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Implementation of Cascaded Multicell Trans Z-Source Inverter Fed Induction Motor Drive with V/F Control

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ABSTRACT:

This paper proposes a new configuration of Z-source Inverter and also the implementation of conventional speed control method for the induction motor drive which is fed through the proposed inverter. Inverters with high-output voltage gain usually face the problem of high-input current flowing through their components. The problem might further be exaggerated if the inverters use high frequency magnetic devices like transformers or coupled inductors. Leakage inductances of these devices must strictly be small to prevent over voltages caused by switching of their winding currents. To avoid these related problems, cascaded trans-Z-source inverters are used. This paper also proposes a closed loop speed control of an induction motor fed by a high performance cascaded Trans Z-source inverter (ZSI), the speed control is based on V/F control strategy. Simulations are carried out in MATLAB/Simulink environment. It was observed that using a closed loop scheme with a proportional controller gave a very superior way of controlling the speed of an induction motor while maintaining a constant maximum torque.

I. INTRODUCTION:

Z-Source inverter is a single-stage converter performs both buck and boost energy conversions by utilizing LC-impedance network. Among voltage or current type Z-Source inverters, voltage-type Z-Source inverters are popular in motor drives, fuel cell and photovoltaic powered system. Though conventional voltage-source inverter can be used for above mentioned applications their voltage step-down operation makes them too perate at low modulation ratio. Hence results in poor harmonic performances. On the other hand, Z-Source inverters can be implemented with maximum modulation ratio. Any surge in every demand is balanced by varying the Inverter shoot-through time duration for gaining voltage boosting operation done in addition to voltage buck operation taken from conventional voltage source inverter. Many PWM schemes with lower switching loss and optimized harmonic performance have been used for controlling the Z-Source inverters. These schemes are developed by introducing shoot-through states to the conventional VSI sate sequences with more states to surface under low load or small inductance conditions.

The added states influence the produced voltage gain. Hence, it's harder to control. For reducing load influence, proper parametric tuning must be done in order to reduce the high-frequency current ripple within the circuit.Though parametric tuning is effective in stabilizing gain, it cannot remove the chopping current flowing in to the DC source and can affect the source characteristics. It is due to the high frequency operation of the input diode 'D' shown in fig.3 during voltage boost operation that can be filtered by placing a second-order LC filter before 'D' which in turn increase the overall cost of the system and produce unwanted dynamic and resonant complexities to the systems. Hence, instead of using an external LC filter, this project proposes an embedded Z-Source inverter where the input DC sources is embedded within the LC impedance net work, using inverter and capacitive elements for voltage filtering in current-type Zsource inverter. Despite these changes, the voltage or current gain of the system is constant. This Z-Source inverter can be used where source filtering is difficult. Nowadays, renewable energy applications are on greater demands, more particularly solar cell. A key component of PV generating system is the grid connected inverter. The transformer-less inverter topologies can be classified into two categories: two stage inverter topologies and single stage inverter topologies. System performance depends on local climate, the orientation and inclination of PV array and inverter performance. The traditional photo electric systems contain VSI and CSI. They are either buck or boost, but not buck-boost converter .The common problem of this topology is that their main circuits cannot be interchangeable and also shoot through will occur when any two switches of the same phase leg is turned on which is a major killer to converter's reliability.

To reduce the cost and to increase the system reliability Z-source inverter as a single stage transformer-less inverter topology is first proposed.By utilizing the unique LC network, a shoot-through zero state can be added toreplace the traditional zero state of the inverter and to achieve the output voltage boostfunction. Hence, Z-source inverter provides a feasible single stage power conversionconcept suitable for secondary energy source such as photo electric system as theyusually produce low variable DC voltage. Since its proposal, developments related to Z–source inverters have been taking place in various directions, covering its modulation,modeling, control and other topological inventions. But unfortunately, a closer view at the existing network would reveal that it causes chopping current to be drawn from thesource, if no explicit hardware filter is added.This chopping current not only raises the semiconductor current rating, but alsocomplicates the maximum power point tracking (MPPT) objective set for most renewableenergy sources.

In view, a new class of Z-source topologies, named as the embedded Z–source inverters, was proposed in, which however mainly focused on design of voltageand current type ZSI. The above literature does not deal with feedback controlmethodology for photovoltaic systems. This work plans to design, model and simulateopen loop and closed loop controlled ZSI fed induction motor powered by solar electricsystem with implicit source filtering and reduced capacitor sizing.

