

Modelling and Simulation of Electrical Vehicle Using Matlab Simulation

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Abstract

Effect of vehicle emission over global warming is immense. Many country has a serious issue regarding it and searched a way towards development of new fuel technology. Presently for future of electric vehicle the most promising source of power is battery electric power. Most of worldwide manufacturer of Automobile industry is highly focusing over development of research related to the battery-run economic efficient vehicle. The calculation of mathematical modelling is presented step by step with modelling and simulation of an Electric Vehicle (EV). In this paper Electric Vehicle, which is manufactured by the renowned vehicle manufacturers of Indian, Mahindra & Mahindra, which is known as "Mahindra e2o", is modelled and simulated on MATLAB/Simulink. The EV model is provided with the recuperation mechanism of vehicle. Analysis of its performance is done using simulation results with respect to different velocity of vehicle at end for range and battery SOC of EV and at last vehicle range and SOC is analysed at last for different input parameter with graph.

Index Terms—Mathematical Modeling; MATLAB/Simulink; Electric Vehicles; SOC Optimization; Automotive drive cycles.

I. INTRODUCTION

The transportation sector is a primary contributor to global greenhouse gas emissions, accounting for approximately 24% of direct CO₂ emissions from fuel combustion. Vehicular emissions have a profound impact on global warming and urban air quality. Electric Vehicles (EVs) produce zero tailpipe emissions and lead the way in this transition[2]. Shifting to EVs is

a necessary step to fight climate change, decrease reliance on fossil fuels, and improve public health[4].

To predict how these vehicles perform, researchers need mathematical modeling and simulation tools[5]-[10]. This paper looks at the Mahindra e2o, a compact four-seater battery-electric city car launched in India. It serves as a great case study because of its straightforward yet complete EV design. Key specifications include a 3-phase AC Induction Motor rated at 19 kW peak power, a Lithium-ion battery pack with a nominal voltage of about 48V and a capacity of 200 Ah, a single-speed fixed gear reduction with a ratio of 8.59, and a claimed range of 120 km under ideal conditions[3]. This study creates a detailed model using a MATLAB/Simulink approach, a common method for designing and analyzing electric vehicle systems[1].

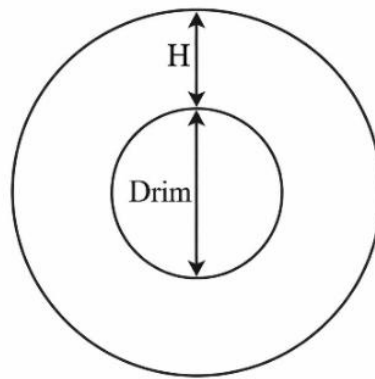


Fig 1: Wheel rim layout used for dynamic calculation.

II. FUNDAMENTAL FORCES AND VEHICLE DYNAMICS

The basic equation that explains vehicle longitudinal dynamics comes from Newton's Second Law. The net force propelling the vehicle forward must equal the sum of all opposing forces (road load) plus the force required for acceleration:

$$F_{tractive} = m \cdot a + F_{road\ load} \quad eq\ (1)$$

Where $F_{road\ load} = F_{aerodynamic} + F_{rolling} + F_{grading}$

A. Aerodynamic Drag Force

As a vehicle moves, it displaces air, creating a resistive force proportional to the square of its velocity:

$$F_L = \frac{1}{2} \cdot \rho \cdot A \cdot c_d \cdot v^2 \quad eq\ (2)$$

where ρ is air density ($\sim 1.2\text{ kg/m}^3$), A is the frontal cross sectional area (2.36 m^2 for e2o), c_d is the drag coefficient (0.3), and v is velocity in m/s.

B. Rolling Resistance Force

This force arises from the deformation of the tire and the

road surface:

$$F_R = m \cdot g \cdot f_r \quad eq (3)$$

The coefficient f_r increases slightly with speed. A common empirical model is:

$$f_r = f_{R0} + f_{R1} \cdot \left(\frac{v}{27.78}\right) + f_{R4} \cdot \left(\frac{v}{27.78}\right)^4 \quad eq (4)$$

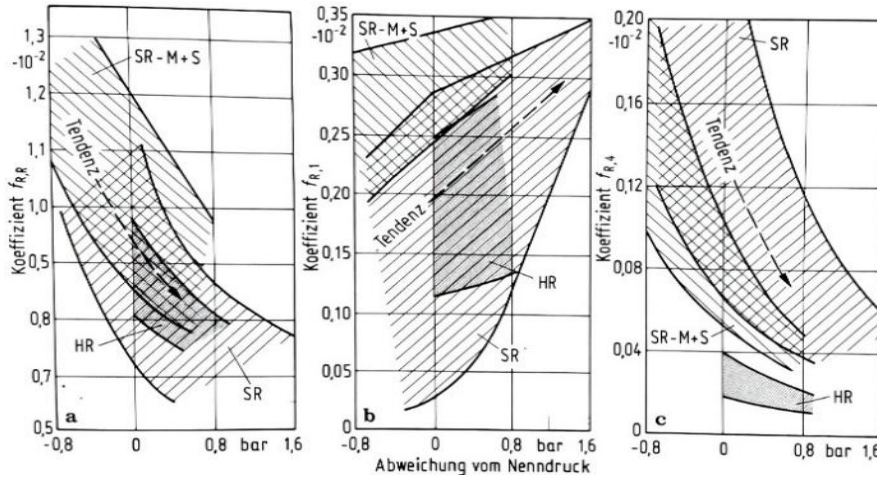


Fig 2: f_{R0} , f_{R1} and f_{R4} for different tyre pressures

III. ANALYTICAL CALCULATION FOR 50 KMPH

Here is the analytical step by step calculation process for EV with velocity= 50kmph = 13.89 ms⁻¹ that was taken into account in this section. These calculations will form the basis of the elements within the simulation model.

