DESIGN AND PERFORMANCE ANALYSIS OF BATTERY ELECTRIC VEHICLE USING MATLAB- SIMULINK

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Abstract:

The usage of Electric Vehicles is increasing day by day because they won't release any greenhouse gases into the atmosphere. So, EV manufacturers accepting the challenge to increase the range and reliability. This paper presents the design and performance analysis of electric vehicle by using a particular drive cycle. In this article, Electric vehicle with less run time is discussed and performance parameters like State of charge of the battery, speed and current are analyzed. Electric Vehicles are designed and simulated by using MATLAB software. It was most widely used by the students for design and its performance analysis. Step-by-step approach to design an EV is discussed in detail in this paper.

Keywords: Electric Vehicle, Longitudinal Driver, H-bridge converter, State of charge, PMDC motor, vehicle body.

I. Introduction:

Fossil fuels play dominant role in the transport sector. Due to large demand vehicles for transportation, the usage of fossil fuels has been increasing. When the fossil fuels are burned, CO_2 will be released into the atmosphere which leads to Global Warming i.e., increase of earth average surface temperature. So, it is necessary to shift our focus to another alternative fuel to run the vehicle. According to the Energy Policy Act of 1992, Electricity is considered as one of the alternative fuels. The sources of Electrical energy include solar energy, Wind Energy, nuclear energy. The concept of Electric vehicle is introduced into the market which uses electricity for its propulsion. Electric vehicles reduce greenhouse emissions, fuel costs and improves fuel economy. [1]

Electric vehicles are classified into many types. They are Battery Electric Vehicles, Plug in Hybrid electric vehicle and Hybrid Electric vehicle. Battery Electric vehicles are driven by electric motor using electrical energy stored in the battery. BEV's have a driving range of 150 to 400 miles. These vehicles don't use gasoline for propulsion [2]. Vehicle propulsion was purely done by the battery. Plug in Hybrid electric vehicles are driven by both electric motor and internal combustion engines. In electric zone, these vehicles can travel 20 to 40 miles of distance and then it runs with gasoline. Hybrid Electric vehicles (HEV's) are driven IC engine and one or more electric motors. In this vehicle, Internal combustion engine is operated by gasoline and through regenerative braking battery gets charged without plugging in.

Demand for electric vehicle has been increased because of high cost of fossil fuels. According to the Wikipedia report, 13.6 million electric vehicles are sold all around the world in 2023. Definitely the numbers increase in the next financial year.

In this paper, detailed approach to design an electric vehicle will be shown in MATLAB/SIMULINK.MATLAB software is used by many manufacturers to predict the performance of the electric vehicle under different environments. To design a complete EV model, there are different steps. It includes design of drive cycle, Driver controller, vehicle body, motor and motor controller. The Block diagram for complete EV model is shown in the following figure.

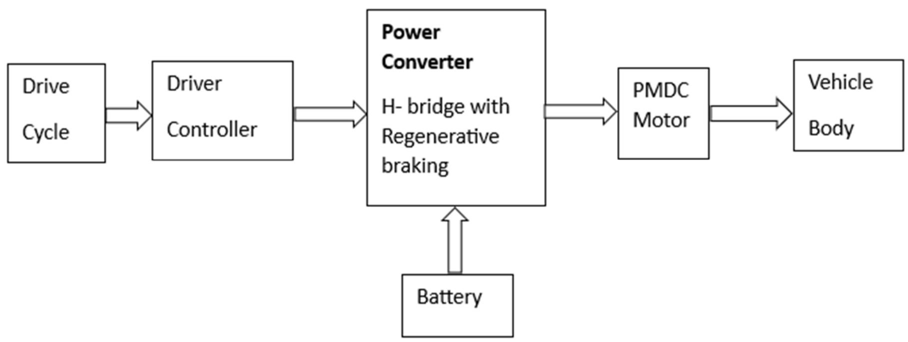

Fig.1. Block Diagram used for design

For the design and Performance analysis of electric vehicle, specifications of 2019 Tesla Model 3 standard range RWD are taken.

