Modelling Of Electric Vehicles: State-of-the-Art Review

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Abstract –**With the growth of the population and the advent of the industrial revolution, people began embarking on extensive travels in search of employment. Internal combustion engine vehicles (ICEVs) used for transportation emit various harmful gases upon combustion. The exhaust gases are a mixture consisting mainly of carbon dioxide (CO_2). Disturbing noise levels are another problem associated with large fleets of ICEVs in large cities. Electric Vehicles (EVs) are the replacements for the ICEVs, as they eliminate air pollution and sound pollution, also help in retaining back the reserves of gasoline for the future generation to come. The vehicles driven by electric motors that consume the stored electrical energy in rechargeable batteries are EVs. Electric motors are much better than ICEVs and could do a great job of powering vehicles, helping to solve the serious climate problem, air pollution and noise problems caused by ICEVs. This paper provides an exhaustive review of the current state of the art of the modeling, simulation and analysis of electric vehicle. It covers the important aspects of modeling of the results for a given drive cycle of electric vehicle. The paper intends to guide the new scholars willing to work in the area of electric vehicles. In addition, MATLAB/simulation is done to display various parameters of the electric vehicle.**

Keywords – Electric Vehicles, Plug In Hybrid Electric Vehicles, Hybrid Electric Vehicles, Battery Electric Vehicles, Internal Combustion Engine Vehicles, MATLAB/Simulink

I. INTRODUCTION

Transportation relies heavily on combustion engines, especially internal combustion engines, for a number of reasons. They facilitate the efficient movement of people and products, opening up new routes and improving mobility all around. Because of their versatility, combustion engines can run on a variety of fuels, including biofuels, natural gas, diesel, and gasoline. Because of their adaptability to various energy infrastructures and geographic locations, fuel sources are flexible. Because of their high energy density, combustion engines are able to store and discharge a large quantity of energy in a comparatively small amount of area. This feature is essential for powering vehicles that must travel great distances between fuel stops. Combustion engines make it possible to refuel quickly in comparison to some alternative energy sources like electric batteries. This is crucial in applications such as commercial transportation and emergency services, where minimizing downtime is imperative. In many regions of the world, the infrastructure for combustion engines, which includes fueling stations and facilities for maintenance, is already well established.

The transition to new fuels and technologies may go more smoothly with the help of the existing infrastructure. The automobile industry, heavily dependent on combustion engines, exerts a substantial impact on the global economy. Through taxes and tariffs, it generates substantial revenue for governments, supports a variety of related industries, and provides employment. The endurance and long-range capabilities of combustion engines make them ideal for long-distance transportation, aviation, and marine activities. In terms of performance, emissions control, and efficiency, combustion engine technology has always advanced.

These advancements contribute to an enhanced overall sustainability of transportation, leading to a reduction in environmental impact. Although these benefits exist, there is a growing awareness of the environmental impact associated with combustion engines, especially concerning air pollution and greenhouse gas emissions. To address these environmental concerns, there is a global push to develop and implement alternative, more sustainable transportation technologies like biofuels, hydrogen fuel cells, and electric vehicles. Internal combustion engines (ICEs) have been the dominant technology for powering vehicles for many years. While they offer benefits, there are also several disadvantages associated with internal combustion engines, particularly in the context of concerns related to the environment, efficiency, and sustainability [1-2]. The disadvantages of internal combustion engines include greenhouse gas emissions, air pollution and dependency on finite fossil fuels, lower energy efficiency, noise pollution, maintenance requirements, and vulnerability to price fluctuations. Conventional vehicles, typically powered by ICEs running on gasoline or diesel, face several challenges and drawbacks that have led to increased interest in alternative technologies, such as electric vehicles [3-4]. A number of nations are planning to phase out vehicles that run on fossil fuels like gasoline (petrol), diesel, kerosene, and fuel oil. The gradual elimination of all fossil fuel use and production, known as fossil fuel phase-out, Striving to minimize fatalities and health issues associated with contamination of air, address change in climate, and bolster energy autonomy. Sustainable energy sources used as substitutes for fossil fuels in both transportation and heating. Biofuel, electrification, and green hydrogen are fossil fuel alternatives. The need for electric vehicles (EVs) arises from the pursuit of a more sustainable and environmentally friendly transportation system, addressing challenges associated with traditional internal combustion engine vehicles The figure.1 beneath shows the worldwide investment in energy change with respect to various categories.

