Dynamic Modelling of an Electric Vehicle

Nasrun Sithara Ramees, Hashir Khan, Ahamad Rishard

School of Electrical Engineering and Computer Science(SEECS), NUST,

Islamabad, Pakistan

***Abstract*— A sustainable and clean energy system electric vehicles become a prominent and efficient solution. The drive train simulation model consists of a battery, a motor, power electronics and a control system. In the process of motoring and regeneration, energy flow and performance is determined by the change in speed and torque. Our simulation results from our simulink model proved that the major factor which contributed to difference between the reference speed and actual speed is the weight of the electrical vehicle.**

***Keywords*— EV, Battery SOC, Longitudinal driver train**

I. INTRODUCTION

Overall, the goal of electric vehicle modeling is to develop accurate and comprehensive models of the vehicle and its components that can be used to optimize the design and control of the electric vehicle and improve its performance, efficiency, and range.

- ii. Mathematical Modelling of the system

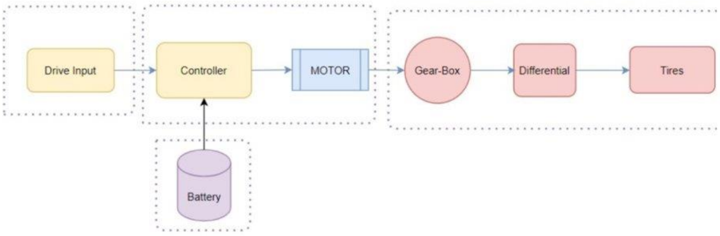
In the driver input part, we have a PI controller that is in-built which consists of the longitudinal driver simulink block. We make use of this PI controller to improve the steady-state response of the system. The PI controller works according to the following formula:

$$y = \frac{K_{ff}}{v_{nom}} v_{ref} + \frac{K_p e_{ref}}{v_{nom}} + \int \left(\frac{K_i e_{ref}}{v_{nom}} + K_{aw} e_{out} \right) dt + K_g \theta$$

v_{nom}	Nominal vehicle speed
K_p	Proportional gain
K_i	Integral gain
K_{aw}	Anti-windup gain
K_{ff}	Velocity feed-forward gain
K_g	Grade angle feed-forward gain
θ	Grade angle
y	Nominal control output magnitude
y_{sat}	Saturated control output magnitude
e_{ref}	Velocity error
e_{out}	Difference between saturated and nominal control outputs
v_{ref}	Reference velocity signal

It basically relates the nominal control output magnitude which is sent to the H-brige which is used to control the speed of the motor. As a result, it controls the actual speed.

The drive train consists of six components: electrical motor, power electronics, battery, motor controller, vehicle interface and battery controller. The motor controller controls the power supplied to motor whereas the battery controller controls the power from the battery.



The EV control system is modelled using the theories of mechanical, electrical and control systems. The following are the main components of an EV:

Power electronics consists of converters and inverters that are connected to the battery and the motor which regulates the voltage, current and frequency of the electrical power flow.

Battery can be modelled using internal resistance, internal capacitance and a voltage source. The state of charge (SOC) of the battery can be estimated using methods such as coulomb counting or Kalman filtering.

The **Electric Motor** can be modeled using a set of differential equations that describe the torque and speed of the motor as a function of the input voltage and current.

Control System is used to regulate the speed and torque of the motor based on inputs such as the accelerator pedal position, brake pedal position, and vehicle speed. These algorithms can include proportional-integral-derivative (PID) controllers, model predictive control (MPC), and adaptive control.

Regenerative braking is when the vehicle brakes, the electric motor can be used as a generator to convert kinetic energy into electrical energy that can be stored in the battery. It is controlled using algorithms that balance the tradeoff between maximizing energy recovery and ensuring a smooth ride.

Thermal management, the control system must also manage the temperature of the battery and motor to prevent overheating and damage. A solution to this can be using various cooling systems such as air or liquid cooling, as well as control algorithms that limit the power output of the motor when the temperature exceeds a certain threshold.

