# A Nine Switch Z-Source Inverter for Independent Control of Two Three-Phase Motors

Ruby Jose

*Department of Electrical and Electronics Engineering*
*Amal Jyothi College of Engineering, Kottayam, Kerala, India*

Reshmi V.

*Department of Electrical and Electronics Engineering*
*Amal Jyothi College of Engineering, Kottayam, Kerala, India*

**Abstract- Increased power demand in India due to the rapid industrialization necessitates the design of a system with low cost, reduced losses and higher efficiency. Large number of motors is required in industrial applications. Two methods of control exist for PM motors. These conventional methods have the problem of increased cost, complexity of apparatus and lack of independent control. Here a nine switch z-source inverter is introduced for controlling two ac loads with independent mode. It is used to boost up the voltage in a single stage. It has the advantage that the number of switching devices is reduced by two as compared to two three phase inverter. There is a wide range of applications for such inverter in electric vehicles, industrial robots, electric train, aircraft drive system, electric ship propulsion system etc.**

**Keywords – PM Motors, Nine Switch Z-Source Inverter,Methods of Control,Voltage Boost**

## I. INTRODUCTION

Converting DC input sources to AC output waveforms is most important in most of the electronics and electrical power applications. Inversion of power is the change of DC power to AC power at a desired output voltage or current and frequency. A static semiconductor inverter circuit does this electrical energy inverting transformation. The terms voltage-fed and current-fed are used in relation with the output from inverter circuits. Conventionally, inverters are classified into two broad categories – voltage source inverter (VSI) and current source inverter (CSI).

In a VSI, the DC input voltage has to be kept constant and is also independent of the load current drawn. The inverter dictates the load voltage while the drawn current shape is specified by the load. These topologies are widely used because they behave as voltage sources naturally as required in many industrial applications, such as adjustable speed drives (ASDs), which are the most famous application of inverters. Similarly, these structures can be used as CSIs, where the independently controlled AC output is a current waveform. These structures are widely used in medium-voltage applications, where good-quality voltage waveforms are required. Static power converters, mainly inverters, are constructed from power switches and the AC output waveforms are therefore constructed of discrete values.

Permanent magnet (PM) motors are regarded as an interesting solution for wide range of inverter-fed variable speed drives. The use of permanent magnet synchronous motors (PMSMs) is spreading in industrial field. This increased interest in PM motors has led to the investigations on their feasibility for vehicle propulsion. PMSM has been widely used in many industrial applications such as robots, rolling mills and machine tools. [3] They have advantages like high efficiency compared with dc motor and induction motor, high power factor, less weight, high power density and maintenance free operation. [4] A variety of these motors are needed for factory applications like manipulating industrial robots.

A PMSM is an AC electric motor that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets. The rotors are driven by the stators through a synchronous rotational field generated by the three-phase currents passing through the stator windings. There are two methods to control dual PM motors. One method is to provide two separate inverters to drive each motor. This method makes the experimental apparatus complex and expensive. The second method of controlling two PM motors is by connecting the two motors in parallel and driving them with a single inverter. The demerit of this method is that it does not allow independent control of two motors due to the rotor angle differences between the two motors. There are many different modulation techniques for controlling an inverter. Here the focus is given to sinusoidal pulse width modulation as it has proven successful and relatively easy to implement in the control system.

Presently, three phase motor drives with three phase voltage source inverters (VSI) are spreading widely in industrial fields. The inverter is the power converter that converts dc power to AC power. The use of inverter is increasing more and more in recent years because the inverter is necessary to realize the variable speed, variable torque and rotor position of three-phase ac motor. The ac motors have advantages of saving space, saving weight and high efficiency compared with dc motors that is employed in industrial area. Generally, the independent drive of two ac motors which are two three-phase induction motors(IM) or two three-phase PMSM motors are required in driving electrical or hybrid vehicle, machine tools etc. Pulse width modulation (PWM) is a common technique for speed control which can overcome the problem of poor starting performance of a motor.