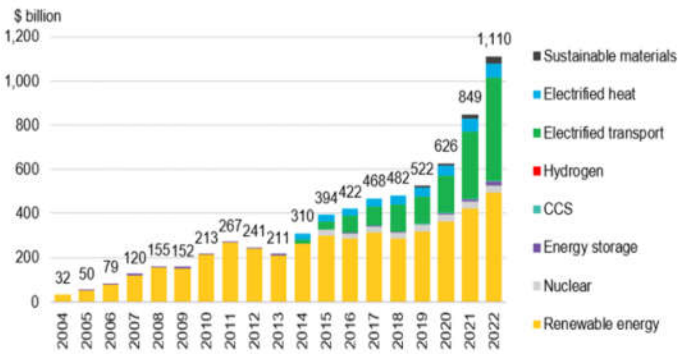

Figure 1. Worldwide Investment in Energy Change As Per Various Categories

To encourage the purchase of electric vehicles, some nations have offered consumers a variety of incentives, such as tax breaks or subsidies, while taxing fossil-fuel vehicles at an increasingly high rate. Renewable energy, electric vehicles and the infrastructure that goes along with the various de-carbonization initiatives that businesses, governments, and individuals have been investing [5-6].

Additionally, the present-day vehicles harness just 25% of the energy produced from petroleum, the remainder is scattered into the environment.

An electric vehicle may represent a significant advance in gasoline conservation and vehicle efficiency. The surge in the automobile industry during the twentieth century, influenced by urbanization and economic growth in industrialized nations. This paper presents classification, modelling, analysis and simulation of electric vehicle for a given drive cycle. The diverse forces affecting the electric vehicle (EV) are also elucidated and analysed. [7-10].

The paper is structured as follows, classification of electric vehicles is described in section II, different parameters, properties, forces acting on electric vehicles is briefed in section III, IV describes the simulation results of electric vehicles and finally, in section V the paper is concluded by tabulating all the results simulated followed with a brief explanation.

II. CLASSIFICATION OF ELECTRIC VEHICLES

The classification of EVs is contingent on their power source and the degree to which electricity is utilized for propulsion are mainly classified as per source of propulsion [11-15]. The figure.2 beneath depicts the electric vehicles classification.

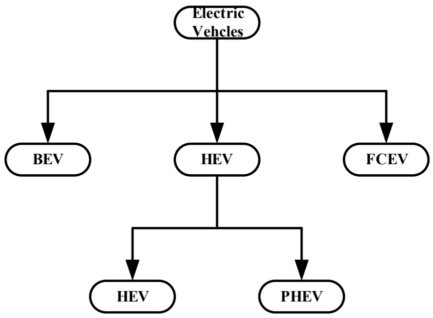

Figure 2. Classification of Electric Vehicles

Battery Electric Vehicles (BEV) - BEV are fully EV that rely solely on electric batteries for power. They lack an internal combustion engine, with their wheels exclusively driven by electric motors. These vehicles operate solely on electric batteries for their power.

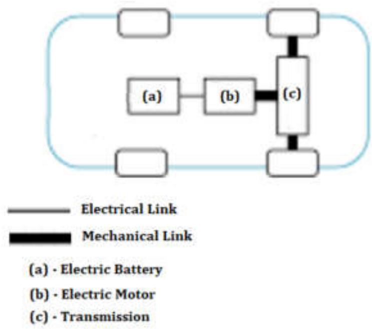

Figure 3. Battery Electric Vehicle

They use electric motors for propulsion and rely on charging stations to recharge their batteries. BEVs produce zero tailpipe emissions during operation, making them an environmentally friendly option. Zero tailpipe emissions are a characteristic of BEVs and charged by plugging into electric power sources, such as charging stations or home outlets. The figure.3 beneath shows Battery Electric Vehicle.

Hybrid Electric Vehicle (HEV) - They utilize an electric motor to assist IC engines. HEVs incorporate both electric motor and an internal combustion engine, yet they do not have the capability for external charging. Indeed, the electric motor is charged through regenerative braking and the power generated by the internal combustion engine. HEVs use the electric motor particularly during city driving. The figure.4 beneath shows hybrid electric vehicle.

