assignment had numbers much higher than that of the BSFC chart that was used for the calculations. The BSFC chart was adjusted, and the values were brought more in line with the provided BSFC chart with the lowest value jumping from around 230 to 450. (Sandford, 2021)

3.1.3 Equivalent Mass

The equivalent mass was calculated for only one gear. This was like the values calculated during the first drive cycle with only the ICE drivetrain. This could be because the motor involved with the driving of the buggy has a much lower moment of inertia than what the gasoline powered engine might be. By nature, electric motors have much lower moments of inertia because of a lower weight and less moving parts. Equivalent mass was calculated using the equation below and the new equivalent mass can be seen in the figure below.

Equation 2. Equivalent Mass.

$$\text{Equivalent Mass} = \text{Total Mass} + 4 * \frac{\text{Wheel Inertia}}{\text{Rolling Radius}^2} + \text{Engine Inertia} * \frac{\text{Overall Gear Ratio}}{\text{Rolling Radius}^2}$$

3.1.4 Driving Force

Driving force was needed to calculate acceleration. Drive torque at the output shaft was calculated using **Error! Reference source not found.**

Equation 3. Drive Torque at Shaft.

$$\text{Drive Torque at Shaft} = \text{Torque} * \text{Gear Ratio} * \text{Efficiency}$$

Equation 4. Drive Force at Wheels

$$\text{Drive Torque at Wheels} = \text{Drive Torque at Shaft} * \text{Final Drive Ratio} * \text{Efficiency}$$

Where efficiency in each of the equations above accounts for the loss in power through the drivetrain. With a new direct drive hybrid system, the drive train eliminates any transmissions, drive shafts, or clutches. This reduces the losses through the drive train, losses with an ICE drive system were estimated at around 7% (Wong, 2001). With direct drive electric system losses were assumed at 1%.

Driving torque was then re calculated using **Error! Reference source not found.**

Equation 5. Driving Force.

$$\text{Driving Torque} = \frac{\text{Driving Force at Wheels}}{\text{Rolling Radius at Wheels}}$$

3.2 Hybrid Cycle Changes

Converting to a hybrid powertrain simplified some areas of the drive cycle calculations. Using a direct drive electric motor eliminated the need for and transmission and gear changes. This mean that one gear ratio could be chosen to keep the buggy under the 30-mph limit while maintaining maximum fun. Not having to account for a transmission meant calculating velocities and power demands much simpler.

Reference to a BSFC chart was made redundant because the driving motor was made electric the Only reference to a BSFC chart was for the ICE generator which was run at a constant RPM under constant load through a charging system so theoretically a singular BSFC value could be used. In reality, multiple values would be needed but for this report the situation is ideal.

4 Results

4.1 Velocity and Aero

Figure 1 shows the velocity of the Buggy over time. This shows that the velocity drops when braking and remains constant at the maximum speed allowed by the gearing. The electric motor allows for an almost constant increase in velocity up the inclines because it provides enough power and torque to do so.

