IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

Impact Factor: 6.252

Volume 2, Issue 8, June 2022

Experimental Analysis and Simulation of Hybrid Electric Vehicle Using Lithium-ion Battery and Supercapacitors

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Abstract: *Due to increasing environmental concerns, Hybrid vehicles are getting attention all over the globe. As our dependency on fossil fuels kept on increasing the supply of fuels keeps depleting and prices keep increasing. The need for alternative fuels is evident now more than ever. Nearly 25% to 30% of total greenhouse gases emitted are due to transportation industry. Harmful gases like CO2, NO2, NO and CO cause environmental damage and adverse effects on human health. To minimize these emissions hybrid vehicles were introduced. Hybrid vehicles can be powered by multiple setups like ICE and Battery combination, CNG and Battery combination etc. One such combination which could potentially be a game changer in this industry is combination of Lithium-ion Battery and Supercapacitor. The Main concern with electric vehicle in its limited range. This can be potentially solved by the use of supercapacitor. The function of supercapacitor in this setup will be to provide the motor of the vehicle with the required power where the battery fails to provide adequate power. The different types of batteries which can be used in this setup are Lead acid battery, Nickel bromide And Lithium-ion. From these Lithium-ion battery are used because of their higher density rechargeable properties and higher efficiency. Lithium-ion battery use inter calculated lithium compound as the material at positive electrode and graphite at negative electrode. The present work is focused on the analysis of Lithium-ion battery and Supercapacitor used in hybrid combination with DC motor in hybrid electric vehicle using simulation and scale model to compare and check different parameters like state of charge of battery, current, voltage, average speed of voltage etc.*

Keywords: Hybrid vehicle, Types of Batteries, Supercapacitor, Lithium-ion Battery, Average speed, State of charge, Simulation, etc.

I. INTRODUCTION

An electric vehicle or battery electric vehicle is an automobile that is propelled by one or more electric motors, using energy stored in batteries. Compared to internal combustion engine vehicles, electric cars are quieter, have no exhaust emissions, and lower emissions overall. This reliable yet overlooked form of transportation has evolved over the years from simple utility vehicles to powerful geared vehicles and now electric assisted vehicle. The direct and obvious advantage of adopting electric mobility is the cleaner environment. Electric vehicles don't emit pollutants into the air like their ICE counterparts. The EVs are silent as well unlike their ICE counterparts. This means EVs ensure a cleaner and quieter environment. Using Batteries is a convenient option for electric vehicle. Electric vehicle can also be used with hybrid combination which means using other second form of energy to utilize it when the first is drained.

Hybrid combination of electric vehicle are possible with supercapacitor, solar power, fuel cell battery, flywheel etc. A couple or combination of battery and supercapacitor is preferred as the supercapacitor has certain advantages over others. Supercapacitor is like a battery which means to store and release electricity. But rather than storing energy in the form of chemicals, supercapacitors store electricity in a static state, making them better at rapidly charging and discharging energy. Supercapacitors already exist in cars with regenerative braking systems.

This is thanks to their greater power density than chemical reaction-based batteries, which allows them to rapidly store and discharge electricity, handy for collecting energy generated under braking then quickly releasing it upon acceleration. The above report consists study and analysis of the working setup and calculations of the hybrid electric vehicle with supercapacitor as a storage system.

Problem Statement

Due to Rising Fuel prices and Increase in Pollution. Hybrid Electric Vehicle is a convenient. To meet the energy and power demand of automobile, battery and supercapacitor is best option to make hybrid energy storage system compared to other sources. This will reduce pollution due to negligible combustions of energy sources of HESS and increase in use of non-conventional energy sources for charging the batteries. Among other types of batteries, lithium-ion battery is best option to use for electric vehicles due to its powerful energy storage, small size and higher charging and discharging cycles. This will reduce pollution as it runs on Batteries. Electric vehicles are cheaper to run and environment friendly. This report consists study and analysis of the working setup and calculations of the hybrid electric vehicle with supercapacitor as a storage system.

