DESIGN AND ANALYSIS OF HESS FOR ELECTRIC VEHICLE APPLICATION

DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

CONTROL AND INSTRUMENTATION

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2021-22

CERTIFICATE

I, **Utkarsh Rastogi**, Roll No. 2K19/C&I/13 student of M.Tech. Control and Instrumentation (C&I), hereby declare that the dissertation/project titled **"DESIGN AND ANALYSIS OF HESS FOR ELECTRIC VEHICLE APPLICATION"** under the supervision of Sikandar Ali Khan of Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology has not been submitted elsewhere for the award of any Degree.

Place: Delhi

Date: 18/06/2021

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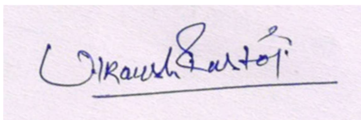

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ABSTRACT

Nowadays, the energy warehouse structures of EVs have to now no longer acquire big quantities of strength however additionally percentage out rapid dissimilarities of the burden. The increase and implementation of Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV) are these days obtaining a massive momentum particularly because of environmental and gasoline sources to deal with. An electric powered automobile model is simulated withinside the Mat lab wherein an electric powered automobile load on the idea of speed, acceleration, torque, strength at load is analyzed. Suitable factors of Indian power cycle incorporating like drag coefficient, coefficient of rolling resistance, etc. parameters are analyzed. A Mat lab Simulink of the Brushless DC motor, Inverter circuit, commutation switching circuit, Buck converter, PID controller, sensor circuit, and ultra-capacitance battery control version is evolved for the evaluation of an electric powered automobile. In an electric-powered automobile, the available electricity as a consequence of the battery might not be constantly enough to fulfill the weight ultimatum, especially at some stage in height ephemeral conditions. Hence, an ultra-capacitor financial institution is used as a further electricity garage detail in an electric-powered automobile, which could deliver electricity to satisfy the height strength ultimatum and may enhance the overall performance at some stage in short-lived conditions. The mixed use of battery and ultra-capacitor improves the performance of the system, the battery operates inside shielded limits, battery dwelling receives more desirable, brings down the battery size, and enlarging the automobile overall performance. The obstacles are decreased electricity density, low lifestyles cycle, immoderate cost, and limited using span. Ultra-capacitors are related to the battery because it has a double-layer electrochemical capacitor with an extended lifestyles cycle, successful to build up one thousand instances greater strength than a traditional capacitor, more advantageous electricity density, and green rate and law of discharge.

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LIST OF ABBREVIATIONS

BLDC	Brushless Direct current motor
EMS	Energy Management System
ESS	Energy Storage System
EV	Electric Vehicle
FC	Fuel cell
FLC	Fuzzy Logic Control
HESS	Hybrid Energy Storage System
HEV	Hybrid Electric Vehicle
PI	Proportional Integral
PID	Proportional Integral Derivative
PSO	Particle Swarm Optimization
SC	Super capacitor
SOC	State of Charge
UC	Ultra-capacitor

CHAPTER 1 INTRODUCTION TO ELECTRIC VEHICLE

1.1 DEVELOPMENT OF ELECTRIC VEHICLE IN INDIA

Recently, United Kingdom determined to forestall the sale of recent petrol and diesel vehicles via way of means of 2030. The United Kingdom strives to set up the allowing infrastructure for electric-powered vehicles (EVs). Necessary factors of an Electric Vehicle Manufacturing:

1. Controlling Pollution
2. Mitigating Climate changes
3. Using to be had Sustainable Energy Options

Challenges of Electric Vehicle Manufacturing:

1. Lack of Battery Cell Manufacturing
2. Building Charging Infrastructure
3. Limited Grid Capacity

1.2 CURRENT POLICY OF THE INDIAN GOVERNMENT

• **FAME Scheme**: The Indian authorities have created momentum to inspire the producing of Hybrid Electric Vehicles and generate in a few segments mandates the adoption of electrical vehicles (EV) and the purpose is to attain 40% EV penetration via way of means of development till 2030.

• **Fiscal Incentives**: Various monetary call for incentives were taken for the manufacturing and intake of EVs and charging infrastructure – consisting of offering rest in profits tax rebates, exemption from customs duties, etc.

Other Factors:

1. Increasing Research and development in Electric Vehicle
2. Creating awareness among the Public
3. Creation of a reliable Electricity Pricing

Conclusion:-

Operation mass transition to electric powered mobility for a rustic of 1.five billion human beings isn't an clean feat. Thus, a goal framework with a robust not unusual place imaginative and prescient is wanted for evaluating country guidelines and a platform for public-personal collaboration.

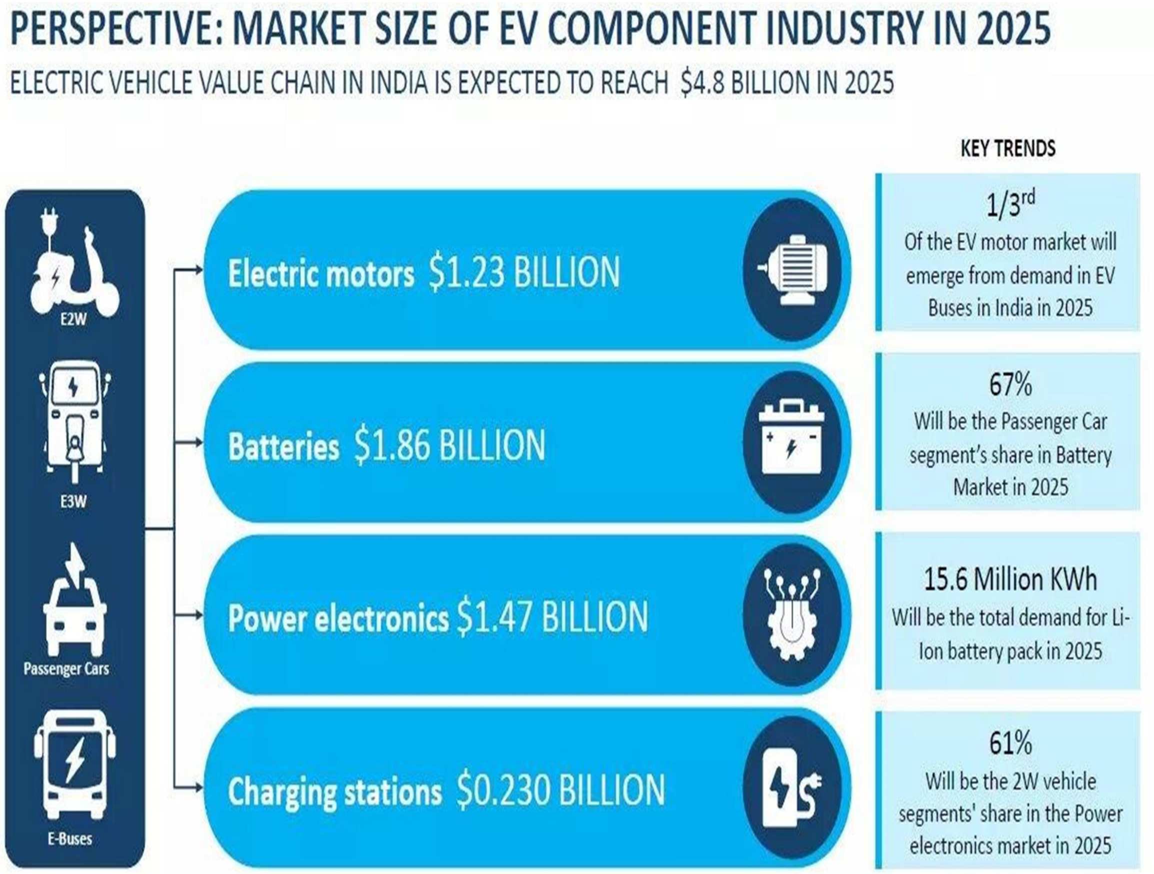


Figure 1: Perspective: Market Size of EV component industry in 2025

India is the fourth biggest car marketplace with inside the global and the second-biggest two-wheeler marketplace. The pollutants degree in lots of Indian towns has reached an alarming stage. Electric strength has diverse programs with inside the subject of Electronic gadgets, Tele-communication, Aerospace, and Industrial programs and there are 900+ vehicles /a thousand humans with inside the US. There are 800+ vehicles/ a thousand human beings in Europe. In India, there are simply 20 vehicles consistent with a thousand humans. Note - Most of the above are Petrol and Diesel vehicles.

1.3 SAKSHAM

The Petroleum Conservation Research Association (PCRA) and Ministry of Petroleum and Natural Gas, have released a month-lengthy marketing campaign, “SAKSHAM” with a view to create cognizance of a number of the clients for fossil fuels.

Key takeaways:

1. The marketing campaign shall spotlight each of the damaging effects on fitness and the surroundings with the growing carbon footprints.

2. 'SAKSHAM's concept is to persuade clients to replace in the direction of cleanser fuels and produce in behavioral extrude to apply fossil gasoline intelligently.

3. The marketing campaign additionally unfolds recognition of approximately seven crucial drivers that the Prime Minister these days mentioned, that might assist India to transport in the direction of a purifier strength-the usage of the country.

The elevated use of electrical cars to decarbonize mobility and also will cause Digital innovation throughout all strength systems. Oil changes are anticipated to stay vulnerable for the time being: Oil expenses are susceptible in the mean time for numerous reasons.

1. On the only hand, the improved oil manufacturing with inside the United States and Canada during the last few many years has introduced down the charge of oil. Canada brought 2 million barrels/day to its oil manufacturing with inside an equal period.

2. This multiplied oversupply with inside the marketplace will cause decrease costs.

Conclusion:

1. Norway has effectively used its sovereign wealth fund to make prudent oil investments to get large returns from excessive oil charges.

2. India is presently profiting from low oil charges — and wishes to devise for the time while costs could be getting higher.

1.4 Problem Statement of an Electric Vehicle

Hydrocarbon combustion is significantly accountable for the degradation of air quality, especially in densely populated areas, and for human-related greenhouse fuel line emissions. To lessen the combustion of fossil gasoline and to triumph over the supply of crude oil and its procurement is a steeply-priced and environmentally touchy process. Nowadays, the disruption with inside the delivery of oil consequences in rate swings and monetary uncertainty. Additionally, crude oil is a limitless deliver, and extensive quantities of authentic international reserves have already been consumed. There are several technology assets of energy and environmentally producing strength assets including wind, sun, and hydrostatic technology are locating a growing public favor. They lessen the danger of delivering disruption and growth efficiency. Presently, The blessings of electrical transportation with power saved in batteries and ultra-capacitor version to be used in vehicles. If the performance, range, and provider existence of the battery are better, the consumer is inclined to buy an electric-powered vehicle.

1.5 Background to Electrified Vehicles

There are many sorts of electrified automobiles which might be characterized with the aid of using their electricity storage kind and through the diploma of electrification. There are strategies of an electric-powered car layout which can be specifically gas and electric powered. Depending at the relative strength generated from a combustion engine and an electric powered motor, the automobile can be categorized as 'micro hybrid', 'moderate hybrid', or 'complete hybrid'. Some hybrid electric-powered automobiles are able to multiply electric-powered operation if their batteries are charged with an outside strength supply; such varieties of electric-powered cars are called plug-in hybrid electric-powered cars (PHEV). Electric automobiles are classified on the idea of energy supply as battery electric powered cars (BEV), or gas molecular electric powered automobiles (FCEV). The hybrid electric-powered car designing especially makes use of a parallel or collection configuration of engine and motor. The engine with inside the parallel configuration is automatically related to the power wheels and might function the automobile independently.

1.6 Electric Vehicle Sales and Performance Analysis

In a year badly impacted via way of means of the pandemic and resultant lockdowns, the car enterprise Electric region too has felt the stress of a gradual financial system and tepid sales.

Electric passenger vehicle sales up 115 per cent (6000 units as against 2,800 units)

Category	FY2021(units)	FY2020(units)	Growth (percentage)
Two-wheelers	1,40,000	1,53,000	-6.39
Three-wheelers	88,000	1,50,000	-39.65
Cars	6000	3000	110
Total	2,40,000	2,95,000	-19.46

Table 1: Sales analysis of FY 2020 and FY 2021

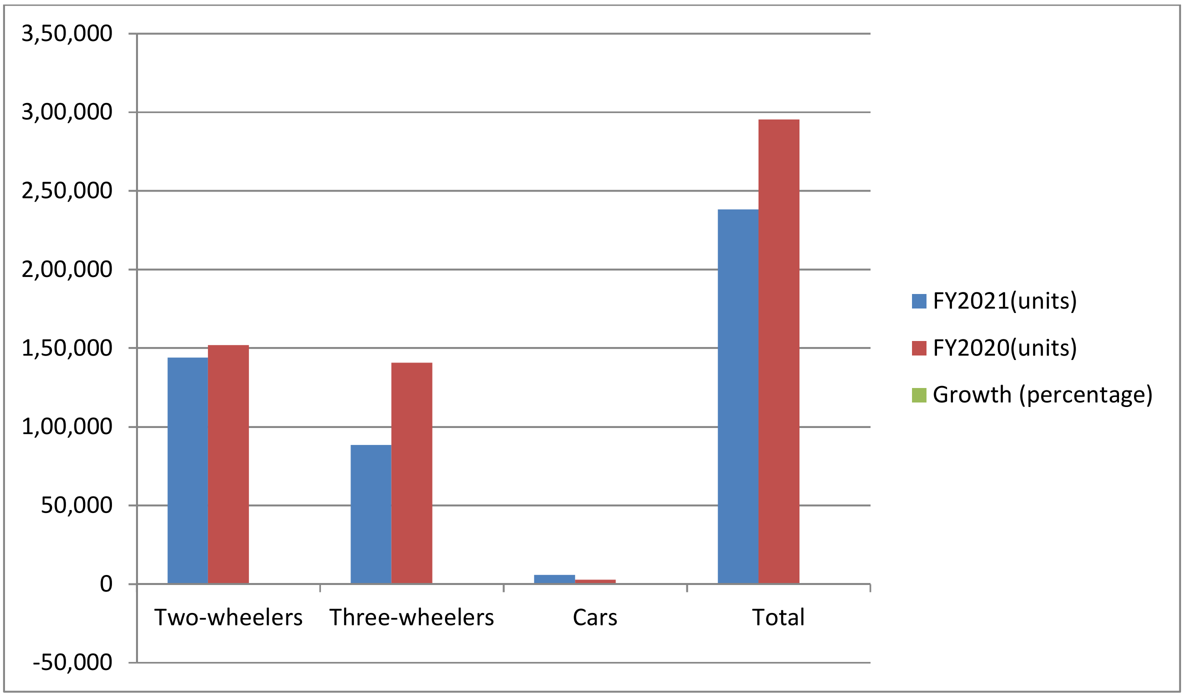


Figure 2: Bar Graph of Sales analysis of FY 2020 and FY 2021

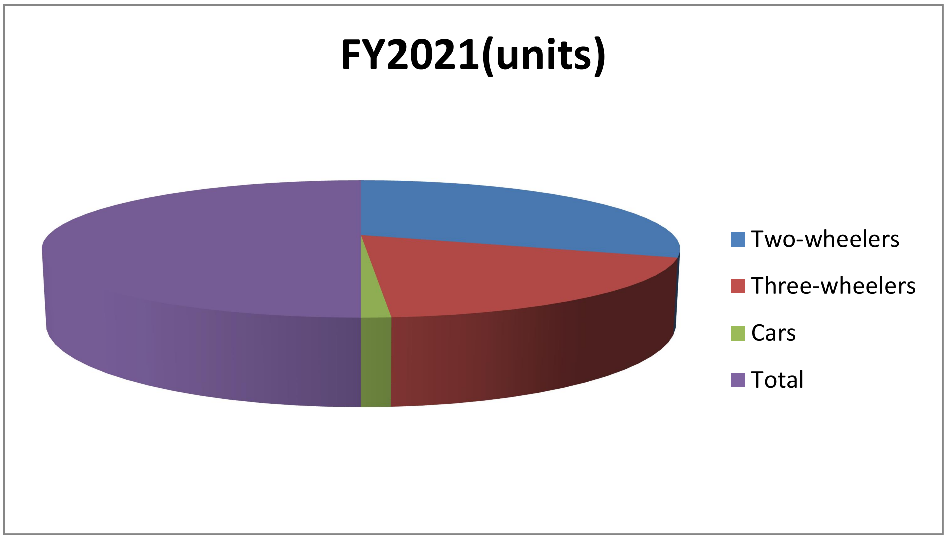


Figure 3: FY2021 Sales analysis of two wheeler and three wheeler Electric vehicles

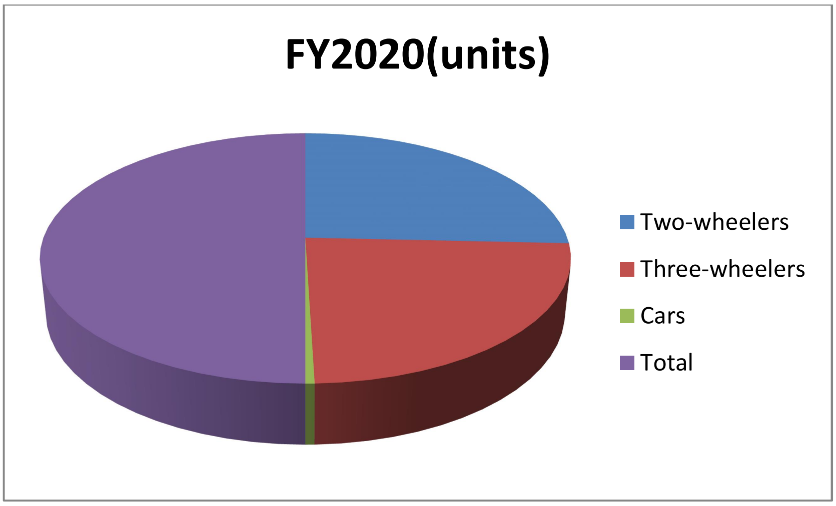


Figure 4 FY2020 Sales analysis of two wheeler and three wheeler Electric vehicles

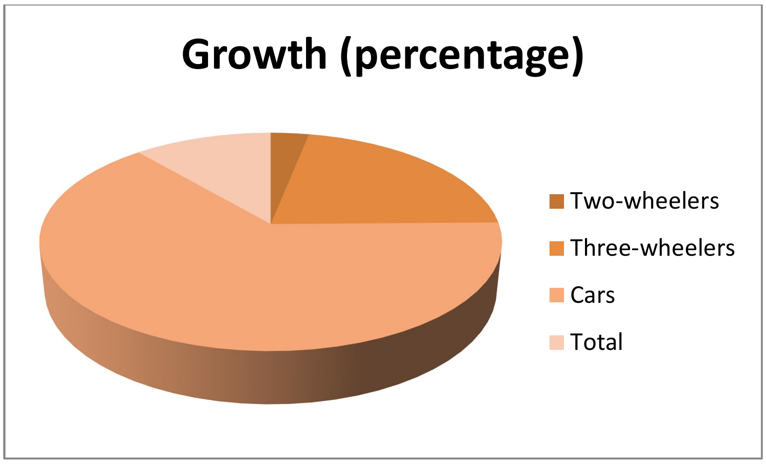


Figure 5:FY2021 Sales analysis of Growth percentage of two and three wheeler Electric vehicles