II. Traditional inverters:

Traditional source inverters are Voltage Source Inverter and Current SourceInverter. The input of Voltage Source Inverter is a stiff dc voltage supply, which can be abattery or a controlled rectifier both single phase and three phase voltage source inverterare used in industry. The switching device can be a conventional MOSFET, Thyristor, ora power transistor.Voltage source inverter is one which the dc source has small or negligibleimpedance. In other words a voltage source inverter has stiff dc source voltage at its inputterminals. A current-fed inverter or current source inverter is fed with adjustable dccurrent source. In current source inverter output current waves are not affected by theload.

A. Voltage source inverter:

When the power requirement is high, three phase inverters are used. When three single phase inverters are connected in parallel, we can get the three phase inverter. The gating signals for the three phase inverters have a phase difference of 120°. These inverters take their dc supply from a battery or from a rectifier and can be called as sixstep bridge inverter. Fig.1 shows the three phase voltage source inverter.

A large capacitor is connected at the input terminals tends to make the input dc voltage constant. This capacitor also suppresses the harmonics fed back to the source. The Voltage Source Inverter (VSI) is widely used.

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However, it has the some conceptual and theoretical barriers and limitations. The AC output voltage is limited and cannot exceed the AC input voltage. Therefore the Voltage Source Inverter is only buck (step down) inverter operation for DC to AC power conversion or boost (step-up) operation for AC to DC power conversion.

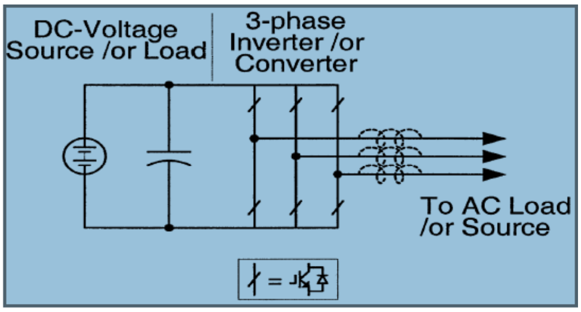

Fig.1. Voltage source inverter

For applications where over drive is desirable and the available dc voltage is limited, an additional dc-dc boost converter is needed to obtain a desired ac output. The additional power converter stage increases system cost and lowers efficiency. The upper and lower devices of each phase leg cannot be gate on simultaneously either by purposeor by EMI noise. Otherwise a shoot through problem by Electromagnetic interference noise's misgating on is major killer to the inverter reliability. Dead time to block both upper and lower devices has to provide in the Voltage Source Inverter which causes the wave form distortion, etc.

B. Current source inverter:

A Current Source Inverter (CSI) is fed from a constant current source. Therefore load current remains constant irrespective of the load on the inverter. The load voltage changes as per the magnitude ofload impedance. When a voltage source has a large inductance in series with it, it behaves as a Current Source .The large inductance maintains the current constant. The traditional three phase Current Source Inverter (CSI) structure is shown in Fig.2.

A dc current source feeds the three phase main inverter circuit. The dc current source can be a relatively large dc inductor fed by a Voltage Source such as a battery or a rectifier.

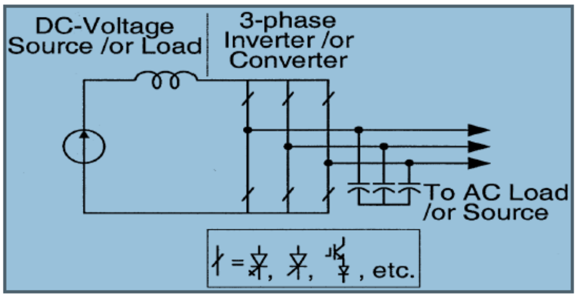

Fig.2. Current source inverter

It consists of six switches and with antiparallel diodes. This diode provides the bidirectional current flow and unidirectional voltage blocking capability.

C. Z Source Inverter:

It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter, for providing unique features that cannot be observed in the traditional V- and I-source converters where a capacitor and inductor are used respectively.

A two-port network that consists of a split-inductor and capacitors and connected in X shape is employed to provide an impedance source (Z-source) coupling the converter (or inverter) to the dc source to 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 anti parallel combination.

