Design of a Hybrid Electric Vehicle Powertrain for Performance Optimization and Configurations

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Abstract: The exhaustion of oil reserves and the increasing need for energy have compelled automakers to investigate novel eco-friendly car alternatives, such hybrid and electric cars. Because it directly affects the car's handling and fuel efficiency under various driving circumstances, choosing the right hybrid configuration is crucial. The main goal of this research is to perform an extensive parametric study on an electric hybrid vehicle (HEV). This study's main objective was to create a HEV powertrain by first matching parameters and sizing components, then optimising the system to satisfy predetermined design restrictions. In order to determine the power requirements of various components, vehicle dynamics have to be analysed and calculated. To accomplish the design goals, optimisation techniques were used after the initial parameterization. Next, using MATLAB software designed especially for an Indian vehicle cycles (IDC), the optimised HEV was simulated. The powertrain components' ideal range was determined using the simulation results, guaranteeing effective operation in real-world driving situations.

Keywords: Hybrid Electric Vehicle, Vehicle Performance, Component Sizing, Optimization etc.

I. INTRODUCTION

One of the greatest technological achievements of modern times is the invention of combustion-powered automobiles, which are an essential part of our daily life. However, the environment with hydrocarbon resources are facing significant challenges due to the highly developed automotive sector and the growing global automobile population. The risks to modern living posed by declining air quality, issues related to global warming, and decreasing petroleum supplies are growing. By the end of the century, conventional cars will be the main source of urban pollution. Matlab-Simulink modelling and simulation of electric vehicles is very helpful in examining the energy flow, effectiveness, and efficiency of an EV drivetrain. Because testing and developing prototypes are expensive and time-consuming processes, simulation and modelling are essential tools for automotive engineers to determine the optimal energy control strategy, precise component sizing, and energy-saving measures.

When used as a vector of energy for vehicle propulsion, electricity allows for the replacement of oil by a wide range of primary sources of energy. This might support the EU and UN's goals of lowering carbon dioxide emissions by ensuring the security of the energy supply and the widespread adoption of renewable or carbon-free sources of energy in the transportation sector. At the time of usage, electric vehicles emit zero carbon dioxide (CO_2) from their tailpipe and no nitrogen monoxide (NO), nitrogen dioxide (NO_2), non-methane hydrocarbons (NMHC), or particulate matter (PM). Electric vehicles operate silently and smoothly, which results in minimal noise and vibration. Significant amounts of airborne pollution are released by road vehicles. In the United States, for instance, 27% of volatile organic compounds in the air, 28% of lead, 32% of nitrogen oxides, 18% of suspended particles, and 62% of carbon dioxide are released. Twenty-five percent of America's energy-related dioxide, the primary greenhouse gas, is released by vehicles.

The number of pollution cases in the world continues to rise faster as more people have access to transportation that is both public and private. Two of the most significant technical breakthroughs of the last century have been the electrification for our energy system and the emergence of automobile mobility. demonstrating the significant shift in lifestyle brought on by the expansion of fossil fuel supplies. While transportation uses 27% of the nation's power supply, electrical generating today makes up 34% of the main source of energy consumed in the United States, up from minimal energy markets in 1900. Energy expansions have been made possible by the increased usage of fossil fuels: nearly all 250 million cars currently operating on American roads are powered by refined crude oil, while natural gas and coal account for over 65 percent of the power used to produce the country's electricity. However, fewer than two percent of the power utilised in either market comes from renewable sources. The decade-long energy revolution in transport and power has had an impact on numerous distinct, sizable non-overlapping markets. Electricity is used significantly in the transportation markets, but it provides very little energy to the industrial, residential, and transportation sectors. However, oil only makes up a third of the energy needed to produce power. The amount of oil used for transportation accounts for only 3% of total energy input for electricity.