A. Calculation of Resistive Forces

It is drag resistance due to wind as the vehicle drives forward:

$$F_L = \frac{1}{2} \cdot \rho \cdot A \cdot c_w \cdot v^2 \quad eq (5)$$

$$F_L = 0.5 \cdot 1.2 \cdot 2.36 \cdot (13.89)^2 \cdot 0.3 = 81.6 \text{ N}$$

For rolling resistance, using equation (4):

$$f_r = 0.009 + 0.0015 \cdot \left(\frac{13.89}{27.78}\right) + 0.0012 \cdot \left(\frac{13.89}{27.78}\right)^4 = 0.0098 \quad eq (6)$$

$$\text{Therefore, } F_R = 0.0098 \cdot 1000 \cdot 9.81 = 96.14 \text{ N}$$

Bearing and Mechanical Friction (F_B):

$$F_B = m \cdot g \cdot k_B \quad eq (7)$$

Value of k_B is assumed to be 0.005. Thus,

$$F_B = 0.005 * 1000 * 9.81 = 49.05 \text{ N} \quad eq (8)$$

B. Calculation of Vehicle Shaft and Motor Parameters

Shaft Force (F_S):

$$F_S = F_L + F_R + F_B = 227.03 \text{ N} \quad eq (9)$$

Shaft Power (P_S):

$$P_S = F_S * v = 3150 \text{ W} \quad eq (10)$$

Shaft Speed (n_s):

$$n_s = \frac{v}{2\pi R_{\text{wheel}}} * 60 = 485 \text{ rpm} \quad eq (11)$$

Shaft torque (M_S):

$$M_S = F_S * R_{\text{wheel}} = 62.12 \text{ Nm} \quad eq (12)$$

Assuming gearbox efficiency η_g as 0.98 and gear ratio i as 8.59:

Motor torque (M_m):

$$M_m = \frac{M_S}{i * \eta_g} = \frac{62.04}{8.59 * 0.98} = 7.4 \text{ Nm} \quad eq (13)$$

Motor Speed (n_m):

$$n_m = n_s * i = 4166 \text{ rpm} \quad eq (14)$$

Motor Power (P_m):

$$P_m = \pi * n_m * \frac{M_m}{30} = 3230 \text{ W} \quad eq (15)$$

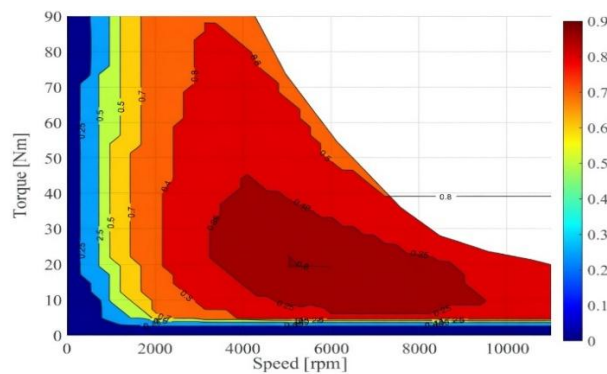


Fig 3: Efficiency-Torque-Speed Curve of ASM – Inverter System.

C. Calculation of Battery Parameters

By looking at constant support use P_{aux} of 350W:

$$P_B = P_{aux} + \frac{P_m}{\eta_m} = 4130W \quad eq (16)$$

From discharge curves, $R_{Bi} = 8 m\Omega$ and $U_{B0} = 53.6 V$ for the battery pack. Battery current I_B is:

$$I_B = \frac{U_{B0}}{2R_{BI}} - \sqrt{\left(\frac{U_{B0}}{2R_{BI}}\right)^2 - \frac{P_B}{R_{BI}}} \quad eq (17)$$

$$I_B = \frac{53.6}{0.016} - \sqrt{\left(\frac{53.6}{0.016}\right)^2 - \frac{4132}{0.008}} = 78A \quad eq (18)$$

IV. SIMULATION MODEL DEVELOPMENT

The EV is modelled using MATLAB/Simulink. The main blocks are the aerodynamic model, the gearbox model, the motor-inverter model, and the battery model.

A. Aerodynamic and Road Load Block

This block is responsible for calculation of total road load force dynamically. It depends on derivation of velocity (to estimate inertial force) and trigonometric functions (for slope. resistance)

B. Gear Box and Motor-Inverter Model

The gear box translates torque and speed from the motor to the wheel (motoring & recuperating). In the motor block torque and speed are used as input to a 2-D look-up table giving efficiency (η_m).

