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FACULTY OF ENGINEERING

Hybrid Motorcycle Modeling and Analysis Using GT-SUITE Program

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GRADUATION PROJECT REPORT

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ABSTRACT

Today, as a result of the increase in environmental pollution and resource use, different searches and different solutions come to the fore. The main reasons for these problems are the use of fuels obtained from petroleum and the increase in the need for these fuels. In order to prevent these problems, the use of electric motors in motor vehicles has gained importance with the advancement of technology.

In this project, it is aimed to transform internal combustion motorcycles into hybrid motorcycles due to reasons such as environmental pollution, oil reserve problems and increasing fuel costs. In this study, literature studies were examined. As the first part of this study, the historical development of hybrid electric vehicles, advantages and disadvantages of fully electric vehicles, advantages and disadvantages of hybrid electric vehicles, subsystems used in hybrid vehicles, information about hybrid motorcycles are examined.

Then, modeling was done on the program used in line with the determined criteria. This modeling was run for analysis in line with the created parameters and determined cases. In line with the obtained performance data, speed data, acceleration data and fuel consumption data, analyzes and evaluations related to electrical technology and hybrid technology were made.

ABBREVIATIONS

ICE	:Internal Combustion Engine
EV	:Electric Vehicle
HEV	:Hybrid Electric Vehicle
PHEV	:Plug-in Hybrid Vehicle
ACIM	:Asynchronous Motors
DCM	:DC Motors
BLDC	:Brushless DC Motors
PMSM	:Permanent Magnet Synchronous Motors
SRM	:Switched Reluctance Motors

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1. INTRODUCTION

1.1. Historical Development of Hybrid and Electric Vehicles

The first completely electric vehicle model was developed by Professor Stratingh in the Netherlands in 1835. Also, in 1838, Robert Davidson produced the electric locomotive that could reach a speed of 6.4 km / h. Lead-acid batteries were developed after 1859 and started to be used in electric vehicles. In 1882, Siemens manufactured the world's first electric trolleybus, called the Elektromote, in Berlin. In 1886, Karl Benz produced and offered for trade the first automobile powered by an internal combustion engine, the Motorwagen. In 1895, Morris and Salomon developed the electric vehicle called Electrobats. In England, 15 electric taxis were started to be used by the "London Electric Taxi Company" in 1897. In 1901, the "New York Taxi" company started to use electric vehicles as taxis. In 1900, the French Electroautomobile and in 1903 the Krieger electric-gasoline vehicles were produced, and the hybrid configuration model was tested for the first time. The experimental design of the first hybrid electric vehicle was maden by the Ferdinand Porsche in this period and named it "Mixt Wagen". "Woods Motor Vehicle Company" produced the Hybrid Electric Vehicle in 1916. The parallel hybrid electric vehicle model was developed by connecting the four-cylinder gasoline engine in the vehicle directly to the electric motor/generator assembly and also to the front drive axle via the conventional pusher shaft. From the early 1920s to the 1960s, almost all electric vehicle manufacturers continued their production using internal combustion engines.[1]

While interest in electric vehicles declined between 1920 and 1960, internal combustion engine vehicles were the center of attention around the world. The main reasons behind the decrease the interest in electric vehicles were the following;

- As a result of the improvement of the physical conditions of the intercity roads in the USA, the need for longer-range vehicles began,
- Gasoline prices falling with the discovery of crude oil in Texas,
- Charles Kettering invented the starter motor in 1912. As a result, there is no need to manually turn the crank to give the engine its first movement,

- Henry Ford started to the mass production of vehicles with internal combustion engines and vehicle costs started the decrease. While the selling price of electric vehicles was around $1,750 in 1912, gasoline vehicles were around $650.

Electric vehicles could not produce a competitive environment due to the above situations. There were almost no electric vehicles on the market in the 1935s, and development studies were not carried out until the 1960s. It has been understood over time that the gases released from internal combustion engines cause air pollution, and therefore some small-scale manufacturers have started to produce electric vehicles to avoid air pollution. Thus, the interest in electric vehicles started to increase again in the 1960s. The oil crisis in the mid-1970s also caused many countries such as America, England, Germany, France, Italy and Japan to accelerate their electric vehicle research again. In the 1980s, governments began to increase the interest in electric vehicles due to their environmental friendliness and to provide economic support from official sources. After 1990, with the newly developing battery technologies, many vehicle companies started to develop electric vehicle models.[2] With the development of electric vehicles, studies have accelerated to eliminate some of the deficiencies and problems that arise in these models. In line with these studies, the importance given to hybrid electric vehicles is increasing.

1.2. Electric Vehicles

When it comes to electric vehicle, all kinds of wheeled vehicles that are powered by an electric motor come to mind. Electric vehicles work by transmitting the electrical energy accumulated in the batteries by various methods to the engine. The vehicle wheel is driven by the rotor, which is in the electric motor and is in motion by turning. As the rotor rotates, electric current is transmitted, electrical energy is converted into motion energy. Electric vehicles generally consist of the battery required for energy storage, the electric motor for the propulsion system, the motor driver to drive the electric motor, and the powertrain for the mechanical transmission. In all electric vehicles, a secondary power source can be used to supplement the main battery. Additional power sources can be batteries and supercapacitors. These auxiliary power supplies can provide high power for short periods in peak operating conditions of the vehicle (for example, during hill climbing or acceleration). We have heard frequently in the vehicle market recently, Tesla Model S, is an example of electric vehicles.[3]

Electric vehicles have many advantages but there are any disadvantages as well as advantages.

1.2.1. Advantages and Disadvantages of Electric Vehicles

Advantages ;

- Low emission; the energy needed by the electric motor is provided by batteries. Here, the energy required for the emergence of power is obtained not from the combustion of fuel, but from batteries. Therefore, gasoline, diesel or other combustible fossil fuels are not used in EVs. For this reason, since no fuel is consumed in EVs, no environmentally polluting emissions are released and these vehicles are called "zero emission vehicles".
- Low noise and vibration
- High Efficiency
- Low cost in maintenance and repair; since the number of parts that need to be lubricated and adjusted are less compared to conventional vehicles, maintenance and repair costs are lower.
- Energy recovery; due to the regenerative braking in the braking mechanism, longer brake life is provided and kinetic energy is recovered and converted into electrical energy. This energy gained during braking charges the batteries.[4]

Disadvantages ;

- Cost of electric vehicles; one of the most important factors affecting the EV market negatively is the high cost of these vehicles. For example; General Motors' EV1 model is available for $33995, while the gasoline Chevrolet Cavalier is available for $13670. The main reason for the high cost of EVs is the high cost of batteries. Although the production cost is high in EVs, they are lower in fuel consumption and fuel costs compared to conventional vehicles. For example; The average annual fuel cost of conventional vehicles is $690, while EVs average $390 to $480.
- Service stations; with the launch of EVs, these vehicles must also have sufficient service stations to perform the necessary maintenance and service work. However, sufficient service stations and personnel have not been provided yet. With the

development of this technology, studies are carried out with the aim of eliminating these deficiencies.

- Vehicle range: the range of the batteries that provide the wheel drive in EVs is limited. While vehicles using fossil fuels can travel an average of 600 kilometers with a full tank, EVs can travel an average of 200 kilometers after being fully charged. This is an important obstacle to the increase in the use of EVs.
- Battery technology: in EVs, the charging time of the batteries is quite long. While the tanks of vehicles using fossil fuels are filled in 5-6 minutes, an average of 5-8 hours is required to fully charge the EVs.[5]

1.3 Hybrid Electric Vehicles

HEVs are vehicles with multiple power systems. These power systems are the electric motor and the internal combustion engine. In HEVs, the wheels can be driven by an electric motor or by both an internal combustion engine and an electric motor. The aim of HEVs is to develop a hybrid structure that combines the advantages of electric vehicles and internal combustion engine vehicles in order to overcome the range and power problems seen in electric vehicles. [6]

HEV energy conversion system consists of energy storage system, power unit and vehicle propulsion systems. HEVs generally consist of sub-elements such as ICE, transmission, electric motor, fuel tank, battery and power electronics. Batteries, supercapacitors and flywheels are mainly used for energy storage. Batteries are used for energy storage in today's HEVs. Auto engines, diesel engines, gas turbines or fuel cells are used as hybrid power units. HEVs can be classified as serial hybrid, parallel hybrid, series-parallel hybrid vehicles according to which type of engine the power required for the drive of the wheels is provided. In addition to these systems, there are also plug-in hybrid vehicles (PHEV). Examples of HEVs are Toyota Yaris, Toyota Prius and Kia Niro.

1.3.1. Series Hybrid, Parallel Hybrid, Series-Parallel Hybrid (Complex) Vehicles

In hybrid electric vehicles, the wheels can be driven by an electric motor or by both an internal combustion engine and electric motors. As such, hybrid vehicles have been diversified among themselves according to the combination of engines driving the vehicle. There are 3 types of hybrid vehicles: serial hybrid vehicles, parallel hybrid vehicles and serial-parallel hybrid vehicles. In series hybrid vehicles, there is no mechanical connection between the internal combustion engine and the wheels. The wheels are driven by electric motors. The internal combustion engine in serial hybrid vehicles provides energy for the electric motor. Parallel hybrid vehicles are vehicles in which the internal combustion engine and electric motor drive the vehicle together. The internal combustion engine and the electric motor are mechanically interconnected. Serial-parallel hybrid vehicles, show the characteristics of both serial and parallel vehicles, as the name suggests. These vehicles have an internal combustion engine, generator and electric motor. They are mechanically linked to each other. Various functions such as charging the battery, power sharing in the power transmission of the motors are performed together or separately according to the necessary conditions. The structures of series hybrid, parallel hybrid and series-parallel hybrid vehicles are shown in Figure 1, Figure 2 and Figure 3 below, respectively.[7]

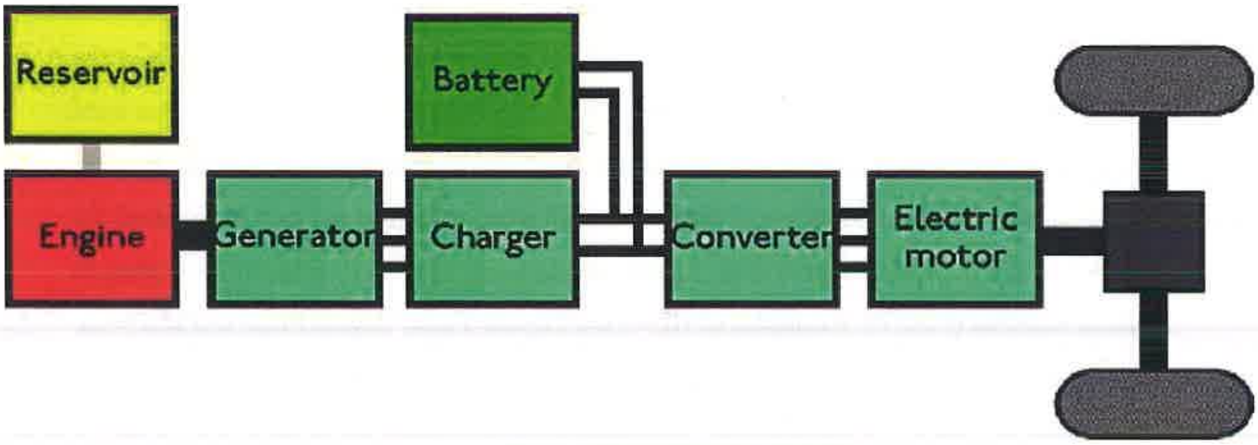

Figure 1 Series Hybrid Vehicle[8]