Fossil fuels are currently used and relied upon for electrification and transportation at a rate 100,000 times quicker than their natural creation rate. The expense and difficulty of extracting fossil fuels are rising as long as the easily accessible fuels are used. Finding a substitute for fossil fuels is critical to changing the needs on the creation of power systems that utilise renewable resources. Victimisation of electricity produced from a centralised source for transportation purposes has not advanced far. By almost a factor of two, there were more electrical cars than petrol cars in 1900. Around 1900, electric cars were quiet vehicles that produced less pollution. Since electric cars didn't need hand crank starts, which may be challenging and dangerous, they were preferred by the metropolitan social elite. More than 100 manufacturers of electric vehicles developed electric vehicles (EVs) as a result.

II. ELECTRIC VEHICLE

Researchers are paying more and more attention to the simulation and modelling of electric vehicles as they prove to be viable substitutes for sustainable and greener energy emissions in transportation. In order to examine power flow during motoring or regeneration, this work presents the simulation model of a fully electric vehicle using the Matlab-Simulink platform. The motor, battery, motor controller, and battery controller—each represented by a mathematical equation—make up the drive train components. Plotting and conversing are done for every simulation result. The torque and speed parameters during motoring and recovery were utilised to ascertain the drive's performance and energy flow. The foundation for additional research and development is this study.

The electrical motor, electronics for power, battery, rotor controller, battery controller, and vehicle interface make up the six parts of the drive train. The interface that the sensors or controls use to interact with the motor's controller or battery controller is provided by the vehicle interface. Normally, the battery controller manages the power coming from the battery, while the motor controller regulates the power going to the motor. The battery stores energy; typically, lithium-ion cells give the power electronics a high current and voltage of more than 200 V. The voltage, current, and frequency supplied to meet the needs of the motor are influenced by the power electronics.

Plotted in Figure, the power demand for the 100-second simulation is determined by using the driving cycle's input road speed & road torque data. When the torque and speed are both positive, the motor is said to be working in the first quadrant, or forward motion, and positive power is generated. Nevertheless, the motor enters the 4th Quadrant operational region and functions as a generator when the torque turns negative while the speed is positive.

III. POWER TRAIN AND DRIVE CYCLES

Drive cycles and the power train Electric motors (EM) make up the power trains of electric vehicles. Finding the motor specs is the first stage in designing the power train since it determines the motor's power ratings. This is done for the EV drivetrain. The vehicle's driving cycle and its dynamic equation, which calculates tractive force, are used to establish these specifications. The induction motor's specification is impacted by the drivetrain's design restrictions, which include the maximum vehicle speed, the beginning acceleration time, and the value of cruising at rated speed. Ultimately, the motor specifications needed for the drivetrain are determined by the tractive force needed to move the vehicle to the selected drive cycle. The vehicle's operating regions are depicted in Figure 1, and the power train's design restrictions are mentioned below.

i. Initial acceleration.
ii. Cruising at rated vehicle speed.
iii. Cruising at maximum vehicle speed.
iv. Retardation.

