SIMULATION OF PERFORMANCE PARAMETERS OF POWERTRAIN FOR MINI PASSENGER ELECTRIC CAR

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Abstract:
Accurate electric vehicle (EV) powertrain modeling, assessment, and testing are crucial for making crucial designing and management decisions in high-efficiency car models. This journal describes a method for designing and developing an electric car powertrain, which comprises modelling, computing on a vehicle process, as well as in-depth analysis of the results. Although the modelling of the electric car powertrain in software which is simulation environments is essential for the research and designing of EVs, it is crucial to validate these simulations on actual car components to increase the overall efficiency, dependability, and speed of the vehicle. This modelling approach combines the simulation and modelling of an electric car powertrain using MATLAB/Simulink software with the validation of the simulation results on a real automobile. and vehicle-1 and objective is to performance parameter of vehicle are range, energy consumption and acceleration time with variables like, drive cycle (FTP-75, NEDC and MIDC) and Vehicle specification (Vehicle 1 and Vehicle 2) while considering motor speed and torque, power of motor , power of battery , current of battery, SOC, C-rate.

Keywords: Electric vehicle, simulation, MATLAB, powertrain, modeling, high-performance, performance parameter, drive cycle

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NOMENCLATURE

- E= Energy Consumption (Wh/km)
- F_a =Acceleration Force (N)
- F_d=Airdrag Force. (N)
- F_{rr}= Rolling resistive force (N)
- F_g= grade force(N)
- F_T = Tractive force (N)
- ρ = air density (kg/m^3)
- A= Vehicle front area(m^2)
- C_d= air drag co-efficient
- v=Instantaneous driving speed.(m/s)
- C_{rr} = constant rolling friction co-efficient
- m = total mass(kg)
- g= Acceleration of gravity. (m/s^2)
- N_w = Speed of wheel (rpm)
- τ_w =Torque of wheel (Nm)
- N_m =Speed of motor (rpm)
- τ_m =Torque of motor (Nm)
- P_m = Power of motor (kW)
- P_b = Power of battery(kW)
- SOC = State of charge (%)

Specifications

Table-1 specifications for both vehicle

Vehicle Parameter	Value
kerb weight for vehicle 1 (Kg)	525
kerb weight for vehicle 2 (Kg)	840
Rolling co-efficient (C_{rr})	0.015
Air drag co-efficient(C_d)	0.25
Front area(m^2)	1.95
Air density(Kg/m^3)	1.225
Radius of wheel (m)	0.3993
Gear ratio	10
Gross vehicle 1 weight (GVW)(Kg)	693
Gross vehicle 2 weight (GVW)(Kg)	1176
Motor controller efficiency	0.85
Transmission efficiency	0.85
Acceleration due to gravity(g)(m/s^2)	9.81
Motor efficiency	0.87
battery capacity (Wh)	72
battery voltage (V)	48
cell capacity (Ah)	3.6
cell nominal voltage (V)	3.2
Lap distance (FTP-75)(km)	17.77
Lap distance (NEDC)(km)	10.93
Lap distance (MIDC)(km)	22.80

1. INTRODUCTION

When opposed to conventional automobiles that rely on ICE [Internal Combustion Engines], EVs are one of the current alternative means of transportation. Due to the importance that electric vehicles have in reducing pollution and having zero GH petrol emissions, they are used. Due to improvements in battery technology, electric motor technology, control and administration of the power process, and commercial market need, electric vehicles are now gaining popularity.This research aims to model the powertrain performance characteristics for a small electric passenger automobile. The efficiency, range, and performance of the electric vehicle are significantly influenced by the powertrain. The goal is to determine and put into practise tactics that will increase the economy of the powertrain while providing ideal performance and range.The battery modelling, controller, and DC motor should all be included in the folder and should be the main focus of the MATLAB simulation process. created a model for EV using MATLAB/SIMULINK. In the suggested Simulink, the driveline, chassis, brakes, tyres, motor and motor controller, battery pack, and other inputs from MATLAB are used to create the car.It was discovered that the model's driving system is reliant on the speed of the car. In this study, the authors define important vehicle requirements before creating an model-based model of a mini passenger electric car in the MATLAB/Simulink programme. This research describes the modelling and simulation stages for high-efficiency EVs. Real-world testing on the intended EV platform confirm the model's predictions, which are used to assess the effectiveness and performance of the EV. Performance parameter of vehicle are Range, Energy consumption, Acceleration time With variables like, Drive cycle (FTP-75, NEDC and MIDC) and Vehicle specification (Vehicle 1 and Vehicle 2) While considering wheel speed and torque, motor speed and torque, power of motor , power of battery , current of battery, SOC, C-rate.