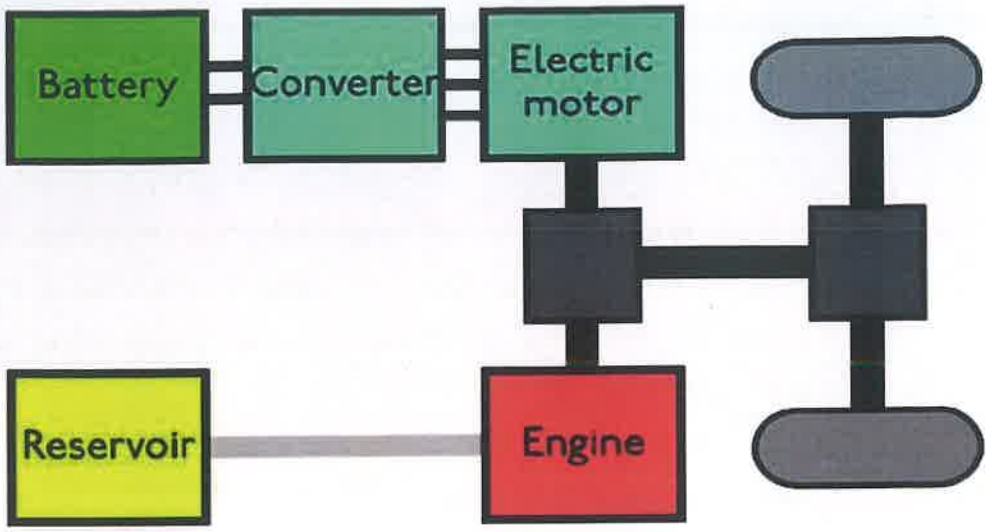

Figure 2 Parallel Hybrid Vehicle[8]

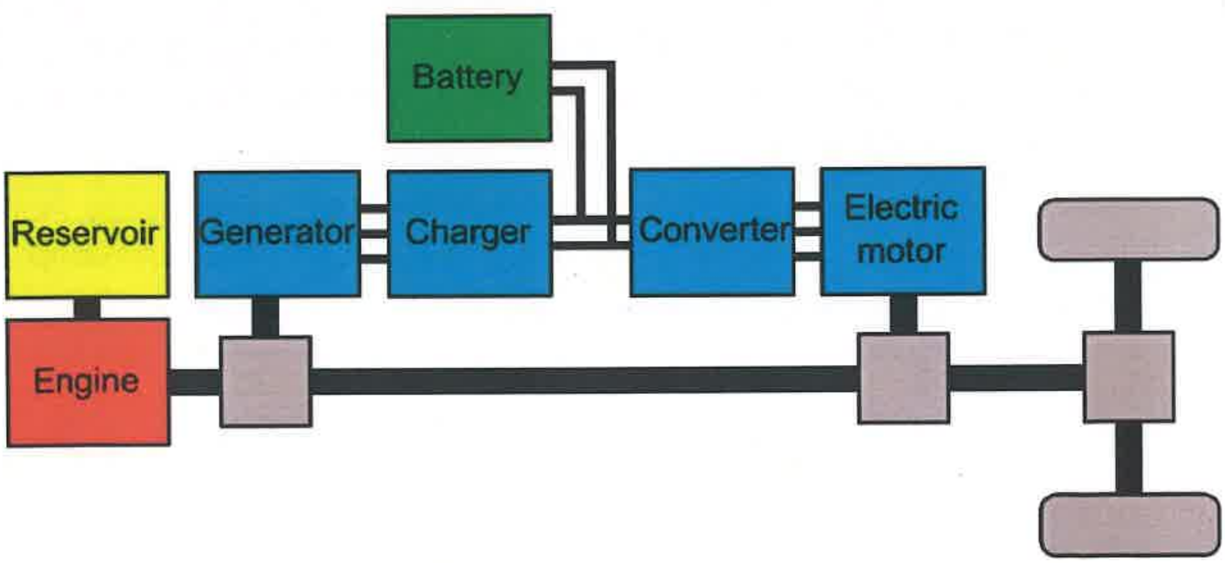

Figure 3 Series-Parallel Hybrid (Complex) Vehicle[9]

1.3.2. Advantages and Disadvantages of Hybrid Electric Vehicles

Advantages ;

- Low emission; the greenhouse gas emission of HEVs is lower than conventional vehicles, but higher than that of EVs. Compared to the HEV conventional vehicle, greenhouse gases and pollutants are 55% lower.

- Fuel efficiency; HEVs have higher fuel efficiency than conventional vehicles. Fuel consumption of HEVs in the same range is 30% lower than that of conventional vehicles.
- Energy recovery; the regenerative braking system found in EVs is also available in HEV. Due to the regenerative braking in the braking mechanism, longer brake life is provided in hybrid vehicles. When the vehicle stops or slows down during braking, kinetic energy is recovered and converted into electrical energy. This energy gained during braking is stored in the battery.
- Dependence on fossil fuels: HEV can also work with alternative fuels. In this way, they are not too dependent on fossil fuels.
- Energy recovery; Due to the regenerative braking in the braking mechanism, longer brake life is provided and kinetic energy is recovered and converted into electrical energy. This energy gained during braking charges the batteries.
- Weight: ICEs used in HEVs are designed to meet the average load instead of the peak load. This reduces the weight of the engine. The reduced weight of the engine also contributes to fuel efficiency.
- Noise and vibration; when the vehicle stops, ICE does not start and because the engine is not running, vibration or engine noise does not occur. In this way, the operating losses of HEVs at idle are almost non-existent.[4]

Disadvantages;

We will list the disadvantages of hybrid vehicles, the disadvantages of serial hybrid system and parallel hybrid systems separately

Disadvantages of the serial system;

- In the serial hybrid system, three propulsion equipment is needed, namely ICE, generator and electric motor.
- The electric motor is specially designed for high slopes to meet the maximum power required. However, the vehicle often runs under maximum power.
- Propulsion equipment is sized to meet maximum power for range and performance, taking into account battery capacity at the first level.
- The power system is heavy.
- The cost is higher.[10]

Disadvantages of the parallel hybrid system;

- Energy management is difficult here as the required power is supplied from two different propulsion equipment.
- Complex mechanical elements are needed in order to properly transmit the power from the ICE and the electric motor to the drive wheels.
- In some cases, the 2 drives do not provide a quiet operation mode.[11]

1.4 Hybrid Motorcycles

Maximum efficiency and maximum performance are aimed in hybrid vehicles. In hybrid vehicles, electric energy can be stored to a certain extent by regenerative braking as well as the charging process in electric vehicles in order to store electrical energy in batteries. Such advantages also increase the orientation towards hybrid engines.

Some motorcycle companies around the world are developing hybrid motorcycles. Our aim in this project is to transform an existing motorcycle with a conventional internal combustion engine into a hybrid motorcycle by making the necessary changes and adjustments. This motorcycle is already equipped with an internal combustion engine. Necessary modifications will be made on this engine, not to drive the wheels, but to provide the necessary power to the electric motor that will drive the wheels, as in serial hybrid vehicles. The electrical energy produced by the internal combustion engine will be stored in suitable batteries found as a result of the necessary calculations. The stored energy in the batteries is sent to the electric motors to drive the wheels, according to the motorcycle's energy needs. When choosing the electric motor, the first thing we need to pay attention to is the volume of the motor and its ability to meet the desired power. When the engine size grows, it causes weight gain and takes up too much space on the motorcycle. This is something we would not want. In order to prevent this situation, the necessary calculations will be made in the later parts of the study and the appropriate engine will be decided. In the following parts of the study, it will be decided which gearbox will be used, which engine type, which battery type, etc., by making necessary evaluations and calculations, taking into account the advantages and disadvantages.

2. MATERIAL AND METHOD

2.1. Motorcycle with an Internal Combustion Engine and Specifications.

In this project, firstly, a motorcycle model with an internal combustion engine will be determined. This model should be suitable for hybrid transformation and analysis.

Considered specifications;

- Design and conformity
- Power and performance data of the internal combustion engine
- Dimensions
- Meeting the expectations of the person who will use it
- Fuel efficiency
- Having suitable for urban and some long-distance
- Having a suitable engine for conversion

The internal combustion engine must meet expectations both in terms of power and fuel efficiency for daily use and long-term use.

To work on this project; Considering the specified features, the most suitable motorcycle type and engine characteristics among the models produced and sold in our country until this time are the "Qooder QV4" model and the engine of this motorcycle.

The biggest reason for choosing such a model for this project is that the design and dimensions of this model are both more suitable for electric motor and battery additions and provide comfort in terms of use.

In addition to its design, the internal combustion engine, which has an engine volume of 400 cc, can meet expectations in daily urban use and some long road conditions. The 23.8 kW power and 38.5 Nm Torque values also show that the internal combustion engine will offer a performance that will meet the expectations unless it is under very difficult conditions.

Figure 4 Motorcycle Model and Design

Capacity	400cc
Bore x Stroke	84 x 72mm
Engine layout	Single cylinder, four-stroke
Engine details	Liquid-cooled, four-valve
Power	32.5bhp (23.8kW) @ 7,000rpm
Torque	28.4 lb-ft (38.5Nm) @ 5,000rpm
Top speed	140 km/h
Transmission	Automatic
Average fuel consumption	4.3 L / 100km
Tank size	14 litres
Max range to empty (theoretical)	260 km
Dimensions	2200mm x 840mm 1360mm (LxWxH)
Kerb weight	280kg

Table 1 Engine Specifications

2.2. Electric Motor

In electric and hybrid vehicles, different types and types of electric motors are preferred according to the way of use. These are Brushed DC motors (DCM), Asynchronous Motors (ACIM), Permanent Magnet Synchronous Motors (PMSM), Brushless DC Motors (BLDC) and Switched Reluctance Motors (SRM), the internal structures of which are shown in Figure.

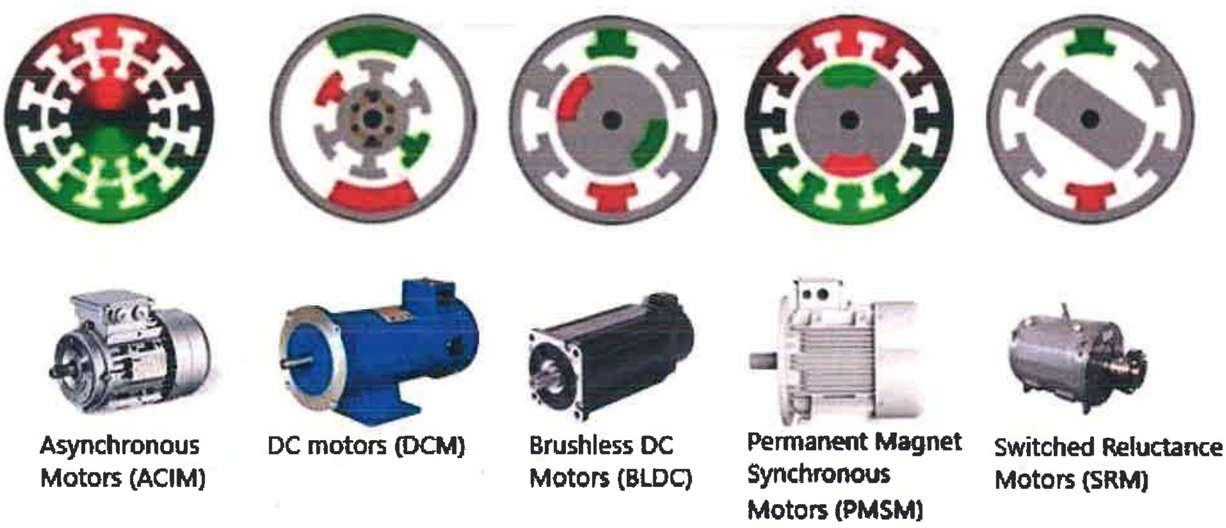

Figure 5 Types of Electric Motors[12]

2.2.1 Asynchronous Motors (ACIM)

The asynchronous induction motor is based on the principle of electromagnetic induction, in which conductors in a changing magnetic field induce an EMF along the conductor. The motor rotates with the interaction of the rotor and stator flux. The advantages of the induction motor are structural simplicity, low cost and low maintenance. No sparking brushes. Therefore, they can be operated in explosive areas, polluted environments with water and dust. The disadvantage is that speed control is difficult. The motor runs at low power factor. Therefore, some power factor correction devices are required. High copper losses lead to a decrease in efficiency. Too much air gap can lead to a decrease in efficiency and sometimes to mechanical friction.[13]

2.2.2 DC Motors (DCM)

A DC motor is one in which the field winding is connected in series to the armature winding. It has brushes and has mechanical commutation. The advantage of DC series motor is that it produces high starting torque.[14] During this condition the motor draws less current and power. DC series motor is widely used in traction because the torque produced is directly proportional to the square of the current. The disadvantages are that the speed regulation is poor and the motor should be loaded before starting. The lifetime is short. Mechanical brushes are susceptible to wear and tear. The electric noise is high. The speed-torque characteristic is moderately flat.

