

University of Wales Trinity Saint David

Wales Institute of Science & Art



Research Proposal

Conversion of Internal Combustion Engine Motorcycle Powertrain into an Electric System

L7 – Postgraduate Research Methodology (ACFA7004)

MSc Motorcycle Engineering

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1. Introduction

According to Harvey and Rankin (2020) established in 1990 European Green deal aims to transform the 27-country bloc from a high to a low-carbon economy, without reducing prosperity and while improving people's quality of life, through cleaner air and water, better health and a thriving natural world. Additionally, the goal of EGD is to make Europe climate-neutral in 2050 and European countries resistant to climate changes (European Environment Agency, 2020). Following these recommendations, the United Kingdom came up with The Ten Point Plan for a Green Industrial Revolution, which wants to end the sale of new petrol and diesel cars and vans by 2030 and hybrid cars and vans that can drive a significant distance with no carbon coming out of the tailpipe until 2035 (HM Government, 2020).

After many years of research by the scientific community, it has been learned that man-made GHG emissions are the main cause of the greenhouse effect. In 2017, the largest producer of GHG was energy-producing industries with 29%, while fuel combustion by users was 25.5% and by the transport sector equal 23.8% (Eurostat, 2020). As combustion of fossil fuels is one of the main producers of harmful compounds such as CO₂ and NO_x, leading automotive companies in the world decided to invest in research on new "eco-dives". For instance, Volkswagen Group as the largest car manufacturer in Europe in 2020 announced that will spend around 73 billion Euro on electrification, hybrid powertrains and digital technology over the next five years (Volkswagen, 2020).

The strategy chosen by the world's leading automotive companies has had an impact on the motorcycle industry as well. Motorcycle companies like Honda, Harley Davidson and Zero have started working on electrifying motorcycles. Unfortunately, Honda motorcycles were not very powerful and have a small range from 40 to 87 km, depending on speed (Honda, 2019). On the other hand, Harley Davidson LiveWire and Zero SR/F motorcycles are characterized by a long-range but a lot of weight (235km and 220kg (Harley Davidson, 2021), 259 km and 249kg (Zero Motorcycles, 2021) respectively) which is not desirable in urban conditions. All these bikes have the same thing in common, they are very expensive (Livewire 29'000 \$, SR/F 19'000 \$)

Figures from the Department for Transport (2020) show that traffic speeds have declined across Britain over the past decade, particularly in urban areas, because people travel more often by car to work. Therefore, The Federation of European Motorcyclists' Associations (FEMA) (2018) believes motorcycles and other powered two-wheelers should be actively promoted as a

great alternative for cars. Their conducted mobility test, showed that the motorcyclist needed 53% less time than the user of public transport and also turned out much cheaper than car driving. Another study done in Belgium by Transport & Mobility showed, that a transition from 10% of the car drivers to motorcycling reduced the total travelling time of all road users and the length of the traffic jams by 40% and emissions would be reduced by 6%. Furthermore, FEMA adds that the growing use of electric scooters and motorcycles would even further reduce emissions. What is more, the Great Britain Transport Statistics of 2019 speaks in favour of motorcycles, where it was presented that the average time to travel to work (without traffic) by motorcycle is equal to the travel time by car. Besides, as FEMA stated motorcycles are more practical because they are small and light that not only they can filter through the traffic and reduce the total traffic time for all road users, they also use less space to park.

Emission regulations and the rapid movement towards electrification force motorcycle owners to buy modern, electric alternatives, which, as previously presented, are very expensive. The solution to this problem may be to convert an old motorcycle to an electric version. The sole purpose of this research project is to create the appropriate kit for converting an Internal Combustion Engine powered medium motorcycle to an electric system. The research will provide a discussion of the methodology as well as the complexities of converting an internal combustion motorcycle to an electric motorcycle. The document will contain a detailed overview of each component used for the conversion and the existing state-of-the-art solutions as well as a critical justification for its selection. All components will be properly sized to fit the actual existing motorcycle to ensure the safety and comfort of the rider. Another goal is to align the electric motorcycle's performance with those of the combustion version, to ensure flexibility, appropriate power and usability. To develop the methodology, goals such as speed limits, range, weight, charge times and driving style with the use of a suitable duty cycle will be considered.

2. Industrial Relevance

Although the first induced electric motor was invented in 1887 by Nicola Tesla (Puiu, 2020), and AC motors have been in industrial use for many years, only the last decade has shown a surge in interest in the electric motor as a drive-in vehicle. Every year, sales of electric cars break annual records. According to International Energy Agency (2020) sales of electric cars topped 2.1 million globally in 2019, surpassing 2018 already a record year to boost the stock to 7.2 million electric cars.

As the data presented by International Energy Agency (2020) show, electric cars are slowly replacing internal combustion vehicles, and along with the increase in electric vehicles, the number of charging stations is also growing, where in 2019, there were about 7.3 million chargers worldwide. Where in the UK with over 15,000 public electric vehicle charging devices (UK Department of Transport, 2019).

Nowadays, electric bikes are not that popular, but motorcycle companies are taking it more and more seriously. Harley Davidson, after LiveWire, announced work on a new mid-power electric motorcycle, which is to be released by 2022 (Toll, 2020). And the Zero company is constantly expanding its range of different classes of electric motorcycles (Toll, 2020). Another big motorcycle company that has taken an interest in the topic of electrification is Triumph Motorcycles. Nick Bloor, the Triumph's Chief Executive Officer, announced the work on the Triumph's electric model TE-1 and admitted that:

“Triumph wants to be leaders in the technology that will enable the electrification of motorcycles, which is driven by customers striving to reduce their environmental impact, combined with the desire for more economical transportation, and changing legislation.”

Triumph Motorcycles (2019)

Electric vehicle technology is still being discovered. One of the world's leading sales of electric vehicles Tesla Inc. (Woods, 2021) represented by CEO Elon Musk announced in 2019 that his engineers are working on a "one million-mile battery pack", where their current batteries have a lifespan of 300'000 to 500'000 miles (Cohen, 2019) and a range of 390 miles in the Tesla Model S from 2021 (Tesla Inc., 2021).

Electric motor technology is being developed in parallel with battery technology. Conventionally used and well-proven Induction Motors are slowly being replaced by Switched Reluctance Motors which are better for high speeds and stand out with significant back EMF

reduction and Permanent Magnet Motors with better efficiency, or their combination, called Internal Permanent Magnet Synchronous Reluctance Motor, which has been presented in the new Tesla Model 3 allowing to achieve higher efficiency and greater torque (Learn Engineering, 2020).

The main goal of the research is to gain knowledge about the thematic areas related to vehicle electrification, such as the principle of operation of various types of electric motors, battery technology and their components that let the vehicle move. Research is not trying to prove or disprove a given hypothesis. Research is not simply to be done based on whether a novel concept has been generated. Given that implementing these concepts in everyday life is not complicated, the initial hypothesis would be that the concept would likely offer a more cost-effective option from a user perspective than buying a modern electric motorcycle.