2. METHODOLOGY: -

2.1. Weight of both vehicles: -

As it will be pure Electric vehicles, there is 2 mini passenger electric vehicle which has different
Kerb weight of vehicle 1 = 525 kg
Kerb weight of vehicle 2 = 840 kg
Vehicle 1 is basically a 2 seater vehicle which has 525 kg of kerb weight so,

Total weight on vehicle-1
= 70kg × 2 people × 1.2 Factor of safety
= 168 kg
Now,
GVW (Gross Vehicle Weight) of vehicle 1 will be
= kerb weight + total weight on vehicle-1
= 525 + 168
= 693 kg
Vehicle 2 is basically a 4 seater vehicle which has 840 kg of kerb weight so,
Total weight on vehicle-2
= 70kg × 4 people × 1.2 Factor of safety
= 336 kg

Now,
GVW (Gross Vehicle Weight) of vehicle 2 will be
= kerb weight + total weight on vehicle-2
= 840 + 336
=1176 kg

2.2. Preparing drive cycle :-

For this paper, author prepared 3 excel sheet. Which is a velocity against time data. This excel sheets are prepared by considering at each and every seconds what is the velocity of vehicle for particular drive cycle. While preparing this excel sheets, author gone through 1180 sec for NEDC, 1180 sec for MIDC and 2474 sec for FTP-75 the velocity of vehicle is determined after that this velocity vs time graph has been obtained. After obtaining this 3 velocity vs time graphs. These graphs are uploaded in MATLAB/ SIMULINK so that for vehicle modeling there will be an input velocity or reference velocity will be their. For uploading drive cycles in MATLAB/SIMULINK first from the library insert a drive cycle block. After that double click on this block and click on the select files and then upload these excel files in MATLAB/ SIMULINK

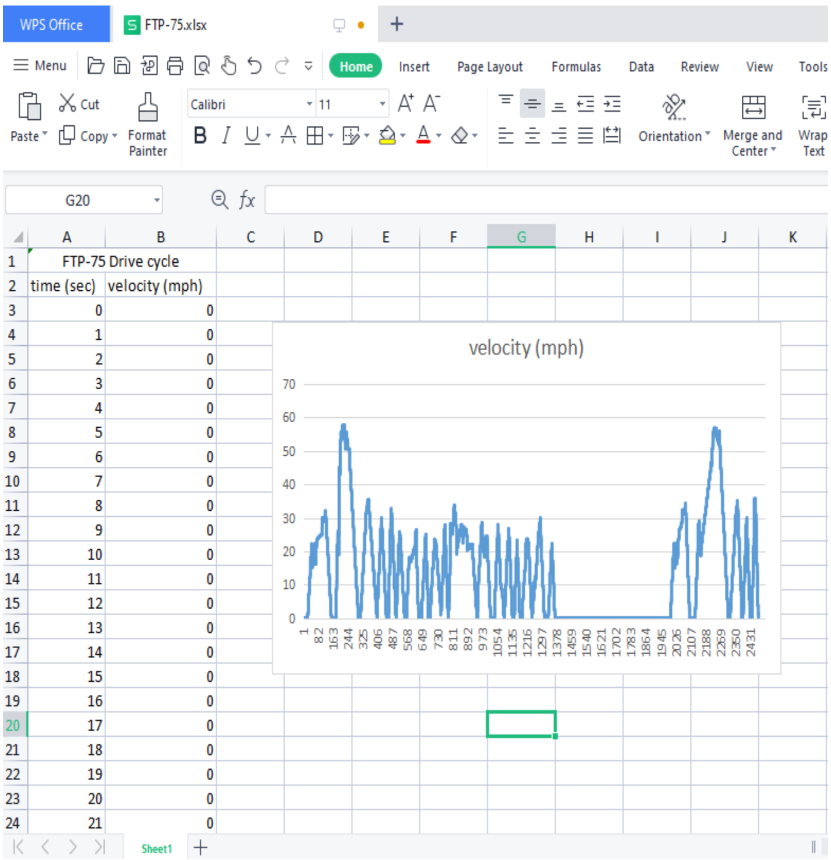
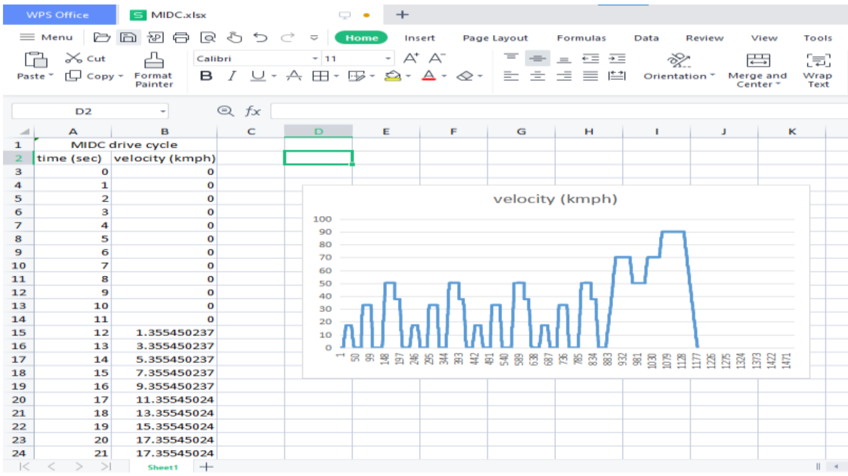
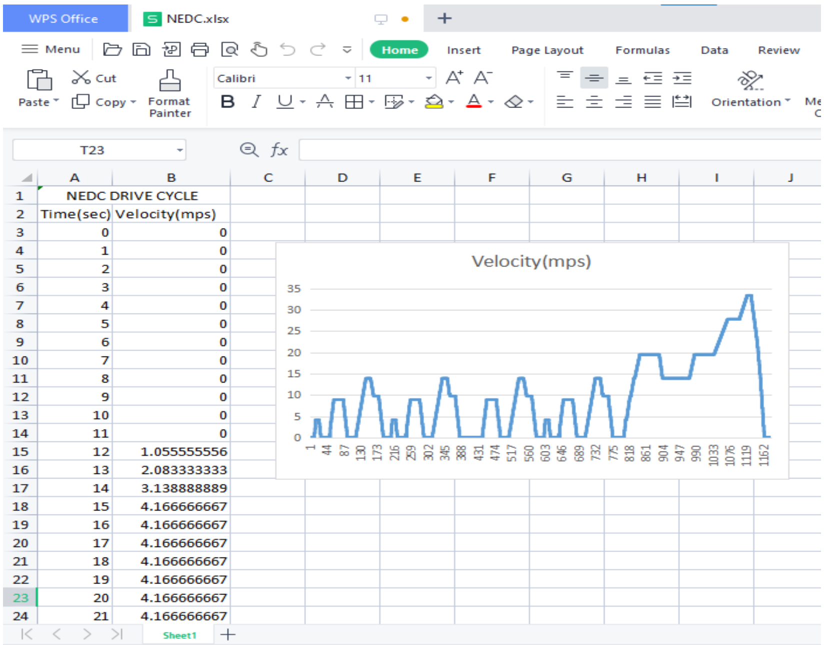