One of the advantages of parallel motor drive by one large power capacity inverter is the reduction of number of inverters and system cost. Multiple numbers of parallel connected motors can be controlled by a large power capacity inverter. Here a nine switch converter is introduced that can independently control two three-phase loads. Nine switch inverter consists of two three phase inverters combined with three common switches. The upper portion and lower portion are treated as two inverters. PWM generates gate signals for these inverters by comparing two reference waves and a carrier wave. The objective of this work is to obtain the independent control of two three-phase loads with reduced switching count and cost of implementation.
Generally one inverter will drive one motor at a time and is called single machine single converter system. Traditionally dual motor drive requires two inverters with coordinated control and this will make the system expensive and cause large size of packaging for the inverter. The advancement of technology in traction and industrial applications such as for electrical railways and steel processing have resulted in the requirement of one inverter to drive multiple motors connected in parallel. The main features of this drive are cost performance, compactness etc. The railway traction drive where two or four motors operate in parallel is one of the practical examples of this application.

PMSM is widely used in low and mid power applications such as computer peripheral equipment, robotics, adjustable speed drives and electric vehicles. There are two methods to control dual PM motors: 1) By providing two separate inverters to drive each motor 2) By connecting the two motors in parallel and driving them with a single inverter.

Many researches on a dual PMSM single inverter system have focused on a parallel connection of two motors. [1] In the case of PMSMs, since each pole position of the PMSM is different to each other, the motor current cannot be controlled to match the rotational co-ordinates by using only one inverter. Therefore, it is difficult to drive the parallel connected PMSMs by using only one inverter, due to the occurrence of the each phase differences between the rotational co-ordinates of the inverter and the PMSM. In that case, the torque vibration occurs due to the resonance between a synchronous reactance and the inertia moment of the motor. Therefore, the torque vibration needs to be suppressed in order to drive the PMSMs in parallel.

While designing power electronics circuitry the focus is given to the reduction in number of active and passive elements. Power electronic inverters and control circuits are needed for these two drives. Traditionally, two separate drives, each employing a three-leg inverter, are used to gain independent control. The first step in the control of two motors was two separate three phase inverters for controlling each motor. As mentioned earlier the disadvantage of this method is that it increases the component cost and size.

Due to its advantages many configurations utilizing reduced switch count has been reported in the literature. For instance in mobile robot motorization two four switch inverters connected back to back, sharing a single-split dc-link capacitor leg to feed two three-phase motors were used. But for applications were the motor needed to be operated at different speeds and current levels this method cannot be used. This is due to the voltage fluctuation in the dc bus, single phase circulating currents through the dc link capacitor, large volume, high cost as well as reliability concern.

Next step in this field was a five leg inverter which adopts a sharing configuration, where two three phase motors are controlled by four independent phase legs and a fifth shared phase leg. Five leg inverters uses ten switches whereas one switch is less in nine switch inverter. [6]

Nine switch inverters have the advantage of reduced component count compared with five leg inverter. This topology also has the merits like low cost, easy control and reliability. In this topology the switch count is reduced by one compared with the previous modification and by three when compared to the conventional method. Thus the components required for gate driver circuit is also reduced, i.e. cost is comparatively less.

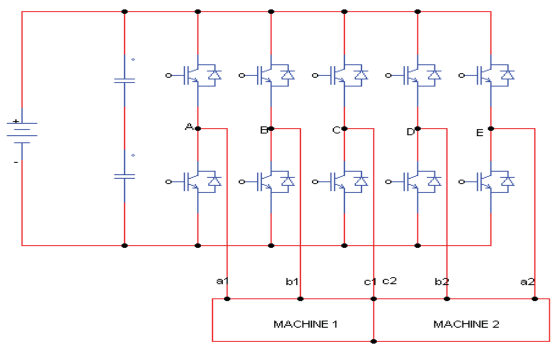



Figure.1: Main Circuit of Five Leg Inverter

The five-leg VSI supplies two three phase ac machines. Two machines share the inverter leg C. Inverter legs A and B are connected directly to phases a1 and b1 of the machine 1. Inverter legs D and E are connected to the phases a2 and b2 respectively of the machine 2.