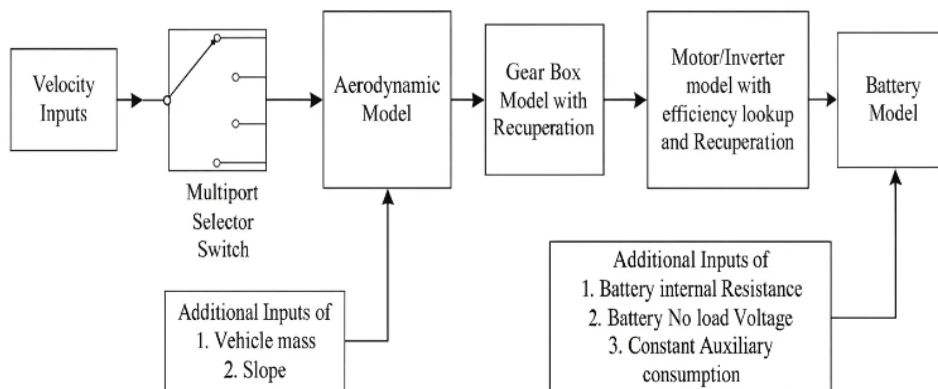


Fig 4: Basic Simulation Block Diagram.

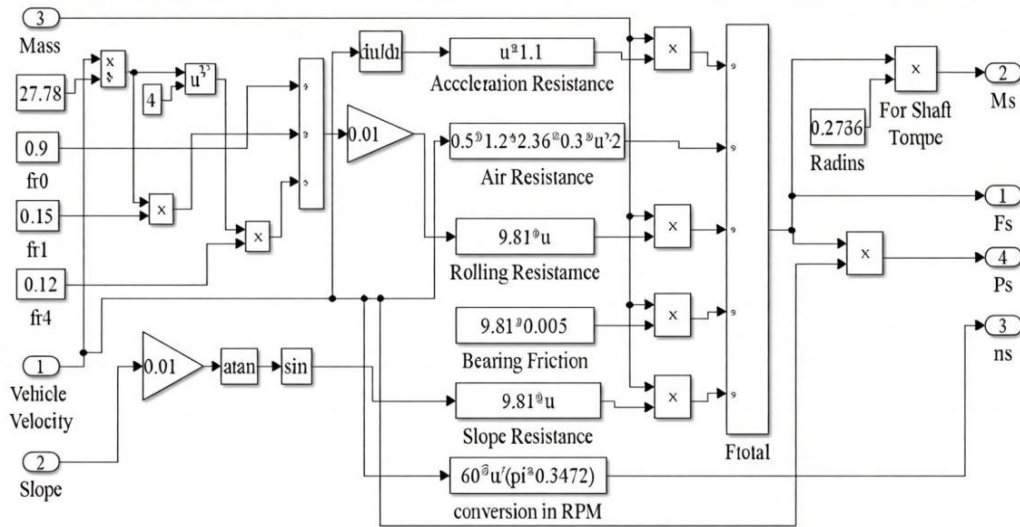


Fig 5: Aerodynamic Model in SIMULINK.

C. Battery Model

The battery is modelled using the R_{int} model. SOC state is being updated by an integrator block, using the Coulomb Counting technique.

V. CREATING STANDARD DRIVE CYCLES

Drive cycles are velocity-time profiles which the EV must follow and is crucial in determining range and energy consumption. The NEDC can be defined by moderate acceleration with a Steady State speed while the IDC is defined by more frequent stops and aggressive acceleration producing severe transient conditions beneficial for regenerative braking testing.

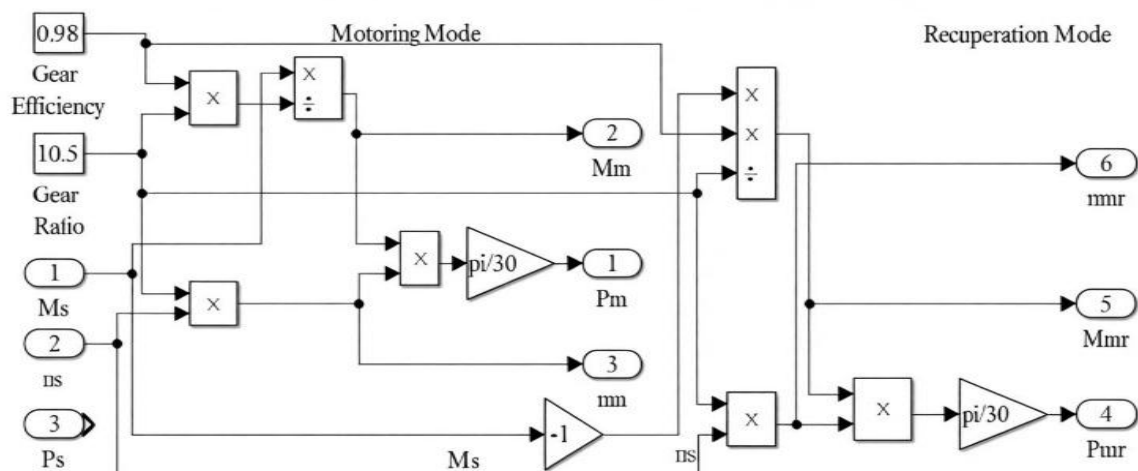


Fig 6: Gear Box Model in SIMULINK.