Fig 1 . FTP-75 drive cycle in excel sheet



time (sec)	velocity (kmph)
0	0
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	1.355450237
13	3.355450237
14	5.355450237
15	7.355450237
16	9.355450237
17	11.35545024
18	13.35545024
19	15.35545024
20	17.35545024
21	17.35545024

Fig 2 . MIDC drive cycle in excel sheet



Time(sec)	Velocity(mps)
0	0
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	1.055555556
13	2.083333333
14	3.138888889
15	4.166666667
16	4.166666667
17	4.166666667
18	4.166666667
19	4.166666667
20	4.166666667
21	4.166666667

Fig 3 . NEDC drive cycle in excel sheet

2.3. Dynamics of Vehicle Motion

Newton's second law states that an object's acceleration is inversely proportional to the net power provided to it. In other words, when there is a net force acting on an item, it accelerates. a vehicle moves by the force of the propulsion unit (the powertrain). The power given to the wheels by the motor, the curb mass of the vehicle (which includes all of its parts including the people within), the state of the road, and the aerodynamics of the vehicle on the road all affect how quickly and how quickly the vehicle accelerates.

F_T is the addition of the acceleration force F_a, F_{rr} rolling resistive of the vehicle's tires, and the airdrag F_d as shown in equation (1)

$$F_T = F_a + F_{rr} + F_d + F_g \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$F_d = \frac{1}{2}(\rho)(C_d)(A)(v^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$F_a = ma \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$F_{rr} = C_{rr} mg\cos\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$F_g = mgsin\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where C_{rr} are the coefficients of rolling resistive, F_g represents the grade in degrees, g is the acceleration caused by gravity, A represents the front area, C_d is the coefficient of drag, and v is the vehicle's speed.

2.4. EV Powertrain Simulation and Modelling

Making important design requirements, as shown in Table 1, is the first step in EV powertrain simulation and modelling. subsequently, using MATLAB/Simulink and these specifications, an equation-based model of an EV is created. The modelling outcomes are subsequently confirmed using real vehicle capacity that has been verified on a chassis dynamometer. There are three distinct driving cycles employed in these equation-based models: FTP-75, NEDC, and MIDC.