Then a nine switch inverter comprising of nine semiconductor switches was developed. It eliminates three switching devices from the dual three phase inverter. The nine switch inverter is composed of two converters with three common switches between them.

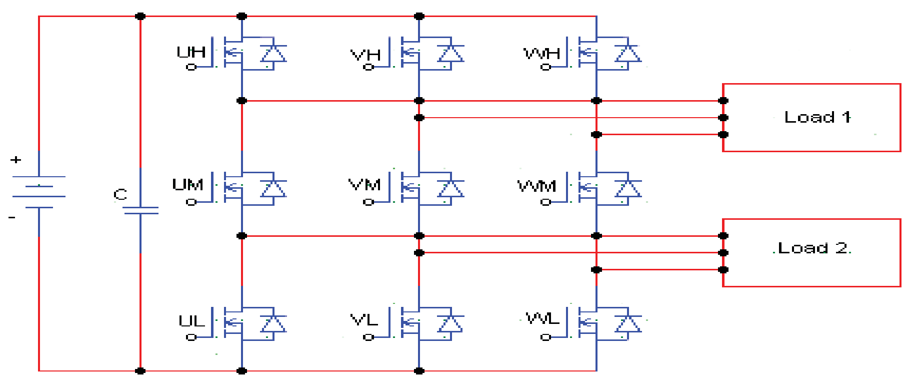



Figure.2: Main Circuit of Nine Switch Inverter

This paper proposes a nine switch z-source inverter which is beneficial when compared to all the topologies discussed so far in the literature. The carrier-based PWM control method is employed here. The validity of this method is verified through simulations.

## II. TOPOLOGY OF NINE SWITCH Z-SOURCE INVERTER

Z-source employs a special impedance network (or circuit) that connect the voltage source converter and current converter main circuit to the power source, load, or another converter, for providing special features that cannot be seen in the conventional voltage source and current source converters where a capacitor and inductor are used, respectively.Nine switch converters are formed by tying three semiconductor switches per phase giving a total of nine for all three phases.

*A. Basic Concept*

Nine switch inverters consist of two three phase inverters along with three common switches. The upper portion in the figure 2 is called as inverter 1 and lower portion is called inverter 2. Inverter 1 consists of the switches UH, VH, WH, UM, VM and WM, whereas inverter 2 consists of UM, VM, WM, UL, VL and WL switches. Thus it is clear that the middle switches UM, VM and WM are shared by the inverters 1 and 2 **[1].** The Z source concept is applicable on all DC-to-AC, AC-to-DC,AC-to-AC and DC-to-DC power conversion.

The configuration of a ZSI consists of two inductors, two capacitors, dc source, Inverter or load and converter. For speed control suitable controllers are also employed.The utilization of ZSI in industrial applications greatly increases the reliability by allowing only lower inrush current; lower harmonic injection and high immunity to Electromagnetic Interference (EMI) noises. In a conventional VSI, the switching of the same phase-leg switches will cause a short circuit or shoot-through which will damage the device. This limitation can be overcome by ZSI. With the use of impedance source network in ZSI, there is no shoot-through problem. Also voltage level higher than input voltage can be obtained which is not possible in conventional VSI without using boost converter. The main feature of z-source is implemented by providing gate pulse including the shoot-through pulses.

