DESIGN AND CONTROL OF HYBRID ENERGY STORAGE SYSTEM IN ELECTRIC VEHICLE

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ABSTRACT

Nowadays environmental protection and energy conservation are growing concerns for the development of high efficiency and environment friendly all-electric vehicles. As in designing hybrid electric vehicle the main problem is of energy storage system. To solve the above problem the hybrid energy storage system is employed which acts as an efficient energy storage system for electric vehicle (EV) application. The main objective of this contribution is to control the hybrid energy storage system for use in electric vehicle. Isolated dc-dc converters are studied for bi-directional performance. The Z-source network which acts as a bidirectional buck-boost converter employs a unique impedance network and provides a novel conversion concept. This project work aims on designing a converter based hybrid energy storage system in an electric vehicle under various conditions like acceleration, regenerative braking and normal speed of operation. The simulation is going to be done in MATLAB software.

Keywords—Hybrid energy storage system, electric vehicle, z-source network ,isolated dc-dc converters, MATLAB.

INTRODUCTION

The environmental protection and energy conservation are growing concerns in view of increasing greenhouse gas (GHG) emissions and energy security for depletion of fossil fuels. Thus, the development of high efficiency and environment benign Hybrid Electric Vehicles (HEVs) and Electric Vehicles (EVs) are in demand for mitigating the GHG. The battery life, range covered per charge and cost are the critical parameters for the success of an electric vehicle.

1.1 ELECTRIC VEHICLE: An electric vehicles (EV), also referred to as an electric drive vehicles, is a vehicle which uses one or more electric motors for propulsion. Electricity can be used as a transportation fuel to power battery electric vehicles(EVs). EVs store electricity in an energy storage device, such as a battery.

1.2 HISTORY OF ELECTRIC VEHICLES

ELECTRIC VEHICLES first appeared in the mid-19th century. An electric vehicle held the vehicular LAND SPEED RECORD until around 1900. The high cost, low top speed, and short range of battery electric Vehicles, compared to later internal combustion engine vehicles, led to a worldwide decline in their use, although electric vehicles have continued to be used in the form of electric trains and other random uses. At the beginning of the 21st century, interest in electric and other alternative fuel Vehicles has increased due to growing concern over the problems associated with hydrocarbon-fueled vehicles, including damage to the environment caused by their emissions, and the sustainability of the current hydrocarbon-based transportation infrastructure as well as improvements in electric vehicle technology. Since 2010, combined sales of all-electric cars and utility vans achieved 1 million units delivered globally in September 2016.

Rechargeable batteries that provided a viable means for storing electricity on board a vehicle did not come into being until 1859, with the invention of the lead–acid battery by French physicist Gaston Planet Camille Alphonse Faure, another French scientist, significantly improved the design of the battery in 1881, his improvements greatly increased the capacity of such batteries and led directly to their manufacture on an industrial scale.

Rapid urbanization has resulted in increasing urban air pollution in major cities across the world. Over 90% of air pollution in cities is attributed to vehicle emissions and very limited use of emission control strategies. Due to these reasons many automobile manufacturers have diverted their attention towards the development of electric vehicles (EV) and hybrid electric vehicles (HEV). However, selection and performance of EVs are dependent on driving behavior of a given city or a region represented by its driving cycle. Driving cycle is considered as a signature of driving characteristics of that city or region consisting of several vehicle operating conditions such as idle, acceleration, deceleration and cruising. These drive cycles are obtained by the movement of test vehicles in the targeted region under different traffic conditions and represents the actual operating scenario for any vehicle. Thus, drive cycle of a region must be considered during the development process of an EV.

1.3 BASIC STRUCTURE OF ELECTRIC VEHICLE:

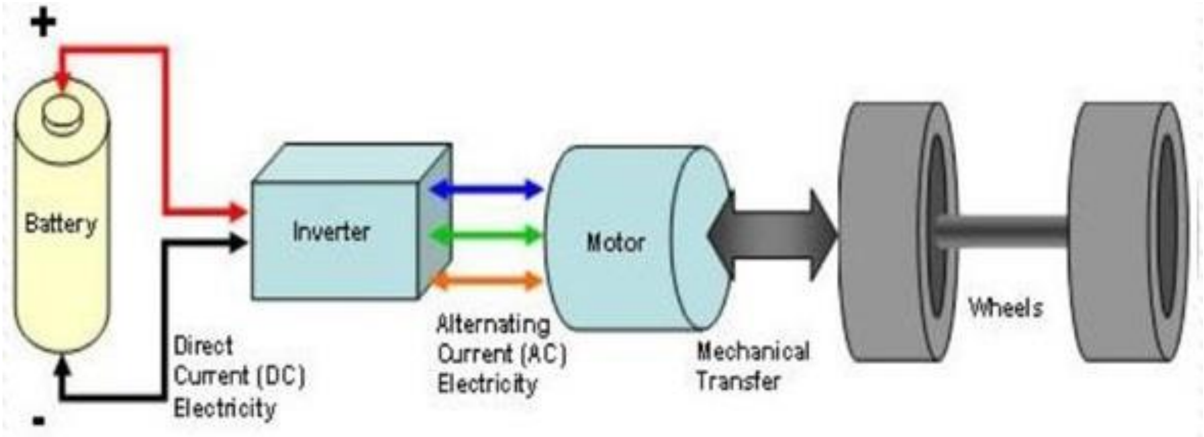


Fig.(1.3a) Electric vehicle

Battery--Battery is a collection of one or more cells whose chemical reactions create a flow of electrons in a circuit. All batteries are made up of three basic components: an anode (the '-' side), a cathode (the '+' side), and some kind of electrolyte (a substance that chemically reacts with the anode and cathode).