The areas of planned research are as follows:

1. Analysis of modern battery technology, their principles of operation, parameters and configuration,
2. Analysis of electric motors, their principles of operation, parameters and energy recovering,
3. Analysis of battery and motor cooling,
4. Analysis and selection of an appropriate motor controller,
5. Analysis and selection of battery charger and monitoring system,
6. Transmission analysis and selection of the right one for a given motorcycle,
7. Selection of components such as electronic throttle sensor, rider display and diagnostic tool,
8. Sizing of the listed components, using the appropriate duty cycle,
9. Integration of electric components in the existing ICE motorcycle frame and chassis torsion analysis.

3. Literature Review

This topic has been discussed before and many people have individually tried and succeed to convert an ICE powered motorcycle to an electric one, for example, Benjamin Nelson (2018), who showed the entire process of converting Suzuki GS on his website. Another one is Jesse Beeker (2019), which replaced a 50cc two-stroke ICE with an electric power plant in moped and presented it in his work "Replacement of a 50cc Two-stroke Engine with an Electric Powertrain". Many groups of students have also taken up the topic, one of them is Matthew D. Lawrence and Saeed Siovoshani (2020) from Wayne State University, which made the conversion of 2006 Suzuki GSXR and presented this in their work "Step by Step Conversion of ICE Motorcycle to a BEV Configuration".

This paper compares the technology of electric cars to the technology of electric motorcycles because the electric vehicle system for an electric bike is very similar to an automotive electric vehicle. One major difference is driven by the need for a minimal solution due to packaging and cost constraints (Beeker, 2019).

As Ehsani et al. (2005) written in their book electric vehicles (EV) use an electric motor for traction and chemical batteries, fuel cells, ultracapacitors and/or flywheels for their corresponding energy sources. However, in the case of motorcycles, batteries are used for energy storage because fuel cells are too large to fit in the motorcycle frame with the stored fuel (most often hydrogen), and flywheels affect the gyroscopic effect which can make turning the vehicle difficult (Afework et al. 2018).

The use of electric motors as a traction motor has advantages when compared with the ICE, the main advantages are zero-emission, high initial torque (Figure 1) (Bhaskar et al. 2019) and increased overall efficiency (Mazgaonkar et al. 2019). As Bhaskar (2019) stated, battery energy looks to be one of the best way to power electric vehicles. Nevertheless, energy storage is the main issue. Even rapid development in battery technologies was not able to ensure the range that is provided by engine operated vehicles. Range excitement can be increased but the weight of batteries has to be taken instead. What is more, cost of battery technology equals even 1/3 of the vehicle cost.

In a fully electric vehicle parts like engine, multispeed transmission, transfer case, fuel tank, intake-exhaust system, long drive shafts and bearings get eliminated and are replaced by a large

battery system and an electric motor (Mazgaonkar, 2019) so compared to the ICE powered vehicle, electric vehicles have reduced the number of parts.

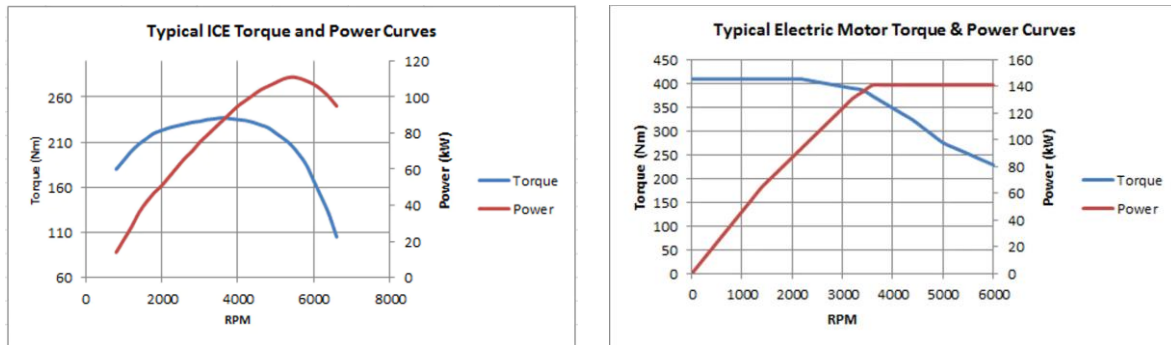


Figure 1 Power and Torque characteristic curves of Typical ICE and Electric Motor (Whitehead, 2019).

As shown above, an electric motor provides full torque from 0 mph, with a linear relationship between how fast the motor is spinning and the power required (Whitehead, 2019).

Electric motorcycle powertrain main parts are a motor, as a replacement for ICE to produce torque to the drivetrain, motor controller as a system controller for the motorcycle, electronic throttle sensor as a replacement to traditional mechanical throttle with cable linkage to the carburettor which provides a command to the motor controller to accelerate the vehicle, battery pack as a power source similar to the fuel tank, and Battery Monitoring System (BMS) (Beeker, 2019). Besides, a mechanical element such as transmission should be added to this, which will transfer the motor's power to the motorcycle's wheels.

As Beeker (2019) describes for safety and functionality reasons, the motorcycle should also have two additional components, a rider interface and a diagnostic tool. Rider interface, which will indicate feedback to the rider from the powertrain, among others, battery health along with remaining range and speed, a diagnostic solution must be provided to perform any service related to potential faults of the system. All of these components must be connected via Control Area Network (CAN) to facilitate robust and flexible data exchange as a means for distributed control.

As the electric motorcycle does not have a charging unit on board, for safety reasons and limited space, the charging unit is off-board but still belongs to the entire system.