*B. Basic Circuit for Pulse Generation*

Carrier based Pulse width modulation is used here. Here how to insert this shoot through state becomes the key point of the control methods. It is obvious that during the shoot-through state, the output terminals of the inverter are shorted and the output voltage to the load is zero. The output voltage of the shoot through state is zero, which is the same as the traditional zero states, therefore the duty ratio of the active states has to be maintained to output a sinusoidal voltage, which means shoot-through only replaces some or all of the traditional zero states. The three-phase ZSI Bridge has nine permissible switching states unlike the traditional three-phase VSI that has eight. The gate signals for upper switches UH, VH, WH are generated by comparing the upper reference wave with the carrier wave in the comparator. The gate signals for lower switches UL, VL and WL are obtained by comparing the carrier signal and lower reference signal. And the gate signals for the middle switches are generated by taking the logical XOR of the gate signals generated for the upper and lower switches.

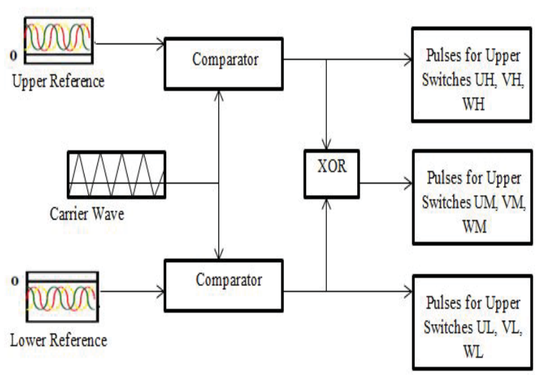



Fig.3: Block Diagram for Pulse Generation

When the upper sine wave reference exceeds the carrier wave the pulses for the upper switches UH, UV and WH are generated. If the lower reference is less than the carrier signal then the pulses for lower switches are produced respectively.

*C. Method of Realization*

For controlling the output voltages of the nine switch inverter two sinusoidal reference signals are required. Let U-phase reference for inverter 1 be$V_{u1}^{ref}$ and a U-phase reference for inverter 2 be $V_{u2}^{ref}$. Now assume that $V_{u1}^{ref}$ and $V_{u2}^{ref}$ are given by,

$V_{u1}^{ref} = A_1 \sin(2\pi f_1 t + \varphi_1)$ (1)
$V_{u2}^{ref} = A_2 \sin(2\pi f_2 t + \varphi_2)$ (2)

Where, $A_1$, A2, f1, f2, φ1, φ2 are amplitudes, frequencies and phases respectively. General modulation rate, m is given by

$$m = \frac{V^{ref}}{\frac{E}{2}} \quad (3)$$

Where, E is a dc source voltage. While calculating the proposed pulse width modulation an offset of $\frac{-E}{4}$ and $\frac{E}{4}$ is added to the references in equations (1) and (2). Thus,

$$m_{1u} = \frac{Vu1ref + E/4}{E/2} = \frac{Vu1ref}{E/2} + \frac{1}{2} \quad (4)$$

$$m_{2u} = \frac{Vu2ref - E/4}{E/2} = \frac{Vu2ref}{E/2} - \frac{1}{2} \quad (5)$$

From these equations the range of the references for inverter 1 and 2 become $-E/4 \leq V_{u1}^{ref} \geq +E/4$ and $-E/4 \leq V_{u2}^{ref} \geq +E/4$. [1]

The gate signals for the switches UH, VH and WH are positive logic values. The gate signals for lower switches are obtained by comparing the carrier wave and the lower reference wave. The gating signal for the middle switches is produced by taking the XOR of the signals obtained for upper and lower switches.

