Design of Closed Loop PI Controller Based Hybrid Z-Source Dc-Dc Converter Using Matlab/Simulink

B.Suneel Kumar[1], M.Divya[2]

[1,2]Dept. of Electrical & Electronics Engineering, Vignan's Lara of Institute of Technology& Science, Vadlamudi, Guntur District, Andhra Pradesh, India

---

***Abstract–** This project presents designing of hybrid Z-source boost dc-dc converter with closed loop PI controller technique for induction motor application. The proposed converter provides high gain than other Z Source dc/dc converter and in adding to the high voltage gain and continuous I/p current, the hybrid three quasi Z Source network proved a mutual ground between the I/P and O/P. In the proposed converter voltage gain is controlled by using PI controller and the output voltage of the proposed system can be changed by using reference value of PI controller. This project also involves analysis and design of hybrid Z-source boost dc-dc converter, PI controller, 3-level diode clamped multilevel inverter, Induction motor using MATLAB SIMULINK and all the simulation results are verified by using MATLAB/SIMULINK R2012b.*

Index Terms-DC-DC converters, voltage boost abilities, Z-source, Induction motor with 5-level multi inverter, PI controller

I. INTRODUCTION

Now a day's high gain dc-dc converter are the main part of renewable energy systems. Before global fossil energy and renewable energy power systems, which are mainly on the photovoltaic (PV) power systems, are developing fastly. In a PV power system, the output voltages of the PV panels are usually low and vary large under the influences of weather and environment, therefore, a step-up operation required. So far, different voltage-boost techniques have been greatly comes, those are voltage multiplier, switched capacitor, switched inductor, coupled inductor, voltage lift, and cascaded boost techniques. However, these methods are all complex with low efficiency and high costs. Thus, the design of the step-up dc-dc converters is very important to the PV power systems

The idea of Z-source network was firstly to suggest by F. Z. Peng, the Z-source network is X-shaped impedance network, which can be applied to dc-ac, dc-dc, ac-ac, and ac-dc power conversion. In Z-source inverter (ZSI) shoot-through state is obtained by using traditional voltage-source inverters (VSIs), cannot boost the voltage. In addition, the buck voltage operation occurs. The original ZSI also has some drawbacks, such as discontinuous input current, the high voltage stress and limited boost factor $1/(1\text{-}2D_s)$ (D_s is the shoot-through duty cycle). Further, the dc voltage source and the inverter bridge could not share a common ground. To defeat the limitations in the real ZSI, the quasi-Z-source network is a simple but efficient solution. The quasi-Z-source inverters (qZSIs) can be classed into continuous-current qZSI and discontinuous-current qZSI. Those also called as quasi-Z-source network I and quasi-Z-source network II. This two proposed quasi-Z-source networks have the same boost factors as the traditional Z-source network, which is $1/(1\text{-}2D_s)$. But this Z-source network have some advantages over the traditional Z-source network, i.e., continuous input current, common ground between the voltage source and the inverter bridge, and reduced capacitor voltage stress.

The PV panels, low voltage DC sources and energy storage devices, like super capacitors, battery and fuel cells are generally needed to be boost to high voltage level for industrial and commercial applications. This boosted voltage is directly connected to multilevel inverters for AC voltage level. Another choice is first boost the low voltage and directly connected to the bridge inverters. Due to the normal structure the large step-up dc-dc converters used flyback and forward converters. In recent years, many new high step-up dc–dc converters were developed by utilizing some following techniques: switched-capacitor (SC), switched inductor, tapped inductor, and coupled inductor. In this paper hybrid three-quasi-Z-source is implemented by induction motor drive. Among all new techniques, for excessive step-up voltage gain the combination of 3-level diode clamped multilevel inverter and induction motor is adapted. In this proposed converter is used pulse width modulation technique to get large voltage conversion ratio, less magnetic components and active switches are employed.

This paper proposes closed loop PI controller of hybrid Z-source dc-dc converter with multilevel inverter and 3-phase induction motor. By using multilevel inverter, as the number of levels increases, the output waveform approaches the pure sine wave more and more, thus we can get accurate result as the number of level increases. Highly popular are the voltage source multilevel inverters, which can be divided into three categories, according to their topology: Neutral point clamped (NPC), Flying capacitor (FLC), and Cascade H-bridge. Among this all diode clamped multilevel inverter reduce the THD value, increase the efficiency and high voltage gain is obtained. To get the analysis of induction motor, 3-level diode clamped multilevel inverter, 5.36HP, 4KW induction motor is used in this proposed converter. The simulation results are verified using MATLAB/SIMULINK R2012b. The proposed converter simulation results are provided in section IV and concluded in section V.