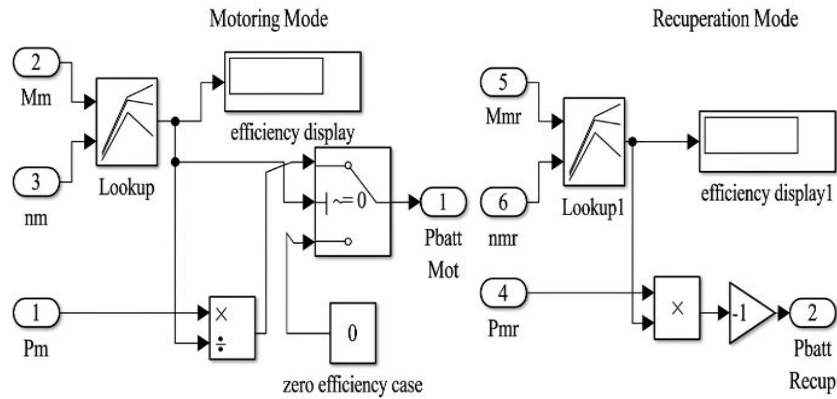


Fig 7: Motor-Inverter Model in SIMULINK.

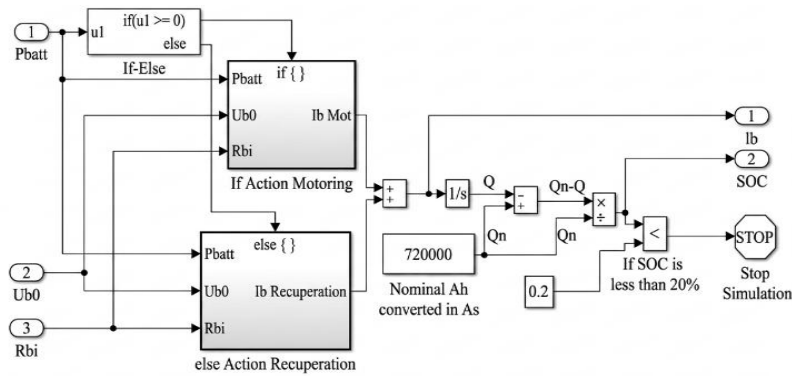


Fig 8: Battery Model in SIMULINK.

The integrated simulation model may be constructed by putting the above models together. The simulation results are presented in the following section.

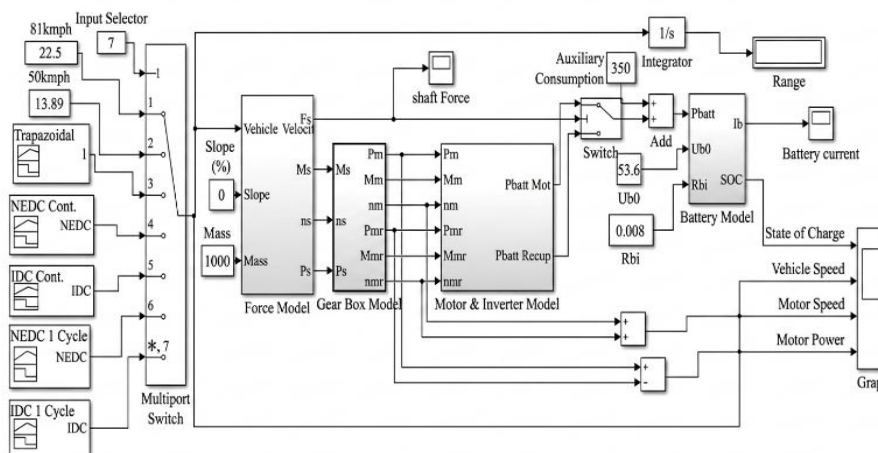


Fig 9: EV model in SIMULINK

VI. SIMULATION RESULT ANALYSIS AND INTERPRETATION

A. NEDC Simulation Results Analysis

NEDC simulation has to represent the car performance according to European standards. Figure 10 shows the full summary of the data.

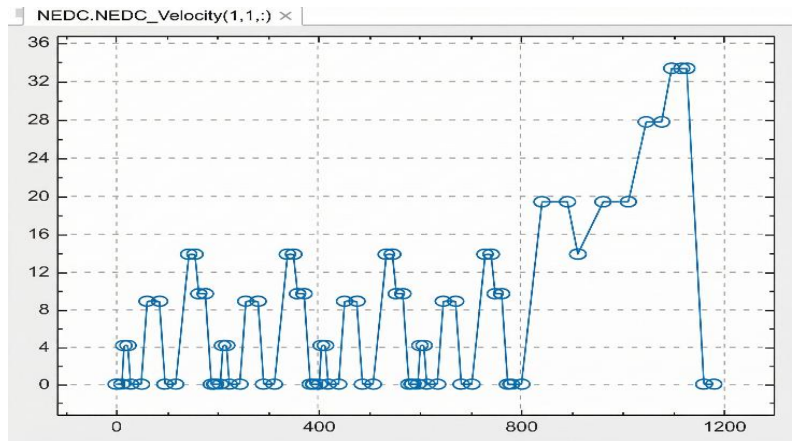


Fig 10: New European Driving Cycle (NEDC).