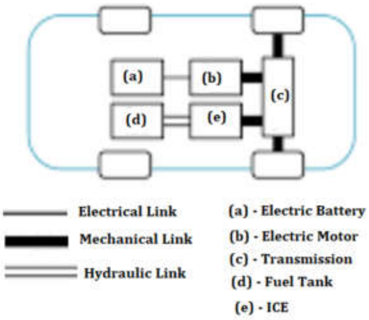

Figure 4. Hybrid Electric Vehicle

Plug-in Hybrid Electric Vehicle (PHEV) - They are alike to HEVs but have a bigger battery pack and electric motor. PHEVs operates in two modes, namely Hybrid mode and all-electric mode, in the former mode The vehicle is propelled by the collaborative

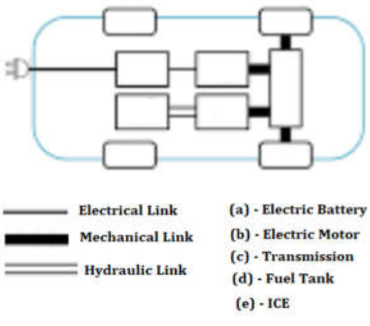

Figure 5. Plug-in Hybrid Electric Vehicle

operation of the internal combustion engine and the electric motor and in the later mode the vehicle is solely powered for propulsion by the electric motor. The figure.5 beneath shows PHEV.

Fuel Cell Electric Vehicle (FCEV) - They use power derived from chemical energy (hydrogen and oxygen) and a battery pack to power the vehicle without charging. Hydrogen fuel cells power this type of EV, these fuel cells produce electricity through a chemical reaction with oxygen .FCEVs emit only water vapor as a byproduct. The figure.6 beneath shows FCEV.

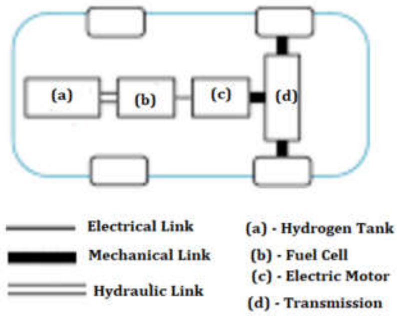

Figure 6. Fuel Cell Electric Vehicle

FCVs are a type of EV that utilize ‘fuel cell technology’ to generate electricity and charge the battery pack. They use the same system as a standard EV powered by one or more electric motors. FCEVs have a gas tank to store hydrogen and can be fueled up within minutes, similar to petrol and diesel-powered vehicles.

III. FEATURES OF AN ELECTRIC VEHICLE

Electric vehicles boast zero emissions, efficient energy use, low operating costs, and advanced technology, making them eco-friendly, cost-effective, and technologically advanced transportation options. Hereby is the description of the energy consumption in an electric drive cycle for an electric vehicle. An electric vehicle encounters various forces during its operation, influencing its overall efficiency and performance. These forces encompass factors like aerodynamic drag force, rolling resistance forces, gradient force and acceleration force. Optimizing and comprehending these forces is essential in the design and engineering of electric vehicles to enhance their efficiency, extend range, and improve overall functionality [16-19].

The various dynamics of an electric vehicle to be simulated are given in Table.1 below.

Table 1. Various Dynamics of an Electric Vehicle

Input Parameters	Values	Units
Wheel Radius	0.16	m
Mass of EV	111	Kg
Mass of Driver	80	Kg
Gravity Acceleration	9.81	m/s^2
Density of Air	1.23	Kg/m^3
GVM	191	Kg
GVW	1873.71	N
Drag coefficient	0.22	- -
Rolling Co-efficient	0.01	- -
Ratio of the Gear	7.80	- -
Efficiency of Transmission	85 %	- -
Efficiency of Motor	90 %	- -
Motor control efficiency	85 %	- -

Electric vehicle performance optimization commonly involves the utilization of advanced technologies such as regenerative braking and aerodynamic enhancements.

The figure.7 beneath depicts aerodynamic drag force acting on an electric vehicle.