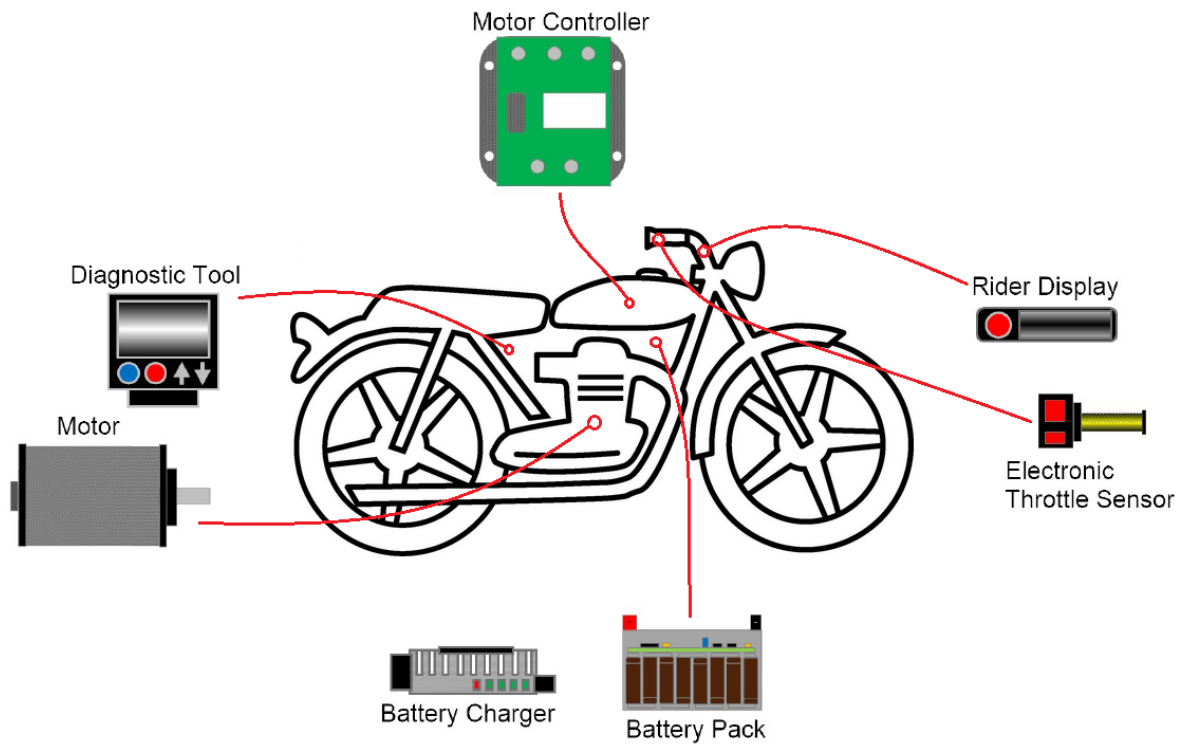


Figure 2 Electric motorcycle powertrain components (Beeker, 2019)

3.1. Traction Model

To successively create an electric motorcycle from an existing ICE powered motorcycle, the energy and power density of the electric powertrain must be taken into account. The e-bike should provide similar metrics to its ICE powered counterpart (Beeker, 2019).

To start the sizing of components, a suitable motorcycle should be selected to meet the requirements. This work focuses on city bikes that are the right weight and size to be agile enough in urban conditions, that should provide fast acceleration during frequent stops as well as short motorway stretches. Motorcycles with 250cc to 350cc engines can be considered such bikes with a suitable weight-to-power ratio. Examples of such bikes include the Honda CB250R or BMW G310R.

After choosing a motorcycle model, the next step is to estimate its electrical requirements and drive power. Using the technical data of the motorcycle, it is possible to estimate the power and energy requirements for a given section of the route. Two examples of such calculation methods are included in the appendix. Method no. 1 presented by Beeker (2019), looks at the driveline and its components as a direct comparison of weight, power and energy. The second and more accurate method, define the amount of energy storage and power needed to drive the electric motorcycle by taking into account road loads.

3.2. Selection of an Electric Motor

The electric motor in EV performs two functions: it converts electric energy from the battery into mechanical energy to make the vehicle move forward, and vice versa, when braking, it converts mechanical energy into electrical energy to recharge the battery (Miller and Lemon, 2013).

Depending on the calculated power and energy requirements of the duty cycle from Method 2 included in Appendix, the traction motor can be selected. The electric motor should be able to operate comfortably at the peak and continuous power demands (Lawrence and Siavoshani, 2020). Based on the business concept, electric power is the amount of effort in moving the charge in units of the time or the amount of electrical energy per second (Siregar et al. 2015). As in formulas below:

$$W = V * I * t \quad (1)$$

Then:

$$P = V * I \quad (2)$$

Where,

W – energy (Joule),

V – voltage (volts),

I – current (amperes),

t – time (seconds)

Having the required power of the electric motor, the next step is to select its type. There are a few types of electric motors used in EVs: Induction Motors, Permanent Magnet Synchronous Motors, Switched Reluctance Motors and DC Motors. Most commonly used are induction motors and permanent magnet motors (Nitabaru et al. 2019). Nevertheless, each of the listed motors has its advantages and disadvantages that should be taken into account when selecting the appropriate type of traction motor in EV appliances. Their merits and drawbacks are shown in the appendix.

3.3. Selection of Battery Pack

The second key component in the electric motorcycle is battery pack. It is the batteries that play a major role when it comes to a vehicle's maximum range, efficiency, charging time and running costs (Miller and Lemon, 2013). Besides, traction batteries were developed to suite the current rating of electric motor used in vehicles (Bhaskar, 2019). Today, there are many types of batteries, the most popular used in EV are: lead acid, nickel cadmium, nickel-metal hydride, molten salt, lithium polymer and lithium-ion batteries. The main factors that define a battery are: specific energy (the amount of electrical energy stored per unit of mass Wh/kg (The Boston Consulting Group Inc., 2020)), specific power, lifespan, performance (temperature stability), cost and safety (Miller and Lemon, 2013). Current generation of EV battery packs mostly use lithium-ion cells with a specific energy of 100-180 Wh/kg and which have expected lifespans of 10 years (Electric Power Institute, 2004). The main reason for this is that Li-ion batteries have high specific energy and power ratings as shown in figure below, as well as excellent efficiency, internal resistance, life cycle and recharging characteristics (International Energy Agency, 2011).

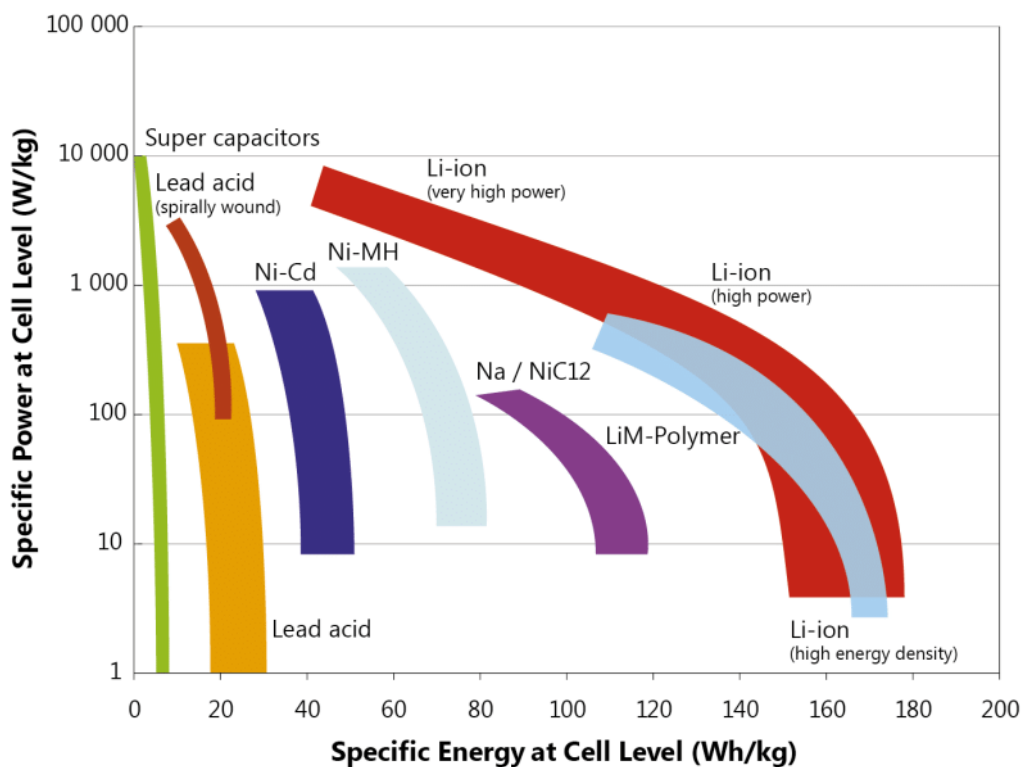


Figure 3 Specific energy and power of the main battery technologies (Miller and Lemon, 2013)