II. SPECIFICATIONS OF ELECTRIC VEHICLE USED IN THIS DESIGN

For design and analysis, certain reference data is required. The simulation used in this study is based on the 2019 Tesla Model 3 Standard Range RWD specifications. [3]

TABLE I. Specifications used for EV design

Parameters	**Values**	**Units**
Full body mass(M)	1611	Kg
Frontal Area	2.22	m^2
Drag Coefficient	0.23	-
Area of the Vehicle	6.62	m^2
No. of wheels per axle	2	-
Gear ratio	9	-
Wheel size	235/45R18	-

Coefficient of rolling resistance	0.01	-
Air Density	1.225	Kg/m^3
Rolling Resistance Force	158	N
Aerodynamic Drag force	246.10	N
Tractive Force	404.139	N
Battery Voltage	360	Volts
Battery Capacity	52.4	kWh
Motor Power	239	KW
Motor Torque	420	N-m
Acceleration 0-100 KM	5.90	Sec
Vehicle range per charge	354	KM

In this vehicle design, Lithium-ion battery of rated capacity 139 Ah is used. The type of motor used is Permanent Magnet Synchronous Motor in the Simulation study. But the PMDC motor is suitable for EV application because of its advantages like less pollution and fuel consumption and power to volume ratio is more.

III. STEPS TO DESIGN AN EV

STEP 1: Drive cycle Setup

Open the MATLAB software and SIMULINK file that appears on the top. Select the drive cycle block from MATLAB library. Design of EV starts with drive cycle setup. Drive cycle is the pre-defined input to the vehicle. It is speed Vs time data. There different types of Drive cycle sources available in MATLAB like FTP75, EUDC, Japanese 10 mode, Artemis Motorway etc. In this design WLTP Class 1 drive cycle is used as predefined input to the vehicle [4].

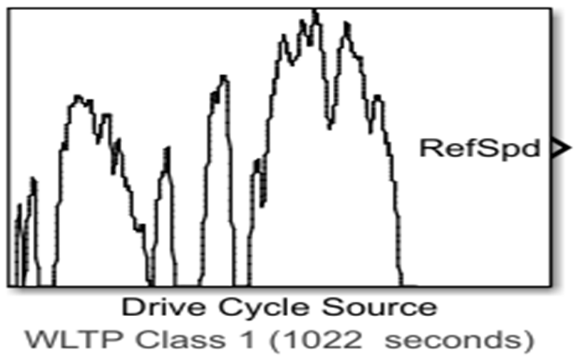

Fig.2. WLTP Class 1 Drive Cycle

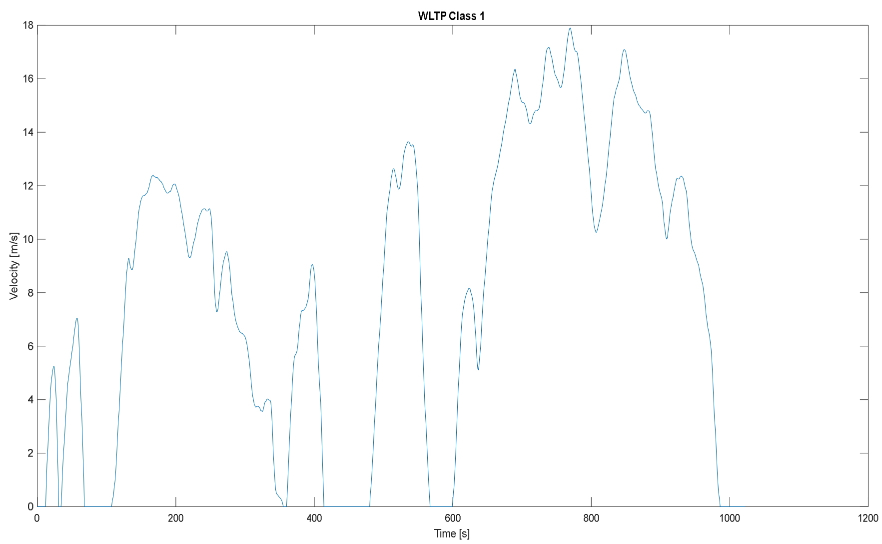

Fig.3. Pre-defined input to the vehicle

STEP 2: Design of Driver Controller

Select the Longitudinal Driver block from the MATLAB library. It compares the reference speed and vehicle speed [5]. Longitudinal driver has inbuilt PI controller. Drive cycle is connected to it. Drive cycle source is the speed data. It should be converted into acceleration. Thus, longitudinal driver block is required. If the reference speed is greater than actual speed, driver press accelerator. If the reference speed is less than actual speed, driver press brakes.