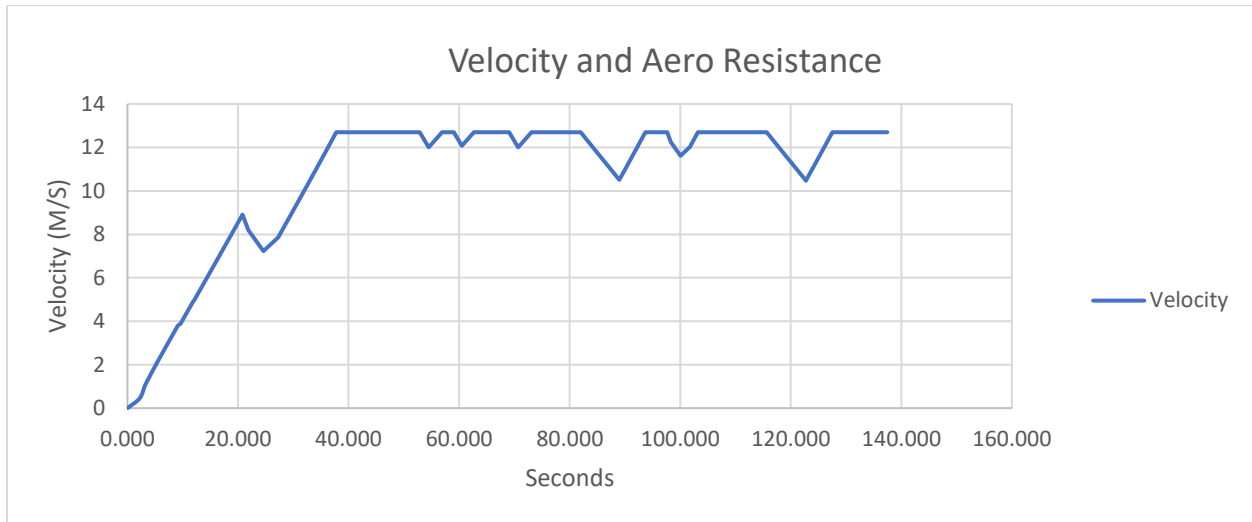


Figure 1. Velocity of Buggy

Figure 2 shows the aerodynamic resistance increase exponentially as the velocity of the buggy increases. The aerodynamic resistance follows the pattern on the buggy velocity through the drive cycle as expected.

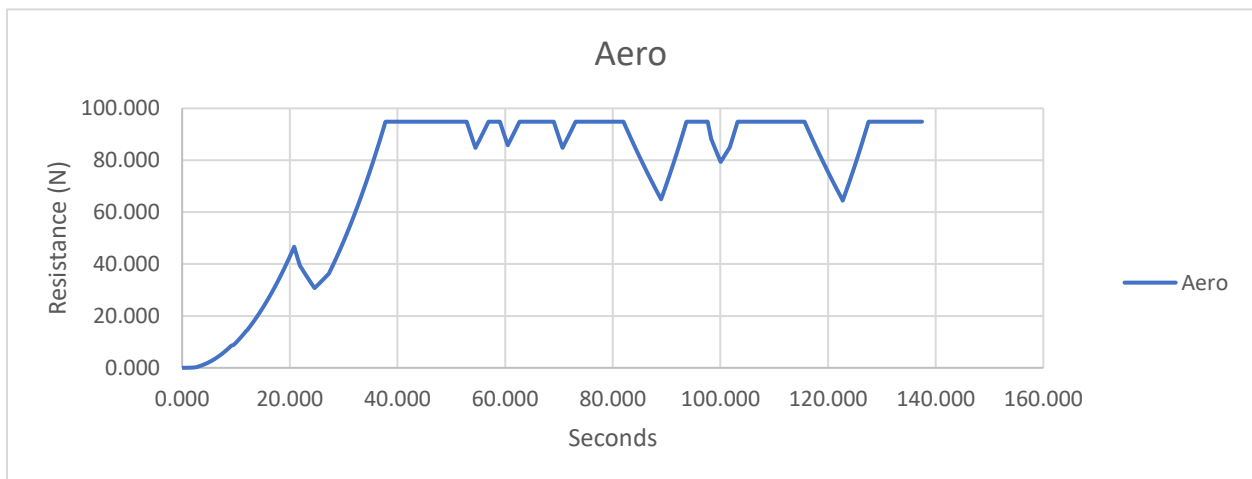


Figure 2. Aero Resistance

4.2 Resistive Forces

Figure 3 Shows the resistive forces acting on the buggy. Total rolling resistance is dependent on rolling resistance on a particular surface with the resistance to the gradient of the inclines and declines added to it.