2.5. E-mini passenger electric car MODEL

The E-mini passenger electric vehicle model represents the whole body of the E-mini passenger electric automobile, with certain subsystems describing individual body sections. There are eight subsystems in all. These include the tyre, the braking system, the body of the vehicle, the gearbox, the motor and controller, the battery, and the longitudinal driver.

The connection between all these subsystems are shown in Fig. 4.

In Simulink's equation-based modelling approach, each vehicle component or subsystem is represented as a collection of equation blocks connected by signals that are calculated and changed at each time step. An overview of the equation-based Simulink model created to satisfy the previously mentioned EV criteria may be seen in Figure.6. The point mass model of the previously discussed vehicle dynamics is represented by the glider model. It adds up the forces specified in equations (1) through (5) that operate on the vehicle body, which is symbolised by a point mass.

After the simulation of model there are total two different velocity which comes in picture

1. Reference velocity and

2. Feedback velocity

This reference velocity is nothing but a velocity signal which comes from the drive cycle block and this velocity is pre-determine by Simulink

This signal or this reference velocity represents how vehicle's driver drive this vehicles or behaviour of driving style

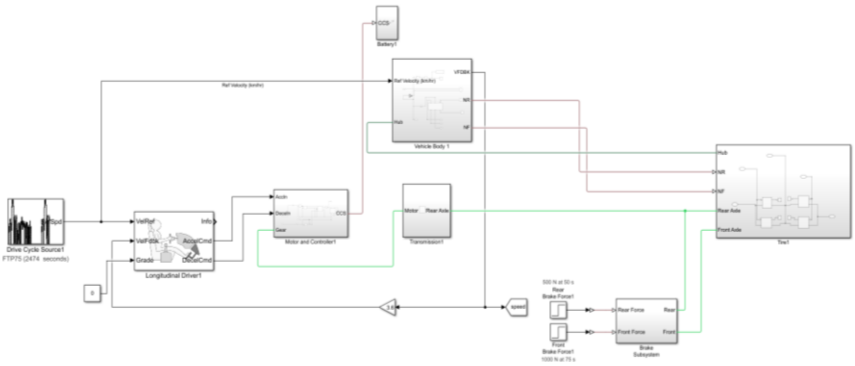


Fig 4. E-mini passenger electric car MODEL

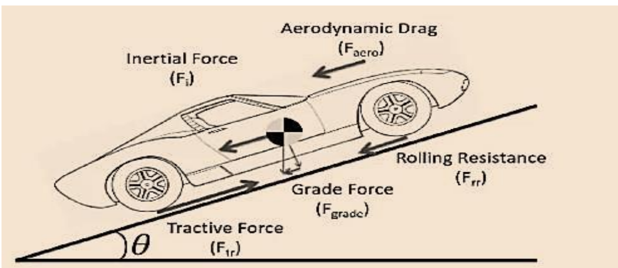


Fig 5. Vehicle body glider model [13]

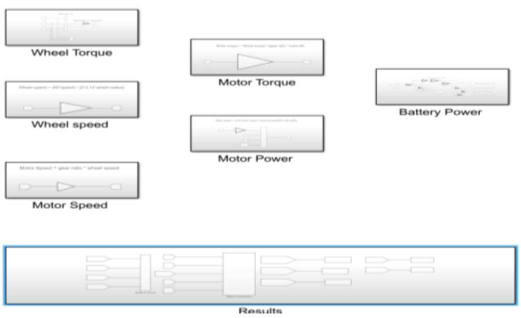


Fig 6. calculation for various parameters

Now, the feedback velocity is represent the velocity of vehicle after simulation which is an actual velocity of vehicle after considering all the losses With the help of feedback velocity, we can calculate all the parameters of vehicle like motor speed and torque, power of motor , power of battery , current of battery, SOC, C-rate and Range, Energy consumption, battery capacity with the help of equation- based model.

2.6. MODELS: -

Model-based design and equation based design with vehicle -1 specifications and FTP-75 drive cycle used for reference velocity At the starting, both E-mini passenger car design and calculation design shown in Fig. 7

In Fig 7 (a) represents the model-based design for E-mini passenger car as well as Fig 7(b) represents the equation-based design for E-mini passenger car

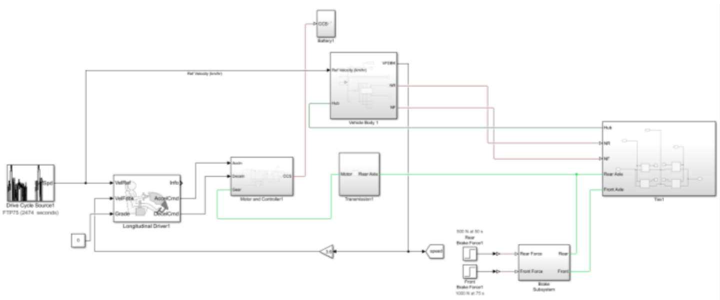


Fig 7 (a). model based design for FTP-75 (vehicle 1)