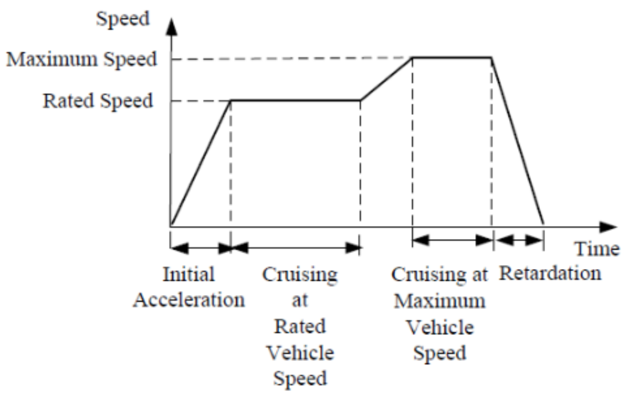

Figure 1 The vehicle operating regions

IV. MATLAB-BASED MODELING AND SIMULATION PACKAGE FOR ELECTRIC AND HYBRID ELECTRIC VEHICLE DESIGN

Purely electric cars (EVs) are a potential technology for the long-term objectives of energy efficiency and decreased air pollution; nevertheless, the public's acceptance of EVs may be hampered by their short range or lack of supporting infrastructure. In addition to the potential for greater energy economy and lower emissions as compared to regular cars, hybrid vehicles can be engineered to overcome the range constraints of fully electric vehicles by combining two different energy sources for propulsion. Energy is stored in petroleum gasoline and an electrical storage mechanism, like a battery pack, in hybrid vehicles. An engine with internal combustion (ICE) and an electric motor, respectively, transform the stored energy into mechanical energy. While the ICE offers a longer range, the electric motor helps to reduce pollutants and increase energy economy.

By testing configurations or energy management techniques prior to the start of prototype manufacturing, computer modelling and simulation can be utilised to shorten the cost and duration of the development process of hybrid automobiles. Texas A&M University created V-Elph, a system-level modelling, simulation, and analysis tool, using Matlab/Simulink to investigate topics including vehicle emissions, fuel economy, and energy efficiency in EV and HEV design. V-Elph makes it easier to conduct in-depth analyses of energy management methods, power plant designs, component sizing, and the optimisation of crucial component characteristics for various hybrid or electric configurations and energy management tactics. Through the use of visual programming approaches, the user can easily alter parameters, architectures, and the visual representation of output data. It also contains comprehensive models of batteries, internal combustion engines, including electric motors that were created at Texas A&M University. The process for creating system-level vehicles with the V-Elph package is covered in this document. Using the simulation programme, an ordinary ICE driven drive train, a parallel EV, a series HEV, and an EV have all been built.

V. SIMULATION OF ELECTRIC VEHICLE INCLUDING DIFFERENT POWER TRAIN COMPONENTS

The fuel is just being consumed at a rate that is higher than its supply, which will eventually lead to a point at which there won't be any more fossil fuels available to meet demand. Imagine living in a world where cell phones are commonplace, but there is no electricity to charge them. It's not a pleasant thought. Environmental issues are a major concern associated with the exhaustible use of fuel. The effects of carbon dioxide gas on the environment are nothing new. Nobel Prize winner Svante Arrhenius first proposed the theory in 1896. Nonetheless, there are two main reasons for carbon dioxide emissions: Both man-made and natural phenomena exist. In recent years, natural phenomena like volcanic aerosol or human-caused economic activity have been recognised as significant drivers to temperature rise, which has been linked to the melting of glaciers.

A. Electric Propulsion

The electrical vehicle's electric propulsion is essentially its heart. It is made up of electronic converters, power converters, and electric machines. Electrical machinery employed for a purpose provides the majority of the labour power needed to mobilise a vehicle. The purpose of a power converter is to provide electrical input in accordance with the machine's immediate needs while maintaining compatibility with the linked load. In accordance with the driver's instruction, the electronic converter sends control signals for the power converter. The development of semiconductor switch devices and the scope of EVs happened simultaneously. Machines powered by electricity have been in use for over a century because of their comparatively consistent ability to deliver power to the load. Electrical machines usually have an efficiency of about 90%, which is higher than the IC engine is far higher

Electrical energy is transformed into mechanical energy by the electrical machine, and vice versa. In addition to being inefficient, electrical energy is regenerative by nature. When an electrical machine is in the braking mode, it can recover energy by generating mode (removing kinetic energy generated by the wheel) and storing it in energy accumulators, such as batteries with high energy density or ultracapacitors with high power density. Since mechanical losses result from irreversible energy conversion, realistically only a portion of the energy is recovered. Both machine families have advantages and disadvantages, and their applications vary depending on the load demand. Due to their controllability and torque to load characteristics, DC machines were introduced in the 1980s. Even with these wonderful qualities, DC machines are no longer in demand because of their size and upkeep needs. The most recent car manufacturers use permanent magnet, AC, and brushless motors in addition to induction, switched reluctance, and induction motors.