2.2.3. Brushless DC Motors (BLDC)

Brushless DC motor is a synchronous motor in which the rotor rotates at the same speed as the stator. It differs from the conventional DC motor by replacing the field winding of the rotor with a permanent magnet. Brushless DC motor or Permanent magnet Brushless DC motor is also called BLDC. Its power density is high thanks to its small dimensions.[13] Since there are no field windings, the losses are less. Their yields are high. By using permanent magnets, the motors have eliminated the need for energy to produce magnetic poles. Disadvantages; motor is more costly than DC series and AC induction motors. The mechanical strength of the magnet makes it difficult to generate a large torque in the motor. BLDC motors do not have brushes to limit the speed, but the internal rotor type motors still have problems with the fixation density of the magnet as it restricts the maximum speed.

2.2.4. Permanent Magnet Synchronous Motors (PMSM)

Permanent magnet motor is a synchronous motor in which the rotor rotates at the same speed as the stator. It differs from conventional motor in construction where the field winding of the rotor is replaced by permanent magnet.[14] The permanent magnet synchronous motor is also called as PMAC (Permanent Magnet AC motor), when the emf induced is of sinusoidal shape. They feature greater torque density and good efficiency. The DC supply powers the permanent magnet or brushless motor, which features electronic commutation as opposed to mechanical commutation. Since they lack field windings, their efficiency is great and losses are minimal. Its cost is the only drawback compared to DC series and AC induction motors.

2.2.5. Switched Reluctance Motors (SRM)

Switched reluctance motors are electrical machines with an extremely simple structure and installation compared to other multi-phase electric motors. Since both the stator and rotor have salient pole structure, these motors are also called double salient reluctance motors. Switched reluctance motors are simple motors that only have a winding on their stator and no windings or permanent magnets on their rotor. Since they do not have windings or permanent magnets in their rotors, they can reach very high speeds. Advantages; The absence of windings or permanent magnets in the rotor greatly simplifies its production. Since the phases are independent of each other, the motor continues to run even if any phase fails. High power and torque can be obtained. It is easy to cool because there is only winding on the stator. Its efficiency is quite high. Disadvantages; A sensor must be connected to the motor shaft in order to know which phase will be stimulated and when. The stator inductance is large and a large voltage occurs at the ends of the winding inductance at the moment of switching. If there is a delay in passing from one phase to the other, the torque will decrease and high noise will be generated.

Criterion	DCM	ACIM	PMSM	BLDC	SRM
Cost	0	++	-	-	+
Torque / Power Density	-	0	++	++	0
Efficiency	-	+	++	++	+
Simplicity	++	++	0	+	+
Ease of Control	++	++	+	+	++
Reliability	-	++	+	+	++
Size	-	+	++	++	+
Overload Capacity	-	+	+	+	++

Durableness	0	++	+	+	++
Fault Tolerance	+	++	-	-	++
Lifetime	-	++	+	+	++

Table 2 Criteria and Evaluations of Electric Motor Types [13]

In this project, I chose Brushless DC Motors (BLDC) as the type of electric motor I will base the analysis on by examining the data in Table 2.

The reasons for this are;

- Since it is considered for a motorcycle, the dimensions of the electric motor and battery to be added are of great importance. In terms of size, the best measurements are provided for this type.
- Since the main purpose is to create a more efficient and less costly hybrid motorcycle, a good engine should be selected for efficiency.
- Torque and power values must be suitable for the motorcycle.

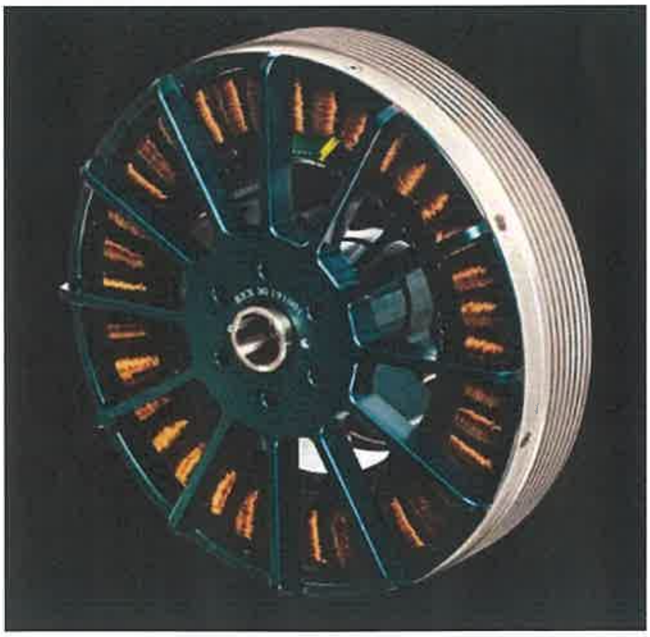

Figure 6 MGM COMPRO Electric Motors[15]

Peak Power	25 kW
Diameter	216 mm
RPM	6000-7000 RPM
Max. Torque	70 N.m
Rotor Length	50 mm
Weight	5250 g

Table 3 Specifications of Electric Motor

2.3. Battery

Batteries use the electrochemically stored form of electrical energy. The operating system is fed directly with the direct current energy generated as a result of the electrochemical reaction. As energy outputs, the chemical energy in the battery is directly converted into electrical energy. Numerous cells make up batteries.

In electric and hybrid vehicle applications, batteries are required to have high specific power (the power given by the unit mass of the energy source), high specific energy (the amount of energy stored in the unit mass of the energy source) and long cycle life. These parameters are directly effective for energy efficiency. Spcifications and datas of battery types are given in Table 4.

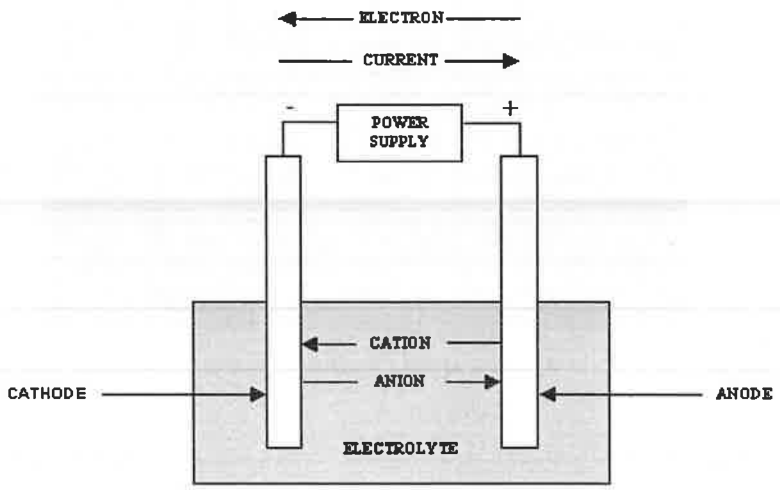

Figure 7 Recharging a Cell [16]

Type of Battery	Maximum Energy Density (Wh/kg)	Maximum Power Density (W/kg)	Number of Cycles	Open Circuit Cell Voltage	Anode Material	Cathode Material
Lead-Acid	35	150	1000	2.1	PbO_2	Pb
Nickel-Iron	50	100	2000	1.2	Ni	Fe
Nickel-Zinc	70	150	300	1.7	Ni	ZnO_2
Nickel-Cadmium	50	20	2000	1.2	Ni	Cd
Nickel-Metal	70	200	2000	1.23	Ni	Metal Hydride
Sodium-Sulfur	110	150	1000	2.1	S	Na
Sodium-Nickel	100	150	700	2.2	NiCl	Na
Lithium-Iron	150	300	1000	2.1	FeS_2	LiAl
Lithium-Polymer	200	350	1000	2.5	Li	Black Acetylene
Lithium-Ion	140	140	1000	3.7	Carbon Addition	$LiCoO_2$
Al-Air	220	30	-	1.5	Al	O_2

Table 4 Specifications of Types of Battery [4]

2.3.1. Lead-Acid battery

They are widely used in internal combustion engines. They serve as the first motion battery in all ICEs. It consists of a negative lead electrode, a positive lead dioxide electrode, and a sulfuric acid electrolyte solution. Generally, 6 cells are connected in series to provide approximately 12 volts. These types of batteries are also the most widely used batteries in electric vehicles. However, lead acid batteries with gel electrolyte rather than liquid electrolyte are used in electric vehicles, which are more durable and resistant to deep cycles. The cost of these batteries is very high. The life of the lead acid battery is around 1000 cycles. The approximate life in electric vehicles is 1000 cycles or 5 years.

2.3.2 Nickel-Iron Battery

It was developed by Thomas Edison in 1901 to enable electric vehicles to travel longer distances. Nickel iron batteries are reliable, long-lasting, but expensive batteries. What makes nickel-iron batteries advantageous is that the negative electrode uses hydrogen absorbed in a metal hydride.

2.3.3 Nickel-Zinc Battery

Since the dendrites on the zinc plate during charging shorten the service life of rechargeable nickel-zinc batteries, the usage area of these batteries has not become widespread. Recently, it has become possible to use it in EVs due to its high power and energy density feature. The main problem in these batteries is that their lifetime is as short as 300 cycles due to dendrite formation.

2.3.4 Nickel Cadmium Battery

In recent years, nickel-cadmium (NiCd) batteries are accepted as the batteries that provide the best balance in terms of specific energy, specific power, cycle life and reliability. Therefore, research and applications on these batteries are increasing.

2.3.5. Nickel-Metal Hydride Battery

Nickel-metal hydride (NiMH) batteries have recently replaced nickel cadmium batteries in many electric vehicle applications because they have better performance, are not toxic property, and store more energy than nickel cadmium batteries.

2.3.6. Sodium-Sulfur Battery

The battery consists of a negative sodium electrode and a positive sulfur electrode. The battery operates at high temperatures (350 °C) and both electrode components are in liquid state. This is also a disadvantage for these batteries and prevents their widespread use.

2.3.7. Sodium-Nickel Battery

In a sodium-nickel battery, nickel chloride is the positive electrode and sodium is the negative electrode. A sodium chloride electrode is used instead of the sodium salt electrolyte in order to lower the saturation point.

2.3.8. Lithium-Iron Battery

It is the third high temperature battery with high potential use in electric vehicles. Lithium is more preferred for use in batteries, especially since it has a high electrode potential that provides superior energy storage capability.

2.3.9. Lithium-Polymer Battery

Difference of other high-temperature batteries, the lithium-polymer battery uses conductive polymers instead of molten salt electrolyte. It is possible for the battery to operate at low power, at outdoor temperatures.