Electric vehicle battery pack is composed of a large number of electrochemical cells, which are assembled into modules within the pack (Miller and Lemon, 2013). As an example, the Nissan's

Leaf battery pack consists of 48 battery modules, each containing 4 lithium manganese spinel cells with a total of 192 cells. Although configurations vary between manufacturers, all battery packs consist of a large number of cells connected in series and parallel to produce sufficient voltage and current to power the electric drive (Automotive Energy Supply Corporation, 2012).

3.3.1. Lithium-ion Battery Types

Currently, there is no single lithium-ion battery technology that meets all the requirements for an ideal battery for electric vehicles (Figure 3). This has led to fragmented development and the adoption of different lithium-ion chemistries by vehicle manufacturers and OEMs (Figure 5 showed in appendix). Different lithium-ion battery types contain different metal alloys in the cathode, and potentially different anode materials. These materials are selected to optimise key battery characteristics such as specific energy and charging performance (Miller and Lemon, 2013). The most famous of which have been or are currently used in electric vehicles are showed on figure below.

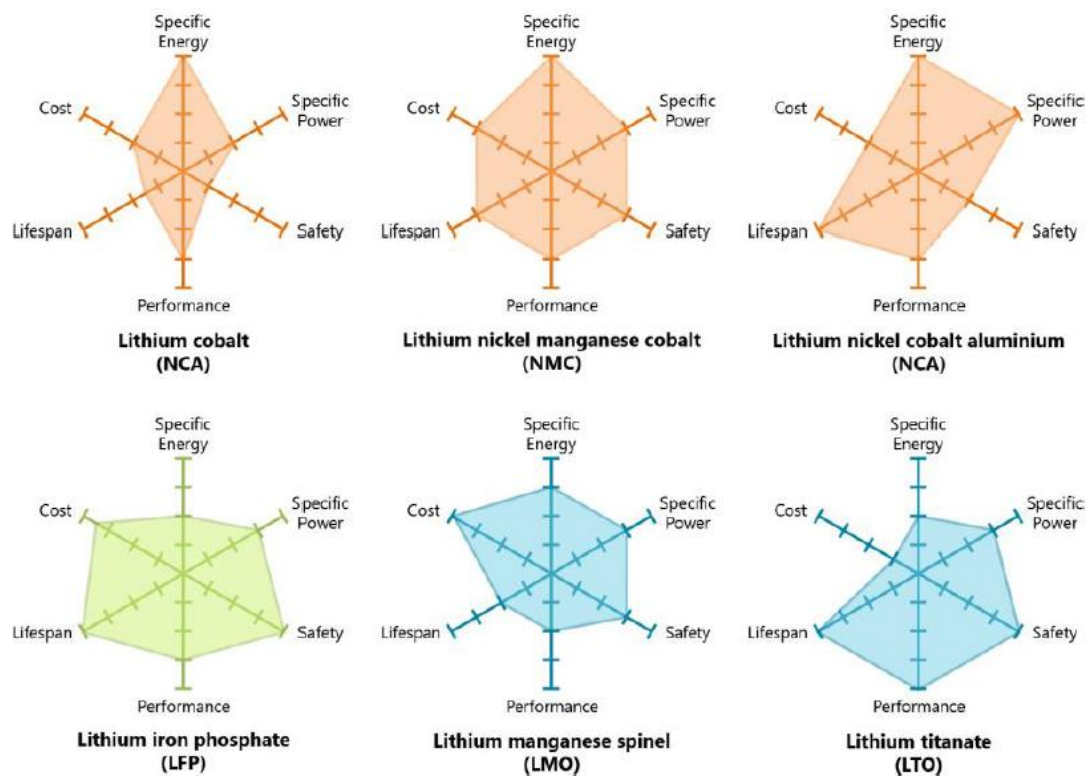


Figure 4 A comparison of lithium-ion chemistries used in electric vehicles (The Boston Consulting Group Inc., 2020)

4. Proposed Methodologies

The methodology of the project is split into 11 main steps, as detailed below:

1. The first step will be to choose a motorcycle that will be used for the EV conversion. The specific choice will depend on being able to access the actual dimensions of the motorcycle frame to then create its 3D model in the Computer-Aided Design Solidworks program. Motorcycles will be considered that do not require major changes to the chassis structure.
2. The second step is to generate the appropriate city cycle, moving the motorcycle through the streets of Swansea equipped with a 2D kit, which will allow to collect data about slope, road surface and motorcycle speed. The route should be long enough to take into account all aspects of city traffic, such as stop and go in traffic with occasional accelerations and high-speed events like sections of the highway.
3. Third step is the modelling to make an equation of tractive effort to determine how much load and how much energy is used during the generated duty cycle. Then a comparison of the created cycle to the WLTP and WMTC cycle. Modelling will be performed in Simulink software, using Method number 2 presented in the Appendix. On this basis, it will be possible to determine the energy requirements of the system and the average power that the electric motor must generate. This approach will enable adequate sizing of traction motor, battery pack and necessary components to propel the vehicle.
4. The fourth step is critical analysis and research on all components for electrical powertrain, such as motor, battery, motor controller, battery management system, transmission and others. Their properties and functionality in a given type of vehicle, dimensions and weight will be taken into account.
5. The fifth step is the modification of the fuel tank to install the battery pack in its place.
6. The sixth step is the creation of a wiring schematic, which will enable the connection of all-electric powertrain components with CAN. This is a necessary step to ensure that each component is supplied with power. After doing this, it is possible to integrate the whole system.
7. The seventh step is system integration, i.e. fitting all components in the motorcycle's frame using the Solidworks software. Component placement is a very important activity

as the motorcycle's frame is not designed to accommodate all of the electrical components. Therefore, to fit them all, custom brackets must be created. The main goal is to keep the frame in its original condition without major alterations to reduce conversion costs. All safety considerations and the cooling of the electric motor and battery must also be taken into account, therefore each component must be rigidly mounted in the right place on the motorcycle frame.