Overall, the mathematical model of an electric vehicle control system is a complex system of equations and algorithms that must balance a variety of factors such as energy efficiency, performance, safety, and reliability.

There are several equations and mathematical models that are used in the control system of an electric vehicle. The following are some of the important equations:

Battery model: The battery can be modeled using an equivalent circuit model, which consists of a voltage source, internal resistance, and capacitance. The voltage across the battery can be represented by the following equation:

V_bat = E - I_bat * R_int - Q / C

where V_bat is the voltage across the battery, E is the open-circuit voltage of the battery, I_bat is the current flowing through the battery, R_int is the internal resistance of the battery, Q is the charge stored in the battery, and C is the capacitance of the battery.

Motor model: The electric motor can be modeled using a set of differential equations that describe the torque and speed of the motor as a function of the input voltage and current. The basic motor equation is:

$$T = k_t * i_a$$

where T is the torque produced by the motor, k_t is the torque constant of the motor, and i_a is the armature current of the motor.

The speed of the motor can be represented by the following equation:

$$w = (V_{bat} - i_a * R_a) / k_v$$

where w is the rotational speed of the motor, R_a is the resistance of the armature winding, and k_v is the back emf constant of the motor.

Control algorithms: Various control algorithms can be used to regulate the speed and torque of the motor based on inputs such as the accelerator pedal position, brake pedal position, and vehicle speed.

Regenerative braking: When the vehicle brakes, the electric motor can be used as a generator to convert kinetic energy into electrical energy that can be stored in the battery. The amount of energy recovered can be calculated using the following equation:

$$E_{rec} = 0.5 * J * (w_f^2 - w_i^2)$$

where E_{rec} is the energy recovered, J is the moment of inertia of the vehicle, w_f is the final speed of the vehicle after braking, and w_i is the initial speed of the vehicle before braking.

These are some examples of the equations used in the control system of an electric vehicle. The specific equations and models used will depend on the particular control system design and application.

II. BACKGROUND AND PROBLEM STATEMENT

The problem statement of electric vehicle modeling involves developing mathematical models that accurately represent the behavior of an electric vehicle and its components, including the battery, electric motor, power electronics, and control systems. Our goal, first, is to create models that can be used to predict the performance, efficiency, and range of the electric vehicle under different operating conditions and to design. Second, is to optimize the components and control systems to meet the desired specifications.

Challeneges in electric vehicle modeling include:

1. Battery modeling: Developing accurate battery models is critical for prediction of the range and performance of the electric vehicle. It must account for the nonlinear behavior of the battery, including the effects of temperature, aging, and cycling.
2. Electric motor modeling: The electric motor is the primary source of propulsion in an electric vehicle, and accurate models of the motor are necessary for predicting its performance and efficiency. Motor models must account for the nonlinear behavior of the motor, including the effects of magnetic saturation and eddy current losses.
3. Power electronics modeling: The power electronics convert the DC voltage from the battery to AC voltage for the electric motor. Models of the power electronics must account for the nonlinear behavior of the components, including switching losses and voltage and current ripple.
4. Control system modeling: The control system regulates the speed based on inputs: accelerator pedal position, brake pedal position, and vehicle speed. It must account for the nonlinear behavior of the components, including the effects of noise and delay.

III. PROPOSED METHOD

The approach we have used in designing the EV model is divided into four main sub systems. These systems include Vehicle Body model, Driver Input, Motor and Controller, Battery pack system. These are the four main components involved in designing any Electric vehicle systems. The motor type used in the EV industries varies depending on the type of applications, More, commonly BLDC, Brushed DC motors, IMs are used. In our project we have used a simple DC motor for simplicity. Next the Vehicle body train includes the gearbox, differentials, and tire systems. The most important component system is the battery pack system which is the heart of every EV. Earlier batteries were used to just start the engine but now they are used to power the vehicle. The main design constraint is to design a efficient way to pass the power from the battery to the motor. If we directly connect the battery to the motor, the motor will start to rotate in the rated speed only, But in a vehicle system the driver should be able to control the speed of the vehicle at any moment he wants. Therefore, a controller system to control the motor is connected in between the motor and the battery. The controller we used is the basic H-bridge. Now the controller can take input from the user and pass it to motor for precise control.

