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Four Switch Three Phase Inverter with Modified Z-Source

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Abstract— The proposed topology combines the advantages of a traditional four switch three phase inverter with the advantages of z-source impedance network. This system gives new inverter configuration which can perform the operation of a chopper and voltage source inverter with low cost and maximum power. And also switching stress is reduced by the switched inductors concept, which will cause the equipment ageing. Here the current can flow in the zero vectors also, because any one of the three phase is connected to the midpoint of the two dc link capacitors. The need for variable speed infuses a greater focus to invite state of art control mechanisms. It is the ability of closed loop algorithm that allows the motors to enjoy speed control over a designed operating range. The results were obtained by using the MATLAB simulation.

IndexTermst; z source inverter, four switch three phase inverter, voltage sags.

I. Introduction

The variable speed drive (VSD) continues to evolve as a technology and recognize the entire perspective of the drive industry. The primary function orients to convert electrical power to the usable form for controlling speed, torque and direction of ac motor. The emergence of power electronic converters espouses a new dimension and provides and provides measures to arrive at the sophisticated nature of utilities. Though the hosts of methods are in existence to control the speed of the drive motors, still better techniques are required to effectively assuage the preferred speed and meet the needs of new and existing circuit applications. To reduce the cost of the inverter and to boost up the voltage, this switched inductor z-source four switch inverter which gives the chopper operation includes and provides the good solution. These switched inductors are mainly used to high boosting the voltage operation and protect the switches during the shoot through period. To achieve high level boost conversion without using chopper, this converter was designed. In a traditional voltage source inverter, the two switches of the same phase leg can never be gated on at the same time, because, that operation would cause a short circuit (shoot-through) to occur that would destroy the inverter. And also there is no greater output voltage than the input DC bus voltage. These drawbacks can be overcome by the new four switch three phase modified Z-source inverter that uses an impedance network (Z-network) to replace the traditional dc link.

The Z-source inverter beneficially infuses the shoot-through states to step up the dc bus voltage by gating on both the switches of a same leg. Therefore, the modified Z-source inverter can step up step down the voltage to a desired output voltage that is greater than the given input dc bus voltage. The reliability of the inverter is improved to protect the circuit; during shoot through state the circuit should not be destroyed. Thus it offers high reliable, low-cost and single-stage structure for buck boost power conversion. Conventionally, three phase, six switch inverters have been widely employed for variable speed induction motor drives. These conventional inverters have few de merits, that are the losses of the six switches, the complexity of the control algorithms and gate drive circuits to provide six PWM logic signals. Some efforts have been made on the application of four switch, three phase inverter for uninterruptible power supply and variable speed drives recently. Few merits of the four switch three phase inverter over the traditional six switch three phase inverter such as, lower cost due switch reduction, minimized switching losses, fewer gate drive circuits to supply logic signals for the switches, easiest control algorithms to produce PWM signals, very less chances of damaging the switches due to lesser interaction among switches. The four switch three phase inverter with modified Z-source shown in Fig.1, that employs the modified impedance network to replace the conventional dc link. The four switch three phase inverter with modified Z-source beneficially uses the shoot-through states to increase the dc bus voltage by gating on both the switches of a same leg. Currently, there are two existing inverter topologies used for adjustable speed drives; The conventional three phase PWM inverter and three phase PWM inverter with a dc-dc boost Converter. The conventional PWM inverter topology produces high stresses to the switching devices and motor and the constant power speed ratio of the motor can be limited. The dc to dc boosted output with PWM inverter topology can gradually reduce the stresses and limitations, though the stresses are alleviated, it suffers from the problems such as high cost and more complexity included with the two-stage power conversion. The newly proposed four switch three phase modified Z-Source Inverter fed IM drive has the great feature that it can boost up the output voltage by applying shoot through state, which was not employed in traditional voltage source inverters. This great featured four switch three phase modified Z- source inverter provides a cheaper, simpler, single stage approach for applications of induction motor drives systems.