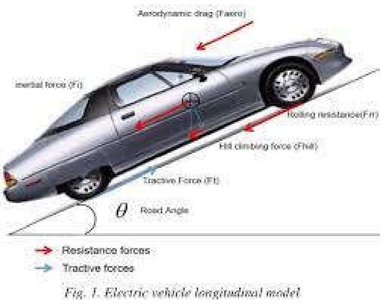

Figure 7. Aerodynamic Drag Force Acting on an Electric Vehicle

The drag force due to aerodynamic is given as

$$Af = 0.5 * \rho * A * C_d * V^2 \qquad (1)$$

Where

Af is the aerodynamic force in Newton

ρ is the aerodynamic force in Kg/m^3

A is the frontal area in m^2

C_d is the drag coefficient

V is the velocity in m/s

The figure.8 beneath depicts the simulation diagram of aerodynamic drag force.

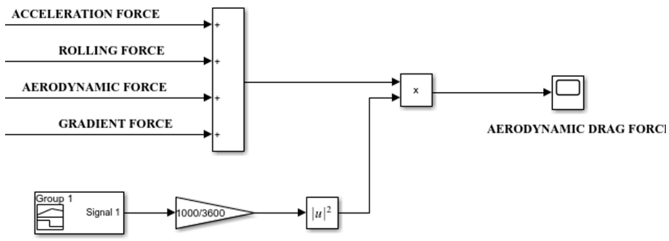

Figure 8. Simulation Diagram of Aerodynamic Drag Force

The figure.9 beneath depicts the rolling resistance force acting on an electric vehicle.

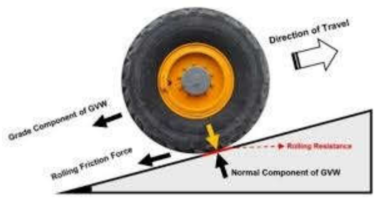

Figure 9. Rolling Resistance Force Acting on an Electric Vehicle

The rolling resistance force of the electric vehicle is given as

$$Rf = GVW * C_{rr} \qquad (2)$$

Where,

GVW is the gross vehicle weight

C_{rr} is the rolling coefficient

The figure.10 beneath depicts the simulation diagram of rolling resistance force.

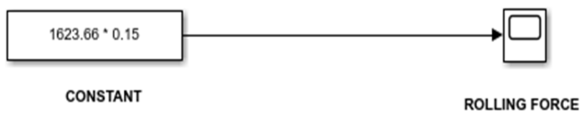

Figure 10. Simulation Diagram of Rolling Resistance Force

The figure.11 beneath depicts the gradient force acting on an electric vehicle.

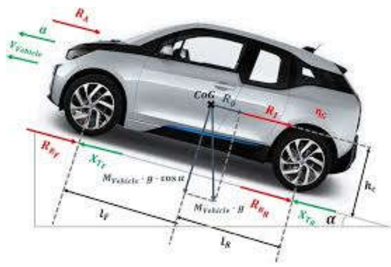

Figure 11. Gradient Force Acting on an Electric Vehicle

The Gradient force is given as

$$Gf = GVW * Sin(\theta) \qquad (3)$$

Where,

GVW is the gross vehicle weight
θ is the inclination angle
The figure.12 beneath depicts acceleration force acting on an electric vehicle.

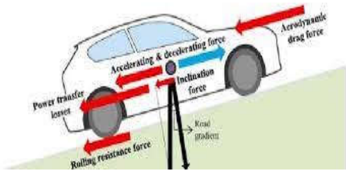

Figure 12. Acceleration Force Acting on an Electric Vehicle

The acceleration force is given as

$$Acf = GVM * a \tag{4}$$

Where,
GVM is the gross vehicle mass, which is the sum of vehicle mass and the driver mass
a stands for the acceleration of vehicle in m/s^2

The figure.13 beneath depicts the simulation diagram of acceleration force.

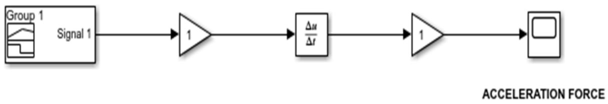

Figure 13. Simulation Diagram of Acceleration Force

The figure.14 beneath depicts the simulation diagram of total tractive force.