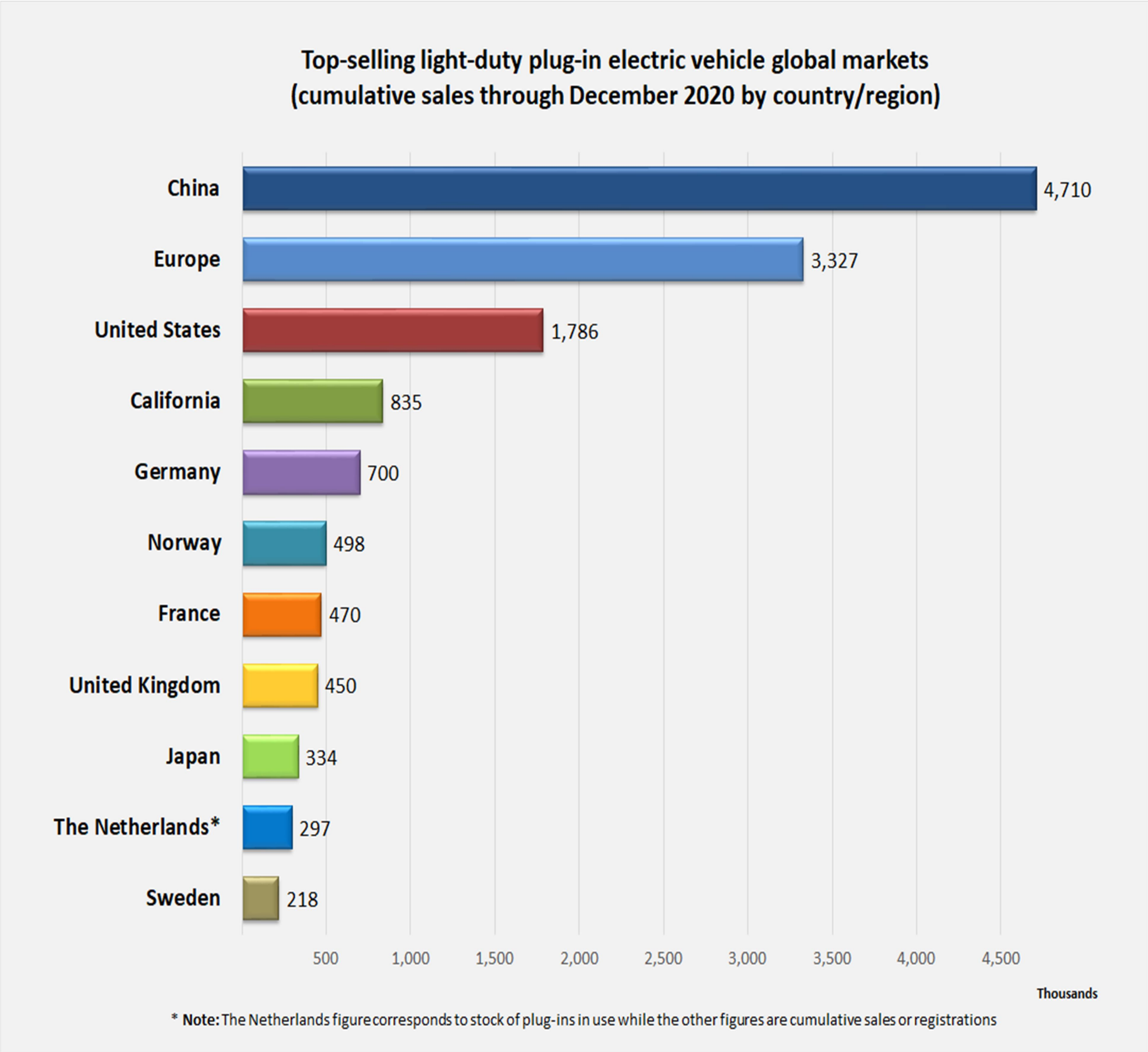


Figure A: Top-selling light-duty plug-in electric vehicle global markets (Cumulative sales through December 2020 by country/region)

1.7 Best-Selling Electric Vehicles of 2021 (So Far)

S. No	Electric Vehicle Models	Units Sold	Base Price (USD)	Fuel Economy	EPA Range
1.	Tesla Model Y	33629	41190	129/140/119	326
2.	Tesla Model 3	23116	38690	142/150/133	353
3.	Chevrolet Bolt	9025	37495	118/127/108	259
4.	Ford Mustang Mach-E	6614	43995	100/105/93	305
5.	Tesla Model X	5106	91190	105/109/101	371
6.	Audi e-tron and e-tron Sport back	4324	66995	78/78/77	222
7.	Tesla Model S	4155	81190	117/121/112	402
8.	Nissan Leaf	2925	32620	111/123/99	226
9.	Porshe Taycan	2008	81250	79/76/84	227
10.	Hyundai Kona Electric	1556	38575	120/132/108	258
11.	Volkswagen ID.4	474	41190	91/104/89	250
12.	Hyundai Ioniq Electric	445	34250	133/145/121	170

Table 2: showing analysis of Unit sold, Base price, Fuel economy and EPA range

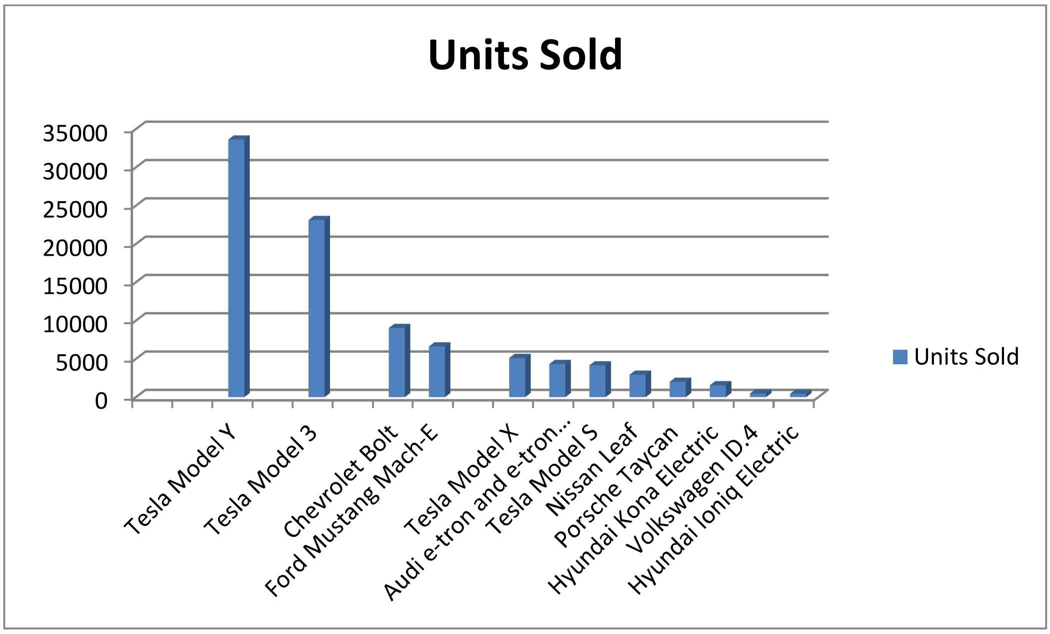


Figure 7: Units sold electric cars pie chart 2

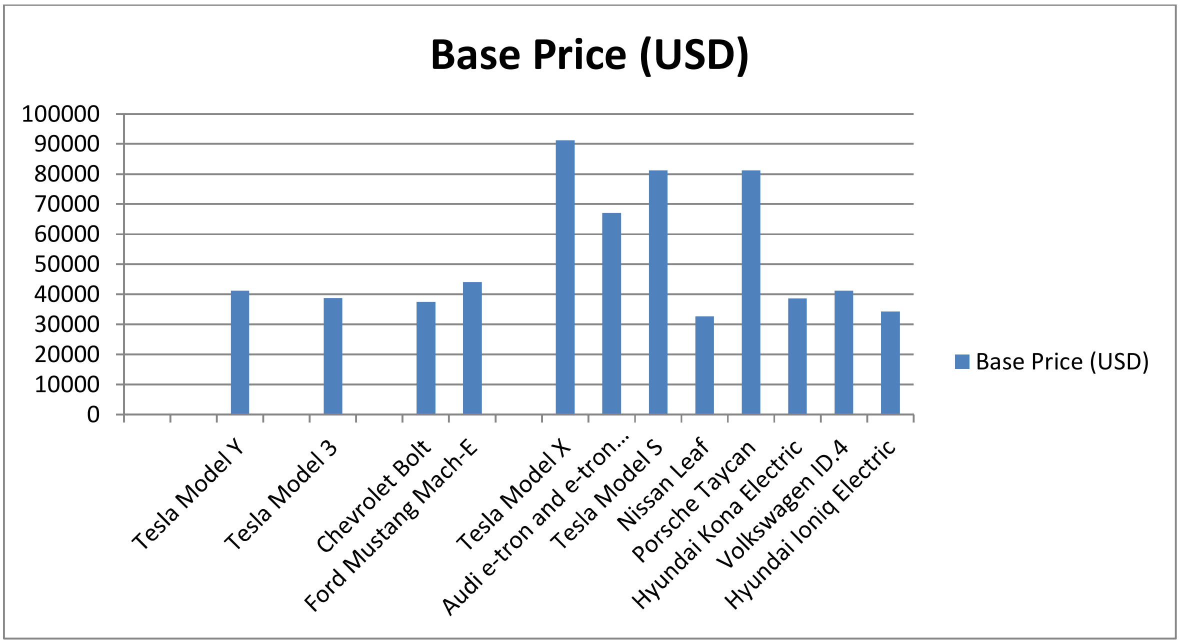


Figure 8: Base price analysis of Electric Cars

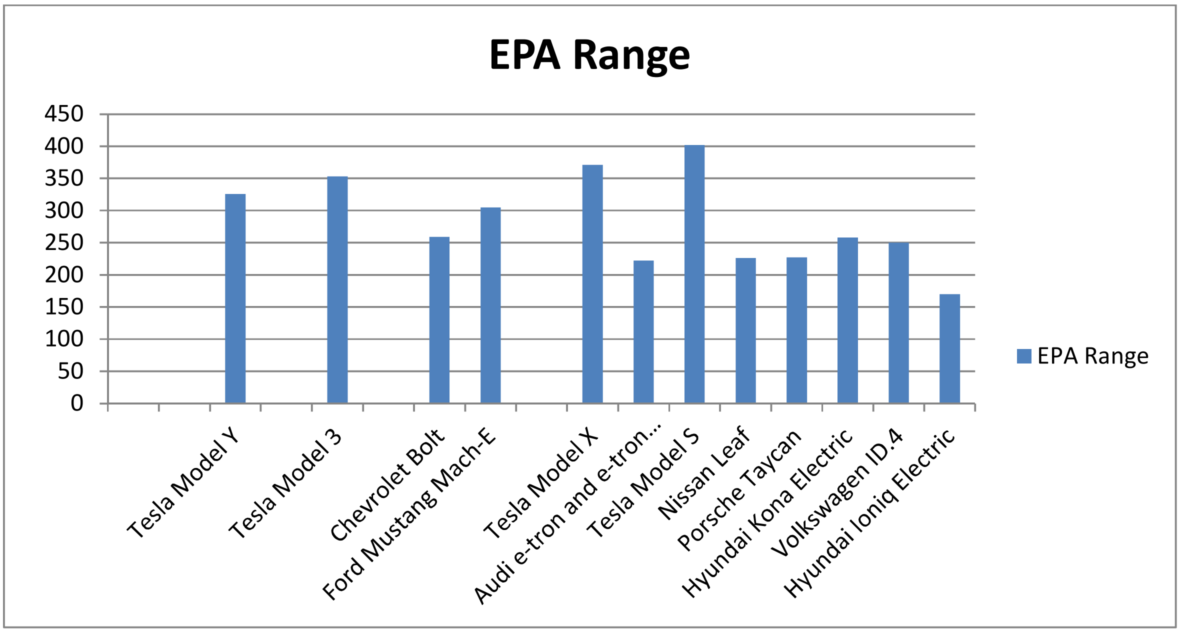


Figure 9: EPA Range analysis of Electric Cars

1.8 Benefits of Using an Electric Vehicle?

1. They lessen carbon emissions to a massive quantity and saves money.

2. The electric-powered vehicles react quickly, have excessive-efficiency, and feature appropriate torque characteristics.

3. Electric automobiles are regularly extra digitally linked than traditional automobiles, 4. The electric-powered automobiles charging stations offer a choice to manage charging from a telephone app.

1.9 What are the Disadvantages of Owning an Electric Vehicle?

1. Have a shorter variety than gas-powered cars.

2. The recharging of an electric-powered automobile battery takes time.

3. More highly-priced than gas-powered cars.

CHAPTER 2: LITERATURE REVIEW

This chapter demonstrates the technical heritage of electrical automobiles and their power utilization as hybrid storage systems. This concludes with a dialogue on the general automobile simulation and evaluation.

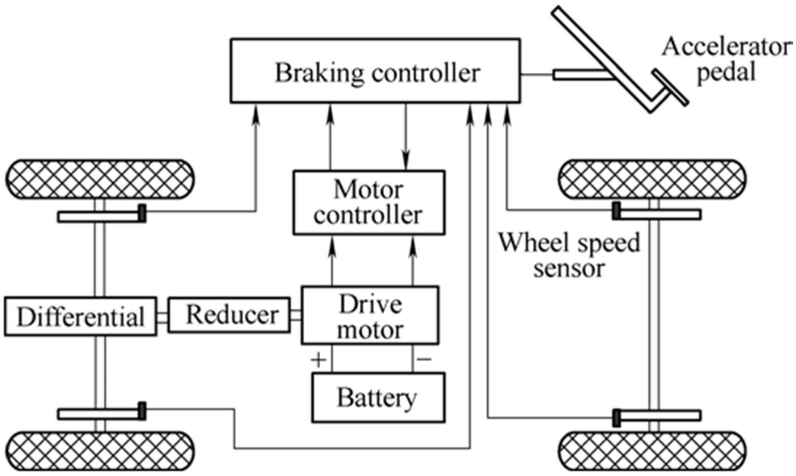


Figure 10: Electric Vehicle Overview

1.0 Electric Automobile Requirements

The force schedules encompass numerous automobile velocities. Acceleration and distance are calculated from the rate profile, and with the assist of the above information of the automobile which include mass, coefficient of drag, transmission ratios, and performance maps, overall automobile energy utilization may be decided effectively.

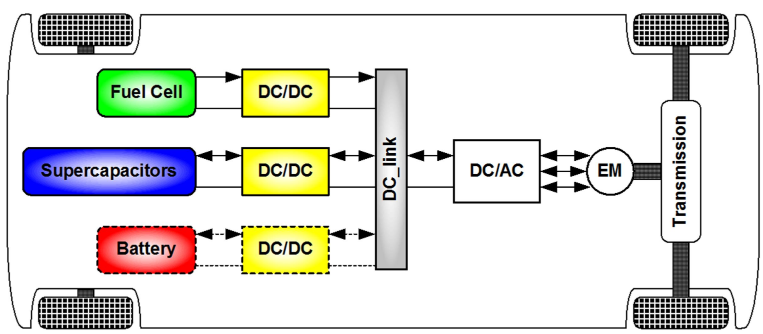


Figure 11: Outline diagram of an Electric Car

Table 2.1 - Drive cycle statistics

Parameters	Acceleration	Battery useable	Energy consumption	Top Speed	Range	Weight
Maximum Value	22.40	200	281	322	750	6500
Minimum Value	2.10	16.7	104	123	95	100
Average Value	2.10	65.6	194.22	177.52	338.98	822.34

The pressure requirements, Fp, of an electric powered automobile have fourfold as follows:

(1) Rolling resistance,

(2) Dynamic drag coefficient factor of pressure,

(3) Force because of Inertia, and

(4) Gravitational Force strength,

The strength expression at a automobile speed, u may be written as follows:

$$P_p = F_p\, u \qquad (2\text{-i})$$

Frr and dynamic drag factor of force, Fad will upload collectively to make the entire drag. For cruising, At a consistent pace without a floor gradient, drag is the most effective used for force requirement. When accelerating, the force of acceleration, Fac have to additionally be calculated to provide the whole force requirement.

$$F_p = F_g + F_{rr} + F_{ad} + F_{ac} \qquad (2\text{-ii})$$

Fg is proportional to mass of the vehicle, m, the speed v, and the perspective of incline, θ.

$$F_g = m\, g\, sin\theta \qquad (2\text{-iii})$$

Rolling resistance is an end result of deformation with inside the wheels and/or street surface, and it's miles given by

$$F_{rr} = C_r\ m\ g \qquad (2\text{- IV})$$

Finally, the force of acceleration is derived from the Newton's second law,

$$F_{ac} = m\ a \qquad (2\text{-vi})$$

Suppose an automobile is shifting internally a hurried city, Fac is intermittently a whole lot better than drag and reasons Fp to differ widely. Fac becomes poor for the duration of the technique of deceleration. As an automobile decelerates, its kinetic power gets reduced, and the distinction in kinetic power on the preliminary and very last velocities.

2.0.1 .Coefficient of rolling resistance (Cr)

Rolling resistance that's every so often referred to as rolling friction or rolling drag is the pressure resisting the movement while a frame (consisting of a ball, tire, or wheel) rolls on a surface. It is specially brought on because of non-elastic effects; that we are able to say that now no longer all of the power wanted for deformation (or movement) of the wheel, roadbed, etc., is recovered while the strain implemented at the frame is removed.

Cr	Surface
0.001-0.0025	Steel wheels on steel rails
0.0015-0.0025	Bicycle tires
0.006-0.01	Truck tire on asphalt
0.01-0.015	Ordinary car tires on concrete
0.03	Car tires on tar or asplate
0.2-0.4	Car tire on loose sand

Table 3: Coefficient of rolling resistance for various surfaces

Parameters	Mean rolling resistance coefficient	SD rolling resistance coefficient	Coefficient of Variation [%]
Surfacing			
Bituminous	0.002	0.001	29%
Grass	0.007	0.002	23%
Gravel	0.006	0.002	33%
Sand	0.030	0.006	18%
Tyre inflation pressure			
180kPa	0.012	0.011	91%
250kPa	0.012	0.011	94%
500kPa	0.011	0.012	114%
Cyclist mass			
70kg	0.011	0.012	107%
80kg	0.012	0.011	98%
90kg	0.012	0.011	93%
Wheel diameter			
26in.	0.013	0.013	100%
29in.	0.010	0.009	93%
Suspension type			
Hardtail	0.011	0.012	103%
Full suspension	0.012	0.011	95%

Table 4: Mean coefficient of rolling coefficient and coefficient of variation (%)

2.0.2 Drag coefficient (Cd)

The drag coefficient is largely a dimensionless amount this is used to quantify the drag or resistance of an object in a fluid environment, which include air or water. The drag coefficient is usually related to a selected floor area.