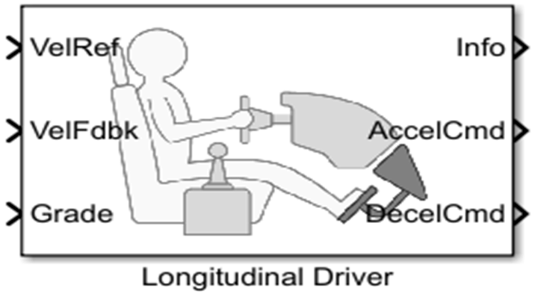

Fig.4. Longitudinal driver block

STEP 3: Design of Motor Controller

For a vehicle's propulsion, an electric motor is crucial. It needs to be managed more effectively. From the Simulink library, choose the H-Bridge converter. Thus, it manages the motor and regenerates electric power when it decelerates. Regenerated power is stored in the battery. Longitudinal driver block can generate both acceleration command and deceleration command.

H-Bridge converter receives the signal from the Controlled PWM voltage block and vehicle moves. Similarly, it also receives deceleration signal so that the motor stops. Regenerative Braking process takes place when the motor speed slows down [5]. All the references are connected to the ground.

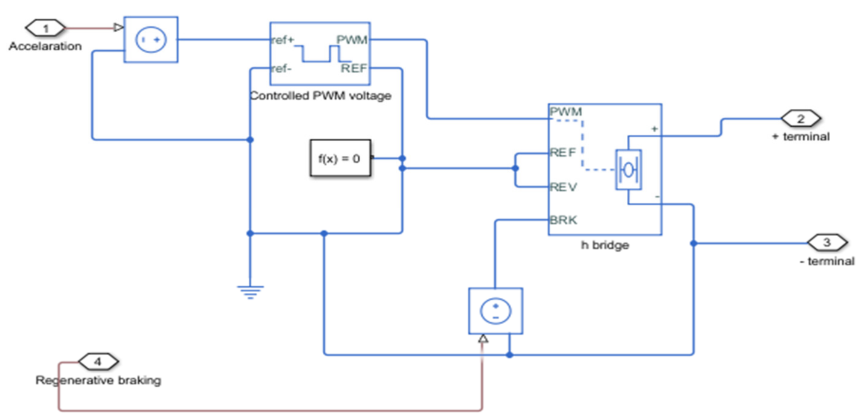

Fig.5. Design of motor controller

The parameters of H- bridge are shown in the figure below

TABLE II: H- bridge parameter setting

H- Bridge Settings in Simulink	
Simulation Mode & Load Assumptions	
Power Supply	Internal
Simulation Mode	Averaged

Regenerative braking	Always enabled (suitable for linearization)
Load current characteristics	Smoothed
Input Thresholds	
Enable threshold voltage	2.5V
PWM signal amplitude	5.0V
Reverse threshold voltage	2.5V
Braking threshold voltage	2.5V
Bridge Parameters	
Output voltage amplitude	360V
Total bridge on resistance	0.1Ω
Freewheeling diode on resistance	0.05 Ω

In the simulation mode, averaged is selected to run the simulation faster.

STEP 4: BATTERY SETUP DESIGN

In this design, Lithium-Ion battery is considered. Its Nominal voltage is 360V, Rated capacity is 139Ah, Initial State of Charge of battery is 100% and Battery response time is 30 seconds. H bridge converter is connected to the battery through the current sensor and controlled current source blocks [5] [6].The measurement port of the battery is connected to the Bus Selector to observe the variation in voltage and current through the Scope and Display.