2.3.10. Lithium-Ion Battery

The structure of lithium-ion cells is similar to lithium-polymer battery cells. However, instead of the negative lithium metal plate, a negative "host" such as graphite or tin oxide is used. During discharge, lithium ions pass from the negative “host” to the positive “host” with the help of the organic electrode.The opposite happens during charging. Lithium ions move like a pendulum between the cathode and the anode. These batteries are charged to 80% charge in less than 1 hour.

2.3.11. Aluminum-Air and Zinc-Air Battery

Another type of battery used in EVs and HEVs is metal-air batteries. Zinc and aluminum are the most preferred metal electrodes in these applications. All metal air batteries use thin gas-permeable cathodes and alkaline water-based electrolytes such as potassium hydroxide.

The battery type that will be taken as an example in this project, to be used in modeling and whose specifications will be used is the battery model with Lithium-Ion batteries. For this battery, Li-Ion batteries were used and the battery assembly was created.

Voltage (V)	3.7
Capacity (mAh)	5000
Dimensions	65 x 26 mm
Weight	92 g
Standart Charge	1 A
Maximum Charge	5 A
Instant Amperes	10 A
Operating Temperature Range	-20°C ~ +60°C

Table 5 Cell Specifications

The model of the battery used and specifications;

- 4 cells are connected in parallel. A group of 3.7 V 20 Ah is formed.
- 6 groups are connected in series. A 22.2 V 20 Ah module is formed.
- There are 10 modules which are connected serial in total in the battery. A 222 V 20 Ah Li-Ion battery is formed.

2.4. Regenerative Breaking

In the case of braking in vehicles with internal combustion engine, the braking energy is converted into heat energy by friction and disappears. Along with the regenerative braking in electric vehicles and hybrid electric vehicles, it is aimed to recover the energy caused by the back electromotive force of the electric motors used during braking and thus to increase the range with higher system efficiency and higher battery charge. The amount of this recovered energy is directly related to the energy intake capacity and the operating condition of the engine. The energy not recovered by regenerative braking is thrown away as heat and the efficiency of the system decreases.

Regenerative braking systems feed the battery unit by turning the kinetic energy of the vehicle into electrical energy by activating the hydraulic brake system together with the use of the internal combustion engine brake or the brake pedal, operating the electric motor like a generator. This system ensures the recovery of a significant amount of energy during frequently repeated stops and starts, especially in city driving. In hybrid electric vehicles, when the brake pedal is pressed, electronically controlled regenerative braking systems provide coordination between hydraulic brake and regenerative brake. In these cases, the braking process is ensured to be as regenerative as possible. In city driving where there is no high speed, braking is mostly provided by the electric motor and regeneration is achieved. However, when it comes to brakes that require short distances and sudden stops, hydraulic brakes are given priority in terms of safety. In order to ensure these coordinations, additional elements are added to the brake system in the vehicle, and it is ensured that how much the driver presses the brake pedal or the force applied to the brake pedal is measured and transitions are made in line with these measurements.

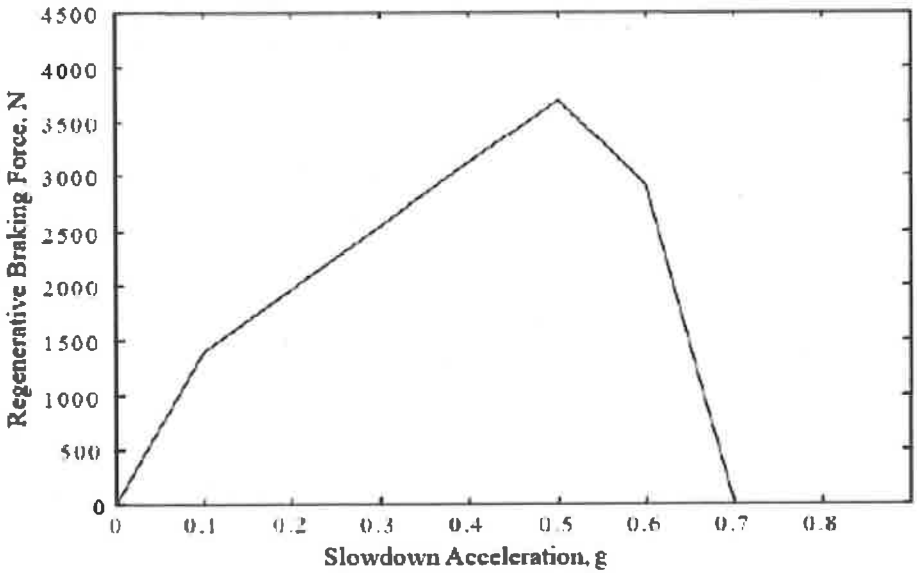

Figure 8 Slowdown Acceleration vs. Regenerative Braking Force [17]

2.5. GT-SUITE

2.5.1 Introduction

GT-SUITE is the industry-leading simulation tool with capabilities and libraries aimed at a wide variety of applications and industries. It offers engineers functionalities ranging from fast concept design to detailed system or sub-system/component analyses, design optimization, and root cause investigation. The foundation of GT-SUITE is a versatile multi-physics platform for constructing models of general systems based on many underlying fundamental libraries.[18]

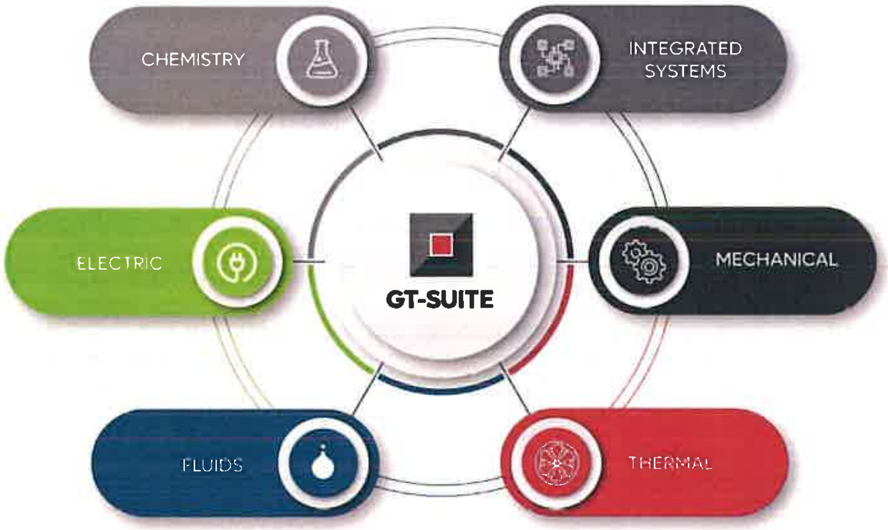

Figure 9 GT-SUITE[18]

The program chosen to be used in the analysis part of the study is the GT-SUITE program. Many models in the library part of the program provide great convenience for the design and modeling to be done before the analysis part. In this part of the study, the Hybrid Model in the library of the GT-SUITE program was used and the study was carried out on this model.

Modifications and changes were made on the templates in this model, which was taken from the GT-SUITE library. The values inside these templates have been changed in line with the technical products decided in the previous sections and their features.

2.5.2. GT-SUITE Hybrid Model

The Hybrid Model pulled from the GT-SUITE library is shown in Figure 10. This model includes internal combustion engine, internal combustion engine controller, electric motor, battery, driver and vehicle. By entering the vehicle template, the modeling of the vehicle can be accessed as seen in Figure 11. The connections between these templates are selected and created according to the relationship between two or more elements as shown in Figure 12. Among these connections, components (actuator, sensor, sum component, switch component, etc.) are used. In these components, it provides the control of the connections created in the elements.