Objectives:

1. Literature survey on various electric vehicle for getting idea about to know earlier work done and to know scope for further work.
2. Cad modeling of proposed setup with assumed parameters.
3. Battery and motor calculation for proposed setup to get efficient working parameters like soc (%), current, voltage variation with respective time for different connection at charging as well as discharging condition.
4. Cost estimation of various hardware required like battery, motor and various electronic devices.
5. Simulation study of proposed electrical vehicle using MATLAB Simulink 2020a.
6. Experimental study of proposed electrical vehicle using fabricated setup.
7. Comparative analysis of experimental setup for validation of proposed idea.

II. STRUCTURAL ANALYSIS

Vehicle Chassis:

The above chassis used is hollow structure made from stainless steel (W2) weighing approximately 22 Kg. The chassis was also powder-coated for its anti-rust property.

Motor

The motor used is BLDC motor. It specifies characteristics such as:

IJARSCT
ISSN (Online) 2581-9429
IJARSCT International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
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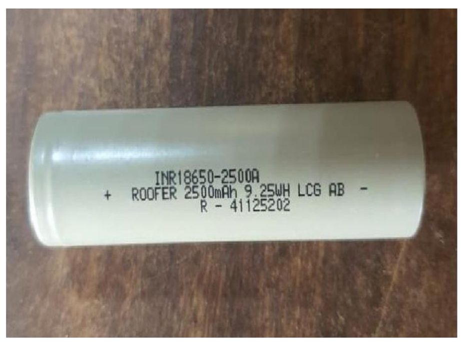
- Power = 750 W
- RPM = 500, Weighted RPM = 400
- Operating Voltage = 48 V
- Brush-less

SOC Meter

The mentioned SOC meter provides charge percentage of battery and other aspects such as headlight, ON/OFF.

Battery:



Lithium-Ion battery cell is being taken for use as it serves the purpose

- Specifications: Operating Voltage = 3.7 V
- Current = 2.5 Ah

Brushless Controller:

Brushless controller is added in the structure for controlling the motor. It controls motor by converting signal coming from throttle.

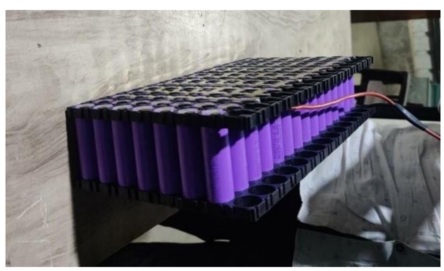
Drive Mechanism:

Transmission of vehicle is based on this drive mechanism.

Rear Axial Transmission

Motor drives the shaft at the rear which makes the system rear wheel drive. The shaft rotates with the gear at end which powers the wheels.

Battery Pack:



It consists of combination of 91cells in parallel-series combination.

- Specification = Operating Voltage = 48V
- Current = 18 Ah Length = 208 mm Breadth = 112 mm

It consists of 15 capacitors in series of rated voltage 3.0 & 370F

- Specification: Operating Voltage=45V
- Current = 16Ah Length=310mm Breadth=75mm

Drive Mechanism

Cad Model of The Proposed System (Software used: CATIA V5)

Motor Calculations:

To design a car carrying a load of 150 kg and to run at maximum speed of 30 km/hr.

Resistance force (F)

$F_{total} = F_{rolling} + F_{gradient} + F_{aerodynamic\ drag}$

$F_{rolling}$ (rolling resistance) = Cr.m.a.

Cr = coe of rolling resistance m = motion of vehicle in kg

a = acceleration due to gravity (m/s^2) Cr= 0.01, m= 150 kg, a= 9.81 m/s^2 $F_{rolling}$ = 0.01 x 150 x 9.81

[$F_{rolling}$= 14.71 N]

Power required to over rolling resistance = $F_{rolling}$ x (velo. of vehicle m/s)

= 14.71 x 30{1000/3600} = 122.62 ≈ 123-watt Gradient resistance,

$F_{gradient}$ = m.a.sin(θ)[consider (θ) = 0 ° at flat surface] $F_{gradient}$= 0 N [zero]

$F_{aerodynamic}$ = 0.5x ρ x v^2 x C_A x A_F P = Density of air medium

P = 1.23 kg/m^3 (for air at sea level) V = Velocity of vehicle in m/s

V = 30 km/hr = 8.33 m/s C_A = coe of air resistance C_A = 0.25 (for car)

A_F = frontal area of vehicle (in m^2) How to calculate frontal area of vehicle, Multiply height and width of car.

