All Wheel Drive Electric Motorcycle

EML 4501: Senior Design 1

Milestone #3: Concept Design Report

November 30, 2018

Prepared by:
Kevin Almeida (Mechanical Engineering)
Casey Brennan (Mechanical Engineering)
John Gabler (Mechanical Engineering)
Yakym Khlyapov (Mechanical Engineering)
Sean Lear (Mechanical Engineering)
Aaron Paljug (Computer Engineering)
Eoin Reilly (Computer Engineering)
Fray Tacuba (Mechanical Engineering)
Project Advisors:
Suryanarayana Challapalli
Lei Wei
Kurt Stresau

Executive Summary

Electric vehicles (EV's) are rapidly increasing in consumer popularity. Currently, there are several commercial EV manufacturers of both cars and motorcycles. To date, there are no commercially available two-wheel drive electric motorcycles, and with the exception of some concept drawings and very recent prototyping in the private sector, this concept has not been fully realized. The purpose of this report is to outline the scope of design and assembly of a two-wheel drive electric motorcycle prototype. The overarching approach outlined in the following report includes proposed modifications to an existing motorcycle frame in order to safely and efficiently provide power to both front and rear wheels by way of batteries and electric motors. Ideally, the end goal is a "bolt-on" system targeted towards garage hobbyists who can purchase all of the parts necessary and then perform the conversion in their own garage with the use of common hobbyist tools.

Table of Contents

List of Figures

List of Tables

Terms and Abbreviations

AWD - All Wheel Drive
ICE - Internal Combustion Engine
EV - Electric Vehicle
HX - Heat Exchanger
BMS - Battery Management System
BTMS - Battery Thermal Management System
OEM - Original Equipment Manufacturer
DC - Direct Current
AC - Alternating Current
DOD - Depth of Discharge
A - Ampere
V - Volt
kWh - Kilowatt Hour
RPM - Revolutions Per Minute
EG - Ethylene Glycol
PG - Propylene Glycol

1. Introduction

As a result of increasing awareness of environmental issues associated with fossil fuels, the electric vehicle market is currently expanding at an astounding rate. It is projected that by 2018, the market will have grown by 15% of its 2016 value. Motorcycles are particularly well suited to an electric drivetrain, due to their minimalistic nature and lightweight. All manufactured electric motorcycles are comparable to conventional design in the sense that only the rear wheel is under power. A two-wheel drive electric motorcycle has yet to hit the market. Given the rising popularity of all-wheel drive in the consumer market, a two-wheel drive motorcycle has the potential to be an innovative and popular platform.

The benefits of all wheel drive are obvious and proven by the rise of its use in the market. All wheel drive has been proven as a motorcycle design by several traditional motorcycle manufacturers. However, the complex nature of transmitting power through the front end of a motorcycle requires serious design and has several drawbacks, including weight and power transmission losses. An electric AWD design can be simplified, as is evidenced in this report. Furthermore, having two driven wheels allows for greater traction controllability by implementing wheel speed feedback.

This report will clearly explain the design concepts chosen, the alternatives considered, and the reasons for the decisions. The end result of this project will be a Two Wheel Drive Conversion prototype. Because of the complex nature of this system, and the extensive environmental variables to consider, most of the design will be validated by bench testing, finite element analysis and real-world testing. The design will anticipate the unknown environmental variables by implementing a factor of safety in critical design decisions.

2. Needs Analysis

This goal of the project is to create a two-wheel drive electric motorcycle kit for a 1993-1995 Kawasaki ZXR-750 motorcycle. The customer asked for this largely because it would retain the benefits of standard electric motorcycles while adding a few advantages such as increased traction, traction control, a more efficient power distribution, and the novelty of something unique, fun and innovative for the customer. The primary user of this product is the independent, DIY-focused electric motorcycle enthusiast. Secondary users are budget-minded commuters looking for a cheaper option than buying a new or used OEM electric motorcycle. Tertiary users would be those interested in competing in electric-only motorcycle racing classes. This user would expect the design to address the following needs:

- Safe Highway Speed.

- Reasonable Commuter Range.
- Reasonable Acceleration.
- Reasonable Charge Time.
- Safe and Comfortable Handling.
- Affordability
- Serviceability
- Able to operate in appropriate conditions.

3. Technology Assessment

3.1. Legal Requirements

The analysis, problem solving, and complex engineering involved in design and build of an all-wheel drive electric motorcycle presents a variety of challenges, but it all becomes for naught if the team (and potentially the university) are fined substantially for lack of adherence to state and federal regulations.

In order to minimize the risk of violating environmental regulations, the team will need to be cognizant of the risks involved with battery leaks and ruptures pertaining to its specific battery selection and have plans or mechanisms in place to mitigate these hazards. This will include a specifically designed protective case for the battery system to protect against impact and contain a leak as well as allow for cooling to minimize chances of an internal defect causing a leak or thermal runaway. The aforementioned battery box will also need to be designed keeping in mind easy access to batteries.

Producing a fully street legal electric motorcycle at the culmination of this project would be gratifying, but registering the EV will be unnecessary for the scope of this prototype. Registering a vehicle can be relatively expensive and time consuming. Seeing as the team's most scarce asset is time, it seems prudent to disregard this step and simply settle for an OHV for the purposes of the project. Even if the prototype is legally an OHV it would still be possible to test at a purpose built track which would likely facilitate a higher standard of safety due to a more isolated testing environment. The team intends to comply with all state and federal regulations.

3.2. Aerodynamic Considerations

When it comes to drag, motorcycles tend not to be the most efficient compared to cars. Although they're far lighter and smaller, their weight to area ratio is problematic, particularly at high speeds. To reduce these effects fairings are added on sports bikes to provide lower cross sectional area being hit by incoming airflow, while also bringing the rider closer into the vehicle's form. [29]

3.2.1. Drag and Lift

Incoming airflow acts on the surface area of a body causing a change in pressure across it. Its effects may also depend on surface finish. High speed sports vehicles, forward facing surface area should be minimized, with a smooth profile to prevent turbulence in the airflow. Lift and drag behave the same however, drag is perpendicular. They both are an area, velocity, and initial coefficient dependent variable. Lift and drag have their own unique coefficients (commonly referred to as Cl&Cd). Lift is caused by the change in vertical pressure on its surfaces. Normally for ground vehicles lift is problematic, but to counteract crosswinds throwing racers off roads & to help with under/oversteering, winglets are added to the rear or front to provide a downdraft increasing vertical forces for better traction.[29][30]

3.2.2. Internal Airflow

Most motorcycles actually use incoming flow for internal ventilation. You'll normally see air-ducts welded into the front of the frame or fairings with a nozzle shape to compress high-speed air onto internal components. It is normally cumbersome and inefficient aerodynamically for all the drag it produces, but as with all aircrafts and automobiles the use of air to cool down internal parts is often just more cost & fuel effective. [29]

3.3. Batteries

The importance of the battery in the motorcycle design is very crucial. The design consists of choosing the right Battery Chemistry associated with affordability. The importance of the battery in the electric vehicle can be explained by comparing it to the fuel tank in the Internal combustion engines. The Range of the Vehicle depends on the amount of fuel storage in the fuel tank. As an example, a vehicle with a performance of 30 mpg with a tank capacity of 15 gallons can travel 450 miles. In the case of the electric vehicle, the Battery have to store electrical energy and provide it as the vehicle demands it. Therefore, the design of the battery and selection of the cells are very important. The advances in materials, motivated researches to look for different alternatives to store electric energy. In recent decades, the development had reached new advances in mobile devices as well as automotive applications. The different electrolytes and different materials in the conductors had made the battery cells more capable of storing energy. The recent advances also had many safety concerns due to the inevitable heat generated during high current discharge/charge. Although the battery cells are capable of storing and delivering high amounts of energy during discharge, the durability of the materials decreases when the cells are accidentally over-discharge or they reach the critical temperature. The life of the battery cell can be affected if is operated in very low or very hot environment. The design will have to provide the energy needed to generate enough acceleration, and velocity to displace the motorcycle to meet the requirements and will have to consider the cells limitations. The limitations observed during the selection are energy density, mass, volume, price, C-rating, and availability. The following definition is provided to identify the different characteristics of the different cells compared.

During the early development of the electric vehicle, the capacity of the batteries limited the vehicle performance. The battery is the only source of energy in an electric vehicle. Therefore, its performance and durability are critical. In the past decades, the advances in materials had helped to produce better and more efficient batteries. The researchers have developed cells with better storage capacity and a better discharge rate. Different types of cells are available in the market, but the price, chemistry, safety, mass, volume, and operating temperatures make them different from each other. The different elements used to store the energy influence the qualities of the battery cell. During cell selection, it is crucial to analyze and compare the differences in the cells. Although there are many kinds of battery cells in the market, only a small amount of them are suitable to be used in hybrids and electric automotive applications.

Since its discovery in 1800 the battery fascinated the scientific world and encouraged a whole movement of researchers to focus on electrochemistry [16]. The battery has improved dramatically in its efficiency, but it has retained its fundamental characteristics. The primary components are a positive side known as Cathode, a negative pole known as Anode and insulator commonly an electrolyte. The batteries are divided into two major types,chargeable and nonchargeable, or "Primary and Secondary batteries"[18] . The secondary batteries are the only ones used in electric vehicles due to the elevated cost of non-rechargeable Batteries. Batteries were introduced into electric cars for the first time during 1910 where the electric vehicle was trying to compete against the internal combustion engine. Its decline was inevitable due to the inefficiency of its battery [18]. The rechargeable types of batteries had been a busy topic for researches for the high demand on electronic components. The different types of battery are used to power different electronic components like hand tools, computers, cell phones, and electric vehicles. Over the years the development of different chemical combinations had made it possible to achieve higher energy storage, reduction on weight, reduction in prices, and reduction in volume. The increase of stored energy and the increase in discharge rates had also made them dangerous. Many precautions must be taken during the construction of the battery pack to avoid exposure to extreme temperatures or overcharge [17].

The most common and most well-known battery is the lead-acid. Since it discovered, this type of rechargeable battery had improved significantly in amperage delivery and size. It is very common to find them in automotive vehicles, boats, and motorcycles. The cost of this product is relatively affordable, but due to the nature of the components, lead is a heavy metal, its weight and size are relatively high compared to other types of batteries. The integration of a lead-acid battery into an electric vehicle could be achieved, but it will result in a vast and massive battery pack. Therefore, the application of lead-acid into a purely electric car could be limited if the weight and the volume are not desirable [15].

The NiMH batteries (Nickel-metal Hydride Batteries) became very demanded and famous during the 90s with the development of mobile electronic devices. It was common to find them “on cell phones and portable computers” [15]. NiMH batteries were the preferable battery until the new Lithium-ion batteries were available in the market. The chemical used to develop the NiMH made the cells very safe to operate in high demanding systems, and very safe to the environment. Commonly this cell can be found in hybrid cars. The expected life cycle of NiMH if very high, but the price of individual cells is higher than lithium-ion. This cell is desirable when a deep discharge cycle is needed, for example in a solar-power system. NiMH is very tolerant to rapid charge and discharge and works in a broad temperature range. Its design helps to support the temperature changes due to the addition of an integrated venting system. The integration of a venting system in its design helps to reduce the pressure inside the cell if a formation of gasses in the electrolyte occurs [15].

The Lithium-ion rechargeable cell has a high storage capacity and a small volume per unit. These characteristics make it have a higher power density than NiMH. Lithium-ion is a broad description of this type of cells. Mainly the cells are categorized into Li-ion and Li-po, the difference is mainly in the electrolyte. In the Li-on the electrolyte is fluid, and in the case of LiPo it is a solid polymer. “In this type of cells, it is necessary to integrate a Battery Management System, BMS,” [15]. The management system helps to protect the battery from overcharging and from overheating and helps to increase the life of the cells. The cells are sensitive to temperature due to the nature of its components. The high or low temperatures can deteriorate or overheat the cells when they work under extreme conditions [15]. The most common types of cells found in an electric vehicle are $LiFePO_4$, Li-On, $LiNiMn_2O_4$, $LiNiMnCoO_2$, NCR [13].

3.4. Battery Management Systems & Charging

While further research needs to be done on the different types of battery chemistries that are viable for the project, the most likely option will be a lithium polymer, LiPO, cell. LiPO cells are known for their high energy density for their size, unfortunately this comes with many drawbacks that require significant management to help maintain ideal operating conditions for the cells. This management is performed by the Battery Management System, BMS.

One of the most important functions of a BMS is its ability to balance voltage across cells because LiPo cells are extremely sensitive to voltage drift. Due to slight variations in manufacturing, each cell will age, discharge, and recharge at varying rates. Furthermore, the cells operation outside of safe temperatures can increase the degradation of the cell and be potentially hazardous. To prevent cells’ voltages from drifting significantly apart, the BMS balances the cells through many different methods. Each of the methods falls into two categories, active and passive balancing. *[25]* Refer to Figure 25 for a more in depth break down of the different types of passive and active cell balancing. Passive balancing is very limited in its capabilities. The primary limitation of a passive BMS is each module is only as efficient as the weakest cell in the pack. Once one cell reaches the cutoff point, the rest of the pack is considered empty even if there are cells that have plenty of charge left. The passive system rebalances during charging. Once individual cells begin to reach the upper capacity, the BMS redirects the charging current from those cells and dissipates the extra energy as heat. When the module of cells is done charging, all cells will be back in balance. One reason for choosing a passive BMS is the benefit of its simplicity compared to active systems. For larger deployments of LiPO cells, active balancing systems are typically used. Active cell balancing functions in a fundamentally different manner than passive, maximizing the energy density of a LiPO module. Active cell balancing uses the higher energy density cells to charge the cells that discharge at a quicker rate. Unlike the passive balancing, active balancing is constantly at work using the previous mentioned technique.

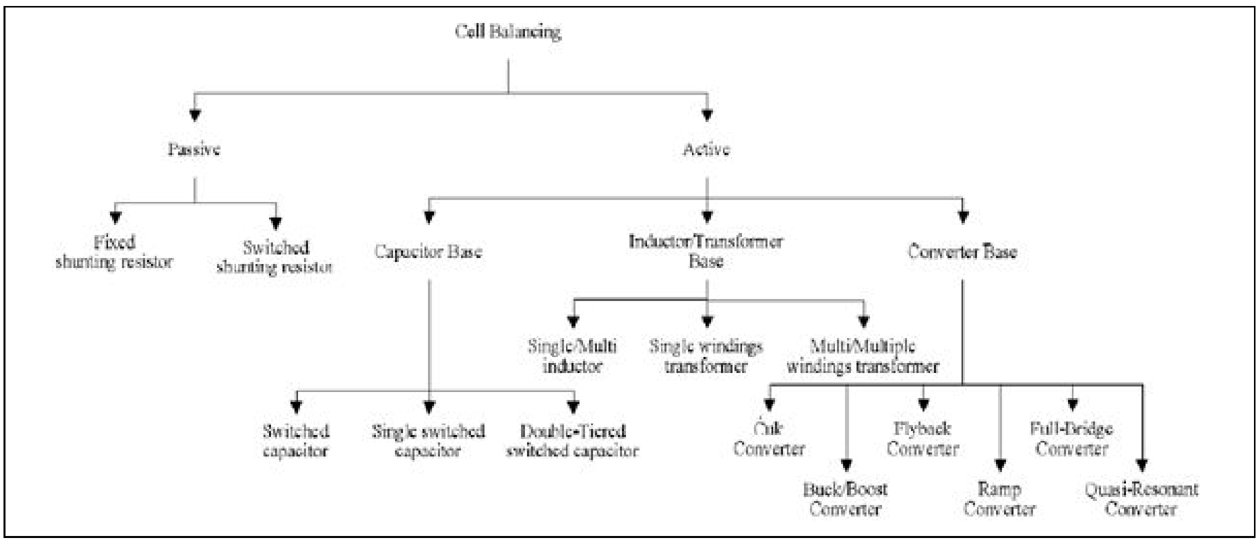


Figure 1. Passive and Active cell balancing topologies [25]

In addition to cell balancing, The BMS reports the state of charge, SoC, the state of health, SoH, and the remaining useful life, RUL, to the main controller of the system. *[25]* The metrics are extremely important for the main controller to calculate important data like range as well as detection of weak cells likely to fail. Failure management is an important feature of a BMS because it increases the safety of LiPO cells but also prevents a single cell failure from rendering the entire module useless.*[26]* To help prevent a total pack failure from the loss of a single cell, the BMS is normally paired with a cell switching circuit *[27]* or the BMS includes a cell switching circuit like the switching matrix design.*[26]* With the large amount of information the BMS manages and calculates, it needs to communicate with multiple systems. Two main systems that the BMS needs to interact with besides the main controller are the thermal management system and the charging system. The thermal system helps keep all the cells in the proper operating temperature range. The BMS also communicates with the charging system to help protect the cells from over-voltage.

Charging for electric vehicles are divided into multiple different levels depending on the input voltages and the maximum amperage that can be supplied. The levels also differ according to the number of power phases used and weather it uses an on-board or off board charger. The most common are Level 1 and Level 2 charging as they are both accessible in residential environments. *[28]* Each charging levels is broken down by specification, geolocation, and connector standard in Table 1.

Table 1: EV Charging Levels [28]

Types of Power Levels	Location for Charger	Typical Usage	Interface for Energy Supply	Expected Level of Power (P: kW)
SAE STANDARDS: AC and DC Charging				
Level 1: Convenient • Vac: 230 (EU) • Vac: 120 (US)	Single Phase • On-board	➢ Office or Home base charging	➢ Any Convenient Outlet	• P: 1.4 (12A) • P: 1.9 (20A)
Level 2: Main • Vac: 400 (EU) • Vac: 240 (US)	Single Phase/ Three Phase • On-board	➢ Publicly & Privately base charging	➢ Electric Vehicle Supply Equipment	➢ P: 4 (17A) ➢ P: 8 (32A) ➢ P: 19.2 (80A)
Level 3: Fast • Vac: 208-600	Three Phase • Off-Board	➢ Like a filling station, Commercial Point	➢ Electric Vehicle Supply Equipment	• P: 50 • P: 100
DC Power Level 1 • Vdc: 200-450	• Off-Board	➢ Dedicated Charging Stations	➢ Electric Vehicle Supply Equipment	• P: 40 (80A)
DC Power Level 2 • Vdc: 200-450	• Off-Board	➢ Dedicated Charging Stations	➢ Electric Vehicle Supply Equipment	• P: 90 (200A)
DC Power Level 3 • Vdc: 200-600	• Off-Board	➢ Dedicated Charging Stations	➢ Electric Vehicle Supply Equipment	• P: 240 (400A)
IEC STANDARDS: AC and DC Charging				
AC Power Level 1	Single Phase • On-board	➢ Office or Home base charging	➢ Any Convenient Outlet	• P: 4-7.5 (16A)
AC Power Level 2	Single Phase/ Three Phase • On-board	➢ Publicly & Privately base charging	➢ Electric Vehicle Supply Equipment	• P: 8-15 (32A)
AC Power Level 3	Three Phase • On-board	➢ Like a filling station, Commercial Point	➢ Electric Vehicle Supply Equipment	• P: 60-120 (250A)
DC Rapid Charging	• Off-Board	➢ Dedicated Charging Stations	➢ Electric Vehicle Supply Equipment	• P: 1000-2000 (400A)
CHAdeMo Charging Standard				
DC Rapid Charging	• Off-Board	➢ Dedicated Charging Stations	➢ Electric Vehicle Supply Equipment	• 62.5 (125A)

The most basic charging style is unidirectional. Unidirectional charging means that the power sink can only take in energy, whereas the more complex bidirectional charging systems allows for stabilization of power. *[28]* Each of connector has its own specification for the number of charging levels and how the vehicle handles each level. For example, SAE specifies that vehicles need to support both Level 1 and 2 charging on board, and Level 3 charging will be handled by the commercial charger. *[28]* With the various physical connectors that can be used for EV applications, the standards and charging requirements will depend the on the connector itself.

3.5. Battery Thermal Management Systems

The amount of knowledge and research that has been completed on the use of Li-ion batteries in electric vehicles makes them a desirable choice for this electric motorcycle design. In addition to the vast amounts of prior knowledge, they are also obtainable in multiple sizes and geometries, and give the most power for the space requirement, which is critical in a spatially-challenged frame such as a motorcycle. Lithium Ion batteries may outperform other chemistries in most categories, but they are only safe and usable within a narrow temperature range. Refer to Figure 2 and Figure 3 to see the relations between battery power and temperature.

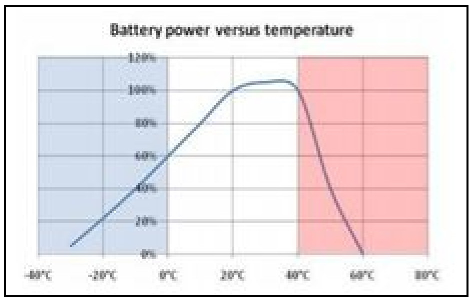


Figure 2: Battery Power versus Temperature [1]

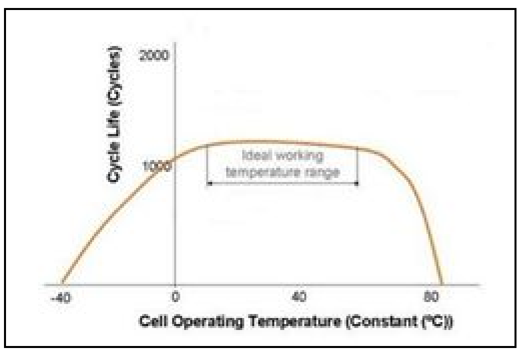


Figure 3: Battery Life versus Temperature [1]

These two figures show that it is important to keep the temperature of the batteries within approximately 15ºC and 45ºC.