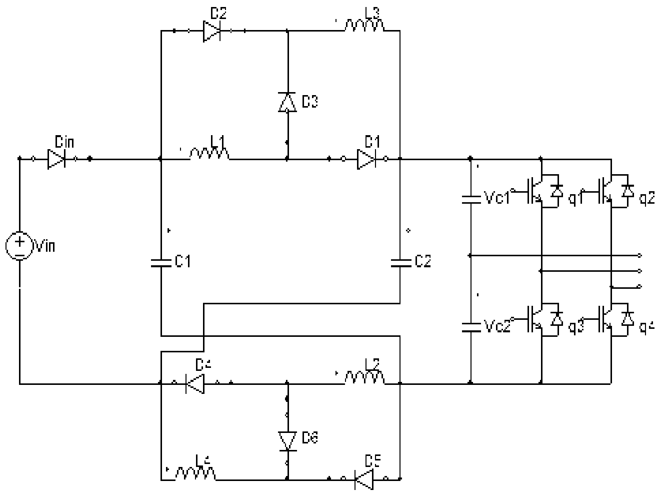

Fig.1four switch three phase inverter with modified z source Inverter

II. MODELING OF THE DRIVE SYSTEM

A. Four switch three phase inverter model

The full drive system modeling has the modeling of the inverter and modified Z source inverter that are discussed in below

The main power circuit of the four switch three phase inverter fed induction motor drive is shown in Fig.2. four switches q_1, q_2, q_3 and q_4 and DC link capacitors C_1 and C_2 are employed in this circuit. The three phase AC supply is rectified by the converter switches. The rectified output connected to the modified z source. The modified z source is connected with the power circuit. Phase 'a' and 'b' are taken from legs, which have the switches. Phase 'c' is connected in the midpoint of the two dc link capacitors. Four switches or diodes are generated the line to line voltages, V_{13} and V_{23} whereas V_{12} is generated according to Kirchhoff's voltage law from a split-capacitor bank in the dc-link. The conduction states of the power switches are included with binary variables from q_1 to q_4. Therefore, a binary value 1 indicates a switch is on, while 0 indicates the switch is in off. The complementary pairs are q_1q_3 and q_2q_4 and, as a consequence, $q_3 = (1-q_1)$ and $q_4 = (1-q_2)$. The assumed stiff voltage available across the two dc-link capacitors, are $V_{c1} = V_{c2} = \frac{V_{dc}}{2}$, where V_{dc} corresponds to a stiff dc-link voltage. The pole voltages V_1, V_2, V_3 are depending on the switching states of the power switches in the inverter. They can be expressed in terms of the binary variables q_1 and q_2, and the dc-link voltage as follows

$$V_1 = 2q_1 - \frac{v_{dc}}{2} \quad \text{......... (2.1)}$$

$$V_2 = 2q_2 - \frac{v_{dc}}{2} \quad \text{......... (2.2)}$$

$$V_3 = 0 \quad \text{......... (2.3)}$$

(0, 0), (0, 1), (1, 0), and (1, 1) are the four switching states of the four switch three phase inverter. Here the motor load is replaced by the resistive load. In the case of the six switches converter, switching states (0, 0) and (1, 1) are represented as zero-vectors, these zero vectors cannot supply the dc-link voltage to the load, so that current cannot flow through the load. In this four switch three phase inverter, any one phase of the motor is always connected to the midpoint of the dc-link capacitors, so that current can flow through the load even at the zero-vectors. During the switching states of (0, 1) and (1,0) the phase which is connected to the midpoint of dc-link capacitors is uncontrolled and the resultant current of the other two phases flow through this phase.

The capacitor voltages are equal when the load is ideally symmetric. So that, during (0, 1) and (1, 0) vector states current cannot flow. The large variations of the voltage across the two dc-link capacitors caused by one phase current circulating through the capacitive bank, That will make the inverter output current to get significant ripples, distortions, and unbalances. The unequal loading of the split dc link capacitors can be achieved by Two of the inverter switching states (1, 1), (0, 0). This causes one half of the link to discharge at a faster rate than the other, resulting in the generation of a voltage imbalance.

