Design and Analysis of Electric Vehicle Powertrain Using BLDC Motor and Under FTP-75 Drive cycle

Thandrapati Vasudha[1], Dr.T.R. Jyothsna[2]
[1,2]Au College of Engineering

Abstract—This paper presents the modelling, simulation, and performance analysis of an Electric Vehicle (EV) powertrain employing a Brushless DC (BLDC) motor under the FTP-75 drive cycle. The proposed system integrates a Li-ion battery, three-phase inverter, BLDC motor, and longitudinal vehicle dynamics modelled in MATLAB/Simulink. The FTP-75 drive cycle serves as a reference input to evaluate real-world driving behaviour, focusing on acceleration, braking, and cruising conditions. A Proportional–Integral (PI) controller regulates the vehicle speed to ensure accurate tracking and dynamic stability. Simulation results demonstrate effective speed regulation, realistic torque and current responses, and stable vehicle operation. The study highlights the significance of accurate parameter selection and control tuning for realistic EV behaviour, offering a strong foundation for future integration of regenerative braking and advanced control strategies.

Index Terms—Electric Vehicle (EV), Brushless DC Motor (BLDC), MATLAB/Simulink, Powertrain, PI Controller, FTP-75 Drive Cycle.

I. INTRODUCTION

The increasing global demand for sustainable transportation has intensified the focus on Electric Vehicles (EVs) as an alternative to fossil-fuel-based vehicles. Among various subsystems, the powertrain plays a pivotal role in determining the efficiency, range, and performance of an EV. The Brushless DC (BLDC) motor, known for its high efficiency, compactness, and reduced maintenance, is widely employed in electric propulsion systems.

This research focuses on designing and analyzing an EV powertrain powered by a BLDC motor using MATLAB/Simulink. The FTP-75 drive cycle, representing real-world urban driving conditions, is used to evaluate the system's performance. The model integrates the battery pack, three phase inverter, BLDC motor, PI-based driver model, and longitudinal dynamics to capture the complete behaviour of the EV system. The aim is to achieve realistic current, torque, and speed profiles while maintaining system efficiency and stability.

II. SYSTEM MODELLING AND SIMULATION

A. Powertrain Architecture

The EV powertrain model consists of four primary components: a Li-ion battery pack, three-phase inverter, BLDC motor, and vehicle dynamics block. The battery acts as the DC energy source, while the inverter performs DC–AC conversion using Pulse Width Modulation (PWM). The BLDC motor converts the electrical energy into mechanical torque, which propels the vehicle through a fixed gear transmission. The MATLAB/Simulink model integrates these subsystems to analyze power flow and dynamic response.

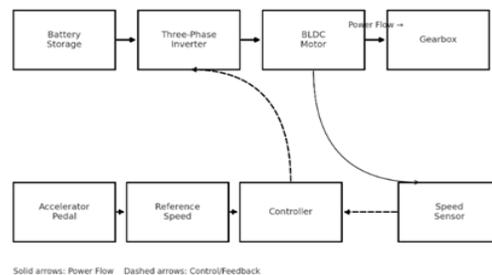Solid arrows: Power Flow   Dashed arrows: Control/Feedback

Figure 1 illustrates the conceptual representation of the EV powertrain used in this study. The system consists of a battery storage unit, three-phase inverter, BLDC motor, gearbox, and control unit. Power flow is represented by solid arrows, while dashed arrows indicate control and feedback signals. The controller compares the reference and actual speeds obtained from the speed sensor to generate appropriate PWM signals for the inverter, ensuring efficient torque control and speed regulation.

B. Battery Modelling

The battery subsystem is modelled using an equivalent circuit that includes an open-circuit voltage (OCV) and an internal resistance (R_int). The terminal voltage is expressed as:

$$V_{bat} = E(SOC) - I_{bat} * R_{int}$$

where E(SOC) is the open-circuit voltage dependent on the state of charge (SOC). The SOC is dynamically updated based on current discharge.

C. Inverter and Motor Modelling

The inverter converts DC power into three-phase AC signals that drive the BLDC motor. The motor's electrical dynamics are given as following below:

$$V_a = R_s I_a + L_s \frac{di_a}{dt} + e_a$$

$$V_b = R_s I_b + L_s \frac{di_b}{dt} + e_b$$

$$V_c = R_s I_c + L_s \frac{di_c}{dt} + e_c$$

The electromagnetic torque produced by the motor is expressed as:

$$T_e = K_t(i_a f_a(\theta_e) + i_b f_b(\theta_e) + i_c f_c(\theta_e))$$

The mechanical dynamics are governed by:

$$J \frac{d\omega_r}{dt} = T_e - T_L - B\omega_r$$

D. Drive Cycle and Control Implementation

The FTP-75 drive cycle is a standard test cycle that simulates urban driving with frequent acceleration, braking, and idling. The cycle spans 2474 seconds with an average speed of 34.1 km/h. The reference speed signal from FTP-75 is fed into a PI-controlled driver model, which compares the actual and desired speeds. The PI controller generates torque demand for the BLDC motor by adjusting the accelerator signal to minimize speed error.