The current spikes during acceleration (up to 450A) can be observed in Fig 11. At constant velocities the current falls down to very small values.

It has been proved from the Fig 12 that distance is about 11 km in 1180sec. In the Fig 14 shows the forces individually. However, for the acceleration resistance, there are tremendous fluctuations. This occurs only during the transients.

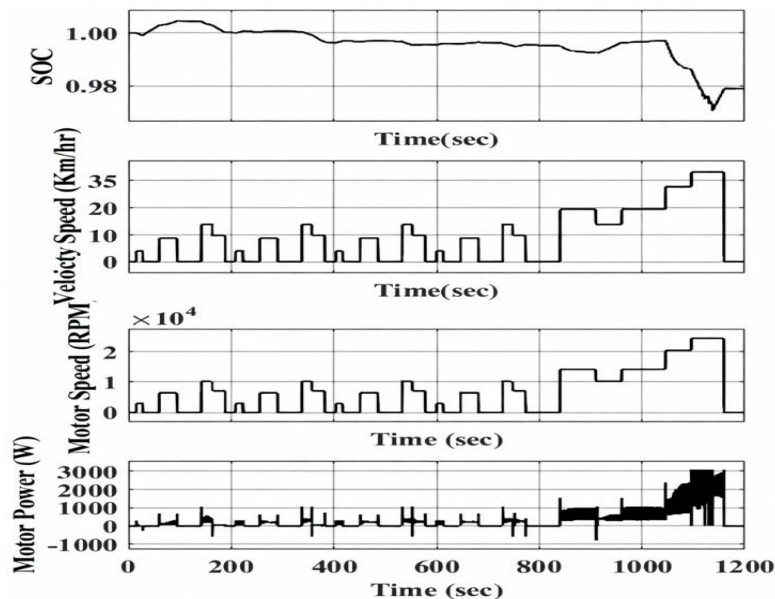


Fig 11: Full NEDC Output Data Table (SOC, Speed, Motor Speed, Power).

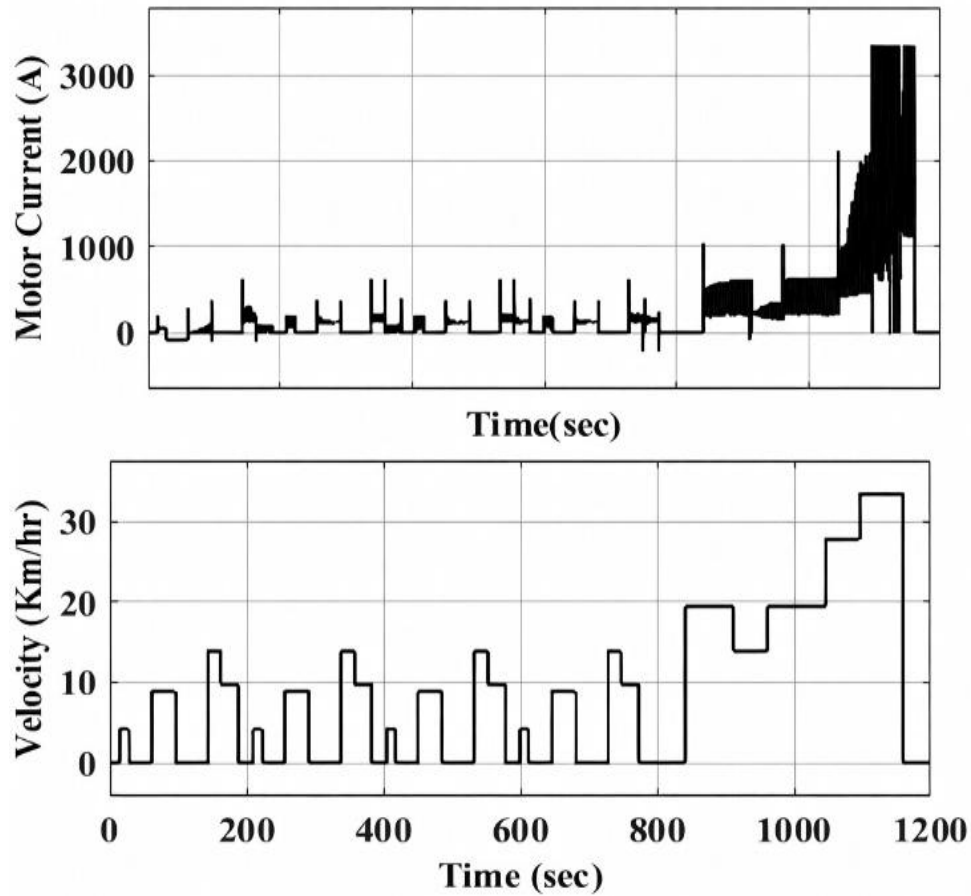


Fig 12: Motor current vs time with velocity overlay. NEDC.