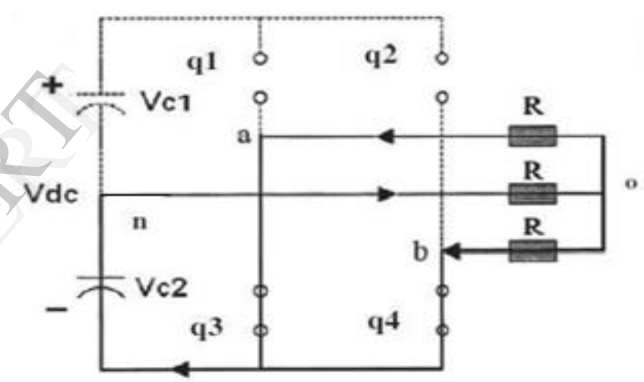

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Fig.2. Inverter Switching State (0,0)

$$V_1 = V_2 = \frac{-v_{dc}}{2}, \text{when } q_1 = q_2 = 0;$$

$$V_1 = \frac{v_{dc}}{2}, V_2 = \frac{-V_{dc}}{2}, \text{when } q_1 = 1, q_2 = 0;$$

$$V_1 = V_2 = \frac{V_{dc}}{2}, when\ q_1 = q_2 = 1;$$

$$V_1 = \frac{-V_{dc}}{2}, \qquad V_2 = \frac{V_{dc}}{2}, when\ q_1 = 0, q_2 = 1;$$

The phase to neutral voltage can be defined as follows:

$$V_{01} = V_1 - V_{n0} \quad \text{......... (2.4)}$$

$$V_{02} = V_2 - V_{n0} \qquad \text{… … …} (2.5)$$

$$V_{03} = V_3 - V_{no} \qquad \text{… … …} (2.6)$$

Normally the induction motor load phase voltages are balanced

$$V_{an} + V_{bn} + V_{cn} = 0$$

$$V_{n0} = \frac{V_{dc}}{6}(2q_1 + 2q_2 - 2) \qquad \text{… … …} (2.7)$$

The phase to neutral voltage can be derived as follows
Substituting Equations (2.7) and (2.1) in (2.4)

$$V_{01} = V_1 - V_{n0}$$

$$V_{01} = \frac{V_{dc}}{6}(4q_1 - 2q_2 - 1) \qquad \text{… … …} (2.8)$$

The same procedure is followed to arrive at V_{02} and V_{03}

$$V_{02} = \frac{V_{dc}}{6}(4q_2 - 2q_1 - 1) \qquad \text{… … …} (2.9)$$

$$V_{03} = \frac{V_{dc}}{6}(-2q_1 - 2q_2 - 1) \qquad \text{… … …} (2.10)$$

TABLE 1 - Switching Functions and the Output Voltages from Inverter:

Switching Function		**Switch on**		***Output Voltage Vector***		
q1	q2	$T_1 = q_1, T_3 = q_2, T_4$ T_2		V01	***V02***	***V03***
0	0	T_2	T_4	$\frac{-V_{dc}}{6}$	$\frac{-V_{dc}}{6}$	$\frac{-V_{dc}}{3}$
0	1	T_2	T_3	$\frac{-V_{dc}}{2}$	$\frac{V_{dc}}{2}$	0
1	0	T_1	T_4	$\frac{V_{dc}}{2}$	$\frac{-V_{dc}}{2}$	0
1	1	T_1	T_3	$\frac{V_{dc}}{6}$	$\frac{V_{dc}}{6}$	$\frac{-V_{dc}}{3}$

The entries in Table1 relates to the output voltage vector corresponding to each switching function

B. Modified z source model

The modified z source inverter avoid the problems arised in the traditional source inverters. This z source inverter employs the switched inductor impedance network coupled with inverter main circuit to the power source. This inverter has unique features compared with traditional voltage source inverter and current source inverters.