Inverter--An inverter converts the DC voltage to an AC voltage. An inverter provides an ac voltage from dc power sources and is useful in powering electronics and electrical equipment rated at the ac mains voltage. The circuits are classified according the switching technology and switch type, the waveform, the frequency and output waveform.

Motor--An **electric motor** is an electrical machine that converts electrical energy into mechanical energy. Electric motors can be powered by direct current (DC) sources, such as from batteries, motor vehicles or rectifiers, or by alternating current (AC) sources, such as a power grid, inverters or electrical generators.

1.4 BENEFITS OF USING ELECTRIC VEHICLE:

- Cheaper to run. Owners of an EV have the advantage of much lower running costs.
- Cheaper to maintain.
- Other savings.
- Better for the environment.
- Health benefits.
- Safety improvements.
- Our energy security.

1.5Hybrid Energy Storage System

Hybrid energy storage system is a combination of two or more energy storage devices. The HES has multiple options that is combination of either battery with super-capacitor or battery with fuel cells or battery with wind generator or any other power generator can be coupled for developing an efficient energy storage system for EV.

Why Hybrid Energy Storage System?

Before we need to know why we go for hybrid energy storage system instead of battery storage system, we need to know about what are energy density, power density, **Energy density**

Energy density is the amount of energy (The generation or use of electric power by a device over a period of time) stored in a storage device per unit mass. Energy density expressed in Watt-hours per Kilogram (Wh/Kg). If energy density of storage device is high it means that the storage device can store greater amount of energy.

Power density

Power density is the amount of power (time rate of energy transfer) per unit mass. It is also an index of maximum current that can be drawn by the energy storage device. Power density expressed in Watts per Kilogram (W/Kg). If a storage device has high power density then it meansthat it can output large amounts of power based on its volume. High power density systems canrelease their energy quickly and also recharge quickly.

Energy density

Energy density is the amount of energy (The generation or use of electric power by a device over a period of time) stored in a storage device per unit mass. Energy density expressed in Watt-hours per Kilogram (Wh/Kg). If energy density of storage device is high it means that the storage device can store greater amount of energy.

1.6 Battery charging technologies in an electric vehicle:

Charging schemes of an ev:

- Normal charging.
- Opportunity charging.
- Fast charging.
- Battery swapping.

The Charging algorithms

- Improve the charging efficiency.
- Reduce the charging time.
- Enhancing the battery life.
- Protect the battery.

1.7MOTOR DRIVE TECHNOLOGIES: The major types of electric traction motors adopted for HEVs include the dc motor, the induction motor (IM).

DC Motors (DC)

DC motors have been prominent in electric propulsion because their torque–speed characteristics suit the traction requirement well, and their speed controls are simple. However, dc motor drives have a bulky construction, low efficiency, low reliability, and higher need of maintenance, mainly due to the presence of the mechanical commutator (brush), even if interesting progress has been made with slippery contacts. Inverter-fed six-phase pole-changing IM drive.

Moreover, the development of rugged solid-state power semiconductors made it increasingly practical to introduce the ac induction and synchronous motor drives that are mature to replace the dc motor drive in traction applications. In fact, the commutator-less motors are attractive, as high reliability and maintenance-free operation are prime considerations for electric propulsion. Nevertheless, with regard to the cost of the inverter, ac drives are used generally just for higher power. At low power ratings, the dc motor is still more than an alternative. Improvement of existing cars ("reengineering") without changing the mechanical part can be achieved by the new dc chopper power electronics. The commutator, if used in proper operation, is a very rugged "inverter"; therefore, the power electronics circuit can be kept relatively simple and thus at low cost.

Induction Motor (IM)

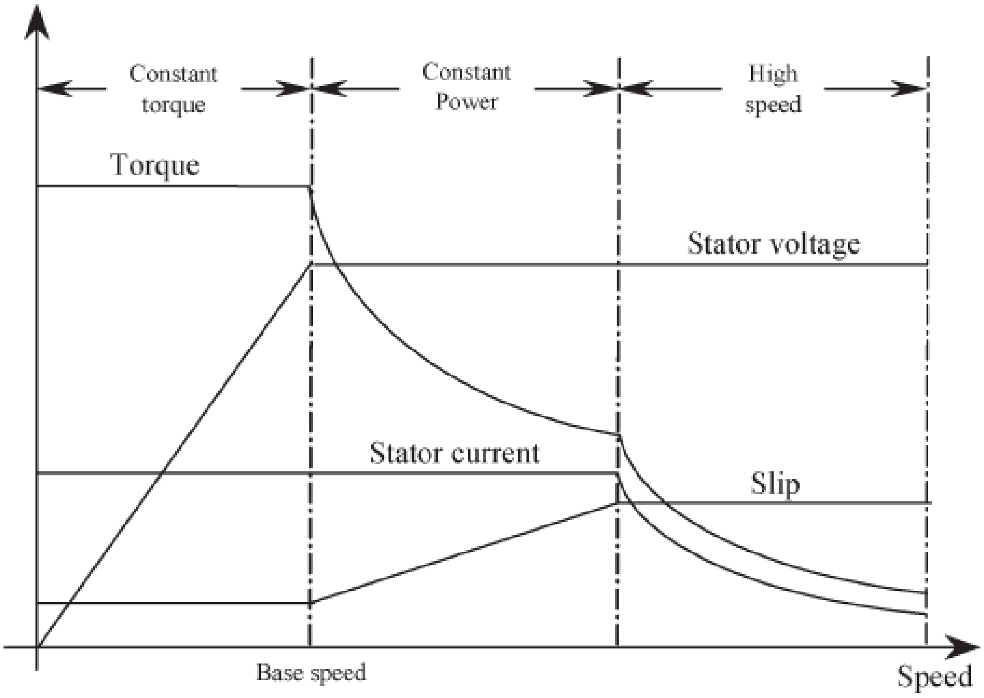
Cage IMs are widely accepted as the most potential candidate for the electric propulsion of HEVs, owing to their reliability, low maintenance, low cost, and ability to operate inhostile environments. They are particularly well suited for the rigors of industrial and traction drive environments. Today, an IM drive is the most mature technology among variousCommutator-less motor drives. For illustration, shows industrial traction IMs show the typical characteristics of an IM drive.