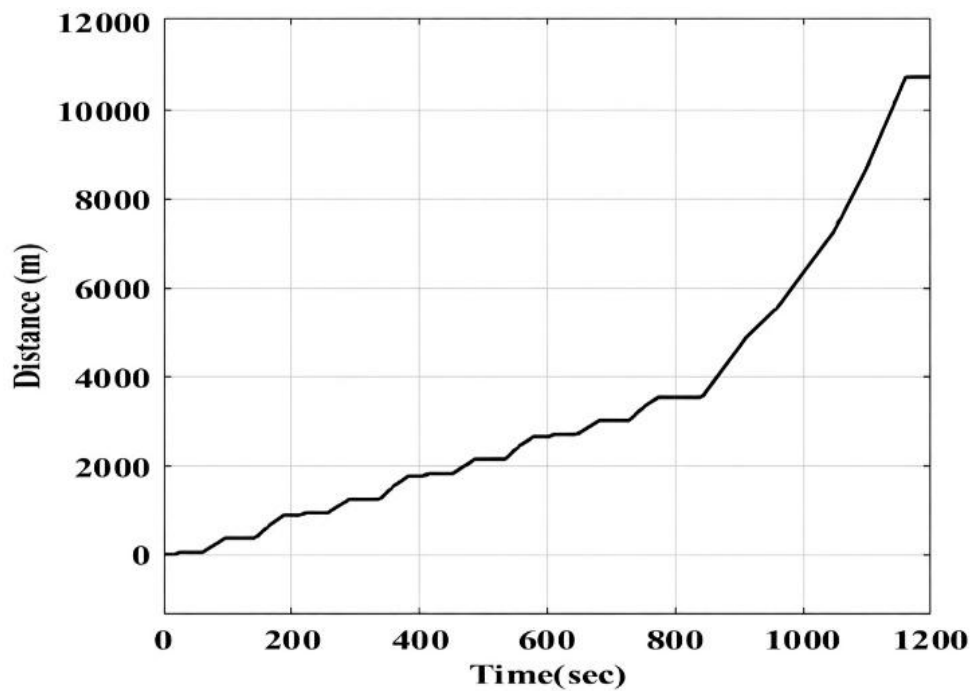


Fig 13: Distance Accumulation Over Time for NEDC.

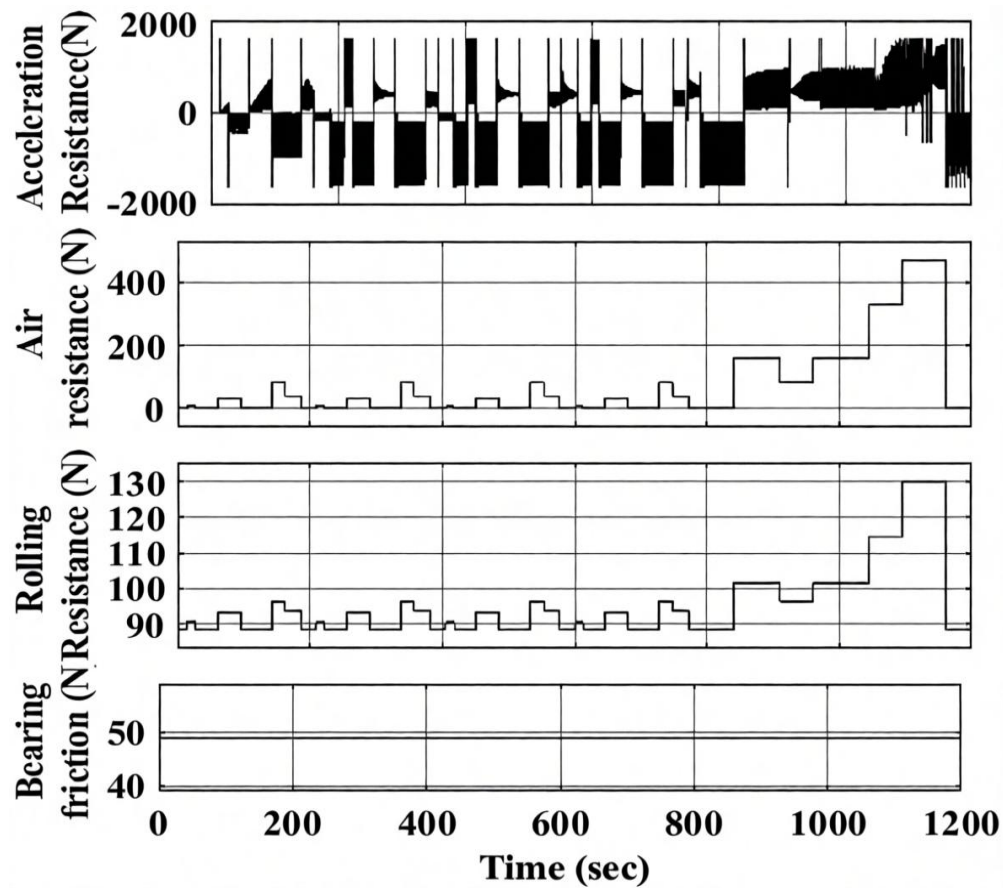


Fig 14: NEDC-Force Components vs Time

B. IDC Simulation Results Analysis

The IDC simulation reveals interesting effects in aggressive urban driving. Recuperation will play a significant role owing to rapid deceleration.