As the battery generates heat it must also dissipate heat at a rate that does not let the battery reach the thermal runaway temperature. Once this thermal runaway temperature is reached it may trigger an internal chain reaction that may cause severe damage or even completely ruin the battery. This can cause safety concerns when used on a motorcycle, unlike a car where the battery pack can be separated from the passenger compartment, a motorcycle has only a small amount of options for locating the battery bank, all of which are close to the rider. If these batteries experience this exothermic reaction it can rupture the battery case and injure the rider. Cell voltage and power output are both adversely affected by cold temperatures. While it may not cause any direct safety concerns it still can have significant negative performance effects on the battery. Lower temperatures cause the electrochemical reaction to become very sluggish which severely limits the power output that the battery is rated for. *[2]* With the varying climates around the world, the electric motorcycle needs to have the ability to both cool the battery pack but also heat the battery pack. As mentioned previously, limitations in time and budget will narrow down the BTMS choices to convective thermal control with the use of either air or liquid mediums.

When dealing with temperature regulation, using ambient air for both natural convection and forced convection is a viable option to control the temperature of the batteries. With a high volumetric rate and an optimized cooling surface, air can remove large amounts of heat energy. Extrusions from the body of the battery compartment called “fins” can be applied. Fins are used to increase the amount surface area of the component, this in turn will also increase the amount of heat transfer from the battery. Heat from the battery will transfer through conduction throughout the fin which removes heat away from the anode, cathode, and the chemicals inside the battery. With the heat transferred into the fin, it has more surface area which will result in better cooling of the battery bank. This process can be described mathematically using fin analysis on the battery case, it can be modeled, designed and then optimized for the specifications required by the project. The effectiveness of this method relies heavily on the amount of air flow provided to the battery, simply put, as the velocity of the airflow increases the heat transfer coefficient also increases meaning more heat can be removed from the battery into the air.

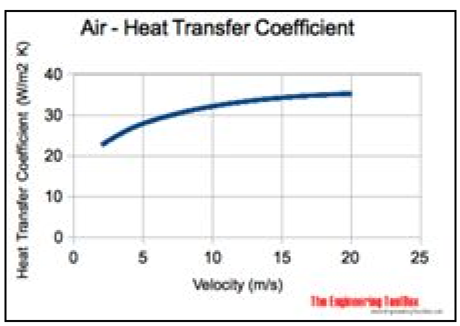


Figure 4: Air Velocity versus Heat Transfer Coefficient [4]

The equation for the heat transfer rate due to convection *[5]* is,

$$\dot{Q}_{conv} = hA_s(T_s - T_\infty)$$

Where the value of h is the heat transfer coefficient, A is the surface area, T_s is the surface temperature, and T_∞ is the temperature of the surrounding air. Convective heat transfer can be aided by ducting to allow greater airflow velocity at a driven speed, or by adding active cooling fans to create airflow at low speeds or a stop. There are also many options such as utilizing insulation or air to air intercoolers with the high temperature side encasing the batteries.

If you were to evaluate the differences between a gas and a liquid for their thermal ability to remove heat, you will find that most liquids are much better conductors of heat. This is the reason liquids are so widely used in heat transfer applications. There are many different mechanisms of transferring heat out of the battery and into the liquid. This design will focus on the use of a heat exchanger. This concept is the same as the cooling method for the internal combustion engine, or ICE, that is being replaced with the electric motor. The lower temperature fluid will flow through passages or channels surrounding the batteries, and the temperature difference will drive the heat transfer process from the battery into the fluid. The fluid then flows to cross-flow heat exchanger, similar to the ICE's radiator, where the heat is transferred from the fluid to the surrounding air. The factors that play into this design are the addition of a fluid around critical electrical components, added space for a radiator and cooling passages, and the addition of a pump which requires an accountable amount of energy. Although there are added components, the heat transfer rates of this type of heat exchanger far surpass that of the air-cooling method. For a fluid heat transfer system to be viable, the fluid properties must be determined beforehand and accounted for in the design of a system such as the one shown in Figure 5 below can be designed and optimized for use in this system.

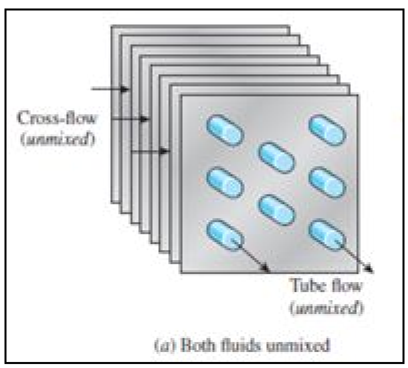


Figure 5: Cross Flow Heat Exchanger [5]

This method is known as an "indirect-contact" method for liquid cooling. There is also an option with "direct-contact" liquid cooling. For direct-contact liquid, a non-conductive medium, such as mineral oil, is used to bridge the air gap between the battery cells and the battery case. This allows for better heat transfer because mineral oil conducts heat better than air. This is generally less preferred as it will require more maintenance as well as creating an environment with little barrier between the components and the liquid. *[1]*

3.6. Motor Controllers

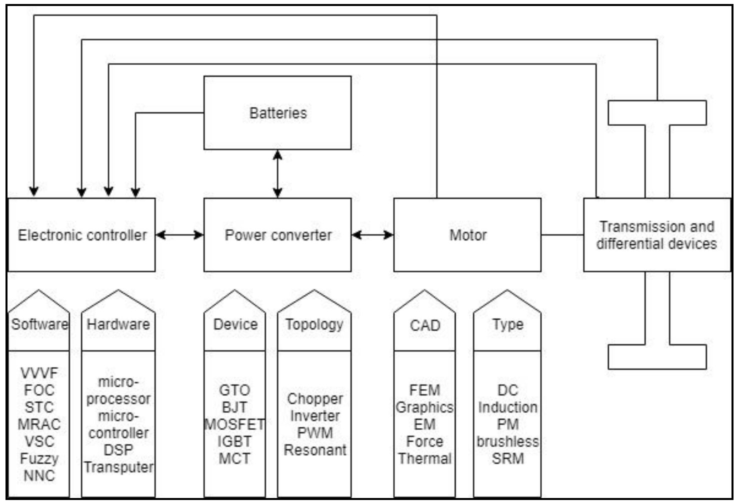


Figure 6: Communication Between Electronic Components [37]

Controlling the motors of a fully electric vehicle involves smart electronics as well as power converters and distributors. Figure 6 above shows the overview of such an electrical control system. Electric vehicles function based on the communication and execution of all the components and processes shown in this figure [37]. Once the vehicle has been powered on, the process of using the vehicle begins with input given by the driver or rider. This is a varied input, dependent upon how far the operator displaces the throttle. A microcontroller or microprocessor receives the input, and communicates to the other components what to do based on other data it already knows, such as how fast the vehicle is currently moving, how much battery power is left, and what state the motors are currently in. This computational device can then decide if any actions need to be taken regarding the motors. If the motors need to change state or produce more torque, the controller or processor will send an electrical signal to the motor controllers. The motor controllers (also known as power converters) will interpret the signal it receives from the processor and then act accordingly. These actions can be to allocate a certain number of amps, supplied by the battery, to the motors, or to change the state of the motors. This is the outline of the process in which input from the driver or rider influences the vehicle's velocity or state [38].

To produce optimal results, it is important for the electrical system to be efficient in changing circumstances. Additional components can be added to account for weight changes and changes in drag. In different conditions that affect the system from the outside, such as wind or rain, the electronics can compensate for changes and likewise change the way power is distributed in order to conserve power and keep electrical components from failing [39].

For the vehicle to function properly, all the electrical components must be compatible with each other. There are a number of factors that influence what motor controllers and other components should be selected. Motor controllers are concerned with switching frequency, power loss, current rating, and voltage rating. The desired voltage rating will depend on the nominal voltage of the chosen battery, as well as how much power regenerative braking will supply. The specifications of the motors that are used will determine what current rating will be optimal, as well as how many devices are used in the entire electrical system and how each one is connected. The higher the switching frequency, the better the aesthetics of the vehicle are, as this will produce less noise and eliminate the need for other larger mechanical components. However, higher switching frequencies also increase the loss of power, which is best to keep as low as possible. Motor controllers that are IGBT-based or MCT-based seem to be the best candidates for motor controllers in an electric vehicle. An insulated-gate bipolar transistor (IGBT) and a MOS-controlled thyristor (MCT) are both electronic components of a circuit used to regulate the flow of current [37].

3.7. Power & Drivetrain

The Table of Comparable and Current E-Moto and E-Moped Models (See Appendix A) gives the project a starting point for power requirements and transmission systems. The most common power transmission is by a single gear ratio from the motor's shaft to the rear wheel accomplished by belt or chain. It is notable that none of these models use a selective gearbox or a variable transmission of any kind. This suggests that for this project, a direct drive or a simple gear reduction achieved by a chain/sprocket or pulley/belt configuration is a simple and workable solution. The front wheel can be driven directly if a hub motor of the right specifications is used, and the rear could be driven by either a hub motor or by a mid-drive motor.

The next step is to determine the minimum power requirement needed for this project. These calculations make the following assumptions:

- The final weight of the converted vehicle will be similar to the stock weight of a ZX-7.
- The rider is of average weight.
- Zero grade on the road.
- A Cd*A value similar to a Honda VF1000, which has a similar profile to the ZX-7.

Using an equation taken from Cossalter's *Motorcycle Dynamics,* (40) we find the following. Given that the energy required to travel at a speed of 60 mph for 50 miles is 5.551 kWh (Equations, Figure 1), and it would take 0.83 hours to travel 50 miles at 60 mph, we can use the relationship, $Power = Energy/time$, to find the power needed to suit the criteria above.

$$P = 5.551 kWh/0.83\ h = 6.688\ kW\ .$$

So, a rough estimation of the power required to maintain 60 MPH FOR 50 mi. is 6.688 kW. This number does not account for any energy gained due to regenerative deceleration, and assumes a constant maximum speed, such as highway conditions, which is the most inefficient case for electric vehicles. However, this power rating also does not account for miscellaneous inefficiencies, such as transmission efficiency or bearing friction.

To achieve the project's requirement for an all wheel drive application, there must be either one motor with two transmissions driving the front and rear wheel, or two motors driving one wheel each. Installing a front driving motor introduces the greatest challenge, as it either requires a traditional electric motor with a complex transmission or a direct drive motor incorporated into the wheel itself. This problem could be solved by using a Hub Motor.

Based on the ZX-7 stock tire size of 120/70/R17 motorcycle tire, a direct drive hub motor for this application would require a maximum RPM of 862 or greater to achieve 60 MPH. Similarly, the ZX-7 stock 190/50/R17 tire requires a minimum of 823 RPM if a hub motor is being used. If a mid-drive motor is used, then the appropriate gearing must be used to achieve at least a maximum RPM of 823 at the output side of the geared drive system.

Traditionally, internal combustion motorcycles have a selective gear transmission in addition to a final gear ratio between the smaller front sprocket on the transmission output shaft and the larger rear sprocket attached to the rear wheel. Internal combustion engine All Wheel Drive motorcycles utilize a mechanical transmission from the engine to the front wheel which passes through the front fork pivot and travels down one side of the forks. This adds significant design complexity, weight, and maintenance to the vehicle.

To meet the goal of this project, power must be transmitted from an electric motor to the front wheel. Doing this by a mechanical transmission would require the design of a complete transmission system to transmit power from a motor mounted to the frame, or fitting a motor onto the front forks assembly of the motorcycle with the appropriate drive system. By adding a motor to the front fork assembly, the design complexity of a transmission that can transmit power through a pivoting connection is avoided. Adding a motor to the front fork assembly of the motorcycle can still require a complex design if the front wheel's rotational axis is able to move with reference to the motor, which would require a transmission design with changing lengths. The simplest solution is to mount the motor in a fixed position with respect to the wheel, or to merge the wheel and motor into one assembly.

A common system to solve this problem in the E-bicycle world is a hub motor. These motors are incorporated in the hub of the wheel and drive them directly. This eliminates the need for a transmission at all. A hub motor works as a normal motor does, but it is designed to keep the axle stationary and to allow the motor casing to spin instead. One requirement of a hub motor is a lever arm or sufficient clamping force on the motor's axle to keep the axle from spinning instead of the casing.

The electric motorcycle currently in production generally use a fixed gear transmission which consists of a belt and pulley configuration or a chain and sprocket configuration. The benefits and drawbacks of each system are reviewed in Table 2, alongside a shaft-drive system common in ICE motorcycles.

Table 2: Fixed Gear Transmission Systems.

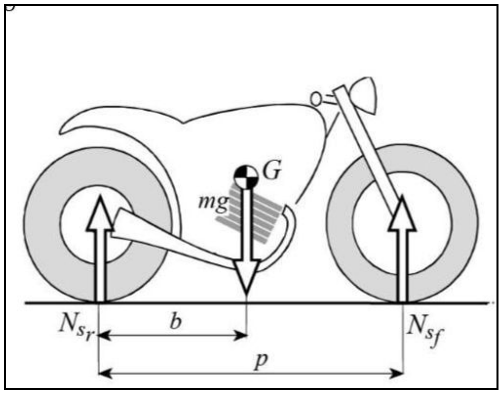
	Efficiency	**Benefits**	**Drawbacks**
Chain & Sprocket (2)	~98%	High part availability Easiest to replace. Easiest for changing gear ratios.	Shortest Lifespan Requires the most maintenance. Loudest
Belt & Pulley	~89%	Requires less maintenance Longer Lifespan Quiter than Chain Easy to change gear ratios.	More complex to replace. Cannot bend as well as chain, larger pulleys are required.
Shaft Drive	~75%	Quietest of all three Minimal Maintenance	Heavy Complex Design Difficult to repair or replace.

3.8. Vehicle Dynamics

The goal of the team is to design a motorcycle that has predictable driving and good stability. Although the core structure of the project is based on a pre-existing motorcycle, modifications made to the motorcycle may affect the dynamics of the motorcycle.

Center of gravity has to be carefully considered during the design of this project. Its position relative to the driver can impede on the handling and performance characteristics of the motorcycle. On average the engine of a motorcycle accounts for 25% of the weight of the entire assembly. In this project it will be substituted with a series of battery modules and a mid-drive motor. A hub motor will be also attached to the front wheel. The location of the motors is currently finalized, however, the placement of the batteries can still be moved around until production of the cases is completed. Depending on the location of the batteries the center of gravity will change, thus affecting the handling characteristics of the motorcycle. A hub motor integration into the front wheel of the motorcycle will shift the center of gravity forward which will result in a tendency of the motorcycle to oversteer (rear wheel slippage during cornering). Oversteer is an undesirable characteristic for a motorcycle and can lead to a crash. Alternatively, the motorcycle can gain a tendency to understeer if the center of gravity is shifted towards the rear of the motorcycle.

The longitudinal position of the center of gravity can be calculated using the following



formula: $b = \frac{N_{sf}p}{mg} = p - \frac{N_{sr}p}{mg}$

Figure 7: The longitudinal position of the center of gravity

After the longitudinal position of the center of gravity was found, its height can be determined by using the following formula: $h = (\frac{N_{sr}p}{mg} - (p - b))(cot(arcsin(\frac{H}{p})) + \frac{Rr+Rf}{2}$

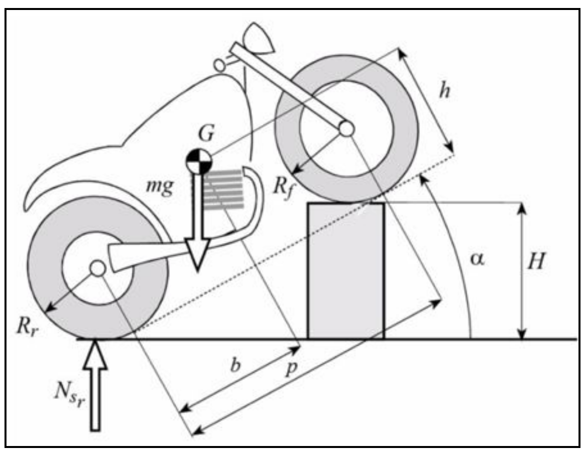


Figure 8: Measure of the height of the center of gravity

Two wheel drive motorcycles provide much better traction, especially on wet or loose surfaces, which is why they are ideal for agricultural & military purposes. In 1985, Yamaha and Ohlins (A Swedish Suspension Company) performed AWD production and research with motocross motorcycles. There were a few variations in the operation, but it was clear that AWD systems provided traction superiority, more predictable cornering, and made it easier to hold a tighter line [2][3]. Another benefit of the system was the increased straight-line stability due to the torque on the front wheel at higher rates of speed. Wheelies were also shown to be easier to control [3].

Although AWD motorcycle drivetrains were studied and implemented before, there was never a full size AWD electric motorcycle made before. Based on the knowledge gained from this study, it gives the team a baseline of what to expect and where to begin when it comes to vehicle dynamics.

4. System Requirements

4.1. Acceleration

Table 3: Acceleration Requirements

Acceleration Requirements:		
Engineering Requirements	**Target Values**	**Standards & protocols**
0-60 MPH Acceleration Time	<=9 seconds, dependant on motor power and torque curve.	Acceleration Time can be calculated once our design has a final weight and tested drag coefficient. Can be validated with test riding on a closed track.
Torque at Front/Rear Wheel	Average value of torque from >=(140.7/152.5) N*m	Analysis of Dynamometer charts for specific motors will account for torque curves in selection. Final vehicle will be tested on a dynamometer to validate design.
Motor Power Front/Rear Wheel	>(12.3/12.2) kW for the ideal case, Power bias can be shifted to accommodate component selection.	Specifications provided by manufacturer and accounted for in component selection. Validated by real-world testing on the dynamometer.
Final Vehicle Mass	<289 kg (120% or less of stock weight)	Designed in CAD and measured by weight scale.
Wheel RPM Front /Rear	>(862/823) RPM for the loaded case.	Specifications Provided by manufacturer and accounted for in component selection. Validated by real-world testing on the track and dynamometer.
Transmission Efficiency	>90% Due to the stacked nature of powertrain inefficiencies of an electric drive, every link in the drivetrain should be as efficient as is feasible.	Validated by real-world testing involving measured input and output torques.

4.2. Range

Table 4: Range Requirements

Range Requirements:		
Engineering Requirements	**Target Values**	**Standards & protocols**
High Battery Energy capacity to provide enough energy to meet speed and torque desired.	7.5-10 kWh @ 48-100V, depending on motor specifications. These numbers account for the limitations introduced by chained inefficiencies.	To reach the desired speed and the desired range, the battery pack must be designed with high reliability. The design should include a battery efficiency of 90% and a factor of safety of 1.1. The battery pack is expected to provide 100 volts and a Capacity of 10 Kwh
The battery should be designed with solid connections between cells to minimize wire connections	The internal connections are to be accomplished by spot welding the cells in parallel, and using a low-resistance wire or bus bars to connect in series.	The battery pack should be able to resist vibration and external temperatures. The batteries will be spot welded between cell to reduce the possibility of losing power while moving.
Software should allow the option of rapid acceleration or the ability to activate or disengage the motors to provide the best energy range	The software should have the ability to choose between performance or eco mode	The user will have the ability to select the between high acceleration and energy saving mode to preserve battery capacity.
The battery pack shall be designed to minimize a drastic change in vehicles CoG.	The battery pack's weight will negatively impact the CoG.	The pack will be built to be as modular as possible to allow manipulation of the CoG.
The battery cells shall be selected considering the best price, energy density, and power density suitable for this project.	The internal chemistry will determine the energy density and the power density of the battery cells.	Specifications are provided by the manufacturer and will be accounted for in component selection.

The motorcycle shall implement regenerative braking to increase battery capacity.	The regeneration system will provide the ability to recharge the battery when the motorcycle is decelerating.	The BMS will have the option to control the Voltage sensor and allow the recharge during decelerating. The regenerating braking could extend the battery range for an additional 4%.

4.3. Control System

Table 5: Control System Requirements

Control System Requirements:		
Engineering Requirements	**Target Values**	**Standards & protocols**
Quick feedback/response between sensor and inputs and the microcontroller	<= 20ms response time	Specifications Provided by manufacturer and accounted for in component selection.
Synchronous and Asynchronous control of the motor controllers	2+ modes for setting motor controller values	Specifications Provided by manufacturer and accounted for in component selection.
Handle peak and continuous power of each individual motor	Each motor controller handles the peak and continuous power output of the selected motor	Specifications Provided by manufacturer and accounted for in component selection.
Minimal latency between communication of the motor controllers and the microcontroller	<= 20ms response time	Specifications Provided by manufacturer and accounted for in component selection.
Efficient use of the power supplied to the motor controllers	85%+ efficiency from input power to the output power	Specifications Provided by manufacturer and accounted for in component selection.
Motor Controller handle switching the direction of the motor.	Forward and reverse “gear”	Specifications Provided by manufacturer and accounted for in component selection.
Motor controller handle bi-directional current to support regenerative braking.	Select a controller that supports regenerative braking.	Specifications Provided by manufacturer and accounted for in component selection.

4.4. Safety

Table 6: Safety Requirements

Safety Requirements:		
Engineering Requirements	**Target Values**	**Standards & protocols**
Necessary PPE	Increase safety margins in the event of a collision.	Operator will at a minimum wear a helmet
Fire Hazard Mitigation	Minimize the chances of a battery fire due to overheating and blunt force impact.	Design and build an impact resistant battery box that also allows significant convection cooling of the battery assembly.
Emergency Disconnect	Easily accessible and easy to operate power disconnect isolating the power source from the system within less than .25 seconds	Emergency stop will consist of a mechanical switch either using a solid state relay with a ground interrupt or simple mechanical interrupt.
Isolated Hydraulic Caliper Brake System	Brake system capable of stopping in the motorcycle within 45 meters (150 feet) without electrical power.	Completely isolated brake system independent of the electrical system, consisting of front and rear brake calipers and rotors..