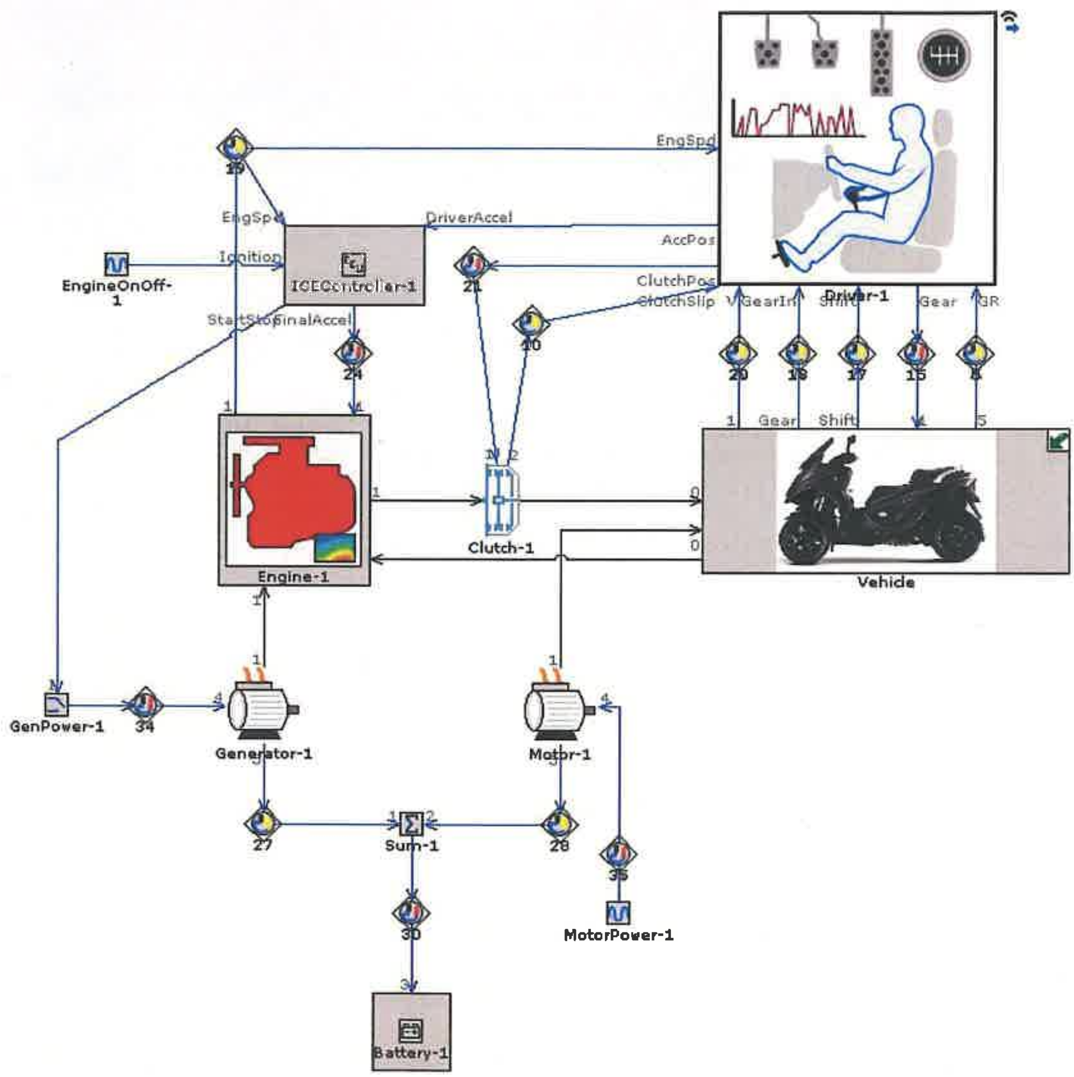

Figure 10 Hybrid Model in GT-SUITE

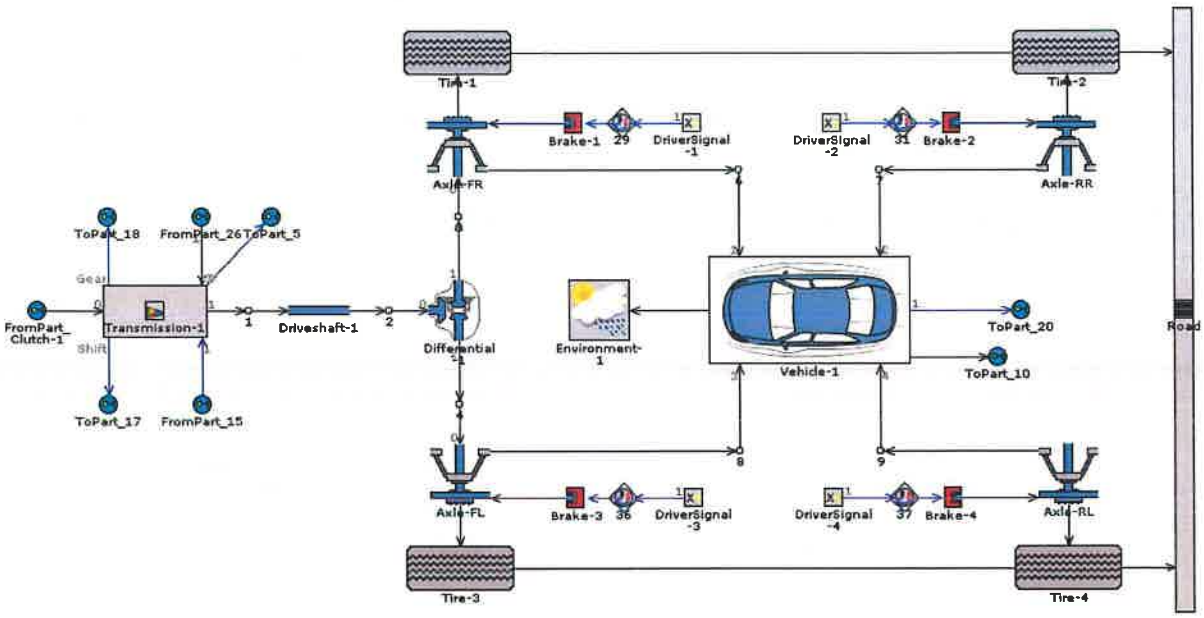

Figure 11 Vehicle Model in GT_SUITE

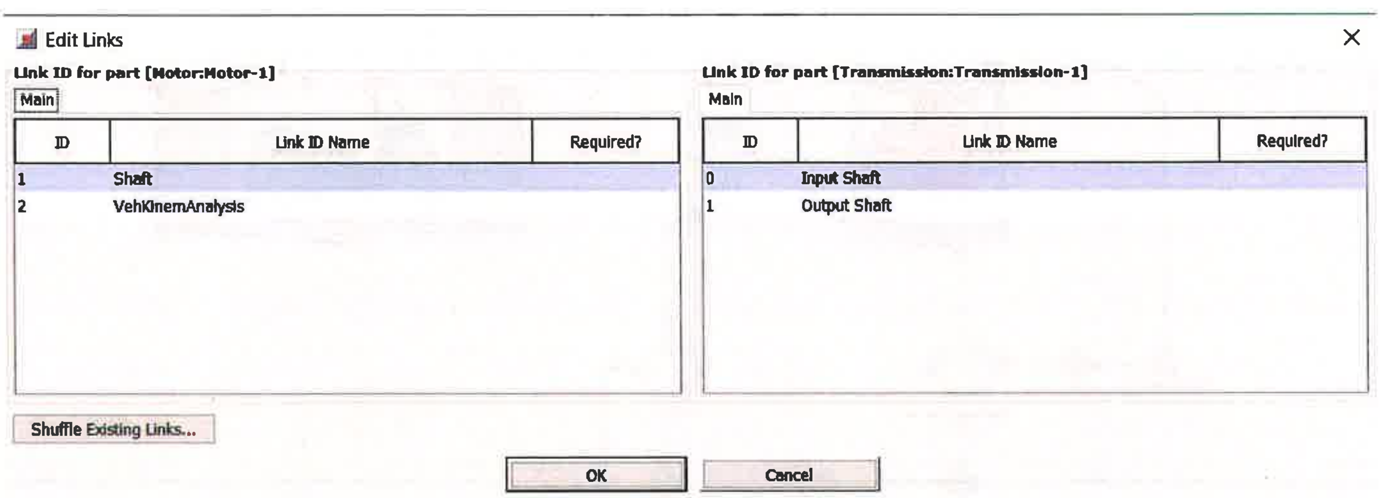

Figure 12 Connection Established Between Electric Motor and Transmission

The properties of the elements determined in the previous sections are entered into the properties section of the templates in the modeling sections. In line with these entered features, the desired models and the data of these models are created.

The specifications of the internal combustion engine shown in Table 1 are entered in the Engine-1 template in the model and the selected internal combustion engine is created in the model.

The specifications of the electric motor shown in Table 3 are entered into the Motor-1 template in the model and the selected electric motor is created in the model.

Although the model is "Parallel Hybrid", the template used as a generator was used for the battery, not as a generator, in order to charge the batteries during regenerative braking. Due to the connection established from the ICE-Controller with the Switch Component, the battery is charged during regenerative braking. The specifications of the electric motor are entered into the template used as Generator-1.

The spcifications of the battery on the Table 5 are entered into the Battery-1 template in the model and the selected battery is created in the model.

After entering the Vehicle template, the vehicle modeling appears. Although the image for the Vehicle-1 template used in this submodeling is a car model, the specifications of the motorcycle model shown in Figure 4 are entered in the template's part Vehicle, Aerodynamics, Axles/Geometry sections. In this way, the desired motorcycle model was created.

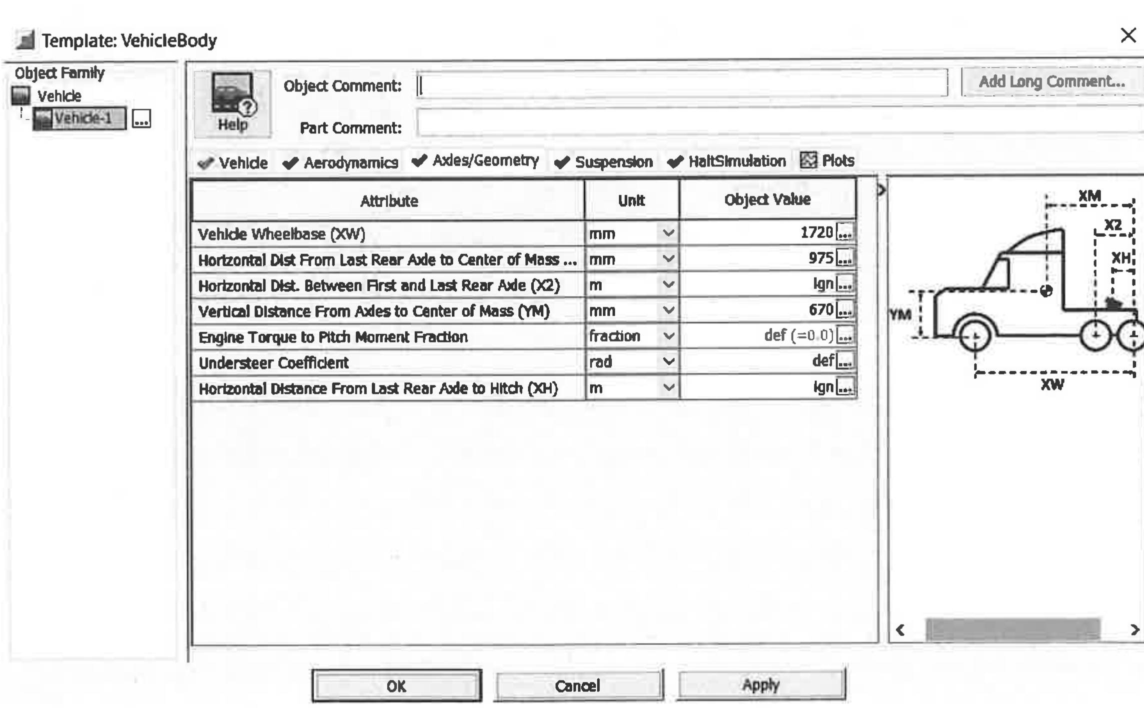

Figure 13 Axles/Geometry Data Contained Within the Vehicle Template.

2.5.3. Creating Cases In GT-SUITE

In the project, comparisons and analyzes will be made in line with the data obtained by running only the internal combustion engine, running only the electric motor and running the hybrid engine over the modeling prepared in GT-SUITE.

First, the route of the motorcycle model will be determined to create the cases. While determining the route, the road length and the slope of the road will be the two most important criteria. I decided on the Istanbul Park Formula 1 track as a route. The biggest reason for choosing this place is that it is the best place to access road length and road slope data.

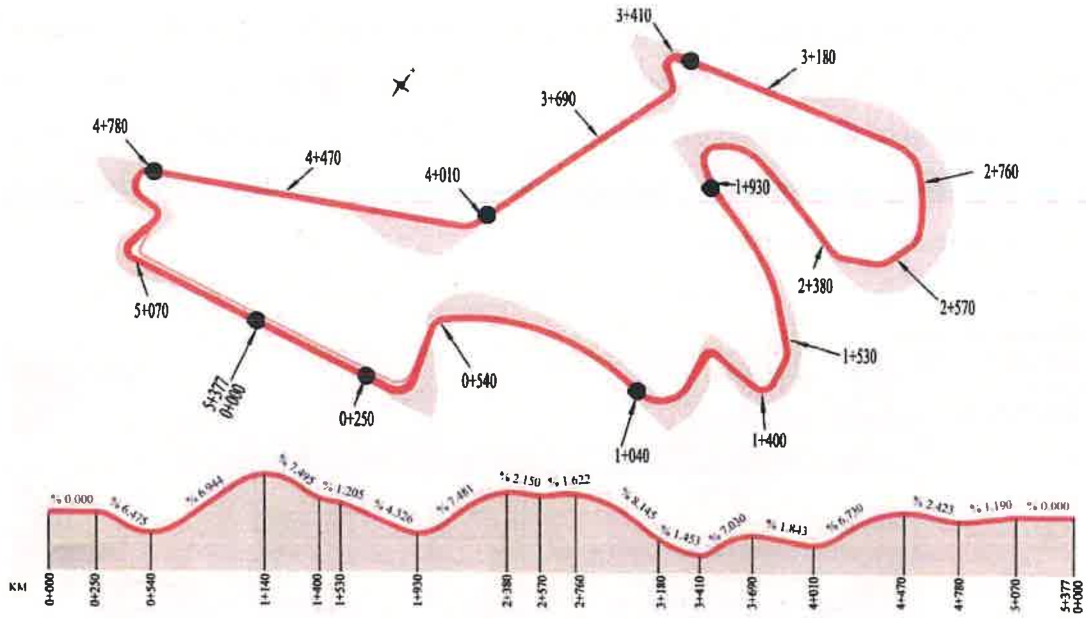

Figure 14 Istanbul Park Track Road and Slope Map[19]

Cases were created using the road length and road slope map shown in Figure14. Cases are formed in such a way that they start from the 0+000 point and stop at the starting point by making 1 full turn. The black points shown on the map in Figure 14 were decided as 50-meter braking points. The reason for creating these braking zones is to see the effect of regenerative braking in the analyses. The data related to the road are entered into the road section in the Vehicle Model, which is shown in Figure 11. In this way, sections of the roads to be used in the cases were created.

Then, parameters were created in order to control the acceleration, deceleration and which engine it will be driven by in the motorcycle model. These parameters are created by entering an input into the relevant sections in the relevant template. For each case, certain values or patterns are entered into these parameters and the model is provided to realize the desired situations.