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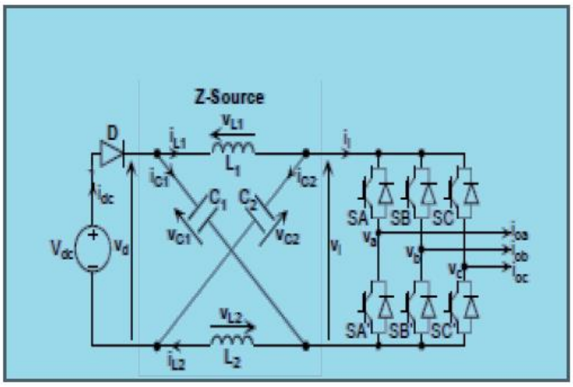


Fig.3.Z Source Inverter

Even though, Z source inverter is better than traditional inverters, there are some disadvantages present in Z-Source impedance network.

1. In Z-source inverter, inductances cause over voltages during switches commutation. Hence high rating of switches is needed in Z-source inverters design.
2. In some applications the efficiency of Z-source inverter lower than conventional two stage buck-boost systems.
3. In some applications Z-source inverter produces discontinuous input current and high values of di/dt due to that LC filter is needed in input side.

D. Z Source Current-Type Inverters:

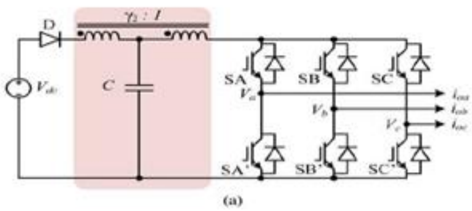
Traditionally, current source inverters (CSI) have been adopted for use in medium and high power industry applications. These inverters, however, support only current buck dc-ac power conversion and need a relatively complex modulator, as compared to conventional voltage source inverters (VSI). To address these limitations, this paper presents an integration of the buck-boost Z-source power conversion concept to the CSI topology to develop single- and three-phase Z-source CSI. For their efficient control, and evaluates different carrier-based reference formulations to identify different inverter state placement possibilities. The project then proceeds to design appropriate" reference-to-switch" assignments or logic equations for mapping out the correct CSI gating signals, allowing a simple carrier-based modulator to control a Z-source CSI with complications such as commutation difficulties and "many-to-many" state assignments readily resolved.

III. TRANS Z SOURCE INVERTER:

It is similar to Z Source except the use of high frequency low leakage inductance transformer and one capacitance. It has low reactive components in compare with conventional ZSI. Due to this, the efficiency appreciably increases. The TZSI topology requires a very low leakage inductance transformer which should be made with high precision. In such a way, the number of passive elements is reduced because only the transformer and the capacitor are needed. As compare with quasi Z source inverters, the TZSI topology features a common dc rail between the source and inverter, which is unlike traditional ZSI circuits. Moreover, use of a transformer with other than a 1:1 transformer ratio allows for a change of output voltage Z source converters, as contrasted with the voltage resulting from the shoot-through index or the modulation index.

Operation of Trans Z Source inverter:

The Voltage source type Trans-Z-source inverter (TZSI) of possible two structures are shown in Fig.4 (a) and 4 (b). The operating principle of TZSI similar to ZSI has equivalence of fig.5 (a) is considered with its operating states shown in Fig.5 (a) and (b)



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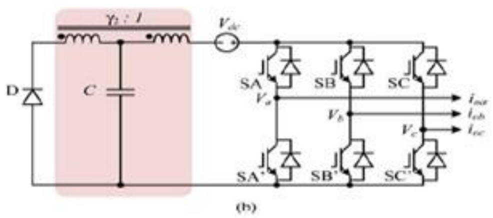

Fig.4. Trans-z-source inverters with source placed in series with either (a) Diode (b) VSI bridge

Like basic Z source inverter it has the three operating states.

1. Active state
2. Conventional Zero state (Null state)
3. Shoot through state.

The operation of the active state is remains as normal inverter bridge operationwhich gives the switching state by space vector modulation technique. Thus, we godirectly for Shoot through state.We use the Zero state to implement the shoot through state. In the shoot-throughstate, the trans-Z-source inverter has two of its switches from the same phase leg turnedON to imitate the boost switch found in a classical dc–dc boost converter.Simultaneously, input diode D reverse biases to form an open circuit.Voltages $V_{W1}$and V_{W2}across the coupled windings W1 and W2 can then bewritten as

$V_{W1}= V_C$ and $V_{W2}= \gamma_2 V_{W1}$…(1)

Where $V_C$represents voltage across the capacitor and γ_2 represents turns ratio ofW2 to W1.Since winding voltages per switching period will average to zero, equation (1) and (2) can be combined as

$D_{st}V_C+ (1 - D_{st}) (V_{dc}- V_C)/ \gamma_2 = 0$… (3)

Where Dstis the fractional time during which the inverter is in its shoot-through state. This time is usually kept constant to avoid introducing low-order ripple to the inverter voltages and currents.