However, the presence of a breakdown torque limits its extended constant-power operation. At the critical speed, the breakdown torque is reached. Generally, for a conventional IM, the critical speed is around two times the synchronous one. Any attempt to operate the motor at the maximum current beyond this speed will stall the motor. Moreover, efficiency at a high speed range may suffer in addition to the fact that IMs efficiency is inherently lower than that of PM motors, due to the absence of rotor winding and rotor copper losses. In general, IM drives were facing a number of drawbacks that pushed them out from the race of HEVs electric propulsion.

These drawbacks are mainly high loss, low efficiency, low power factor, and low inverter-usage factor, which is more serious for the high speed, large power motor. Fortunately, these drawbacks are taken into consideration according to the available literature. Some researches propose taking into account these problems in the design step of the IM used for EVs. To improve the IM drives efficiency, a new generation of control techniques has been proposed. Some of the proposed techniques are particularly devoted to EV applications, which constitute a progress compared to theStudy made.

To extend the constant-power region without over sizing the motor (to solve the problem of breakdown torque), the use of a multiphase pole-changing IM drive, especially for traction

Application, has been proposed. The key was to propose a new sinusoidal pulse width modulation (PWM) strategy in such a way that the two carriers of the six-phase inverter are out of phase during a four-pole operation while they are in phase during a two-pole operation. Another approach to enlarge the constant-power region (up to 10: 1) is to use dual inverters. Finally, it should be noticed that certain research works tend to introduce.



Fig(.1.7.a) charactersitcs of induction motor

REQUIREMENTS OF EV MOTOR COMPARED TO INDUSTRIAL MOTORS:

- Maximum torque (4 to5 times) than rated torque for starting,hill climbing and overtaking etc.
- Maximum speed(4 to 5 times) than rated speed for highway cruising.
- Ev motors demand high power density and good efficiency map for the reduction of total weight and the extension of driving range.
- EV motors desire high controllability,high steady-state accuracy and good dynamic performance.

- EV motors needs to operate in harsh operating conditions such as high temperature,bad weather and frequent vibration.

THE MAJOR REQUIREMENTS OF AN EV MOTOR ARE:

- High torque density and high power density.
- Very wide speed range including constamt torque and constamt power regions.
- High efficiency over wide torque and speed ranges.
- Low cost.
- High efficiency during regenerative braking.
- Good voltage regulation over wide speed generation.
- Capable of being integrated with the engine.(HEV).

The IM seems to be the most adapted candidate for the electric propulsion of urban HEVs.As recently, a new IM technology has been developed for traction application, requiring flat or hub-style motors (hub motor). Other features include a wide range of constant power, very smooth acceleration,less torque ripple, reduced manufacturing costs, and operation at higher temperatures and higher speed.

PROPOSED MODEL

4.1 DESIGN CALCULATIONS OF Z-NETWORK FOR CONVERTER

The Z-source inverter system is shown in Fig. It employs a symmetrical LC impedance network to replace the dc -link capacitor in traditional VSI. Furthermore, with the help of series diode D embedded in the source side, the input dc source can be effectively disconnected from the Z-source network by naturally reverse-biasing the diode D during the unique shoot-through interval, which can be initiated by turning ON all switches of one phase-leg simultaneously. The 3-phase Z-source inverter bridge has nine permissible switching states unlike the traditional three phase Voltage source inverter that has eight states. The traditional three-phase V-source inverter has six active vectors when the load

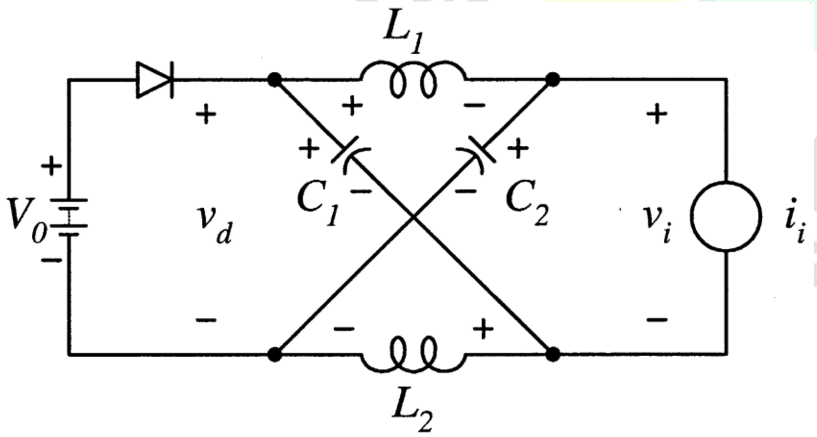


Fig.4.1 z-network for converter

Terminals are shorted through either the lower or upper three devices, respectively. However, the three-Phase Z-source inverter bridge has one extra state when the load terminals are shorted through both the upper and lower devices of any one phase leg (i.e., both devices are gated on), any two phase legs, or all three phase legs. This shoot-through zero state is forbidden in the traditional Voltage-source inverter. Such special operation provides the ability of voltage boosting as well as the unidirectional power conversion (desired in PV and fuel cell systems)

Assuming that the inductors L1 and L2 and capacitors C1 and C2 have the same inductance (L) and capacitance(C) respectively, the Z-source network becomes symmetrical. From the symmetry and equivalent circuits we have

$$L1 = L2 = L; C1 = C2 = C.$$

We know that we are using boot factor technique for bringing the required output voltage.

$$2V_c = B * V_{in}$$

Where, 2Vc = Dc link voltage.

V_{in} = input dc voltage.