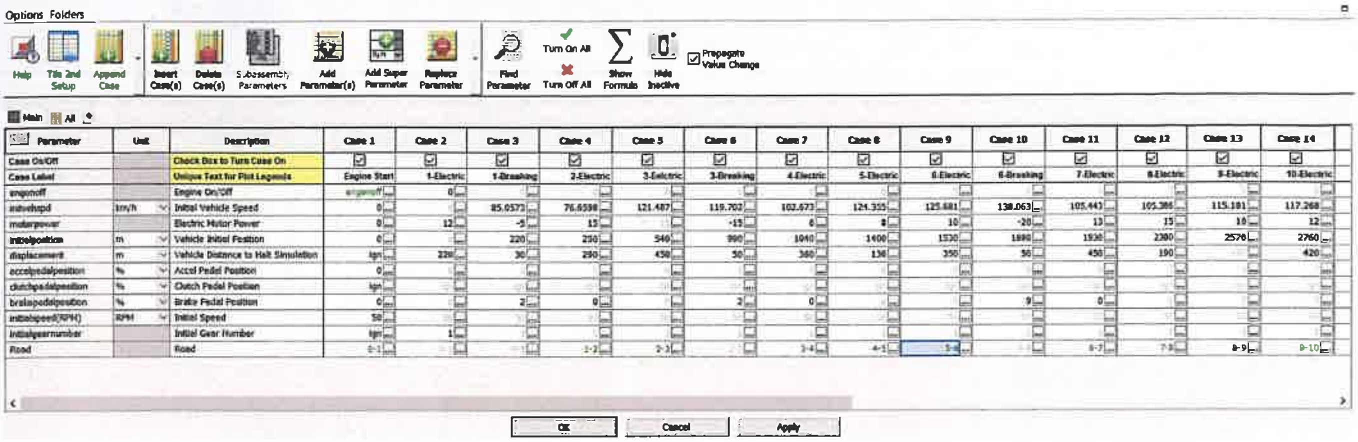

Figure 15 Case Setup Part

The cases were created according to the sections of the roads shown in Figure14. Each section is created as 1 case and each braking point as a separate case. In the cases where only the electric motor is used, only the internal combustion engine is used, and the hybrid engine is used, the thing to note is that it reaches the same speeds in the same sections. The reason for this is to obtain accurate results when performing fuel analysis and fuel comparison.

Case setups created for the sections where only the internal combustion engine is used, only the electric engine is used, the hybrid engine is used and the performance analysis for the battery is made are shown in the tables 7.1, 7.2, 7.3 and 7.4 in the Appendices section.

3. RESULTS AND DISCUSSION

3.1. The Part Where Only the Internal Combustion Engine Is Used

The motorcycle model created in this section was operated using only an internal combustion engine. The purpose of this section is to see the acceleration and fuel consumption values of the motorcycle that has been produced and works with an internal combustion engine.

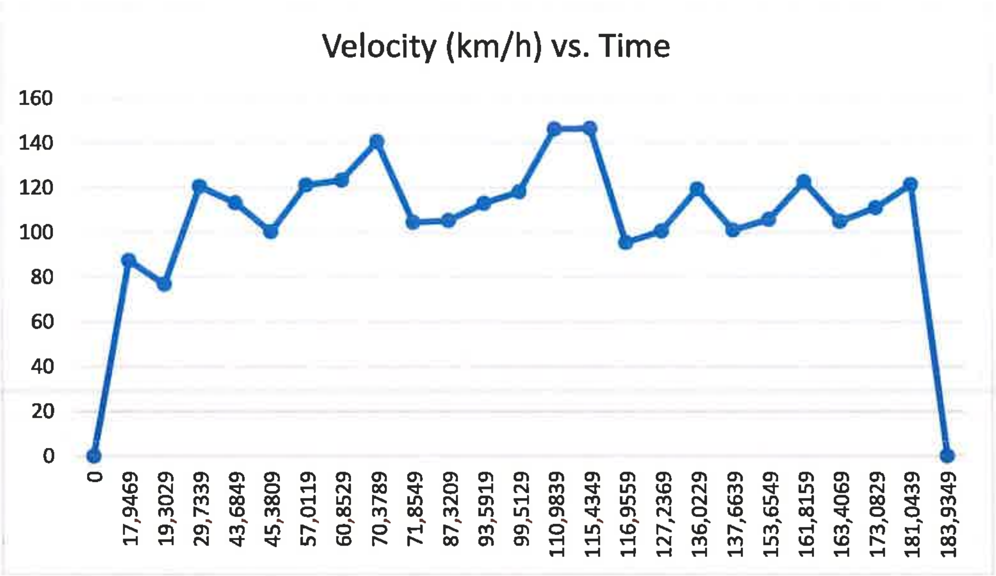

Figure 16 Velocity of Motorcycle vs. Time Graph For The Part Where Only the Internal Combustion Engine Is Used

Speed vs. time graph when the motorcycle starts from the starting point on the track and completes 1 lap according to the acceleration and deceleration sections.

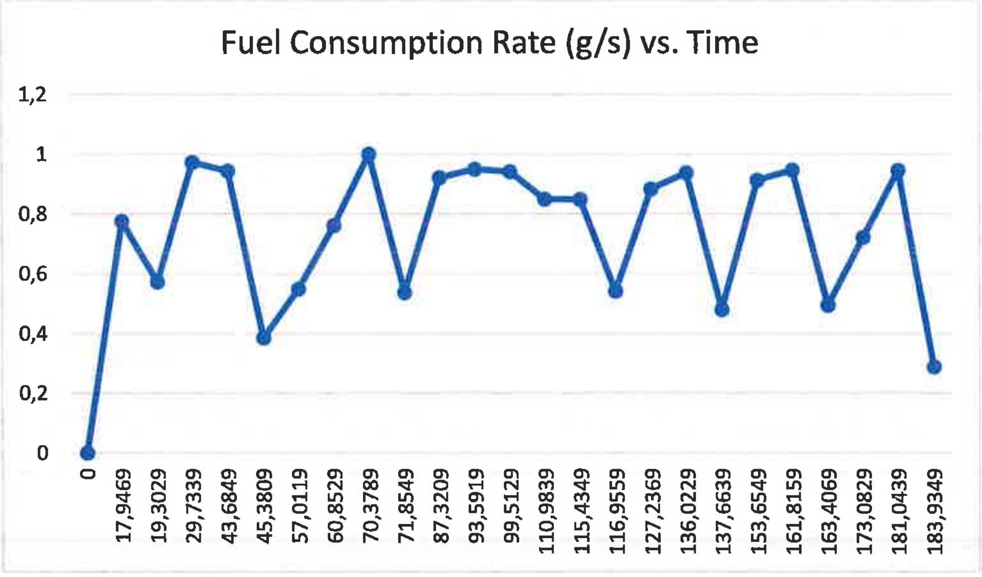

Figure 17 Fuel Consmption Rate vs. Time Graph For The Part Where Only the Internal Combustion Engine Is Used

The graph shown in Figure 17 is the fuel consumption rate graph of the motorcycle that only works with the internal combustion engine. The sections divided by dots in the graph show the cases where the route shown in Figure 14 is divided into sections and created according to these sections.

The sections in the graph where the fuel consumption rate increases are the sections where the motorcycle accelerates on the track. The sections where fuel consumption rate decreases are the braking sections shown with black dots in Figure 14.

If we examine Figure 16 and Figure 17 together, we observe that fuel consumption rate increases in places where the speed of the motorcycle increases and the fuel consumption rate is less in the sections where the motorcycle slows down, but the consumption is never 0.

The total amount of fuel used by the motorcycle throughout 1 lap of the track is calculated in grams by summing the products of the fuel consumption rate multiplied by the time elapsed, section by section.

As a result of these calculations, the fuel burned as a result of 1 lap of the modeled motorcycle on the track using only the internal combustion engine ;

Total Fuel Burned (L) : 0.206604 Liters

If we accept today's gasoline price as 20,48 TL, this amount of fuel burned makes **4,2312 TL.**

3.2. The Part Where Only the Electric Motor Is Used

The purpose of this section is to analyze how there are differences in terms of acceleration and fuel consumption when only an electric motor is used instead of an internal combustion engine in the motorcycle model created based on the increasing importance given to electric vehicles over time.

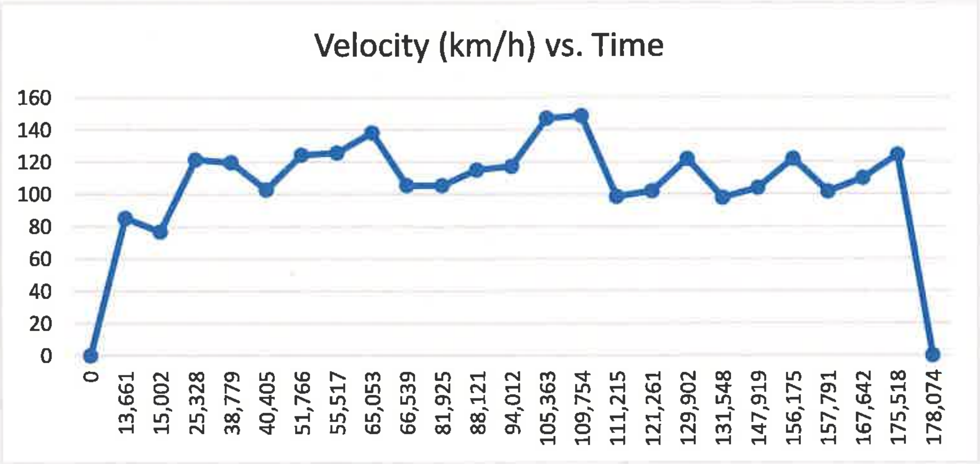

Figure 18 Velocity vs. Time Graph For The Part Where Only the Electric Motor Is Used

In order to get more accurate results while making comparisons, attention was paid to ensure that the motorcycle was at the same speeds in each section at the acceleration and deceleration points determined on the track.

Figure 18 is the, Velocity vs. Time graph when the motorcycle starts from the starting point on the track and completes 1 lap according to the acceleration and deceleration sections.

If we compare it with the section where only the internal combustion engine is used, it is observed that there is a decrease in the completion time of 1 lap when the electric motor is used. Considering this comparison, we can interpret that the electric motor performs better than internal combustion engine in sudden accelerations.