Adjust volume – Rounded corners for cars = 85%, Brakes = 70% [Assumed length = 68.6cm, width = 58.5cm]

Af = (Height x Width) x Adjusting volume

= (0.68 x 0.58) x 0.85 A_f = 0.33524 m^2

F_{aero} drag = 0.5 x ρ x v^2 x C_A x A_f

= 0.5 x 1.23 x (8.33)^2 x 0.25 x 0.33524 = 3.576 N

Power required to overcome this air resistance = 2.575 x velocity

= 2.575 x 8.33 = 21.44 = 25 watt

So total power required to overcome these resistance forces will be equal to total power required to move vehicle.

Power needed for motor = F(roll power) + gradient + power = 123 + 0 + 25

∴ To design an electric car of 150 kg and to run at maximum speed of 30 km/hr we need 150 watt motor.

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Battery Calculations:

→ Motor = 750 W [calculated]

Calculations: - [battery][specifications:- Power = 750 w, V= 48 volts]

Step 1: - Current [In Amp] consumed by motor to run

→ Power = Voltage x Current 750 w = 48 volts x current Current = 15.625 amp ≈ 18 amp

Step 2: - Find out watt how of battery To run 750 watt for 2 hours

Simply multiply (750 w x 2 hours) = 1500 watt/hour Take efficiency of 80% (Li-battery)

i.e. (1500/0.8) = 1875 watt/hour

Step 3: - Convert Watt hour of battery into Ampere hour Power = Voltage x Current

Watt/hour = Voltage x Ampere 1875 = 48 x Ampere

Ampere hour = 1875/48 Ampere hour = 39.06 ≈ 40

∴ To run 750 W motor for 2 hours, 48 volts and 40 Ah lithium-ion battery is needed.

Total Battery Composition Required = 48V/ 18 Ah Battery cell of lithium-ion battery = 3.7 V/ 2.5 Ah

To meet the requirement of voltage we have to make a battery pack by using parallel-series combination.

Batteries in Series [for voltage]

Total Voltage = 48 V 1 Cell = 3.7 V

Total Cell Required = 48/3.7 = 13 Therefore 13 cells are required in series. Batteries in Parallel [for ampere] Total Ampere = 18Ah

1 Cell = 2.5 Ah

Total Cell Required = 18/2.5 = 7 7 Cells are required in parallel.

Therefore, for a battery pack of parallel-series combination Total Cells Required = 13 x 7 = 91

As above calculation, required battery pack should be in parallel-series combination, consisting of 91 cells.

Supercapacitor Calculation:

1Capacitor = 3V/500F

From battery calculation we required 48V capacitor. Capacitor Voltage in series

$V_C=V_{c1}+V_{c2}+V_{c3}+V_{c4}+V_{c5}+V_{c6}\ V_{c7}+V_{c8}+V_{c9}\ V_{c10}+V_{c11}+V_{c12}+V_{c13}+V_{c14}+V_{c15}+V_{c16}$ $V_C=48V$

Capacitance in series (F) $1/C_T=1/C_1+1/C_2+1/C_3+1/C_4+1/C_5+1/C_6+1/C_7+1/C_8+1/C_9+1/C_{10}+1/C_{11}+\ldots+1/C_{16}$

$1/C_T=16/500$ $C_T=31.25F$

As above calculation, required supercapacitor should be in series, consisting of 16 Cells. So the total energy is required is 48V/31F

III. SIMULATION OF BATTERY & MOTOR CONNECTION

Difference between batteries connected in series vs connected in parallel

A. Simulink Circuit for battery series:

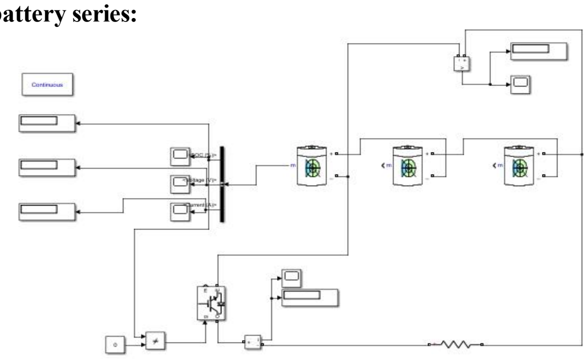

Fig: Simulation model Lithium Ion batteries connected in series

DOI: 10.48175/IJARSCT-5518

IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

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B. Simulink Circuit for Battery Parallel:

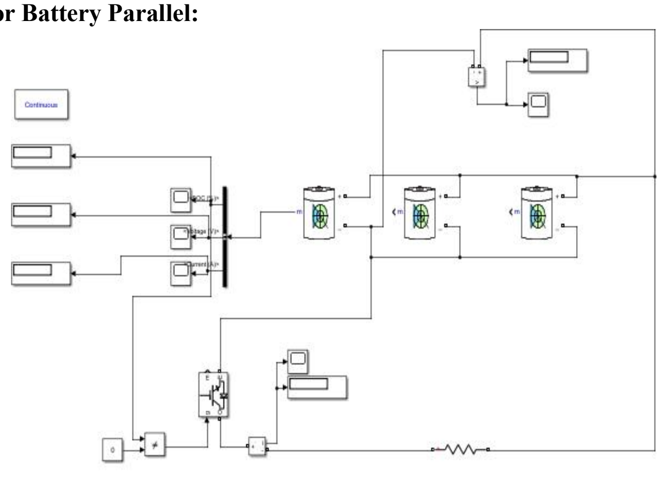
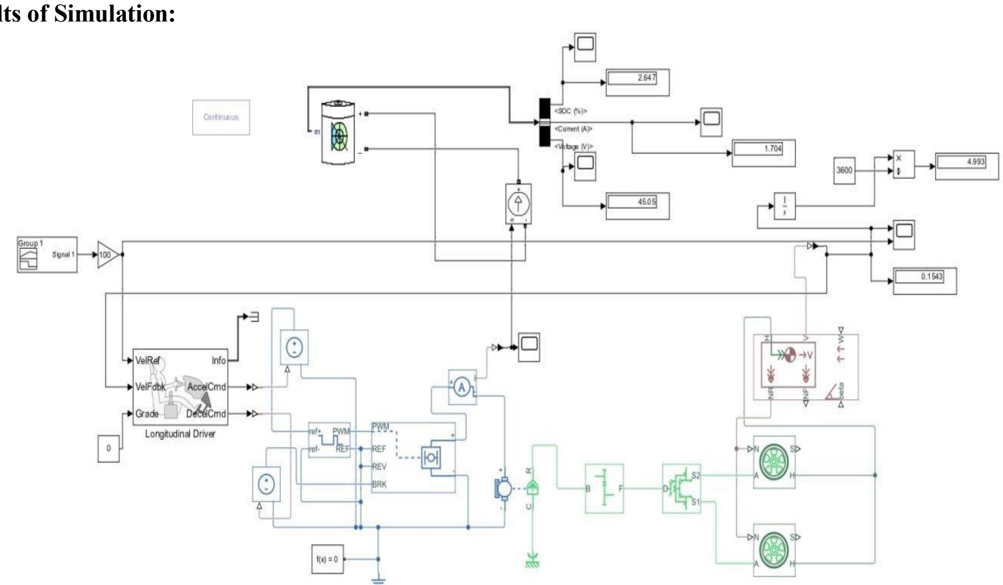


Fig: Simulation model Lithium Ion batteries connected in parallel

Input Parameters for simulation of calculated values:

Software used: MATLAB / Simulink version 2020a	
Time of simulation 1500 seconds	
Battery used Lithium-ion battery Specification Nominal voltage 48V Rated capacity 18Ah Initial stage of charge 100% Battery response time 30 seconds Efficiency = 80%	DC motor Specification Rated power of motor - 750 W Rated rpm of motor – 400 rpm

Results of Simulation:



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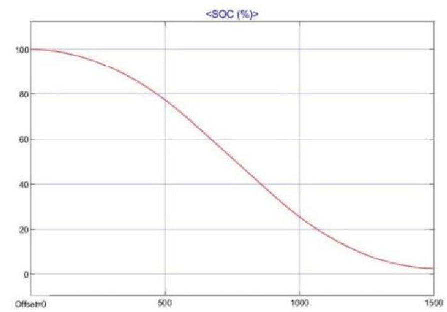
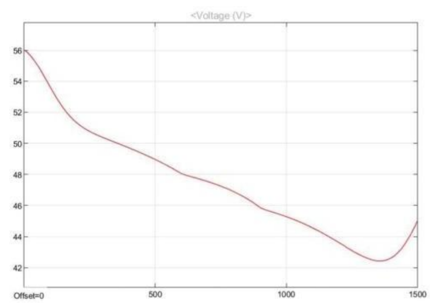
Simulation model of Electric vehicle