The proportional component provides fast correction, while the integral term eliminates steady-state error. Controller parameters were tuned to ensure stable tracking without oscillation.

E. Vehicle Longitudinal Dynamics
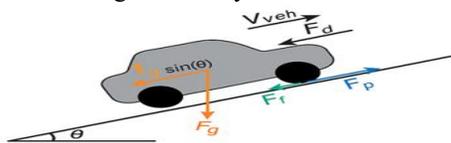
The longitudinal dynamics model represents how the electric vehicle responds to tractive effort from the motor and opposing road loads. It is a critical block in the EV powertrain simulation since it governs the vehicle speed and acceleration under a given drive cycle. By combining the forces acting on the vehicle, this model establishes the relationship between motor torque, vehicle mass, road conditions, and vehicle velocity.

The fundamental governing equation is derived from Newton's Second Law of Motion:

$$F_{trac} - F_{res} = M.a$$

The tractive force generated by the BLDC motor is transmitted to the wheels through the

$$F_{trac} = \frac{T_m.\eta_t}{\tau_\omega}$$

Resistive Forces:
Rolling resistance Force:

$$F_{rr} = C_{rr}.m.g.\cos(\theta)$$

Aerodynamic Drag Force:

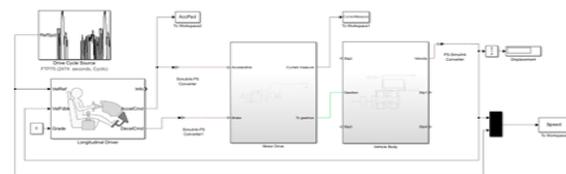$$F_{ad} = \frac{1}{2}.\rho.C_d.A.v^2$$

Gradient Resistance Force

$$F_g = m.g.\sin(\theta)$$

Net Longitudinal Dynamics Equation

$$F_{net} = F_{trac} - (F_{rr} + F_{ad} + F_{gr})$$

III. SIMULATION MODEL AND ITS SUBSYSTEMS

This section presents the complete MATLAB/Simulink model and its individual subsystems used to simulate the proposed electric vehicle powertrain. Each subsystem is responsible for a specific function such as energy supply, control, motor actuation, or vehicle dynamics.
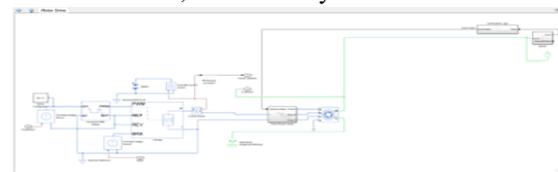
The BLDC motor subsystem controls torque and speed using PWM signals. The inverter converts DC battery voltage into a three-phase AC output synchronized with the rotor position, ensuring smooth commutation and efficient operation.
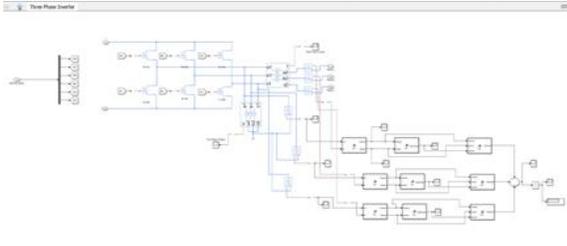
The inverter used in this system consists of six MOSFETs arranged in an H-bridge configuration, where the switching devices are controlled through complementary PWM pulses generated by the controller. The MOSFET-based inverter efficiently converts the DC supply from the battery into three-phase AC signals required to drive the BLDC motor, ensuring smooth commutation and rapid dynamic response. Due to their faster switching speed and lower conduction losses compared to IGBTs, MOSFETs are well-suited for low- to medium-voltage electric vehicle applications, making them an ideal choice for this simulation model.
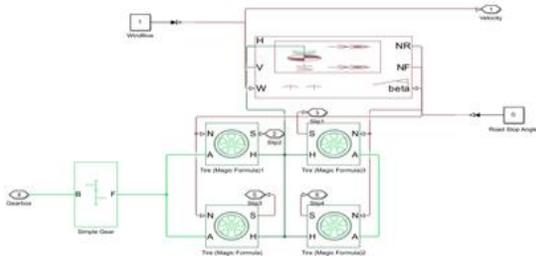
The vehicle body subsystem, shown in Figure 4, models the longitudinal dynamics of the Electric Vehicle by accounting for aerodynamic drag, rolling resistance, gradient resistance, and tire-road interaction. The subsystem receives input torque from the BLDC motor through the gearbox and converts it into linear vehicle motion. It uses the "Vehicle Body" block in Simulink, which includes parameters such as vehicle mass, drag coefficient, and frontal area to replicate realistic driving conditions. The tire model is implemented using the Magic Formula, providing accurate traction and slip behaviour during acceleration and braking. The vehicle speed output is continuously fed back to the driver block for closed-loop control, ensuring the reference speed is maintained as per the FTP-75 drive cycle. This