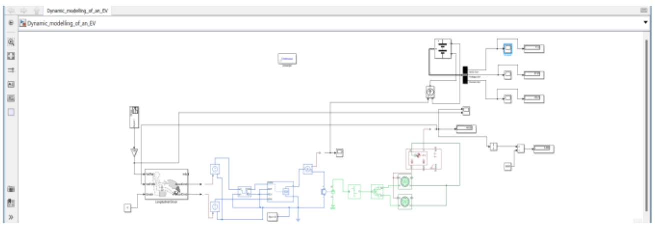


Fig. 1. Complete circuit hardware

1. Vehicle Sub System

The vehicle system models the chassis and vehicle body. Using this model we define certain parameters like the vehicle mass, the drag coeffiecient, the frontal area, etc. which are essential parameters to consider in EV design. Also this block consists of other components like the gearbox, differentials and tires. The gearbox is the device used to make a tradeoff between Torque and speed in a vehicle, The differential is used to provide different rpm rates to both tires at a turn and the tire system makes sure there is enough traction between the tire and the road in wet conditions.

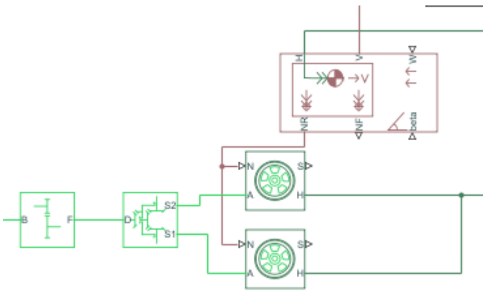


Fig. 2. Vehicle Subsystem part

2. Motor and Control system

The motor part is the replacement of internal combustion engine in a traditional vehicle. The efficiency of the motor plays an important role in the development of the EV market. To control the motor part a controller is needed., the reason being if the motor is directly connected to the battery power system the motor will be running in the rated speed and the speed control is not possible. Thus, a controller is added in between to control the speed of the motor. The controller we have used is the H-bridge controller which involves a common control mechanism by reversing the polarity of the load. The driver will give input to the controller and the controller will change the motor settings accordingly.

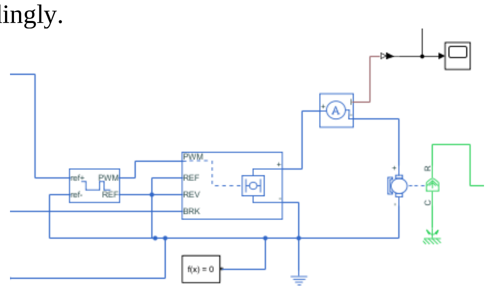


Fig. 3. Motor and controller part

3. Driver-Input Model

To simulate the driver, we have used the longitudinal drivetrain model. Using this model, we can give direct commands including acceleration and deceleration commands.

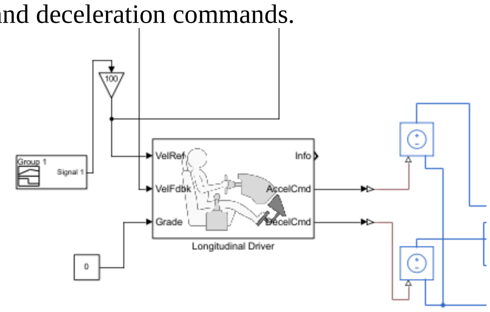


Fig. 4. Longitudinal drive train

4. Battery Pack system

This is the heart of our EV model where the power is generated. The model consists of a Li-Ion battery pack which will give power to the motor. During acceleration the battery SOC will decrease nonlinearly and linearly decrease at constant speed. During deceleration due to regenerative braking the output of the motor is short circuited and battery charges.