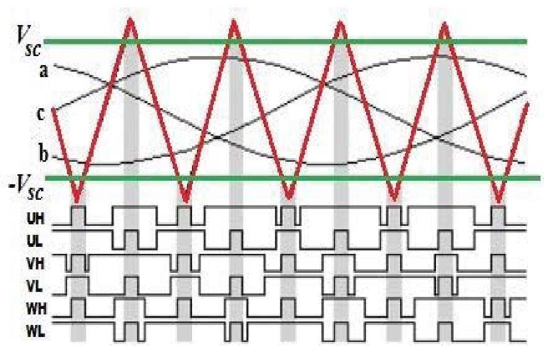



Fig. 4: Principle of Operation of a Nine Switch Z-Source Inverter

Here in the figure 4, $V_{sc}$ and $-V_{sc}$ indicates the shoot-through figure lines. The pulses for the upper and lower sets of switches are shown in the above figure. The upper sets of switches are UH, VH and WH and lower set is UL, VL and WL. In a nine switch z-source inverter if the upper switch is ON, the shoot through pulses for lower switch is generated by comparing the carrier wave with the upper shoot-through figure line. If the carrier wave is greater than the upper shoot-through signal $V_{SC}$ then the shoot-through pulses for the lower switch is produced. Similarly if the lower switch is ON, the shoot-through pulses for upper switch is produced by comparison of carrier wave and lower shoot-through signal $-V_{SC}$. Here if the carrier wave is lesser than the lower shoot-through signal $-V_{SC}$ then the shoot-through pulses for the upper switch is generated.

Closed loop system is fully automatic control system. The control depends on the output of the motor. Based on the speed of the motor the control signal is varied. The result is not disturbed in presence of non -linearity because it consists of feedback mechanism. By doing closed loop system the result is more accurate and reliable. The closed loop system clears the error between input and output signals. Hence the system remains unaffected to any load variations. The complexity is reduced and efficiency is increased.

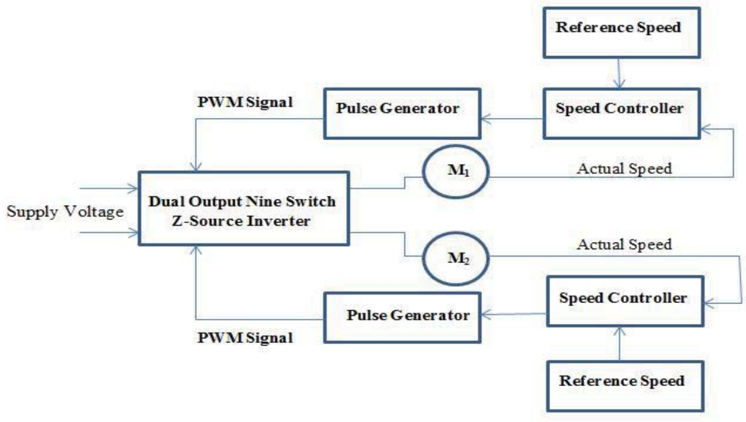



Figure.5: Overall Block Diagram of the Work including the Speed Control

The above figure shows the overall work where an z-source inverter is used to control two three phase loads. As a supplementary work the speed control of the motors is also tried out.Under traditional PWM operation when there is no shoot-through, the capacitor voltage is always equal to the input voltage. At this condition there is no voltage across the inductor and only a pure DC current goes through the inductor. The purpose of inductor is to limit the current ripple through the devices during boost mode shoot-through. During shoot-through the inductor current increases linearly and the voltage across the inductor is equal to the voltage across the capacitor. During non-shoot through modes voltage across inductor is the difference between input voltage and capacitor voltage.

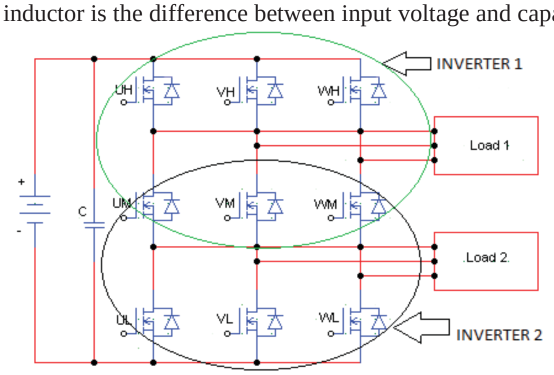



Figure 6: Nine Switch Inverter Representing Inverter 1 and Inverter 2 configuration

This operation based on the modulation can be divided into two modes. In the mode 1, the inverter 1 is driven and the switches UL, VL and WL are in the ON state. Inverter 2 is driven in the mode 2 and then the switches UH, VH and WH are in the ON state.