II. PROPOSED Z-SOURCE BOOST DC-DC CONVERTER

Fig.1 shows the block diagram of the proposed converter. This proposed converter consist of low level DC input voltage, hybrid three Z-source DC-DC converter, diode clamped multilevel inverter and 3-phase induction motor drive. The hybrid three Z-source DC-DC converter is used to get high output voltage from low input voltage and this high step up output voltage is given to the diode clamped multilevel inverter. This inverter is converted the high step up DC voltage into 3-phase AC voltages and given to the 3-phase induction motor drive.

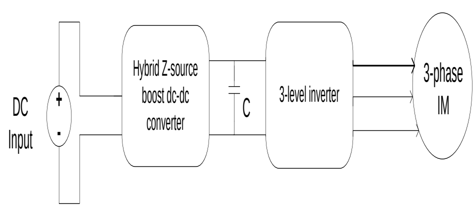

Fig.1. Block diagram

Hybrid three-quasi-Z-source boost dc-dc converter

Similar to the aforementioned topology, the proposed hybrid Z-source network in this section is the integration of the quasi-Z-source network I and quasi-Z-source network II. Fig.5 shows the hybrid three-quasi-Z-source boost dc-dc converters. It can be noticed that the proposed hybrid Z-source network ($L1$-$C1$-$D1$-$C2$-$L2$-$D2$-$C3$-$C4$-$L3$-$C5$-$D3$-$C6$-$L4$) is obtained by replacing all the inductors ($L1$ and $L2$) in the quasi-Z-source network I with the quasi-Z-source network II. In addition to the hybrid three-quasi-Z-source network, the proposed converter employs an active switch S, an output diode $D4$, and an output capacitor $C7$.

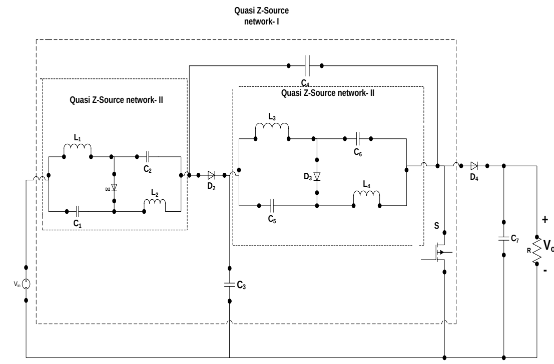

Fig.2. Hybrid three-quasi-Z-source boost dc-dc converter

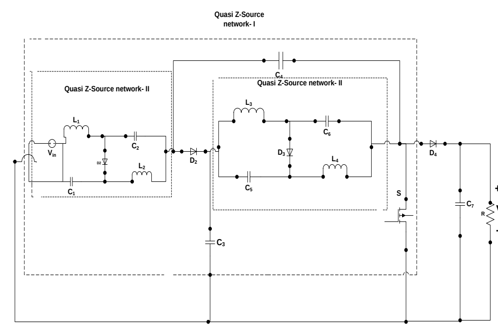

Fig.3. Improved hybrid three quasi-Z-source converter

Though the voltage gain (M = 1/(1-4Ds)) of the proposed converter is higher than that of the hybrid two-quasi-Z-source boost dc-dc converter, it draws a discontinuous current from the dc voltage source. To smooth the input current, a simple improvement on the proposed converter is shown in Fig. 6, where dc voltage source is placed in series with the inductor $L1$. However, the voltage gain of the improved hybrid three-quasi Z-source boost dc-dc converter is not influenced by the modification, which is the same as the hybrid three-quasi-Z-source boost dc-dc converter. In addition to the high voltage gain and continuous input current, the improved hybrid three quasi Z-source networks provide a common ground between the input and output.

III. OPERATING PRINCIPLE OF THE PROPOSED CONVERTER

The operating principles of the proposed converters are analyzed in this section. For analytical purposes, the following conditions are assumed

a) All the components are ideal.
b) All capacitors are so large that the capacitor voltages can be treated as constant.
c) All the proposed converters operate in CCM.