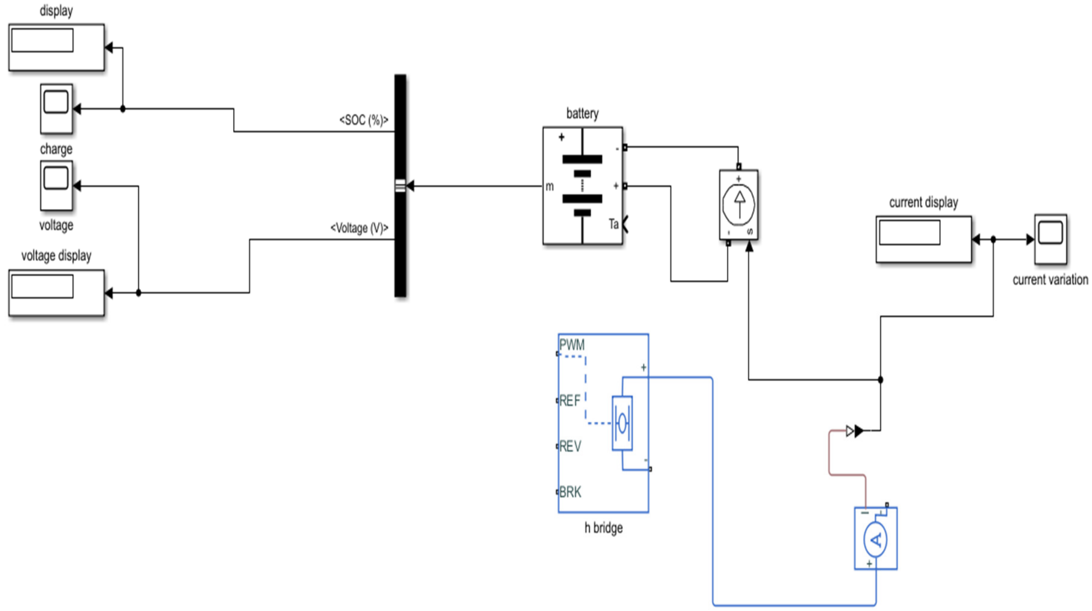

Fig.6. Battery Setup design

Table III: Battery parameter setting

Battery Settings in Simulink	
Type of battery	Lithium-Ion battery
Nominal voltage (V)	360
Rated capacity (Ah)	139
Initial state of charge (%)	100
Battery response time (s)	30

STEP 5: MOTOR DESIGN

In 2019 Tesla Model 3 Standard range RWD, Permanent Magnet Synchronous Motor is used. But in this design, PMDC motor is used. Because of its benefits, which include lower fuel consumption, pollution, and a higher power to volume ratio. The PMDC motor's positive and negative terminals are linked to the positive and negative terminals of the H-bridge. The gear box and the motor's shaft are linked.

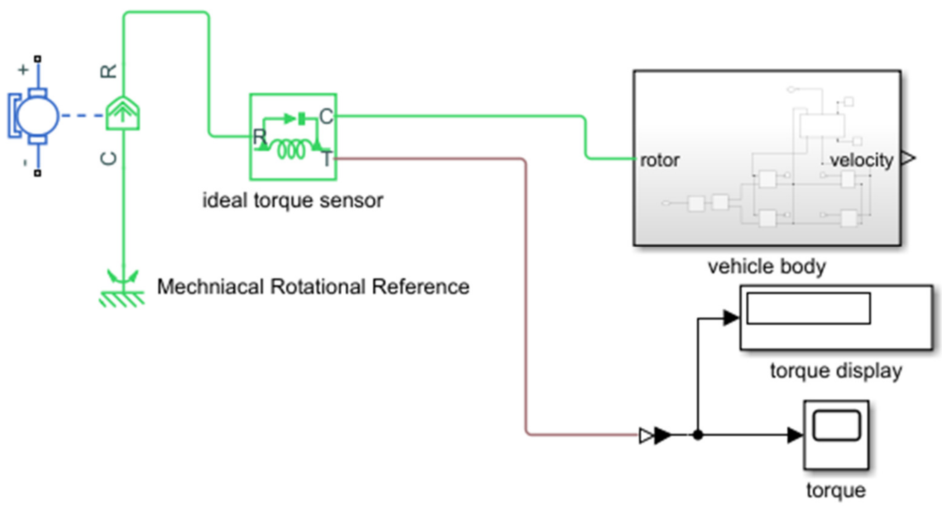

Fig.7. Motor design

TABLE IV: PMDC motor parameter setting

DC motor settings in Simulink	
Electrical Torque	
Field type	Permanent magnet
Model parameterization	By rated load and speed
Armature inductance	2.4 H
No-load speed	4000 rpm
Rated speed (at rated load)	1900 rpm
Rated speed (mechanical power)	163 kW
Rated DC voltage	360 V
Rotor damping parameterization	By damping value

Mechanical	
Rotor inertia	0.65 kg*m^2
Rotor damping	0 N*m*s/rad
Initial rotor speed	0 rpm

STEP 6: DESIGN OF VEHICLE BODY

Select the vehicle body block from MATLAB library. This block has 6 ports.

H stands for hub. The hub terminal of wheels (Tire Magic Formula) is connected to main vehicle body through this terminal. V stands for velocity output of the vehicle. W stands for wind velocity against the vehicle. NR & NS terminals are connected to the rare and front wheels. Beta terminal is the input port for inclination.