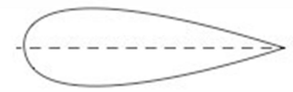
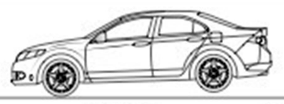
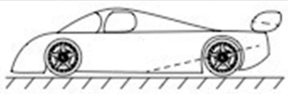
			C_L	C_D
1	Low drag body of revolution		0	0.04
2	Low drag vehicle near the ground		0.18	0.15
3	Generic automobile		0.28	0.35
4	Prototype race car		–3.00	0.75

Figure 13: Different values of C_L and C_D for different types of cars

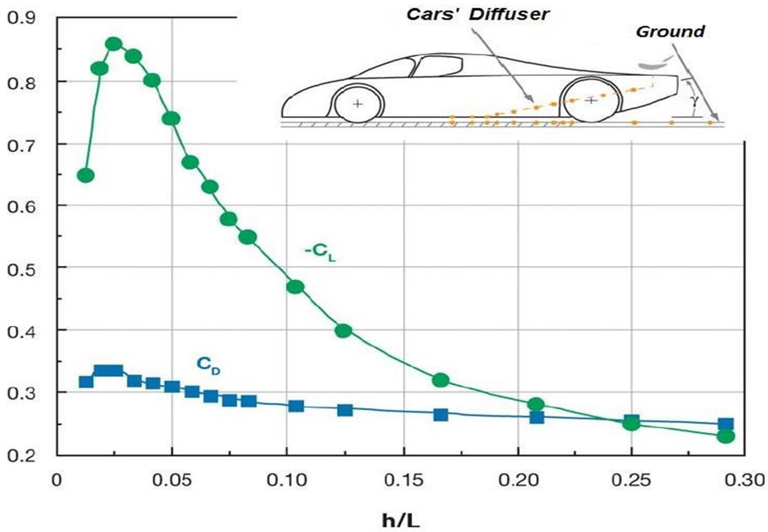


Figure 14: Variation of C_L and C_D versus h/L

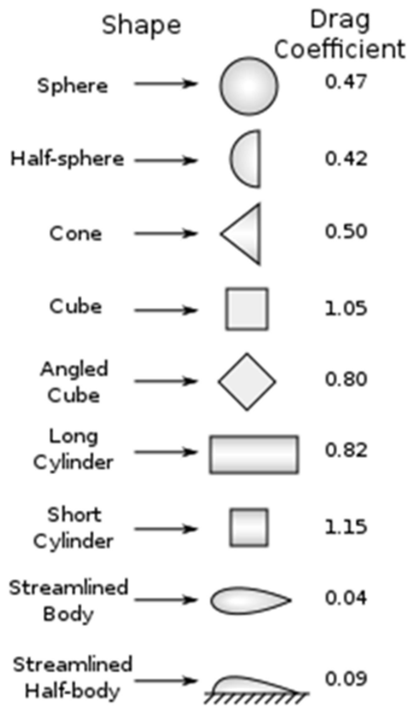


Figure 14(i) Measured Drag Coefficient of Surfaces

Thus, the recovered strength from every prevent from motorway velocity can increase the variety by as much as 1.5%. An electric-powered automobile additionally calls for energy to function outside and indoors lighting, air con or heating systems, driving force instrumentation, etc. for correct functioning.

2.0.3 BLOCK DIAGRAM OF THE PROJECT

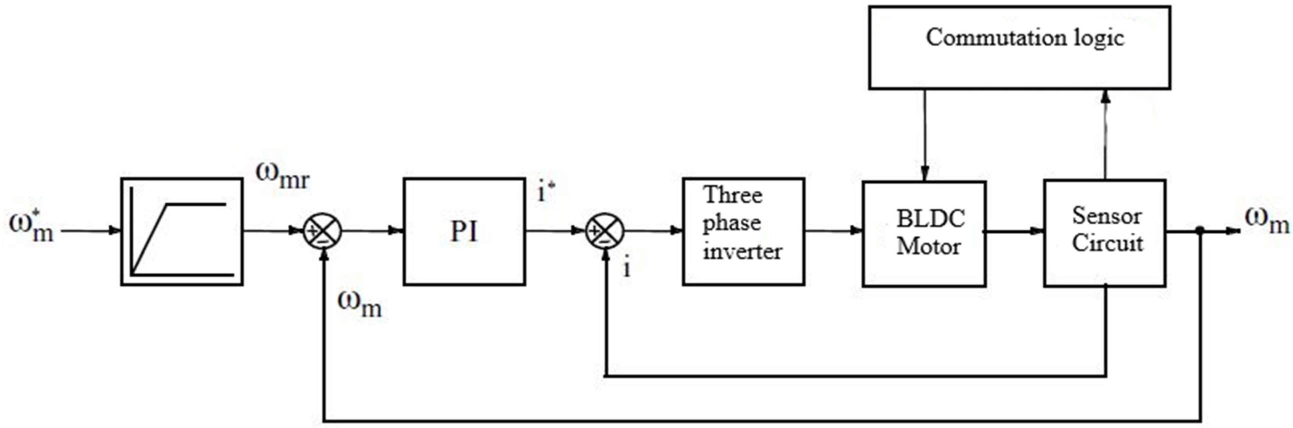


Figure 15: Block diagram of the project

2.1 Electric Automobile Converters and Motors

This chapter describes the prime technologies used in designing an electric automobile

2.1.1 Framework of Transmission and Running Gear

In many configurations of an electric powered automobile there exist a going for walks gear, the maximum generally front-wheel force. Rear-wheel, 4 wheels, and all-wheel force are different ideal configurations analyzed at the manufacturing of strength in vehicles. During braking, automobile weight receives shifted to the front. To keep away from locking the rear wheels, typically braking torque needs to come from the front wheels.

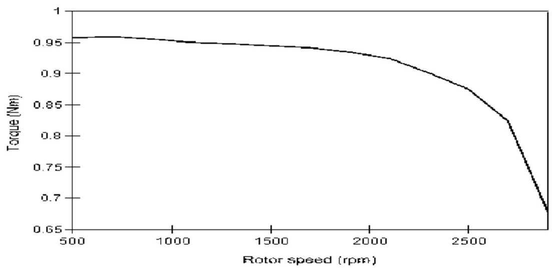


Figure 16: Torque- Rotor speed curve of Brushless DC Motor

2.1.2 Electric Automobile Motors (Brushless DC Motor)

Nowadays there exist a extensive type of electric-powered automobiles and the most effective one used is a commutated DC motor or a brushless DC motor. The BLDC automobiles have excessive torque to weight ratio, higher performance generating extra torque in line with watt, higher reliability, and decreased noise, massive lifetime with the aid of using removing brush and commutator erosion, elimination of ionizing sparks from the commutator.

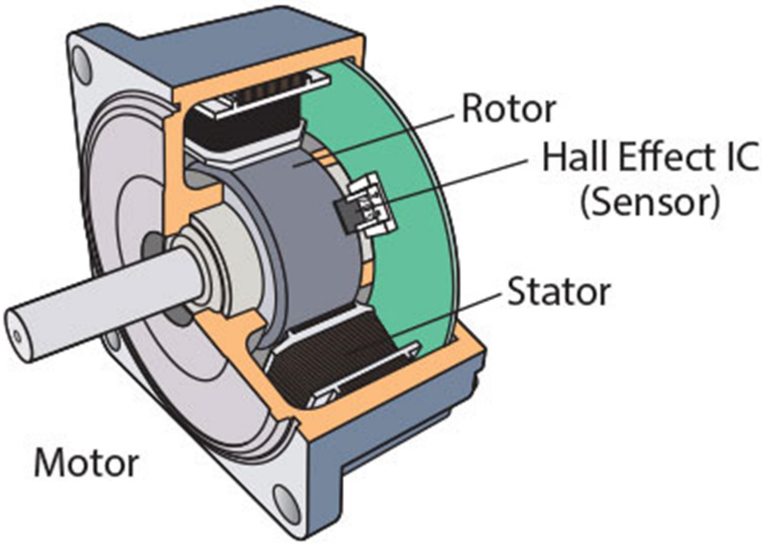


Figure 17: Brushless DC Motor Structure

A BLDC Motor has no winding at the rotor, the rotor winding isn't always subjected to centrifugal forces, and due to the fact the windings are supported with the aid of using the inner housing, the windings may be cooled through conduction, requiring no airflow in the motor for cooling. The BLDC motor has excessive torque and energy in a small, lightweight package. It includes a digital servo device that replaces the mechanical commutation contacts, which detects the attitude of the rotor, and controls semiconductor switches which include transistors that transfer the contemporary via the windings, both through reversing the route of the modern or, in a number of the automobiles turning it off, at the right attitude so the electromagnets create torque is evolved in a single path. A BLDC motor reduces the troubles related to connecting contemporary to the transferring armature. A digital controller replaces the commutator meeting of the brushed DC motor, which always switches the segment for motion of the motor.

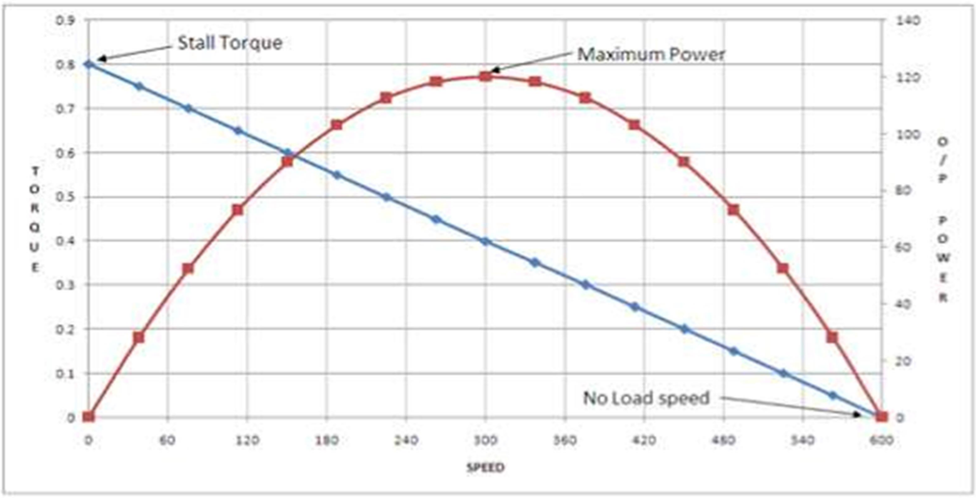


Figure 5: Speed-Torque-Power curve

Figure 2A - Motor torque and power vs. shaft speed

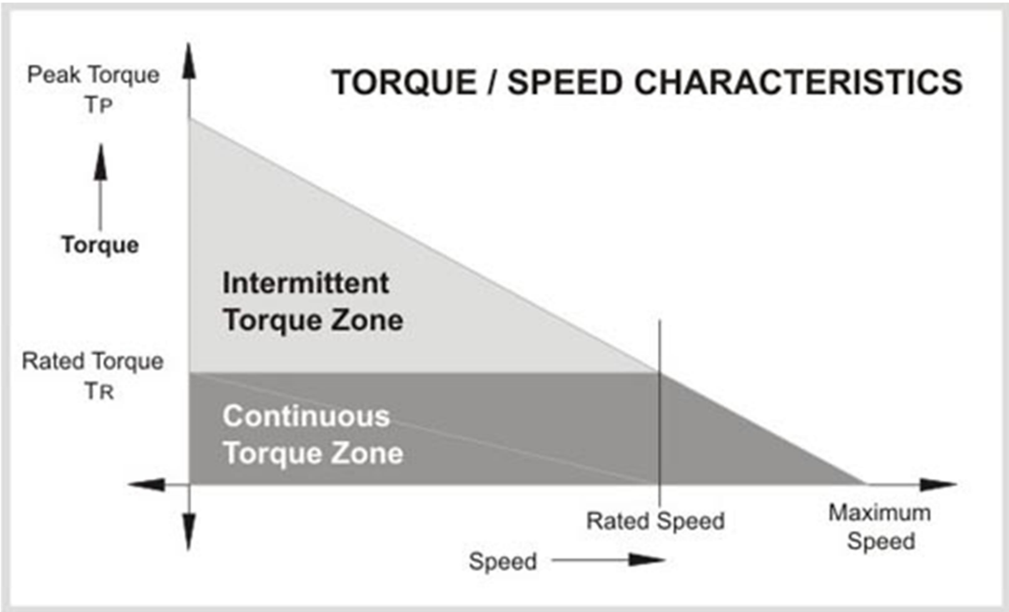


Figure 2.B. Brushless DC Motor Torque/speed characteristics

2.1.3 Electric Automobile Inverters section

The Brushless DC Motors operates with a three-segment delivery of alternating current (AC), and all of the viable assets of electrical strength are furnished with direct current (DC). The method of changing DC to a few stages AC is with a switched three-segment inverter. A linear inverter varies output voltage among zero and enters voltage by including a further adjustable resistor in collection with the output. This approach will offer a big strength strength wastage as current should skip via the delivered resistor. A switched inverter makes use of a fixed of switches to unexpectedly transfer the input voltage on and off, just like dimming a mild via way of means of rapidly switching it on and off.

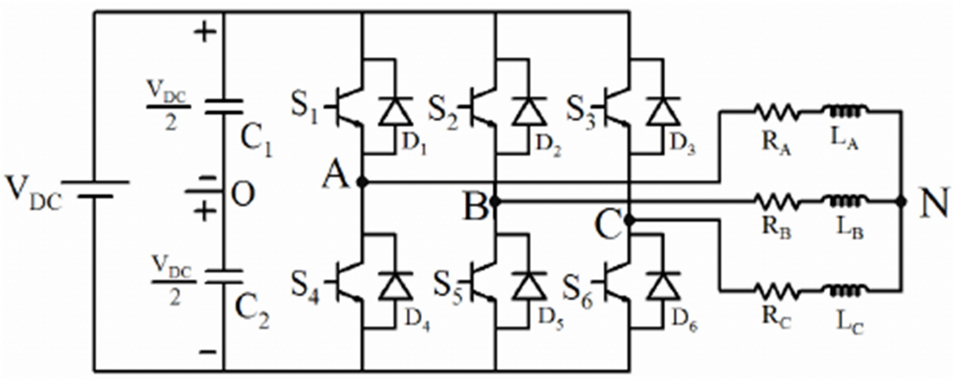


Figure 18: Inverter Circuit

A switched 3-section pulse inverter makes use of six switches to provide 3 sinusoidal outputs. Supply frequency may be modified through growing or reducing the frequency of switching Inverters and automobiles may be simulated; In order to apprehend power losses concerned with inside the inverters simulated, their fundamental empirical family members in phrases of switching frequency, parasitic resistances, and switching losses.

2.1.4 Electric Automobile DC/DC Converters section

It is frequently essential to deliver power at a selected voltage at the same time as storing it at any other place. Additionally, as we realize that the batteries and capacitors each have various voltage stages at some point of their variety of charges, DC-DC conversion is regularly appropriate.

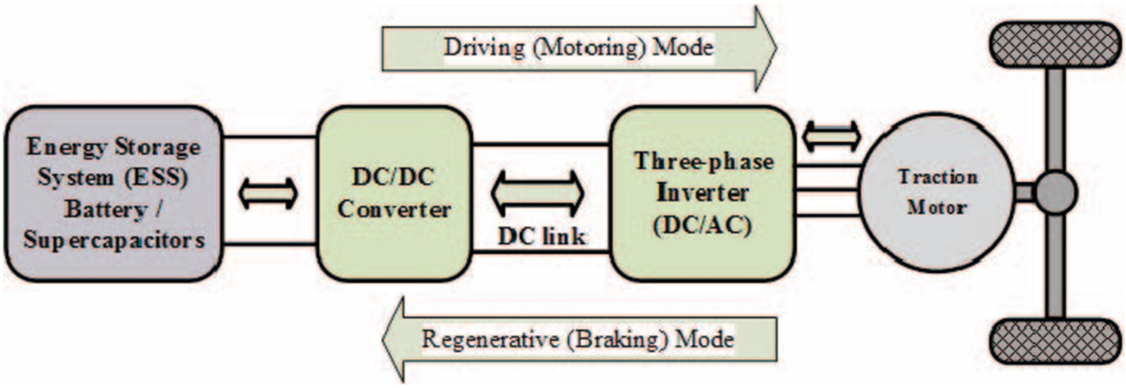


Fig. 1 Electric drive system for a battery powered EV

In an electric powered transmission, voltage transformation is carried out through a transformer, electromagnetically. This technique cannot be used at once in electric-powered transmissions because right here a DC voltage is provided rather than AC as utilized in transformers. This sort of conversion utilized in electric-powered motors is the switched greenback converter. A greenback Converter can remodel the DC deliver voltage both upwards and downwards relying on the transfer responsibility ratio, and it additionally serves as electric isolation among the supply and the load.

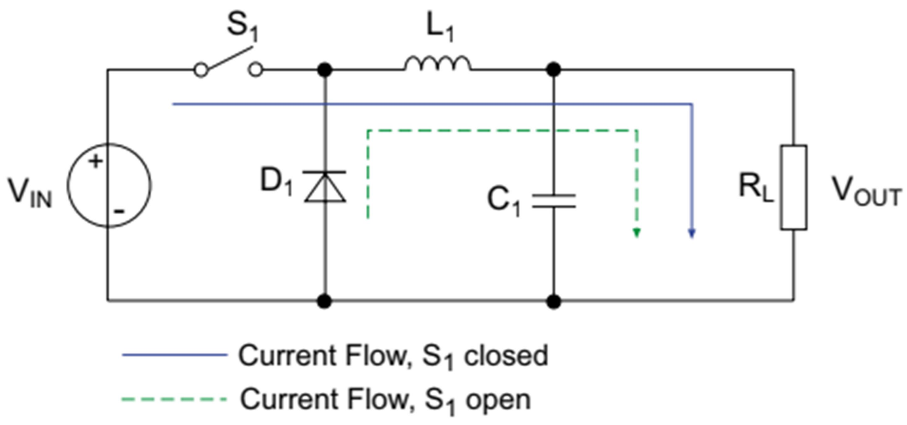


Figure 19: Framework of a Buck Converter

2.2 Electric Vehicle Battery/ super capacitor storage

This chapter covers electricity storing and providing additives in an electric-powered vehicle. Here is the improvement of the project. The Batteries and capacitors are used the chapter finally ends up with a evaluation of storage techniques, and one-of-a-kind instances of hybrid electricity storage.