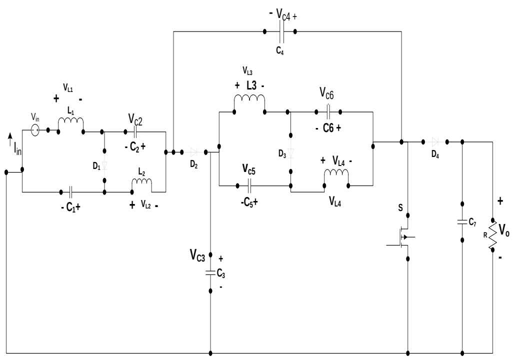

Fig. 4(a) Equivalent circuit of the hybrid three-quasi-Z-source boost dc-dc converter. (1) Mode 0.

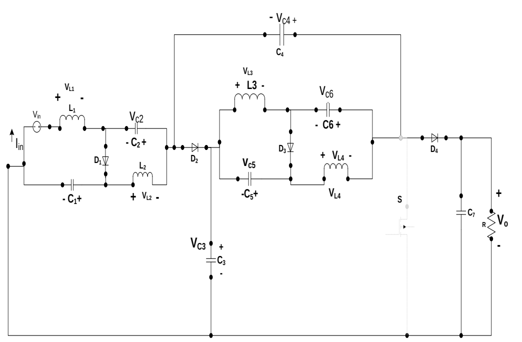

Fig. 4(b) Equivalent circuit of the hybrid two-quasi-Z-source boost dc-dc converter. (2) Mode 1.

Improved hybrid three-quasi-Z-source boost dc-dc converter

Because the hybrid three-quasi-Z-source boost dc-dc converter and the improved hybrid three-quasi-Z-source boost dc-dc converter have the same voltage gain, we take the latter as an example to analyze. The improved hybrid three-quasi Z-source boost dc-dc converter also has two operation states: state 0 and state 1.

1) Mode0*:* Fig. 1(a) shows the equivalent circuit of the proposed converter operates in state 0. During this state, switch S is on, while diodesD1, D2, D3, and D4 are off. CapacitorsC1, C2, C3, C4, C5, and C6 discharge the energy to inductors L1, L2,L3, and L4.

By applying KVL to Fig. 10(a), the following equations can be derived

$$V_{L1} = V_{in} + V_{c2} + V_{c4} V_{L2} = V_{c_1} + V_{c4}$$

$$V_{L3} = V_{c_3} + V_{c6} V_{L4} = V_{c_3} + V_{c5} \qquad (6)$$

Due to the symmetry of the quasi-Z-source network II (L3 = L4, C5 = C6), we have $V_{L3} = V_{L_4} V_{c5} = V_{c6}$ (7)

2) Mode 1:Fig. 1(b) shows the equivalent circuit of the proposed converter operates in state 1. During this state, switch S is off, while diodes $D1$, $D2$, $D3$, and $D4$ are on. Inductors $L1$, $L2$,$L3$, and $L4$ transfer energy to capacitors $C1$, $C2$, $C3$, $C4$, $C5$, $C6$,and the load R.

The following equations can be obtained according to the equivalent circuit in state 1

$$V_{L1} = V_{in} - V_{c1} \quad V_{L2} = -V_{c2} \quad V_{L3} + V_{L4} = -V_{c4}$$

$$V_{C5} + V_{C6} = V_{c4} \quad V_{c1} + V_{c2} = V_{c3} \quad V_0 = V_{c3} + V_{c4} \qquad (8)$$

By applying the voltage-second balance principle to the inductors $L1$, $L2$, and $L3$ (or $L4$), we have

$$V_{c1} = \frac{1-3D}{1-4D} V_{in} \qquad V_{c2} = V_{c5} = V_{c6} = \frac{D}{1-4D} V_{in}$$

$$V_{c3} = \frac{1-2D}{1-4D} V_{in} V_{c4} = \frac{2D}{1-4D} V_{in} \quad V_0 = \frac{1}{1-4D} V_{in} \qquad (9)$$

The voltage gain m is $M = \frac{V_0}{V_{in}} = \frac{1}{1-4D}$ (10)

It can be seen from (10) that the boost ability of the proposed hybrid Z-source network is stronger than that of the hybrid two-quasi-Z-source network. Moreover, they have the same advantages