subsystem effectively captures the dynamic performance of the EV during different driving phases such as start-up, cruising, and hill climbing.

IV. RESULTS AND DISCUSSION

The simulation of the proposed Electric Vehicle powertrain was carried out in MATLAB/Simulink using the FTP-75 drive cycle as a reference input. The system was tested to evaluate its dynamic performance under varying acceleration, braking, and cruising conditions. The outputs obtained include vehicle speed, Motor Speed, Motor Power,

Motor Torque, Inverter input current, Acceleration pedal position
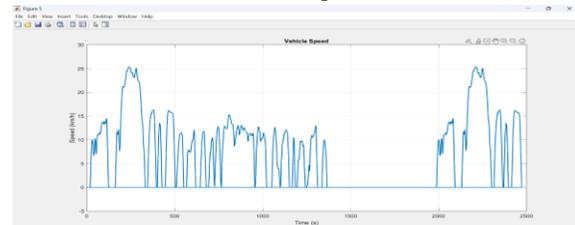
Vehicle Speed:

Figure 5 shows the simulated vehicle speed response. The vehicle accurately follows the FTP-75 reference profile with a maximum speed of approximately 26 km/h, representing low-speed urban operation. The PI controller in the driver subsystem successfully minimizes tracking error, maintaining smooth acceleration and deceleration. Minor deviations observed during transient regions are due to motor inertia and system lag, which quickly stabilize within the desired speed range.
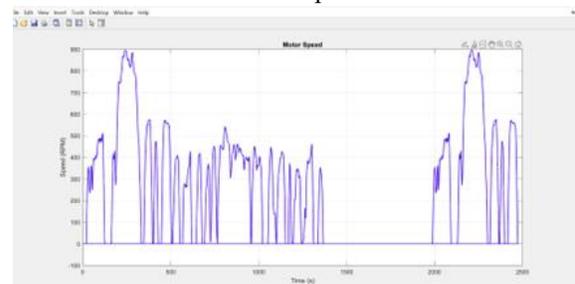
Motor Speed:

Figure 6 illustrates the BLDC motor speed variation, which mirrors the vehicle speed trend. The motor speed peaks around 850 rpm during high acceleration phases and drops to zero during idle periods. This validates the correct torque transmission through the gearbox and efficient operation of the BLDC drive under dynamic load conditions.
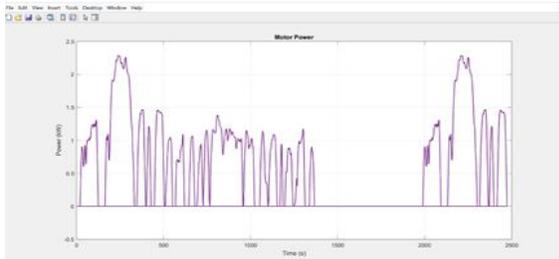
Motor Power:

Figure 7 presents the instantaneous motor power output. The power demand fluctuates according to the vehicle's acceleration and deceleration phases, with peaks of about 2.2 kW during high-load intervals. The observed power pattern confirms the proportional relationship between driver input, torque generation, and speed response.

Motor Torque:

The motor torque profile in Figure 8 shows rapid transitions corresponding to throttle changes. The torque varies between 0 and 100 Nm, reaching its maximum value during initial acceleration and uphill conditions. The high torque bursts reflect the BLDC motor's strong starting capability and responsiveness to driver inputs.