B = boost factor.

V_{in}= 96V.

Gain, G = B*M

Where, M = modulation index.

$$G = \frac{Vac(line\ to\ ground\ peak\ value)}{Vin/_2}.$$

$$G = \frac{415*\sqrt{2}/\sqrt{3}}{96/_2}.$$

$$G = \frac{415*\sqrt{2}*2}{\sqrt{3}*96} = 7.05929.$$

B = 2G – 1.

B = (2*7.05929) – 1 = 13.118.

$$M = \frac{G}{2G-1}.$$

$$M = \frac{7.05929.}{(2*7.05929.)-1} = 0.538.$$

The DC link voltage 2Vc = B*V_{in}

2Vc = 13.118*96 = 1259.328V.

Therefore, V_c = 629.664V.

Boost factor and boosting value of voltage is depends on SHOOT THROUGH time**(To)**

Boost factor,

$$B = \frac{1}{1-2D}.$$

Where D is shoot through duty ratio.

$$D = \frac{To}{Ts}$$

Where, T_o is shoot through time

T_s is time related to switching frequency.

$$D = \frac{To}{1/_{100*10^3}}$$

Because switching frequency is 100 KHz

From $B = \frac{1}{1-2D}.$

D = 0.46188

So T_o = 4.6188 μ sec.

PeakDClinkvoltage$Vdclink = \frac{Vin}{1-2D}\ V.$

$$= \frac{96}{1-(2*0.46188)} = 1259.328\,V.$$

Peak AC output voltage (line to neutral)

$$= \frac{96}{1-(2*0.46188)} = 1259.328\,V.$$

$$Vpac = \frac{M*Vin}{2(1-2D)} = B\left(\frac{M*Vin}{2}\right)V.$$

$$V_{pac} = 338.759\text{ V.}$$

During shoot-through mode, the purpose of the inductor is to limit the current ripple through the device and capacitor voltage is equal to inductor voltage. During active mode the inductor current decreases linearly and inductor voltage is equal to the difference between input voltage and capacitor voltage (but Vc=Vi).Hence inductor voltage is zero and only a pure dc current flows through the inductor. The average current through the inductor is

Inductor = $\boldsymbol{L = \frac{V*To}{\Delta I}}$ **H.**

Where V = Vlog =Vc = 629.664 V.

$$Il = \frac{Pdc}{Vin} = \frac{4.411*10^3}{96} = 45.9479\,A.$$

$$\Delta I = 10\%\ of\ Il$$

$$\therefore L = \frac{629.664\text{V} * 4.618 * 10^{-6}}{4.594} = 6510.2739\,mH$$

Capacitor = $\boldsymbol{C = \frac{\Delta I*To}{\Delta Vc}}$ $\boldsymbol{F}$

= 1.0916μF

SIMULATION RESULTS

A two-port network that consists of a split-inductor L_1, L_2 and C_1, C_2 connected in X shape is employed to provide an impedance source (Z-source) coupling the converter (or inverter) to the dc source, load, or another converter. The dc source/or load can be either a voltage or a current source/or load. Therefore, the dc source can be a battery, diode rectifier, thyristor converter, fuel cell, an inductor, a capacitor, or a combination of those. Switches used in the converter can be a combination of switching devices and diodes such as the antiparallel combination as shown in Figure

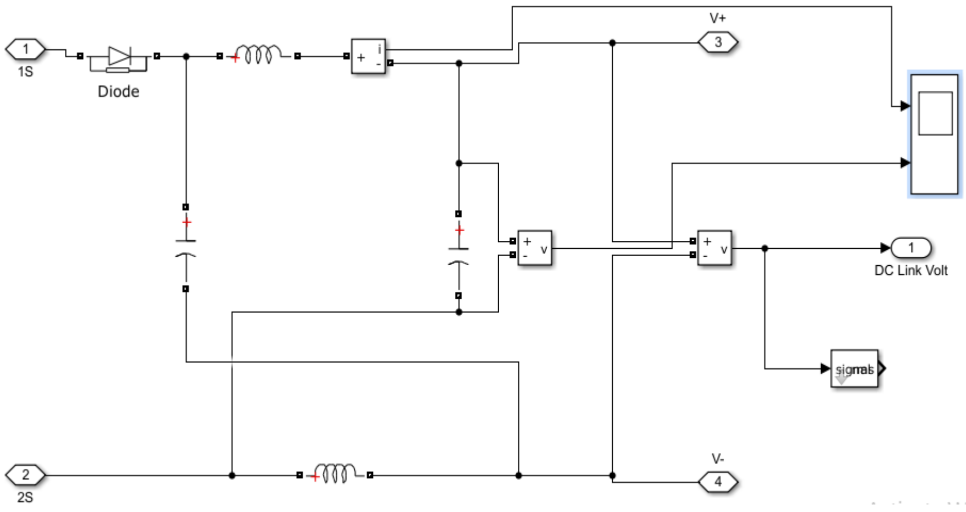


Fig.5.a Z-network

The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. To describe the operating principle and control, this paper focuses on an application.