8. The eighth step is aesthetics and appearance. During the conversion, most of the fairings were removed, therefore, to provide better aerodynamics, appearance and cover to the attached electric powertrain parts, new fairings will be modelled in the Solidworks software.
9. The ninth step is torsion analysis on the frame to verify the stiffness of the designed is within range of the stock frame of the donor motorcycle.
10. The tenth step is to reuse the created duty cycle to simulate the course of driving the finished electric version of the motorcycle. The weight change will be taken into account. Then the performance of the electric version will be compared to the version equipped with ICE.
11. The eleventh step is a critical analysis of the profitability of such conversion and a discussion of the difficulties and problems associated with it.

4.1. Alternative method

An alternative measurement method would be to physically use a real motorcycle and then convert it to an electric version, however, the significant time and cost that would be involved in conducting the conversion would be required is very prohibitive. This would allow for not only real performance data to be obtained, but also conduct a far more in-depth battery life study. Nevertheless, the main purpose of this work is to research and sizing the components that would be most suitable for this type of conversion to ensure a similar performance with the version equipped with ICE.

5. Results Collection & Analysis

Primarily, the data obtained will be quantitative, by searching for relevant articles as well as websites of individual people who have taken up such a challenge. Based on their experience, problems and difficulties associated with this research will be explored. However, an element of more subjective, qualitative data is expected to be gathered during the research and conceptual phases of the project. This is likely to take the form of market research in which the design concepts and philosophies of existing manufacturers are collated and analyzed.

Probably the most important metric that is to be analyzed is the sufficient energy and power supplied on the wheel of an electric motorcycle. Because, without the appropriate parameters of the motor and the battery, the vehicle will not provide sufficient force to move the motorcycle forward.

The problem may be getting the real dimensions of the motorcycle frame. Exact dimension data will be needed to create a 3D model. Nevertheless, should such an opportunity arise, the data will be compiled by dimensioning a real motorcycle at the university's workshop. Thanks to this, further integration of the system will be possible.

6. Project Planning/Timescales

Below is the research process time plan (bigger version in appendix). The project will start on May 15, 2021, due to the examinations that preceded it. The most time-consuming part will be Literature Review and modelling in Simulink and Solidworks software. The report will be generated in parallel with the modelling in Solidworks. Planned completion of the project on 09/15/2021.

DISSERTATION

Mateusz Gręś

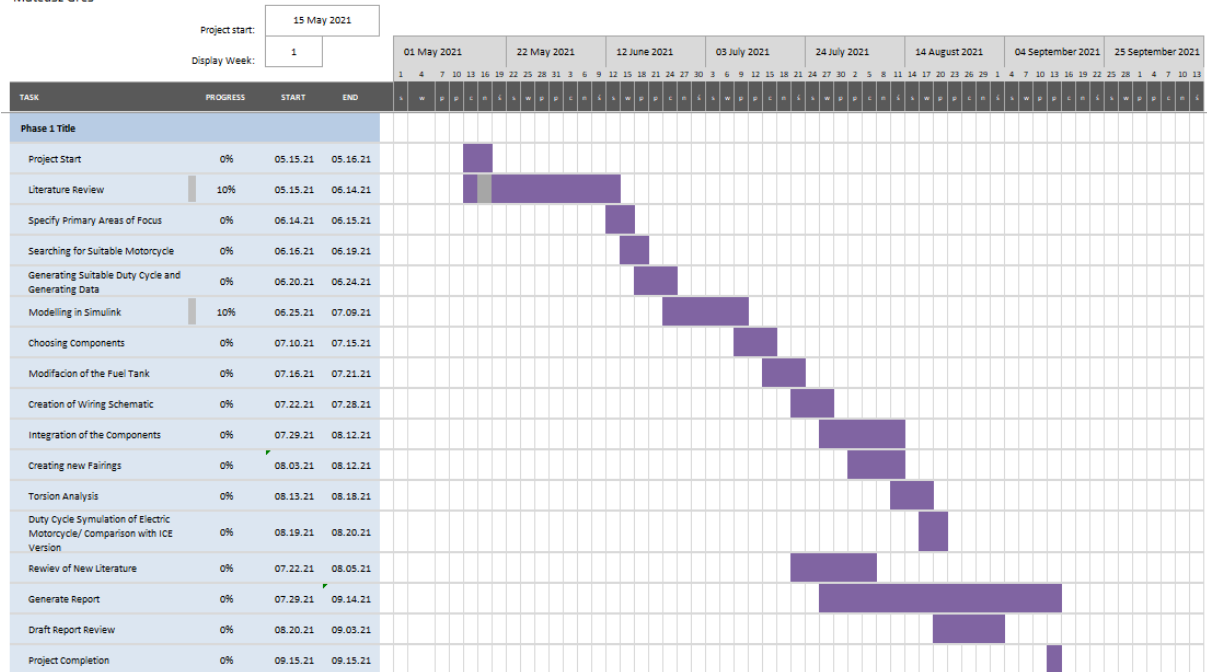


Figure 5 Gannt Chart - Timescale

7. Evaluation

It is a belief that the proposed research project is of great importance in the modern world, where legal regulations are aimed at limiting the production of greenhouse gasses. Widely used electrification in all industries is a step forward in improving air quality and creating an environment that is more friendly to living organisms.

As previously mentioned, motorcycles can be an alternative to passenger cars as a means of everyday transport. However, due to the narrow market of electric motorcycles, and hence their high price. Hopefully, by using the conversion of existing bikes equipped with an Internal Combustion Engine into an Electric Powertrain, it is a more economical option. Which will allow to easily, without major interference in the structure of the motorcycle, change the less economical and environmentally harmful Internal Combustion System into an electric equivalent, which will not only ensure cheaper travel, but also zero emission of harmful compounds to the atmosphere, and will contribute to the reduction of GHG.

It should be noted that the project has some limitations where the main area of research weakness is due to limited time and finances. A real bike conversion would give real data on the exact weight of the kit, the true energy consumption during the duty cycle, and the exact fit of the components. Moreover, this would allow an accurate calculation of the efficiency of the entire electric powertrain system and a comparison with the simulation data.

One of the most important aspects of the project is to consider it as a way to learn more about modern electric vehicle technology. To achieve this, there is no formulated hypothesis surrounding the scope of the research, which allows for the orientation of the work of the obtained data rather than risking the hypothesis to bias the data analysis.

8. Nomenclature

EV – Electric Vehicle,

ICE – Internal Combustion Engine,

WMTC - Worldwide Harmonised Motorcycle Emissions Certification,

WLTP - Worldwide Harmonised Light Vehicle Test Procedure,

FEMA - The Federation of European Motorcyclists' Associations,

GHG – Greenhouse gasses,

EGD – European Green Deal,

TTE – Total Tractive Effort,

CEO - Chief Executive Officer,

CAN – Control Area Network,

PM – Permanent Magnet Motor,

IPM - Interior Permanent Magnet Motor,

SPM - Surface-Mount Permanent Magnet Motor,

SRM – Switched Reluctance Motor,

IM – Induction Motor,

AC – Alternating Current,

DC – Direct Current,

BLDC – Brushless Direct Current Motor,

EMF – Electromotive Force,

BMS – Battery Monitoring System.