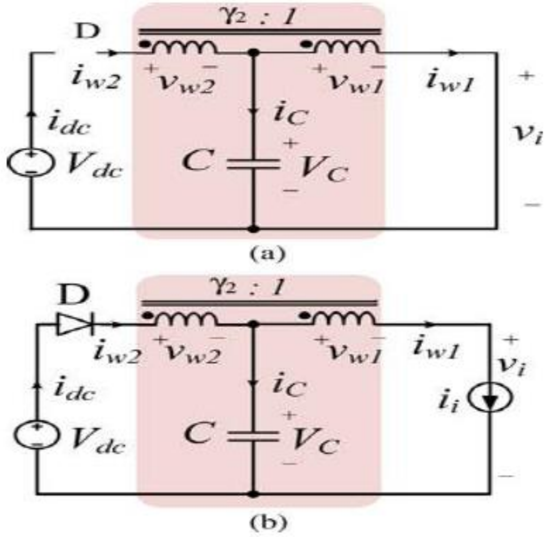

Fig.5. Equivalent circuits of CMC Trans ZSI in (a) shoot-through (b) non shoot-through states.

Simplifying then leads to

$$V_c = \frac{V_{dc}(1 - Dst)}{(1 - (\gamma 2 + 1)Dst)} \quad \text{... (4)}$$

In the non-shoot-through state, the dc-link voltage applied to the load when in an active state is written as $\hat{v}i = V_C - V_{w1}$

Upon substituted by (2) and (4), ˆvi becomes

$$\hat{V}_i = \frac{V_{dc}}{(1 - (\gamma 2 + 1)Dst)} \quad \text{... (5)}$$

When modulated appropriately, this dc-link voltage gives rise to the following peak ac amplitude ˆvacas

$$\hat{v}_{ac} = \frac{M\hat{V}_i}{2} = \frac{0.5\, M\, V_{dc}}{(1 - (\gamma 2 + 1)Dst)} \quad \text{... (6)}$$

Where M represents the inverter modulation index. The denominator of equation (6) must clearly be greater than zero, and as understood from the shoot-through state can only replace the traditional null state. Because of these two restrictions, DstandM are constrained by the following inequalities

$Dst<1/(\gamma_2 + 1)$
$M \leq 1.15(1 - Dst)$ … (7)

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The demanded voltage gain can clearly be raised by increasing Dstorγ_2. The former means lowering M, which generally is not preferred since it leads to poor dc-link utilization and hence unnecessarily high-voltage stresses across the components. Increasing $\gamma 2$ is therefore a better alternative if the transformer can be designed accordingly, while yet maintaining excellent coupling. The same averaging process can be applied to the second trans-Z-source circuit drawn in Fig. 3.1(b) with the same voltage expressions in (5) and (6) produced. Its different source placement mainly leads to a lower capacitor voltage written as

$$V_c = \frac{V_{dc} Dst\, \gamma 2}{(1 - (\gamma 2 + 1) Dst)} \qquad \ldots (8)$$

The main difficulty of single module with high power rating source (load), its source is in series with the lower voltage windingW1, the circuit in Fig.4 (b) unfortunately experiences a higher instantaneous source current. Such high current is caused by the sudden transfer of energy from W2 to W1 when the input diode D reverse biased. A simple way to resolve it is to connect multiple capacitors and windings in parallel which, unlike series connection, will not overly complicate the circuit operation.

IV. Cascade Multicell (CMC) Trans Z source inverter:

An alternative way of realizing the trans-Z-source inverter with high gain is shown in Fig.6

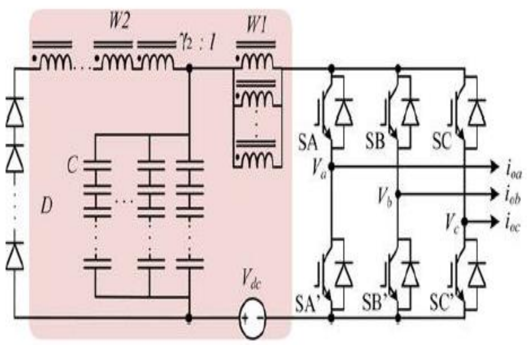

Fig.6. Trans z source inverter realized with multiple transformers with lower turn ratios.