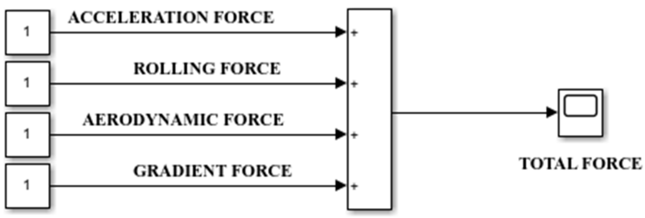

Figure 14. Simulation Diagram of Total Tractive Force

The total tractive force is given as

$$TTF = A_f + R_f + G_f + Ac_f \tag{5}$$

It is the torque, the twisting force generated by a vehicle's engine, that sets the wheels in motion and maintains their rotation. The transmission of this force from the engine to the wheels occurs through the drivetrain.
The wheel torque is given as

$$Wheel\ Torque = Total\ Tractive\ Foce * Wheel\ Radius \tag{6}$$

The figure.15 beneath describes the simulation diagram of wheel torque.

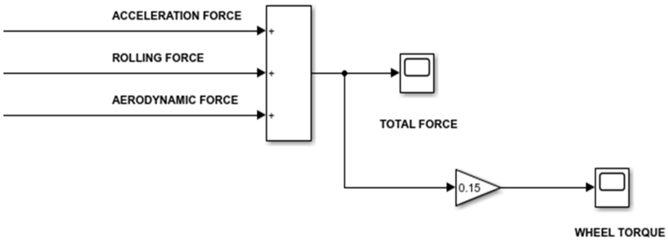

Figure 15. Simulation Diagram of Wheel Torque

The wheel speed is given as

$$Wheel\ Speed = V * \frac{60}{2*\pi*wheel\ radius} \tag{7}$$

The figure.16 beneath illustrates the simulation diagram of wheel speed.

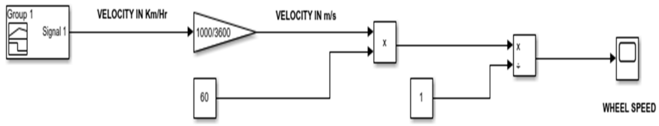

Figure 16 . Simulation Diagram of Wheel Speed

The motor torques is given as

$$Motor\ Torque = \frac{Wheel\ Torque}{Gear\ Ratio*TTF} \tag{8}$$

The figure.17 beneath depicts the motor torque simulation diagram.

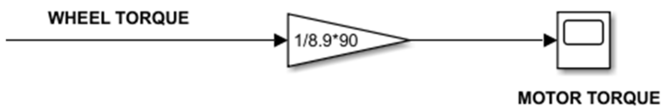

Figure 17. Simulation Diagram of Motor Torque

The motor speed is given as,

$$Motor\ Speed = Gear\ Ratio * Wheel\ speed \tag{9}$$

The figure.18 beneath describes the simulation diagram of motor speed.

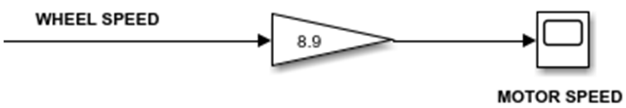

Figure 18. Simulation Diagram of Motor Speed

The motor power is given as,

$$Motor\ Power = \frac{2*\pi*M_S*M_t}{60} \tag{10}$$

Where,
M_s is the motor speed
M_t is the motor torque
The figure.19 beneath describes the simulation diagram of motor power.

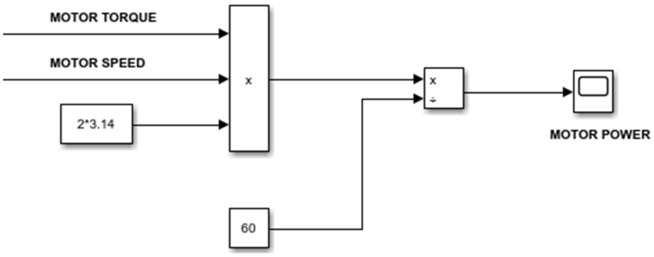

Figure 19. Simulation Diagram of Motor Power

The motor energy is the integer of power over the time

The figure.20 beneath describes the simulation diagram of motor energy.