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Appendix

1. Traction Model

Below are the technical specs of the Honda CB 250R.

Table 1 Honda CB250R 2019 technical specs (Motorbike Catalog, 2019)

Weight to power ratio (with driver -75kg)	10,9 kW/kg
Power	20 kW (9000 RPM)
Torque	23 Nm (8000 RPM)
Weight	142 kg
Top speed	142 km/h
Acceleration [0-100 km/h]	7,8 s
Transmission	Manual (6 gears)
Fuel consumption (city)	2,9 - 3,5 litre / 100km
Fuel consumption (highway)	4,5 – 5,4 litre / 100km
Fuel tank	10 litre
Average range	300 km

1.1. Method 1

The method presented by Beeker (2019), is the individual specification approach, where the quick and practical method for determining electrical requirements and feasibility can be achieved. This method looks at the driveline and its components as a direct comparison of weight, power and energy. The starting point is the source of energy, in the case of Honda, it is gasoline with an energy value of 9.5 kWh (Heywood, 1988).

Using equation 3, the energy for a Honda fuel tank is approximately 95 kWh.

$$Energy\ Consumed = Energy\ Density/Volume\ Consumed \quad (3)$$

On the other hand, assuming that the motorcycle travelled at an average speed of 60 km / h, and to cover 300 km at this speed, 5 hours are needed, its power consumption, using formula 4, is 19 kW.

$$Power\ Consumption = Energy/Time \quad (4)$$

The result is quite satisfactory, but unfortunately, the thermal efficiency of the engine and energy losses during the transmission of power from the engine to the wheels, which for a motorcycle is about 12%, should also be taken into account (Auto Tech, 2016).

So using formula 5 ultimately of 95 kWh is 11.4 kWh that is used for propulsion.

$$\text{Propulsion Energy} = \text{Energy Consumed} * \text{Engine Mechanical Efficiency} \quad (5)$$

However, using formula 6, the overall propulsion power is 2.28 kW.

$$\text{Propulsion Power} = \text{Power Consumption} * \text{Engine Mechanical Efficiency} \quad (6)$$

Knowing Propulsion Energy for an ICE equipped motorcycle allows for the reverse calculation to get an equivalent electric powertrain specification. The goal of an electric bike previously stated is to achieve equal performance with an ICE powered motorcycle. Therefore, estimating the efficiency of the entire electric power train as 85% (Lawrence and Siavoshani, 2020) and using formula 7, it is possible to determine the appropriate electrical energy storage requirement, which for this motorcycle is 13.4 kWh.

$$\begin{aligned} \text{Electrical Energy Storage Requirement} \\ = \text{Propulsion Energy} / \text{Electrical Efficiency} \end{aligned} \quad (7)$$

However, to reduce the battery size and overall weight of the motorcycle, capacity will be reduced by approximately 1/3. This will ensure the appropriate range of the motorcycle for urban conditions, and the weight reduction will increase agility in urban conditions. Therefore, the battery capacity should be around 8 kWh.

Having data such as the average propulsion power and energy storage requirement allows to define appropriate powertrain and investigate components such as cost, weight, safety and design.

Table 2 Target specifications for an electric powertrain to replace an ICE engine

Specification	ICE Powertrain	Electric Powertrain
Weight [kg]	142	142 (or equivalent)
Energy Stored [kWh]	95	13,4 (8 needed)
Efficiency [%]	12	85
Energy for Propulsion [kWh]	11,4	11,4 (6,8 needed)
Range (km)	300km	300km (approx. 200km needed)
Average Propulsion Power [kW]	2,28	2,28

1.2. Method 2

A more accurate method to define the amount of energy storage and power needed to drive the electric motorcycle is the method that takes into account road loads. The first step is to create an appropriate duty cycle that will be generated for the requirements of such a motorcycle or to use commonly used cycles such as The World Motorcycle Test Cycle (WMTC) which is a system of driving cycles used to measure fuel consumption and emissions in motorcycles (Moawad and Rousseau, 2014), part 1 contains a lot stop and go riding or Worldwide Harmonized Light Vehicle Test Procedure (WLTP) class 3 (WLTP Facts EU, 2016).

For such a model, the original motorcycle specifications presented in Table 1 are needed, as well as the actual weight of the rider with all accessories and outfit. To build the model, calculate all resistances acting on the motorcycle during the duty cycle.

Based on Wong (2011), the resistances acting on the vehicle include:

Rolling Resistance:

$$F_{ROLL} = \mu_r * m * g \quad (8)$$

Gradient Resistance

$$F_{GRAD} = m * g * \sin\theta \quad (9)$$

Acceleration resistance

$$F_{ACC} = m * a \quad (10)$$

Aerodynamic Resistance

$$F_{AERO} = \frac{1}{2} * \rho * A * C_d * v^2 \quad (11)$$

Where,

m – total mass of vehicle and rider [kg],

g – gravity constant [m/s^2],

a – vehicle's acceleration [m/s^2],

A – vehicle's frontal area [m^2],

μ_r – rolling resistant coefficient,

θ – road gradient [$^\circ$],

v – vehicle's velocity in [m/s],

ρ – air density [kg/m^3].

Using these formulas, the Total Tractive Effort can be counted. TTE is the force at the rims of the outer edges of the moving vehicle's driving wheels, coming from ICE/E-motor powered by petrol/battery (Vashist, 2019).

$$F_{TTE} = F_{AERO} + F_{ROLL} + F_{GRAD} + F_{ACC} \quad (12)$$

With the Total Tractive effort and radius of the wheel the torque required to the wheels can be calculated (R_w).

$$T_w = F_{TTE} * R_w \quad (13)$$

Possessing torque on the driven wheel, the gear ratio of the transmission (i_g) gear ratio of the final drive (i_o) and efficiencies of transmission (μ_t), it is possible to calculate the torque of ICE/Electric Motor.

$$T_{ICE/EM} = \frac{T_w}{i_g i_o \mu_t} [Nm] (Ehsani et al. 2005) \quad (14)$$

Whereas the rotational speed of the ICE/Electric Motor (N_p), from the equation below:

$$N_p = \frac{v * 30 * i_g i_0}{\pi * R_w} [RPM] (Ehsani et al. 2005) \quad (15)$$

Then:

$$P_{ICE/EM} = \frac{T_{ICE/EM} * N_p}{9549,3} [kW] (Wong, 2001) \quad (16)$$

Thanks to these calculations, from the formula for engine torque, it is possible to determine the required power in each second of the tested cycle using formula no. 12. Therefore, the battery can be sized appropriately to meet the demands of the motor. When power is negative, it means regenerative braking is occurring. For EV applications a traction motor acts as an integrated starter and generator to provide assistant torque to the powertrain, to recover kinetic energy during braking by charging a battery and then to provide fast engine restart (Gao and Long, 2010).