## III.SIMULATION ANALYSIS

The simulation of nine switch inverter for the control of two PMSMs, with and without z-source was done. The rotor speed, electromagnetic torque and stator current of both motors are obtained for both the cases. The output line voltages of both the upper and lower inverter portions with and without z-source was obtained and analyzed.

Table 1: Simulation Parameters for Nine Switch Inverter

| Component | Parameters | Value |
|---|---|---|
| PMSM | d-axis inductance | 0.0085 H |
| | q-axis inductance | 0.0085 H |
| | Pole pairs | 4 |
| | Torque constant | 1.05 Nm/A |
| | Stator Resistance | 2.875 Ω |

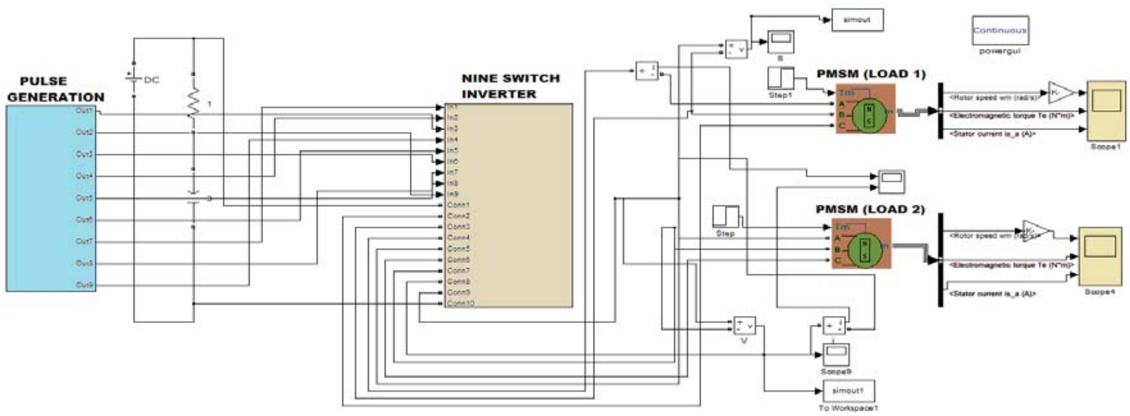



Fig. 6: Simulation Circuit for Nine Switch Inverter

The simulation circuit of nine switch inverter is shown in which two PMSM motors are driven by using a nine switch inverter.

Table 2: Simulation Parameters

| | | |
|---|---|---|
| Z-Source Network | Capacitance | 384.6µF |
| | Inductance | 100 µH |
| | DC input voltage | 250 V |