B. Electric Power Source

Electrochemical batteries & Ultra capacitors, commonly referred to as Super capacitors, are the two primary energy sources and storage devices employed in this study. Generally referred to as electric batteries, these are created by joining separate cells to provide a predetermined standard voltage at the terminals of each cell. Batteries were energy devices known as electrochemical devices because they transform chemical energy into electrical energy. These days, batteries are crucial as both energy-producing sources and energy-storing devices. As previously stated, batteries are essentially composed of individual cells connected by appropriate means, therefore in order to gain a deeper comprehension of batteries, we will now concentrate on the cells.

C. Vehicle kinetics

The overall force applied to a moving vehicle is determined by these equations. For a vehicle to continue going consistently, these forces essentially need to be overcome.

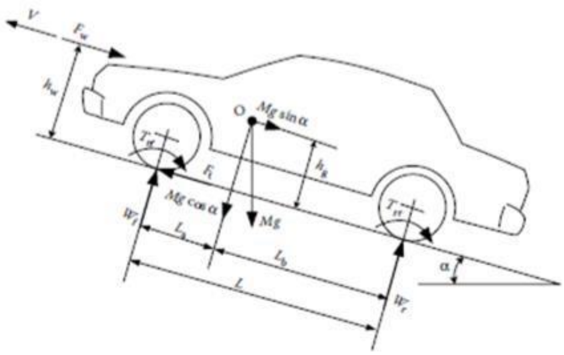

Figure 2 Calculation of vehicle rolling uphill

Where,
FgxT=Gravitational force,
FROLL = Rolling resistance,
FAD = Aerodynamic drag force,
xT is tangential direction on the roadways. Force Due To Gravity.

A vehicle's weight creates an element that is constantly pointed downward when it moves on or off a slope. This part either facilitates or hinders forward motion (grade lowering) or forward motion (grade climbing). Only uphill driving is taken into account in vehicle performance study. Grading resistance is the common term for this grading force.

Grading resistance, can be expressed as,

$F_g = Mg \sin \alpha$.

Where,
m = mass of the vehicle,
g = acceleration due to gravity,
β = slope angle (grade angle) with respect to horizon.
Rolling Resistance Force.

D. Rolling Resistance Force

Hysteresis in the tyre materials is the main cause of the resistance to rolling of tyres on hard surfaces. A tyre at rest with a force, P, acting at its centre is seen in Figure. Pz, the reaction force that results from the pressure being distributed equally to the centre in the contact region between the tyre and the ground, is aligned with P. The front half of a contact area loads while the tyre rolls, while the rear half unloads. Thus, an unequal distribution of ground-based reaction forces is caused by hysteresis. In the contact area, the pressure within the leading half is higher than the pressure in the trailing half. The reaction force on the ground is somewhat shifted forward as a result of this phenomena. With the typical load applied to the wheel centre, the forwardly shifted ground reaction force produces a moment that prevents the wheel from rolling. The primary reason of rolling resistance on soft terrain is ground surface deformation. The leading half experiences an almost total shift in the ground reaction force.

Calculation of rolling resistance force.

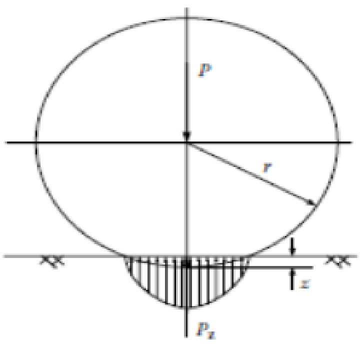

Figure 3 Rolling Resistance Force

Where,
Crr = coefficient of rolling resistance, (~ 0.01 to 0.035, for tires on road)

m = mass of vehicle
g = acceleration due to gravity
c. Aerodynamic Drag:

When moving through the air at a specific speed, a force opposes the motion of the vehicle. Aerodynamic drag is the term used to describe this force. Two factors primarily cause it: form drag and skin friction. 90% of it is made up of skin drag and form drag. Shape drag: The air in front of the vehicle is pushed by its forward motion. High air pressure results from the air's inability to instantly move aside, which causes its pressure to rise.
Furthermore, the space created by the vehicle's forward motion cannot be instantly filled by the air behind it. As a result, there is a low air pressure area. As a result, as the vehicle moves, two zones of pressure are created: one that pushes the object forward (high pressure) and the other that pulls it backward (low pressure). The form drag is the force that acts on the vehicle as a result.
Because the geometry of the car's body entirely determines this drag, it is known as "shape drag." Skin friction: Air near the vehicle's skin moves nearly at the vehicle's speed, whereas air farther away from it stays still. Air molecules travel at a variety of speeds in between. The second part of aerodynamic drag is caused by friction created by the difference in velocity between two molecules of air. Vehicle characteristics affect aerodynamic drag.speed V, vehicle frontal area, Af , shape of the vehicle body, and air density, ρ:

Fw = 1/2ρAfCD(V − Vw)2,

where Vw is the wind speed component on the vehicle's moving direction; this component has a positive sign when it is in the same direction as the moving vehicle as well as a negative sign when it is in the opposite direction. CD is the aerodynamic drag coefficient, which describes the shape of the vehicle body. The aerodynamic drag coefficients are displayed for common vehicle body designs in Figure 4.
Where,
ρ = air density,
A = frontal area,
Cd = aerodynamic drag coefficient, (depends upon design of the vehicle)
V = vehicle longitudinal speed,
Vw = wind speed.

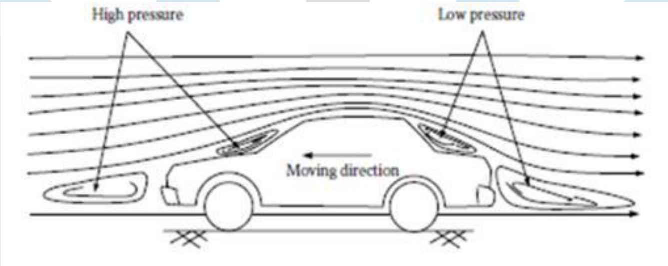

Figure 4 Aerodynamic drag coefficients for a typical vehicle

VI. SIMULATION

The ICE and the motor, which is connected to the gearbox, are the two propulsion sources seen in the above image. The battery pack powers the motor. The system includes a boost converter to increase the dc voltage because the battery pack frequently delivers voltage that is likely slightly less than needed. The dc-ac converter for the engine subsequently transforms this voltage into an ac variable form. Here, the power plant is also used to protect the battery towards nonlinearities. All of the battery's electrical system's components receive gating signals from the Electronics Control Unit (ECU). The system's brain is responsible for sending information to and from inside in the system for overall controllability.
The vehicle's dynamics, which are determined by the several types of friction and air drag it will experience while moving, make up the model's end system.

Electric Motor Modelling
When designing an electric machine with hybrid drive applications, there are three primary methods to consider. The first method employs efficiency maps to calculate the amount of electricity consumed given a specific mechanical power load, ignoring the dynamics between the machine and inverter. The second approach uses the dq-axis to account for the machine's electrical dynamics. Like the second approach, the third approach considers electrical dynamics but represents the real three-phase current within an electric machine. We'll talk about each of the three modelling techniques below.

Efficiency-Based Electric Machine Modelling The Electrical Difference System (EDS) block diagram is displayed for the purpose of simulating an electric machine's efficiency is shown in Figure 5.