2. Savings

With use of the data presented in Table 2, it is possible to estimate how much money can be saved on commuting and how much harmful carbon dioxide will not be released into the atmosphere.

Assuming, that to cover a 70 km way to work and back, a motorcycle equipped with ICE requires 2.45 litres of gasoline. Where, at the current price of Fuel of £ 1.2, this would be £ 2,94. However, charging the batteries at home at 0.17 pounds per kWh, 70 km will cost 0.4 pounds. So for every 70km, £ 2.52 can be saved.

Estimating, there are 240 working days a year, it turns out that around £ 605 can be saved on commuting in a year. On the other hand, assuming that one liter of gasoline produces 2.3 kg of CO₂ (Natural Resources Canada, 2014), and that for 70 km it is 5.64 kg. In this case, carbon dioxide emissions can be reduced by as much as 1,354 kg per year.

For comparison, as on the official website of Viessmann Werke (2021), it says a typical fully grown tree can absorb around 21 kilograms of carbon dioxide per year. So, about 65 trees are needed to absorb carbon dioxide from the ICE version of the motorcycle used just as a work transport. Moreover, humans are creating about 40 billion tonnes of CO₂ each year, meaning that we would need to plant 40 billion trees annually to offset the emissions created. Even if this were possible, land space would be significantly reduced (Viessmann Werke, 2021). These numbers show how important it is for our ecosystem to reduce harmful particles.

3. Traction Motor Selection

3.1. Induction Motor (IM)

An induction motor or asynchronous motor is an AC electric motor in which energy comes from magnetic fields generated through coils wrapped around the output shaft (Power Electric, 2020).

In recent years, induction motors (IM) attract increasingly higher interest in electrified propulsion system designs due to their low costs, good robustness and independence of rare earth materials, which have high price volatility. Furthermore, induction motors are efficient at high rotor rpm and can spin without EMF loss at no-load conditions at different environmental conditions, which makes it an ideal candidate to boost electric traction torque for performance EV applications (He et al. 2020).

The disadvantages of IMs include slightly lower efficiency compared to Permanent Magnet motors. Higher power losses, which are increased because of the cage losses, however, it can be reduced by using better motor design. Moreover, relatively low power factor, nevertheless, the weakening of the flux can be used to extend the speed range in the constant power operation region with the use of dual inverters (Osmanbasic, 2020).

3.2. Direct Current Motor (DC)

DC electrical motors convert direct current electrical energy into mechanical energy (Storr, 2020). They have easy speed control and can withstand a sudden increase in load. However, they have the main drawback of high maintenance due to brushes and commutators. Nevertheless, DC Motors are divided into Brushed DC Motors and Brushless DC Motors (BLDC), where commutation is done electronically, making BLDC Motors maintenance free. BLDC motors are characterized by high efficiency around 95-98% and high power density. BLDC Motors are also divided into an in-runner type where the rotor of the motor is present inside and the stator is outside like conventional motors and into out-runner type (Karthik, 2019).

Out-runner type is very popular on mopeds, scooters and bicycles because the rotor of the motor is present outside and the stator is present inside, so the wheel is directly connected to the exterior rotor. This type of motors does not require an external gear system. In a few cases, the motor itself has inbuilt planetary gears, allowing to reduce the weight of the motorcycle as it does not need a gear system and free up space in the motorcycle frame that can be used to add

a battery pack. However, this construction has limitations as to the size of the motor (Karthik, 2019).

3.3. Permanent Magnet Synchronous Motors (PMSM)

PMSM is composed of three-phase field winding in the stator, and permanent magnets mounted in the rotor (Miller and Lemon, 2013). PMSMs have been widely used as traction motors for EV applications due to their high power density, high efficiency across wide operating conditions, and relative ease for high precision control (He et al. 2020) small size and because they do not need field windings, they do not have field circuit copper losses (Greg, 2017).

Unfortunately, there are also disadvantages of PM motors, permanent magnets cannot produce a high flux density as that as an externally supplied shunt field does, risk of demagnetization of the poles and also because the operating principle of PMs is based on magnets, the magnetic field is present all the time (Greg, 2017). In addition they depend on expensive rare earth metals such as neodymium for creating the strong permanent magnets (Elvestad, 2008).

3.4. Switched Reluctance Motor

The topic of Switched Reluctance Motors as an application for compact electric vehicles has been extensively covered by Nitabaru et al. in their article in 2019. In this work, the author listed the following properties of SRMs that they do not require permanent magnets, have no drag torque and enable clutchless motor applications. Moreover, they are demonstrating high efficiency in the high-speed rotation range, high power density and they are simple in construction and robust (Karthik, 2019). However, as an application for electric vehicle two drawbacks are occurring.

The first drawback is generating torque ripples produced due to the principle of torque generation, which can result in a vehicle start-up failure on an uphill. The second drawback is the occurrences of excessive phase currents or phase currents that do not contribute to torque (Nitabaru et al. 2019). Such currents can be produced during the shift between positive and negative torque that is required during SRM control and regenerative braking. Nevertheless, they can be overcome by using a new commutation method. Compared to BLDC motors SRMs require switching between the power running control and regenerative braking. For this reason, a very important aspect is to establish a commutation control method that can effectively switch the modes (Nitabaru, 2019).