5. Concept Generation and Selection

5.1. Concept Generation

5.1.1. Motor Location and Type selection:

Overview:

Initially, the team determined that there we four logical approaches to methods of powering both wheels of the motorcycle. These options are as follows and are also available in Table #3:

Option 1: Install two hub motors, one for each wheel. This would be the simplest option in many respects. Hub motors are integral to the wheel, so each would be a direct drive system eliminating the necessity of designing and building a kinetic power transmission method. Keeping the two motors in sync would be relatively simple as well. The center of gravity would also be lowered, making more stable but less maneuverable. While having a high torque, hub motors are typically incapable of the angular velocity required to achieve the necessary speeds. without overvolting. Since a hub motor is, by nature, direct drive system, this cannot be adjusted with gearing. Additionally, hub motors are inherently expensive.

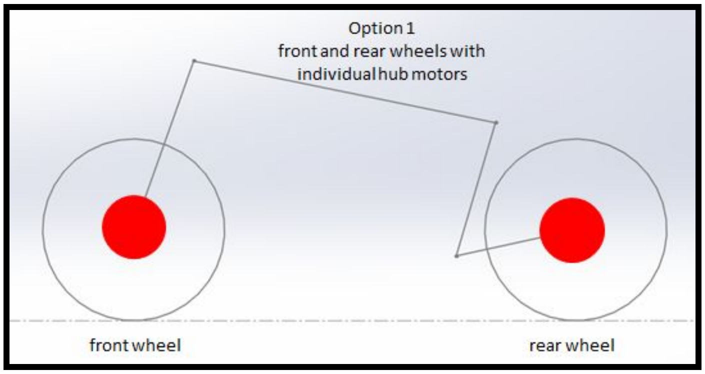


Figure 9: Option #1 for Motor Locations

Option 2: Both wheels driven by one mid drive motor. While the simplest method with respect to the electrical system, and the cheapest method with respect to motor cost, it is the most complex power transmission system by a significant margin. The potential custom machining material, and R&D costs would far outweigh the savings generated by purchasing only one motor.

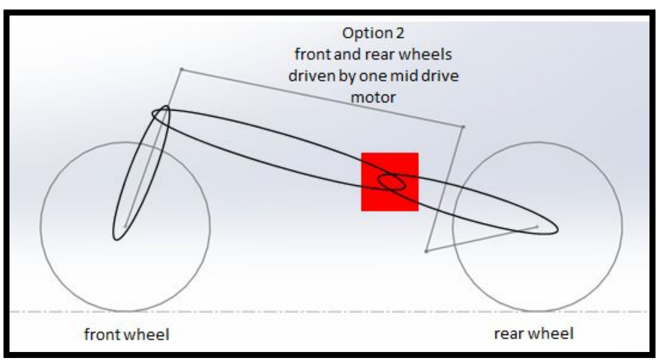


Figure 10: Option #2 for Motor Locations

Option 3: Both wheels driven by individual mid drive motors. This approach would drastically simplify the complexity apparent in option 2, but the electrical system and controller programming required will increase in complexity relative to option 2. This method is comparable in cost and handling center of mass and a significant increase in the sprung weight of the bike. If the center of mass is too far forward, and too high, it will make the vehicle difficult to safely operate. Increasing the sprung weight will cause the fork springs to compress faster when stopping and potentially bottoming out during a hard stop causing extremely unsafe scenarios.

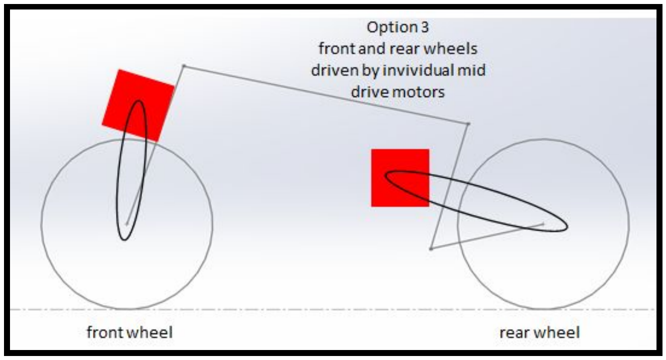


Figure 11: Option #3 for Motor Locations

Option 4: Hub motor powering front wheel and mid drive motor powering rear wheel. This approach will maintain an acceptable unsprung weight while still providing power to both wheels with relatively simple power transmission methods. The chief hurdle for option 4 is the complexity of the programming required. Since hub motors are inherently direct drive it will be less likely to achieve the same top speeds as the mid drive motor with effective gearing. The proposed solution is to program the hub motor controller to shutdown before the motor is overvolted minimizing the risk of overheating At high speeds, the mid drive motor will be doing most of the work and at lower speeds, the hub motor will be providing the majority of torque. The cost is reasonable, and the complexity of mechanical power transmission is simplified while still theoretically achieving the required design specifications.

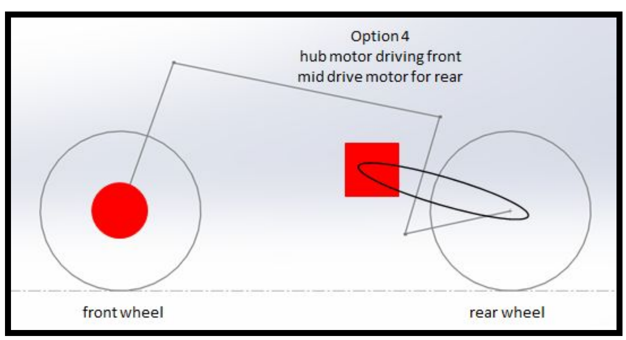


Figure 12: Option #4 for Motor Locations

Table 7: Motor Placement Concept Alternatives

Concept Alternatives:Motor Placement and Type									
Criteria	Importance Weight %	**Option 1**		**Option 2**		**Option 3**		**Option 4**	
		Front: Hub Motor Rear: Hub Motor		**Front: Mid Drive Motor Rear: Mid Drive Motor**		**Front: Fork Mounted Motor Rear: Mid Drive Motor**		**Front: Hub Motor Rear: Mid Drive Motor**	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Max Speed (rpm)	20.00%	1	0.2	3	0.6	4	0.8	4	0.8
Max Torque	20.00%	4	0.8	2	0.4	4	0.8	4	0.8
Low Cost	20.00%	3	0.6	2	0.4	3	0.6	3	0.6
Low Unsprung Weight	10.00%	4	0.4	4	0.4	1	0.1	3	0.3
Simplifies Power Transmission	15.00%	4	0.6	1	0.15	3	0.45	3	0.45
Simplifies Programming	15.00%	3	0.45	4	0.6	3	0.45	2	0.3
Totals:	100.00%		3.05		2.55		3.2		3.25

Conclusion: As seen above, in Table 3, the optimal motor configuration choice is option 4 due to its high likelihood of achieving the design requirements in terms of acceleration and velocity.

5.1.2. Motor Construction

5.1.2.1. Rear Motor

Overview: Having decided on a mid-drive motor configuration for the rear powertrain, the next step is to decide upon a motor construction. The two main types of motors are AC and DC current motors. There are many subsets of construction within these two main types, so this section will focus on the four options commonly used in EVs.

Option 1: PMDC (Permanent Magnet DC)- PMDC motors are a brushed DC motor. They are less efficient than BLDC because of the brushes (which introduce efficiency loss due to arcing

and waste heat). PMDC motors are simple and easy to control and have a fairly high starting torque.
Option 2: BLDC (Brushless DC)- Brushless DC motors are one of the most common motors used in today's industry. They are highly efficient, simple in design, cheap, and plentiful in industry. While BLDC motors seem to be a great choice for an electric motorcycle, there are actually fewer available at the higher power ratings required in this project.
Option 3- Series DC- Series DC motors are a brushed DC motor with high starting torques and a non-linear relationship between motor speed and current. These motors are heavier than other comparable DC motor designs, and are less controllable.
Option 4: Synchronous PMAC (Permanent Magnet AC)- PMAC motors are brushless AC motors that take a sinusoidal input. These motors are efficient, with a high starting torque. The sinusoidal input requires a more complex controller, but offers a much higher degree of control.

Table 8: Rear Motor Construction

Concept Alternatives: Rear Motor Construction									
Criteria	Importance Weight %	**Option 1**		**Option 2**		**Option 3**		**Option 4**	
		PMDC		**BLDC**		**Series DC**		**Synchronous PMAC**	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Efficiency	20.00%	2	0.4	4	0.8	2	0.4	4	0.8
Starting Torque	20.00%	3	0.6	2	0.4	4	0.8	4	0.8
Maintenance	10.00%	2	0.2	4	0.4	2	0.2	3	0.3
Greater Control	20.00%	2	0.4	2	0.4	1	0.2	4	0.8
Controller Availability	10.00%	4	0.4	1	0.1	3	0.3	3	0.3
Cost	10.00%	3	0.3	3	0.3	3	0.3	2	0.2
Weight	10.00%	2	0.2	3	0.3	1	0.1	2	0.2
Totals:	100.00%		2.5		2.70		2.30		3.40

Conclusion: For this project, a PMAC motor is the best choice. This decision was based on its superior efficiency, starting torque and control over comparable motor designs.

5.1.3. Rear Motor Power Transmission

Overview: Following the selection of motor type and location above (option 4), the next logical step is the selection of power transmission method from the mid drive motor to the rear wheel. Several conventional options present themselves.

Option 1: V-Belt and pulleys are very common and have several benefits including noise and weight reduction. They are typically more expensive and more work to maintain and their efficiency is typically around 85% due to the elastic nature of the belt.

Option 2: Drive shafts are expensive, heavy and difficult to maintain. They do offer some benefits in the realm of reliability and noise reduction, but overall they are not an intelligent design choice for the motorcycle, due to their low efficiency, around 75% resulting from the high moment of inertia.

Option 3: Chain and sprocket, boasting an efficiency of about 98%, is an ideal selection for small vehicles where power is at a premium and noise is not an issue. As the goal is to build a prototype for proof of concept the available gearing options are ideal and relatively high maintenance is mostly irrelevant.

Table 9: Power Transmission Concept Alternatives

Concept Alternatives: Mid Drive Motor Power Transmission							
Criteria	Importance Weight %	**Option 1**		**Option 2**		**Option 3**	
		V-Belt		**Drive Shaft**		**Chain**	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
High efficiency	35.00%	2	0.7	1	0.35	4	1.4
Low Cost / High Availability	20.00%	2	0.4	1	0.2	4	0.8
Reliability	15.00%	3	0.45	4	0.6	3	0.45
Maintenance / Life Span	10.00%	3	0.3	2	0.2	2	0.2
Low Noise	5.00%	3	0.15	4	0.2	1	0.05
Weight	15.00%	4	0.6	1	0.15	2	0.3
Totals:	100.00%		2.6		1.7		3.2

Conclusion: A chain and sprocket power transmission is ideal for AWDEMOTO's application due to its high efficiency and reliability. As this is a proof of concept prototype, the short lifespan and high maintenance issues that chain drives experience to carry little relevance.

5.1.4. Battery Cell Selection

During the battery cell selection the different nominal voltage, Nominal Current, mass, volume, C-rating, and price were compared using information obtained from different sellers. Many of the cells compared were able to reach the minimum requirements, but the different chemistry and endurance of the cells are different. The battery cell compared were Lithium-ion Manganese Oxide ($LiMn2O4$), Nickel–Cadmium (NiCd), Lithium Iron Phosphate ($LiFePO4$), "Nickel / Cob (NCR), Lithium Manganese Nickel (INR), and Lead Acid. It was important to calculate the number of cells connected in series and parallel to calculate the total number of cells needed. The number of cells connected in series can be calculated using equation 1, and the number of cells connected in parallel can be found using equation number 2. [18].

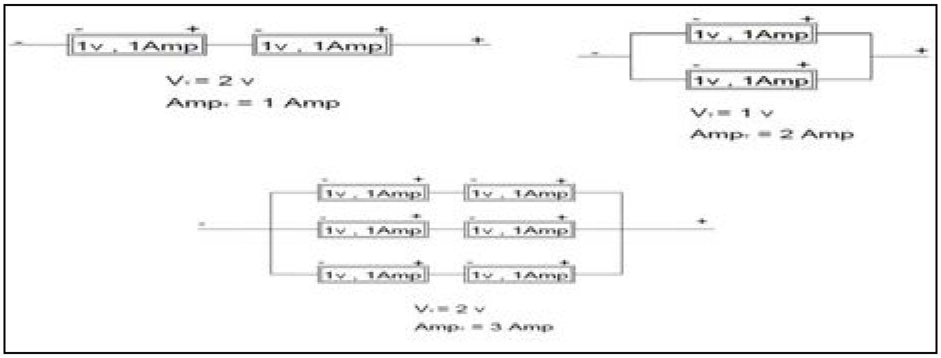


Figure 13: Series and Parallel circuit analysis

After knowing the configuration of the cells, the total number of cells can be calculated using equation 3. With this information, the rest of the calculations can be made using the information collected from the Battery Data Sheets obtained from AA portable power corp website. The total weight can be calculated using equation 5, and the total volume can be calculated using equation 6 [18]. The following graph shows a summary of the result found in the calculations.

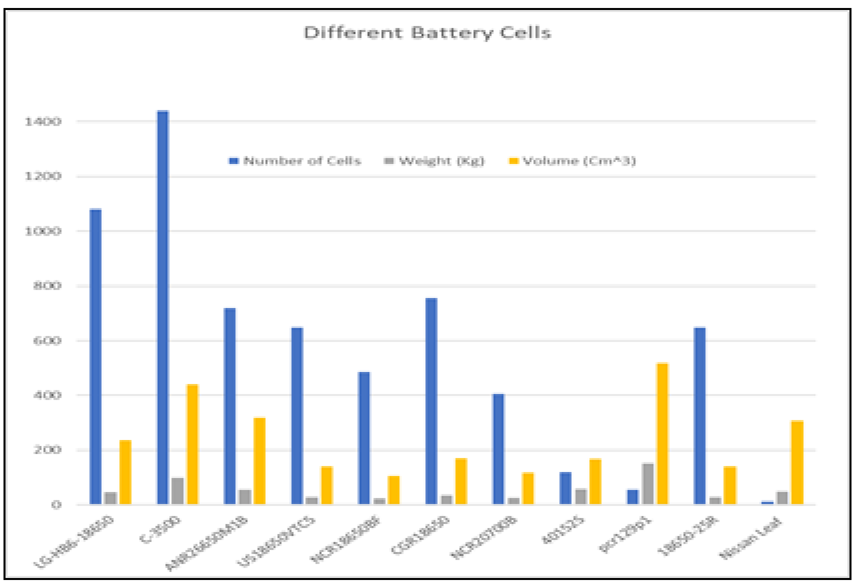


Figure 14: graph comparing number of cells, Weigh, Volume

Observing the results from Figure 15, the Lead Acid battery (pcr129p1) would be the most inexpensive battery pack, but it will have a weigh of 152.4 Kg and a Volume of 518.6 cm^3 as shown in graph 4. The next to observe are the two cells first (LG_HB6 and C-3500) this cell seems to have a high number of cells needed which will require much more wiring to connect the cells in series and parallel. The cells with the least number of cells, limiting to 500 cells, and the most lighter is 401525, Nissan Leaf, NCr20700B, and NCR1865BF. After observing these cells, the price to construct the battery pack can be compared between them. The battery pack more affordable will be the Nissan Leaf followed by the 18650-25R, and NCR18650BF as shown in the following graph.

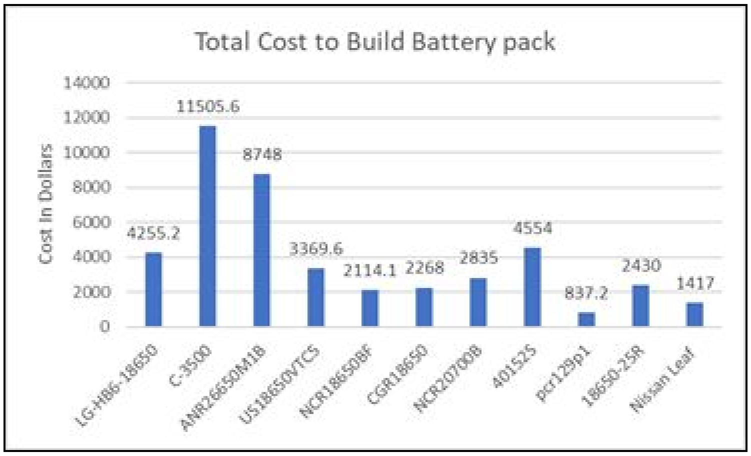


Figure 15: Battery pack cost

Finally, the maximum performance can be used to compare the cells. the C-Rating and the pulse discharge can be calculated to show the cells maximi current delivery. The C-Rating is a factor which can be used to calculate the maximum continuous discharge, and the pulse discharge is the maximum discharge during 10 seconds. The following graph shows the result in max discharge and max pulse discharge using the data collected from different cells.

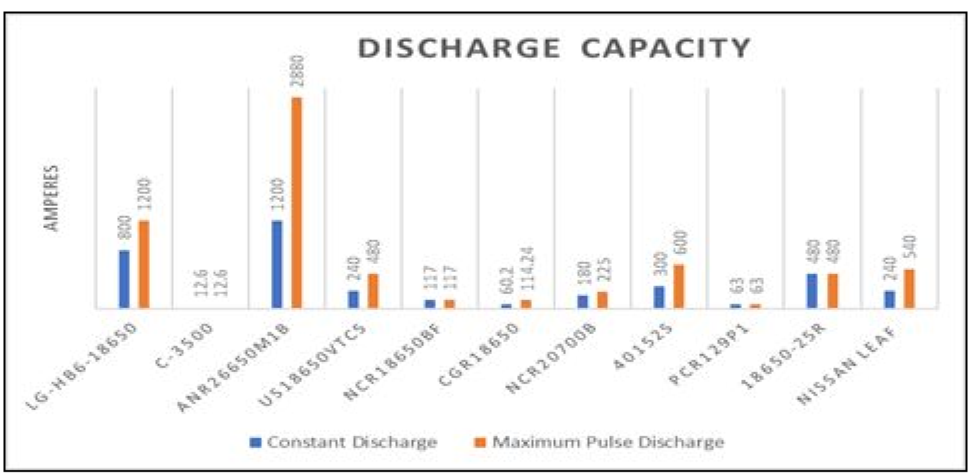


Figure 16: Discharge Max Capacity

The best choice to design the battery pack seem to be the 18650-25R (INR), but the last thing to consider is the price of both. The Nissan Leaf ($LiMn2O4$) would cost $1417 while the 18650 will cost $2430, and possible third option is the 40152s($LiFeO4$) which has a price of $4554. One of the Batteries cells considered to build the battery pack was 40152S due to its Hight C-Rating value. The Cell can safely deliver a constant discharge of 20A and 150A of maximum discharge.

After deciding the type of cells required, it was important to obtain the manufacturer's specifications. One of the most important graphs in the specifications sheet is the temperature during discharge. During the High discharge, the Batteries are expected to generate heat. Therefore, the heat generated had to be taken into consideration. The INR18650-25R as seen in the next graph it can generate heat and cause an increase in internal temperature up to 90*C when discharged at 20A. The graph demonstrates how important is the heat generated during rapid discharge.

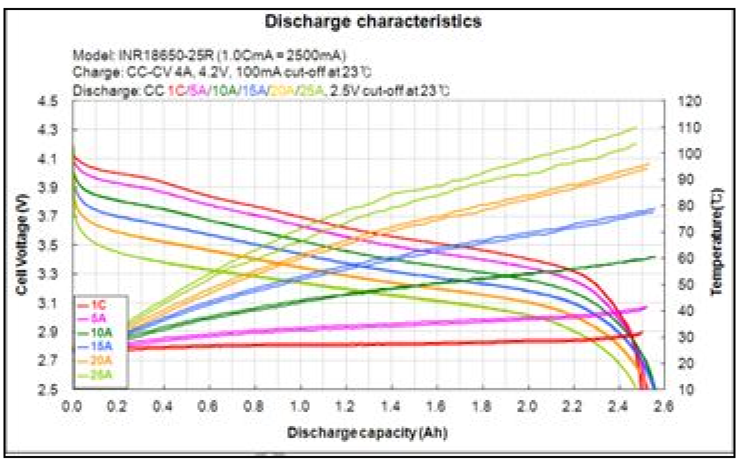


Figure 17: Discharge Graph: from Samsun date sheet[24]

The Lithium-ion Phosphate *40152S* has lower heat generated during high discharge current as seen in the next graph. The discharge of 35A can Cause temperatures of approximately 45*C. These Cells offer a great advantage compared to the previous one, but the Price is higher as seen in graph number 5. During max Amperage withdraw is expected to reach a higher temperature, and is important to limit the max discharge.