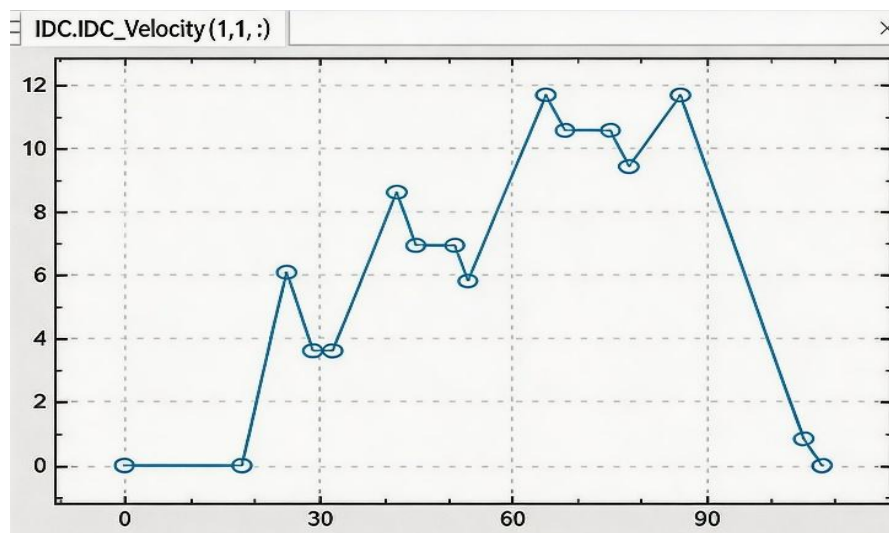


Fig 15: Indian Driving Cycle (IDC).

From Figure 16 it can be observed that the SOC is being depleted in a stepwise fashion; however current draws ("bumps" in recuperation) cancel out depletion compared to NEDC. Figure 17 demonstrates that the current draws are highly proportional to the rate of acceleration with values exceeding 80A.

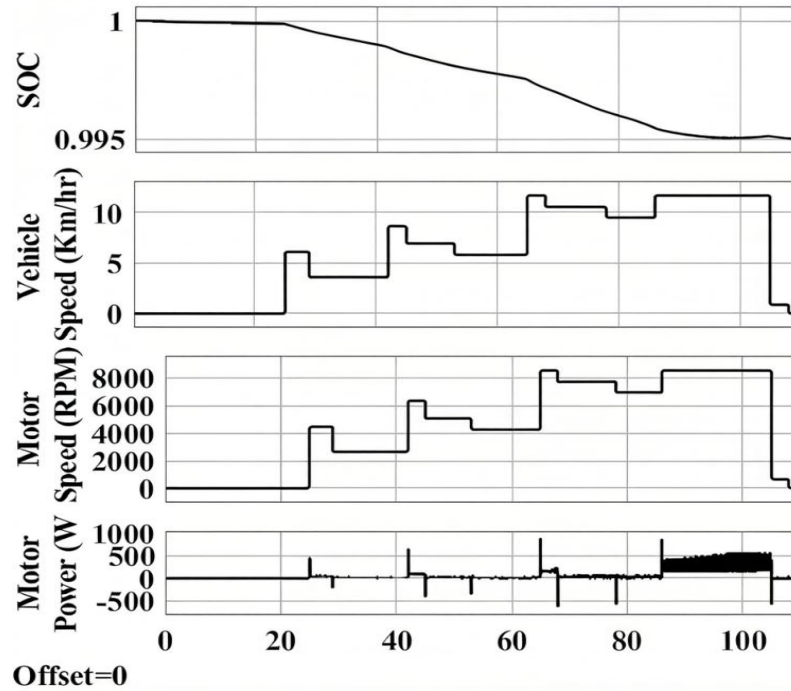


Fig 16: SOC V/S Vehicle Speed (along with motor parameters for IDC).

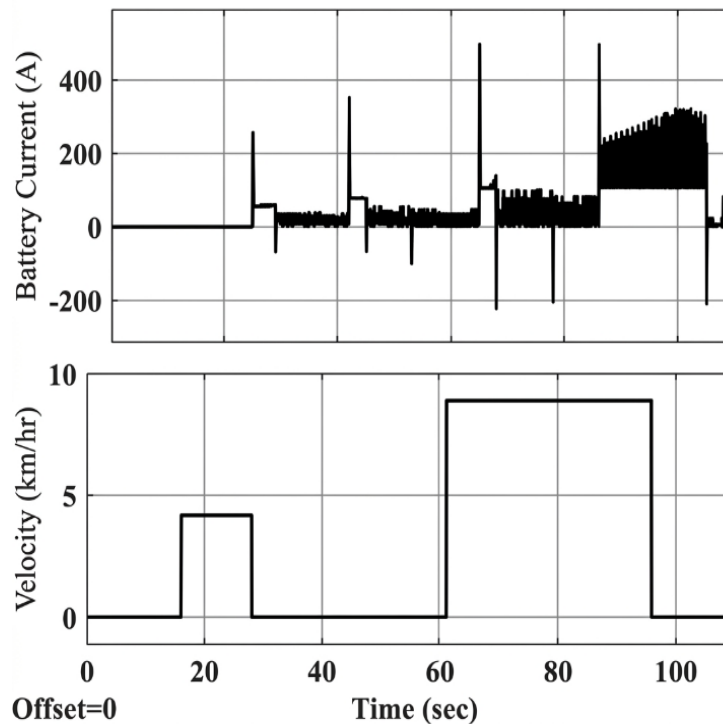


Fig 17: Current vs. Time for the battery with an overlay of velocity (IDC).