2.2.1 Batteries- Lithium Ion, Lead Acid, NiCad

The battery is one of the strategies of storing electric electricity. With the usage of batteries, a different one-of-a-kind technology has additionally developed, particularly secondary or rechargeable cells are one of the satisfactory options for to be had power density.

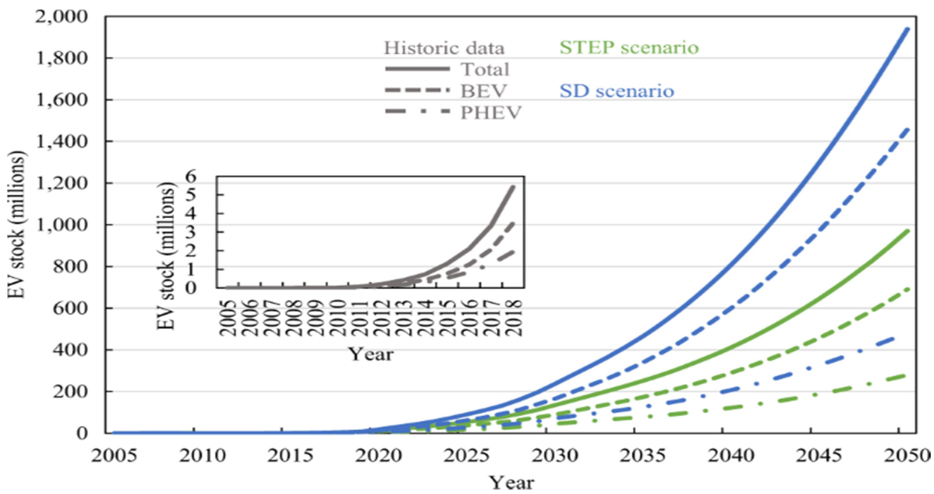


Figure 20: Lithium Ion Batteries

I. Lithium – ion Batteries

A lithium-ion battery is a chargeable battery. In it, one electrode fabric of intercalated lithium compound is used. The battery includes an electrolyte and the 2 electrodes are the constituent additives. Ions of lithium flow from the negative electrode to the positive electrode at some point of discharge and returned from the positive electrode to the negative electrode while charging. The battery era has made it the favourite energy supply for the designing of electrical and hybrid electric-powered vehicles.

Applications:

1. Electronic gadgets,
2. Tele-communication,
3. Aerospace,
4. Industrial applications

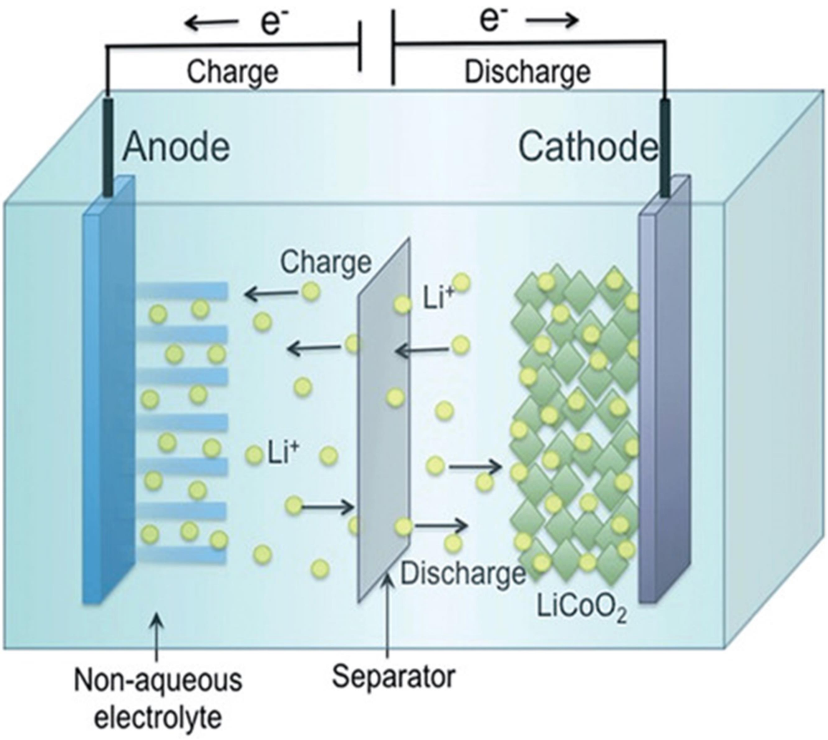


Figure 2 B (i): Lithium Ion Battery diagram

The primary mode of operation is equal for the entire sort of batteries; a cathode and an anode are separated with the aid of using an electrolyte of lead or Nickel-cadmium or a gel as in Nickel-metallic hydride or Lithium-ion. During discharging, positive ions move from the anode, then skip via the electrolyte and go in the direction of the cathode, and the reverse condition occurs for the duration of charging.

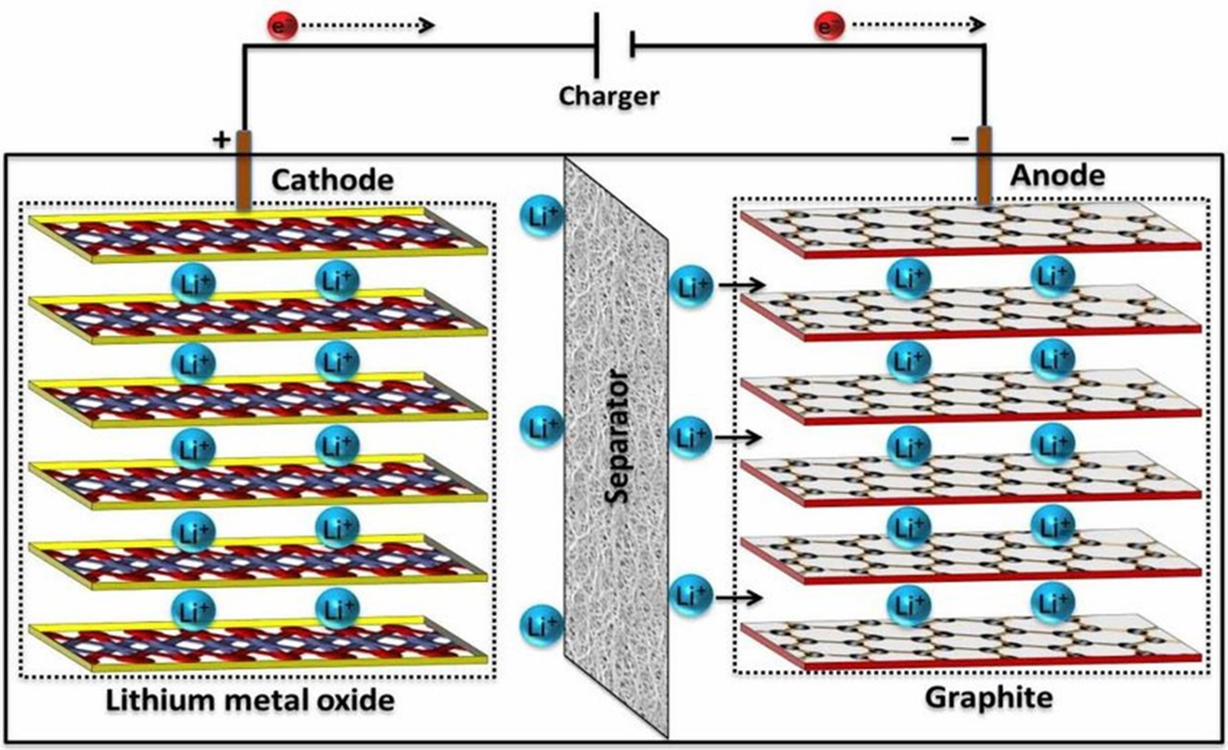


Figure 2 B (ii): Lithium Ion Battery Internal structure

$$E_{batt} = V_{avg}C \qquad \text{(2-vii)}$$

A battery's state of charge (SoC) is the degree of the to be had power in the battery. Batteries are generally designed to function in the set situation SoC, additionally referred to as the SoC swing. The SoC with the bottom energy ultimate in the battery is known as the depth of discharge.

Specifications	Lead Acid	NiCd	NiMH	Li-ion Cobalt	 Manganese	 Phosphate
Specific energy density (Wh/kg)	30–50	45–80	60–120	150–190	100–135	90–120
Internal resistance[1] (mΩ)	<100 12V pack	100–200 6V pack	200–300 6V pack	150–300 7.2V	25–75[2] per cell	25–50[2] per cell
Cycle life[4] (80% discharge)	200–300	1000[3]	300–500[3]	500–1,000	500–1,000	1,000–2,000
Fast-charge time	8–16h	1h typical	2–4h	2–4h	1h or less	1h or less
Overcharge tolerance	High	Moderate	Low	Low. Cannot tolerate trickle charge		
Self-discharge/ month (room temp)	5%	20%[5]	30%[5]	<10%[6]		
Cell voltage (nominal)	2V	1.2V[7]	1.2V[7]	3.6V[8]	3.8V[8]	3.3V
Charge cutoff voltage (V/cell)	2.40 Float 2.25	Full charge detection by voltage signature		4.20		3.60
Discharge cutoff voltage (V/cell, 1C)	1.75	1.00		2.50 – 3.00		2.80
Peak load current Best result	5C[9] 0.2C	20C 1C	5C 0.5C	>3C <1C	>30C <10C	>30C <10C
Charge temperature	–20 to 50°C	0 to 45°C		0 to 45°C[10]		
Discharge temperature	–20 to 50°C	–20 to 65°C		–20 to 60°C		
Maintenance requirement	3–6 months[11] (topping chg.)	30–60 days (discharge)	60–90 days (discharge)	Not required		
Safety requirements	Thermally stable	Thermally stable, fuse protection common		Protection circuit mandatory[12]		
In use since	Late 1800s	1950	1990	1991	1996	1999

Table 5: Specifications of different types of Batteries

Cadmium is an environmentally adverse material to extract, process, and dispose of, and hence Nickel-cadmium, or a gel as in Nickel-steel hydride or Lithium-ion.

Battery Technology Comparison

Specifications	Lead-Acid	NiCd	NiMH	Li-Ion: Cobalt	Li-Ion: Manganese	Li-Ion: Phosphate
Specific energy density (Wh/kg)	30 – 50	45 – 80	60 – 120	150 – 190	100 – 135	90 – 120
Internal resistance (mΩ/V)	<8.3	17 – 33	33 – 50	21 – 42	6.6 – 20	7.6 – 15.0
Cycle life (80% discharge)	200 – 300	1,000	300 – 500	500 – 1,000	500 – 1,000	1,000 – 2,000
Fast-charge time (hrs.)	8 – 16	1 typical	2 – 4	2 – 4	1 or less	1 or less
Overcharge tolerance	High	Moderate	Low	Low	Low	Low
Self-discharge/month (room temp.)	5 – 15%	20%	30%	<5%	<5%	<5%
Cell voltage	2.0	1.2	1.2	3.6	3.8	3.3
Charge cutoff voltage (V/cell)	2.40 (2.25 float)	Full charge indicated by voltage signature	Full charge indicated by voltage signature	4.2	4.2	3.6
Discharge cutoff volts (V/cell, 1C*)	1.75	1	1	2.5 – 3.0	2.5 – 3.0	2.8
Peak load current**	5C	20C	5C	> 3C	> 30C	> 30C
Peak load current* (best result)	0.2C	1C	0.5C	<1C	< 10C	< 10C
Charge temperature	-20 – 50°C	0 – 45°C	0 – 45°C	0 – 45°C	0 – 45°C	0 – 45°C
Discharge temperature	-20 – 50°C	-20 – 65°C	-20 – 65°C	-20 – 60°C	-20 – 60°C	-20 – 60°C
Maintenance requirement	3 – 6 months (equalization)	30 – 60 days (discharge)	60 – 90 days (discharge)	None	None	None
Safety requirements	Thermally stable	Thermally stable, fuses common		Protection circuit mandatory		
Time durability				>10 years	>10 years	>10 years
In use since	1881	1950	1990	1991	1996	1999
Toxicity	High	High	Low	Low	Low	Low

Source: batteryuniversity.com. The table values are generic, specific batteries may differ.
*"C" refers to battery capacity, and this unit is used when specifying charge or discharge rates. For example: 0.5C for a 100 Ah battery = 50 A.
**Peak load current = maximum possible momentary discharge current, which could permanently damage a battery.

Table 6: Battery Technology Comparison

Lithium-ion batteries are having the best power and energy density at room temperature, and are consequently the most important consideration for current Electric vehicles. The lithium-ion batteries do have the downside of poor overall performance at low temperatures (< -10 [°C]) due to the fact their inner resistance will increases.

Table 1 Main battery types comparison

Parameter / Battery Type	Acid-Lead	NiCd	NiMH	Li	UltraCapacitor
Voltage / cell (nom.)	2	1.2	1.2	3.6	2.7
Density of energy	High	Low	Medium	High	High
Fast charge / discharge	No	Yes	Yes	Yes	Yes
Operating temperature	-20÷40 °C	-40÷60 °C	-20÷60 °C	-30÷60 °C	-40÷65 °C
Internal resistance	Low	High	Medium	Low	Low
Memory	No	Yes	No	No	No
Lifetime (cycles)	1,000	>3,000	>3,000	>1,000	>200,000
Cost	Medium	Low	Medium	High	High

Table 7 - Battery cell comparison

2.2.2 Ultra capacitors

Any two conducting plates of the capacitor separated by a dielectric gap have a capacitance, given by

$$C = \varepsilon_r \frac{A}{4\pi d} \qquad \text{(2-viii)}$$

Where C is the capacitance in Farads, ε_r is the relative static permittivity, A is the overlapping area of the conductors and d is the gap between them.

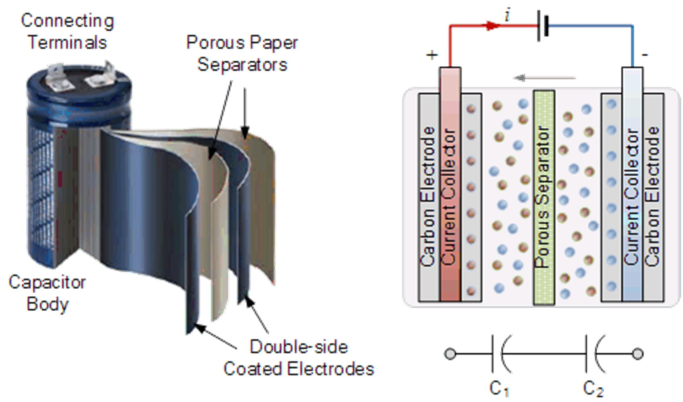


Figure 21: Construction of Ultra-Capacitors

The energy stored between the conducting plates of the capacitor isproportional to the square of the voltage:

$$E = \frac{CV^2}{2} \qquad \text{(2-i)}$$

Capacitors have a dielectric layer among their plates to be able to grow the capacitance; this dielectric layer has an electric-powered subject energy limit beyond which it's going to fail. The dielectric restricts outcomes in most voltage to which the capacitor can be charged.

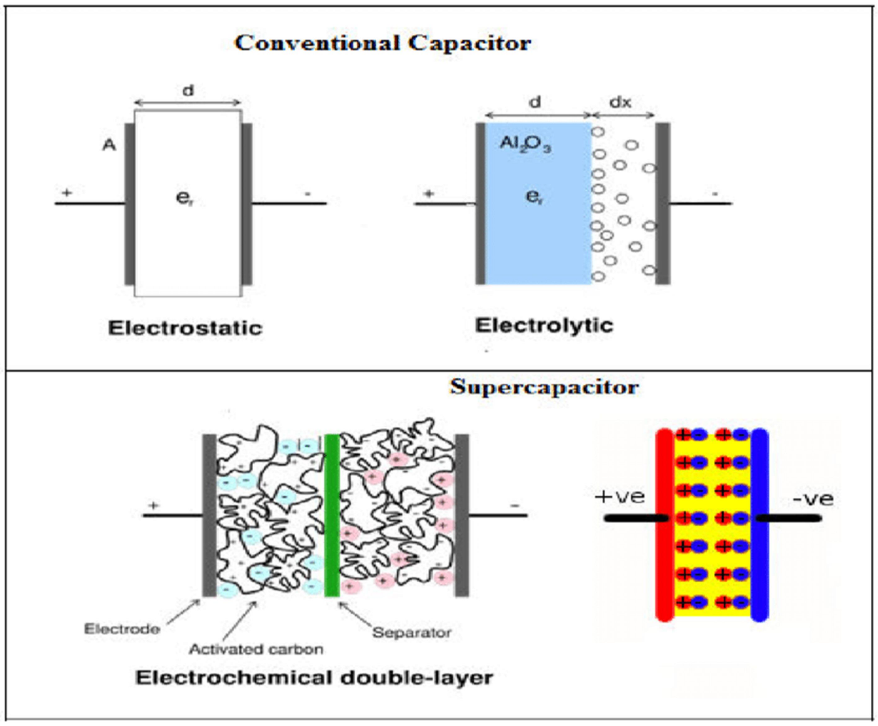


Figure 22: Capacitor and ultra-capacitor schematic

The output energy from capacitors is bounded through thermal parameters. A small equal collection resistance (ESR) of the tool outcomes in the warmth technology that the output modern raises sharply. Ultra-capacitors have numerous benefits in electric-powered cars; they may be very robust, have right mechanical vibration dealing with capabilities, and withstanding cold temperatures. Ultra-capacitors can be charged and discharged extra than 400,000 times, and final longer than 15 years. While those capacitors are able to very excessive Power delivery, ultra-capacitors have very low power density. This makes them appropriate most effective for automobiles with a very quick range.