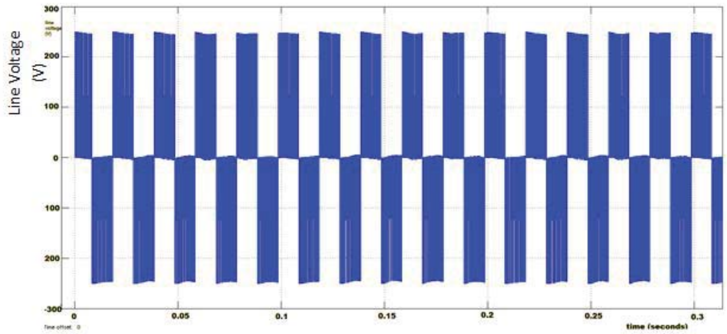
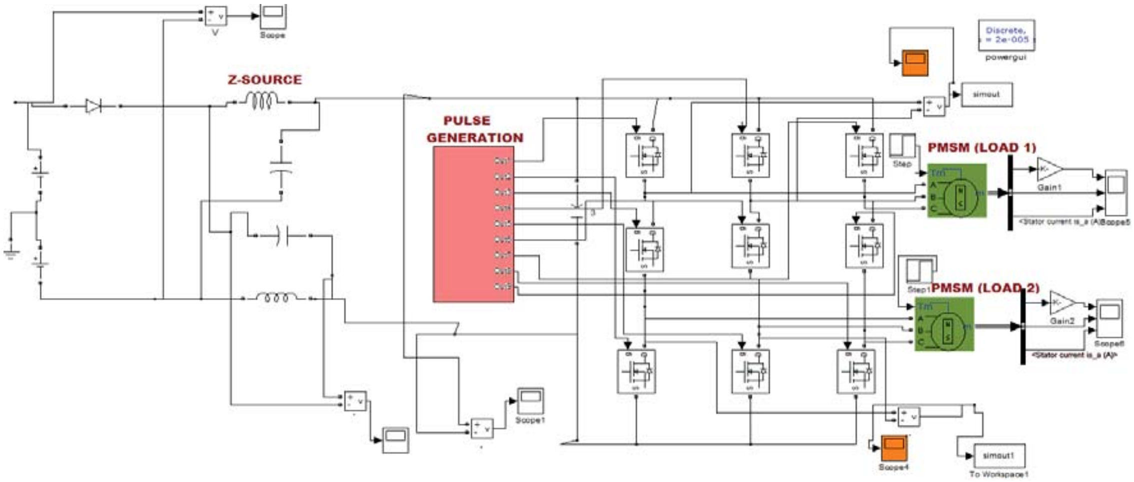



Figure 7. Output Line Voltage Waveforms of Upper Inverter of a Nine Switch Inverter




Fgure.8: Simulation Circuit for Nine Switch Z-source Inverter

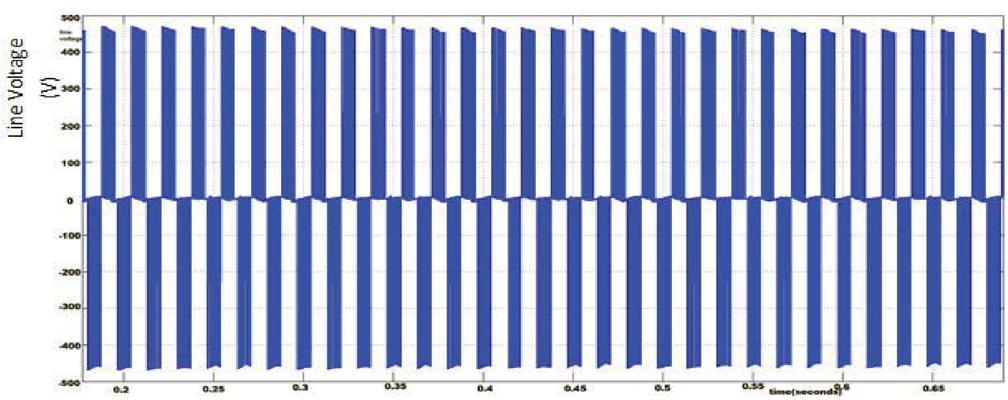



Figure.9: Output Line Voltage Waveforms of Upper Inverter of a Nine Switch Inverter

From fig.7,it is clear that the output line voltage is almost equal to the input dc voltage.

## IV.RESULT AND CONCLUSION

A nine switch z-source inverter which controls two motors boost up the voltage in a single stage. The boosting up of voltage by a boosting factor of 1 .78 is obtained using a z-source at its front end. The rotor speed, electromagnetic torque and stator current is obtained for nine switch inverter and nine switch z-source inverter. From the output voltages it is clear that without any additional boost converter stages boosting is done in a single stage using a nine switch z-source inverter. The figure below shows that the speed control of two motors is done. Here the reference speed is taken as 400 rpm in the simulation. PI controller is used for speed control of both the motors.