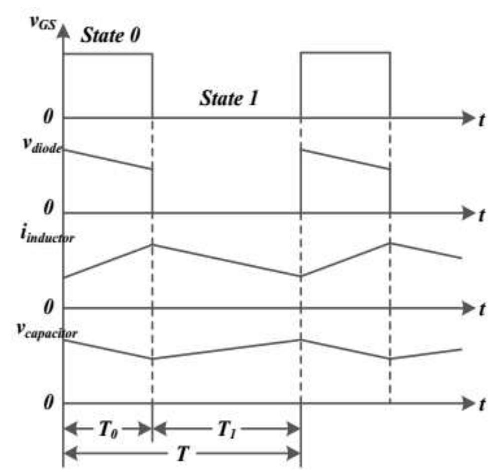

Fig.5. Key waveforms of the hybrid Z-source networks

TABLE-I SIMULATION AND EXPERIMENTAL PARAMETERS

parameter	value/part number
Input voltage	100V
Z-source inverter	330µf
Z-source capacitor	470µh
Output capacitor	470µf
Full load	100w
switching frequency	30kHz
switch(MOSFET)	FQA140N10 or IFR840
Diodes	MBRF30H150CT or MUR460
Output voltage	420V

Table-1 shows the simulation parameter of design of closed loop PI controller based hybrid Z-source dc-dc converter using Matlab Simulink. The required value and parameters for design the circuit.

A. Multilevel Inverter

In this circuit there are two pairs of switches and two diodes are consists in a three level diode clamped inverter. The DC voltage is divided into three voltage levels with the help DC capacitors. The voltage across each capacitor is $V_{dc}/2$. At any time a set of two switches is on for a three level inverter. Fig.5 shows the three-level diode clamped multilevel inverter.

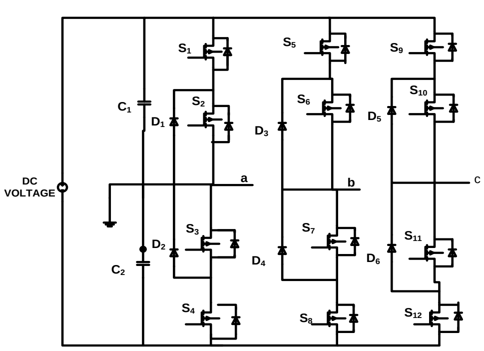

Fig.6. Diode clamped multilevel inverter circuit for 3-phase 3-level inverter

TABLE-II Switching states in one leg of three level diode clamped inverter

Switch state	State	Pole voltage
S1=ON, S2=ON S3=OFF, S4=OFF	S= +ve	V_{a0}= Vdc/2
S1=OFF, S2=ON S3=ON, S4=ON	S= 0	V_{a0}= 0
S1=OFF, S2=OFF S3=ON, S4=ON	S= -ve	V_{a0}= -Vdc/2

Table-II shows the switching states in one leg of three-level diode clamped inverter. A three-level inverter, also known as a neutral-clamped inverter, consists of two capacitor voltages in series and uses the center tap as neutral. Each phase leg of the three-level inverter has two pairs of switching devices in series. The center of each device pair is clamped to the neutral through clamping diodes. The output obtained from a three-level inverter is a quasi-square wave output if fundamental frequency switching is used. Multilevel inverter are being considered for an increasing number of applications duo to their high power capability associated with lower output harmonic and lower commutation losses. Multilevel inverters have become an effective and practical solution for increasing power and reducing harmonics of AC load.

The phase output voltage Van has three stats: Vdc/2, 0, -Vdc/2. The gate signals for chosen three level DCMLI are developed using MATLAB/SIMULINK. The order of numbering of the switches for phase a is S1, S2, S3 and S4 and likewise other two phases.

Below table-III shows the 3-phase induction motor parameter ratings. The two transistors *S1*, *S2* bear the same voltage stress about 120V. Low-voltage-rated MOSFETs with a small on-state resistance can therefore be used to improve the efficiency. With the resonant design, the two diodes *D1*, *D2* operate under ZCS condition. With synchronous rectification achieved by *S1* and *S2*, the excitation current will drop to below zero when the output power is lower than 120W. As a result, a part of energy charged in the capacitor *C* will flow back to the input source and this will produce more conduction losses.

One method to overcome this problem is to increase the magnetizing inductance *Lm* and another one is to avoid the converter operate under low power condition. In contrast, a lower input voltage causes more conduction losses as the input current is higher. This is why there is a slightly higher efficiency when the input voltage is higher.