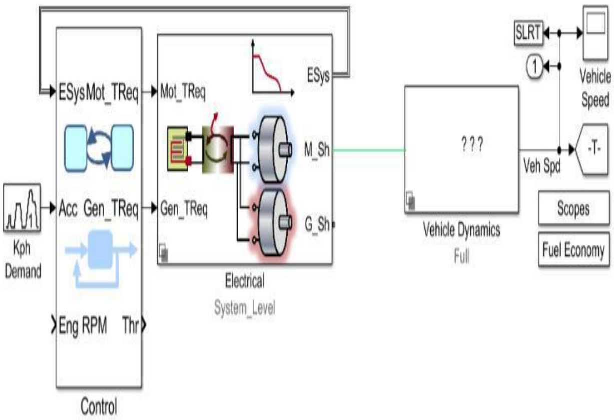

Figure 5. Electric Motor Modelling

As can be seen, the control block determines how the motor and acceleration are controlled. The generator & motor models in an electrical vehicle are part of the electrical system. The car's power train is displayed in the vehicle dynamics block, which is the final block. The internal schematics, together with the various voltage and current readings, are shown in the fig. 6:

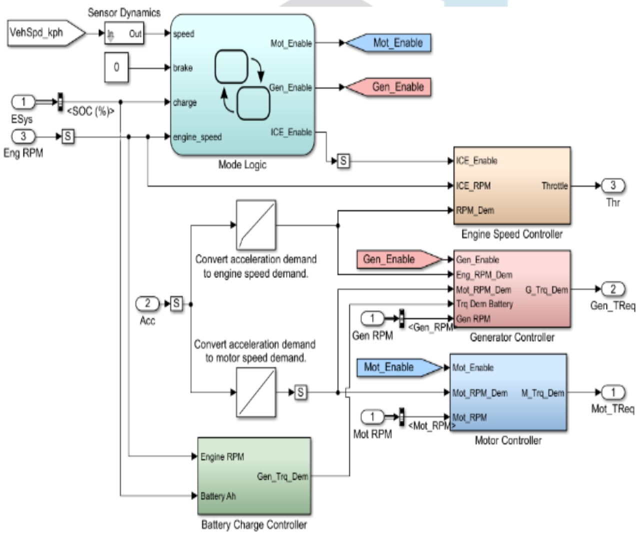

Figure 6 The internal diagrams and the different voltage and current reading

The internal control system of the simulation under development is depicted in the above figure.In this case, the brake input receives a constant input while the vehicle speed serves as the input for the speed.Both the engine and the charge are provided appropriately. The signals that operate the generator and motor are the result of this state flow mode logic; even the signals for the ICE are created here.The commands for the battery's charge controller are also obtained here, as indicated in the figure. The mode logic provides the necessary inputs for the other three blocks, which are the motor controller, generator controller, and engine speed controller.

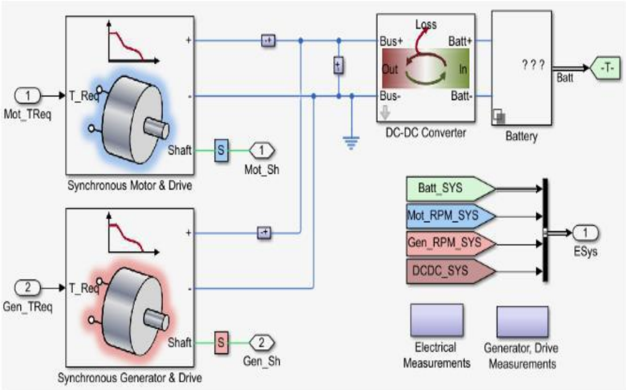

Figure 7 internal blocks of the electrical system of the whole simulation model

The core electrical system building blocks for the entire simulation model are depicted in the above diagram. It has blocks that explain how the generator and motor, which are connected to the dc-dc converter and transmit signals to the battery, work. The component labelled "Electrical measurements" contains the scopes that display electrical waveforms. The generis model of the engine, to which the engine shaft inertia is coupled, is housed within the engine's internal block. In the picture, a rotational damper is also displayed. The engine sensor is represented by the block with the letter S on it. The internal block is shown Below in fig.8.