2.2.3 Comparison of Storage Technologies

In this subject matter numerous energy storage strategies are as compared and analyzed. A descriptive evaluation of power storage strategies is mentioned as follows:

Classification of Energy Storage Technologies			
Mechanical storage system	Electro-Chemical Energy Storage (ECES)	Chemical Energy Storage	Thermal Energy Storage
Pumped Hydro Storage (PHS)	Batteries Storage (Lead acid, Li-ion, NiCd, NaS and ZEBRA)	Hydrogen Storage H_2 storage/ Fuel Cells (PAFC, AFC, PEMFC, MCFC, SOFC)	Sensible Heat Storage (Hot and cold water storage, aquifer storage and molten salt sotage)
CAES (D-CAES and A-CAES)	Flow Batteries Redox flow/Hybrid flow		
	Capacitor Storage	Biofuels	Latent Heat Storage (PCM materials)
Flywheel Storage (Low, intermediate and high speed)	Electromagnetic Energy Storage (SMES)		

Table 8 - Comparison of storage and conversion technologies

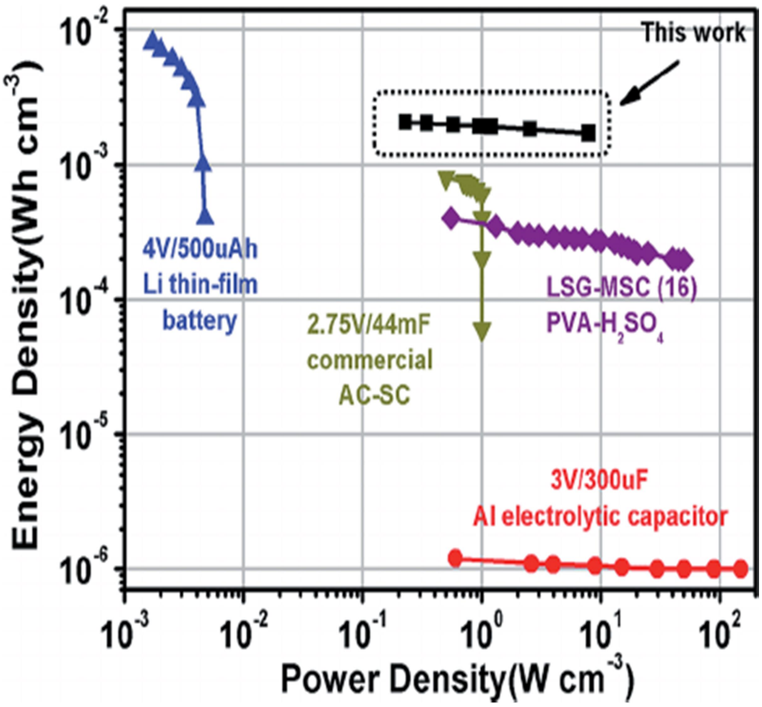


Figure 23 - Energy density vs. power density, volumetric

1. Batteries and ultra-capacitors may be recharged with power generated from the charger supply Safety concerns also are gift however much less extreme than observed with inside the case of hydrocarbons. Batteries and ultra-capacitors each have a constrained electricity output and power density.

2. Ultra-capacitors deliver the favored electricity output; that may force an electric-powered automobile as much as few kilometers. Batteries are afflicted by a much less extreme deficit and now have a drawback in energy and energy density. Both technologies have their very own uniqueness among energy and power.

2.2.3 Electric Automobile Hybrid Energy Storage system

The benefits and drawbacks of the power storage system are mentioned here. In order to understand the advantages a set of a couple of electric powered storage tools, specifically, a strength offering tool is paired with a power storage device, such that power and the energy ability are elevated to be able to meet the height energy and power demands.

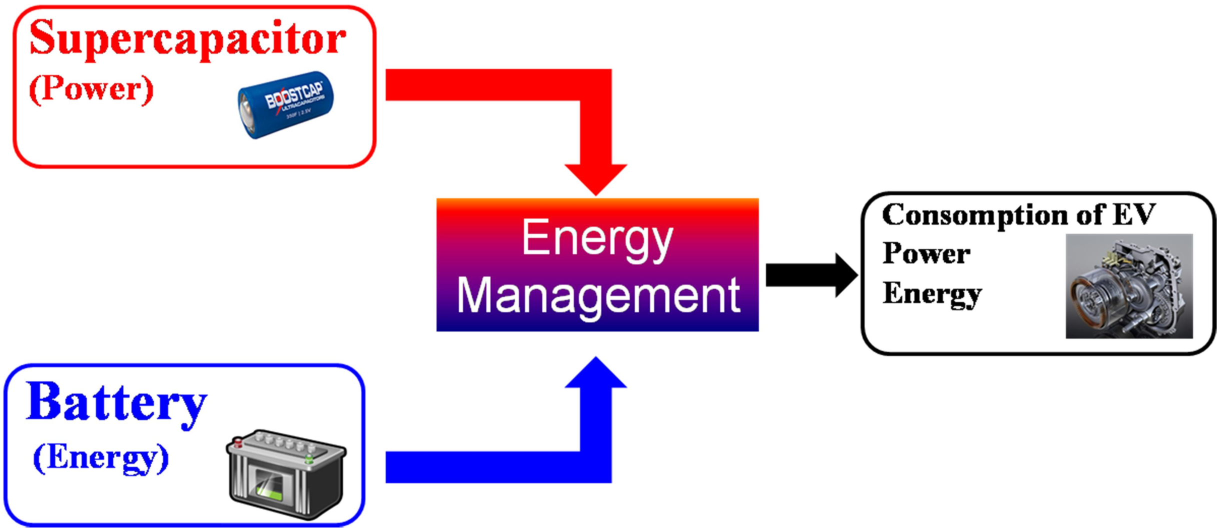


Figure 24: Consumption of EV power energy

Hybrid storage systems are more versatile, growth factor provider lives, efficiency, decreasing value, and mass relative to storage systems. With the addition of a financial institution of ultra-capacitors to a % of batteries, the battery % can be decided on for power density, and the ultra-capacitor financial institution for energy delivery, and so power potential increases. The capacitors have the belongings of common contemporary reversals; they also can be hired to take in regenerative braking energy. Its outcomes in longer battery carrier existence and improved powerful capability.

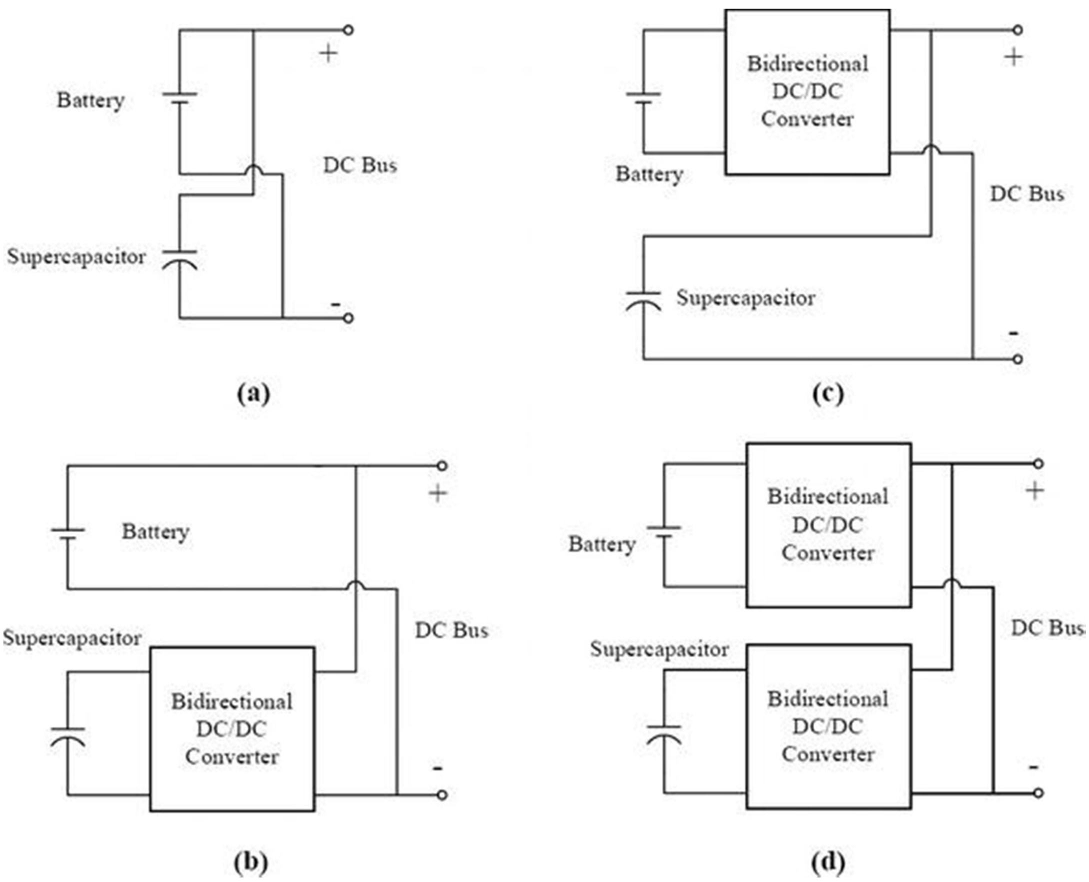


Figure 25: Bidirectional DC-DC Topologies

The power and energy gadgets i.e the battery and the ultra-capacitors, DC-DC conversion necessities change. Each device has its personal DC-DC converter, and every converter is attached both in parallel and in series. Alternatively, an unmarried or a dual-enter DC-DC converter is used to attract strength from special assets simultaneously.

Battery vs supercapacitor

Function	Supercapacitor	Lithium-ion (general)
Charge time	1–10 seconds	10–60 minutes
Cycle life	1 million or 30,000h	500 and higher
Cell voltage	2.3 to 2.75V	3.6 to 3.7V
Specific energy (Wh/kg)	5 (typical)	100–200
Specific power (W/kg)	Up to 10,000	1,000 to 3,000
Cost per Wh	$20(typical)	$2 (typical)
Service life (in vehicle)	10 to 15 years	5 to 10 years
Charge temperature	–40 to 65°C (–40 to 149°F)	0 to 45°C (32° to 113°F)
Discharge temperature	–40 to 65°C (–40 to 149°F)	–20 to 60°C (–4 to 140°F)

Figure 26- Battery Vs. super-capacitors

2.2.4 Hybrid Control and Power Management

An energy storage system using multiple sources allocates demand across the sources. Power requirements during acceleration of more than three times the average power output of the whole drive cycle. If the demand current is greater than the maximum battery current then the battery power is equal to at the battery maximum and the capacitor power is calculated by subtracting the battery maximum from the total demand. The DC-DC converter is a bidirectional, integrated buck-boost, buck-boost converter of similar topology. A programmed DC-DC converter controller is used to feed the power.

2.2.4 Hybrid Energy Storage Design Strategy

An effective hybrid energy storage system (HESS) achieve the following combination of

(1) It should have an increased vehicle performance by supplying more power,

(2) It helps to extend the service life of storage system,

(3) It helps to improve the cold-weather performance, and

(4) It reduces the volume and weight

The high capacity lithium-ion batteries package with Ultra-high power batteries will give high power capability. On the vehicle kinetic energy, the entire design of the hybrid system model is based. The total amount of kinetic energy at a high power peak is equal to the kinetic energy at the maximum expected speed of an electric vehicle.

PERFORMANCE COMPARISON	BETWEEN SUPERCAPACITOR AND LI-ION	
Function	Supercapacitor	Lithium-ion (general)
Charge time	1–10 seconds	10–60 minutes
Cycle life	1 million or 30,000h	500 and higher
Cell voltage	2.3 to 2.75V	3.6 to 3.7V
Specific energy (Wh/kg)	5 (typical)	100–200
Specific power (W/kg)	Up to 10,000	1,000 to 3,000
Cost per Wh	$20 (typical)	$0.50-$1.00 (large system)
Service life (in vehicle)	10 to 15 years	5 to 10 years
Charge temperature	–40 to 65°C (–40 to 149°F)	0 to 45°C (32°to 113°F)
Discharge temperature	–40 to 65°C (–40 to 149°F)	–20 to 60°C (–4 to 140°F)

Source: Battery University

Table 10: Performance comparison between super capacitor and Li-ion

The foremost task is to balance enough strength storage for good enough electric-only range, coupled with enough strength functionality for acceleration (and deceleration) performance. It includes an Indian power cycle model, calculation of the speed, acceleration, drag force, torque, and advanced energy. The simulation model of a motor and its transmission system. The designing of an inverter and the bidirectional DC-DC converter and the buck converter. Then designing the sensor and the control circuit for the energy management and hybrid energy storage system calculations.

CHAPTER 3 SIMULATION OF CIRCUIT COMPONENTS

3.0 Performance Analysis of TATA NEXON Electric Vehicle

Dimensions	Nexon EV
Length	3993mm
Width	1811mm
Height	1606mm
Drag Coefficient (Cd)	0.236
Frontal Area	965-1020
Force (Nm)	12.057
Wheel radius	20.32cm (40.64 diameter)
Maximum Torque (Nm) (Torque=F*r)	**245**
Maximum Power output (hp)	**129**
Battery (kwh)	30.2kwh
Range (km)	311km
Time taken to cover 100kph	**9.9 sec**
Charging time	**Approx. 1 hour**

1.1 Inputs parameters required

The input parameters required are the mass of the vehicle, the drag coefficient, the frontal area (m2), the rolling resistance coefficient, the wheel radius (m), the transmission ratio, and the motor ratio are the high input parameters.

3.2 Vehicle Components

3.2.1 Simulation of Indian Drive cycle and Drag force schematic

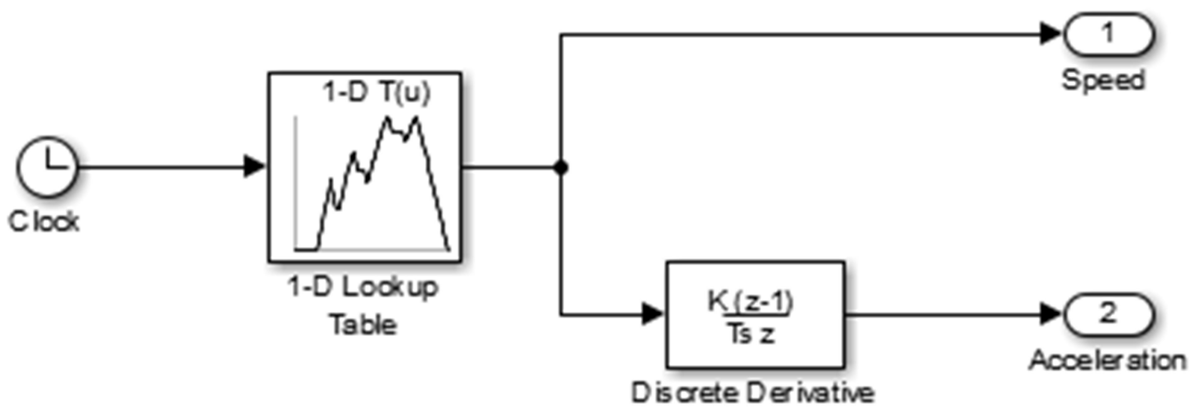


Figure 3.D – Indian Drive cycle input

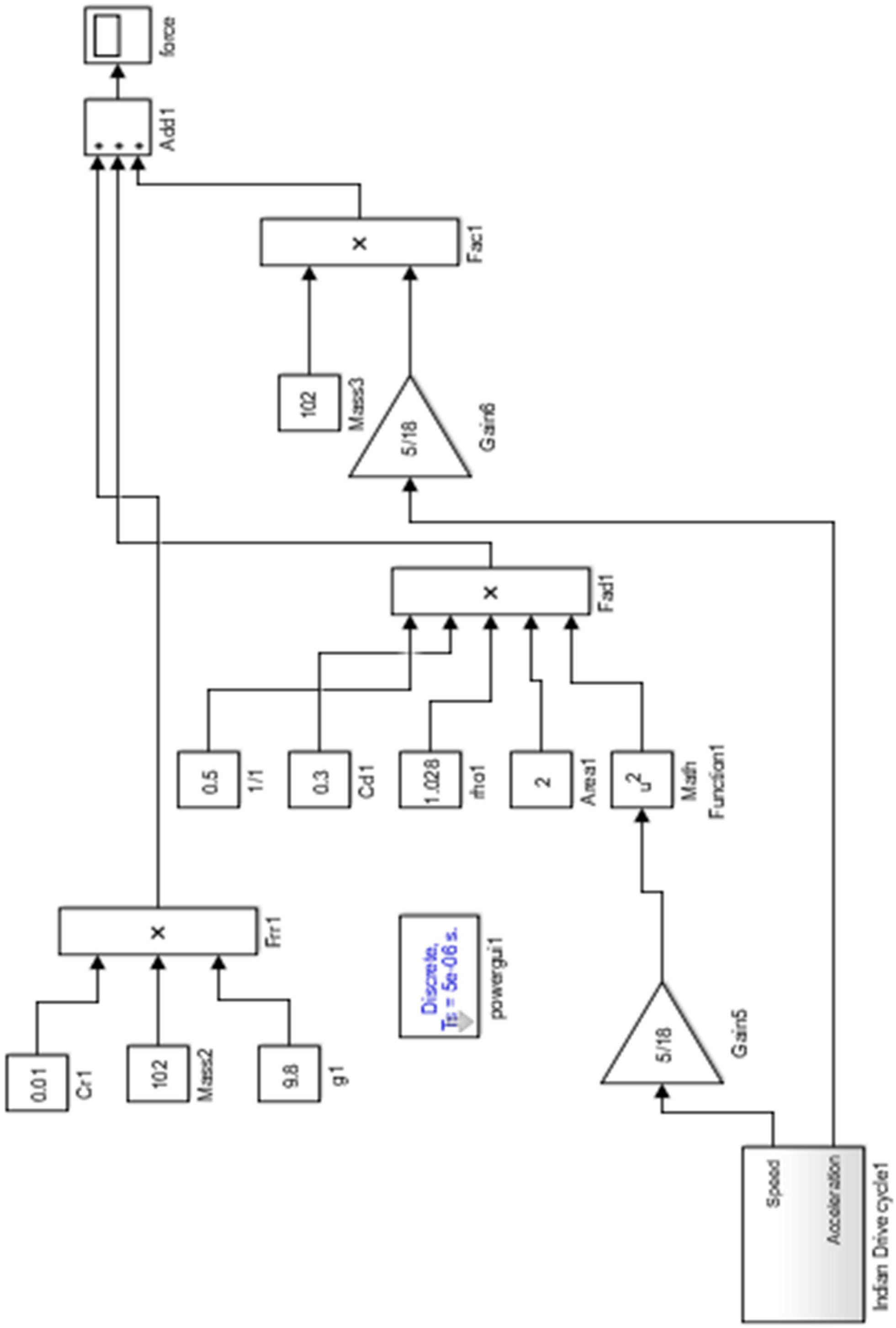


Figure 3.E - Drag force schematic

3.2.2 Simulation of Running power and Torque

The drag force, automobile speed, torque, acceleration, and cruising strength are determined. At a given acceleration, the entire mechanical strength evolved is obtained. The acceleration, torque, and power are calculated.