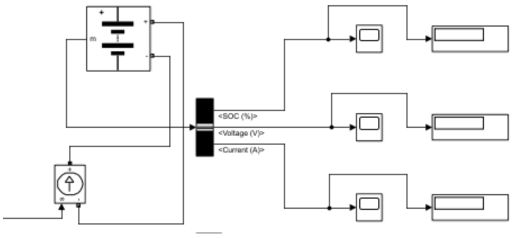


Fig. 5. Battery Pack

Fig. 5. Complete circuit

IV. Results And Discussions

The relationship between input speed and the reference speed graphs were plotted to two common EV types.

1. Nissan Leaf
2. 600-kg EV

The reference speed graphs are as follows.

The parameters used

Vehicle Type	Body weight (Kg)	Frontal Area (ft/s^2)	Drag Co. ef	No-load Speed (rpm)	Rated Speed (rpm)	Nominal Battery voltage(V)
Nissan Leaf	1567	24.5	0.32	10000-15000	8000-10000	350
Mini-EV	600	15	0.33	10000-15000	7000	200

Fig. 6. Parameters graph

A Reference Speed signal was applied to simulate the driver in the Simulink.

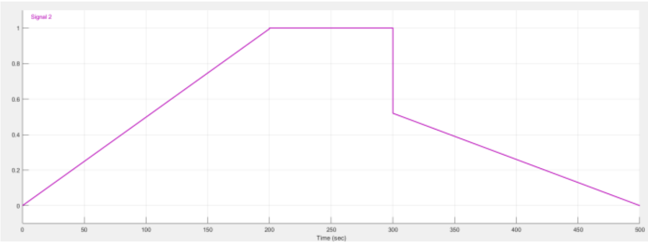


Fig. 7. Reference speed signal

The following were the output graphs of speed, Battery SOC and Battery current for the Nissan Leaf model.

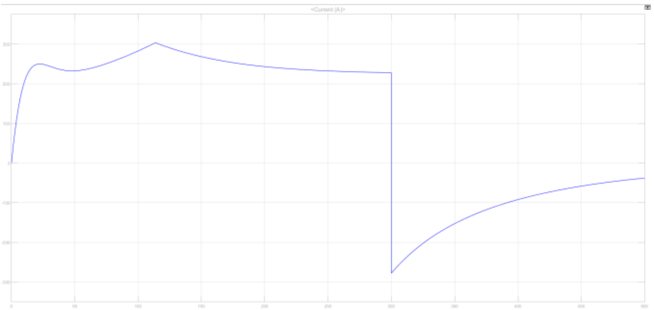


Fig. 8. Battery current plotted against time

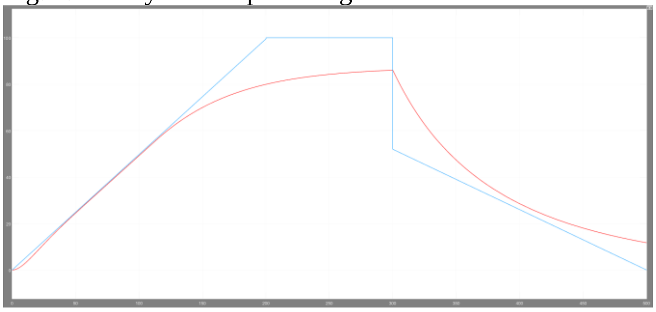


Fig. 9. Reference speed vs actual speed plotted against time

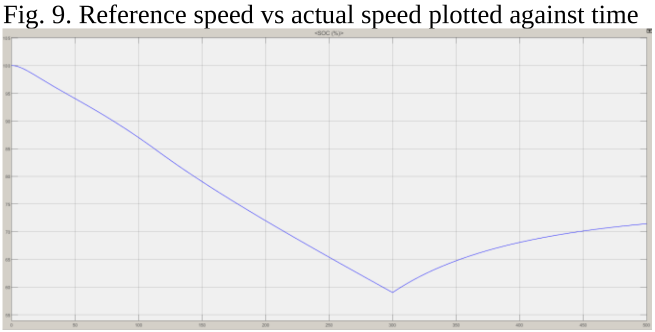


Fig. 10. Battery SOC plotted against time.