Vehicle Model	Type	Motor (kW)	Motor Type	Battery (kWh)	Battery Chemistry	Battery Supplier
Audi A3 e-tron	EV	20	AC PMSM	26.5	Lithium manganese spinel	-
Audi e-tron Spyder	PHEV	30	AC PMSM	9.1	Lithium manganese spinel	-
BMW ActiveE	EV	125	AC HSM	32	Lithium nickel manganese cobalt	SB-Limotive
BMW i3	EV	130	AC HSM	22	Lithium nickel manganese cobalt	SB-Limotive
Bolloré Bluecar	EV	50	AC WRSM	30	Lithium vanadium oxide	Bolloré Group
BYD e6	EV	75	AC PMSM	48	Lithium iron phosphate	BYD Energy
BYD S6DM	PHEV	85	AC PMSM	16	Lithium iron phosphate	BYD Energy
Chery M1EV	EV	45	AC PMSM	16	Lithium iron phosphate	China BAK Battery
Chevrolet Spark EV	EV	100	AC PMSM	20	Lithium iron phosphate	A123 Systems
Chevrolet Volt	PHEV	111	AC PMSM	16	Lithium nickel manganese cobalt	LG Chem
Citroën C-Zero	EV	47	AC PMSM	16	Lithium titanate	GS Yuasa
Coda Sedan	EV	100	AC PMSM	31	Lithium iron phosphate	LIO Energy Systems
Detroit Electric e63	EV	150	AC AFPM	25	Lithium polymer	-
Dodge Circuit EV	EV	200	BLDC	26	Lithium iron phosphate	A123 Systems
Fiat 500e	EV	83	AC PMSM	24	Lithium iron phosphate	A123 Systems
Fisker Karma	PHEV	120	AC PMSM	20	Lithium iron phosphate	A123 Systems
Ford C-Max Energi	PHEV	88	AC PMSM	7.6	Lithium nickel manganese cobalt	Magna/JCI-Saft
Ford Focus Electric	EV	107	AC PMSM	23	Lithium nickel manganese cobalt	Magna/JCI-Saft
Honda Fit EV	EV	92	AC PMSM	20	Lithium titanate	GS Yuasa
Hyundai BlueOn	EV	61	AC PMSM	16.4	Lithium polymer	LG Chem
Indica Vista EV	EV	55	AC PMSM	26.5	Lithium iron phosphate	Energy Innovation Group Ltd.
Lumeneo Neoma	EV	34	AC PMSM	14.2	Lithium nickel manganese cobalt	Dow Kokam
Lumeneo Smera	EV	30	AC PMSM	9.3	Lithium nickel manganese cobalt	Dow Kokam
Mia Electric	EV	9.7	AC PMSM	8	Lithium iron phosphate	EVida
Mitsubishi i-MiEV	EV	47	AC PMSM	16	Lithium titanate	GS Yuasa
Nissan Infiniti LE	EV	100	AC PMSM	24	Lithium nickel manganese cobalt	AESC
Nissan LEAF	EV	80	AC PMSM	24	Lithium manganese spinel	AESC
Peugeot iOn	EV	47	AC PMSM	16	Lithium titanate	GS Yuasa
Renault Fluence ZE	EV	70	AC WRSM	22	Lithium manganese spinel	AESC
Renault Zoe	EV	65	AC WRSM	22	Lithium manganese spinel	AESC
Reva L-ion/G-Wiz	EV	13	AC PMSM	9.6	Lithium manganese spinel	-
Smart Fortwo ED	EV	30	AC PMSM	15	Lithium iron phosphate	Tesla/Li Tech
Subaru G4e	EV	65	AC PMSM	-	Lithium vanadium oxide	-
Tazzari Zero	EV	15	AC IM	12.3	Lithium iron phosphate	-
Tesla Model S (40 kWh)	EV	175	AC IM	40	Lithium nickel cobalt aluminium	Panasonic
Th/nk City	EV	37	AC IM	4.4	Zebra battery or lithium ion	A123 Systems
Toyota Prius PHV	PHEV	60	AC PMSM	4.4	Lithium nickel cobalt aluminium	Panasonic
Toyota RAV4 EV	EV	115	AC IM	41.8	Lithium nickel cobalt aluminium	Panasonic
Volvo C30 DRIVE Electric	EV	82	AC PMSM	24	Lithium nickel manganese cobalt	EnerDel
Wheego Whip	EV	45	AC IM	30	Lithium iron phosphate	Flux Power

Figure 6 Electric motor and battery specifications for current generation electric vehicles on the market (Miller and Lemon)

DISSERTATION

Mateusz Gręś

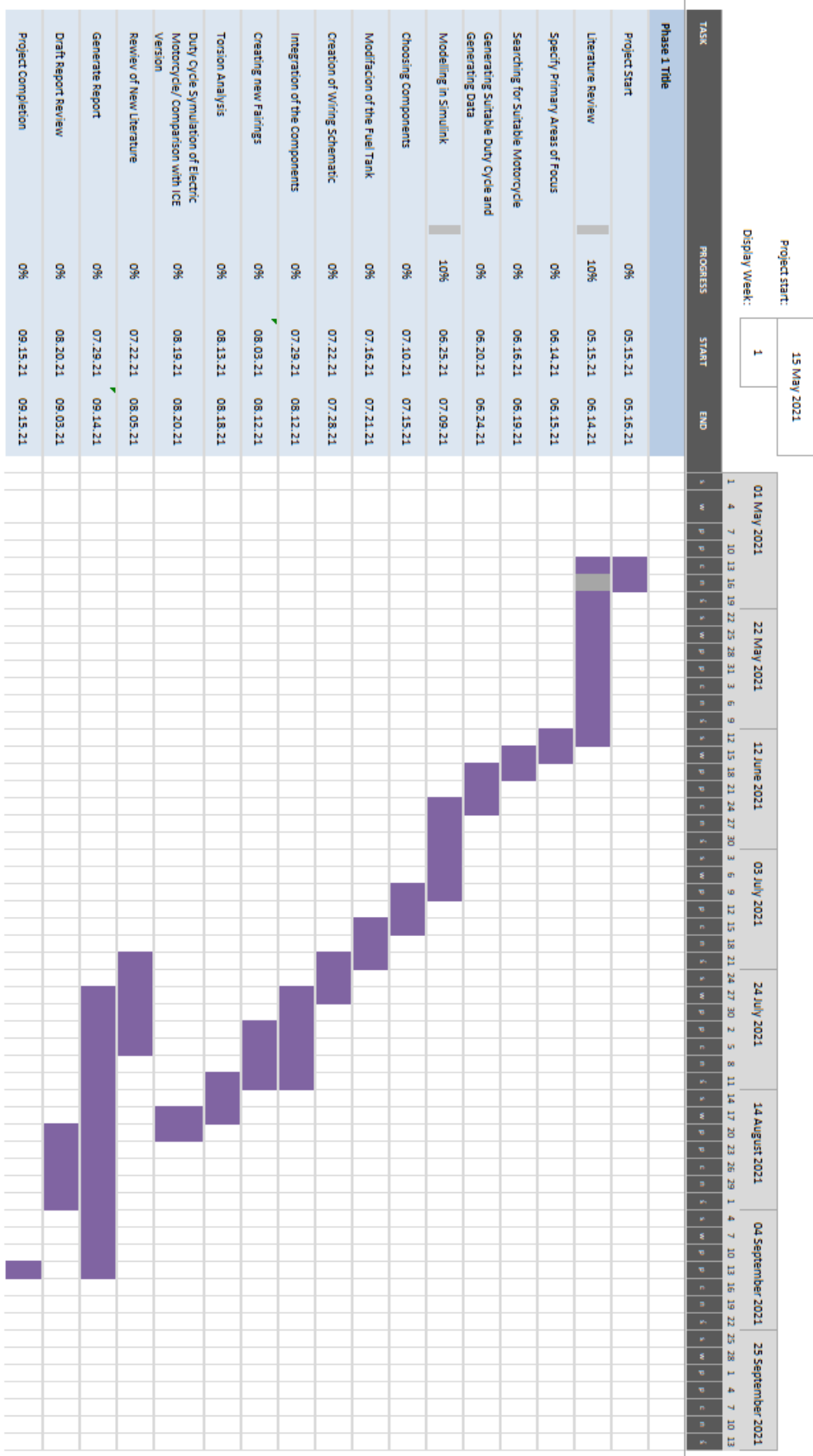


Figure 7 Gantt Chart Timescale (bigger version)