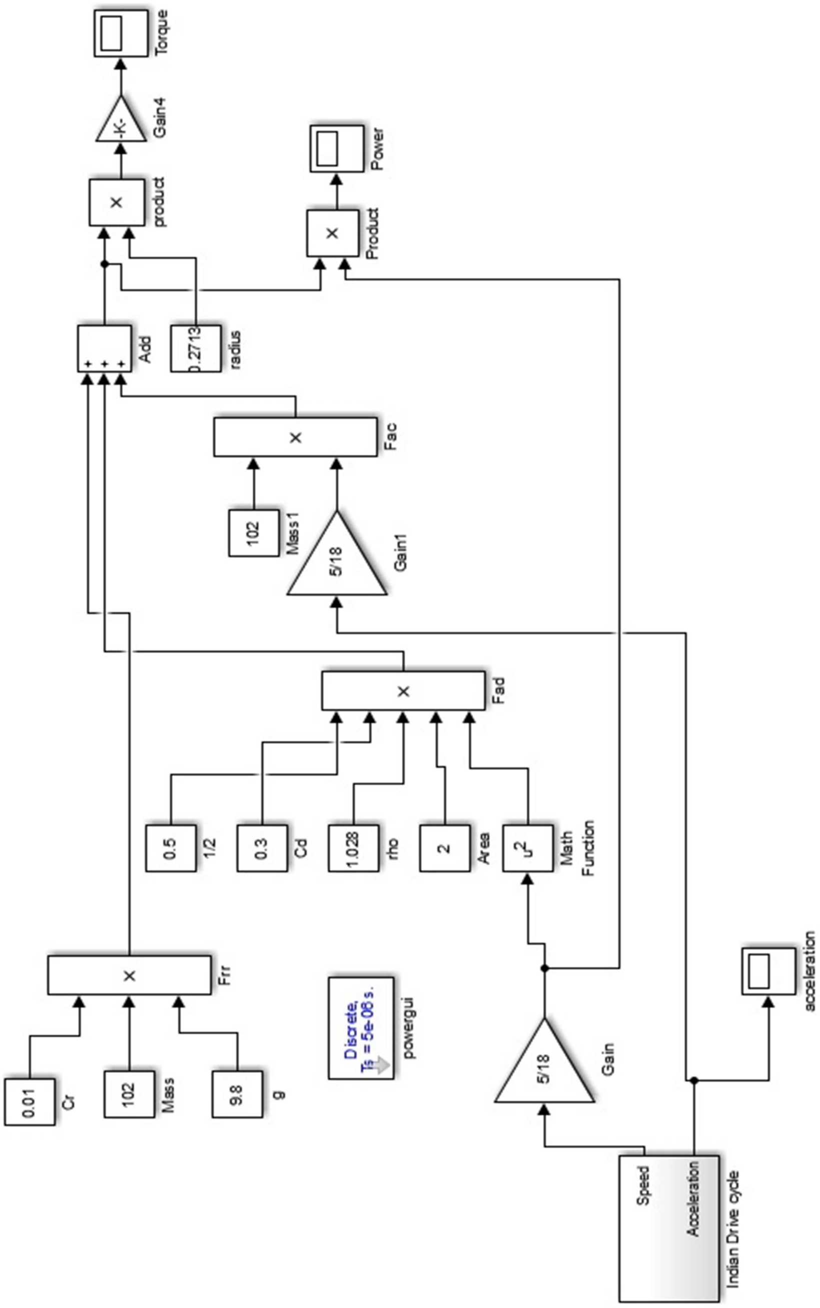


Figure 3.F - Torque and Power calculation simulation

3.2.3 Simulation of Brushless DC Motor

The torque requirements until the torque and power demand aren't met via way of means of an single motor. The allowances for periodic overloading and could cause an electric-powered automobile version to think about each vehicle modeled collectively and running as a single machine. An advantage of 0.95 was applied in order to get the desired output. This will deliver the most performance of the motor to higher alignment with actual automobiles. The torque call for a motor is decided with the aid of using wheel radius, transmission ratio, and the whole mechanical strength requirement. The fraction is used to enter electric strength this is required to provide the preferred mechanical output strength. The motor ratio is described because of the distinction in velocity of the motor and its entering electric frequency.

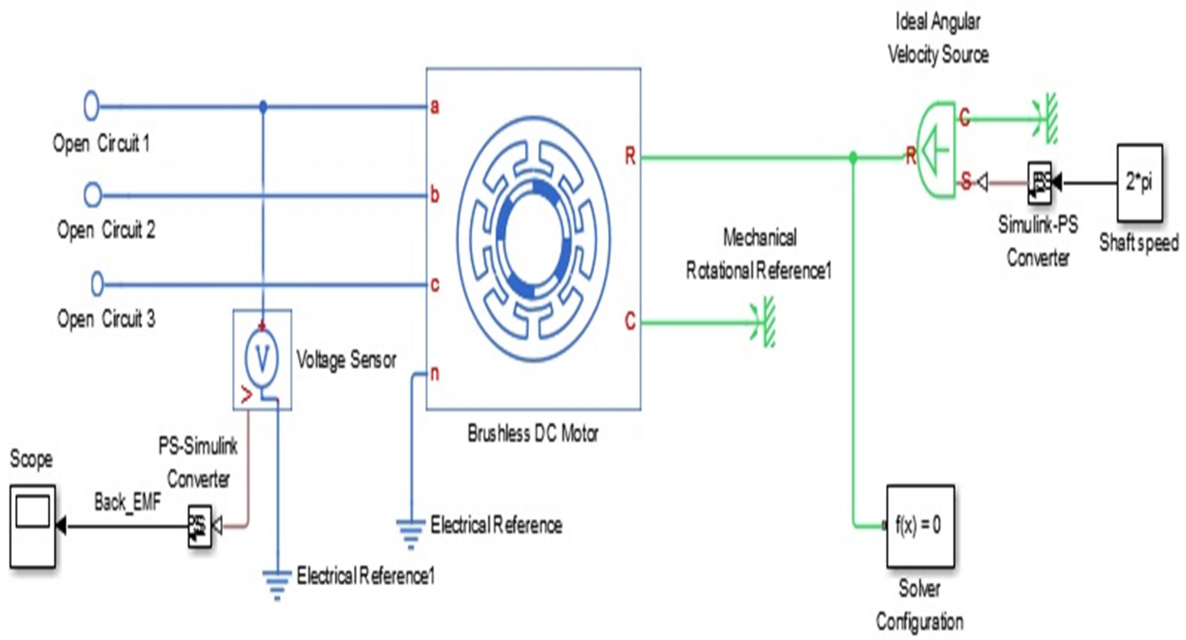


Figure 3.G – Brushless DC Motor schematic

3.3.4 Simulation of an Inverter and its components

The six power-electric switches which chop input DC to supply 3 levels AC will lose a few strengths to parasitic resistance and that they encompass the snubber circuits with each on-off cycle. The simulation of the inverter model is as follows:

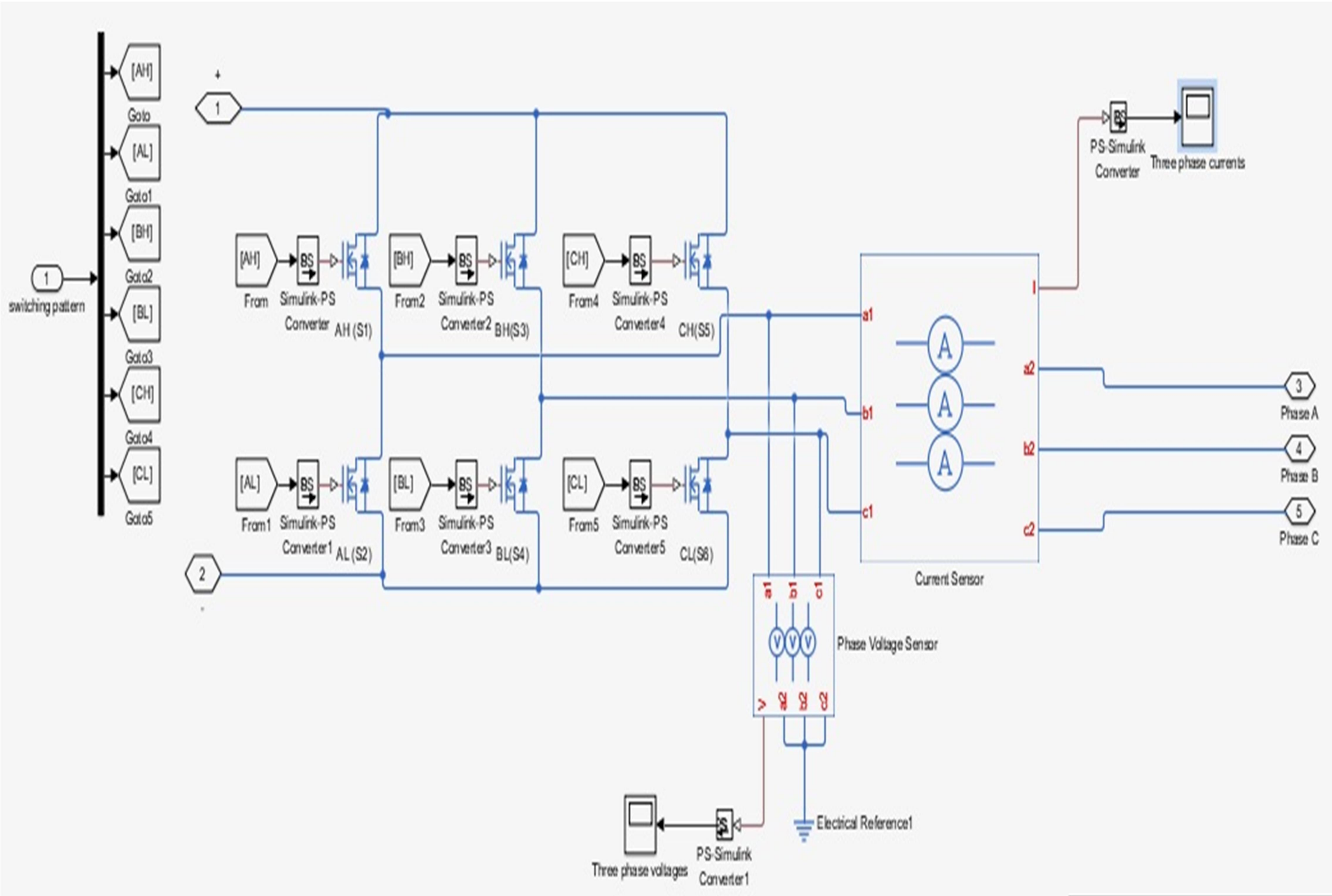


Figure 3.H – Three phase Inverter schematic

3.3.4 Simulation of Controller Circuit and sensor circuit

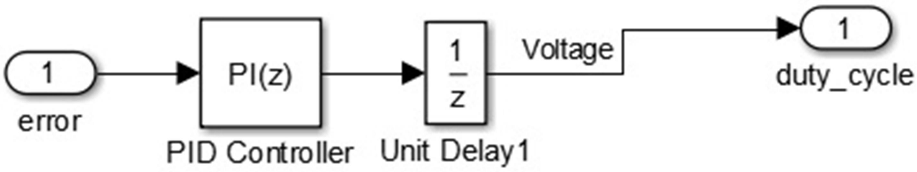


Figure 3.I – Controller circuit

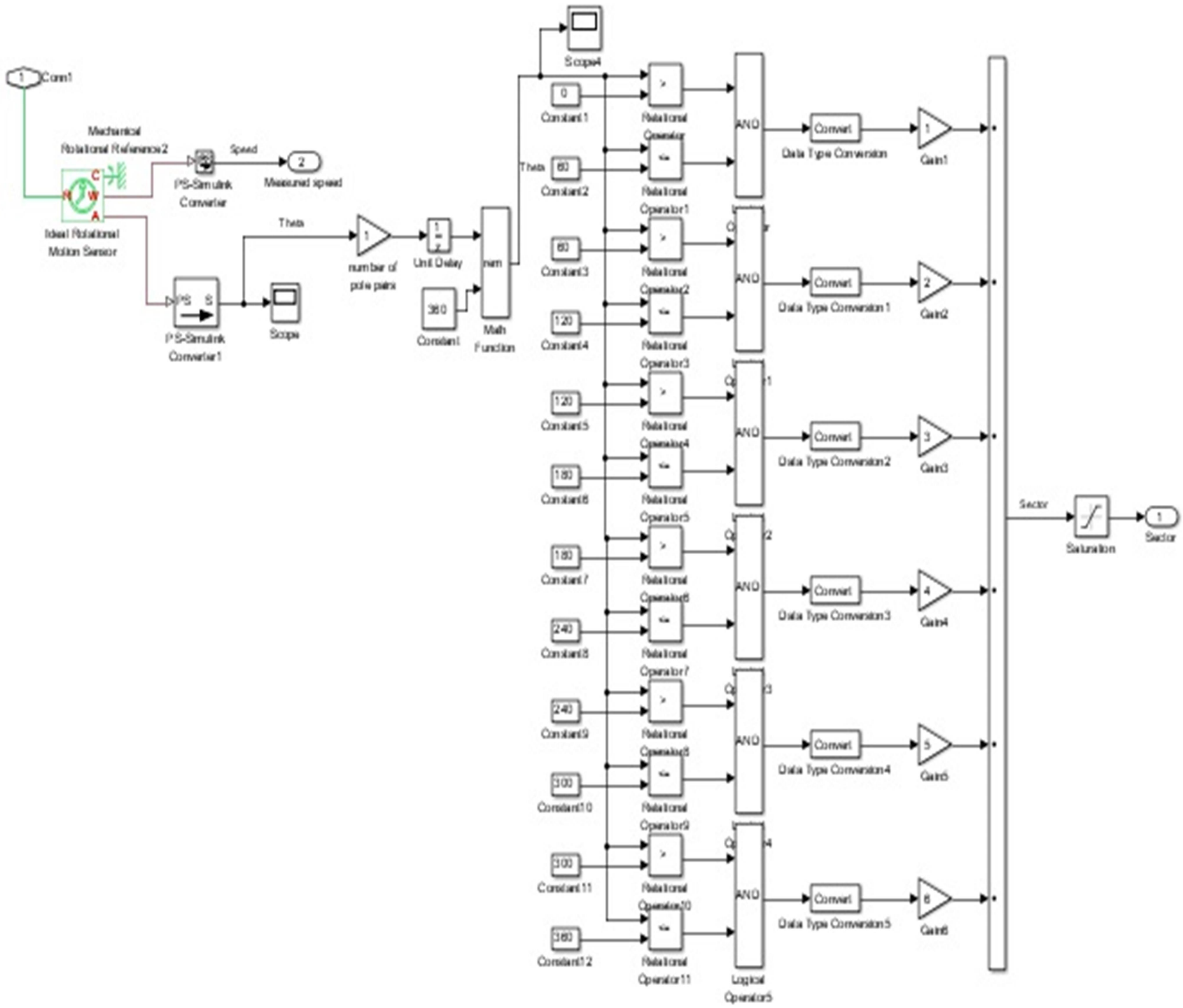


Figure 3.J – Sensor circuit

3.3.5 Simulation of commutation logic circuit

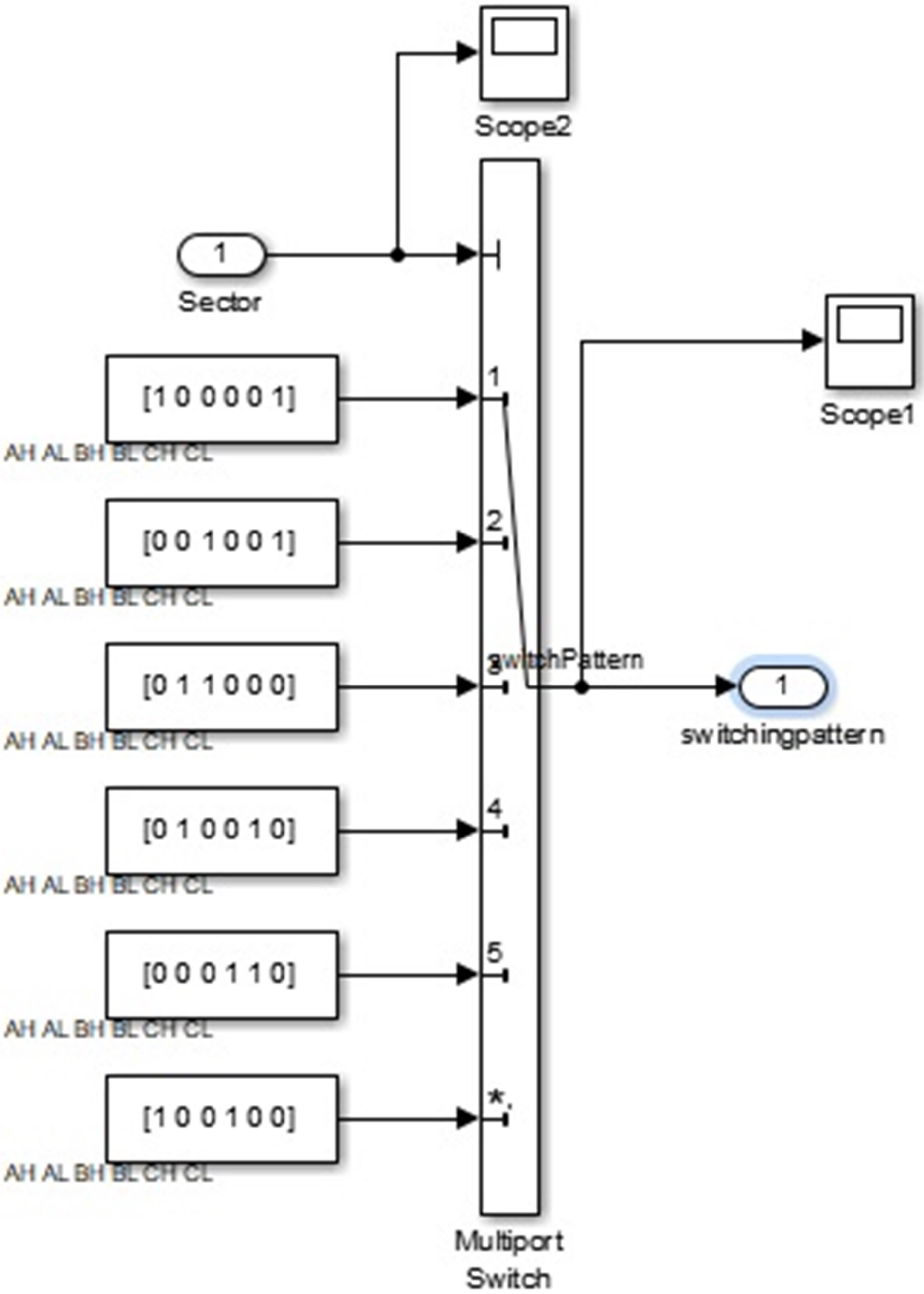


Figure 3.K – Commutation logic circuit schematic

3.3.6 Simulation of complete circuit schematic

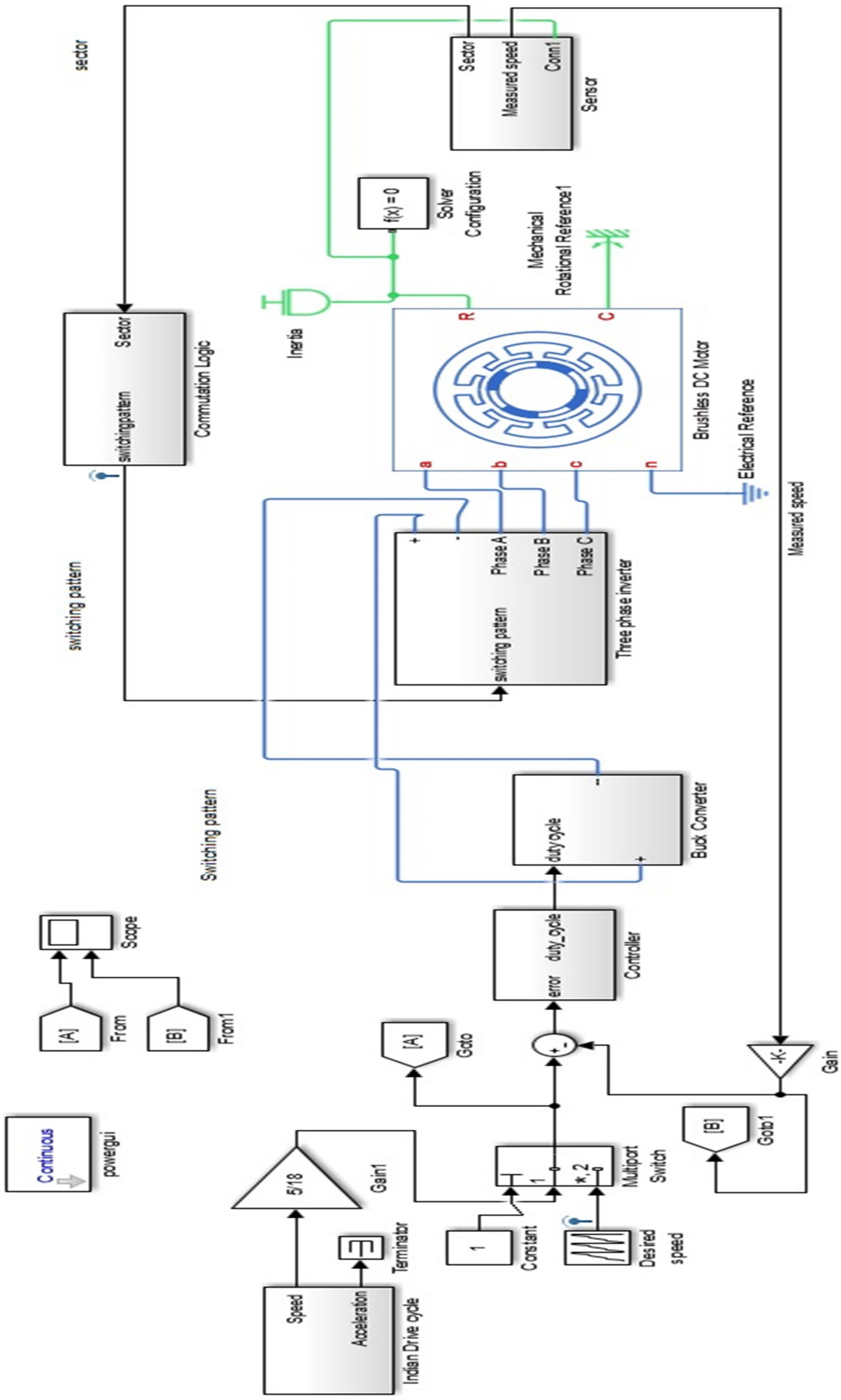


Figure 3.L – Complete circuit schematic

	S1	S2	S3	S4	S5	S6
AH	1	0	0	0	0	1
AL	0	0	1	0	0	1
BH	0	1	1	0	0	0
BL	0	1	0	0	1	0
CH	0	0	0	1	1	0
CL	1	0	0	1	0	0

Figure 3.M Commutation circuit logic

CHAPTER 4 SIMULATION OF HESS (HYBRID ENERGY STORAGE SYSTEM)

The HESS subsystem simulation models of lithium-ion batteries and/or capacitors had been used for the analysis of the energy and power system. The controlled current assets have been used with the derived input from the DC-DC converter subsystem in order to stimulate demand. The put-off time is adjusted to the smallest value of anomalous voltage measurements.

(1) The capacitor of the system coupled with the battery arrangement,

(2) An ultra-high power battery system

(3) A management of conventional battery design

To get the actual result, the additives used for evaluation in the storage system had been stored identically in every size category to the unique storage systems. A battery-capacitor system is small in size and has consistent volume constraint parameters.

4.1 Simulation of a complete HESS Model with battery and super capacitor

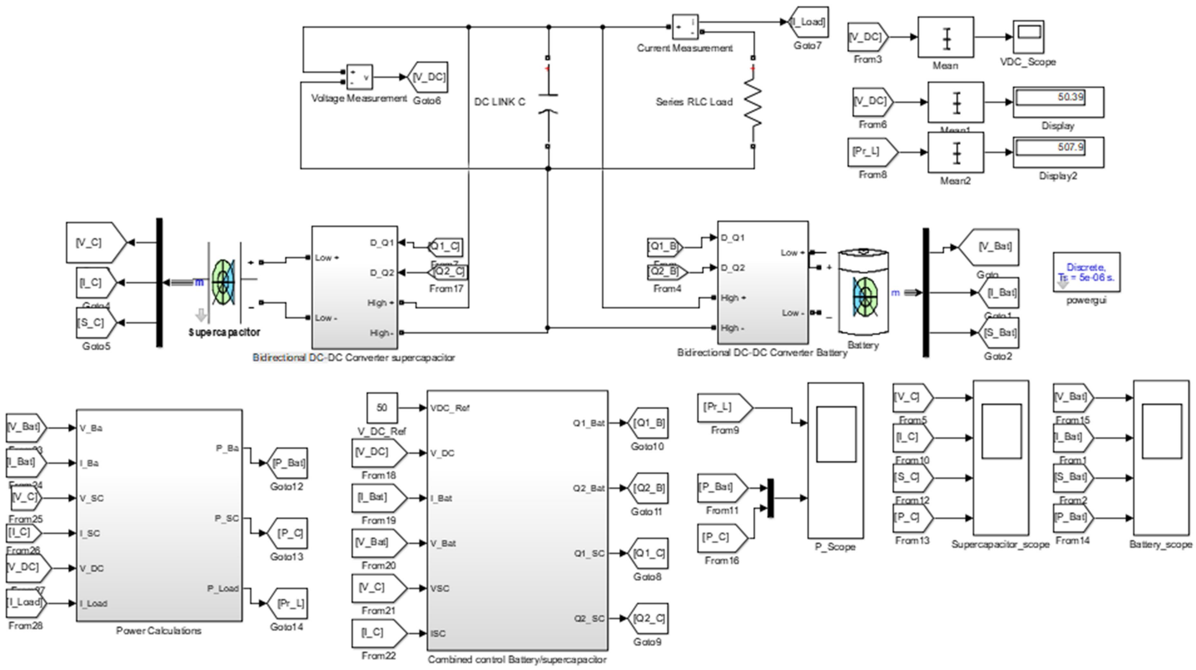


Figure 3.N: Simulation of a complete HESS Model with battery and super capacitor

4.2 Simulation of Bidirectional DC-DC Converter super capacitor

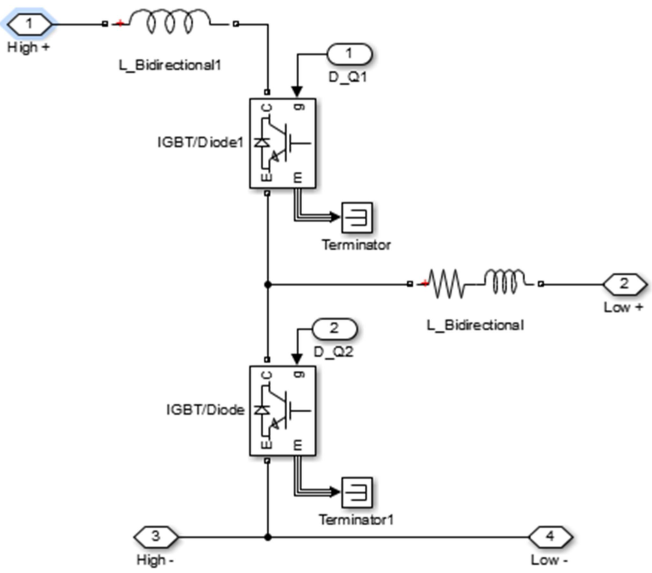


Figure 3.O: Bidirectional DC-DC Converter super capacitor

4.3 Simulation of Bidirectional DC-DC Converter Battery

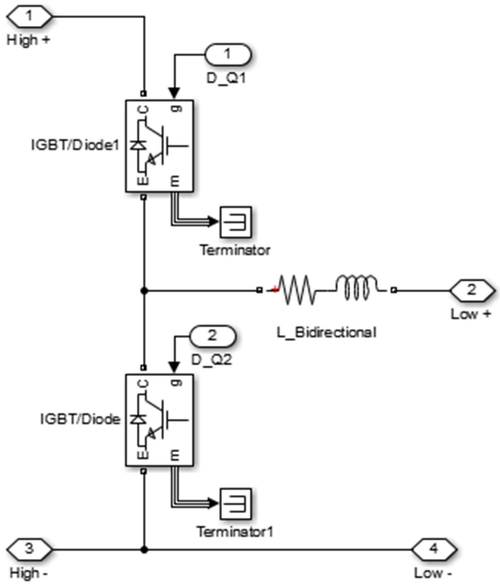


Figure 3.P: Bidirectional DC-DC converter battery

4.4 Sub-system for Power calculations

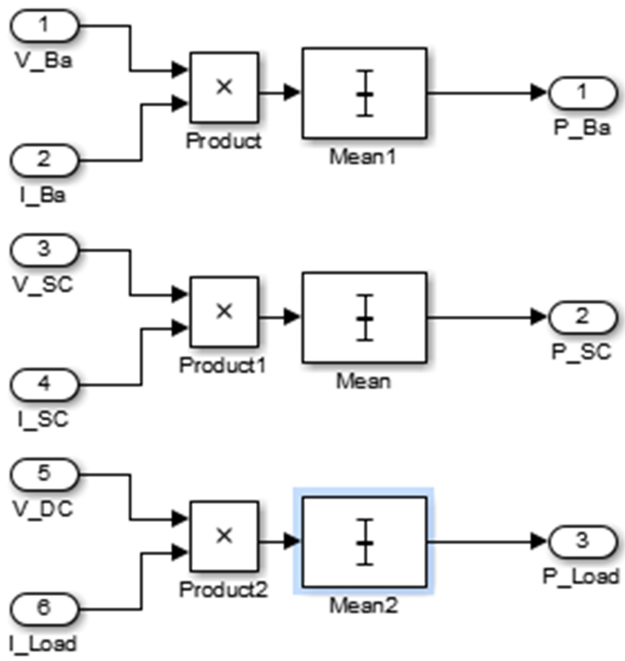


Figure 3.Q: Power calculations

4.5 Simulation of Combined control Battery/super capacitor

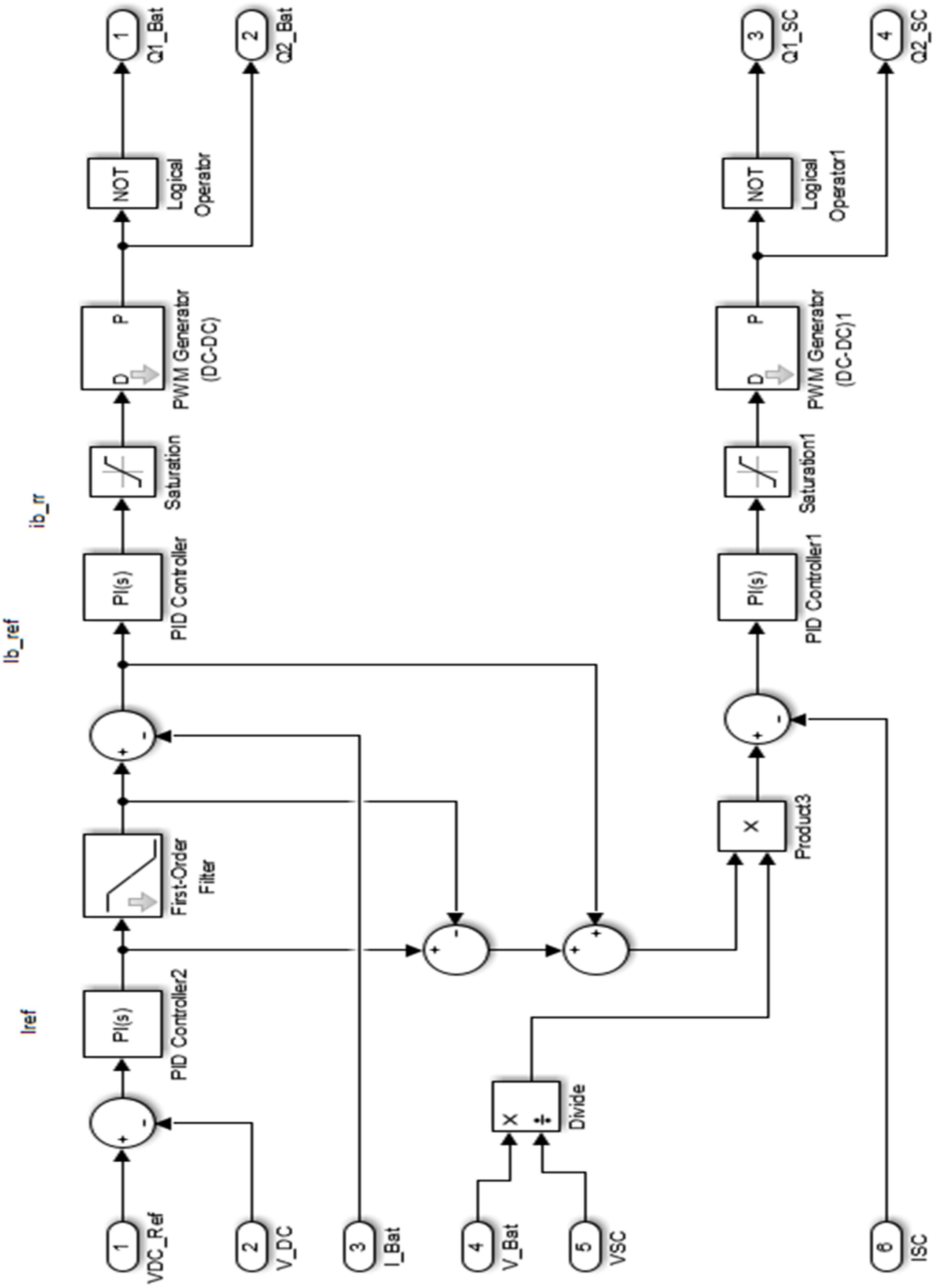
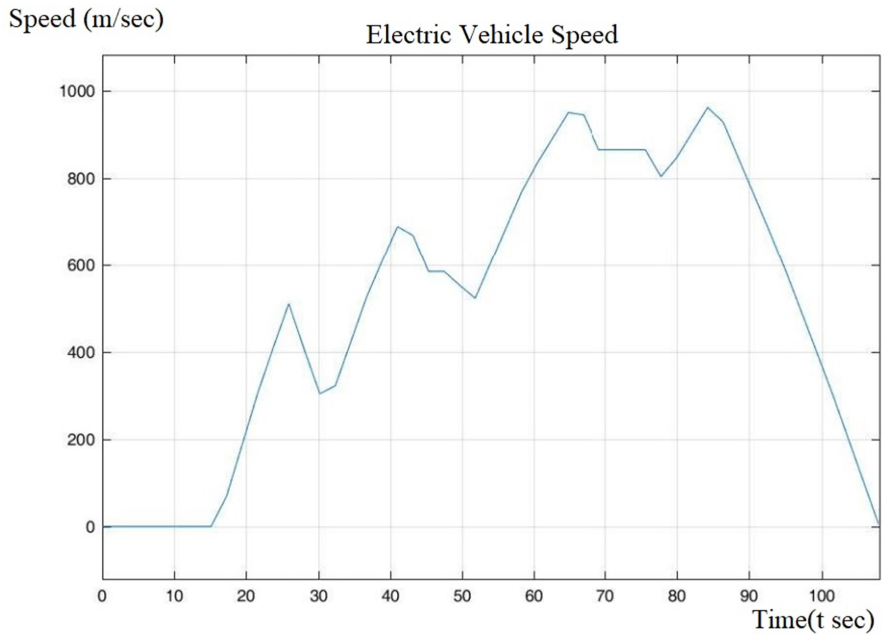


Figure 3.R: Combined control Battery/super capacitor

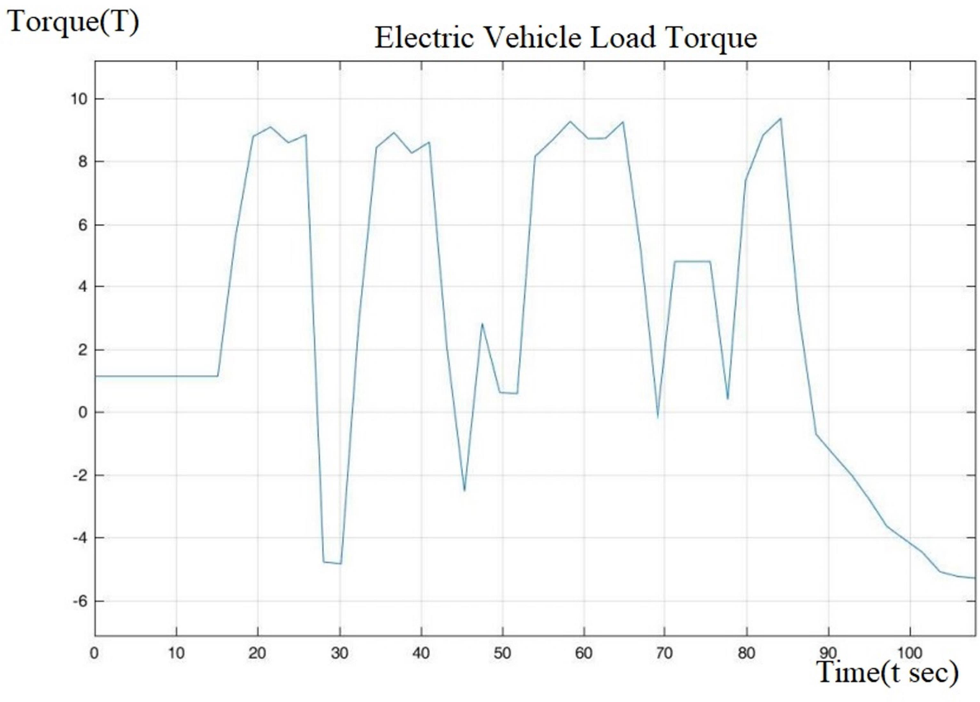
CHAPTER 5: ELECTRIC VEHICLE SIMULATION RESULTS

Due to hardware limitation it is not possible to run the whole drive cycle. Therefore four distinct conditions are extracted and the whole system is simulated. These four conditions i.e Average speed, Top speed, accelerating mode, decelerating mode. The following simulation results of speed, BLDC motor voltage and current, Battery voltage, battery current, and battery state of charge, super capacitor voltage, super capacitor current, and super capacitor state of charge is analysed as follows:

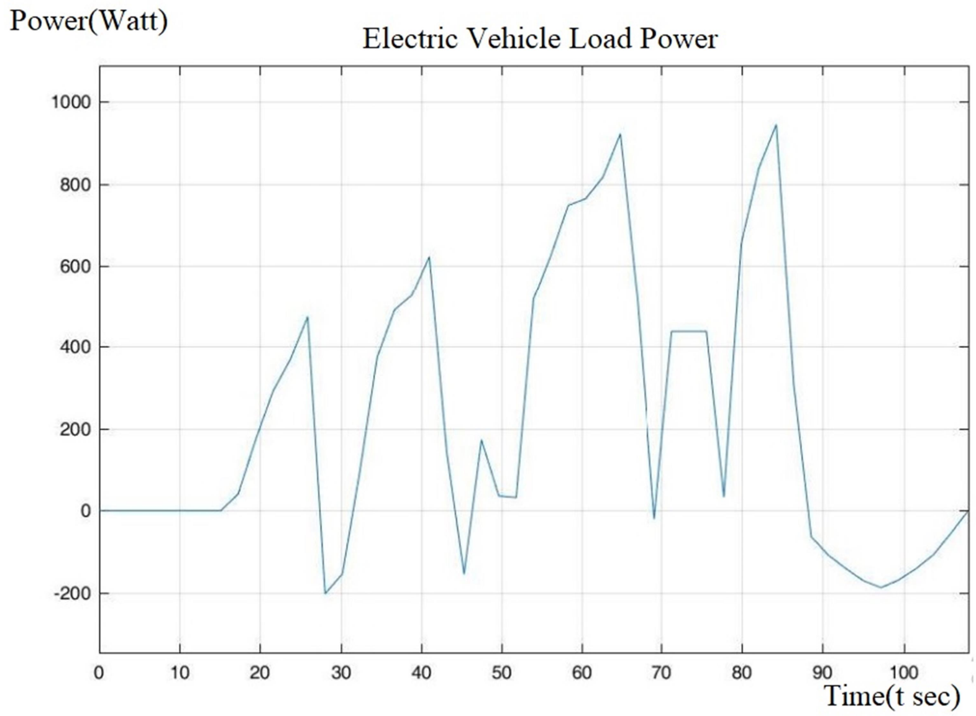
1. Results of Electric Vehicle Load Speed Calculations:



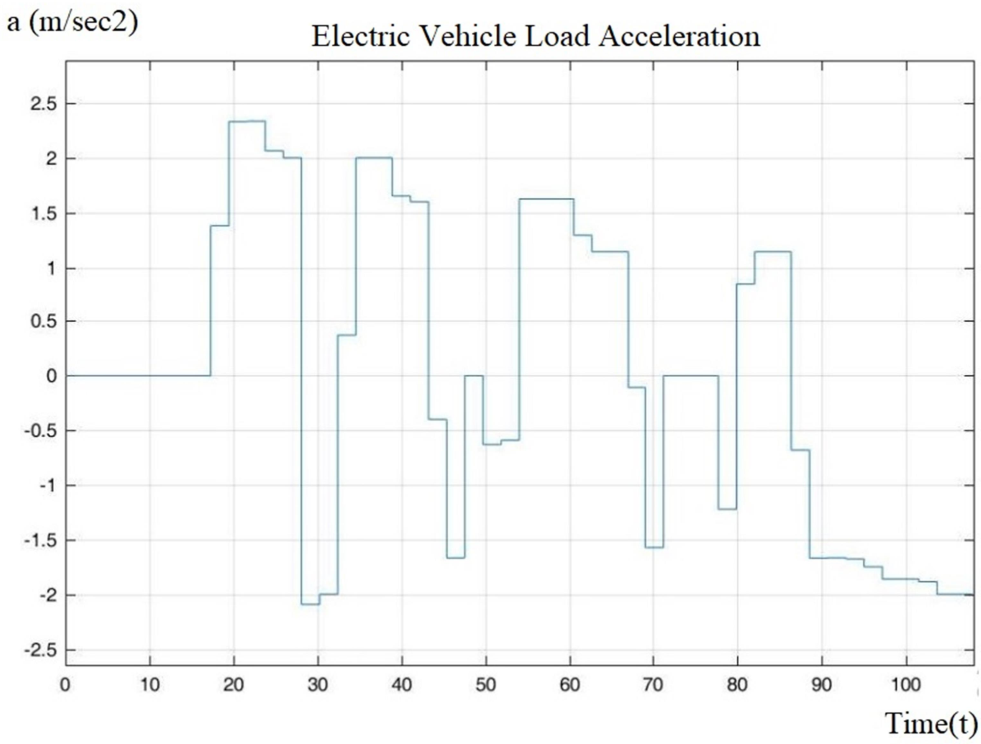
2. Results of Electric Vehicle Load Torque Calculations:



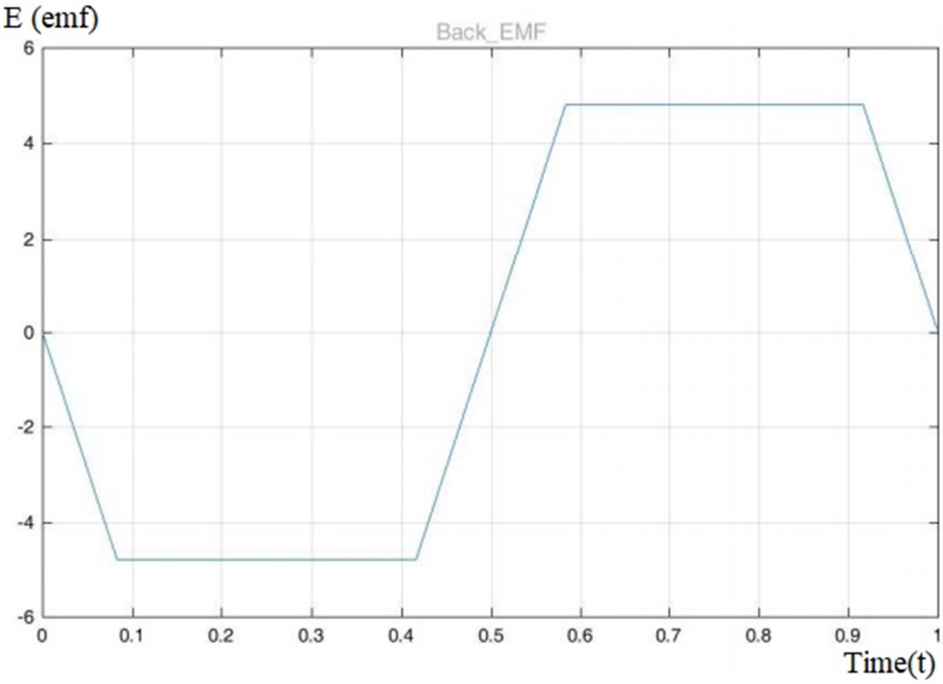
3. **Results of Electric Vehicle Load Power Calculations:**



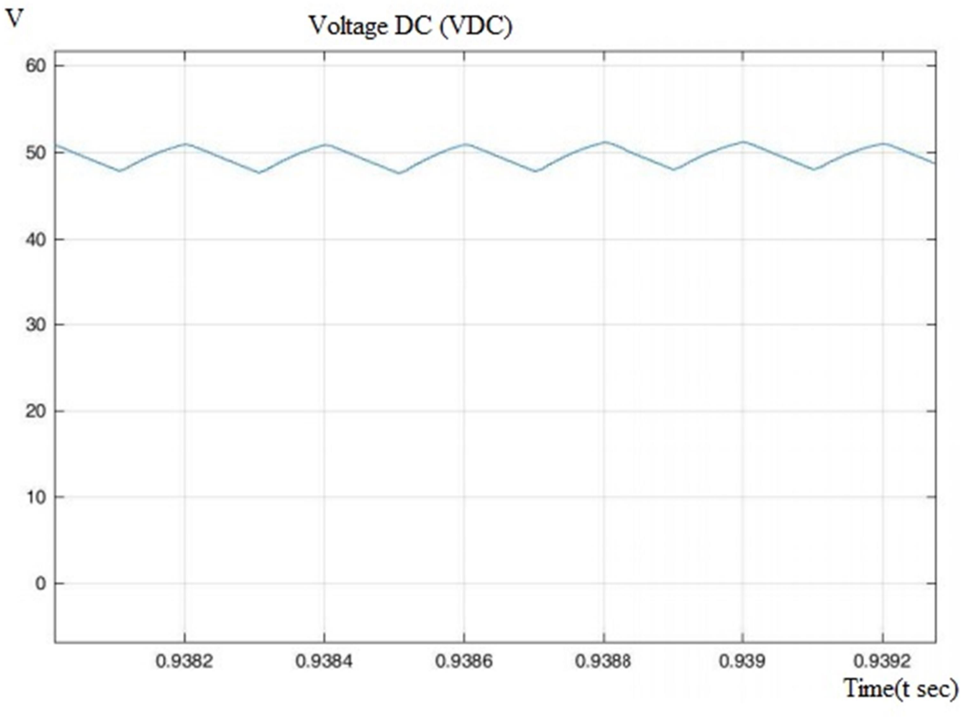
4. **Results of Electric Vehicle Load Acceleration Calculations**



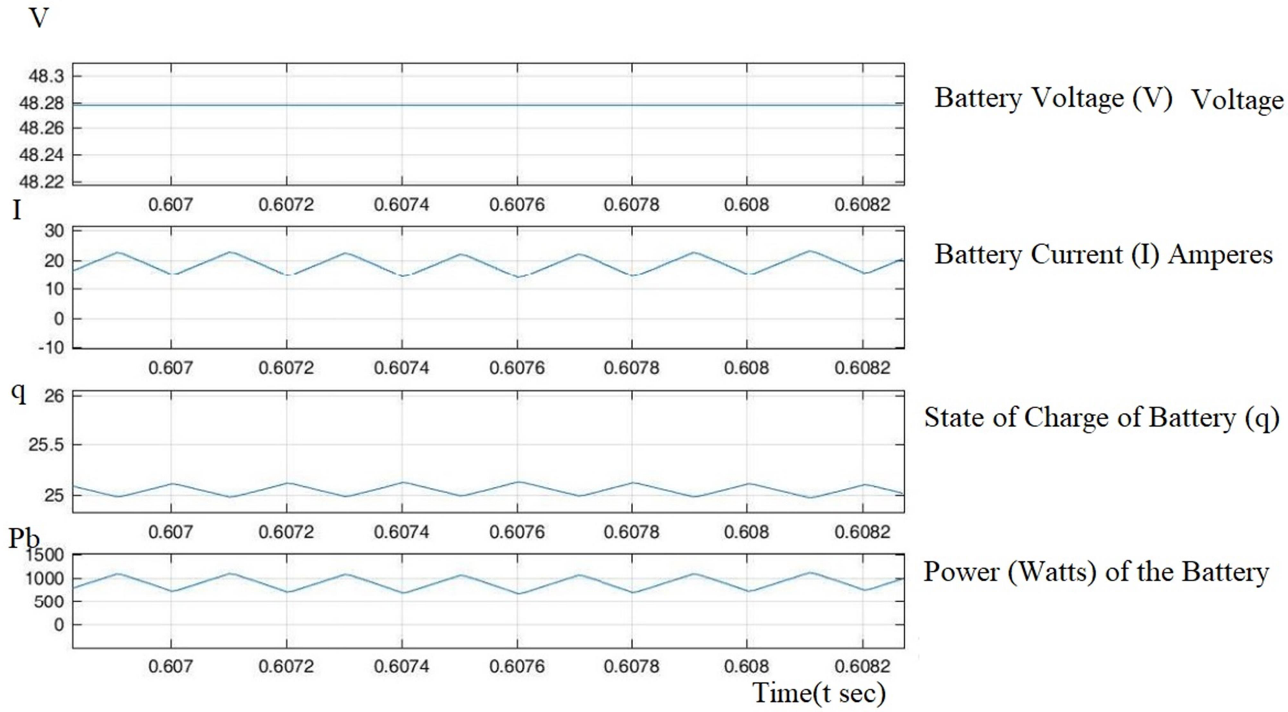
5. **Results of Electric Vehicle Load Brushless DC motor Back emf waveform:**



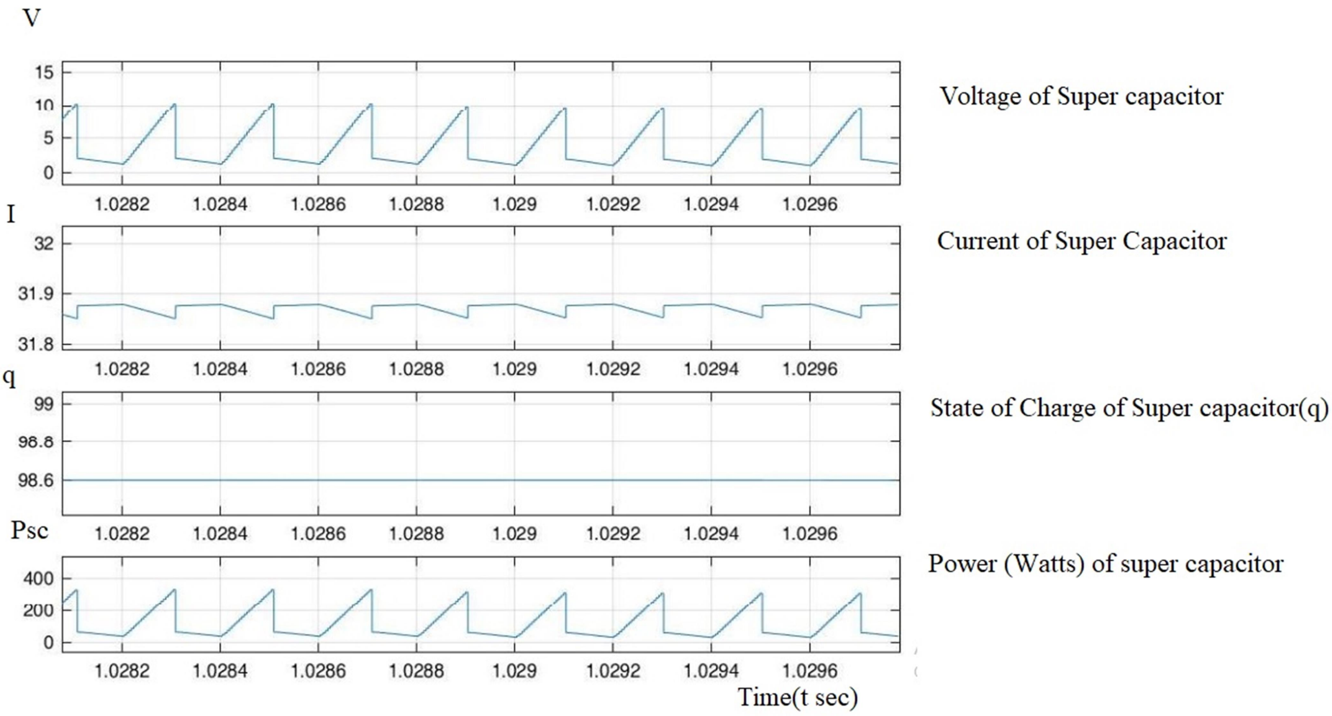
6. **Result of V_{DC} reference HESS waveform:**



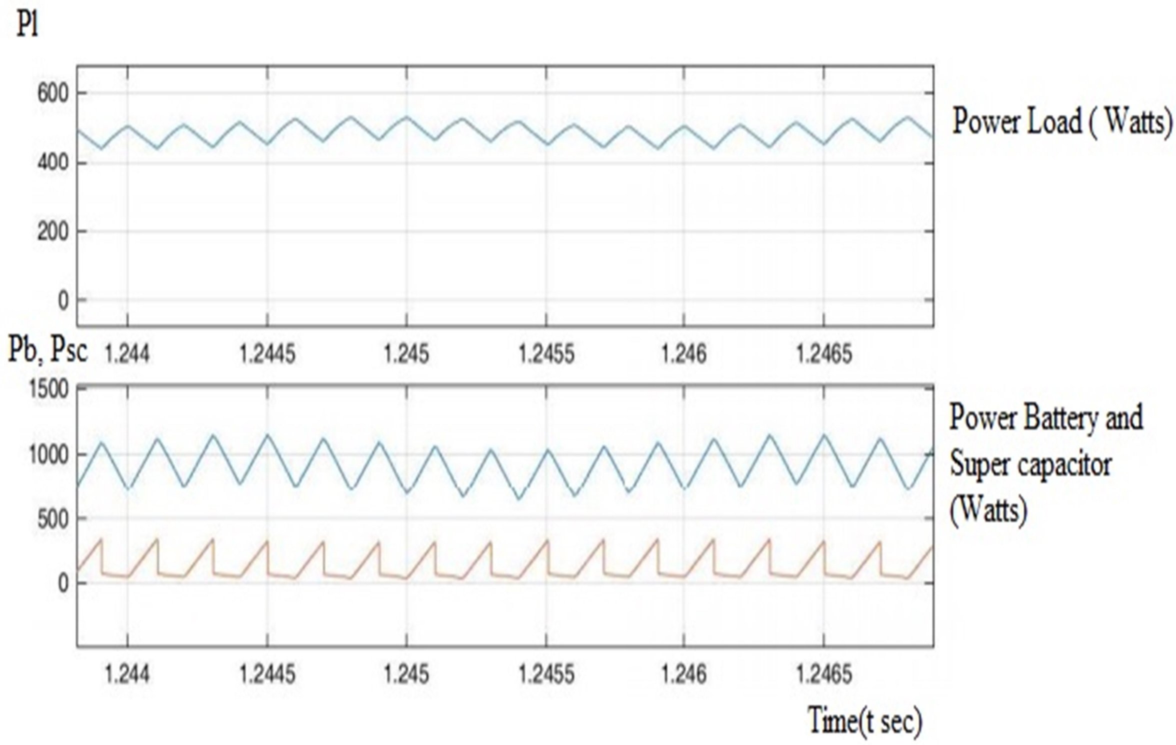
7. **Results of Electric Vehicle Load Battery parameters waveform:**



8. **Results of Electric Vehicle Load Super capacitor parameters waveform:**



9. **Results of Electric Vehicle power of load, battery and super-capacitor parameters waveform:**



CHAPTER 6: FUTURE SCOPE OF WORK AND REFERENCES

6.1 Future scope of work

1. The involvement of no physical testing is an important issue of the study. The quality of modeling and simulation of the diverse systems. Approximations made for the batteries' internal resistance parameter

2. The battery version relies on without delay on the battery type, nominal discharge rate and capability of the battery, etc. For higher information, the preferred price is chosen to supply the output. When depleted at a slower price, the Simulink battery model does not produce output for the hybrid storage leverages the elevated beneficial capability of a battery.

6.2 REFERENCES

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