Four wheels are necessary to model a four-wheeler. Rear wheel drive is achieved by connecting two wheels to the front axle and two wheels to the rear axle. The rear axle is where the motor's power is connected. [4] [6]

Ports of the wheel include:

H stands for Hub, S is tire slip, N is the normal force applied to the tire, A is axle connection. Gear should connect to the rear wheel.

6.1. CALCULATION OF ROLLING RADIUS

The Size of the wheel used for the design is 235/45R18

Here 235mm indicates width of the tire (W).

45 indicates Aspect ratio (%). It gives the relationship between width of the tire and height of sidewall.

18 inches (457.2mm) indicates rim diameter (D)

Rim radius and tire side wall height should be known in to calculate wheel's diameter [7].

Tire side wall height(H) = [Aspect ratio (AR)*W]/100

= 105.75mm

Wheel diameter (d_w) =Rim diameter (D) +2(height of the tire)

= 668.7mm

Wheel radius (r_w) = $d_w/2$ = 0.33435 mm

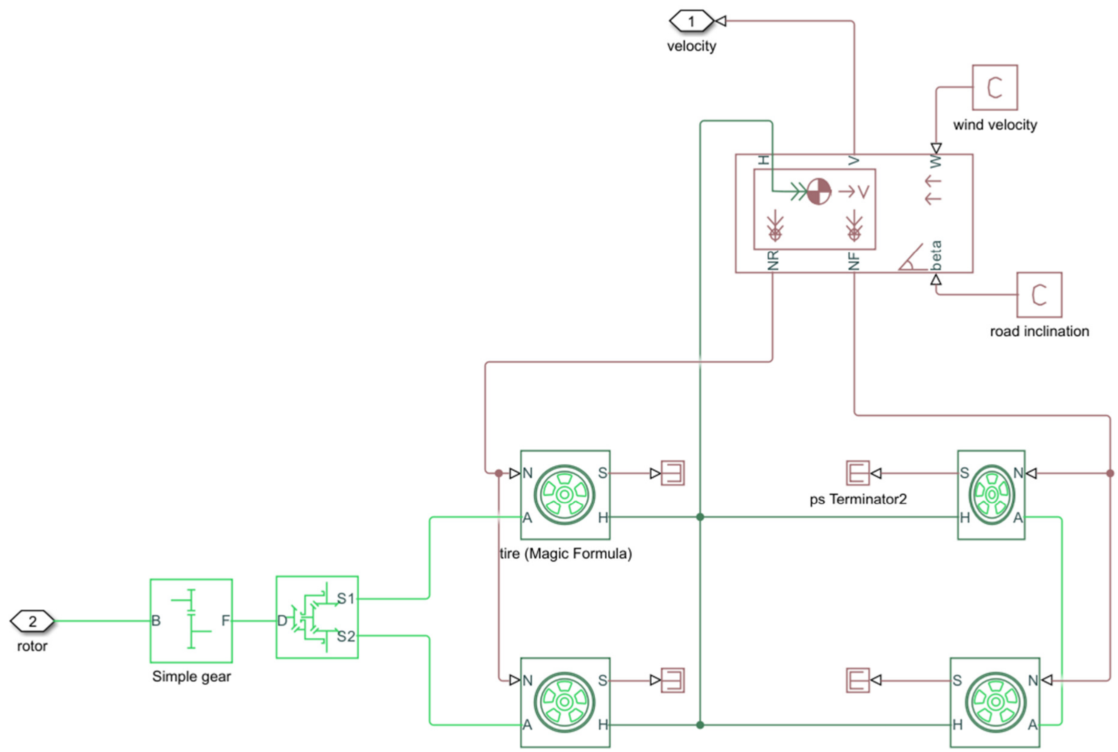

Fig.8. Vehicle body design

TABLE V: Vehicle body parameter setting

Vehicle Body settings in Simulink	
Main	
Mass	1611 kg
Number of wheels per axle	2
Horizontal distance from CG to front axle	1.4m
Horizontal distance from CG to rear axle	1.6m
CG height above ground	0.5m
Externally-defined additional mass	Off
Gravitational acceleration	9.81 m/s^2
Negative normal force warning	Off
Drag	
Frontal Area	2.22 m^2
Drag Coefficient	0.23
Air density	1.225 kg/m^3
Pitch	
Pitch dynamics	Off

The distance travelled by the electric vehicle is obtained by connecting the velocity output port of vehicle body to an integrator. The integrator is connected to the gain block convert the distance from meters to kilometers. Velocity port of the main vehicle body is connected to the velocity feedback terminal of longitudinal driver block in order to match vehicle speed with the reference speed. The following Figure shows the Simulink model of EV.