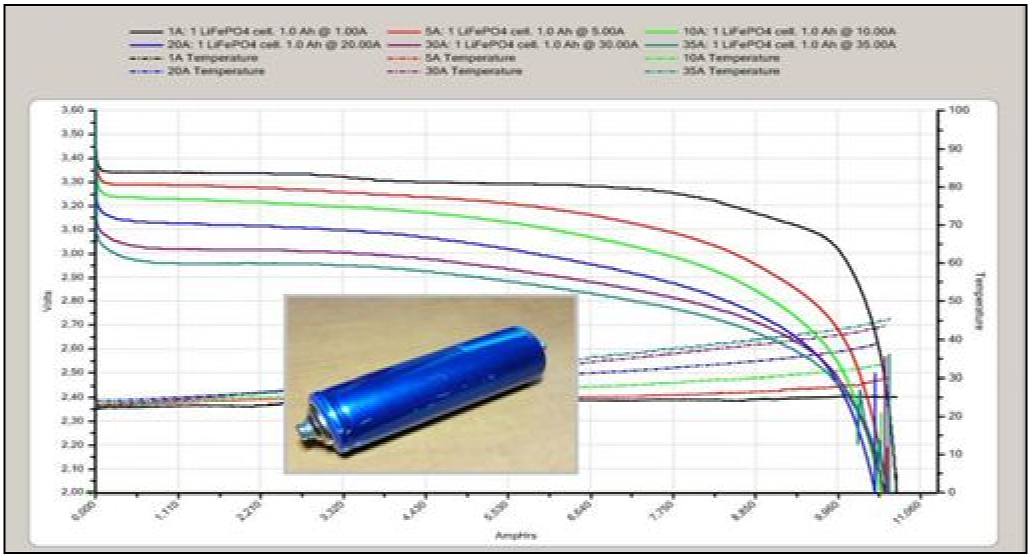


Figure 18: Cylindrical Cell Discharge [24]

Figure 19: Cylindrical Cells design

Considering the two types of batteries cells, the Cylindrical and the Prismatic the two different configurations can be designed. The cylindrical design will need to have an extra space in between cells to provide a cooling system to flow in between eh different cells. The compartment will consist of a box enclosure to keep the batteries safe from rain and dust, but the design will need to have an opening to allow air flow to reduce the heat generated. The connection between the cells can be made using by copper bus bar and 6mm bolts, but this will increase the price of the final pack.

Finally, using the battery cell matrix the design selected is the laminated Pouch Bag with the chemistry of Lithium-ion Manganese Oxide ($LiMn_2O_4$). Due to its Design, the Laminated cells have a greater C-rating value compared to the Cylindrical type. The Pouch bags are very suitable to design were dimensions are crucial. The cell has a great advantage in the dimensions, but also other considerations must be used to get the best performance of the battery. The pouch-bag cells need to be securely enclosed and compressed due to the thermal expansion during discharge and recharge. One of the cells that meet all these characteristics is the Nissan

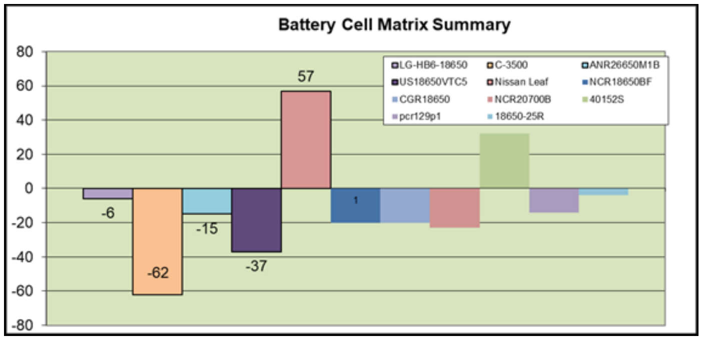


Figure 20: Selection matrix graph summary

Leaf. The cells are already arranged in modules with two cells in parallel and two cells in series. The Nissan module will simplify the design of the battery pack. The heat generated during discharge can be observed in the following picture obtained from the manufacturer's website. A test performed at 100A discharge generate temperatures of 30*C. The design battery pack will consist in Connecting Thirteen Modules in series ,to increase the voltage, using a Bus bar as a conductor to connect the modules. The busbar Cross-section area can be calculated using equation 9 and 10 with (allowing 0.1% of voltage drop). The minimum cross-section area on the conductor calculated is (44.9mm^2).

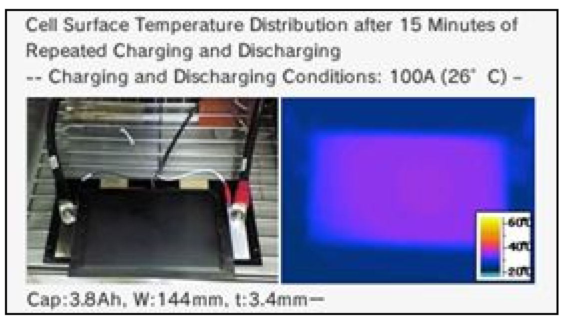


Figure 21: Nissan Leaf Automotive Energy Supply Corporation[20]

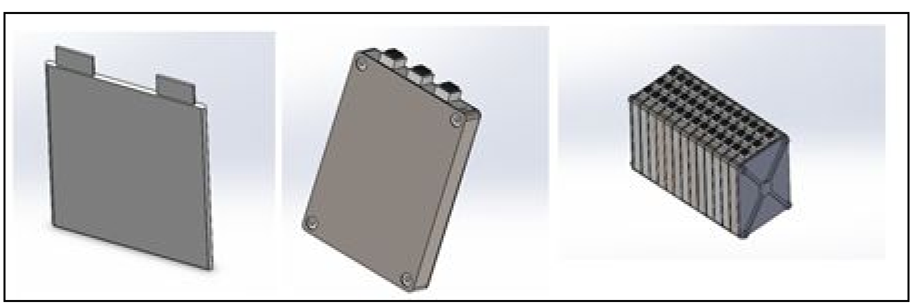


Figure 22: Pouch bag cells design

The cells are going to be placed in the bottom section and the top section of the Motorcycle equally distributed. The Chassis will be extended to reinforce and securely hold the battery modules to protect the cells. The enclosure design will be placed and fastened on the chassis extension. It will hold four modules in each side, and five in the upper side of the chassis.

.

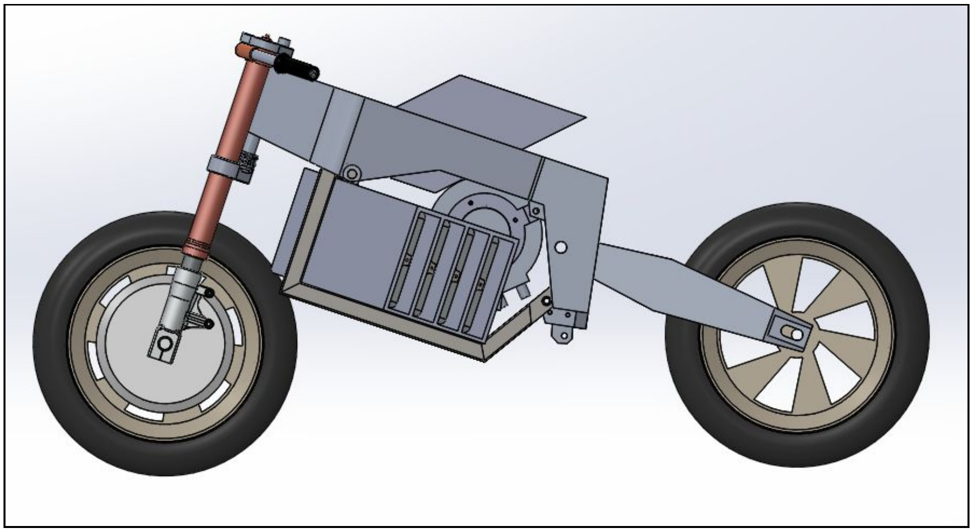


Figure 23: Chassis Extension Design Side View

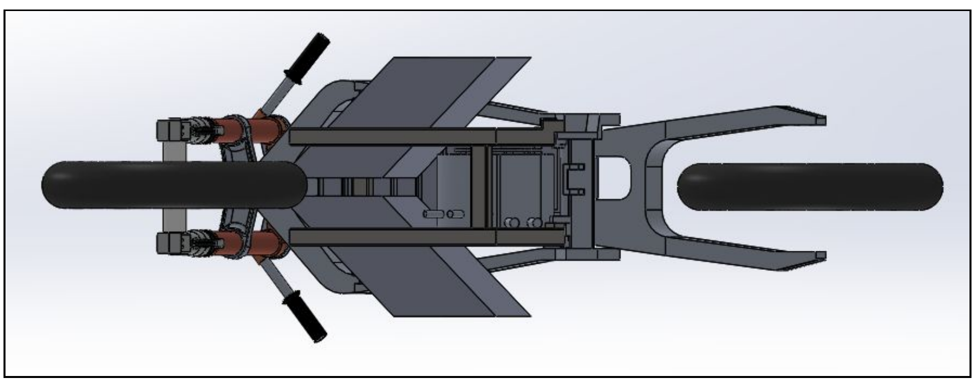


Figure 24: Chassis Design Bottom view

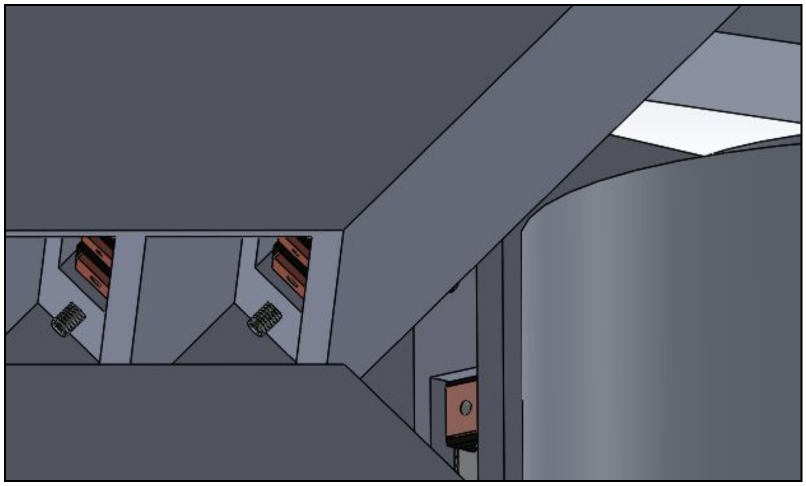


Figure 25: Battery modules bottom view

Table 10: Battery Cell Matrix

battery Cell Matrix

Concept Selection Legend: Better +, Same S, Worse -

Key Criteria	Importance Rating	Benchmark Option	LG-HB6-18650	C-3500	ANR26650M1B	US18650VTC5	NCR18650BF	CGR18650	NCR20700B	40152S	pcr129p1	18650-25R	Nissan Leaf
			Solution Alternatives										
Minimum Number of Cells	8		-	-	S	S	S	S	S	+	+	S	+
Max Constant Current	7		+	-	+	S	-	-	S	+	-	S	+
Max Pulse Current	9		+	-	+	-	-	-	-	+	-	S	+
Total Weight	7		S	-	S	-	+	+	+	+	-	+	+
Total Volumen	5		S	-	-	+	+	+	+	+	-	+	S
Temperature (at Max Discharge)	10		-	-	-	-	-	-	-	S	-	-	+
Cost	10		-	-	-	-	S	S	-	-	+	S	+
Nominal Voltage	3		S	S	S	S	S	S	S	S	S	S	S
Nominal Current	3		S	S	S	S	S	S	S	S	S	S	S
Aditional cooling Requirents	6		+	-	-	-	-	-	-	+	+	-	+
Sum of Positives			3	0	2	1	2	2	2	6	3	2	7
Sum of Negatives			3	8	4	5	4	4	4	1	5	2	0
Sum of Sames			4	2	4	4	4	4	4	3	2	6	3
Weighted Sum of Positives			22	0	16	5	12	12	12	42	24	12	57
Weighted Sum of Negatives			28	62	31	42	32	32	35	10	38	16	0
TOTALS			**-6**	**-62**	**-15**	**-37**	**-20**	**-20**	**-23**	**32**	**-14**	**-4**	**57**

5.1.5. Conductor

Wire Cross-section Area

Other important calculation was the cross-section area of the conductor to connect the battery pack and the electric motors. The cross section area is important to select the appropriate to cable diameter. The diameter can be calculated using the equations used by electric wire manufacturers, and make king some assumptions in the length of the cable. The initial consideration to connect the modules was calculated using equation 10, with a voltage drop of 1%, and using the AWG to select the Wire gage.

$$CM = 25\frac{350Amps * 5ft}{(98.8 * 0.01)} = 44281.4\, mils$$

In the table of AWG wire gage, the wire with an approximated CM value is the 3 AWG. The 3 AWG gage has a is has a Circular Mil of 52439.49 using the equation 11 the diameter can be calculated

$$Diameter(mm) = \frac{(CM)^{1/2}}{1000}x25.4\text{=5.8166mm}$$

With the diameter obtained from the table , the resistance and power consumed can be calculated using equation 7 and 8.

$$Resistance = 1.72x10^{-8}Ohm - m * \frac{4*(1.524m)}{\pi*(5.8166x10^{-3})^2}\text{=0.000986 Ohm}$$

$$power\ consumed\ by\ the\ wire = (350)^2 * (0.000986) = 120\, watt$$

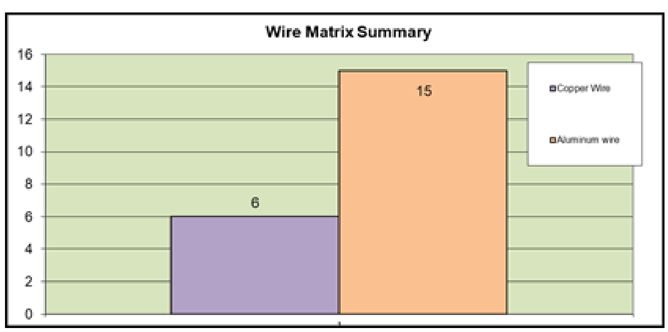


Figure 26: Wire Matrix Summary

Due to the high current, the Wire will be choosing be made of copper with a Voltage drop lower than 1% to avoid the unnecessary wire heating and waste in energy through the conductor. The wire 4/0 AWG has a Diameter of 11.684mm and consumes 30W.

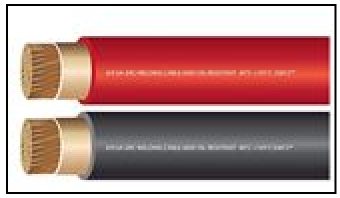


Figure 27: Wire selected

The same procedure can be used to select the correct wire correction area to connect the modules too the BMS, and also to calculate the cross section of the connectors to connect the cell in series. The wires connecting the Modules and the BMS will use an AWD 8 which only consume 0.7 Amp (assuming the wires will be 5ft long).

Table 11: Wire Conductor Matrix

Wire Conductor Matrix				
			Solution Alternatives	
Concept Selection Legend: Better +, Same S, Worse - Key Criteria	Importance Rating	Benchmark Option	Copper Wire	Aluminum wire
Cost	4		S	+
Circular Mils	2		-	S
Power Consumed	6		+	+
Conductor Resistance	5		S	+
weight	2		+	S
Sum of Positives			2	3
Sum of Negatives			1	0
Sum of Sames			2	2
Weighted Sum of Positives			8	15
Weighted Sum of Negatives			2	0
TOTALS			6	15

Fuse Protection

The fused choose to protect the circuit was a fuse of an allowance of 500 amps. The maximum amp expected a range from 350 to 450 amps. Due to the sensitivity of the Battery cells, the wiring system will be protected to reach a maximum of 500 amps. To prevent any malfunction in the system or over discharge.

Figure 28: 500 Amp Fuse with Holder

5.1.6. Temperature Sensor

Finally, the last parameter to analyze is the temperature generated during the discharge. This parameter is very important even if the cells are rated for a high discharge rate because the cells lifespan and performance decreases significantly when exposed to extreme temperatures. Also, the cells suffer from an effect called a temperature runout which refers to the maximum temperature before the cells self-destroys itself. The Battery run-out it's very dangerous but can be safely avoided if temperature sensors are integrated into the system not only to monitor the temperatures during charge and discharge but also to recognize an internal issue in the module.

Figure 29: Common Thermo Sensor

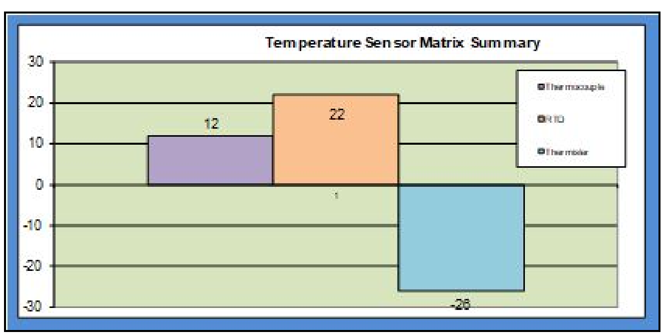


Figure 30: Temperature Sensor Matrix Summary

The deterioration of the internal components of the battery cells can be identified by the increase of it's internal resistance which can cause an increased in the internal heat generated. The integration of the temperature sensor will help to provide an extra safety feature, and to inform the rider if an overheating is suspected. The Programming team will perform a power shutdown if a temperature passes the temperature indicated by the manufacturer. Other types of sensor were considered which includes thermocouples, thermistors, and NTC. The best thermo-sensor selected is based in RTD sensor for its great stability, durability, and precision. The temperature generated inside the cells is expected to increase gradually and not rapidly. One thermo-sensor will be integrated inside the Nissan Leaf Module and then it will be connected to the BMS. All 13 thermistor sensors will be safely attached to the surface of the cell and will be calibrated to the range desired according to the battery cell discharge [22].

Table 12: Temperature Sensor Matrix

Temperature sensor Matrix					
	Solution Alternatives				
Concept Selection Legend Better + / Same S / Worse - **Key Criteria**	***Importance Rating***	Benchmark Option	Thermocouple	RTD	Thermister
Linearlity	**10**		-	+	-
Sensivity	**6**		-	S	+
Stability	**7**		-	+	-
Accuracy	**7**		S	+	S
Durability	**7**		+	S	-
cost	**10**		+	-	-
Response Time	**10**		+	S	+
Self Heating	**8**		+	+	-
		Sum of Positives	4	4	2
		Sum of Negatives	3	1	5
		Sum of Sames	1	3	1
		Weighted Sum of Positives	35	32	16
		Weighted Sum of Negatives	23	10	42
		TOTALS	**12**	**22**	**-26**

5.1.7. Motor Controller

5.1.7.1. Front

Overview: The front motor controller selection for the AWDEMOTO is entirely dependent upon the front motor selection. As outlined elsewhere in this document, the front motor selected for this vehicle is a brushless DC hub motor. Therefore, the motor controller for this motor should be designed specifically for a brushless DC motor. It is also a goal for this vehicle to be efficient with the energy it consumes and to run as far as it can on a single charge, specifically more than 50 miles. The front motor controller should thus be equipped to handle regenerative braking, as this will recycle energy and increase the range of the vehicle. The controller should also be able to output a continuous current at a higher amperage than the front motor is rated for. This allows the controller to be able to operate the motor at its highest RPM. The vehicle's control system will monitor the controller and ensure it never provides an amperage higher than what the motor is rated to handle. The front motor controller will also need to communicate with the rest of the control system to determine the amount of power it should be drawing and to pass on the metrics it measures and tracks. For this vehicle, that communication will be done through the CAN bus protocol. This controller must therefore be compatible with the CAN bus.

Option 1: The RoboteQ - RGBL1896 is a 96V brushless DC motor controller. It is fairly large in size at 140mm x 200mm x 58mm, and moderately weighted at 5lbs. It outputs up to 200A continuous current and up to 300A peak current. It offers support for regenerative braking, and compatibility with the CAN bus. In addition, it contains built-in ports for Hall sensors and encoders, which provide feedback on wheel speed and direction.

Option 2: The Kelly - KBL9635E1 is a 96V brushless DC motor controller. At 162mm x 253mm x 84mm and 6.9lbs, it is a relatively large and bulky controller. It outputs up to 140A continuous current and up to 350A peak current. It does not come standard with CAN bus compatibility but a version of the same controller with CAN bus compatibility is sold at a higher price than standard. Support for regenerative braking is standard. This controller has multiple voltage monitors and contains support for Hall sensors for wheel speed feedback.

Table 13: Front Motor Controller Alternatives

Front Motor Controller Options							
		Option 1		**Option 2**		**Option 3**	
		RoboteQ - RGBL1896		**Kelly - KBL9635E1**		**Sabvoton - SVMC96120**	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Continuous Current Output	25%	4	1	4	1	3	0.75
Peak Current Output	15%	4	0.6	4	0.6	4	0.6
Cooling Solution	15%	3	0.45	3	0.45	3	0.45
Communication Interface	20%	4	0.8	4	0.8	2	0.4
Price	5%	1	0.05	3	0.15	4	0.2
Regenerative Braking	20%	4	0.8	4	0.8	4	0.8

Total	100.00%		3.70		3.80		3.20

For this project, the Kelly - KBL9635E1 has been chosen for the front motor controller. While it is a large controller, it fulfils the requirements for this part the best out of the other choices. It outputs 140A continuous current, which is almost a perfect match for the 138.8A continuous current rating for the front hub motor that was selected.