The unique feature of the Z-source inverter is that the output ac voltage can be any value between zero and infinity regardless of the fuel-cell voltage. That is, the Z-source inverter is a buck–boost inverter that has a wide range of obtainable voltage. The traditional V- and I-source inverters cannot provide such feature. To describe the operating principle and control of the Z-source inverter, let us briefly examine the Z-source inverter structure. Bridge has nine permissible switching states (vectors) unlike the traditional three-phase V-source inverter that has eight. The traditional three-phase V-source inverter has six active vectors when the dc voltage is impressed across the load and two zero vectors when the load terminals are shorted through either the lower or upper three devices, respectively. However, the three-phase Z-source inverter bridge has one extra zero state (or vector) when the load terminals are shorted through both the upper and lower devices of any one phase leg (i.e., both devices are gated on), any two phase legs, or all three phase legs. This shoot-through zero state (or vector) is forbidden in the traditional V-source inverter, because it would cause a shoot-through. We call this third zero state (vector) the shoot-through zero state (or vector), which can be generated by seven different ways: shoot-through via any one phase leg, combinations of any two phase legs, and all three phase legs. The Z-source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique buck-boost feature to the inverter. The inverter bridge is equivalent to a short circuit when the inverter bridge is in the shoot-through zero state. Note that the inverter bridge can be also represented by a current source with zero value (i.e., an open circuit) when it is in one of the two traditional zero states. All the traditional pulse width-modulation (PWM) schemes can be used to control the Z-source inverter and their theoretical input–output relationships still hold It should be noted that each phase leg still switches on and off once per switching cycle. Without change the total zero-state time interval, shoot-through zero states are evenly allocated into each phase. That is, the active states are unchanged. However, the equivalent dc-link voltage to the inverter is boosted because of the shoot-through states. It is noticeable here that the equivalent switching frequency viewed from the Z-source network is six times the switching frequency of the main inverter, which greatly reduces the required inductance of the Z-source network.

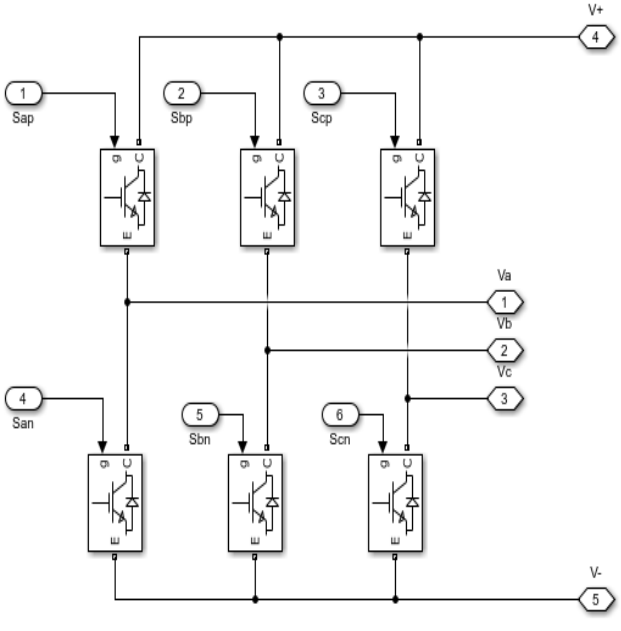
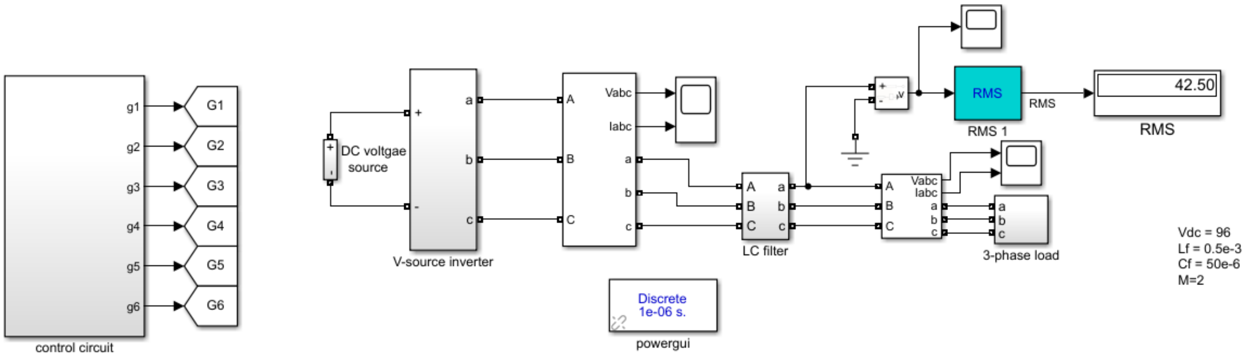


Fig.5.b Power circuit

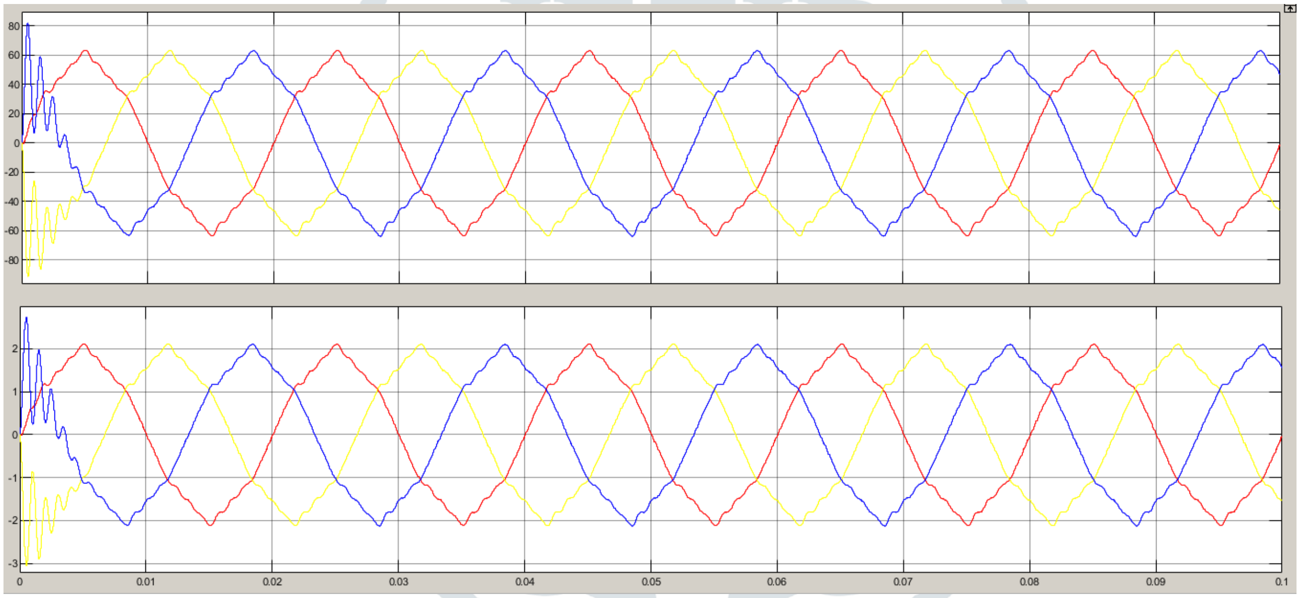
In the traditional PWM technique of the voltage source inverter, there are eight permissible switching states: six active and two zero states. During the two zero states, the upper three or the lower three switches are turned on simultaneously, has shorting the output terminals of the inverter and producing zero voltage to the load. During one of the six active states, the dc voltage is impressed across the load, positively or negatively. In addition to the eight traditional switching states, the Z-source inverter has several shoot-through zero states, during which both the upper and lower switches of one or multiple same phase legs are turned on. It is obvious that during a shoot-through zero state, the output terminals of the inverter are shorted and the output voltage to the load is zero. Therefore, the shoot through states has the same effect (i.e., zero voltage) to the load as the traditional zero states; however, these shoot through states can boost the dc voltage. The active states have to be kept unchanged to maintain the output voltage waveform, and the traditional zero states can be replaced partially or entirely by the shoot through zero states depending on how much voltage boost is needed.