TABLE-III 3-PHASE INDUCTION MOTOR SPECIFICATIONS

Parameter	Rating
Nominal power	4KW
Line-line RMS voltage	400V
Frequency	50HZ
Rotor nominal speed	1430RPM
Stator resistance	1.405
Stator inductance	0.5839mH
Rotor resistance	1.395
Rotor inductance	0.5893mH
Mutual inductance	172.2Mh
Pole pair	2

IV SIMULATION RESULTS

The simulation results of the proposed system have been discussed in this system. The proposed system has been simulated by using MATLAB/SIMULINK. The MATLAB/SIMULINK model of the proposed hybrid three-quasi-Z-source boost DC-DC converter is MATLAB 2012b. In this section demonstrate all simulated wave form of the proposed converter. Fig.7 shows the simulation diagram of the proposed converter. This proposed converter is combination of hybrid three quasi-Z-source boost DC-DC converter, 3-level diode clamped multilevel inverter and induction motor drive.

Simulation modeling of design of design of closed loop pi controller based hybrid Z-source dc-dc converter using matlab simulink and it shows the results of output voltage, torque, speed, current, three phase voltages and currents, line voltages, line current, diode currents, inductor currents, and capacitor voltages.

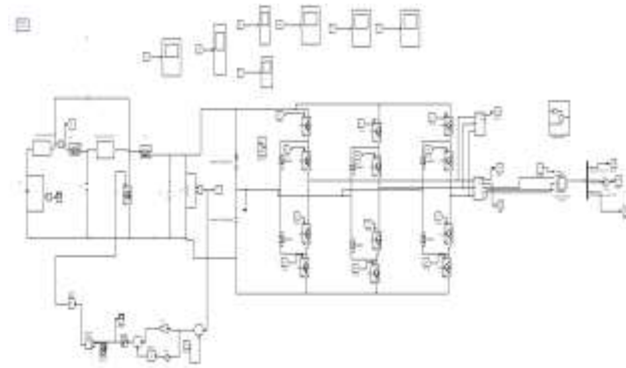

Fig.7. Simulation diagram for proposed converter with PI controller, induction motor

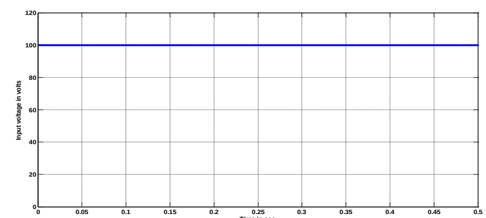

Fig.8. Simulation waveform of proposed converter input voltage V_{in}=100V

Fig.8.Shows the input voltage of proposed converter and it is 100V. The modeling of closed loop PI controller based hybrid z-source dc-dc converter using matlab and it will be settling at the time 0.5

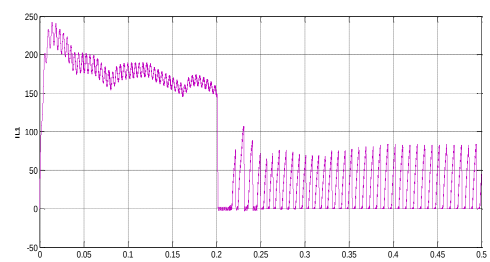

Fig.9. Simulation waveform of inductor current IL1

Fig.9 shows the simulation waveform of proposed converter inductor current. The inductor current is settling at time 0.5, because the proposed converter I connected to the multilevel inverter and induction motor.

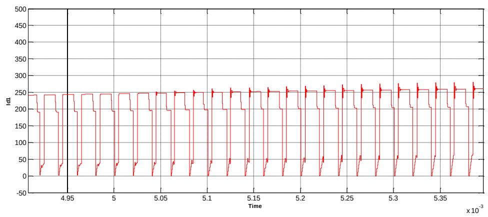

Fig.10. Simulation waveform of inductor current (ID1) = 260A

Fig.10 shows proposed converter simulation waveform of the diode current (ID1). The diode current ID1=240A, are operated in this proposed converter under 3-level multilevel inverter technique of coupled inductor. The losses cross the diodes are less.