Instead of a transformer with high turns ratio as in Fig. 4, multiple smaller transformers with lower turns ratios are used. Their W1 windings are connected in parallel to share the extreme high instantaneous current stress, while their W2 windings are connected in series to withstand the higher voltage demanded. Turns ratios of these smaller transformers should be chosen based on available core and wire sizes that can more readily produce better coupling. At times, layout and packaging of the application considered might also have a role in deciding the transformer sizes.To avoid direct series connection, an alternate cascading technique is discussed after describing the generic trans-Z-source cell shown in Fig.7.

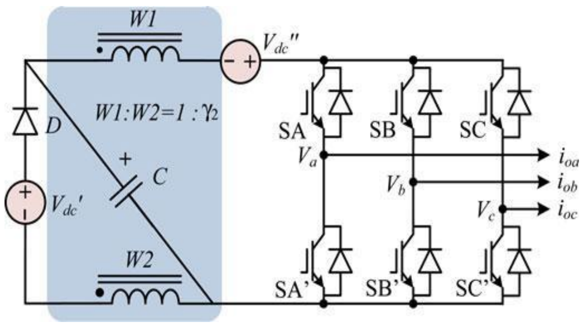

Fig.7. Generic trans-Z-source cell

Unlike Fig.3, the generic cell in Fig.7 has two dc sources labeled as V'_{dc} and V''_{dc} . When they are set as $V'_{dc} = V_{dc}$ and $V''_{dc} = 0$, the network in Fig. 3(a) is obtained. Inversely, for $V'_{dc} = 0$ and $V''_{dc} = V_{dc}$, the network in Fig. 3 (b) is produced. Fig. 5 is, therefore, a generic representation of the two networks shown in Fig.3. Moreover, it is intentionally drawn with an X-shaped structure that resembles the original Z-source network. With this cell, the alternate cascading technique can be performed based on the following few steps:

1) Begin with cell 1 with its windings labeled as $W1_1$ and W2
2) Duplicate a copy of cell 1, and name it as cell 2. Windings of cell 2 are labeled as W 1_2 and W 3 with their turns ratio marked as γ_3

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3) Flip cell 2 vertically and place it below cell 1
4) merge cell 1 and cell 2 with W2 of cell 1 replacing W 1_2 of cell 2
5) Shift W 1_2 of cell 2 to be in parallel with W 1_1 of cell 1
6) Duplicate cell k with windings W 1_k and W (k + 1), and turns ratio γ_{k+1}
7) Repeat the flipping and merging until all N cells are cascaded (until k = N).

The resulting CMC trans-Z-source inverter is shown in Fig.8 which clearly does not have any direct series connection. No balancing resistors and losses are therefore needed, meaning that the inverter in Fig. 6 is likely more efficient than the direct series-connected circuit shown in Fig. 4. The CMC inverter would however still require parallel connections of windings $W1_k$(k =1 toN) and capacitors (not shown in Fig.8 forclarity) to manage the flow of high instantaneous current during shoot through. Such parallel connections will not be a concern in practice, unlike series connections. Corresponding gain expressions for the CMC inverter can then be determined by analyzing the shoot-through and non-shoot-through states separately, before averaging them to arrive at the final expressions.