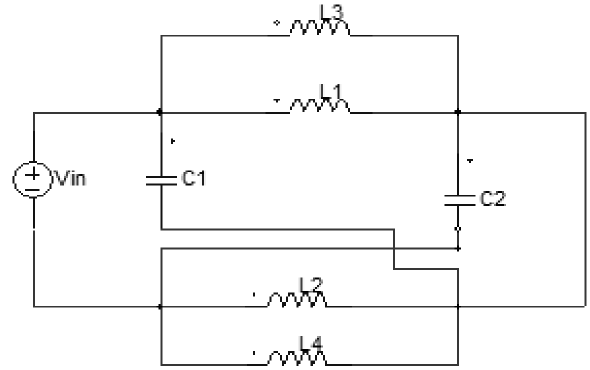

Fig. 3: Equivalent circuit of the impedance-source inverter

C. Analysis Of The Z-Source Network

In impedance network, four switch three phase inverter with induction motor load, the dc voltage is fed to the Impedance network consisting of four equal inductors (L1, L2, L3, and L4) and two equal capacitors (C1, C2). The network inductors are connected in series arms and capacitors are connected in diagonal arms. The modified Z network bucks or boosts the input voltage depending upon the boosting factor. This network also acts as a second order filter.. The inverter main circuit consists of four switches. Gating Signals are generated from the Discontinuous Pulse Width Modulation. Assume the inductors (L1, L2, and L3andL4) and capacitors (C1 and C2) have the same inductance and capacitance values respectively.

From the above equivalent circuit:
$V_{C1} = V_{C2} = V_C$
$V_{L1} = V_{L2} = V_{L3} = V_{L4} = V_L$
$V_L = V_C$
$V_d = 2V_c$
$V_i = 0$

The peak dc-link voltage across the inverter bridge is:
$V_i = V_C - V_1 = 2V_c - V_o = \frac{T}{T_1 - T_o}.V_o = B.V_o$

Where:
$B = \frac{T}{(T_1 - T_o)}$ i.e., $\geqslant 1$

B = A boost factor

The output peak phase voltage from the inverter:
$V_{ac} = M.\frac{V_i}{2}$
Where, M is the modulation index.
M≤1-D
where

$$M = \frac{amplitude\ of\ referencewaveform}{amplitude\ of\ carrier\ waveform}$$

In this source:

$V_{ac} = M.B.V_o/2$

In the traditional sources:

$V_{ac} = M.\frac{V_o}{2}$

For Z-Source:

$V_{ac} = M.B.\frac{V_o}{2}$

The output voltage can be stepped up and down by choosing an appropriate Buck-Boost factor (BB):

BB = B.M (it varies from 0 to α)

The capacitor voltage can be expressed as:

$V_{C1} = V_{C2} = V_C = \left(1 - \frac{T_0}{T}\right).V_o/(1 - \frac{2T_0}{T})$

The buck-boost factor BB is determined by the modulation index m and the boost factor B. The boost factor B can be controlled by duty cycle of the shoot through zero state over the non-shoot through states of the PWM inverter. The shoot through zero state does not affect PWM control of the inverter, because it equivalently produces the same zero voltage to the load terminal. The available shoot through period is limited by the zero state periods that are determined by the modulation index.

III. REQUIREMENT OF THE INDUCTORS AND CAPACITORS IN Z SOURCE NETWORK

In the traditional voltage source inverter voltage ripples are suppressed, in the current source inverter the current ripples are suppressed. The modified Z-source network is a combination of four inductors and two capacitors. In this combined circuit, the Z-source network is the energy storage/filtering element for the modified Z-source inverter. This modified Z-source network provides a second-order filter and is more effective to suppress voltage and current ripples than capacitor or inductor used alone in the traditional inverters. Therefore, the smaller inductors and capacitors are required compare than the traditional source inverters. Detailed design guide and formulae of the modified Z-source network will be presented in a near future paper. When the four inductors (L1, L2, L3 and L4) are small and near to zero, the Z-source network reduces to two capacitors (C1andC2) in parallel and becomes a traditional V-source. Considering additional filtering and energy storage provided by the inductors, the modified Z-source network should require less capacitance and smaller size compared with the traditional voltage source inverter. Similarly, when the two capacitors (C1 and C2) are small and near to zero, the modified Z-source network reduces to four inductors (L1, L2, L3 and L4) in series and becomes a traditional current source. Considering additional filtering and energy storage by the capacitors, the Z-source network should require less inductance and smaller size compared with the conventional current source inverter.