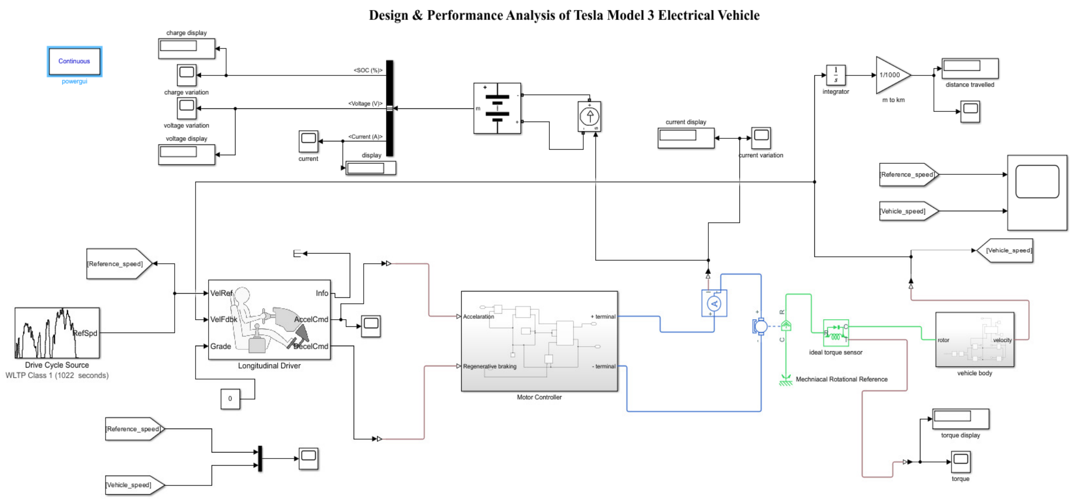

Fig.8. Complete EV design

IV. RESULTS AND ITS ANALYSIS

A Continuous Solver block should be added before simulating the EV model. The pre-defined input to the vehicle id WLTP Class 1 drive cycle. Its simulation run time is 1022 seconds. Set the simulation run time as 1022 seconds. The electric car covered 8 km after the Simulink model ran for 1022 seconds, and the battery's state of charge was 98.37%.

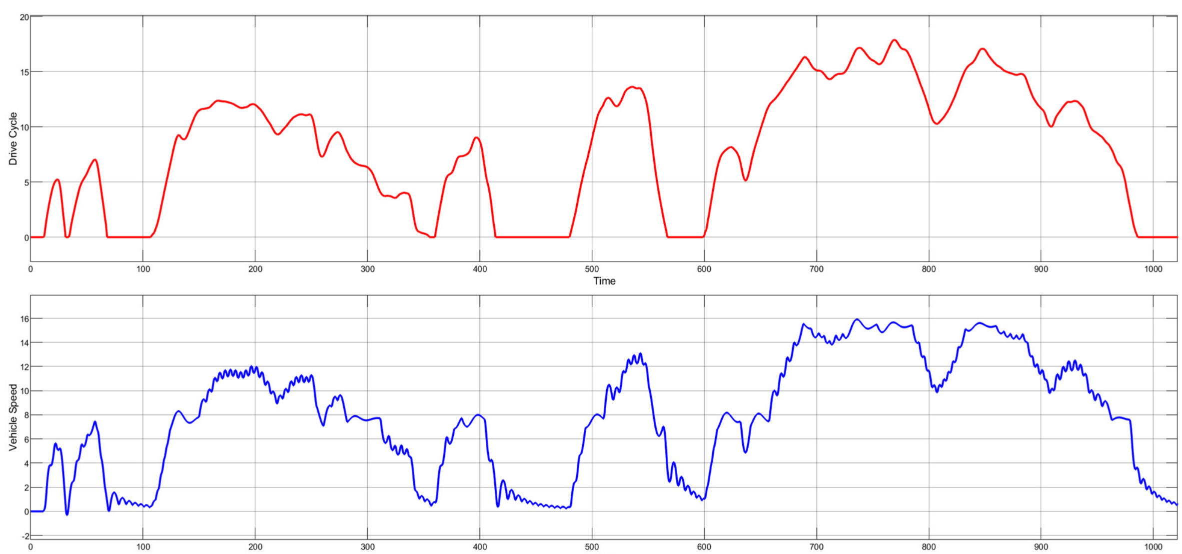

Fig.9. Drive Cycle and Vehicle speed V/s time

The WLTP Class 1 drive cycle is shown in red in the above picture, while the vehicle speed is shown in blue. The high gear ratio and drag coefficient are the cause of the discrepancy between the vehicle speed and the drive cycle.