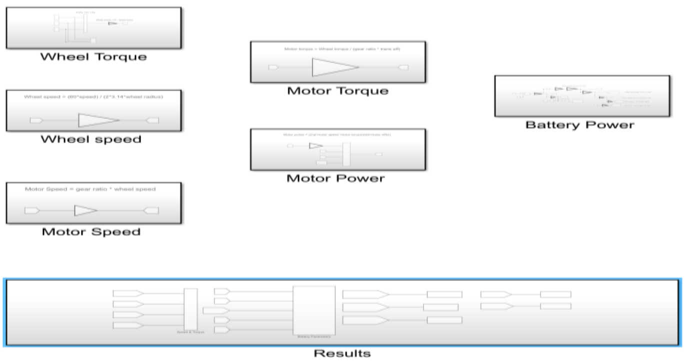


Fig 7 (b). equation-based design for FTP-75 (vehicle 1)

3. Results and Discussions: -

After the simulating model based design, we get results for each models are in some parameters which are acceleration force, aerodynamic force, rolling resistance force, tractive force, tractive power, wheel speed and torque, motor speed and torque, power of motor , power of battery , current of battery , battery C-rate, SOC, range, energy consumption, battery capacity.

There are total 6 caeses for 2 vehicle for each 3 drive cycles

Case 1: Vehicle 1 connected with FTP-75 drive cycle

1) Speed vs time

As we can see here, in FTP-75 cycle the max speed(91.5kmph) can achieve at 2474 sec

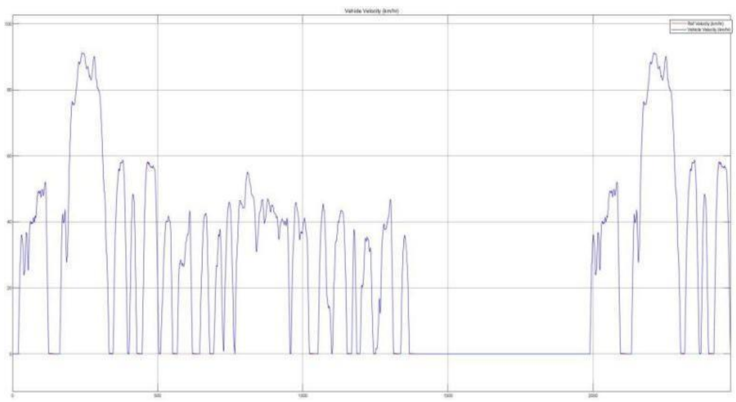


Fig 8. Reference velocity and Feedback velocity variation with time for vehicle 1

In fig 8, graph represent actual speed of vehicle and FTP-75 drive cycle speed.
In fig 8, graph is for 2474 sec After simulating the model, reference velocity and feedback velocity graph is overlapping.

Feedback velocity of vehicle is as follows as FTP-75 drive cycle.

This graph show this model is works with high accuracy.
Vehicle speed gets max speed of 91.5 kmph at 242 sec and 2208 sec.
Vehicle's major deceleration is from 283 sec to 335 sec and 2252.27 sec to 2305 sec at this time vehicle speed goes from 90 kmph to 0 kmph

2) All forces vs time

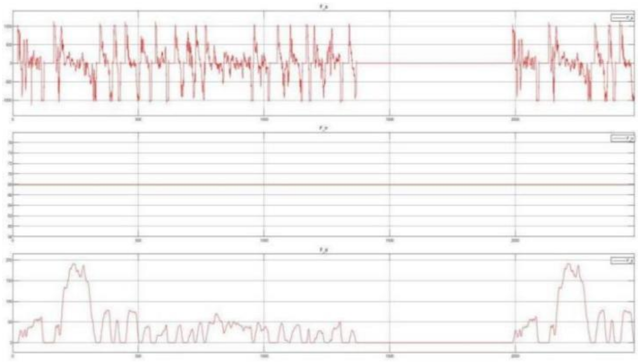


Fig 9 . All resistive forces variation with time acting on vehicle 1

3 resistive forces are acceleration force, aerodynamic force, rolling resistance force which resist vehicle to move while driving Above graph is represents the 3 resistive force acting on the vehicle based on the our input speed profile In above graph is for 2474 sec Aerodynamic force:- This is how the aerodynamic force is according to speed profile input given to vehicle as aerodynamics force is proportion to square of speed so it gives similar shape to speed profile input which we have given F_{dmax} = 194 N at max speed at 242 sec

$$F_d = \frac{1}{2}(\rho)(C_d)(A)(v^2)$$

Aerodynamic drag force goes 187.5 N to 0 N from 283 sec to 335 sec.
Acceleration force :- The force is negative value shows strong deceleration as you can see here the speed is here drops from 50 to 0 kmph in 111 to 130 sec there is strong deceleration 90 to 0 kmph in 280 to 333 sec there is strong deceleration.