Motor Torque:
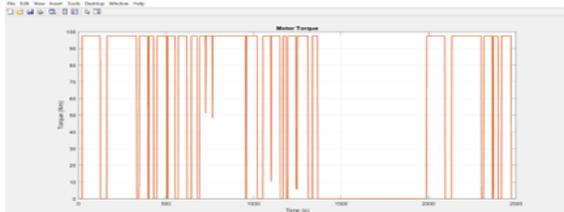
The motor torque profile in Figure 8 shows rapid transitions corresponding to throttle changes. The torque varies between 0 and 100 Nm, reaching its maximum value during initial acceleration and uphill conditions. The high torque bursts reflect the BLDC motor's strong starting capability and responsiveness to driver inputs.

Accelerator Pedal Position:
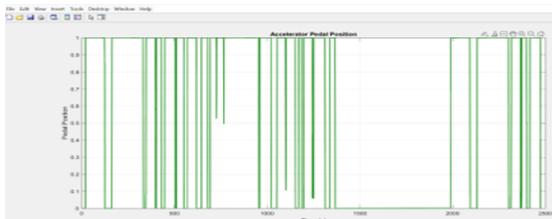
Energy Efficiency and Mileage Evaluation:
The overall energy efficiency and mileage of the EV system were calculated by integrating total electrical energy consumed over the drive cycle.

The energy consumption is computed as:

$$E_{total} = \int_{0}^{t_f} P(t).dt$$

Mileage (km/kWh): The simulation results yield a mileage of 11.07 km/kWh, indicating that the vehicle travels 11.07 km for every kWh of electrical energy supplied by the battery.

Uphill (5° Gradient) Performance:

To assess hill-climb capability independent of the FTP-75 drive cycle, a separate constant-grade test was performed by applying a 5° road slope to the Grade input of the Vehicle Body/Longitudinal Dynamics model. A steady ref.erence speed was commanded (constant-speed setpoint), and the driver PI loop adjusted torque demand to counter the additional gravitational component

Total resistive force:

$$F_{res} = mg \sin \alpha + mgC_{rr} \cos \alpha + \frac{1}{2} \rho C_d A v^2$$

Observed Results:

Vehicle speed during Uphill condition:
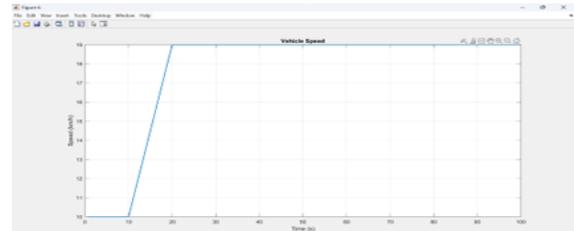
The vehicle speed response under uphill conditions is shown in Figure 10. The vehicle starts from rest and gradually accelerates until it reaches a steady-state speed of approximately 19 km/h after 20 seconds. Once the speed stabilizes, the controller maintains this constant velocity throughout the climb. The smooth rise without overshoot indicates that the PI controller effectively manages throttle input and compensates for the additional load caused by the 5° incline. This stable response verifies that the EV system maintains uniform motion under moderate uphill terrain.
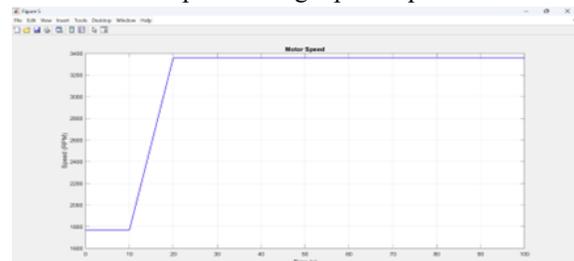
Motor Speed during Uphill Operation:

Figure 11 represents the BLDC motor speed profile during the uphill simulation. The motor accelerates from around 1800 rpm at startup to a steady speed of approximately 3400 rpm, corresponding to the vehicle's constant road speed of 19 km/h through the 6:1 gear ratio. The speed curve exhibits a linear rise during the initial acceleration phase (0–20 s) and remains constant thereafter, confirming smooth mechanical transmission and consistent electromagnetic torque generation by the motor during the climb.

Motor Power Output under uphill condition
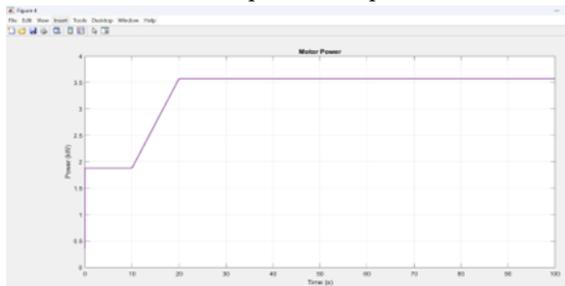
The motor power output, shown in Figure 12, increases from 2 kW at lower speeds to around 3.6 kW once the vehicle reaches its rated climbing velocity. The higher power demand arises from the gravitational resistance forces which must be overcome in addition to aerodynamic and rolling losses. This demonstrates that the BLDC motor efficiently supplies the necessary tractive power while maintaining steady-state operation without fluctuations, reflecting good dynamic response and controller stability.