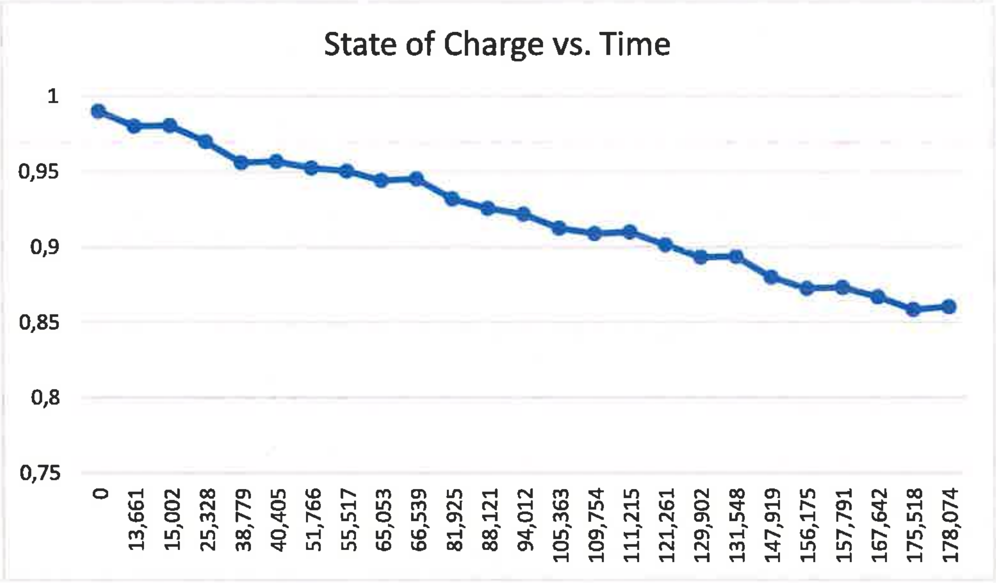

Figure 19 State of Charge vs. Time Graph For The Part Where Only the Electric Motor Is Used

The graph in Figure 19 shows the change in the charge rate of the battery as a result of 1 lap on the track, with the battery being assumed to be 99% full. The section between two points on the graph shows the acceleration and deceleration sections on the track as in the previous sections. In the calculation of the consumption in this section where only the electric motor is used, the change in the charge rate in the battery will be taken as a basis. As can be seen in the graph, the charge rate of the battery increases slightly with the activation of regenerative braking at braking points. With the help of this graph, we can see more clearly that regenerative braking directly affects the consumption of electric and hybrid vehicles.

$$Kilowatt\ Hours\ (kWh) = [Amp\ Hours\ (Ah) \times Voltage\ of\ Battery\ (V)]/1000 \quad (3.1)$$

To calculate the total consumption from the charge change in the battery, the difference between the initial charge and the last charge of the battery is found. This difference is in Amp Hours. With the formula specified in Equation 3.1, the value we find in Amp Hours is converted to Kilowatt Hour unit.

The change in the charge rate of the battery at the end of 1 lap on the determined track was calculated as 2.623 Ah.

$$[2.623\ Ah * 200\ V]/1000 = 0.5246\ kWh$$

Consumer	Business
Tariff	Monochronic
Consumption (kWh)	0.5246
900 kWh and Below (Business and Monochronic)	2.368288
900 kWh and Above (Business and Monochronic)	3.266517
Distribution Cost (Business and Monochronic)	0.342716
Cost of Energy	1,24 TL
Electricity Consumption Tax (%5)	0,06 TL
Distribution Cost	0,18 TL
Vat Value (%18)	0,27 TL
Total	**1,75 TL**

Table 6 Electricity Amount Calculation

After calculating the parameters that have an effect on the electricity cost in Table 6, it is seen that our motorcycle model, which only works with an electric motor, consumes 1,75 TL of electricity at the end of 1 lap (5.377 km).

3.3. The Part Where Hybrid Motor Is Used

In this section, consumption and speed analyzes of a motorcycle model working with a hybrid engine, which is the main purpose of my study, are made.

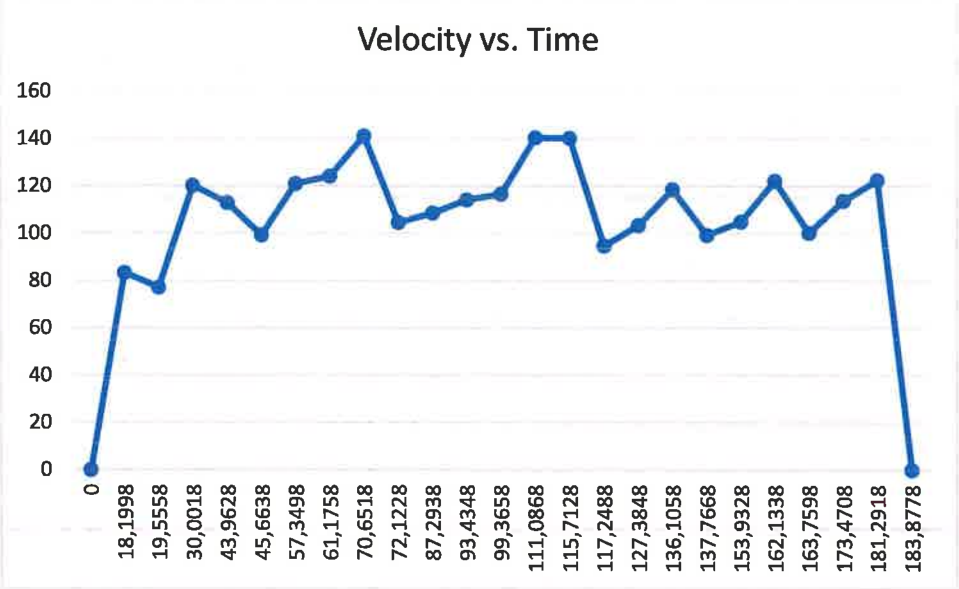

Figure 20 Velocity vs. Time Graph For The Part Where Hybrid Motor Is Used

Like previous parts, in order to get more accurate results while making comparisons, attention was paid to ensure that the motorcycle was at the same speeds in each section at the acceleration and deceleration points determined on the track.

Figure 20 is the Velocity vs. Time graph when the motorcycle starts from the starting point on the track and completes 1 lap according to the acceleration and deceleration segments. If we compare it with the sections where only the internal combustion engine and only the electric motor are used, it is observed that the acceleration is slower when the hybrid engine is used than when only the electric motor is used, but faster than when only the internal combustion engine is used.

As a result of the acceleration analysis, we observe that the electric motor performs better in sudden accelerations than the internal combustion engine. On the other hand, we can say that the hybrid engine serve as a bridge between today's and future technology during the transition to full electric technology.

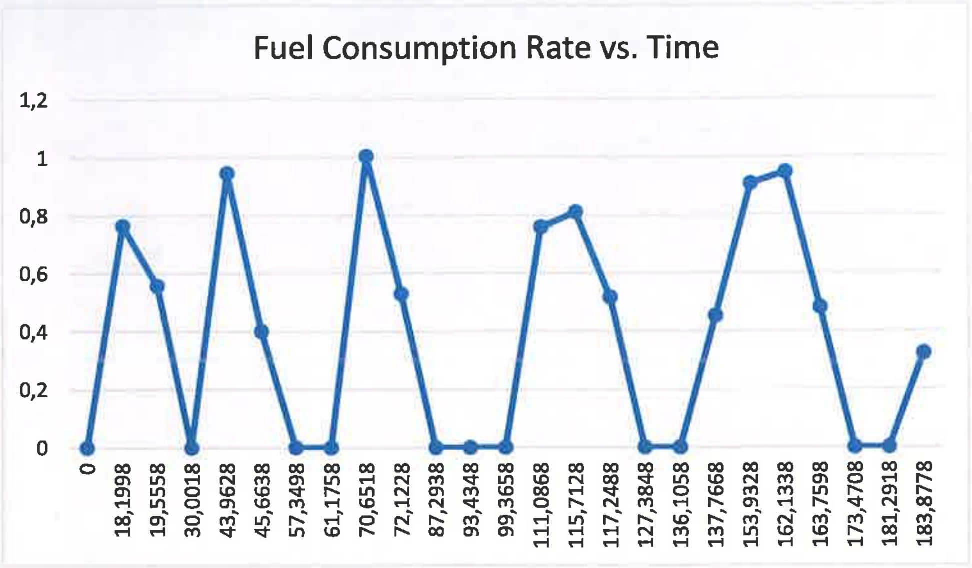

Figure 21 Fuel Consmption Rate vs. Time Graph For The Part Where Hybrid Motor Is Used

The graph shown in Figure 21 is the fuel consumption rate graph of the motorcycle powered by the hybrid engine. The dotted segments in the graph show cases where the route shown in Figure 14 is segmented and built according to these segments.

The sections in the graph where the fuel consumption rate increases are the sections where the motorcycle accelerates on the track with the internal combustion engine. The sections where the fuel consumption rate decreases are the braking sections shown with black dots in Figure 14. In addition, the sections where the fuel consumption rate drops to 0 are the sections where the internal combustion engine is switched off and the electric motor is activated.

The total amount of fuel used by the motorcycle throughout 1 lap of the track is calculated in grams by summing the products of the fuel consumption rate multiplied by the time elapsed, section by section.

As a result of these calculations, the fuel burned by the internal combustion engine of the motorcycle as a result of 1 lap of the modeled motorcycle on the track using a hybrid engine;

Total Fuel Burned (L) : 0.1026828 Liters

If we accept today's gasoline price as 20,48 TL, this amount of fuel burned makes 2,10 TL.

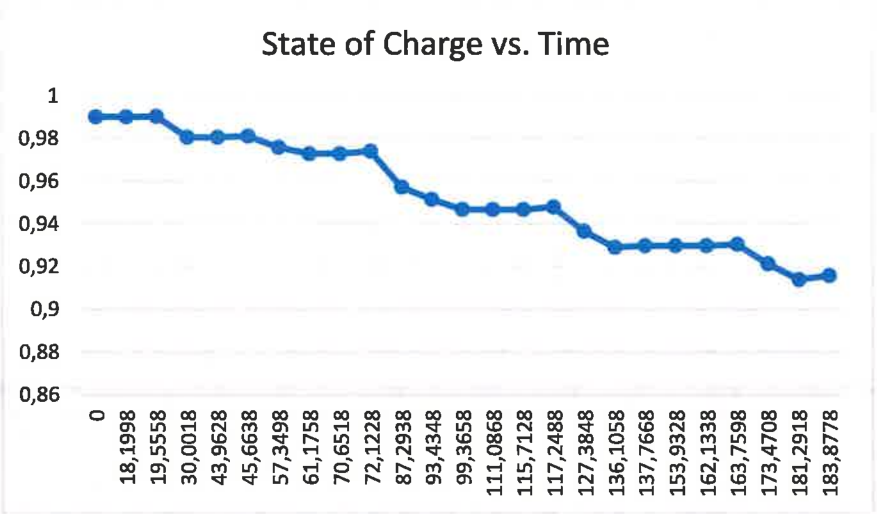

Figure 22 State of Charge vs. Time Graph For The Part Where Hybrid Motor Is Used

The graph in Figure 22 shows the change in the charge rate of the battery as a result of 1 lap on the track, with the battery being assumed to be 99% full. The section between two points on the graph shows the acceleration and deceleration sections on the track as in the previous sections. In the calculation of the consumption in this section where hybrid motor is used, the change in the charge rate in the battery will be taken as a basis.

The change in the charge rate of the battery at the end of 1 lap on the determined track was calculated as 1.5 Ah.

As in the previous section, following the steps in Equation 3.1 and Table 6, electricity consumption and cost will be calculated for the hybrid engine.

After the calculations, it is seen that our motorcycle model running with a hybrid engine consumes 0,85 TL of electricity at the end of 1 lap (5,377 km).

In order to find the total consumption of the motorcycle model running with the hybrid engine at the end of 1 lap, we will add the consumptions of the internal combustion engine and the electric motor. The total consumption of the internal combustion engine is 2,10 TL and the total consumption of the electric motor is 0,85 TL. The total consumption of the motorcycle running with a hybrid engine at the end of 1 lap is **2,95 TL**. When we compare the consumption rates, it seems that the hybrid engine offers a performance between the performances of the internal combustion engine and the electric motor, as in the acceleration analysis.

3.4. Performance Analysis of the Battery

In this part of my project, the time taken from fully charged to fully discharged and how many kilometers will be traveled with a fully charged battery will be calculated. The cases created for this, the motorcycle will start at 0 km/h on a flat road and accelerate until it reaches the maximum speed, and then it will continue at a constant speed until the battery runs out.

As a result of this analysis, the time taken for the battery to reach 0% charge from 99% charge rate was calculated as 1224.292 seconds. During this time, the motorcycle traveled 49485.7442 meters.