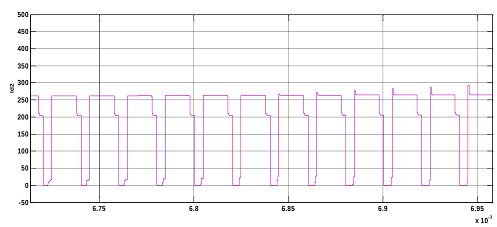

Fig.11. Simulation waveform of inductor current (ID2) = 260A

Fig.11 shows proposed converter simulation waveform of the diode current (ID2). The diode current ID2=260A, are operated in this proposed converter under 3-level multilevel inverter technique of coupled inductor. The losses cross the diodes are less.

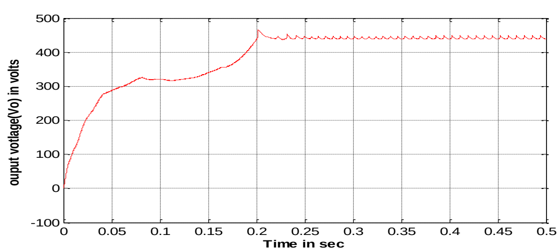

Fig.12. Simulation waveform for output voltage (Vo)=420A Fig.10 shows proposed converter simulation waveform of the output voltage(Vo). The output voltage = 420A, are operated in this proposed converter under 3-level multilevel inverter technique of coupled inductor.

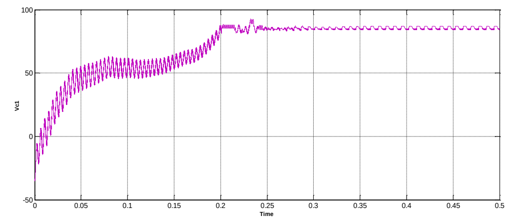

Fig.13. Simulation waveform of the capacitor (V_{C1}) =92V

Fig.13 Simulation waveform of the voltage across the capacitor (C_1). The capacitor (C_1) output value 92V, settling voltage at the time 0.5 sec. The proposed converter under operate s in 3-level multilevel inverter and induction motor technique.

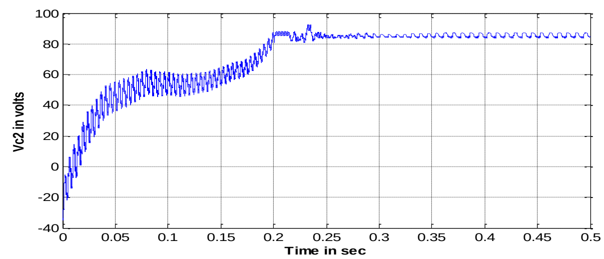

Fig.14. output wave form of output capacitor voltage (V_{C2})=85V

Fig.14 Simulation modeling of multilevel inverter with induction motor and it show the results of capacitor voltage (V_{C2}). Fig shows the V_{C2} waveform is varying from 0V to 85V, and it is setting at 0.5 sec.

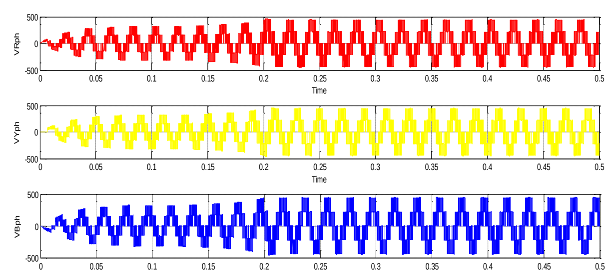

Fig.15. Simulation waveform of phase voltages

Fig.15 shows the phase voltages of proposed converter V_{Rph} = 420V, V_{YPh} = 420V and V_{Bph} = 420V. The operation under proposed converter combines with 3-level multilevel inverter and induction motor.

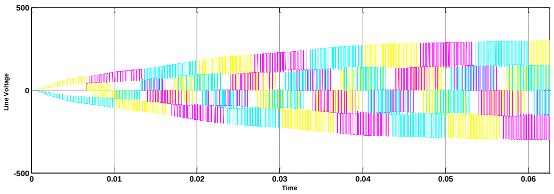

Fig.16. Simulation waveform of three line voltage

Fig.16. shows the three phase line voltage of PI controller and the result of line voltage is and settling time at 0.50 sec. Operate at proposed converter under the diode clamped inverter and induction drive.