Motor Torque under Uphill Condition:
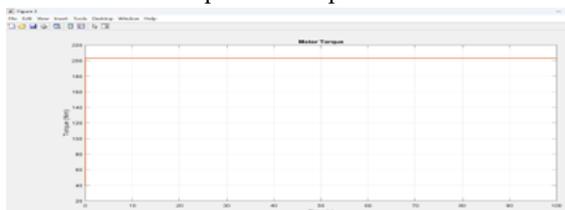
As illustrated in Figure 13, the motor torque remains nearly constant at approximately 200 Nm throughout the uphill run. This torque level provides sufficient tractive effort to sustain motion against the combined resistive forces acting on the 5° incline. The constant torque behaviour signifies that the motor operates in its rated torque region, ensuring stable hill-climbing capability without current saturation or instability. This verifies that the designed EV powertrain possesses the torque reserve required for moderate gradient driving scenarios.

V. CONCLUSION

The simulation and analysis of the Electric Vehicle powertrain using a BLDC motor were successfully carried out in MATLAB/Simulink under the FTP-75 drive cycle and a separate 5° uphill gradient condition. The results demonstrate that the designed system accurately follows the drive-cycle reference, delivering stable torque and speed performance with high efficiency. The vehicle achieved a mileage of 11.07 km/kWh, indicating excellent energy utilization for a lightweight electric vehicle. Under uphill operation, the BLDC motor maintained a steady torque output of approximately 200 Nm and reliable performance, confirming its suitability for urban and hilly terrain driving. The proposed EV model thus provides a realistic and efficient platform for further development of advanced control strategies and power management systems.

VI. FUTURE SCOPE

The model developed in this work can be further improved by adding a regenerative braking system to recover energy during braking and increase overall efficiency. More advanced controllers such as Fuzzy Logic, PID-Fuzzy, or Model Predictive Control (MPC) can be used to get better speed and torque control. A detailed Battery Management System (BMS) with thermal modelling and State of Charge/Health estimation can be included to study real-time battery behaviour. In the future, hardware testing using Hardware-in-the-Loop (HIL) setup can be done to validate the simulation results. The model can also be tested for different road gradients and drive cycles to analyze vehicle performance under various driving conditions.

REFERENCES

[1] Philip Larsson and Niclas Rasmussen, "Design, Control and Evaluation of a Prototype Three Phase Inverter in a BLDC Drive System for an Ultra-Light Electric Vehicle," Master's Thesis, Chalmers University of Technology, Sweden, 2013.

[2] Patel et al., "Modelling and Simulation of BLDC Motor Drive for Electric Vehicle Application Using MATLAB/Simulink," 2016.

[3]   Meenakshi and Rajalakshmi, "Design and Analysis of Electric Vehicle using Brushless DC Motor," 2019.

[4]   Hitesh S. and Sunanda C., "Modeling and Performance Analysis of an Electric Vehicle with MATLAB/Simulink," International Research Journal of Engineering and Technology (IRJET), Vol. 7, pp. 1098–1104, June 2020.

[5]   D. Arora and S. P. Singh, "Performance Evaluation of Electric Vehicle under Standard Drive Cycles using MATLAB/Simulink," International Journal of Engineering Research and Technology (IJERT), Vol. 9, Issue 4, pp. 785–790, 2020.

[6]   S. S. Rathod and A. V. Kulkarni, "Modeling and Simulation of Electric Vehicle Powertrain using FTP-75 Drive Cycle," International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), Vol. 10, Issue 7, pp. 14563–14570,2021.

[7]   M. K. Sharma and R. A. Patel, "ADVISOR Simulation of Electric Vehicle Performance on FTP-75 City Driving Cycle," International Journal of Innovative Science, Engineering & Technology (IJISET), vol. 1, no. 8, pp. 62–67, Oct. 2014.

[8]   S. Ozkan, "Development of an Electric Vehicle Model and Analysis under FTP-75 Driving Cycle Using MATLAB/Simulink," International Journal of Automotive Science and Technology, vol. 7, no. 2, pp. 100–110, 2023