$$F_a = m \times a$$

The value in the negative value shows strong deceleration and positive value shows strong acceleration
$F_{a(91.5kmph)}$) = 0 N: - vehicle is at its maximum speed, its acceleration will be zero.

Rolling resistive force: - force is constant as it does not depend on speed input or RRF is independent of vehicle speed
$F_{rr(upto\ 2474sec)}$ = 68 N

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

Gradient force is zero as there is no slope

$$F_g = mg\sin\theta$$

3) Tractive force vs time

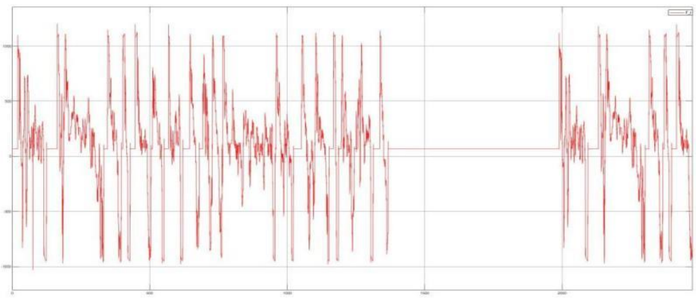


Fig 10. Tractive Force variation with time acting on vehicle 1

Tractive force is the sum of all resistive forces

$$F_T = F_a + F_d + F_{rr} + F_g$$

Required tractive force at max speed, $F_{T(91.5kmph)}$ = 265 N

Here tractive force is fluctuating widely, this may indicate poor traction or unstable driving conditions

4) Tractive Power vs time

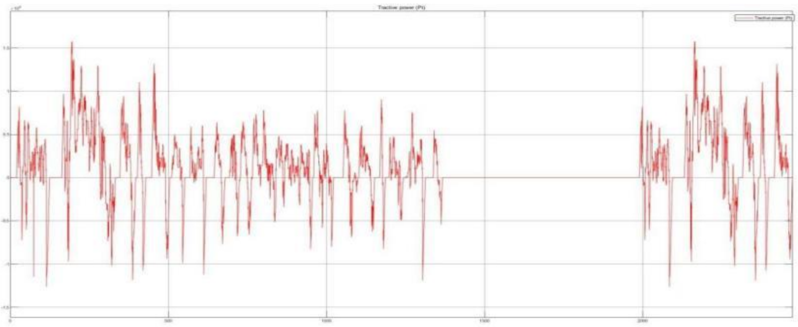


Fig 11 Tractive Power variation with time acting on vehicle 1

This is how the required tractive power is according to speed profile input given to vehicle as tractive power which is addition of all the resistive forces multiply by vehicle velocity

$$P_T = F_T \times v$$

$P_{T(91.5kmph)}$ = 8.8 kW

5) Speed and torque vs time

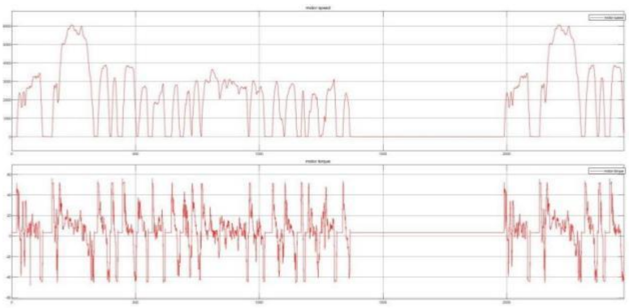


Fig 12. motor Speed and torque changes according to time acting on vehicle 1

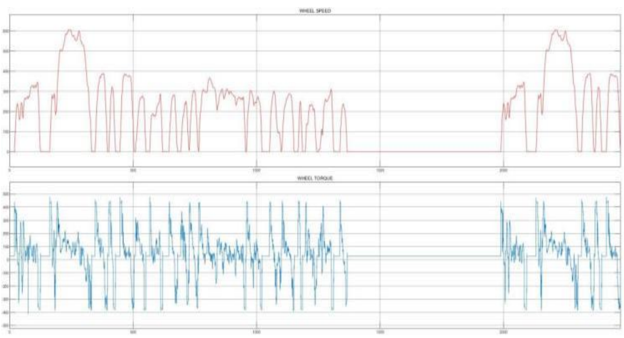


Fig 13. wheel Speed and torque changes according to time acting on vehicle 1

Figure 12 shows motor speed and torque changes according to drive cycle time.
Figure 13 shows wheel speed and torque changes according to drive cycle time
variation of wheel speed and motor speed requirement are based on the effective gear ratio use $N_{w(91.5kmph)}$ =610.4 rpm and $N_{m(91.5kmph)}$ = 6104 rpm