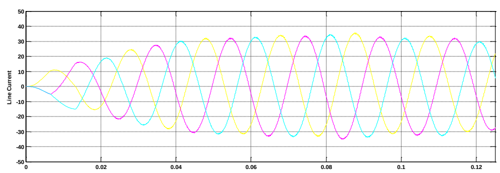

Fig.17. Simulation waveform of the three phase line current

Fig.17 shows the three phase line current of PI controller and the result of 3-phase line current are and settling time at 0.5Fig three phase currents of PI controller combine with DCLMI and IM, and the currents are I_R, I_Y and I_B. settling time at 0.5 sec

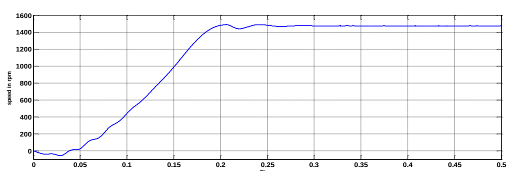

Fig.18. Simulation waveform of speed in rpm N = 1430 rpm

Fig.18 Simulation waveform of motor speed in rpm =1430rpm. These speeds from proposed converter combine with diode lamped multilevel inverter and coupled inductor. And settling time is 0.5sec.

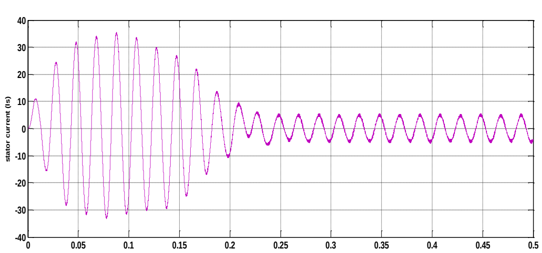

Fig.19. Simulation waveform of stator current I_S=6A

Fig.19 shows the stator current of induction motor I_S=6A. This is under proposed converter and 3-level multilevel inverter and coupled inductor, and settling at the time 0.5 sec.

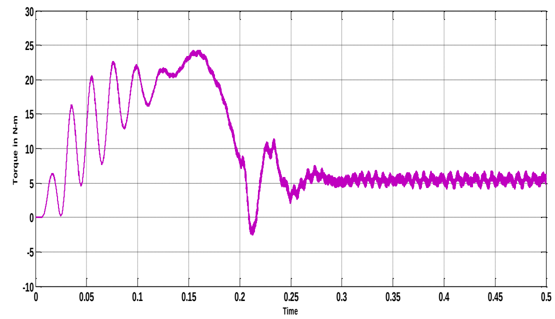

Fig.20. Output wave form of torque in N-m

Fig.20 shows the simulation modeling of PI controller and it shows the results of torque. Fig shows the torque waveform and, torque is varying from the 0 to 7 N-m, and it will be settling at 0.5 sec.

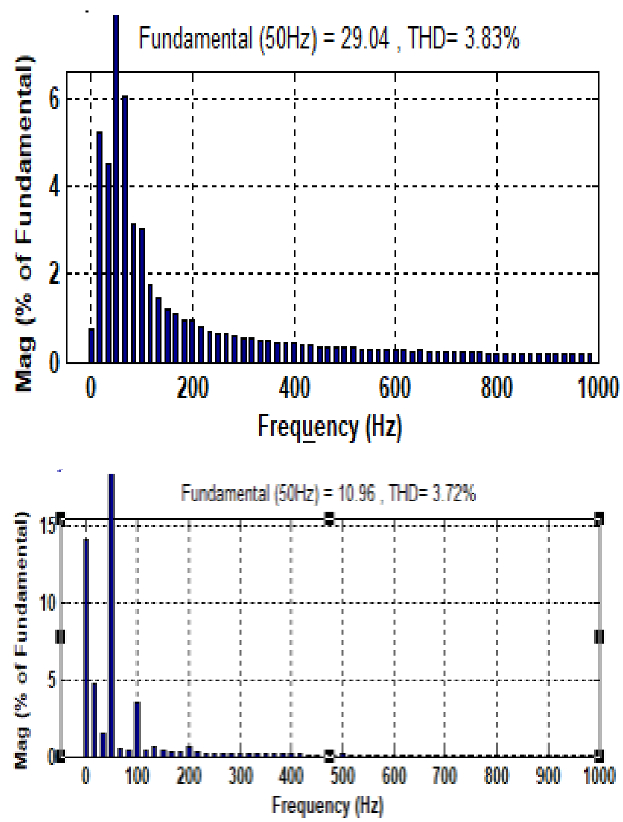

Fig.21. Output waveform of THD in percentage

Fig.21 shows the THD% output waveform of PI controller and its shows the result of THD%. THD is drawn between frequency Vs % of fundamental, the percentage of THD is 3.72% and settling time at 0.5 sec.