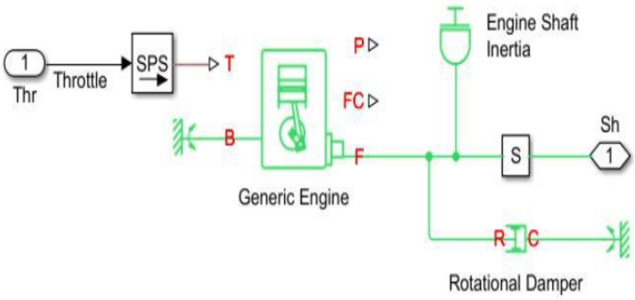

Figure 8 Internal blocks of the electrical system with sensor and rotational damper

The EV's power train is the most fascinating of all; the fundamental building blocks its constant are displayed here,

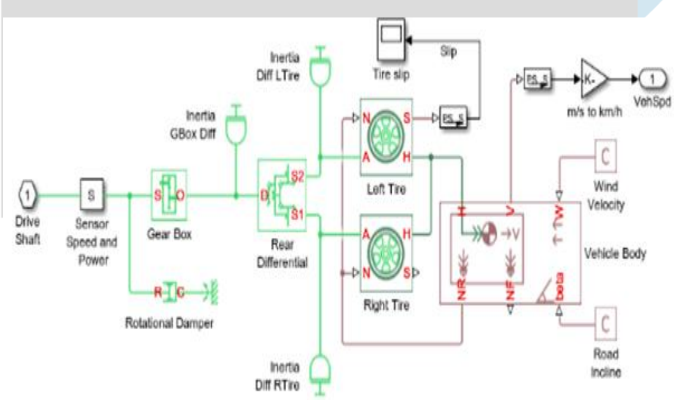

Figure 9 The power train of the EV

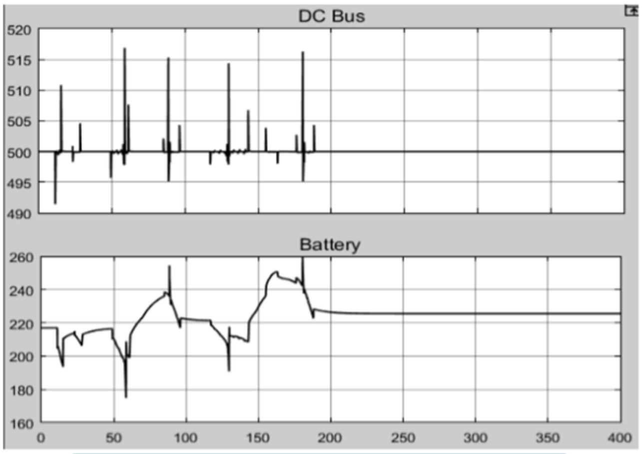

Figure 10 The voltages of the DC bus and battery

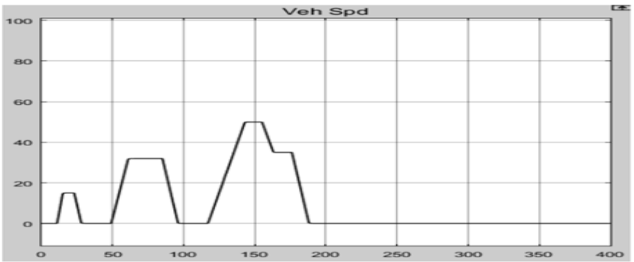

Figure 11 The speed of the vehicle

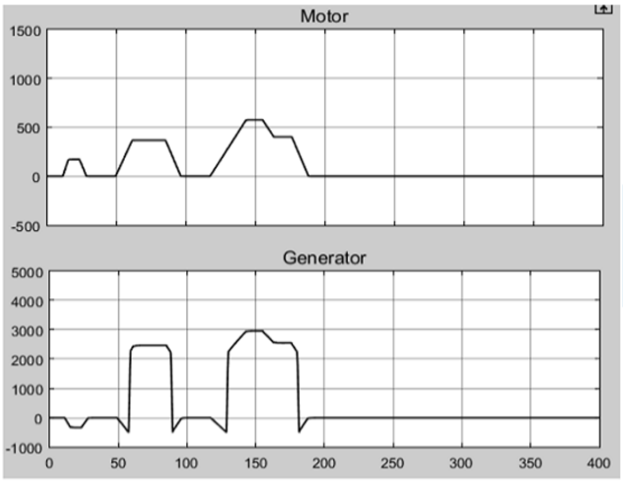

Figure 12 The waveform of the motor and generator

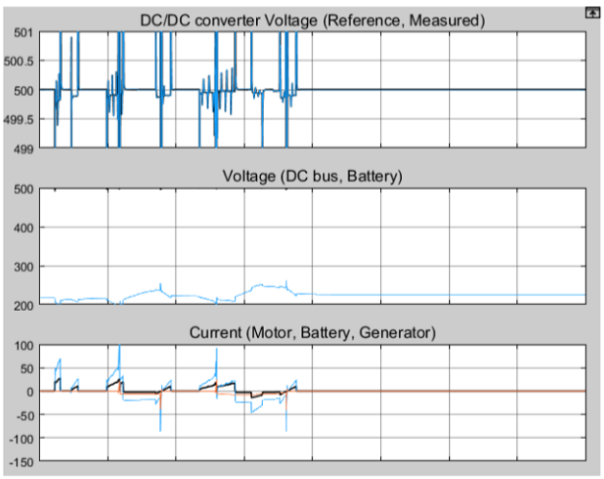

Figure 13 Waveform of converter and V and I of battery

VII. CONCLUSION

Initially, the majority of commercial software was examined for simulating electric vehicles, and Matlab/Simulink was chosen to create a dynamic simulation model for EVs. This was because the tools employ a physical modelling approach, which has greater advantages than a signal-based approach, and the models that are created can be easily incorporated into the control design process. The deployment and test simulation models for various controllers are combined onto a single platform by the EV model's flexible structure. It has the ability to quickly simulate and test vehicle controller designs with sufficient dynamic behaviour details for electrical systems. The modelling and simulation of battery packs using Matlab/Simulink is covered in this research along with studies on EV design simulations, including fuel economy, energy efficiency, and vehicle emissions.