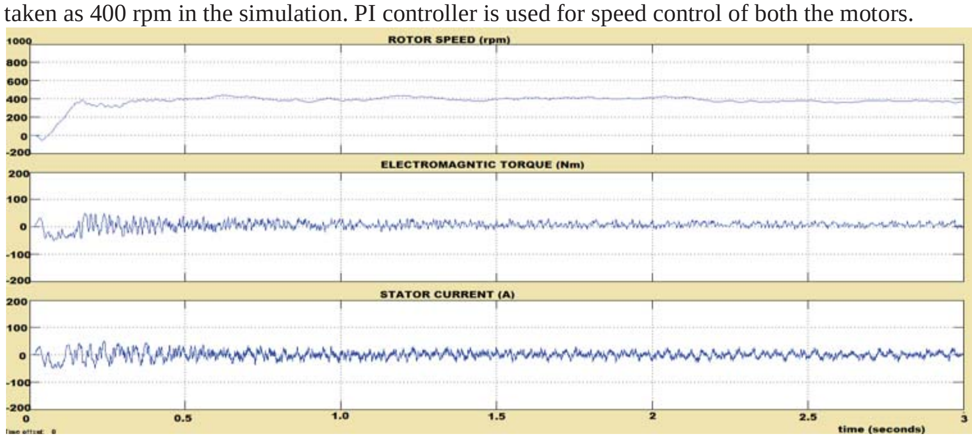



Figure.10: Rotor speed, electromagnetic torque and stator current of two motors using Nine switch z-source inverter

ACKNOWLEDGMENT

The authors would like to thank the enormous support of the EEE department and college authorities. However, it would not have been possible without the kind support and help of many individuals and organizations. Hence we would like to extend our sincere thanks to all of them. We would like to express our sincere gratitude to our institution for their co-operation and encouragement which have helped us in completion of this work. Our thanks and special gratitude also go to our colleagues in developing this project study and people who have willingly helped us out with their abilities and contributions.

REFERENCES

[1] T. Kominami and Y. Fujimoto, “A novel three-phase inverter for independent control of two three-phase loads,” in *Proc. IEEE-Ind. Applicat. Soc.(IAS)s*, 2007, pp. 2346–2350.

[2] Bose, B.K (2002). Modern Power Electronics and AC Drives. Upper Saddle River, NJ: Prentice Hall PTR

[3] Kamel, H.M., Hasanien, H.M., and Ibrahim, H.E.A., ``Speed control of permanent magnet synchronous motor using fuzzy logic controller.” IEEE Electric Machines and Drives Conference, 2009,1587-1591.

[4] L. Zhang, P.C Loh and F. Gao, “An Integrated nine switch power conditioner for power quality enhancement and voltage sag mitigation,” IEEE Transactions on Power Electronics,vol.27,no. 3, pp. 1177-1190, Mar. 2012.

[5] Nokawa,Oka,Omata and Matsuse,.:“Performance for Position Control of Two Permanent Magnet Synchronous Motors with the Five Leg Inverter.”,IEEE Industrial Electronics,IECON,pp.1182-1187,2006.

[6] P.M.Kelecy and R.D.Lorenz,“Control methodology for single inverter,parallel connected dual induction motor drives for electric vehicles,” in *IEEE 25$^{th}$ Annual Power Electronics Specialists Conference,PESC ’94 Record*, 1994, vol. 3, pp. 987-991.

[7] G.J. Su ,J.S Hsu,"A Five-Leg Inverter for Driving a Traction Motor and a Compressor Motor ",IEEE Transactions on Power Electronics,Vol.21,No.3, May 2006, pp.687-692.

[8] P.C Loh, F.Gao and F.Blaabgerg, “Topological and modulation design of three-level z-source inverters”,IEEE Transactions on Power Electronics,Vol.23,No.5,September 2008.