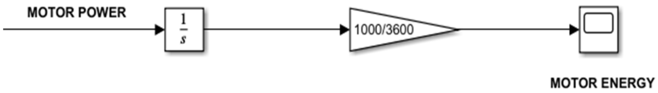

Figure 20. Simulation Diagram of Motor Energy

The battery power is given as

$$Battery\ Power = \frac{M_p}{MC_{eff}} \tag{11}$$

Where,
M_p is the motor power
MC_{eff} is the motor controller efficiency

The figure.21 beneath describes the simulation diagram of battery power.

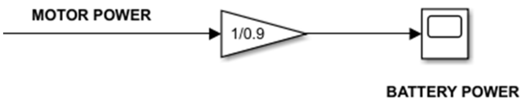

Figure 21. Simulation Diagram of Battery Power

The energy contained in the battery is determined by calculating the integral of power over time.

The figure.22 beneath describes the simulation diagram of battery energy.

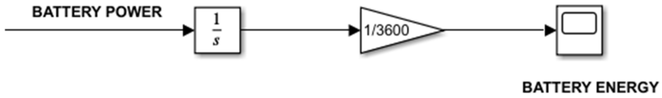

Figure 22. Simulation Diagram of Battery Energy

The total distance travelled is determined using velocity is in km/hr and time in hrs, the integral of velocity over time gives total distance travelled

The figure.23 beneath describes the simulation diagram of total distance travelled.

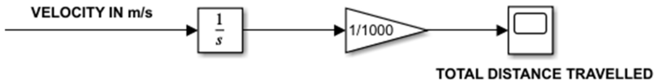

Figure 23 . Simulation Diagram of Total Distance

The energy used per km is determined using efficiency.
The Efficiency is given as

$$Efficiency = \frac{Total\ Energy}{Distance}$$

The figure.24 beneath potrays the simulation diagram of energy used per km.

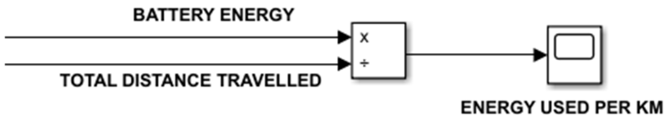

Figure 24 . Simulation Diagram of Energy Used Per Km

The electric drive's energy consumption is specified as...

$$\begin{aligned} &\text{The electric drive's energy consumption} \\ &= \text{Total energy delivered by the battery} \\ &- \text{ The aggregate energy consumed by the motor} \end{aligned}$$

The simulation diagram for the energy consumption of the electric drive is shown in the figure.25 beneath.

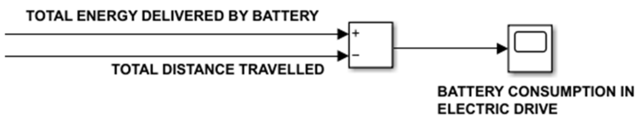

Figure 25. simulation diagram for the energy consumption of the electric drive

IV. SIMULATION RESULST

A MATLAB simulation on an electric vehicle investigate various attributes, each of which is follows herein.

The figure.26 below displays the EV velocity Vs Time characteristics.

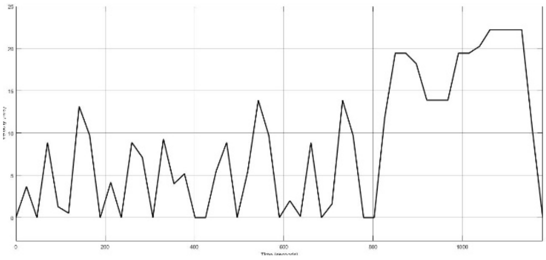

Figure 26. EV Velocity Vs Time Characteristics

The figure.27 below displays the EV aerodynamic force Vs Time characteristics.

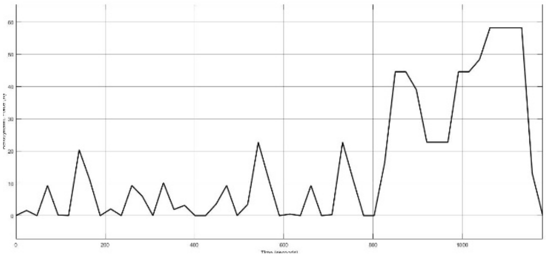

Figure 27. EV Aerodynamic Force Vs Time Characteristics

The figure.28 below shows EV rolling force Vs Time characteristics.