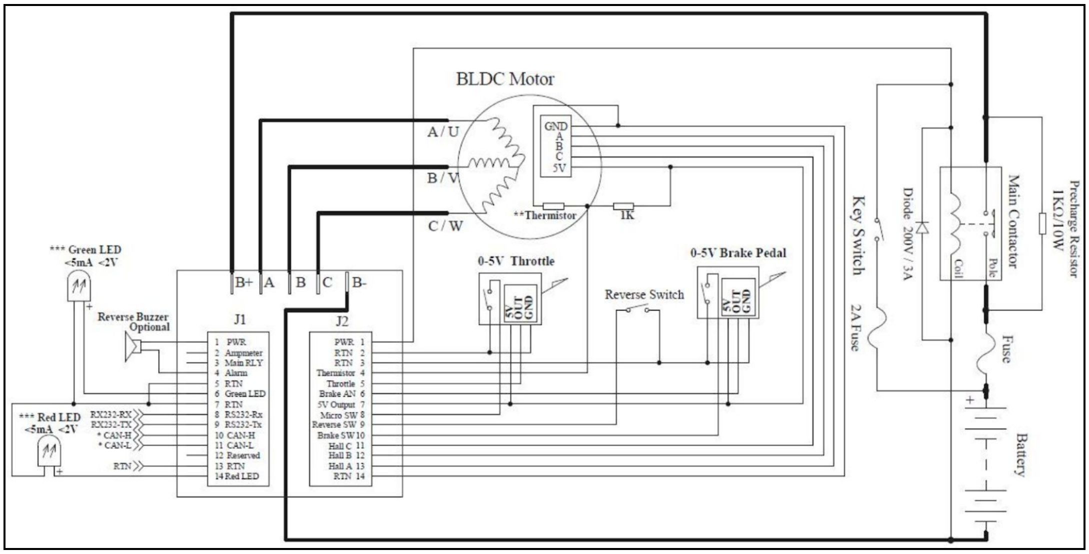


Figure 31: Standard Wiring for Controllers Less Than 120V [41]

The Kelly controller is capable of communicating across the CAN bus, as well as several other communication protocols. It comes equipped with support for Hall sensors and voltage monitors. Overall, this controller provides all the necessary functionality to provide power to the front motor and communicate with the rest of the vehicle's control system. The controller can be wired and tested in a method similar to what is shown above in Figure 31, with varying discrepancies made based on different configurations used for this specific vehicle [41].

5.1.7.2. Rear

When selecting the rear motor controller, the selection of the rear motor was taken into account so that the controller selected could drive the selected motor. As previously discussed, the selected rear motor for this vehicle is a Synchronous Permanent Magnet AC, PMAC, motor. Therefore, the motor controller must support a PMAC motor while trying to match the various selection criteria. It is also a goal for this vehicle to be efficient with the energy it consumes and to run as far as it can on a single charge, specifically more than 50 miles therefore, one of the criteria is the ability to support regenerative braking, as this will recycle energy and increase the range of the vehicle. Another important criteria is support for a continuous current that nearly matches the specification of the selected motor. This allows the controller maximize the use of the motor. The control system will help regulate the amount of amperage used by the controller to prevent the supplied amperage from being greater than the motor's specification.. To make sure that the control system is able to seamlessly communicate with all components in it, all the components need to support the CAN bus protocol. Through the CAN bus the controller will report various metrics and data that will assist in achieving optimal performance.

Option 1: Sevcon G9930 is a well known motor controller in the DIY electric conversion community. Sevcon controllers are known to have a very steep learning curve to correctly program for any motor. Having this extra complexity associated with the controller coupled with its inability to match the rear motor's peak and continuous current draw will make it more difficult to meet the project goals. The Sevcon controller only supports a continuous current of 120A whereas the motor can use 250A continuously.

Option 2: Kelly - KLS96601-8080IPS is another well known motor controller in the EV conversion community. The Kelly controllers are preferred for novices working on EV projects because their software simplifies a lot of the complex configuration need to control a motor. Furthermore, the Kelly controller almost exactly matches the capability of the selected rear motor without consuming a large portion of the budget. The controller can match the peak current draw of 600A and supports slightly less than the desire continuous current draw at 240A versus the motor specification of 250A.

Table 14: Rear Motor Controller Alternatives

Rear Motor Controller Options					
		Option 1		**Option 2**	
		Sevcon G9930		**Kelly KLS96601-8080IPS**	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Continuous Current Output	25%	3	0.75	5	1.25
Peak Current Output	15%	5	0.75	5	0.75
Cooling Solution	15%	3	0.45	3	0.45
Communication Interface	20%	5	1	5	1
Price	5%	2	0.1	3	0.15
Regenerative Braking	20%	2	0.4	4	0.8
Totals:	100.00%		3.05		3.60

For this project, the Kelly - KLS96601-8080IPS has been chosen for the rear motor controller. The Kelly's superior current output, both peak and continuous, and more competitive price make it the best option for AWDEMOTO. Furthermore, the Kelly controller has additional support for hall sensors and sine/cosine sensors, used for monitoring speed, and better documentation, both technical and community supported, will make it easier to integrate in the complete control system. With the front motor controller also being a Kelly branded controller, it eliminates the redundancy of learning how to configure the controller and writing control software.

5.1.8. Microcontroller

Overview: In the automotive industry, a standard microcontroller operates at about 140MHz and is able to handle all of the necessary control and feedback systems on board. With safety being a major concern for the project, all possible options will greatly surpass the industry norms to help minimize any limitations. With all other major components communicating over the CAN bus protocol it is vital that the microcontroller can process CAN messages and send them, even if additional hardware is required. The controller must also have an array of available I/O for any additional sensors or miscellaneous inputs or control functions that need to be performed. With how vital the software will be to the functionality of the motorcycle, the microcontroller must also have a well-established community online to assist with any potential troubleshooting.

Option 1: BeagleBone Black is a very popular microcontroller developed by Texas Instruments. The BeagleBone Black has a fairly large presence in the DIY / Tinker community. The BeagleBone Black sports a 1GHz processor with 512MB of ram and two 46 pin headers. Additionally, there is a wireless option available with WiFi and bluetooth connectivity. The BeagleBone Black also supports the CAN bus interface without any additional hardware.

Option 2: Raspberry Pi 3 B+ is the probably the most popular microcontroller on the market today with one of the biggest online communities. The Raspberry Pi has better hardware than the BeagleBone Black with a quad-core processor at 1.4GHz, 1GB of ram, and wireless by default. However, the Raspberry Pi only supports one 40 pin header and requires additional hardware to interface with the CAN bus or modification to the Pi itself.

Table 15: Microcontroller Alternatives

Microcontroller Options					
		Option 1		**Option 2**	
		BeagleBone Black		**Raspberry Pi 3 B+**	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating
Community Support	20%	4	0.8	5	1
CPU Frequency	20%	3	0.6	4	0.8
RAM Capacity	20%	3	0.6	4	0.8

CAN Bus Interface	10%	5	0.5	2	0.2
Additional Communication Interfaces	30%	5	1.5	2	0.6
Totals:	100.00%		4.00		3.40

Even though the BeagleBone Black does not have as powerful hardware as the Raspberry Pi, it still far exceeds the industry norm and will be more than enough for the control and feedback system. The amount of additional IO the BeagleBone can support plus out of the box support for the CAN bus protocol without any hardware or modifications to the board, makes it the clear choice for AWDEMOTO. The BeagleBone Black also supports a slightly smaller form factor that will assist with the limited build space in the motorcycle chassis.

5.1.9. Charging System

5.1.9.1. Battery Management System

Overview: The Battery Management System (BMS) tracks a number of metrics concerning the main battery and provides services for the battery and control system as well. The BMS will prolong the overall life span of the battery pack and provide information to the system about the battery pack's state and health, such as the temperature, total charge, discharge rate, and any failures. For this project, the Nissan Leaf Lithium-ion Manganese Oxide ($LiMn2O4$) cells have been chosen for the battery pack. These will be arranged in a 6-S 4-P configuration, thus the BMS will need to be able to manage 4 parallel sets of 6 cells in series, a total of 24 cells. The BMS needs to be able to communicate data to the rest of the control system. For this vehicle, the control system will communicate across the CAN bus. Via a CAN bus protocol, the BMS must provide the control system with information on the current charge state of the battery pack, the state of health of the battery pack, and current charge and discharge limits. The BMS as an isolated system must also be able to balance the cells, either via active, passive, or charge-shunting balancing. This will extend battery life and improve safety.

Option 1: The Orion BMS is a smart BMS that covers a wide range of needs for a typical BMS. It can handle battery configurations up to multiples of 12 cells in series. For each cell in series, it provides metrics on cell health and cell charge state. It balances each series configuration using a smart passive cell balancing method. This method uses resistors to remove up to 200mA of charge per cell for healthier cells, which far exceeds the typical cell discharge rate even for very unhealthy cells. The Orion BMS features fully accessible CAN bus, and it can report very unique data to the rest of the system. Rather than simply cutting off current draw when it exceeds the current limit of the battery pack, the Orion BMS actually calculates the exact current limit in real-time, so that the current draw never exceeds the limit. This is helpful for the control system as a whole to maintain stability.

Option 2: The Renesas – ISL78600 is a BMS that supports up to 12 cells in series per unit. It monitors each cell to determine its state of health and charge, and measures the overall temperature of the pack as well. It uses passive cell balancing resistors to dissipate charge from the healthiest cells. It provides enough data and management for each cell, but communicates this data via SPI rather than the CAN bus.

Option 3: The Dilithium Design BMS supports 24-cell monitoring, with the cells able to be in different configurations. It performs basic cell monitoring for each individual cell, and provides state of health and charge information as well as temperature readings for the cells. It communicates over a wide variety of protocols, including the CAN bus. It balances cells via a passive cell balancing method.

Table 16: Battery Management System Alternatives

BMS Options							
		Option 1		Option 2		Option 3	
		Orion BMS		Renesas ISL78600		Dilithium Design BMS	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Cell Balancing	10%	3	0.3	3	0.3	4	0.4
Communication Protocol	30%	4	1.2	2	0.6	4	1.2
Low Cost	10%	1	0.1	2	0.2	2	0.2
Cell Management	20%	3	0.6	3	0.6	2	0.4
Data Collection	30%	4	1.2	3	0.9	3	0.9
Total	100.00%		3.4		2.6		3.1

For this project, the Orion BMS has been chosen for the main battery pack BMS. The data it provides on a per cell basis is above and beyond what is necessary for this vehicle. It communicates across the CAN bus, which is critical, and manages the health of the battery pack well. By providing data on the number of charge and discharge cycles performed, it can use multiple measurements to ensure accuracy of the data it provides and ensure the accuracy of the balancing it performs.

5.1.9.2. Charger

Overview: Charging LiPO batteries is considered one of the most dangerous tasks because LiPO batteries are extremely sensitive to slight variations in conditions and not staying within their specification for voltage and temperature. Due to these tight tolerance, selecting an appropriate charger is critical. The charge must be able to communicate with the BMS and be compatible with the BMS to enable and disable the charger. The charger must be able to communicate across the CAN bus and also have been validated to work with the BMS. Next, the charge affects how long it will take to recharge the battery pack. To completely charge the pack within the eight hour time limit specified in the requirements, the charge must support a charging rate of at least 715W per hour.

Option 1: TSM2500 and Charge Controller stands out because it comes bundle with everything need to wire up the standardized SAE J1772 connector found on most American EV/PEVs. The J1772 connector is used for all publicly available chargers around Orlando. The charge also comes with additional safety features that helps prevents dangerous events, like the drive-by wire, which prevents the vehicle from supplying power to the motor. The TSM2500 is capable of charging at 3.3kW per hour which exceeds the eight hour charge time. The cost of this solution makes it impractical as it will consume at least 11% of the total budget. This solution says that it has been validate to work with the Orion BMS on its website, but there is no documentation on Orion's website to support this claim.

Option 2: Elcon HK-J-H650-6 is 3.3kW charger that allows for both air and liquid cooling to assist with charging times. The Elcon charger also sports an IP67 protection class, meaning that it is rated for varying environmental factors like rain and snow without the potential of damaging the charger or rest of the system. With operating temperature range of -40 - 60℃, the Elcon can handle the harsh Florida summers as well as Northeastern blizzards. The Elcon also supports CAN bus communication and has been validated to work the the Orion BMS per Orion's website. Additionally, the Elcon supports an auxiliary 12V charger if the design dicates a separate 12V battery instead of a DC-DC converter for other subsystems. One of the few negatives with the Elcon

Option 3: Elcon HK-J-H650-12 is a 6.6kW charger with all the same features as the previous charge but with a larger charging capacity. Originally the cost difference between the two chargers made it impractical to use this revision, but after more research, there are suppliers with a marginal cost difference between the two models.

Table 17: Charger Alternatives

Charger Options							
		Option 1		Option 2		Option 3	
		TSM2500 and Charge Controller		Elcon HK-J-H650-6		Elcon HK-J-H650-12	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Communication Protocol	30%	3	0.9	3	0.9	3	0.9
Charging Capacity	30%	3	0.9	3	0.9	5	1.5
Software	20%	4	0.8	2	0.4	2	0.4
Standard Port Compatibility	5%	5	0.25	2	0.1	2	0.1
Misc Accessories	5%	5	0.25	0	0	0	0
Cost	10%	1	0.1	3	0.3	3	0.3
Totals:	100.00%		3.20		2.60		3.20

Though the Elcon HK-J-H650-12 and TSM2500 and Charge Controller have the same score in the evaluation matrix, the validation by Orion with the Elcon charger makes it the clear choice. Furthermore, the Elcon was designed to operate in harsh weather conditions that a likely to occur at some point during operation. Rated at 6.6kWh, the motorcycle will be able to charge in about an hour. The short charge time makes the motorcycle more practical despite its limited range.

5.1.10. Rear Motor Thermal Control

5.1.10.1. Rear Motor Thermal Management System

Overview:

The electric motor will be one of the main contributors to heat generation on the AWDEMOTO. With the close proximity to the batteries along with the inverse relation of temperature to motor performance, this heat generation must be minimized through the use of cooling the motor. Initially, the team researched three different methods of cooling the mid drive motor. These options are as follows and are also available in Table 14:

Option 1: Air cooled motors are widely used in industrial applications such as powering pumps and even driving conveyor belts. These types of motors use convection, both natural and forced, to cool the components. These designs can include fans mounted on the rotating shaft in order to induce a condition for forced convection. Unfortunately, for use in the AWDEMOTO project there is limited room for this design. This leads to investigation on forced convection through the movement of the motorcycle, this can include the use of cooling fins mounted to the housing of the motor as seen in Figure 31 below. With a general maximum temperature for motors sized in the range needed for this project at 140℉-150℉ and the location behind the batteries, this may introduce heated air to the motor, this rise in temperature can adversely affect the performance of the motor by decreasing the amount of operating torque at higher RPMs. [8]

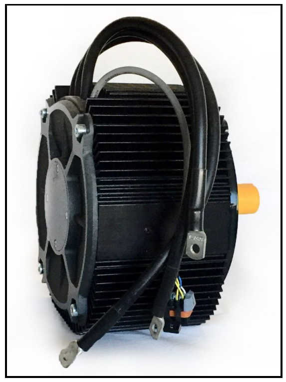


Figure 32: Air Cooled Electric Motor with Fins

While the use of an electric motor is significantly quieter than the use of an ICE, there is very little sound attenuation when comparing an air-cooled motor to one that uses a liquid for cooling. One of the largest advantages of the air-cooled motor is the simplicity of the design, it does not require the use of oil coolers or radiators along with the pumps and hoses that are also necessary for those designs. Along with the simplicity, there is also no direct hazardous or environmental considerations that need to be accounted for due to the use of air for cooling. This simplified system also allows for the cost to be lower than its counterparts, while it is typically not a substantial difference in price it still is taken into consideration.

Option 2: Oil can be used to effectively cool electric motors through both internal and external flow. Oil has a much larger ability to remove heat than air does, this allows the motor to perform better than air cooled motors at higher RPMs due to the heat being removed from the windings. As the motor spins faster more heat is generated due to friction and the oil not only lubricates the surfaces in the case of an internal oil system, but it also removes the heat. As the oil is heated it can be pumped to an oil cooler where the air can remove the heat from the oil and return the cooled oil to the motor to repeat the cycle over and over again. With the added material including the use of the oil, these motors tend to run more quietly than their air cooled counterparts, this may or may not be offset by the use a pump powerful enough to move the viscous oil depending on the chosen oil pump. With the additional components needed for oil cooled motors it becomes more difficult to integrate this into the AWDEMOTO frame, there needs to be a pump, hoses, and a heat exchanger all added into the design. This is where the majority of the increased cost associated with this type of motor comes from. The major drawback of an oil cooled motor is the potential for a leak in the system. This leak could cause hazardous situations such as a fire if the temperature was at the flash point, and with the nations increasing environmental regulations the leaking oil could end up causing trouble where specialty cleaning services may be required. It shall be noted that the team will not utilize any oil that will cause irreversible damage to the environment.

Option 3: Liquid cooled motors are more common than oil cooled but not quite as popular as air cooled motors. The liquids used in cooling electric motors are great thermal conductors making them very effective at removing the heat from the motor. Similar to the oil cooled motors, there is much less degradation to performance at higher RPMs due to the sheer amount of heat being removed, this allows continuous torque performance throughout the range of output from the motor. Similar to the oil cooled motor, this system requires the use of a pump, hoses, and a heat exchanger, this increases the cost associated with a liquid cooled electric motor but when discussing life expectancy and the lack of power and torque lost it is a very small factor for what is gained. This system requires very similar modifications to the AWDEMOTO frame as the oil cooled system. Take note in the figure below how similar in size the physical motor is compared to the air-cooled variant.

Figure 33: Liquid Cooled Electric Motor

Another important factor is discuss is the hazardous conditions that are brought about when discussing the liquid cooled motor. There are many different types of liquids that may be used in cooling applications ranging from distilled water to highly toxic chemicals designed specifically for cooling electric motors. This team will not take into consideration any explicitly harmful chemicals for the use of cooling any components on the AWD E-Moto, with the worst case scenario of total fluid loss there will not be any serious environmental impacts if the chosen motor is liquid cooled.

Table 18: Mid Drive Motor Thermal Management Concept Alternatives

Mid Drive Motor Thermal Management Concept Alternatives								
Criteria	Importance Weight %	Option 1		Option 2		Option 3		
		Air Cooled		Oil Cooled		Liquid Cooled		
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	
Heat Transfer Rate	40.00%	2	0.8	4	1.6	4	1.6	
Performance	30.00%	2	0.6	3	0.9	4	1.2	
Low Total Cost	10.00%	4	0.4	2	0.2	3	0.3	
Sound Attenuation	5.00%	1	0.05	3	0.15	3	0.15	
Modification to Motorcycle	10.00%	4	0.4	2	0.2	2	0.2	
Low Hazardous Conditions	5.00%	4	0.2	1	0.05	3	0.15	
Totals:	100.00%		2.45		3.1		3.6	

After evaluating the three different options for thermal management of the the mid drive motor as seen in Table 14 above, it was decided that the best choice for the design of the AWDEMOTO was a liquid cooled motor. While it may come a slightly higher cost than an air cooled motor, the overall rating assigned through the use of a weighted ratings chart was of a greater value than the air cooled and oil cooled electric motors. There were 6 categories that each motor was evaluated on; rate of heat transfer, the level of performance that is achievable, the total cost of all associated components, the sound attenuation of the design, any necessary modifications that will need to be made to the motorcycle, and finally the hazardous conditions associated with the methods of cooling.

5.1.10.2. Rear Motor Coolant Type

Overview: With the decision to choose a liquid cooled electric motor for the AWDEMOTO project, a coolant type had to be determined in order to select the correct motor for this application. Keeping hazardous conditions under consideration, the team chose three different types of liquids used in cooling electric motors and then further investigated those options.

Option 1: The use of distilled water is widely used in many cooling applications including the standard ICE of which comes in the stock motorcycle. Distilled water has the ability to remove large amounts of heat when coupled with a heat exchanger. The thermo-physical properties of distilled water do not allow it to be utilized in colder climates due to the high freezing temperature of $0^{o}C$ relative to option 2 and option 3. In addition to the higher freezing point, the boiling point is also lower than the other two options. Distilled water can have a boiling point of under 100°C which is drastically lower than the other two options, this would cause issues on motors that run at elevated temperatures but with the use of an electric motor the motor temperature will not reach the distilled water's boiling point. While distilled water may not have the most desirable thermodynamic properties, it does not have any regulatory constraints or any hazardous conditions which for the purpose of this project is very desirable. Unfortunately water can become very corrosive to certain types of metals or polymers, this must be taken into consideration in the selection of any motors if distilled water is the selected cooling agent. Finally, when comparing the cost to option 1 and option 2, it is lower than either of them.

Option 2: The use of a water and ethylene glycol (EG) mixture is the most common use of a coolant in the automotive and motorcycle industry. This liquid was developed directly for the use of cooling engines. The thermo-physical composition of this liquid when mixed with water to have a freezing point of -37°C and a boiling point of 107°C. Although the operating temperatures are more desirable, the actual ability to remove heat is slightly worse than that of pure distilled water as seen in option 1. This difference is very minute and if a water and EG is selected, the system would be designed to be capable of cooling the motor of the AWDEMOTO sufficiently. Similar to the pure distilled water, there are very little regulatory constraints as well as corrosive properties. Since this liquid was designed for use in vehicles that travel on the road it has been researched for many years as to not cause the environment any direct harm, while it still does have water in the mixture it is diluted as to limit any corrosive properties. The EG mixture does present some hazardous conditions, if ingested the user shall contact emergency medical services immediately. The cost associated with an EG mixture is still relatively low when compared to option 3.

Option 3: The use of a propylene glycol (PG) mixture is much less common than that of option 1 and option 2. After further investigation the PG has almost identical heat transfer properties as the EG mixture with the drawback of being more viscous. This increase in the viscosity equates to more pumping power required to fully circulate the PG from the motor to the heat exchanger and then back to the motor. Using a PG mixture proves to have very little corrosive properties as well as not being a toxic chemical. Since it is not widely used in industry there are no real regulatory constraints and with the low levels of toxicity and the low levels of corrosivity there are no foreseeable environmental impacts. The PG mixture is the highest in cost between the three different options and the difference in performance does not justify the increase in price for this particular project.