IV. RESULTS AND DISCUSSIONS

In order to verify the performance of the inverter configuration and its control strategy is developed by mat lab software. Induction motor current waveforms and voltage waveforms of the Four Switch three phase modified Z-Source inverter are identical conditions with traditional six switch three phase inverter. It is evident that starting phase current is in the acceptable range. The steady state three phase current shown in Fig. 5 indicates almost balanced conditions of the four switch three phase inverter which is also verified by six switch three phase inverter response. The effectiveness of the Z-Source Inverters is proven by no overshoot, no undershoot and zero steady-state error of the speed response. It is found that the performance of the four switch three phase inverter based drive is much close to that of the traditional 6 switches three phase inverter. The analysis and simulation results show that this inverter can dramatically reduce the complexity of the control algorithms and cost. Voltage stress of the inverter is reduced. This stress reduction will protect the inverter. So that this switched inductors type four switch three phase inverter reduced the switching stress and avoid the ageing in the drive system. The output voltage of the four switch three phase with modified z source inverter is shown fig.9. The three phase output voltage and current wave forms are shown in fig.5 and the speed curve of the induction motor is shown in fig.6. Here the induction motor acts as a three phase load.

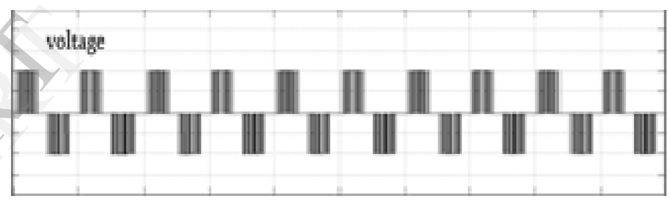

Fig 4 four switch three phase modified Z source inverter voltage wave form

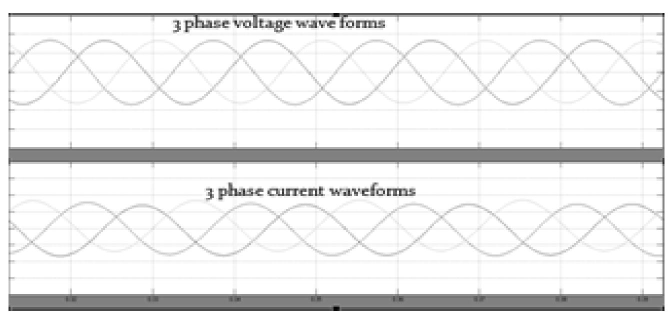

fig 5 output voltage and current waveforms

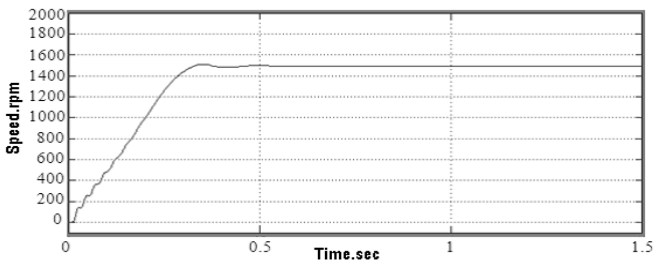

Fig 6 Four switch three phase modified z source inverter speed response

From the above three figures (fig 4, fig 5, fig 6)the concepts has been proven to design this switched inductor four switch three phase inverter which will reduce the total cost of inverter inclusive of chopper operation. The following table will show the performance of the proposed inverter. By grading the modulation index the output voltage is going to be controlled with boosted value.

TABLE 2 – Performance of Four Switch Three Phase Inverter With Modified Z source.

Modulation Index	***Input Voltage, In volts***	***Output Voltage, In volts***
0.2	59	72
0.3	59	81
0.4	59	130
0.5	59	147
0.6	59	162
0.7	59	180
0.8	59	188
0.9	59	191
1.0	59	200

Some the graph results are shown below, this graph results shown the compared output between two inverters and the gain improved. Grading and degrading will decide the control technique. The following results give the step up performance. The variations in capacitor and inductor having the step up and step down operation. By reducing the inductor value to zero, we can operate this inverter as voltage source inverter and also by degrading the capacitor value to zero; this inverter acts as current source inverter