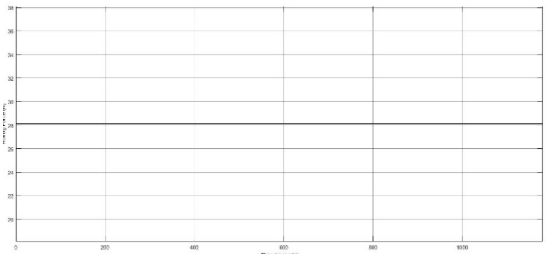

Figure 28. EV Rolling Force Vs Time Characteristics

The EV acceleration force Vs Time characteristics is shown in the figure.29 below.

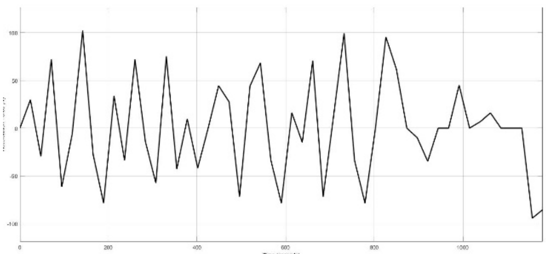

Figure 29. EV Acceleration Vs Time Force Characteristics

The figure.30 below depicts EV total force Vs Time characteristics.

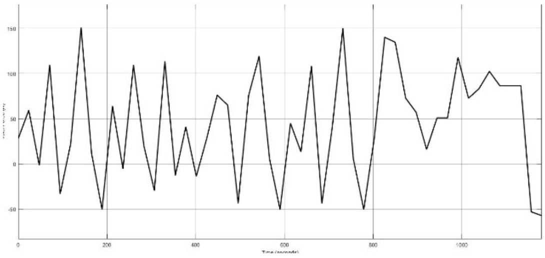

Figure 30. EV Total Force Vs Time Characteristics

The figure.31 below depicts the EV motor speed Vs Time characteristics.

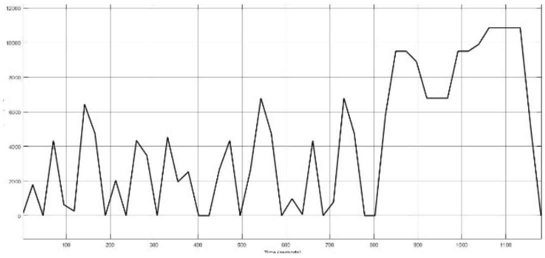

Figure 31. EV Motor Speed Vs Time Characteristics

The figure.32 below EV total distance travelled Vs Time characteristics.

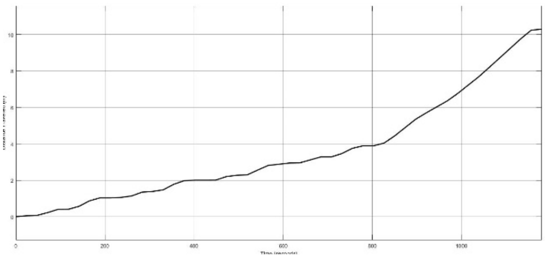

Figure 32. EV Total Distance Travelled Vs Time Characteristics

V. CONCLUSION

This paper addresses the necessity for electric vehicles (EVs) and provides a clear overview of various types of EVs. For a given drive cycle of electric vehicle, the electric drive is simulated and various characteristics are analyzed. The EV attains a maximum speed of 23 m/s.

The electric vehicle (EV) experiences a maximum aerodynamic force of 58N, a constant rolling force of 28N, maximum acceleration force of 101N and a maximum total force of 150N. The EV travelled a total distance of 10.3Km and consumed a total energy of 283.5 Wh. An Efficient electric vehicle design aims to minimize the aerodynamic drag and rolling resistance to improve overall energy efficiency and maximize the vehicle's range on a given amount of stored energy.

The findings are succinctly outlined in the Table.2 below.

Table 2. Simulation Results for Various Parameters

Sl No	Features	Value
1	Maximum Speed Attained	23 m/s
2	Max Aerodynamic Force	58 N
3	Constant Rolling Force	28 N
4	Max Acceleration Force	101 N
5	Max Total Force	150 N
6	Total Distance Travelled	10.3 Km
7	Total Energy Used	283.5 Wh

Hence, for a given drive cycle the EV can travel to a maximum distance of 10.3 Km.

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