5.1.OPEN LOOP SIMULINK MODEL OF VOLTAGE SOURCE INVERTER



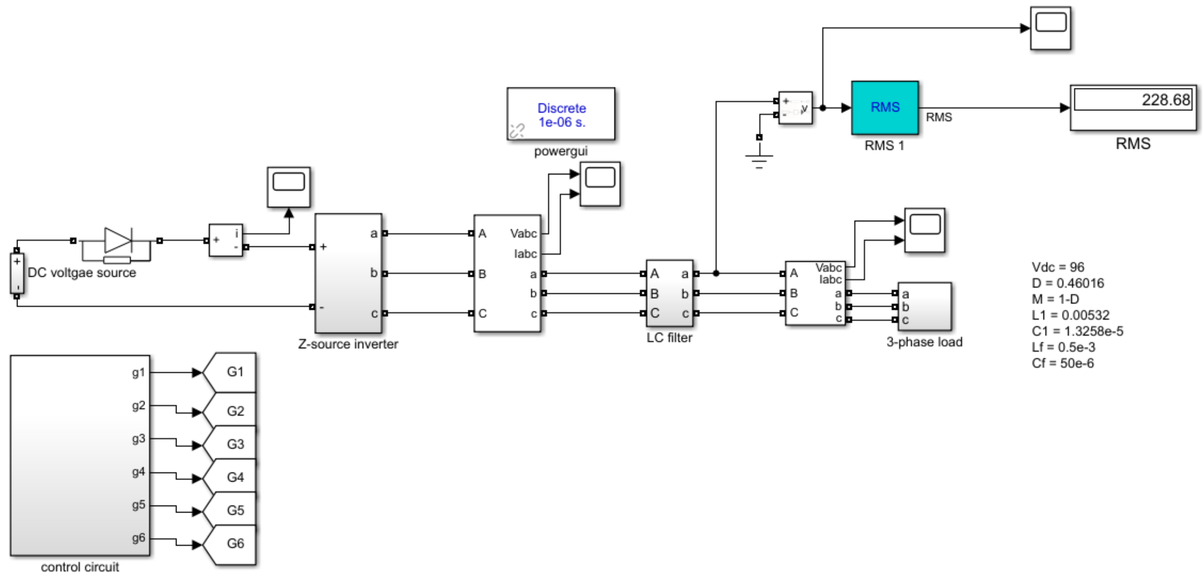
Fig(.5.1.a)open loop control of voltage source inverter

Results:



Fig(.5.1.b) Ouputs of voltage and currents of voltage source inverter

5.2.OPEN LOOP SIMULINK MODEL OF Z-SOURCE INVERTER



Vdc = 96
D = 0.46016
M = 1-D
L1 = 0.00532
C1 = 1.3258e-5
Lf = 0.5e-3
Cf = 50e-6

Fig(.5.2.a)open loop control of z-source inverter

Results:

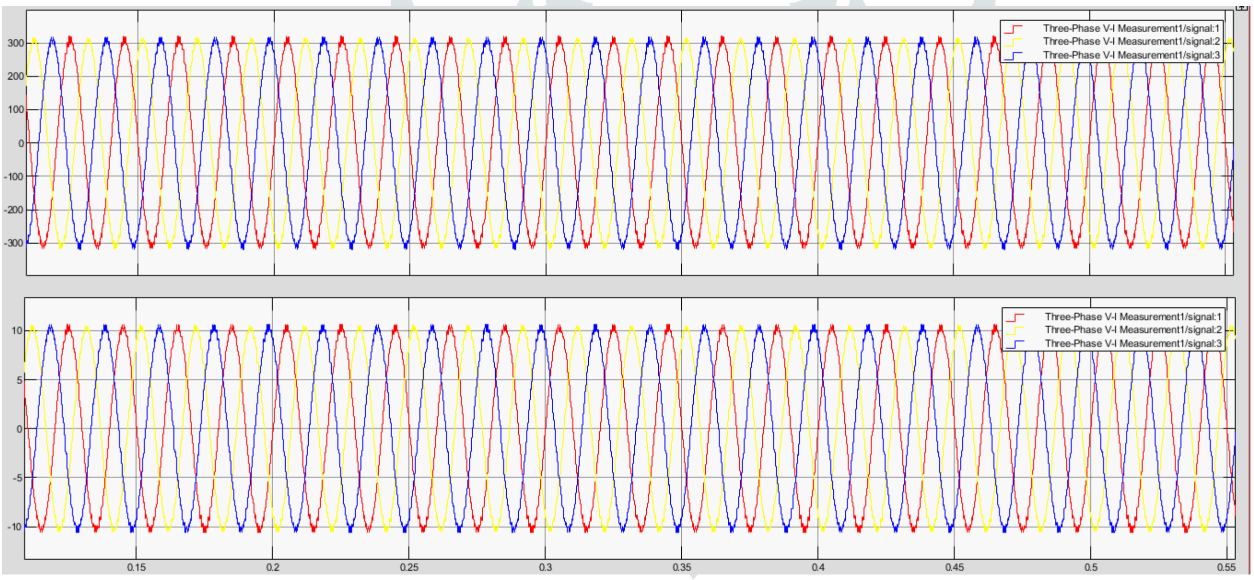


Fig.(5.2.b)Output voltage and currents of Z source inverter

Table 1: Comparison of VSI and ZSI Performance in open loop with r -load

VSI		ZSI	
INPUT VOLTAGE	OUTPUT VOLTAGE	INPUT VOLTAGE	OUTPUT VOLTAGE
96V	42.50V	96V	228.68V

5.3.SIMULINK MODEL OF Z-SOURCE INVERTER WHEN CONNECTED TO INDUCTION MOTOR IN ACCELARATION MODE:

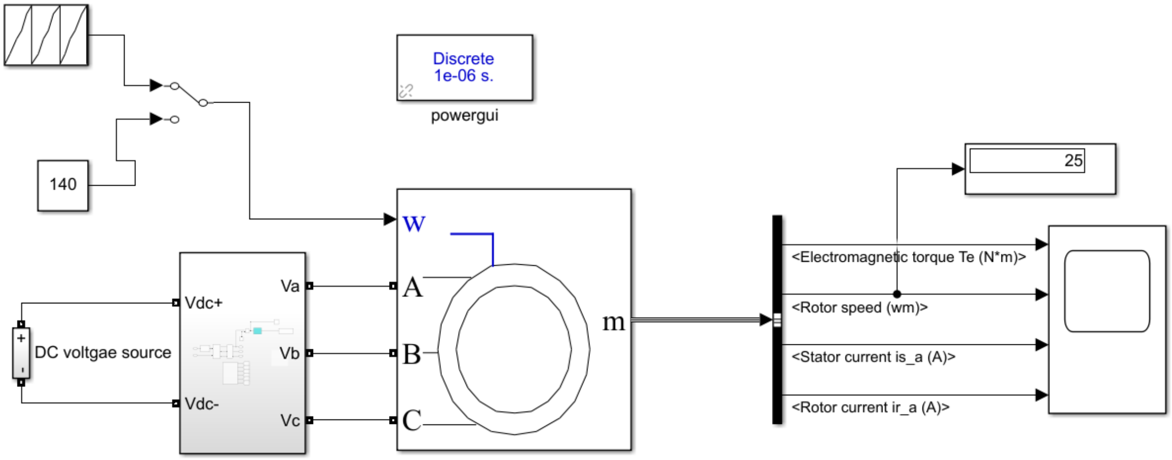


Fig.(5.3.a)open loop control of ZSI in acceleration mode

Results:

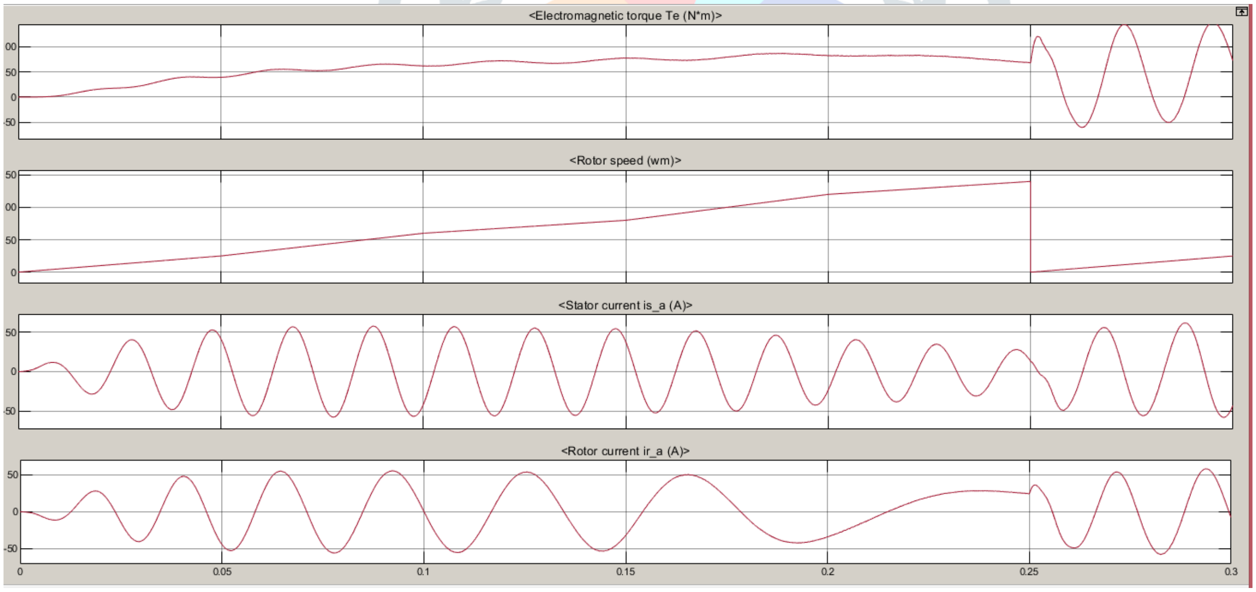


Fig.(5.3.b)Output of torque, rotor speed, stator current and rotor currents of induction motor