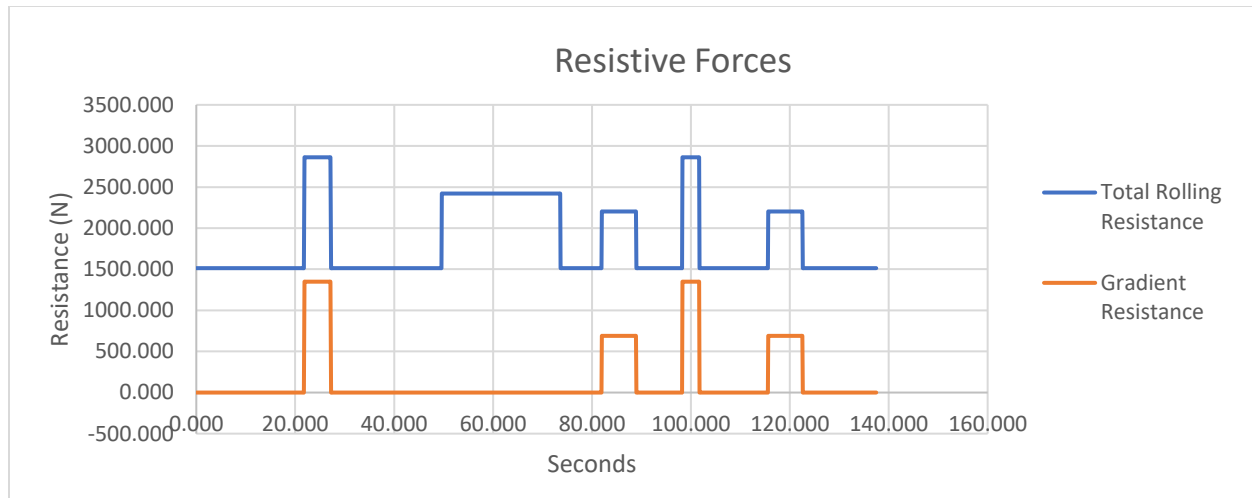


Figure 3. Resistive Forces on Buggy

4.3 Power and Torque Demand

Figure 4 shows the power demand on the motor through the entire drive cycle. New for this drive cycle are periods where there is no power demand on the motor due to the driver being off the throttle.

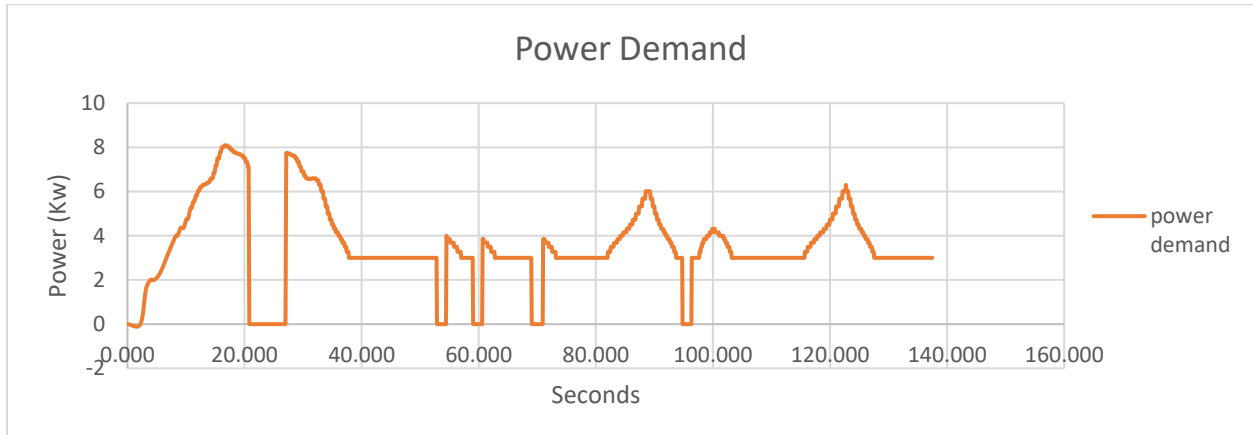


Figure 4. Power Demand of Buggy

Figure 5 shows the torque demand throughout the drive cycle.