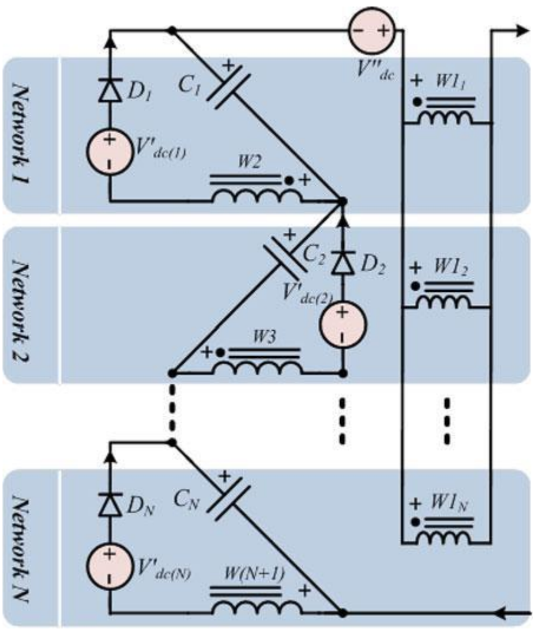

Fig.8. CMC trans-Z-source inverter

The governing winding expressions can be written as

$$V_{w1} = \sum_{\sigma=1}^{N} V_{c\sigma} + V''_{dc}$$

$$V_{w(k+1)} = \gamma_{k+1} V_{w1} \qquad \dots (9)$$

Their correspondences when in the non-shoot through state with all diodes conducting can be written as (during non-shoot through state of CMC Trans ZSI).

$$Vw1 = V_{w(k+1)}/\gamma_{k+1}$$

$$V_{w(k+1)} = V'_{dc(k)} - V_{Ck}. \quad \dots (10)$$

Averaging (9) and (10) for each winding then gives

$$V_{ck} = \gamma_{k+1} D_{st} \frac{V'_{dc} + V''_{dc}}{(1 - (\gamma T + 1) D_{st})} + V'_{dc(k)}$$

$$\gamma T = \sum_{\sigma=1}^{N} \gamma_{\sigma+1}$$

$$V_{dc} = \sum_{\sigma=1}^{N} V'_{dc(k)} \qquad \dots\dots\dots\dots (11)$$

Considering non shoot through state, the peak dc-link voltageand peak ac voltage amplitude can be written as

$$\hat{V}_i = \frac{V'_{dc} + V''_{dc}}{(1 - (\gamma T + 1) D_{st})}$$

$$\hat{V}_{ac} = M\hat{V}_i/2 = \frac{0.5\, M(V'_{dc} + V''_{dc})}{(1 - (\gamma T + 1) D_{st})}$$

$$Dst < 1/(\gamma_T + 1)$$

$$M \leq 1.15(1-Dst) \dots (12)$$

Note again that Fig.8 is a generic representation of the CMC trans-Z-source inverter with all possible source locations shown. These sources can be set to zero, where desired, with only one of them needed to be nonzero for powering the inverter. Considered as an example $V'_{dc(1)}$ = ….. = $V'_{dc(N)}$ = 0 and V”dc ≠ 0, ˆvi in(12) then simplifies to equation (6) except with γTreplacingγ2.

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V. ELECTRICAL DRIVE IMPLEMENTATION WITH TRANS Z-SOURCE INVERTER:

Input to the Trans Z-Source inverter is obtained from solar cell. The ripple in theoutput voltage of solar cell is filtered using Z-filter. Pure DC is given to the three-phaseinverter. The inverter converts DC in to three-phase balanced AC. The output of theTrans Z-Source inverter is used to control the harmonics present in the load. Theproposed Z-source inverters are therefore competitive alternatives that can be used forcases, where source filtering is critical.

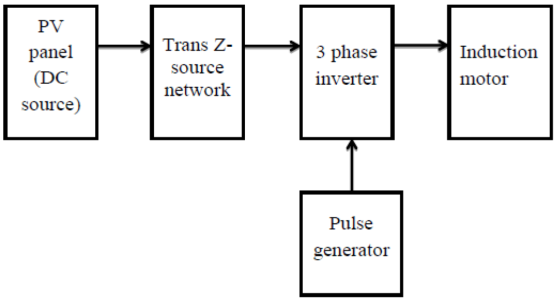

Fig.9. Block diagram of Drive system

VI. SIMULATION AND RESULTS:

This paper implemented with the simple boost control technique for the pulse control of the CMC Trans Z source inverter bridge circuit. This also driven with one of the conventional speed control method, v/f control for the induction motor load.The execution of CMC Trans Z-source inverter is carried for V_{dc}=160v, coupled transformer with winding inductances as L=160mH and capacitance of C = 680μF and operating circuit at 5KHz carrier frequency w.r.t reference of 50Hz.