Negative value shows the power is regenerated and moves back to battery and recharge the battery.
When vehicle is decelerates wheel generate torque which directly goes to motor and it generate power to charge battery.
$\tau_{w\,(91.5kmph)}$ = 135 Nm
At max speed $\tau_{m\,(91.5kmph)}$ = 12.4Nm,

6) Battery paraters vs time

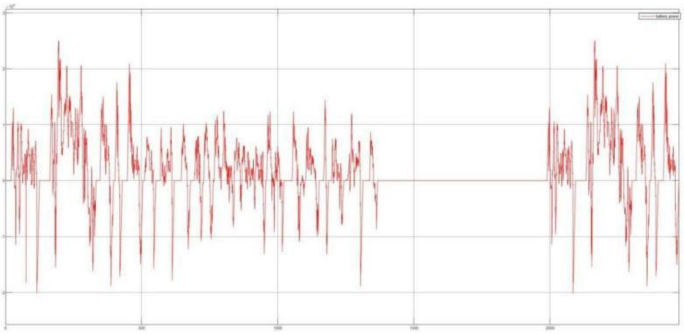


Fig 14. Battery power variation with time for vehicle 1

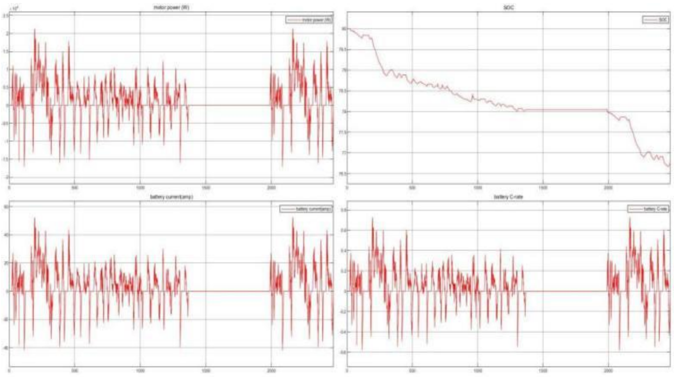


Fig 15. Battery parameter variation with time for vehicle 1

State of charge (SOC)- How SOC remaining in our battery pack after one complete cycle.

The SOC remain after completing the complete cycle around 78% so 2% of the charge is used for completing the cycle.

At max speed the $P_{m(91.5kmph)}$ = 9.6 kW and $P_{b(91.5kmph)}$ = 11.5 kW.

Battery current: - This is a battery current which we required from given profile input so it requirement around 28 amp after vehicle travels at max speed of battery pack and the battery C-rate around 0.2C.

7) Energy consumption vs time: -

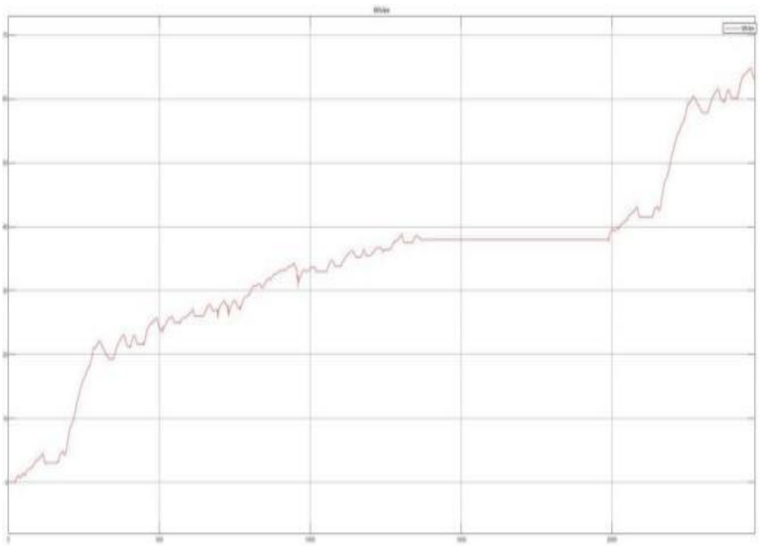


Fig 16. energy consumption variation with time of vehicle 1

When mini passenger car completes one cycle of FTP-75 drive cycle, The vehicle consume around 63.4 Wh/km