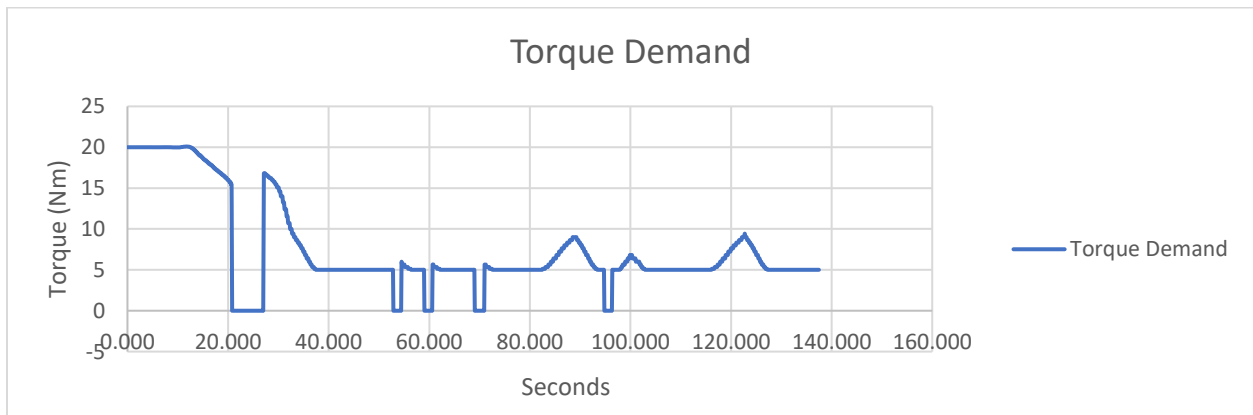


Figure 5. Torque Demand of Buggy

4.4 Acceleration and Tractive Force

Figure 6 shows the acceleration of the buggy through the drive cycle. With a positive acceleration when increasing velocity and a negative acceleration when reducing velocity.

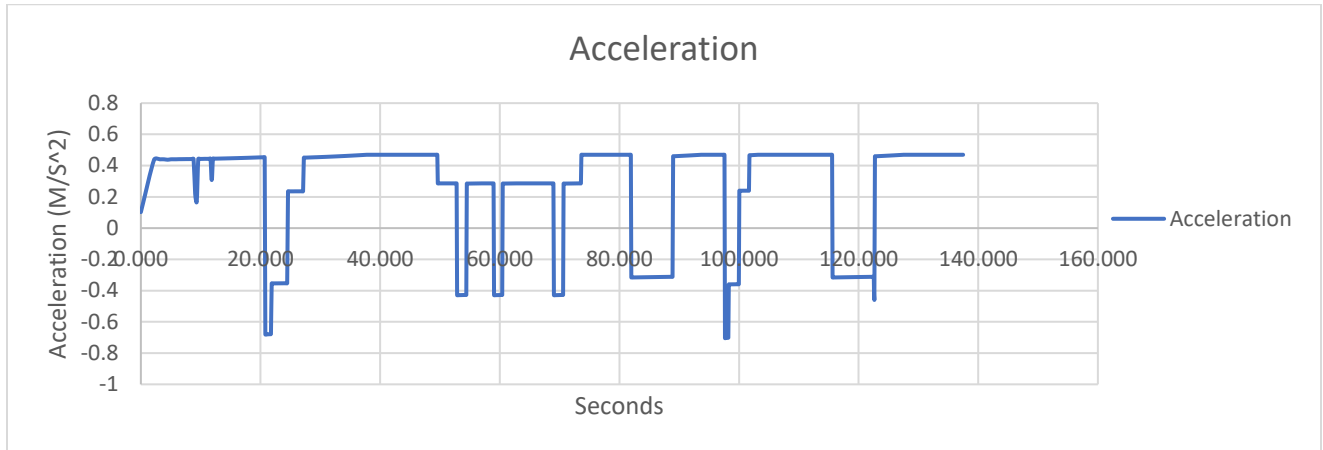


Figure 6. Acceleration of Buggy

Figure 7 shows the Tractive force required by the buggy during the drive cycle.