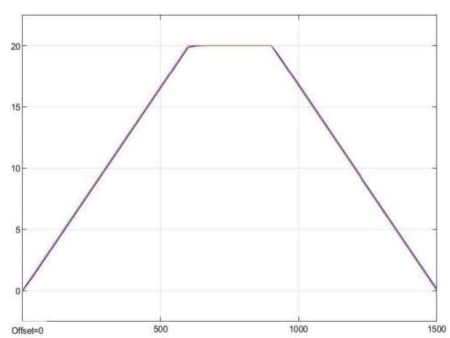
SOC (%)



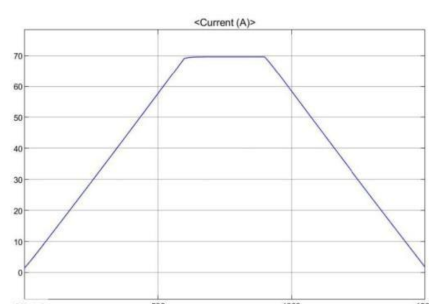
Voltage (V)



Speed vs Time Graph



Current (C)



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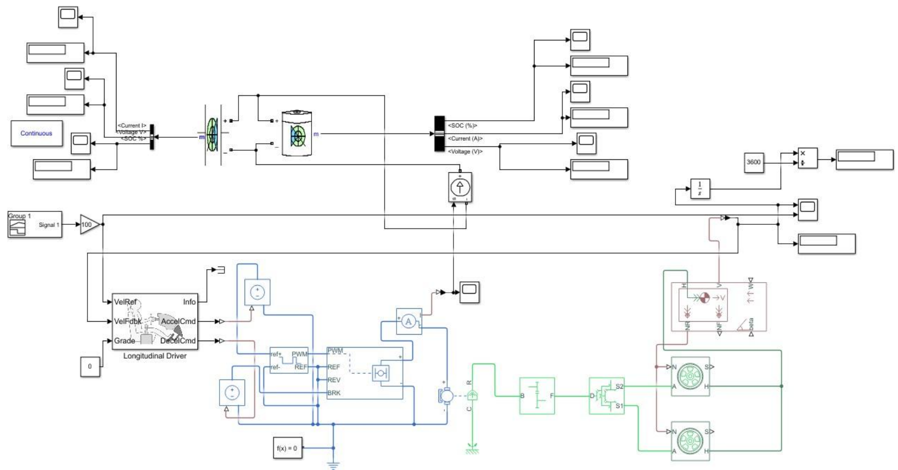
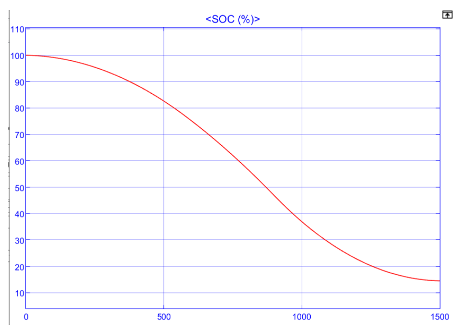
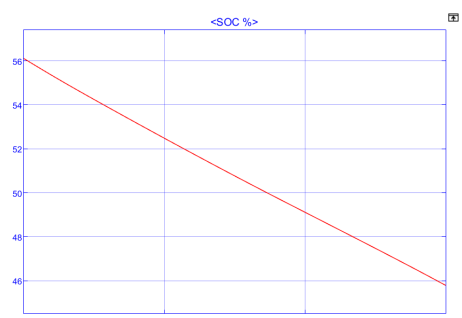