5.4.SIMULINK MODEL OF Z-SOURCE INVERTER WHEN CONNECTED TO INDUCTION MOTOR IN CONSTANT SPEED MODE:

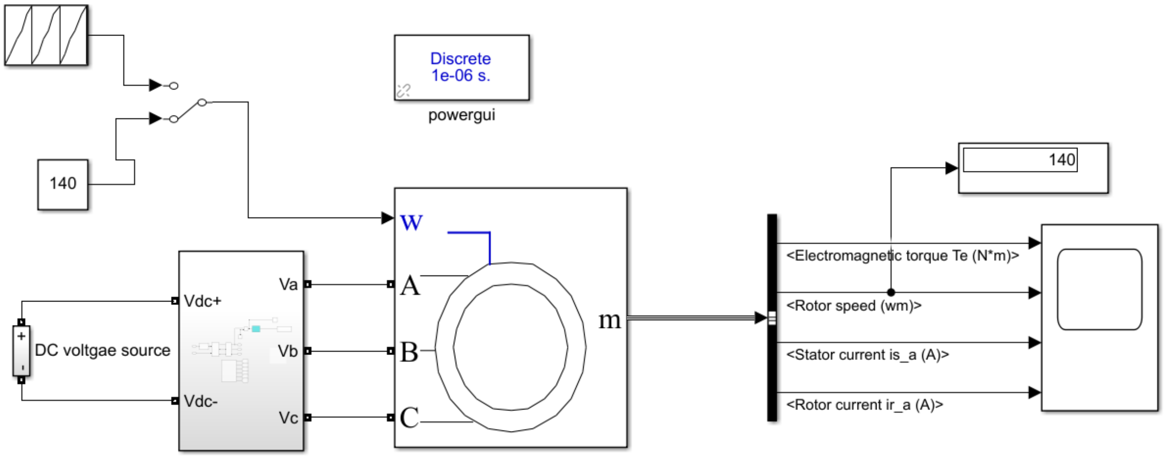


Fig.(5.4.a)open loop control of ZSI in constant speed control

Results:

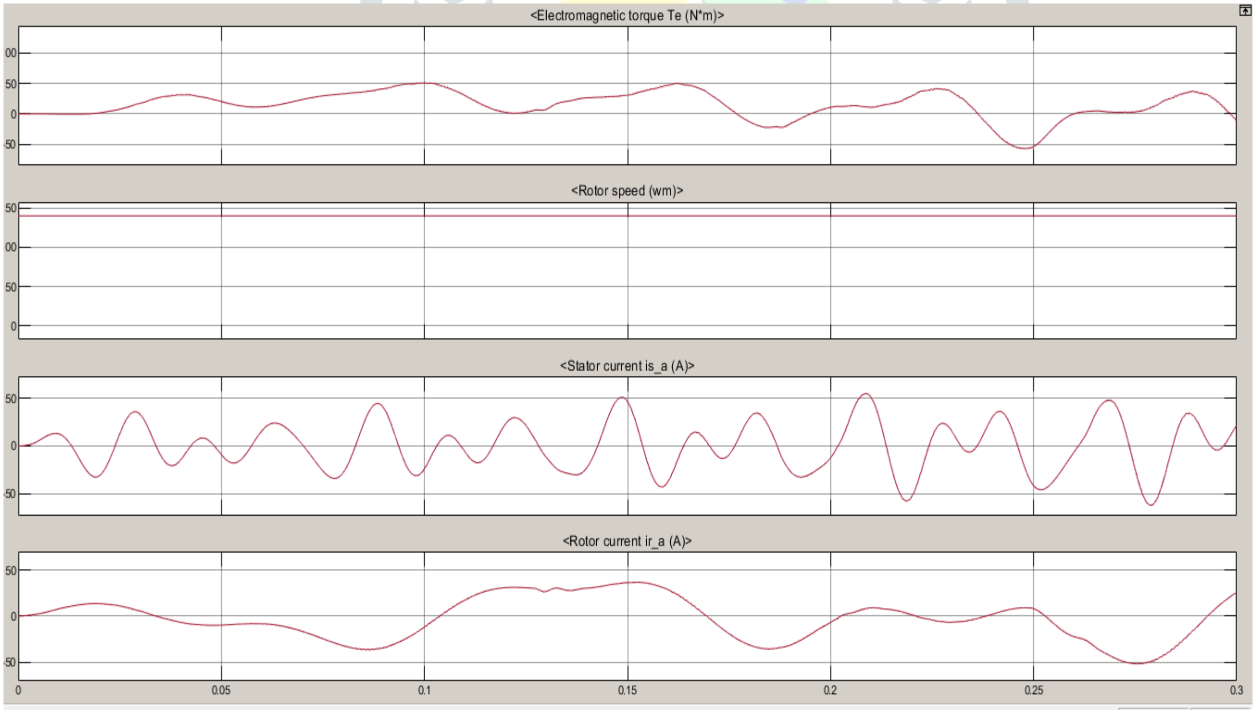


Fig.(5.4.b)Output of torque, rotor speed, stator current and rotor current of induction motor

Conclusion:

Acceleration mode: The pattern of speed in this mode is decreasing while the torque is increasing, this shows that the vehicle is accelerating linearly.

Constant speed mode: The pattern of speed and torque in this mode is nearly constant, which are approximately nearer to the desired values.

Braking mode: The pattern of speed in this mode is increasing while the torque is decreasing, this shows that the vehicle is perfectly operating in the braking mode. By this we can conclude that the ZSI based induction motor drive had performed satisfactory. The converter topology investigation for isolated dc dc converters revealed that the high gain topology if applied will lead to a better performance and safety for the EV drive.

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