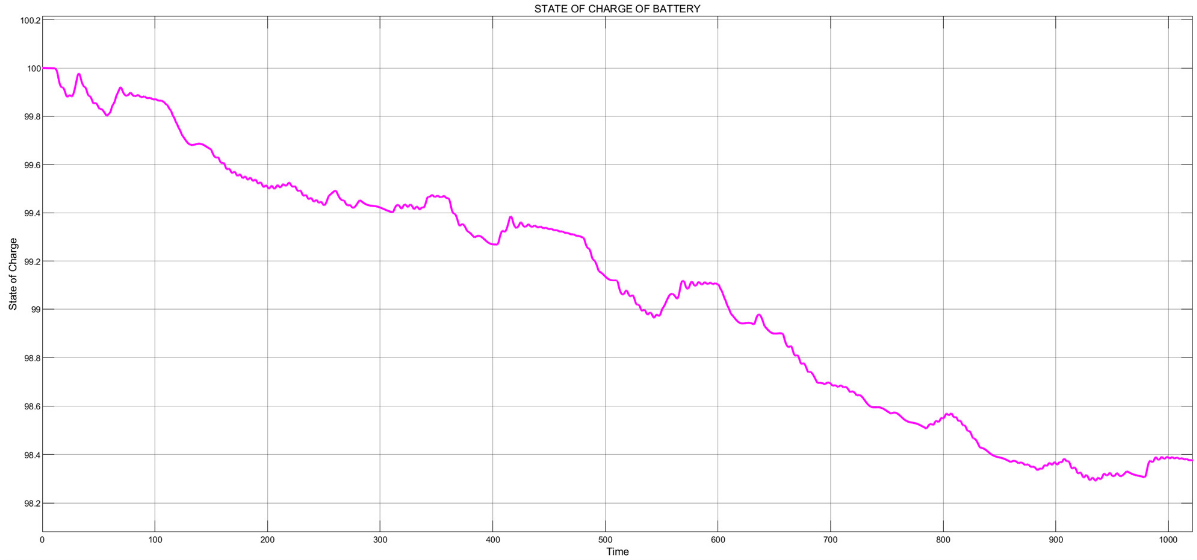

Fig.10 State of charge V/s time

The vehicle travelled 8KM with the given drive cycle. The state of charge of the battery is reduced from 100% to 98.37%. This is due to high battery capacity of the vehicle i.e., 139Ah. The spikes in the graph indicates Regenerative braking.