Table 19: Mid Drive Motor Coolant Type Concept Alternatives

Mid Drive Motor Coolant Type Concept Alternatives							
Criteria	Importance Weight %	Option 1		Option 2		Option 3	
		Distilled Water		Water-Ethylene Glycol		Propylene Glycol	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Thermo-Physical Properties	40.00%	2	0.8	3	1.2	2	0.8
Low Regulatory Constraints	15.00%	4	0.6	4	0.6	4	0.6
Non-Corrosive Properties	15.00%	3	0.45	4	0.6	4	0.6
Low Hazardous Conditions	15.00%	4	0.6	3	0.45	4	0.6
Low Cost	15.00%	4	0.6	3	0.45	1	0.15
Totals:	100.00%		3.05		3.3		2.75

After evaluating the three different options listed in Table 14 for liquids used in the mid drive motors' cooling systemv. This product is widely used in industry and is commonly referred to as "Antifreeze". EG was developed specifically for removing heat and most liquid cooled electric motors are designed for use with this liquid. Most commercial pumps and heat exchangers are also designed for use with EG and the actual liquid can be purchased at most local automotive part stores and vehicle service stations.

5.1.11. Battery Thermal Management Systems

Overview: Individually, the batteries are a very large contributor to the heat produced in the AWD E-Moto project. With the large amount of heat generated from the batteries and the forced close proximity to the mid drive motor and motor controllers, limiting the amount of heat soak in the area. Refer to Section 3.5 where the topic of Lithium-Ion battery performance degrades when temperature increases. This concept applies to most electrical components that are used within this project, therefore reducing any amount of heat inside the battery and motor compartment, the more efficiently the AWDEMOTO will operate.

Option 1: Passive cooling is defined as the use of forced convection to cool down the component in question. This forced convection can be provided in the form of electric fans as well as the act of the AWDEMOTO moving causing the surrounding air to flow over the components. The main cost associated with passive cooling will be the necessary addition of cooling fans, when a battery is charging it is still producing heat, if there is no way for the heat to escape then the chances for the battery to overheat continuously increase. With the addition of the cooling fans, there will need to be design considerations taken into account for fan mounting. The vehicle is currently very limited in available space so the use of any commercial fan may be limited. Once the vehicle is in motion, the act of air moving over the batteries will cause the forced convection needed to remove the heat, this will require ductwork to be designed into the battery containment system.

Option 2: Liquid cooling of the battery pack provides an excellent method or removing the heat created from the batteries. Tesla currently utilizes liquid cooling within the Model S battery pack as the power density is too great to be thermally controlled though ambient air. If designed correctly, the use of liquid could be used both during charging and operation allowing the battery pack to be maintained at an optimal temperature during use. With the optimal temperature being maintained the lifespan of the battery is not affected as it could potentially be if it were to overheat. For use of liquid cooling, the spatial requirements would drastically increase due to the addition of a heat exchanger, pumps, hoses, and a tank to hold the fluid. All of these components also come at an added expense to the owner between initial design but also maintenance and replacement parts. The power required to power the pump as well as any cooling fans utilized during charging situations would require the 12 volt system to be charged more often also decreasing the amount of energy stored for powering the AWDEMOTO in motion. This would further limit the range of the vehicle.

Table 20: Battery Thermal Management System Concept Alternatives

Battery Thermal Management System Concept Alternatives					
Criteria	Importance Weight %	Option 1		Option 2	
		Passive Cooling		Liquid Cooling	
		Rating	Weighted Rating	Rating	Weighted Rating
Low Cost	20.00%	4	0.8	1	0.2
Charging Heat Transfer Rates	25.00%	2	0.5	3	0.75
Operating Heat Transfer Rates	25.00%	3	0.75	4	1
Limits Motorcycle Modifications	15.00%	3	0.45	1	0.15
Low Power Requirements	15.00%	4	0.6	2	0.3
Totals:	100.00%		3.1		2.4

After evaluating the two different options in Table 16 above, the team decided to utilize passive cooling for BTMS purposes. The power density that the AWDEMOTO is designed to have does not warrant the added cost both financially and in the additional design work for additional parts. During testing phases the battery module temperature will be monitored as to not allow it to overheat and during operation the natural flow of air in designed cooling passages will be sufficient for cooling and maintaining proper battery temperature. The only addition of hardware with the selection of passive cooling is the requirement of cooling fans, these cooling fans must be sized correctly as to provide the proper amount of heat removal for prolonged battery life and optimum performance.

5.1.12. User Input

Emergency Disconnect

When operating an experimental prototype, there is never a guarantee in terms of safety. Electrical fires are very serious concern, and incredibly hard to put out. In the event of a catastrophic electrical system failure, the team would prefer- especially for the testing phase of the prototype- to have an easily accessible, simple to use, mechanical interrupt of the electrical system. The goal of this would be to cause a physical interrupt of current between the battery and the rest of the electrical system.

Potential E-Stop Input Options

- Key Ignition
- Safety Switch Lever Modification
- Standalone push button
- Push-button Contactor/Relay Assembly
- Handlebar Switch/Contactor Assembly

Push Buttons & Ignition Switches

Figure 34: Allen-Bradley Control Panel Parts

Companies like Allen-Bradley, Siemens, and E.A.O. make a wide range of E-Stops and Indication Lights for company safety purposes. Allen Bradley however has a very useful system that allows for easy modification depending on the purposes of the device. The only complication comes with the contact rating, for these are made primarily for 12-24V systems. They're good for 600V but only at a 2.5A current. Initially this was considered simply because they're very reliable and the team had an abundance of them.

Figure 35: ED250 Emergency Disconnect

Although reliable, there are other options specifically made for Electric motorbikes that consider the high voltage output. ED250 emergency disconnect has a rated load of 250 A, and a break current of 500A @ 96V which is incredibly close to the bike's needs. It is also lightweight and only 35$. [35]

Emergency Stop Final Selections

Table 21: Options for Emergency Disconnect Configuration

E-Stop Input Options							
		Option 1		Option 2		Option 3	
		Key Ignition		Standalone Push Button		PushButton Contactor Assem.	
Criteria	Importance Weight %	Rating	Weighted Rating	Ratin g	Weighted Rating	Rating	Weighted Rating
Assemble	5%	4	0.2	5	0.25	3	0.15
Easy to Activate	30%	2	0.6	4	1.2	4	1.2
Auxiliary Contacts	10%	0	0	0	0	5	0.5
Safety	40%	1	0.4	5	2	5	2
Cost	10%	4	0.4	5	0.5	1	0.1
Weight	5%	5	0.25	5	0.25	2	0.1
Total	100.00%		1.85		4.2		4.05

At face value the simplest option would most likely be a ED250, ED400 Emergency disconnect or some other commonly used push button produced for high voltage purposes in Electric bikes. The simplest and safest option would be a standalone e-bike disconnect that fits the power & current output needs.

A contactor or relay option may be considered in the later future for use with the power supply and the 12-24 V system (lighting, pilot lights, screen displays,etc.) but there are simpler options for power distribution.

5.1.13. Front Suspension Type

To achieve the goals of handling and stability set by the project the team looked into three different types of front suspension. Although the motorcycle was originally equipped with an inverted telescopic fork, the team proposed to compare the original fork to a number of different types of forks and decide what will be the best solution for the motorcycle.

Option 1: keep the original inverted fork and modify it for use with a hub motor. This is the simplest option as it allows the team to reuse OEM parts, including caliper mounts, axle mounts and triple tree configuration. In order to accomodate the chosen hub motor configuration for the front wheel, a wider triple tree has been designed and will need to be fabricated for the prototype. Moreover, stock front fork has an ability to adjust dampening and can be easily stiffened by changing the springs inside the fork. The original inverted fork also has the least amount of unsprung weight compared to any of the proposed options in this report, which will help with stability and increase mechanical grip during cornering.

On the other hand, a simple inverted telescopic fork has a number of weaknesses. Firstly, there is a wheel base alteration while motorcycle is undergoing any type of acceleration. Secondly there is a mass transfer during acceleration that reduces the mechanical grip in the rear which makes the rear brake less effective and makes the motorcycle less stable.

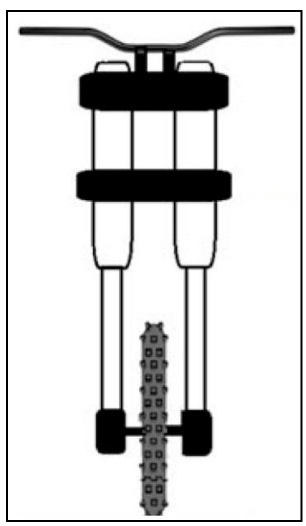


Figure 36: Inverted Telescopic Fork

Option 2: Use of a leading link suspension design. such design implements a use of a rigid frame and a pivot arm that is dampened by a spring-damper assembly. Such design allows for a stiffer fork that can handle more torque generated by the front wheel. Moreover, leading link fork has no dive during braking, thus keeping the wheelbase constant throughout the suspension travel of the motorcycle. Another benefit of this suspension design is its ability to adjust the rake and trail relatively easy. This would allow the team to fine tune the handling characteristics of the motorcycle without any major fabrication work.

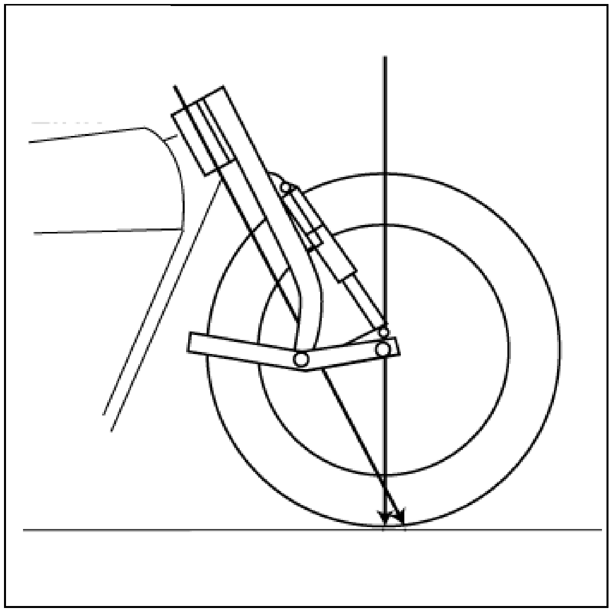


Figure 37: Leading Link Fork

Conversely, leading link suspension will require significant custom fabrication work to be retrofitted on a motorcycle that was originally equipped with a telescopic fork. Additionally, leading link forks are harder to use during low speed maneuvers. Moreover, unsprung weight is higher compared to the inverted telescopic forks. Since the unsprung weight is already increased due to the choice of a front hub motor, it would be unwise to contribute further.

Option 3: Hossack front suspension, compared to a conventional telescopic fork, offers two primary benefits. First being a separate single spring damper assembly and second being a fully rigid upright. Such suspensions fully mimic a car suspension, with a slight re-arrangement of the components. Hossack offers a constant head angle, constant wheelbase and a constant trail. Moreover, this suspension type increases rigidity of the fork while decreasing unsprung weight and potentially decreasing overall weight of the motorcycle.

However, despite the benefits of this particular suspension type, its complexity makes it practically unusable in the scope of this project.

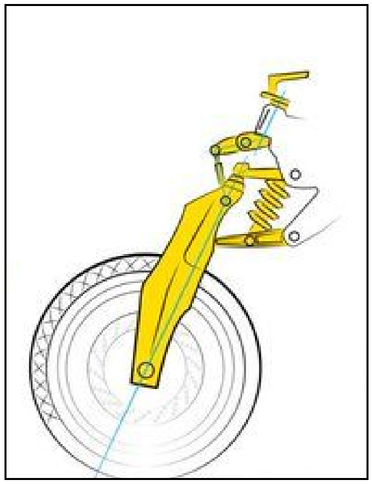


Figure 38: Hossack Fork

Table 22: Front Fork Concept Alternatives

Concept Alternatives: Fork Design and Type							
Criteria	Importance Weight %	**Option 1**		**Option 2**		**Option 3**	
		Inverted Telescopic Fork		**Leading Link Fork**		**Hossack Fork**	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Weight	10	2	0.2	1	0.1	3	0.3
Low Speed Handling	20	3	0.6	1	0.2	3	0.6
High Speed Handling	10	2	0.2	3	0.3	3	0.3
Wheel Base Alteration	5	1	0.05	3	0.15	3	0.15
Behaving Under Braking	5	1	0.05	3	0.15	3	0.15
Rigidity	10	2	0.2	2	0.2	3	0.3
Complexity	30	3	0.9	1	0.3	1	0.3
Totals	100		2.2		1.4		2.1

After evaluating the three different options for the front fork design as seen in Table 18 above, it was decided that the best choice for the AWD E-Moto is an inverted telescopic fork. There were 7 categories that each fork design was evaluated on: weight, low speed handling, high speed handling, wheel base alteration, behaving under braking, overall rigidity and complexity. It is clear that the Hossack fork may be better than a conventional telescopic fork in certain tasks it is also very complex and would require more time and resources for implementation than this project has to offer. If the project will continue its development beyond the senior design scope it may be beneficial to invest into a development of a Hossack fork.

5.1.14. External Coverings

There are a few reasons the team needs to plan out external covering:

- **Aerodynamics:** To reduce all negative aspects of drag & lift as possible
- **Collision Protection:** sliding, or crashing
- **Environmental Factors:** Water,debris & corrosion
- **Ventilation:** For efficient internal airflow

Basic topics to discuss for this are fairings & winglets, battery cage coverage, and fuel tank repurposing.

Modifications Made To Kawasaki ZX-7R To Accommodate for new Coverage Designs

- Fork Spacing: Yokes need to be remade, width will change, new brackets for lighting
- New Battery cage
- Change in Center of Gravity: Front hub motor, battery weight distribution

5.1.15. Fairings & Winglets

Even though there has been consideration for all options of fairings, the majority of them would be an expenditure on our project. Fairings only have a large impact for lowering cross sectional area when one is dealing with high-speed racing. There may be a repurposing of scrapped fairings for rear and front lighting, but all other fairings would solely be for aesthetics.

5.1.16. Battery Cage Protective Covering

The team will most likely be using 12 modules of Nissan Leaf batteries. The configuration of the battery cases will change overtime. A battery cage will be made to fit onto existing mounting holes. Its size and battery location will heavily depend on whether or not there is a need for internal airflow to them, the center of gravity needs, and how much volume the internal parts will take up. Until then the actual design concepts that can be made are minimal. Ideally though one would want the batteries to stick out as little as possible from the center, although a dustbin shaped covering over the center frame could give enough space, the cheapest and fastest option would be fiberglass, aluminum, or plastic plating. The team could even use existing mid-frame fairings and add mounting brackets to the cage. The easiest solution to covering would either be fiberglass or aluminum plating, another option would be an extra hybrid aluminum frame with fiberglass or plastic covers on it to better fit on the sides.

Battery Cage Covering Selection

Table 23: Battery Cage Protection Options

Battery Cage Covering Options									
		Option 1		Option 2		Option 3		Option4	
		Fiberglass Plates		Aluminum Plating		Plastic/Fiberglass Mold Over Cage		Hybrid Aluminum frame	
Criteria	Importance Weight %	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Safe	20%	2	0.4	3	0.6	1	0.2	4	0.8
Cost	10%	2	0.2	3	0.3	3	0.3	1	0.1
Mounting	18%	4	0.72	4	0.72	2	0.36	5	0.9
Aerodynamic	2%	3	0.04	2	0.04	2	0.04	3	0.08
Easy to Mold	3%	4	0.12	3	0.09	4	0.12	1	0.03
Easy to Modify	7%	4	0.28	2	0.14	1	0.07	3	0.21
Easy to Repair	20%	3	0.6	2	0.4	1	0.2	3	0.6
Weight	20%	3	0.6	1	0.2	1	0.2	1	0.6
Total	100.00%		2.96		2.49		1.49		3.32

Using a hybrid framing cover that mounts on to the existing battery cage is somewhat cumbersome, the frame doesn't need to be aluminum, but it is expected.using flat plating to cover the cage is still far more practical and time efficient. A hybrid will be the safest option. If the batteries find a more practical fitting into the cage perhaps flat plating can work.

5.1.17. Fuel Tank Repurposing

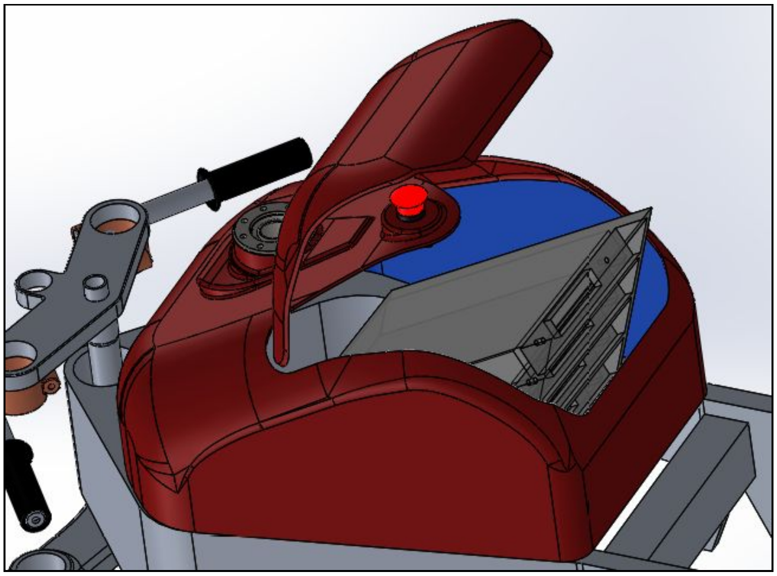


Figure 39: Current Fuel tank if modified for Awdemoto

Repurposing the fuel tank is probably one of the most important parts of external coverage because it is providing organization and protection for wiring and mounting by adding internal space, providing a mounting area for a charge port & E-stop, protects internal components from water damage & corrosion, aerodynamically beneficial, and it provides a resting spot while the bike is stationary. The most practical idea would be to just cut into the existing tank and modify it with a door to check internal components. However depending on the flexibility the team will have with cost a CNC a foam model of the hull can be created and a fiberglass/plastic mold over it, or we can use a similar model Kawasaki fuel tank to fit on. Repurposing the pre-existing fuel tank is the most efficient option. The only complication that may arise from this will be with how difficult it is to work with aluminum.

6. Significant Accomplishments and Future Work

6.1. A basic CAD model has been generated to assist with component placement plan, and fixture design. This will also be used for FEA analysis in the future.

6.1.1. The original ICE was a stressed member of the frame. In this project, the battery mount sub-frame was designed to act as a stressed member as well as mount batteries. and controller system.

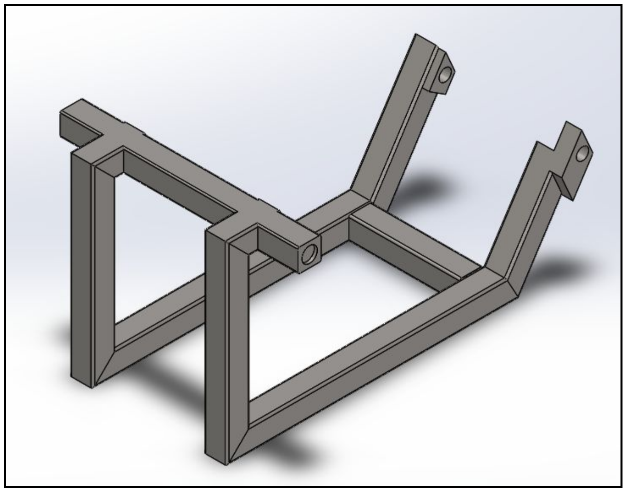


Figure 40: Preliminary Bolt on Stress Member and Battery Mount.

6.1.2. The mid drive motor and hub motor were modeled to facilitate FEA and fixturing for mounting. This was essential to determine the necessity of designing and manufacturing a new triple tree to accommodate the larger width of the hub motor.

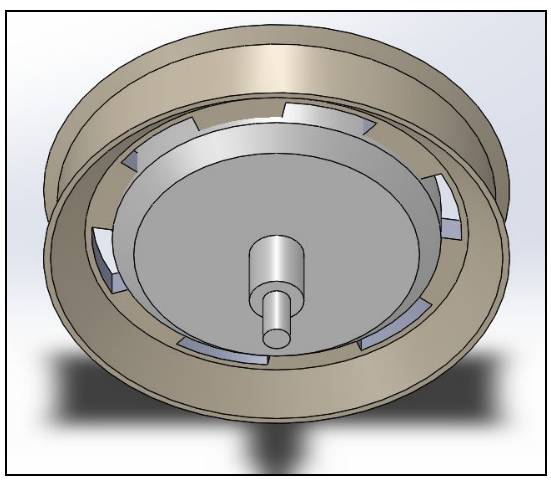


Figure 41: Integrated Hub Motor and Wheel

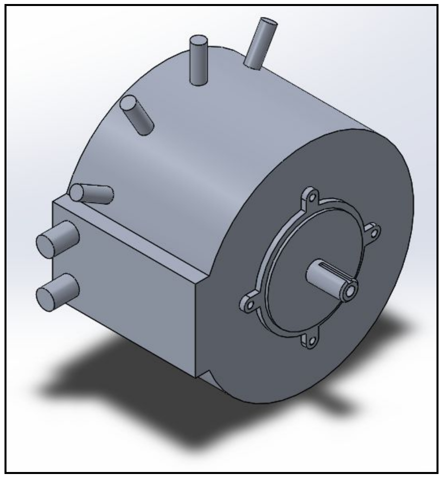


Figure 42: Mid Drive Motor

7. Conclusions and Recommendations

As can be seen in this report, the many systems inherent to an AWD design have many options and considerations for implementation. The critical systems chosen for this design have been outlined in Section 5 of this report, with non-critical systems addressed in Appendix B. In broad terms, the AWD design in this project will be accomplished by a dual-motor, hybrid drive consisting of a direct drive, alloy rim, BLDC hub motor for the front wheel, and a PMAC mid drive motor coupled with a fixed gear, chain and sprocket transmission for the rear wheel. The combined motor power shall meet or exceed 25kW, with a combined torque of 292 N*m at the wheels. The battery pack shall consist of Lithium Ion Manganese Oxide pouch cells, in a 24S2P configuration to achieve a 90 volt nominal, 60Ah battery pack capable of a 240 A continuous and 500A peak discharge. The motors shall incorporate a wheel speed feedback system utilized by a microcontroller communicating with the motor controllers to coordinate the system as a whole. This prototype shall be used to test the validity of the AWD drivetrain on an electric motorcycle comparable to an internal combustion motorcycle in terms of power. Recommendations for the next stage of the project include FEA analysis of the mechanical structures, a bench test of the critical component systems, and an extensive CAD model of the prototype. The final prototype is recommended to be tested on a dynamometer and a closed track to determine the effects of a high-powered hub motor on the front wheel. Finally, beyond the scope of this school project, it is recommended for the sponsor to continue design iterations of this concept to exceed the accomplishments possible in a two-semester timespan.