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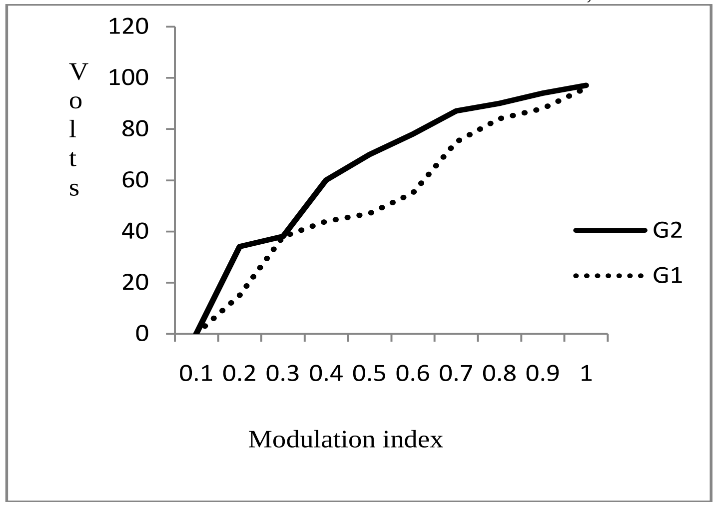

Fig.7. comparison between six switch (G1) and four switch three phase inverter (G2)

In fig. 7 the two inverter outputs are compared and it shows its performance. Here the input voltage is constant (100v). The output is varied with the modulation index

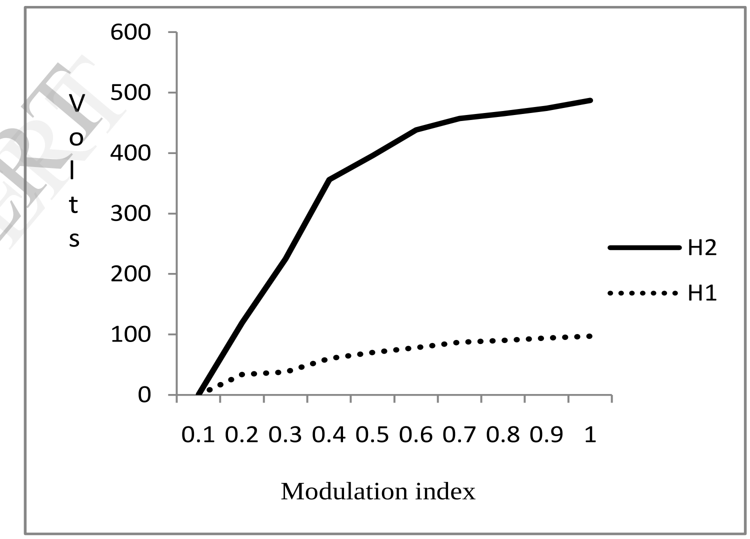

Fig.8. comparison between four switch inverters with (H2) and without (H1) modified Z source

In the above fig.8 the performance variations in the two inverters are shown.

H1-four switch three phase inverter without modified Z source
H2-four switch three phase inverter with modified Z source

For modulation index 1, the modified z source inverter output voltage is greater than the four switch inverter without modified z source.

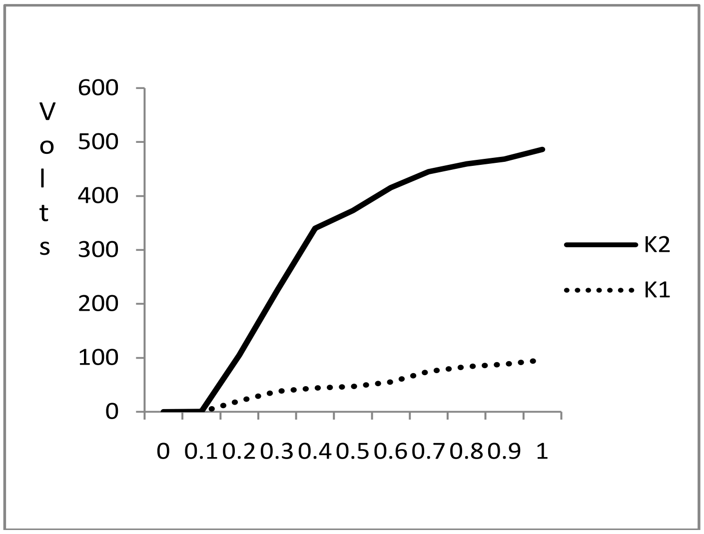

Fig.9. comparison between six switch inverter and modified z source inverter

K1-six switch three phase inverter output performance curve
K2-four switch three phase modified z source inverter output performance curve