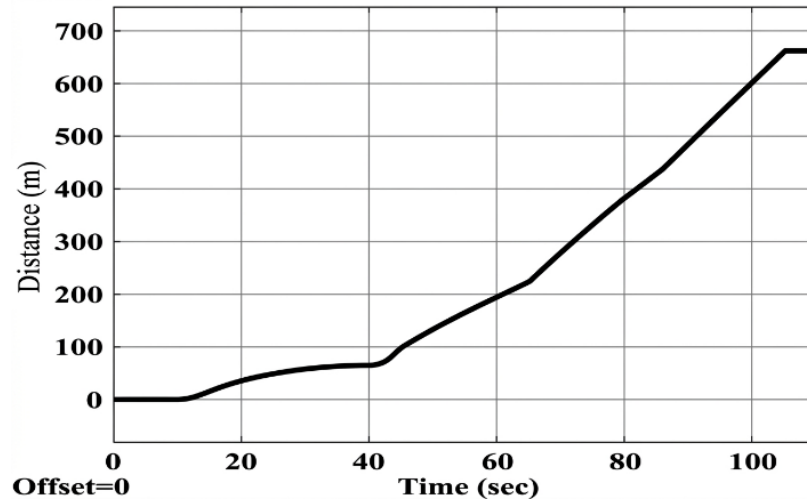


Fig 18: IDC Time vs. Distance.

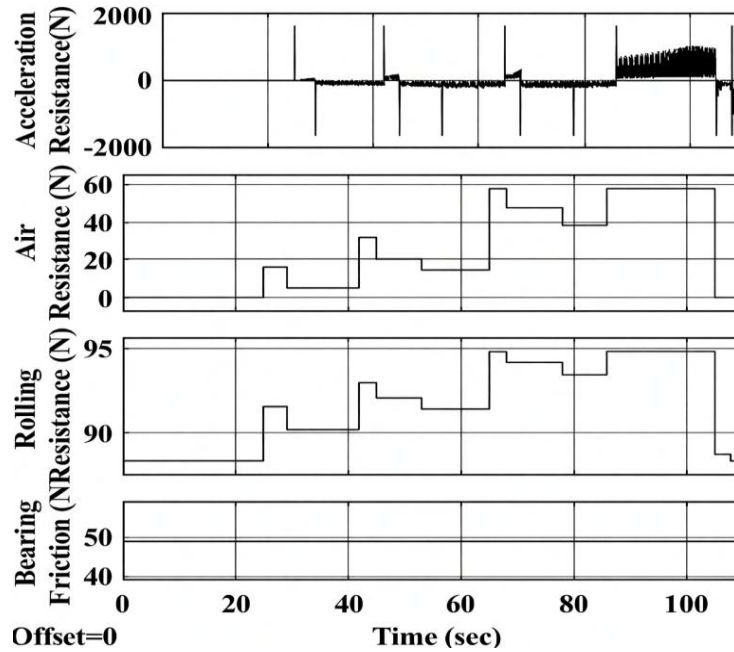


Fig 19: Combined Force Components Plot for IDC.

During IDC force analysis (Figure 19), the values of the accelerative forces vary from -2000N to +2000N, showing the heavy cyclical stress applied to the powertrain, although offering good possibilities of regenerative energy use.

C. Summary of Key Results and Parametric Variations

In Table I and II is illustrated the entire range at the extremes (80% and 100% SOC) and in the variation with the parameters: Mass, Gear ratio and Aerodynamics.

Increasing the gear ratio from 8.59 to 10.5 shifts the operating point to an island of greater efficiency, allowing the motor to achieve a higher speed and lower torque, thereby significantly increasing the range, and most effectively in the highly transient IDC.

VII. CONCLUSION

This paper has provided step by step analytical calculation and simulation modeling of an Electric Vehicle using MATLAB/ Simulink. We also have models for recuperative braking system

TABLE I

SIMULATION RESULTS FOR DIFFERENT INPUTS

Input Type	Input	80% SOC Range (km)	100% SOC Range (km)
Driving Cycles	NEDC	64.04	79.89
	IDC	82.92	103.60
Constant Velocity	50kmph	102.80	128.50
	81kmph	67.56	84.46

TABLE II

SIMULATION RESULTS AS THE PARAMETERS CHANGE

Parameter	Simulated For	Variations of Parameters		Range of Vehicle (for 80% SOC) [km]	
		From	To	Before	After
α	NEDC	0	2	64.04	41.76
	IDC			82.92	51.61
m	NEDC	1000	1140	64.04	59.22
	IDC			82.92	74.66
C_w	NEDC	0.3	0.26	64.04	67.6
	IDC			82.92	83.85
A	NEDC	2.36	2.25	64.04	64.78
	IDC			82.92	83.17
i	NEDC	8.59	10.5	64.04	64.74
	IDC			82.92	87.53

Showed that, IDC mode results in much greater range (82.92km at 80%SOC) compared with pure steady highway speed cruising (NEDC results in 64.04km), since energy is recovered

more aggressively. This results were compared with theoretical target of 120km under constant moderate speed that was proposed by the manufacturer, and the effectiveness of the EV model was proved.

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