References

[1] Jiling Li, Zhen Zhu, 2014, "Battery Thermal Management Systems of Electric Vehicles", Chalmers University of Technology, *Division of Vehicle Engineering & Autonomous Systems*
Link:http://publications.lib.chalmers.se/records/fulltext/200046/200046.pdf

[2] John Rugh, Ahmad Persaran, Kandler Smith, "Electric Vehicle Battery Thermal Issues and Thermal Management Techniques", *National Renewable Energy Laboratory.*
Link:https://www.nrel.gov/docs/fy13osti/52818.pdf

[3] Mohammad Khan, Maciej Swierczynski, Soren Kaer, "Towards an Ultimate Battery Thermal Management System: A Review", Department of Energy Technology, *Aalborg University.*

[4] Link:https://www.engineeringtoolbox.com/convective-heat-transfer-d_430.html

[5] Yunus Cengel, Afshin Ghajar, "Heat and Mass Transfer Fundamentals & Applications", *McGraw-Hill Education*

[6] Satisha Mohapatra, "An Overview of Liquid Coolants for Electronics Cooling"
Link:https://www.electronics-cooling.com/2006/05/an-overview-of-liquid-coolants-for-electronics-cooling/#

[7] Lasance, C. and Simons, R., "Advances in High Performance Cooling for Electronics", *Electronics Cooling, Vol. 11, No. 4, 2005, pp. 22-39.*

[8] Erick Hendrickson, "Optimize Your Vehicle by Cooling Electric Motors and Generators"

Link:https://www.machinedesign.com/motion-control/optimize-your-vehicle-cooling-electric-motors-and-generators

[9] EPA (2018, September 28) e-CFR Title 40 Part 273.
https://www.ecfr.gov/cgi-bin/text-idx?SID=0501d91ec562faafa833c60c2404d806&mc=true&no de=pt40.27.273&rgn=div5#se40.29.273_12

[10] James D. (2018, July 27) What Tesla's New Patent Can Tell Us.
https://www.inverse.com/article/47509-tesla-battery-patent-ruptured-battery-safety

[11] Zero Motorcycles. retrieved from: https://www.zeromotorcycles.com/technology/

[12] FLDMV (2018) Florida Statutes Title XXIII Chapter 316. retrieved from: http://www.leg.state.fl.us/Statutes/index.cfm?App_mode=Display_Statute&URL=0300-0399/03 16/0316.html

[13] Dirt Legal. retireved from: https://www.dirtlegal.com/blog/how-to-make-your-dirt-bike-street-legal

[14] FLDMV (2018) Motorcycle Registration in Florida. retrieved from: https://www.dmv.org/fl-florida/motorcycle-registration.php

[15] *Berg, H., Batteries for electric vehicles: materials and electrochemistry, Cambridge, United.* Kingdom: Cambridge University Press, 2015.

[16] Britannica, T. E. of E., "Alessandro Volta," Encyclopædia BritannicaAvailable: https://www.britannica.com/biography/Alessandro-Volta.

[17] *Jiang, J., and Zhang, C., Fundamentals and applications of lithium-ion batteries in electric drive* vehicles, Singapore: Wiley, 2015.

[18] Larminie, J., and Lowry, J., Electric vehicle technology explained, West Sussex, England: J.Wiley, 2003.

[19] *Toll, M., DIY lithium batteries: how to build your own battery packs, Place of publication not.* identified: Toll Publications, 2017.

[20] "58Ah Nissan Leaf Battery Module - 2 cells 58Ah," *60Ah Nissan Leaf Battery Module*Available: http://hybridautocenter.com/HAC4/index.php?option=com_hikashop&ctrl=product&task=show&cid=91&name=58ah-nissan-leaf-battery-module&Itemid=605.

[21] "EV Relays (DC Contactors)," *Measurement sensor - Displacement Sensors | Technical Guide | Automation Controls | Industrial Devices | Panasonic*Available: https://www3.panasonic.biz/ac/e/control/relay/vehicle/ev_special/index.jsp.

[22] "Overview of Temperature Sensors," *Cable Lengths and Transmission Speeds - National Instruments*Available: http://www.ni.com/white-paper/4218/en/#toc2.

[23] *Kids Korner - Carbon Cycle*Available: https://c03.apogee.net/contentplayer/?coursetype=foe&utilityid=wppi&id=4581.

[24] "LiFePO4 40152S Battery: 3.2V 30Ah (96Wh, 150A rate)," *BatterySpace.com/AA Portable Power Corp. Tel: 510-525-2328*Available: https://www.batteryspace.com/lifepo4-40152s-battery-3-2v-30ah-96wh-150a-rate-9-0.aspx.

[25] Daowd, Mohamed, et al. "Passive and Active Battery Balancing Comparison

Based on MATLAB Simulation." 2011 IEEE Vehicle Power and Propulsion Conference, 2011, doi:10.1109/vppc.2011.6043010.

[26] Yang, Xiangjiang, et al. "Design of a Battery Management System Based on Matrix Switching Network." 2015 IEEE International Conference on Information and Automation, 2015, doi:10.1109/icinfa.2015.7279273.

[27] C. Chen, et al. "Design and Realization of a Smart Battery Management System." International MutliConference of Engineers and Computer Scientists 2012 Vol II, 2012.

[28] Habib, Salman, et al. "A Comprehensive Study of Implemented International Standards, Technical Challenges, Impacts and Prospects for Electric Vehicles." IEEE Access, vol. 6, 2018, pp. 13866–13890., doi:10.1109/access.2018.2812303.

[29] Aerodynamics, By Tony Foale.1986-1997(https://motochassis.com/Articles/Aerodynamics/AERO.htm)

[30] Motorcycle Cornering Improvement: An Aerodynamical Approach based on Flow Interference, by Vojtech Sedlak.

[31] tests, Motorcycle Specifications reviews road. *Motorcycle Specifications*, Ftp://Motorcyclespecs.co.za, 5 July 2005, www.motorcyclespecs.co.za/model/kawasaki/kawasaki_zx7r%2000.htm.

[32] Dillard, Ted. "5k Ohm Throttles: Domino vs. Magura." *The Electric Chronicles: Power in Flux*, 27 Mar. 2015, evmc2.wordpress.com/2014/03/30/5k-ohm-throttles-domino-vs-magura/.

[33] "KBL BLDC Motor Speed Controller." *KDZ48401,24V-48V,400A,PM with Regen - Kelly Controls, LLC*, kellycontroller.com/kbl9625124-96v250abldc-controllerwith-regen-p-1123.html..

[34] "SW500 Busbar Contactor." *Albright*, www.albrightinternational.com/products/sw500/.

[35] "ED250 Emergency Disconnect Switch." *ElectricMotorsport.com*, www.electricmotorsport.com/ev-parts/contactors-relays/albright-ed250-style-emergency-disconnect-switch.html.

[36] "Albright SW202 Style 72V (400A Cont.) Reversing Contactor." *ElectricMotorsport.com*,

www.electricmotorsport.com/ev-parts/contactors-relays/albright-sw202-style-72v-400a-cont-reversing-contactor.html.

[37] C. Chan and K. Chau, “An Overview of Power Electronics in Electric Vehicles,” *IEEE Transactions on Industrial Electronics*, vol. 44, no. 1, pp. 3–13, Feb. 1997.

[38] B.-C. Chen, Y.-Y. Wu, Y.-D. Huang, and C.-N. Huang, “Modeling and Control of Hybrid Electric Motorcycle with Direct-Driven Wheel Motor,” *SAE Technical Paper Series*, Aug. 2004.

[39] D. G. Dorrell and M. Popescu, “Drive Motor Designs for Electric Motorcycles,” *2012 IEEE Energy Conversion Congress and Exposition (ECCE)*, 2012.

[40] Cossalter, Vittore (2006). *Motorcycle Dynamics* (Second ed.). Lulu.com. pp. 37–72, . ISBN 978-1-4303-0861-4.

[41] “Kelly KBL Brushless Motor Controller User’s Manual,” *Kelly Controls, LLC*, http://kellycontroller.com/mot/downloads/KellyKBLUserManual.pdf

[42] “Hall Effect Sensor,” *ElectronicsTutorials*, https://www.electronics-tutorials.ws/electromagnetism/hall-effect.html

Equations

Energy Required to go 50 miles @ 60 mph:

$$E_{ij} = \frac{1}{3600}\left[m_{ij}.g.(f.cos\varphi + sin\varphi) + 0.0386.(\rho.C_x.A.v_{ij}{}^2) + (m_{ij} + m_f).\frac{dv}{dt}\right] d_{ij},$$

where:

E_{ij} = Mechanical energy required at the wheels to drive on a distance d_{ij} [kWh]
m_{ij} = Total vehicle mass [kg]
m_f = Fictive mass of rolling inertia [kg]
g = Gravitational acceleration [m/s²]
f = Vehicle coefficient of rolling resistance [-]
φ = Road gradient angle [°]
ρ = Air density [kg/m^3]
C_x = Drag coefficient of the vehicle [-]
A = Vehicle equivalent cross section [m^2]
v_{ij} = Vehicle speed between the point i and the point j [km/h]
d_{ij} = Distance driven from point i to point j [km]

m_{ij} = *wet weight of stock motorcycle* (530 *lbs*) & *the weight of an average rider* (180 *lbs*) = 322.051 *kg*
m_f = *Fictive mass of rolling inertia. Unknown at this time, so disregarded for now.*

f = *vehicle coefficient of rolling resistance* = 0.02
φ = *road gradient angle* = 0
ρ = *air density* = 1.225 kg/m^2
$C_x * A$ = *Drag coefficient of the vehicle multiplied by the Frontal Area, assumed to be* 0.42 m^2
v_{ij} = *vehicle speed between point i & j* = 96.5606 km/hr
d_{ij} = *distance between point i & j* = 80.4672 km
$dv/dt = 0$, this equation will assume a steady speed of 60 miles per hour for 50 miles.

$$E_{ij} = 1/3600[m_{ij} * g * (f cos\varphi + sin\varphi) + 0.0386(\rho * C_x * A * {v_{ij}}^2) + (m_{ij} + m_f) * dv/dt] * d_{ij}$$
$$E_{ij} = 1/3600[322.051\ kg * 9.81\ m/s^2 * (0.02(1) + (0)) + 0.0386(1.225\ kg/m^2 * 0.42\ m^2 * (96.5606\ km/h)^2)$$
$$+ (322.051 + 0) * 0] * 80.4672 km$$
$$E_{ij} = 5.551\ kWh$$

Equation used to calculate battery pack & Conductor Cross-section area

1. $number\ of\ Cells\ in\ Series = \frac{Voltage\ Required}{Nominal\ Voltage\ from\ Cell}$
2. $Number\ of\ Cells\ in\ Parallel = \frac{AmH\ Required}{Nominal\ AmH\ from\ Cell}$
3. $Total\ Number\ of\ Cells = (\#cells\ in\ series)x(\#\ of\ cells\ in\ parallel)$
4. $Total\ Cost(\$) = (Total\ number\ of\ cells)\ x\ (Cost\ per\ individual\ cell)$
5. $Total\ Weight\ (Kg) = (Total\ Number\ of\ Cells)\ x\ \frac{(weight\ of\ Individual\ cell\ in\ grams)}{1000}$
6. $Total\ Volume = (\#cells\ in\ paralle\ x\ Diameter(cm))x(\#of\ cells\ in\ Series\ x\ D(cm))x(cell\ Lenght(cm))$
7. $Resistance = \rho * \frac{L}{A}$ *Where ρ is the Resistivity of the material, L is the Length of the conductor,*

   and A is the Cross-section Area. (ρ copper=1.72 x10^-8 Ohm-m)
8. $power\ consumed\ by\ wire = I^2 * R$
9. *Wire area (AWG standard)* $CM = (Diameter(in)x1000\ mils)^2$
10. *Wire Sizing* $Cm = \frac{25*I*L}{Voltage\ Drop}$ *where L is in ft*
11. $Diameter(mm) = \frac{(CM)^{1/2}}{1000}$
12. $Area = \frac{\pi}{4} * D^2$

Appendix A

Table of Comparable and Current E-Moto and E-Moped Models.

	Zero S ZF7.2	Zero FXS ZF7.2	Alta RedShift SM	Energica EVA	Lightning LS-218	UBCO 2X2
Peak Power (HP/kW)	34/25@4300 rpm	46/34@4300 rpm	42/31	109/80	200/150	3.2//2.4
Peak Torque (ft*lbs/N*m)	78/106	78/106	38/52	133/180	168/228	135/184
Cooling	Air	Air	Air (motor) Liquid (controller)	Oil	Liquid	air
Transmission	Direct Drive 90T/18T Belt	Direct Drive 90T/18T Belt.	Single gear (3.5:1) to 15/50 Chain	Direct Drive 16/44 Chain	Direct Drive	Single stage planetary gear reduction
Motor Type	IPM Z-Force 75-5 Radial Flux, permanent Magnet Brushless	IPM Z-Force 75-5 Radial Flux, permanent Magnet Brushless	PMAC 14k rpm	PMAC	IPM	DC hub Flux Drive motors
Controller	SEVCON GEN 4 SIZE 4 550 amp, 3-phase brushless controller with regenerative deceleration	550 amp, 3-phase brushless controller with regenerative deceleration	Not available	Not available	Not available	Not available
Range City/Highway/ combined	89/45/60	100/40/57	50 combined	<125	<120 miles	Not Available
Weight (lbs)	313	251	283	~560	496	139

Max Speed (mph)	91	85	80	125 (goverened)	218	30
Style	Streetfighter	Enduro	Enduro	StreetFighter	Faired Street	Moped
Battery Voltage	102 (28S @3.65 cell)	102 (28S @3.65 cell)	350	300	380	50
Battery Density	Not Available	Not Available	185W/kg	Not Available	Not Available	Not Available
Battery Type	Li-ion Pouch	Li-Ion pouch	Li-ion	Lithium polymer	Li-Ion	Li-ion
Battery Capacity	7.2 kWh	7.2 kWh	5.8 kWh	11.7kWh	12 kWh	2.4 kWh
Charging type	1.3kW, Level 1/2	650 W, Level 1/2	Unknown kW, Level 1	3 kW, Level 1/2/3	Unknown kW, Level 1/2/3	350W, Level 1
MSRP	$10,995	$10,495	$13,495	$23,400	$38,888	$6,999

Engineering Requirements vs User Requirements Relationship Matrix

	End User Requirements										
Total Impacts	Safe Highway Speed	Reasonable Commuter Range	Reasonable Acceleration	Reasonable Charge Time	Safe & Comfortable Handling	Affordability	Serviceability	Able to Operate In Appropriate Conditions	Traction Control	Selective Two Wheel Drive	Engineering Requirements
6	■	■	■	■		■	■				2.2.1.1
3				■		■	■				2.2.1.2
6	■	■	■					■	■	■	2.2.1.3
5	■	■	■		■		■				2.2.1.4
6	■	■	■	■		■	■				2.2.1.5
5		■			■	■		■	■		2.2.1.6
2					■			■			2.2.2.1
4			■		■			■	■		2.2.2.2
3			■		■			■			2.2.2.3
3					■			■	■		2.2.2.4
4					■	■		■	■		2.2.2.5
3			■		■			■			2.2.2.6
4			■		■	■			■		2.2.3.1
4			■		■	■			■		2.2.3.2
6	■	■	■		■	■	■				2.2.3.3
4			■		■	■			■		2.2.3.4
5	■	■	■		■	■					2.2.3.5
4					■	■		■	■		2.2.3.6
6		■		■		■		■	■	■	2.2.3.7
4			■		■	■		■			2.2.4.1
6	■		■		■	■		■	■		2.2.4.2
6	■		■		■	■		■	■		2.2.4.3
6	■	■	■		■			■	■		2.2.4.4
7	■	■			■	■	■		■		2.2.4.5
7	■	■	■		■	■	■			■	2.2.4.6
2						■	■				2.2.5.1
7	■	■	■	■	■	■	■				2.2.5.2
5					■	■	■		■	■	2.2.5.3
2						■	■				2.2.5.4
2					■			■			2.2.6.1
2						■	■				2.2.6.2
4					■	■	■	■			2.2.6.3
5					■	■	■	■	■		2.2.6.4
6			■		■	■		■	■	■	2.2.7.1
7			■		■	■	■	■	■	■	2.2.7.2
	12	12	20	5	27	26	15	19	18	6	Contributors

Mechanical Engineering Design Competence Evaluation						
Rate this design project in illustrating effective integration of mechanical engineering topics						
Project Title: AWDEMOTO (All Wheel Drive Electric Motorcycle)						
ME Design Areas	Critical/ Main Contributor	Strong Contributor	Necessary but not a Primary Contributor	Necessary but Only a Minor Contributor	Only a Passing Reference	Not Included In This Design Project
Thermal-Fluid Energy Systems			X			
Machines and Mechanical Systems		X				
Controls and Mechatronics	X					
Materials Selection			X			
Modeling and Measurement Systems				X		
Manufacturing					X	

EML 4105C	Fall 2017 Semester	
Project: AWDEMOTO		
Topic	Criticality to Project	Section
Thermal-Fluid Energy Systems	4/6	3.5, 5.1.6, 5.1.10, 5.1.11 Appendix B.3, B.4
Machines and Mechanical Systems	5/6	3.7,3.8, 5.1.3, 5.1.12, 5.1.14,
Controls and Mechatronics	6/6	3.4,3.6 4.3, 5.1.7, 5.1.8, 5.1.9,
Materials Selection	4/6	3.3, 5.1.4, 5.1.14, 5.1.15,5.1.16, 5.1.17 Appendix B.2

Modeling and Measurement Systems	3/6	6.1
Manufacturing	2/6	Appendix B.2

Appendix B

1. Illumination Selection

Although not implicitly required for the functional prototype, at the very minimum, installation of a headlight was deemed necessary by the team for safety reasons. There are three primary headlight technologies on the market that would suit the teams needs for this application.

Option 1: Halogen light: This is ancient technology. Halogen bulbs burn hot (often in excess of 250℃ or 425℉), are fragile and have a relatively short life span. Additionally Halogen bulb efficiency inconsequential compared to the other available options. They are however relatively cheap and still easy to find regardless of being rapidly phased out.

Option 2: HID also known as Bi-Xenon. HID lights typically provide a blue white light of higher energy and shorter wavelength than the yellow white typically created by halogen bulbs. They are much more efficient, typically providing around at least 120 Lumens per Watt compared to a halogens roughly 20 Lumens per Watt.

Option 3: LED (light emitting Diodes) lights are the most modern technology being considered. There are by far the most efficient with a lower amp draw than typical HID lamps, but with a lower amp draw. The price point is almost identical to HID, but availability and options are far more diverse.

Table 24: Headlight Type Concept Alternatives

Concept Alternatives: Headlight Type							
Criteria	Importance Weight %	Option 1		Option 2		Option 3	
		Halogen		HID		LED	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Cost	30.00%	4	1.2	2	0.6	3	0.9
Efficiency	15.00%	2	0.3	3	0.45	4	0.6
Availability	20.00%	4	0.8	3	0.6	3	0.6
Aesthetics	15.00%	1	0.15	3	0.45	4	0.6
Penetration	20.00%	2	0.4	3	0.6	4	0.8

Totals:	100.00%		2.85		2.7		3.5

Conclusion: Due to high availability, efficiency and effectiveness, The team chose to plan on using LED lights when the time comes to purchase head and tail lights for the prototype.

2. Wheel Type Selection.

The existing rear wheel will be re-used, however with the selection of a front wheel hub motor, additional criteria arise in parallel to the motor selection. Since hub motors typically are purchased as a wheel / motor assembly, one of the driving factors behind motor selection is the type of wheel it will come in. There are primarily two types of wheels easily procurable and prevalent in contemporary motorcycles. The ideal type of wheel selection is dependent on the application it will be used for. In the instance of this prototype, efficiency and cost are the primary driving factors.

Option 1: Spoked wheels typically have a higher level of durability due to axial loading of each spoke, but as a result of their more durable nature are also heavier and more expensive. Tubed tires create an additional drawbacks such as increased weight and complexity. Individual spokes can be replaced, so if certain parts of the wheel are damaged, repairs can be made but this can be difficult as each spoke needs to be a specific length otherwise the wheel will come out of true over time. Applications for spoked wheels typically include off road motorcycles and enduros.