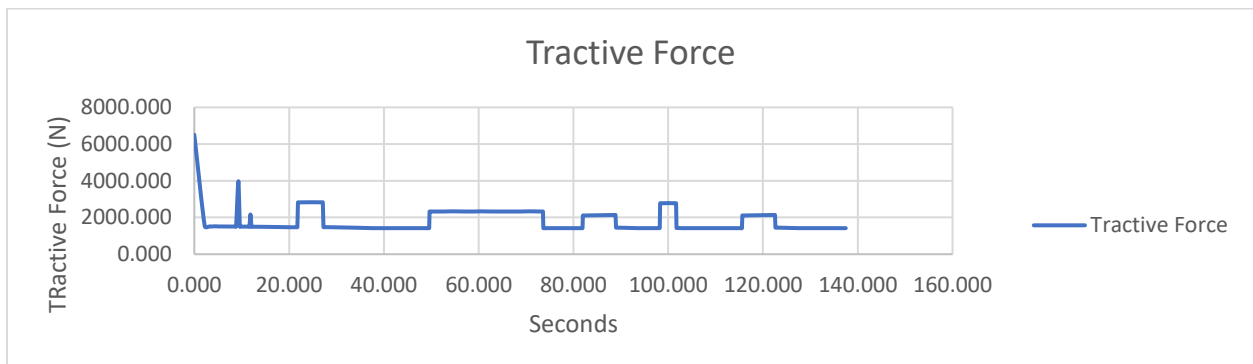


Figure 7. Tractive Force Available to Buggy

4.5 Energy in the Storage Cell and Fuel Consumption

The results from the new drive cycle are displayed below showing the energy left in the power cell in Joules. The power level drops and power demand increases, then increases as the ICE generator charges the battery back to almost full charge. While when the generator is not running the battery loses energy much faster than if the ICE generator is running.