V. CONCLUSION

A family of hybrid Z-source boost dc-dc converters for PV power systems has been presented in this project. The proposed converters use the hybrid Z-source networks, which are obtained by combining the traditional Z-source networks. Longer from the high step-up abilities, the proposed hybrid Z-source networks cover all the advantages of the traditional Z-source networks, like continuous input current, reduced capacitor voltage stress and common ground between the voltage source and the inverter bridge. In this converter voltage gain is controlled by using PI controller and the output voltage of the proposed system can be changed by changing PI controller reference value. In addition to the high voltage gain and continuous input current, the hybrid three-quasi-Z-source network proved a common ground between the input and output. By using 3-level multilevel inverter and coupled inductor the switching sequences are generated using the pre calculated switching angles in such a way to reduce THD. The topology can be applied to a higher number of levels of multilevel inverter. But, the disadvantage of using multilevel inverter is with the increase in levels, switching circuit gets complicated.

The simulation results are verified by using MATLAB/SIMULINK R2012b.

Finally, the simulation and experimental results verify the features of the proposed converters.

REFERENCES

[1]F. Blaabjerg, Z. Chen, and S. B. Kjaer, "Power electronics as efficient interface in dispersed power generation systems," *IEEE Trans. Power Electron.*, vol. 19, no. 5, pp.1184-1194, Sep.2004.

[2] Y. P. Hsieh, J. F. Chen, T. J. Liang, and L. S. Yang, "Novel high step-up dc-dc converter for distributed generation systems," *IEEE Trans. Ind. Electron.*, vol.60, no.4, pp.1473-1482,Apr.2013.

[3] B. Ge, H. Abu-Rub, F. Z. Peng, Q. Lei, A. T. de Almeida, F. J. T. E.Ferreira, D. Sun, and Y. Liu, "An energy stored quasi-Z-source inverter for application to photovoltaic power systems," *IEEE Trans Ind.Electron.*,vol.60,no.10,pp.4468-4481,Oct.2013.

[4] M. Prudente, L. L. Pfitscher, G. Emmendoerfer, E. F. Romaneli, and R.Gules, "Voltage multiplier cells applied to nonisolateddcdcconverters,IEEETrans.PowerElectron"vol. 23,no.2,pp.871-887,Mar.2008.

[5] B. Axelrod, Y.Berkovich, and A.Ioinovici, "Switched-capacitor/switched-inductor structures for getting transformer less hybrid dc-dc PWM converters," *IEEE Trans. Circuits Syst.I, Reg.Papers,vol.55,no.2,pp.687*-696,Mar.2008.

[6] O.Abutbul, A.Gherlitz, Y.Berkovich, and A. Ioinovici, "Step-up switching-mode converter with high voltage gain using a switched-capacitor circuit," *IEEE Trans. Circuits Syst.I, Fundam. Theory Appl.*,vol.50,no.9,pp.1098-1102,Aug.2003.

[7] R. J. Wai, C. Y. Lin, R. Y. Duan, and Y. R. Chang, "High-efficiency dc-dc converter with high voltage gain and reduced switch stress," *IEEE Trans. Ind. Electron.*,vol.54,no.1,pp.354-364,Jan.2007.

[8] F. L. Luo, "Six self-lift dc-dc converters," *IEEE Trans. Ind. Electron.*,vol.48,no.6,pp.1268-1272,Dec.2001.

[9] L. Huber and M. M. Milanovic, "A design approach for server power supplies fornet working applications," In*Proc. IEEE,APEC,2000,pp.1163*-1169.

[10] F. Z. Peng, "Z-source inverter," *IEEE Trans. Ind. Appl.*, vol.39,no.2,pp.504-510,Mar./Apr.2003.

[11] J. Anderson and F. Z. Peng, "Four quasi-Z-source inverters,"in*Proc.IEEEPowerElectron.Spec.Conf.*,Jun.2008,pp.2743-2749.

[12] Y. Tang, S.Xie, C. Zhang, and Z. Xu, "Improved Z-source inverter with reduced Z-source capacitor voltage stress and soft-start capability," *IEEE Trans. Power Electron.*, vol. 24, no. 2, pp. 409-415, Feb. 2009.