The package makes use of visual programming approaches so that the user may easily modify parameters, architectures, and output data visualisation. Models of batteries and electric motors are included. It is possible to ascertain the precise needs for the provided specifications by utilising the generated results. Determining the precise requirements for the target group is a crucial aspect of designing an electric car. By doing so, the vehicle and drive system design may be optimised, hence improving the quality of electric vehicles. The real-world application has demonstrated its effectiveness in the realm of electric car design.

The simulation has effectively demonstrated that the simulator operates in accordance with the specifications and is a very helpful tool in any kind of vehicle. design in scheming battery and the controller, which would be very painstaking and time consuming otherwise. In order to assess the performance of batteries while they are being used in electric vehicles, we present in this study a battery simulation framework known as the virtual battery. The suggested modelling approach compactly and modularly portrays the EV sub-system. Once these models are created, it will be easy to conform to an integrated model that accurately depicts the performance of the entire vehicle.

This fully functional model saves time and development expenses by quickly verifying any changes made to the vehicle's design or control approach. Given the proposal's applicability, modelling it for any other EV configuration and comprehending the dynamics of electrically powered vehicles would be simple. We provide simulation results to demonstrate the multi-domain characteristic. Furthermore, they support the analysis of the dynamics of the battery under regenerative braking. It would be feasible to precisely ascertain the effect that a battery malfunction would have on the remaining car components and the overall operation of the vehicle under problematic circumstances if this entire model were fully validated.

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