4. FEASIBILITY AND COST ANALYSIS

PARTS	Only Internal Combustion Engine	Only Electric Motor	Hybrid Motor
Fuel Consumption (L)	0.206604	0	0.1026828
Electricity Consumption (kWh)	0	0.5246	0.255
Cost (TL)	4,2312	1,75	2,95

Table 7 Cost Analysis

As we can see from the cost analysis in Table 7, electric motors are much more efficient and cost-effective than internal combustion engines. In hybrid engines, it performs between the performances of the internal combustion engine and the electric motor.

Fuel consumption, reducing environmental pollution, emissions, etc. Electric motors offer much better data than internal combustion engines. However, in line with today's technology and conditions, it will take a long time to completely switch to electrical technology. Hybrid engines, on the other hand, have increased the importance given to speeding up this process, providing better data than internal combustion engines and serving as a bridge in the transition to full electric technology.

In line with this developing technology, it can be made more efficient, more usable and more preferable with studies every day.

5. CONCLUSION

The aim of my project is to create a motorcycle model with a hybrid engine over the GT-SUITE program by using the data and design of a motorcycle model with an internal combustion engine, which has been produced and used before, and to make analyzes such as acceleration performance, fuel consumption and cost on this model. Comparisons and analyzes were made in line with the data obtained by driving the created hybrid motorcycle model one full lap using the internal combustion engine, electric motor and hybrid engine in line with the cases created on the basis of the Istanbul Park track. In addition to this section, in order to observe the performance of the battery used for the hybrid engine, the motorcycle model was accelerated on a flat road starting from 0 km/h until it reached the maximum speed and then continued with constant acceleration until the battery charge rate was 0%. At the end of this section, the performance data of the battery is obtained.

As a result, in line with the analyzes and the data obtained; A vehicle with hybrid technology shows a performance between internal combustion engine vehicles and fully electric vehicles in many parameters such as fuel consumption, driving performance, environmental pollution, etc. This performance increases the importance given to hybrid technology in line with the difficulties encountered in transitioning to fully electric vehicles.

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7. APPENDICES

7.1. The Case Setup of The Part Where Only The Internal Combustion Engine Is Used

meters	Case Label	engonoff	initvehspd	motorpower	initialposition	displacement	accelpedalposition	clutchpedalposition	brakepedalposition	initialspeed(RPM)	initialgearnumber	
nits			km/h	kW	m	m	%	%	%	RPM		
ription	Unique Text for Plot Legends	Engine On/Off	Initial Vehicle Speed	Electric Motor Power	Vehicle Initial Position	Vehicle Distance to Halt Simulation	Accel Pedal Position	Clutch Pedal	Brake Pedal Position	Initial Speed	Initial Gear Number	Typ
se 1	Engine Start	engonoff	0	0	0	ign	0	100	0	0	ign	
se 2	ICE-1	1	0	0	0	220	100	ign	0	150	1	
se 3	Breaking	1	833.178	0	220	30	0	ign	2	5009.5	2	
se 4	ICE-2	1	767.483	0	250	290	100	ign	0	4614.48	2	
se 5	ICE-3	1	120.338	0	540	450	100	ign	0	4630.63	3	
se 6	Breaking	1	113.078	0	990	50	0	ign	2	4351.27	3	
se 7	ICE-4	1	100.286	0	1040	360	50	ign	0	3859.62	3	
se 8	ICE-5	1	121.023	0	1400	130	75	ign	0	4656.98	3	
se 9	ICE-6	1	123.202	0	1530	350	100	ign	0	4740.84	3	
se 10	Breaking	1	140.553	0	1880	50	0	ign	12	5408.51	3	
se 11	ICE-7	1	104.39	0	1930	450	100	ign	0	4016.91	3	
se 12	ICE-8	1	105.16	0	2380	190	100	ign	0	4046.57	3	
se 13	ICE-9	1	112.819	0	2570	190	100	ign	0	4341.28	3	
se 14	ICE-9	1	118.112	0	2760	420	80	ign	0	4544.97	3	
se 15	ICE-10	1	146.063	0	3180	180	80	ign	0	4658.19	3	
se 16	Breaking	1	146.407	0	3360	50	0	ign	15	4262.6	3	
se 17	ICE-11	1	953.321	0	3410	280	100	ign	0	3668.46	3	
se 18	ICE-12	1	100.461	0	3690	270	100	ign	0	3865.74	3	
se 19	Breaking	1	119.238	0	3960	50	0	ign	5	4588.31	3	
se 20	ICE-13	1	100.887	0	4010	460	100	ign	0	3882.14	3	
se 21	ICE-14	1	105.733	0	4470	260	100	ign	0	4068.61	3	
se 22	Breaking	1	122.513	0	4730	50	0	ign	5	4714.31	3	
se 23	ICE-15	1	104.83	0	4780	290	75	ign	0	4033.87	3	
se 24	ICE-16	1	110.759	0	5070	257	100	ign	0	4262.03	3	
se 25	Breaking	1	121.133	0	5327	50	0	100	18,2	4661.23	3	

7.2. The Case Setup of The Part Where Only Electric Motor Is Used

rameters	Case Label	engonoff	initvehspd	motorpower	initialposition	displacement	accelpedalposition	clutchpedalposition	brakepedalposition	initialspeed(RPM)	initialgearnumber	
Units			km/h	kW	m	m	%	%	%	RPM		
scription	Unique Text for Plot Legends	Engine On/Off	Initial Vehicle Speed	Electric Motor Power	Vehicle Initial Position	Vehicle Distance to Halt Simulation	Accel Pedal Position	Clutch Pedal	Brake Pedal Position	Initial Speed	Initial Gear Number	Type
Case 1	Engine Start	engonoff	0	0	0	ign	0	ign	0	50	ign	
Case 2	1-Electric	0	0	12	0	220	0	ign	0	50	1	
Case 3	1-Breaking	0	850.573	-5	220	30	0	ign	2	50	1	
Case 4	2-Electric	0	766.598	15	250	290	0	ign	0	50	1	
Case 5	3-Eelctric	0	121.487	15	540	450	0	ign	0	50	1	
Case 6	3-Breaking	0	119.702	-15	990	50	0	ign	2	50	1	
Case 7	4-Electric	0	102.673	6	1040	360	0	ign	0	50	1	
Case 8	5-Electric	0	124.355	8	1400	130	0	ign	0	50	1	
Case 9	6-Electric	0	125.681	10	1530	350	0	ign	0	50	1	
Case 10	6-Breaking	0	138.063	-20	1880	50	0	ign	9	50	1	
Case 11	7-Electric	0	105.443	13	1930	450	0	ign	0	50	1	
Case 12	8-Electric	0	105.386	15	2380	190	0	ign	0	50	1	
Case 13	9-Electric	0	115.181	10	2570	190	0	ign	0	50	1	
Case 14	10-Electric	0	117.268	12	2760	420	0	ign	0	50	1	
Case 15	11-Electric	0	147.057	12	3180	180	0	ign	0	50	1	
Case 16	11-Breaking	0	148.505	-20	3360	50	0	ign	15	50	1	
Case 17	12-Electric	0	985.468	13	3410	280	0	ign	0	50	1	
Case 18	13-Electric	0	101.99	14	3690	270	0	ign	0	50	1	
Case 19	13-Breaking	0	121.817	-10	3960	50	0	ign	6	50	1	
Case 20	14-Electric	0	976.697	13	4010	460	0	ign	0	50	1	
Case 21	15-Electric	0	103.919	13	4470	260	0	ign	0	50	1	
Case 22	15-Breaking	0	121.911	-10	4730	50	0	ign	5	50	1	
Case 23	16-Electric	0	101.546	10	4780	290	0	ign	0	50	1	
Case 24	17-Electric	0	110.065	15	5070	257	0	ign	0	50	1	
Case 25	17-Breaking	0	124.225	-20	5327	50	0	100	17.95	50	1	

7.3. The Case Setup of The Part Where Only The Electric Motor Is Used

arameters	Case Label	engonoff	initvehspd	motorpower	initialposition	displacement	accelpedalposition	clutchpedalposition	brakepedalposition	initialspeed(RPM)	initialgearnumber	
Units			km/h	kW	m	m	%	%	%	RPM		
escription	Unique Text for Plot Legends	Engine On/Off	Initial Vehicle Speed	Electric Motor Power	Vehicle Initial Position	Vehicle Distance to Halt Simulation	Accel Pedal Position	Clutch Pedal	Brake Pedal Position	Initial Speed	Initial Gear Number	Typ
Case 1	Engine Start	engonoff	0	0	0	ign	0	100	0	50	ign	
Case 2	1-ICE	1	0	0	0	220	100	ign	0	50	1	
Case 3	1-Breaking	1	83.276	-5	220	30	0	ign	1	5007.08	2	
Case 4	2-Electric	0	770.364	15	250	290	0	ign	0	4631.8	2	
Case 5	3-ICE	1	120.213	0	540	450	100	ign	0	4625.81	3	
Case 6	3-Breaking	1	1.130.228	-10	990	50	0	ign	1	4349.41	3	
Case 7	4-Electric	0	99.235	8	1040	360	0	ign	0	3818.57	3	
Case 8	5-Electric	0	120.998	13	1400	130	0	ign	0	4656	3	
Case 9	6-ICE	1	124.099	0	1530	350	100	ign	0	4775.35	3	
Case 10	6-Breaking	1	141.119	-20	1880	50	0	ign	10	5430.26	3	
Case 11	7-Electric	0	104.473	17	1930	450	0	ign	0	4020.14	3	
Case 12	8-Electric	0	108.544	15	2380	190	0	ign	0	4176.78	3	
Case 13	9-Electric	0	114.185	13	2570	190	0	ign	0	4393.86	3	
Case 14	10-ICE	1	116.57	0	2760	420	70	ign	0	4485.64	3	
Case 15	11-ICE	1	140.377	0	3180	180	70	ign	0	5401.74	3	
Case 16	11-Breaking	1	140.239	-20	3360	50	0	ign	12	5396.42	3	
Case 17	12-Electric	0	947.018	17	3410	280	0	ign	0	3644.12	3	
Case 18	13-Electric	0	103.351	14	3690	270	0	ign	0	3976.96	3	
Case 19	13-Breaking	1	118.544	-10	3960	50	0	ign	4	4561.59	3	
Case 20	14-ICE	1	991.957	0	4010	460	100	ign	0	3817.05	3	
Case 21	15-ICE	1	104.987	0	4470	260	100	ign	0	4039.93	3	
Case 22	15-Breaking	1	122.105	-10	4730	50	0	ign	5	4698.61	3	
Case 23	16-Electric	0	100.246	15	4780	290	0	ign	0	3857.48	3	
Case 24	17-Electric	0	113.763	15	5070	257	0	ign	0	4377.62	3	
Case 25	17-Breaking	1	122.594	-20	5327	50	0	100	14,7	4715.11	3	

7.4. The Case Setup of The Performance Analysis of The Battery

Parameters	Units		Case 1	Case 2
Case Label		Unique Text for Plot Legends	Electric	Electric
engonoff		Engine On/Off	0	0
initvehspd	km/h	Initial Vehicle Speed	0	145
motorpower	kW	Electric Motor Power	20	12
initialposition	m	Vehicle Initial Position	0	859,3442
displacement	m	Vehicle Distance to Halt Simulation	ign	ign
accelpedalposition	%	Accel Pedal Position	ign	ign
clutchpedalposition	%	Clutch Pedal	ign	ign
brakepedalposition	%	Brake Pedal Position	ign	ign
initialspeed(RPM)	RPM	Initial Speed	50	50
initialgearnumber		Initial Gear Number	1	1
Road		Types of Roads	0-1	0-1
speed	km/h	Vehicle Speed to Halt Simulation	145	ign
casetime	s	Maximum Simulation Duration (Time)	100	1200
charge		Initial State of Charge (SOC)	0.99	0.9455344