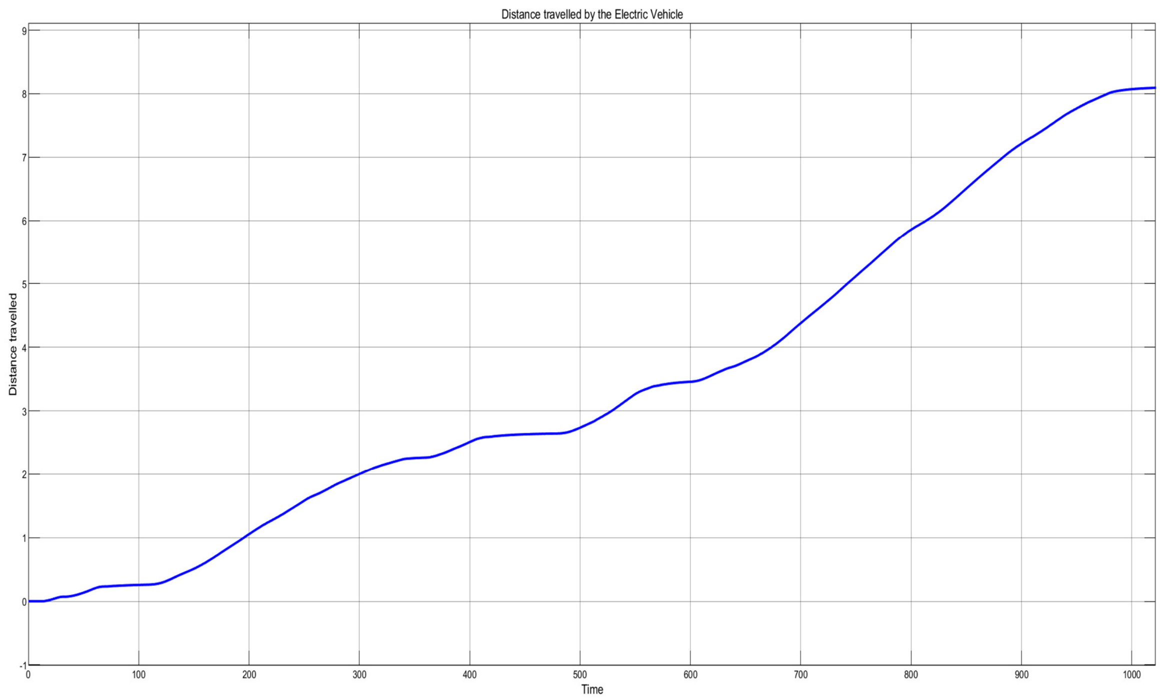

Fig.11. Distance travelled v/s time

The vehicle travelled for 17 minutes and the distance covered is 8Km.

V. CONCLUSION

In this paper, step-by-step approach to design an Electric vehicle has been discussed. By using the MATLAB/Simulink as the design tool, the performance of electric vehicle has been observed. An electric vehicle covered 8 km in 17 minutes for a specific drive cycle (WLTP Class 1). The battery has a 98.37% state of charge. In this way the manufacturers can analyze the performance of EV with a pre-defined velocity profile and can predict the vehicle operation in real world environment.

REFERENCES

[1] Hannah Ritchie and Pablo Rosado, "Fossil Fuels," [Online]. Available: https://ourworldindata.org/fossil-fuels.

[2] "Alternative Fuels Data Center," [Online]. Available: https://afdc.energy.gov/fuels/electricity_basics.html.

[3] "2019 Tesla Model 3 Standard Range RWD - Specifications," [Online]. Available: https://www.evspecifications.com/en/model/bc5896.

[4] "Build Full Electric Vehicle Model," [Online]. Available: https://in.mathworks.com/help/autoblks/ug/explore-the-electric-vehicle-reference-application.html.

[5] Dileep Kumar Kohar, Akshaya K. Pati and Sarita Nanda, "Design Approaches and Performance Analysis of Electric Vehicle using MATLAB/Simulink," *2023 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS),* pp. 1-6, 2023.

[6] Slough J, Belcher M, Tsui T and Bhattacharya S, "Modeling and Simulation of Electric Vehicles Using Simulink and Simscape," *In 2021 IEEE 94th Vehicular Technology Conference (VTC2021-Fall),* pp. 01-06, 2021.

[7] "How to calculate wheel radius," [Online]. Available: https://x-engineer.org/calculate-wheel-radius/.

[8] Inoue Y, Kosaka T, Matsumori H and Matsui N, "Modeling and Simulation of Battery-powered Electric Vehicle on MATLAB/Simulink," *In2021 24th International Conference on Electrical Machines and Systems (ICEMS),* pp. 694-698, 31 Oct 2021.

[9] Hashemnia N and Asaei B, "Comparative study of using different electric motors in the electric vehicles," *In2008 18th international conference on electrical machines,* pp. 1-5, 6 Sep 2008.

[10] Vempalli SK, Ramprabhakar J, Shankar S and Prabhakar G, "Electric vehicle designing, modelling and simulation," *In2018 4th International Conference for Convergence in Technology (I2CT),* pp. 1-6, 27 Oct 2018.

[11] Abulifa AA, Ahmad RR, Soh AC, Radzi MA and Hassan MK, "Modelling and simulation of battery electric vehicle by using MATLAB-Simulink," *In2017 IEEE 15th*

Student Conference on Research and Development (SCOReD, pp. 383-387, 13 Dec 2017.

[12] Pacejka H, "Tire and vehicle dynamics," *Elsevier,* 8 Dec 2005.

[13] Dr.T.S.N.G. Sarada Devi and Mrs. G. Jhansi Rani, SPECIAL HYBRID ELECTRIC VEHICLES, vol. 1, LAMBERT, 2023.