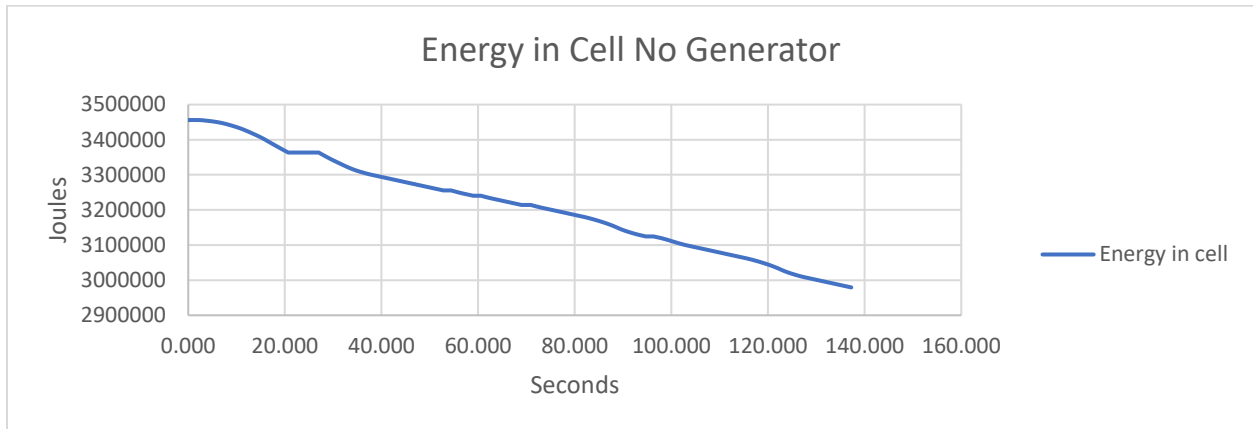


Figure 8. Energy in Cell with No Generator

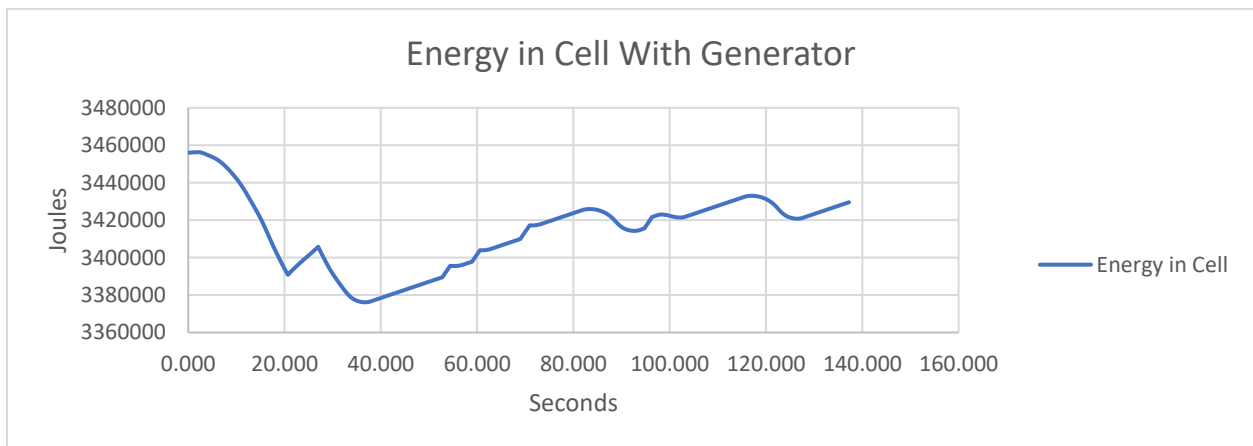


Figure 9. Energy in Cell with Generator

4.6 Conclusions

The buggy will be able to complete 131 laps of the circuit with the same inputs every lap. 13 laps more than just the ICE powered buggy while using 0.03 liters of fuel, significantly less than the ICE powered buggy. The ICE generator would last 700+ laps on one 29-liter fuel tank, much more than the battery will last. This would allow for the fuel tank to be much smaller than the one currently fitted, a 6L fuel tank would suffice. Current Fuel prices at the time of writing are £1.67 per liter of unleaded gasoline (RAC, 2022), and Energy prices in South Wales are £0.20 per kWh (ERIN YURDAY, NimbleFins, 2022). The cost for 131 laps for a hybrid buggy would be £1.92 for electricity and £8.93 for gasoline coming to a total of £10.85 for 131 laps, or £0.08 per lap. When compared to only ICE power which costs £0.39 per lap.

Battery Capacity Joules	3456000.0
joules Used	476887.196
Laps Per Battery no Genny	7.247
Joules used	26365.527
Laps Genny	131.080
Total Fuel Used (L)	5.358

Table 3. Outputs

Total Fuel Usage (L)	0.237345681
Laps Per Tank	122.1846542

Table 4. ICE Only Output

5 Conclusion

The conversion would save which ever company uses these buggies for corporate entertainment around £0.31 per lap, which could add up to a significant amount if used enough. Although the cost to operate the buggies has dropped the cost to manufacture has significantly increased with a hybrid conversion potentially costing more than £8500 on top of the cost of the original buggy. Further work would include an addition of a kinetic energy recovery system. This was left out because of the prohibitive cost and lack of benefit to the system. Companies and buggy builders would most likely opt for the cheaper option unless the buggies were to be used every single day which is most likely not the case. The benefits of the hybrid system are not short term but rather long term.

6 References

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