Simulation circuit model:

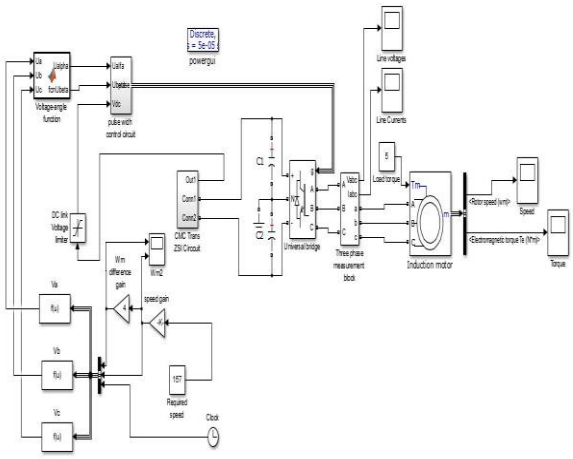

Fig.10. v/f control implemented CMC Trans ZSI

Results

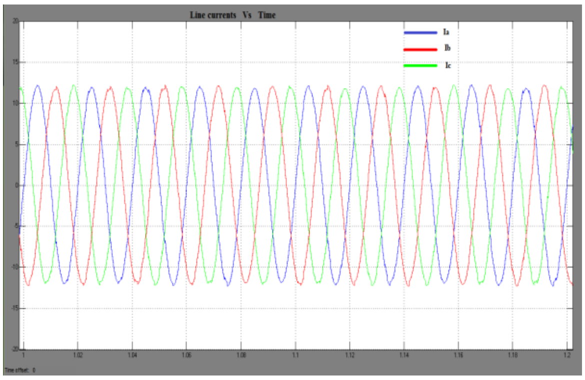

Fig.11.Three phase line currents

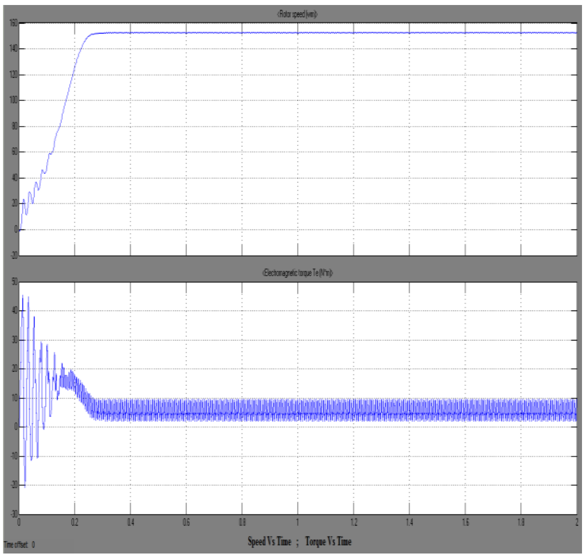

Fig.12.motor speed and torque

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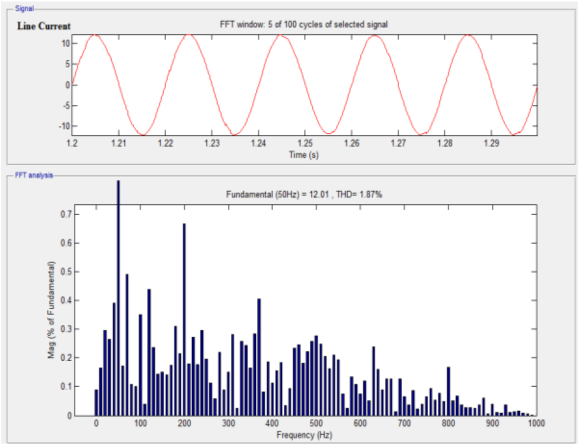

Fig.13. FFT analysis of load line current

CONCLUSION:

From the results of cascaded multicell trans z source inverter implemented byusing simple boost control and with v/f control of motor load, we can conclude that speedof the motor load get faster steady state compare to without v/f control and also than thatof the normal z source inverter, CMC trans z source inverter has the sharp reduced stressof starting transient currents to load and also has less dc link voltage stress at the inverterbridge gives the better performance over the normal z source inverter. Also the circuit hasnumber of cells cascaded to perform the desired operation of speed control and the speed is reliable in operation of control.

Now a days, there is wide range of implementation of solar power panels whichproduces DC voltage by the result of photovoltaic effect and these are arranged in such amanner that they connected in series and parallel combination to get desired voltage andcurrent ratings. Here, we can implement the cascaded multicell Trans z source inverterwhich can be implemented with number of panels cascade and can get the high anddesired power ratings of grid connection or to the load. This contains multiple number ofcells which can be disconnected and reconnected to get the desired performance of load.

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