8) Range vs time :-

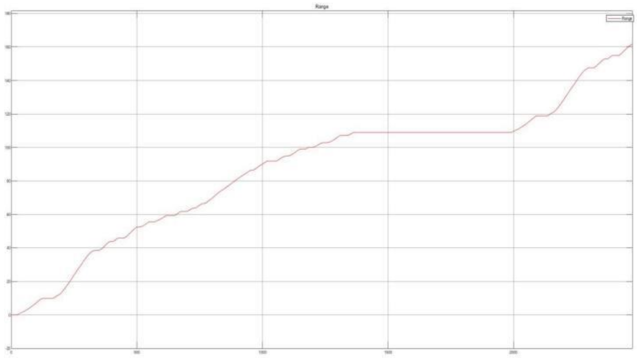


Fig 17. Range variation with time of vehicle 1

When mini passenger car drives untill it's battery gets fully discharge it gets upto 161 km or we can say that mini passenger car has range upto 161 km.

3.1. Calculation for Battery capacity

Battery capacity = 1127Wh

Energy consumption = 63.4 Wh/km

Lap distance(range) = 17.77 km, Total range = 161 km

For total battery capacity

17.77 * X = 161

X = 161/17.77 = 9

Total battery capacity for 161 km range = 9 x 1127 = 10.1kWh

Battery capacity in Ah = 10,143 / 48 = 211.3 Ah

After the simulate same model for NEDC and MIDC drive cycle and for both vehicles we get the results for each and every possible model which is shown in tables

Table 2. Motor and battery parameters for various drive cycles for vehicle -1

Sr no	Parameters	FTP-75	NEDC	MIDC
1	Accln force Fa (N)	0	0	0
2	Rolling resistance force Frr (N)	68	68	68
3	Air drag force Fd (N)	194	332	186
4	Tractive force Ft (N)	265	400	880
5	Tractive power Pt (kW)	8.8	20	15.4
6	Motor speed Ms (rpm)	6104	13000	6000
7	Motor torque Mt (Nm)	14	22.6	30
8	Motor power(Mp) (kW)	9.6	26.4	20
9	Battery power(Bp)(kW)	11.5	31.2	25.1
10	Current(I)(amp)	28	65.5	49.5
11	C-rate	0.2C	0.9C	0.5C
12	SOC(%)	80 to 78	80 to 77.6	80 to 78.5

Table 3. Motor and battery parameters for various drive cycles for vehicle-2

Sr no	Parameters	FTP-75	NEDC	MIDC
1	Accln force Fa (N)	0	0	0
2	Rolling resistance force Frr (N)	115	115	115
3	Air drag force Fd (N)	194	332	186
4	Tractive force Ft (N)	309	447	1385
5	Tractive power Pt (kW)	9.1	26.6	23.4
6	Motor speed Ms (rpm)	6104	13000	9500
7	Motor torque Mt (Nm)	17.5	23	26.8
8	Motor power(Mp) (kW)	12.3	35	31.6
9	Battery power(Bp)(kW)	14.5	41.2	36.9
10	Current(I)(amp)	30	85	79.3
11	C-rate	0.3C	1.2C	1.1C
12	SOC(%)	80 to 77	80 to 76.8	80 to 77.5

Table 4. Comparison between reference vehicle and vehicle 1' parameters

Sr.no.	Parameters	Reference vehicle	FTP-75	NEDC	MIDC
1	Battery capacity(kWh)	210 Ah (~10.1 kWh)	211.3 Ah (10.1kWh)	166.7Ah (8 kWh)	62.5 Al (3kWh)
2	Energy consumption(Wh/km)	91.81	63.4	81.32	29.06
3	Range (km)	110	161	98	90

4. Conclusion and future Scope: -

From the results obtained from the simulation, this study reveals that the reference velocity and feedback velocity for vehicle 1 and vehicle 2 graphs is overlapping.

Actual speed of vehicle is as follows as for all drive cycle. This graph show model is works with high accuracy. MIDC can be the optimized drive cycle and also if any manufacturer makes vehicle with same specification of vehicle-1 it would be cheaper than other mini passenger electric car and it gives a batter efficiency and also comparing with actual vehicle specification, vehicle 1 has almost same battery capacity and more range than actual mini passenger car

Optimization Opportunities: The simulation can identify areas for improvement and optimization, such as fine-tuning the powertrain control algorithms, optimizing gear ratios, or exploring aerodynamic enhancements. These measures can potentially enhance the car's performance and efficiency.

Future Considerations: The report should outline potential future considerations, such as integrating advanced energy management systems, utilizing lightweight materials, or exploring alternative powertrain configurations. These factors can contribute to further enhancing the performance and efficiency of the mini passenger electric car.

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