The following graphs are plotted for 600kg EV.

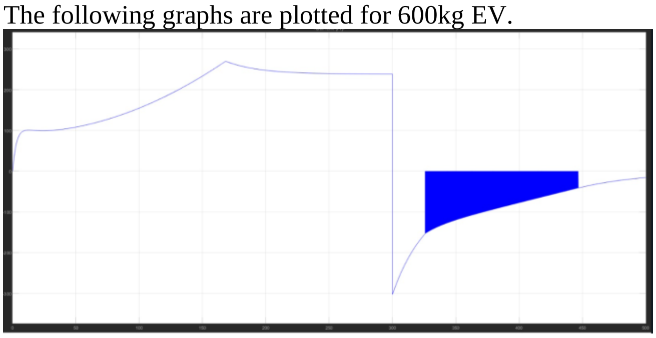


Fig. 11. Battery current against time

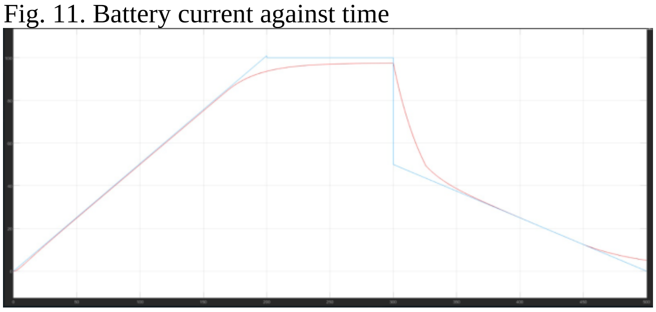


Fig. 12. Reference speed signal

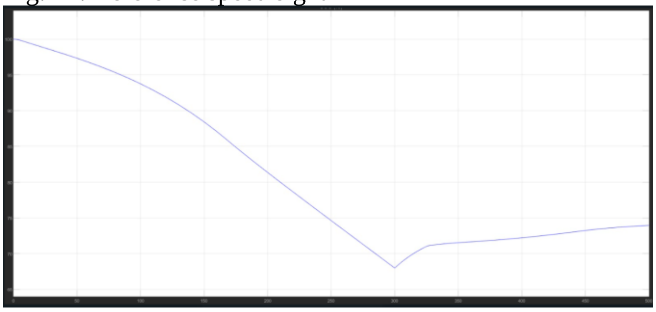


Fig. 13. Battery SOC vs time

V. CONCLUSIONS

The graphs obtained for the speed characteristics suggest that the smaller mass EV has a less steady state error than the Nissan Leaf model. This is because higher the mass the moment of inertia involved and the losses involved are high and the vehicle has more restriction to achieve ideal output. Also the Battery SOC graphs suggests the higher mass vehicle uses more of the battery power to perform the mileage as more power is required to drive the larger mass. This concludes that to built heavy class EVs the technology involved will be more complex and needs more modelling blocks and cannot be modelled accurately with our model. Our model only works accurately for lower mass EVs.

REFERENCES

[1] Mohd, T. a. T., Hassan, M. A., & Aziz, W. N. a. W. A. (2015). MATHEMATICAL MODELING AND SIMULATION OF AN ELECTRIC VEHICLE. *Journal of Mechanical Engineering and Sciences*, *8*, 1312–1321. https://doi.org/10.15282/jmes.8.2015.6.0128

[2] User, & User. (2023b). The Main Components of Electric Vehicles | Parts of EV. *YoCharge - Charging Management Software CMS*. https://yocharge.com/in/ev/components/

[3] Longitudinal speed-tracking controller - Simulink. (n.d.). https://www.mathworks.com/help/vdynblks/ref/longitudinaldriver.html