Option 2: Alloy wheels, typically cast from Aluminum or Magnesium alloys, are generally lighter and cheaper than their spoked counterparts. The increased rigidity of the wheel significantly increases performance, handling and power efficiency. These wheels also perform better at speed than the spoked variety. Primary drawbacks include, no repair method beyond purchasing a new wheel, and

Figure 43: Spoked Wheel (left) Alloy Wheel (right)

Table 25: Front Wheel Type Alternatives

Concept Alternatives: Front Wheel Type Concept Alternatives					
Criteria	Importance Weight %	Option 1		Option 2	
		Spoked Wheel		Alloy Wheel	
		Rating	Weighted Rating	Rating	Weighted Rating
Cost	25.00%	2	0.5	3	0.75
Availability	15.00%	1	0.15	4	0.6
Durability	10.00%	4	0.4	2	0.2
Ease of Repair	10.00%	3	0.3	1	0.1
Weight	20.00%	3	0.4	4	0.8
Efficiency / Performance	20.00%	3	0.6	4	0.8
Totals:	100.00%		2.35		3.25

Conclusion: Alloy wheels (option 2) are the ideal option for this application due to the nature of their construction, pricing and efficiency. The benefits provided by spoked wheels are not significant with respect to the goals and design specifications necessary for this project.

3. Heat Exchanger Pump Motor

The selected motor requires approximately 6 to 15 liters per minute of coolant flow, per manufacturer specifications, in order to maintain the proper cooling requirements. This requirement can be achieved with the use of a multitude of different style pumps ranging from positive displacement pumps to centrifugal pumps. The motor manufacturer recommends the use of a Bosch brushless 12V pump with part number 0-392-023-004 for use with the ME1616. It should also be noted that this pump is compatible with different types of Glycol mixtures.

Figure 44: Bosch Water Circulation Pump

With the manufacturer recommendation for pump selection it was decided that it was not necessary to evaluate multiple options as the selected pump had been tested under normal and abnormal operating conditions.

4. Heat Exchanger Selection

With the design selection of cooling the motor utilizing a liquid, a heat exchanger becomes necessary in order to cool the liquid. The process flow for liquid cooling with the addition of a heat exchanger begins with the cooled liquid passing over the electric motor. This temperature difference drives the process of heat transfer from the higher temperature of the motor to the coolant. This hot coolant then is pumped to the heat exchanger where the flow of air removes the heat from the coolant which is then returned to the motor to repeat the process. The process is the same as the flow through the radiator on the standard ICE that comes with the motorcycle. The use of an air-to-liquid heat exchanger, or radiator, was selected for the motor cooling system due to the wide availability and simple concept/design behind the operation. The use of a liquid-liquid heat exchanger would unnecessarily complicate this project, this requires additional modifications as well as additional parts on the AWD E-Moto. As for the design and selection of a specific heat exchanger, the team is very limited in the space available. The heat exchanger is a decision that will be made after any optimization has been completed on the frame. This style of heat exchanger can be ordered in a wide array of dimensions and materials so after the design has been finalized the heat exchanger can be designed or purchased from a distributor.

5. Ergonomic Design Considerations

5.1. Riding Position

To efficiently and safely operate a motorcycle, the user must be comfortable and be able to handle the motorcycle without putting too much stress on his joints. Handlebars and foot pegs are mostly responsible for riders' position, his comfort and the weight bias of a motorcycle. To operate a motorcycle with a relatively comfortable position the foot pegs have to be matched to the handlebars. By adjusting the position of the rider, the motorcycle can change its center of gravity as well as its weight bias. In this report the handlebars will be matched to the foot pegs and the resulting riding posture will be evaluated.

Option 1: Sport riding posture. To achieve this riding position the motorcycle has to be equipped with rearset foot pegs and clip on handlebars. Stock Kawasaki ZX-7R comes equipped with rearset foot pegs and clip on handlebars. Such riding position results in a forward lean of 48 degrees, a knee angle of 78 degrees (smaller number means more bent) and a hip angle of 50 degrees (smaller means more crouched). Such riding position allows more control at higher speeds as wells as an improvement in overall aerodynamics of the motorcycle. Center of gravity also is improved due to the rider being crouched closer to the motorcycle.

However, such riding position is not ideal for long periods of time and puts a lot of stress on the riders body. Moreover, it makes the bike very unsteady during low speed maneuvers and is not ideal for a commuter motorcycle.

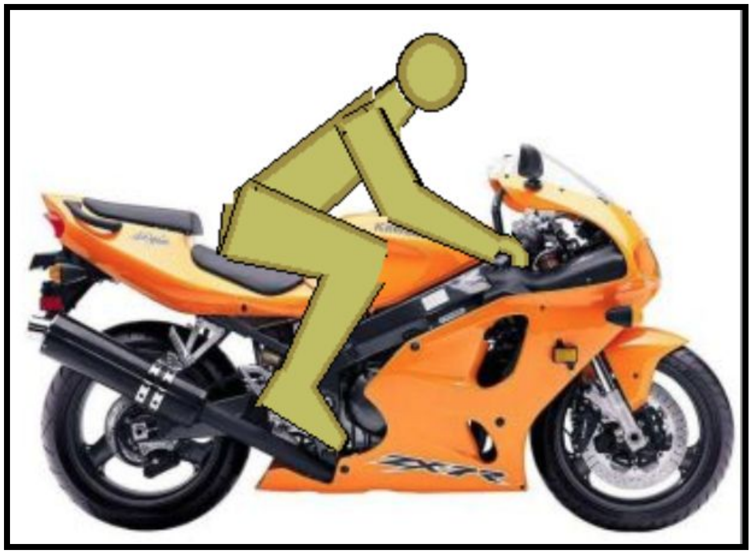


Figure 45: Sport Riding Posture

Option 2: Standard riding posture. This posture is very neutral and allows the most control over the motorcycle during low speed maneuvers and during driving in traffic. Such neutral upright position has the least effect on the rider and puts the least amount of stress on the joints. To achieve such riding position the foot pegs have to move slightly forward compared to the stock location of the foot pegs. The handlebar has to be mounded on the triple tree, and has to be slightly raised and pulled back towards the rider.

Equipped with a handlebar that is raised and pulled back by 5 and 4 inches respectively, the rider will have a new lean angle of 28 degrees, knee angle of 78 degrees and a hip angle of 67 degrees. A two inch offset forward along with a two inch drop of the foot pegs will result in the same lean forward, and a new knee and hip angle of 88 degrees and 71 degrees respectively. such riding position allows to have a good control of the motorcycle over a wide range of speeds while putting the least amount of stress on the joints of the rider.

Figure 46: Standard Riding Posture

Option 3: Cruiser riding posture. This posture puts the rider in a slightly inclined position. The feet are often forward relative to the knees. The controls are slightly higher, the head is upright and neutral. This posture allows the most comfort for the rider. However high speed stability and aerodynamics are marginally worse when compared to a standard and a sport riding position. Equipped with a handlebar that is raised and pulled back by 8 and 7 inches respectively, the rider will have a new lean angle of 8 degrees. A twelve inch offset forward along with a four inch drop of the foot pegs will result in the same lean forward, and a new knee and hip angle of 104 degrees and 76 degrees respectively.

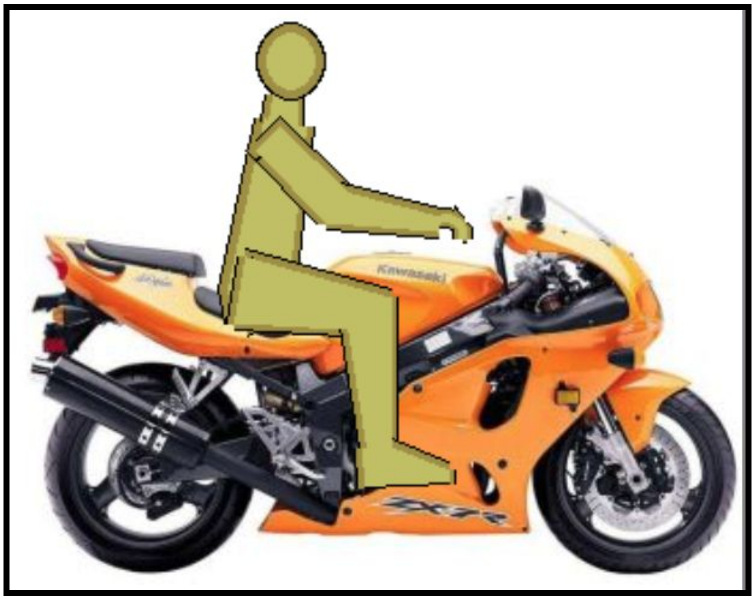


Figure 47: Cruiser Riding Posture

Table 26: Riding Posture Concept Alternatives

Concept Alternatives: Riding posture Concept Alternatives							
Criteria	Importance Weight %	**Option 1**		**Option 2**		**Option 3**	
		Sport Riding Posture		**Standard Riding Posture**		**Cruiser Riding Posture**	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Comfort	30	1	0.3	2	0.6	3	0.9
Low Speed Maneuverability	30	1	0.3	3	0.9	2	0.6
High Speed Maneuverability	10	3	0.3	2	0.2	1	0.1
Weight Bias Towards the Center of the Motorcycle	15	3	0.45	2	0.3	1	0.15
Low overall CG	15	3	0.45	2	0.3	1	0.15

Totals	100		1.8		2.3		2

After evaluating the three different options for the riding posture as seen in Table 25, above, it was decided that the best choice for the AWD E-Moto is a standard riding posture. There were 5 categories that each fork design was evaluated on: comfort, low speed maneuverability, high speed maneuverability, weight bias towards the center of the motorcycle, and low overall center of gravity. It is clear that for purposes of this project standard riding posture will offer the most control over the motorcycle and will be very user friendly. Such riding position will also improve the ease of testing the prototype of the motorcycle during low speed trials and allow for better feedback during testing

6. User Inputs

6.1. Throttle Type

The throttle for biking is normally a potentiometer user input that sends a signal to the controller based on its angle of rotation.The industry standard for Motorcycles is a twist throttle that mounts to the handlebars of the bike. Throttling input comes from twisting the grip forward or backward. When curling the throttle grip backward (towards the rider), on a conventional motorcycle will open the throttle, allowing more air and fuel into the engine. Throttling back or allowing the throttle grip to rotate forward, (away from the rider) will close the throttle, decreasing the amount of fuel and air flowing into the engine until the throttle is closed.

Regenerative Braking

One inherent advantage of an electric motorcycle is the capability to incorporate regenerative braking. While a motor takes electrical energy and converts it into kinetic energy, a generator does the exact opposite. [33]

Commonly used throttles in other E bikes

Figure 48: Microswitch of a regen throttle

Twist throttles are often talked about relative to their resistance. Two common throttles utilizing regenerative braking are Domino & Magura. Ideally we should invest in a throttle that already has a microswitch conductor set up for regenerative braking to reduce the cost of modifying, and to assure reliability. Domino’s new throttle comes with a 5 conductor micro switch built into the internal circuitry, ideal for the team's needs. It also has a larger arc length to turn the throttle compared to a Magura. [32] [33]

Throttle Input Options

Evaluations were made for other options for throttling just in case the team was not skimming over a better idea just because of commonality. So the team evaluated existing devices for throttling input for a pedal and lever system. This are very uncommon options, and non-existent in motorcycles. The team would have to use potentiometer acting pedals and levers, then provide additional mounting for it.

Throttle Selection Conclusion

Table 27: Options for throttle position & genre

Throttle Input Options							
Criteria	Importance Weight %	Option 1		Option 2		Option 3	
		Handlebar Throttle Input		Pedal Throttle Input		Handlebar Lever Throttle input	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Familiarity	20%	4	0.8	2	0.4	1	0.2
Easy to Replace	20%	4	0.8	2	0.4	2	0.4
Low Cost	20%	3	0.6	2	0.4	2	0.4
Simplification	10%	4	0.4	4	0.4	4	0.4
Easy to control	30%	4	1.2	1	0.3	2	0.6
Total	100.00%		**3.8**		**1.9**		**2**

In the end, familiarity and safety are some of the most crucial elements. Meaning that the person that would put time into this would be someone already very involved in the biking world so it would be ideal to make sure that they feel as comfortable as possible while handling the bike. Handlebar twist throttling is the best option, particularly one with an included microswitch for regen-braking.

Additionally, it should be noted that no matter what there will be a common motorcycle mechanical braking system into our design, for obvious precautions.

6.2. Selectable 2WD Control

The purpose of having the switch-among other potential emergencies- is so that when the speed begins to make the hub motor behave more like a generator that actually starts robbing energy, one would want the option to shut it off. An ideal design for this would be to get a simple handlebar switch to attach close to the driver's hand.

6.3. Contactors and Relays

The battery output may be far more than an Allen Bradley E-stop can handles. The vehicle will need an object to intercept the E-stop and the Current flow from the batteries to prevent overwhelming the Contacts. Contactors are normally used for this dilemma, A contactor is really just a relay used to switch on/off a large amount of electrical power.

Contactor Details

- Load Capacity: >9A, <1,000 VAC
- Auxiliary contacts
- Safety features: spring loaded contacts, magnetic arc suppression, & automatic overloading shut off

The Albright SW200 Style Contactor, used in the Royal E-Field Motorbike project is a great choice. In fact, there are actually a large array of potential Albright Contactors. SW200 model is good for 72 volts @ 400A, with a weight of 2.72 lbs. They also have a "Busbar" series that have Current Thermal Ratings ranging from 140-2400 Amperes.[34] Surprisingly they're pretty cheap and used normally for Direct current. The only complication that comes with these Contactors is one would need an additional relay to create a more complex auxiliary system. So if one were looking for better ease for termination and auxiliary input, they might want to look at a series of KAYAL, or ALBRIGHT modular alternatives like an LC1-D DC contactor. [34][36]

7. Electrical Power Transmission

7.1. 12V System

The 12V system will be comprised of all the auxiliary electronics that are still critical to the operation of the motorcycle. The major components in the system will be the pump for the liquid cooled rear motor, the lights, and the main controller. Additionally, the charger and BMS require 12V for operations. Figure 49, is a rough wiring diagram of the control system and some of the components on the auxiliary system.

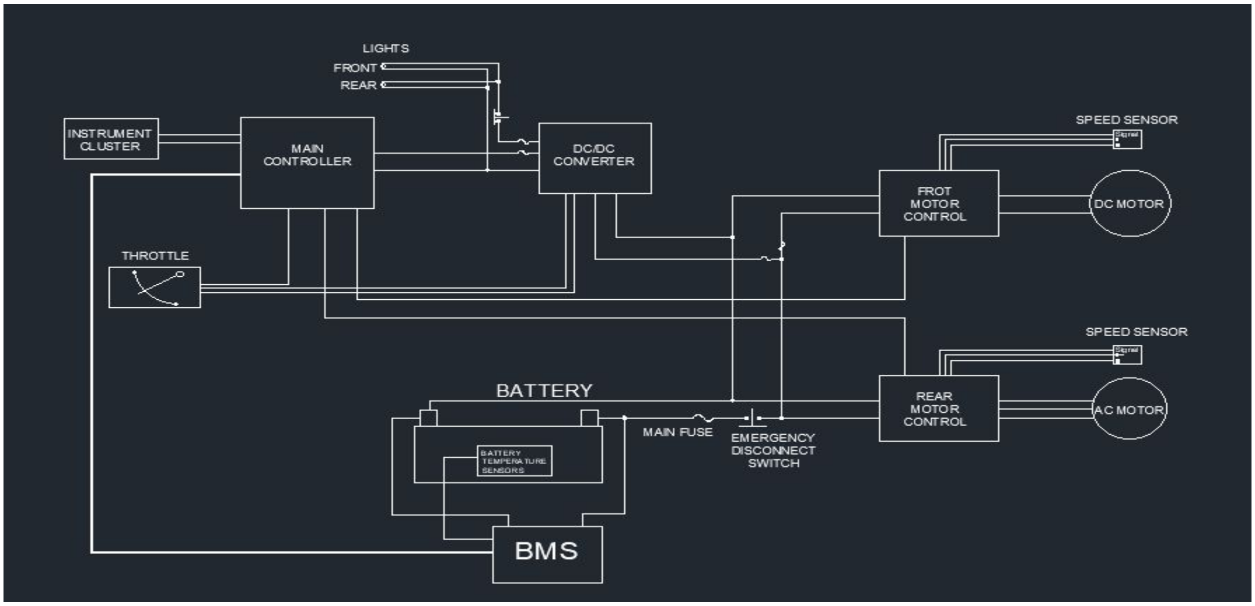


Figure 49: System Diagram [42]

Without the exact wattage rating of the liquid pump, the auxiliary system can be powered by either a DC-DC convertor or a standard 12V automotive grade battery. Because the selected charger supports 12V charging as well charging the primary battery, either approach is equally viable. The deciding factor between an automotive battery and a DC-DC converter will be the total potential power draw of the system because DC-DC converters begin to take up a lot of space, a very limited resource. Furthermore, DC-DC converters can cost 3-4 times the cost of a smaller lead acid battery.

7.2. Contactors

One of the updates planned in the production design is the connector relay. During the on and off position of the main contactor an arc generates inside the relay connectors. The arching can deteriorate the internal components of the contactor. In the electric vehicle industry, a popular design has been adopted to address this problem. In the production design, the same design will be installed in the motorcycle to prevent the premature wear in the main relays. The main contactor will be installed in series with the battery pack. The control pins from the relays will be connected to 12v source from the main key switch and negative from the voltage converter. The cost expected from this addition ranges from $200 to $250 depending on the final components selected [21].

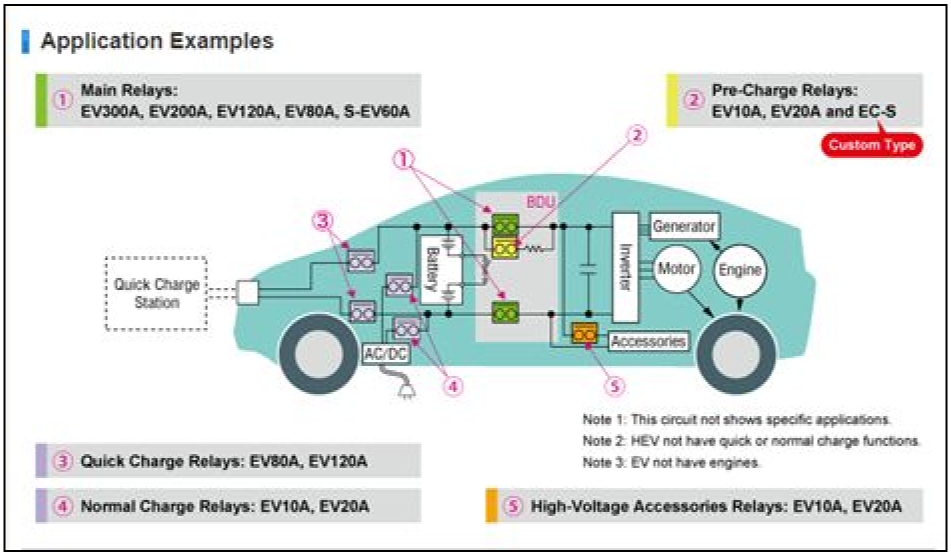


Figure 50: Electric Car Contactor Relay Design: Panasonic Design [21]

8. Feedback Control

8.1. Wheel Speed

It is important to be able to determine the wheel speed for each wheel of the vehicle to ensure safety and avoid inaccuracies in the control system. Since this is an all-wheel drive motorcycle, both wheels will contribute to the speed of the vehicle. The operating conditions of the vehicle, such as whether the vehicle is speeding up or slowing down, whether the vehicle is turning or continuing straight, whether the vehicle is climbing or descending or traveling on a flat surface, and the current speed of the vehicle all will determine the desired power allocated to each motor and the desired wheel speed for each wheel. These factors could also influence the state the motors are placed in. It becomes important, then, to have feedback from outside the control system to report back and describe the actual state of the vehicle and its wheels. The control system will know how much current is being drawn by the motor controllers, and can calculate the theoretical speed, but without external feedback sensors, it will have no way to know with certainty what is actually happening.

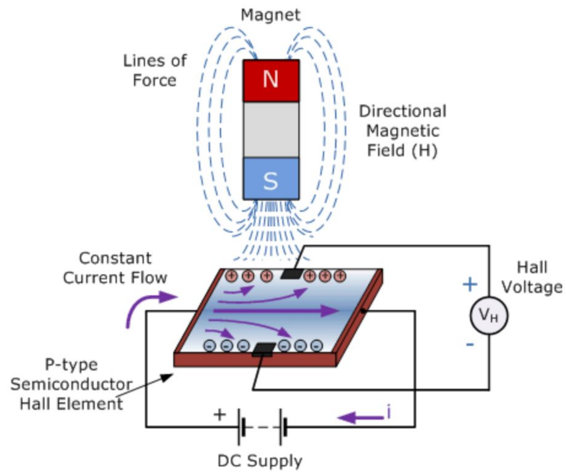


Figure 51: Hall Sensor Processes [42]

The wheel speed for each wheel of the vehicle will be measured by Hall sensors. These are electronic transducers that produce certain voltage readings dependent upon the presence of a magnetic field. As the wheel rotates, magnets inside or outside the motor will rotate and be detected by Hall sensors upon each pass. For this vehicle, three Hall sensors will be used, each 120 degrees electrically out of phase with each other. The number of magnets used will adjust the resolution of the sensors and will be officially determined during testing. These sensors will feed back into the motor controllers which can communicate their readings to the control system over the CAN bus.

8.2. Lean Angle

Lean angle is another important metric that needs to be considered by the control system to help ensure operator safety and motor stability. Since the control system will have no way to know with certainty whether the vehicle is upright, or leaning due to a turn or other circumstances, an external feedback device will need to communicate this information to the system. A gyroscope will be used to measure and relay this information. The electronic gyroscope will be self-contained and mounted as close to the center of gravity of the vehicle as possible, where it can be zeroed on a flat surface. The gyroscope will relay information to the microcontroller, where it can process the changes in the vehicle's axial motion to change the state of the system as needed.