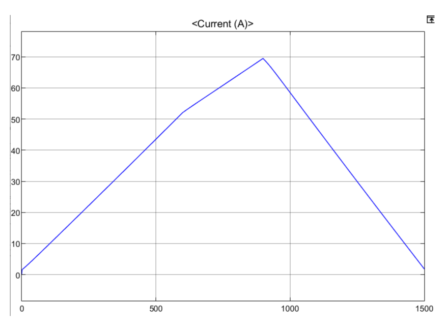
SOC (%) Battery



SOC (%) Supercapacitor



Current(C)



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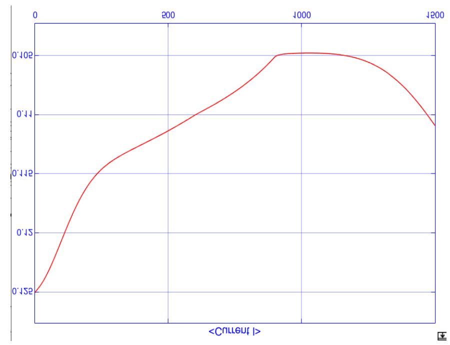
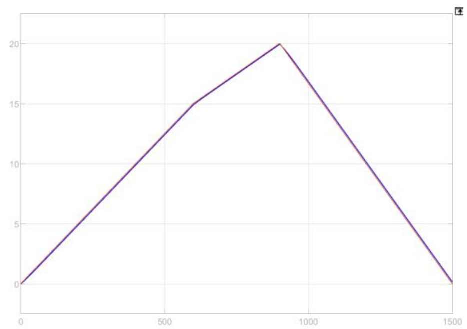
Current(C)



Speed vs Time Graph



Voltage(V)

Working Model Readings and Results

Surface Of Road	Distance (km)	Speed (km/hr)	Voltage (V)	Current (Ah)
Flat	1	12	47.2	8.7
	1	15	46	11.6
	1	20	42.2	25.4
Incline	1	15	43	18
	1	17	40	20
	1	20	39	21

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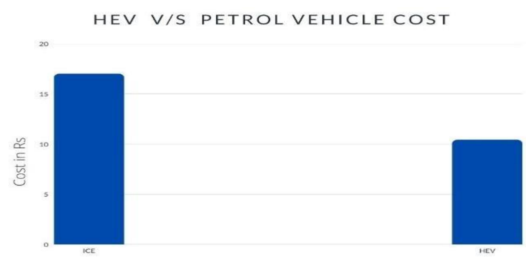

Comparison of working model witch actual ICE Vehicle

Data calculated by running both vehicle for 25min

ICE Vehicle	HEV
Cost per litre=110rs	Cost Per Unit=5rs
Run Time=25 min	Run Time=25min
Average speed=15kmpl	Average Speed=15kmph
Distance Travelled=6.25kms	Distance=6.25 Km
Cost of fuel as per distance=17.19rs	Supercapacitor =5rs/Unit
	Cost of fuel as per distance=10rs

As per distributed data: Cost of ICE vehicle is 17.19Rs as compared to HEV which cost 4.63Rs. Hence, HEV is more efficient than ICE vehicle.

IV. CONCLUSIONS AND FUTURE SCOPE

Conclusions

1. According to calculated dimensions of the chassis the CAD model has been prepared.
2. The battery pack calculation required to run the setup successfully has been calculated.
3. The supercapacitor calculation suitable for the hybrid setup has been calculated.
4. To run the setup successfully with estimated load high voltage and current is required due to which parallel series combination of battery pack and supercapacitors connected in series are prepared.
5. The physical structure model has been prepared successfully.
6. The simulated model and physical structure is compared.
7. HEV improves efficiency of EV and also increases its range while having less running cost when compared with ICE vehicle.
8. The minor differences in simulated data and experimental data is because of factor likes gradient change ambient temperature aerodynamic drag frictional resistance to the road surface and carrying weight of the driver.

Future Scope

1. Using IOT, by programming we can manufacture smart vehicle which will be capable of performing by remote control, automatic switching to hybridization combination, GPS tracking, autopilot driving
2. Smart and easy charging can be introduced by using EUSE (Electric Vehicle Supply Equipment) which communicate with CMS (central management system) to manage user authorization, billing and rate of charging.
3. Range of the vehicle can be improved by undertaking two wheels or four-wheel drive.
4. Regenerative Breaking can be added which slowdowns a vehicle by converting kinetic energy into a form that can be either used immediately or stored until needed.

Final Model

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