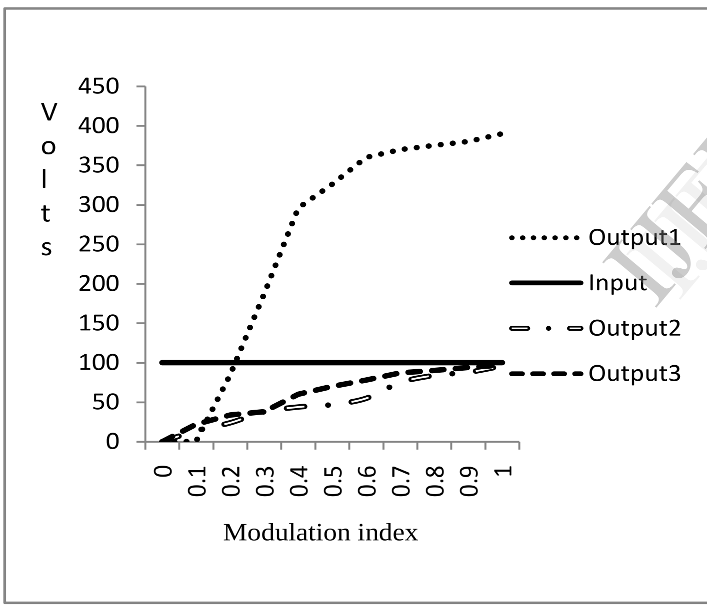

Fig.10. comparison of inverter output with the constant input voltage

Input- constant voltage (100v).
Output1-four switch three phase inverter with modified z source inverter.
Output2-six switch three phase inverter.
Output3-four switch three phase inverter without modified z source.

In fig. 7 the six switch three phase inverter(G1) and four switch three phase inverter without z source(G2) are compared, and performance shown as graph. From the fig 7 graph four switch three phase inverter having the similar performance of six switch three phase inverter. So that four switch three phase inverter is efficient one than the six switch inverter. In fig.8 four switch three phase inverter with(H2) and without modified z source(H1) are compared and the results are shown as graph. From this graph, four switch three phase inverter with modified z source having the more advantages than the without modified z source inverter. The inputs for the both inverters are constant (100v). From this graph, the modified four switch inverter has been proven to have better quality to boost up the voltage without the chopping circuit inclusive of fewer components. Present days the six switch three phase inverters are used, for that four switch three phase inverter modified z source (K2) is compared with the six switch inverter without z source (K1) in fig.9. By employing the modified z source the voltage can be boosted in high level because of the shoot through operation. Here also the output voltage can be controlled for our desired voltage value, by varying the modulation index and the boost factor. This boost factor is fully depends on the shoot through period. Three inverters output voltages are compared with the input voltage for various modulation indexes in fig.10. From these graph results this four switch three phase inverter has proved itself as a better inverter than others.

V. Conclusion

This study has demonstrated that the component minimized modified Z-source inverter topology is a good alternative technology to the traditional inverter for more efficient, more reliable and less cost conversion systems. The operating principle and analysis have been given the current harmonics content simulation results verified the operational and demonstrated the promising features. In summary, the component minimized Z-source inverter ASD system has several unique advantages that are very desirable for many ASD applications:

. • It can produce any desired output ac voltage, even greater than the line voltage
• Provides ride-through during voltage sags without any additional circuits and energy storage
• Minimizes the motor ratings to deliver a required power
• Reduces in-rush and harmonic current
• Unique drives features include buck-boost inversion by single power-conversion stage, improved reliability, strong EMI immunity and low EMI.

The Z-source converter employs unique impedance network (or circuit) to couple the inverter main circuit to the power source, thus providing unique features that cannot be observed in the traditional dc-ac converters. It can boost the input voltage without chopper circuit, increase efficiency and reduce cost with minimized gate component count. The switching stress is reduced, which will make the component to get premature to failure. So the switches are protected from the switching stress.

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