Research Paper

Performance of Eleven Level Zeta Converter Based Multi String Multi Level Inverter Fed Three Phase Induction Motor Drive

Engineering

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ABSTRACT   In this paper Zeta converter fed Multi string multi level Inverter is designed. The use of a high step-up converter is essential for the grid-connected inverter because the input voltage is about 15 V to 40 V for a single PV panel. The proposed converter employs a Zeta converter with a coupled inductor, without the extreme duty ratios and high turns ratios generally needed for the coupled inductor to achieve high step-up voltage conversion; the leakage-inductor energy of the coupled inductor is efficiently recycled to the load. These features improve the energy-conversion efficiency. Here an asymmetrical configuration of Zeta Converter based Eleven-level Multi String Multi Level inverter topology fed Three Phase Induction Motor Drive performance is analyzed. The above results are compared with Multi String Multi Level(MSML) inverter without Zeta converter.

1. INTRODUCTION

Since past decade, multilevel inverters have drawn increasing attention because of their promising applications in power systems and industrial drives. They can be efficiently used in the distributed energy systems in which, output ac voltage is obtained by connecting dc sources such as batteries, fuel cells, solar cells, rectified wind turbines etc at input side of the inverters mentioned in [1]. The ac output voltage obtained from the inverters can be fed to a load directly or interconnect to the ac grid without voltage balancing problems. A single-phase multi string five-level inverter integrated with an auxiliary circuit was recently proposed for dc/ac power conversion described in [2]. This topology used in the power stage offers an important improvement in terms of lower component count and reduced output harmonics. Unfortunately, high switching losses in the additional auxiliary circuit caused the efficiency of the multi string five-level inverter to be approximately 4% less than that of the conventional multi string three-level inverter in [3].

A typical Zeta converter provides either a step-up or a step-down function to the output, in a manner similar to that of the buck-boost or SEPIC converter topologies. The conventional Zeta converter is configured of two inductors, a series capacitor and a diode.. A coupled inductor can be employed to reduce power supply dimensions [4]. Some Zeta and flyback combination converters extend the output range by using this coupled-inductor technique [5]–[7]. Employing softs witching technique, zero-voltage switching and zero-current switching, on the Zeta converter [5], [8], [9]; changing the input inductor of the ZETA converter to a coupled inductor obtains a higher step-up conversion ratio [10]. Many research works on high step-up converter topology have included analyses of the switched-inductor and switched-capacitor types, transformerless switched-capacitor type, the boost type integrated with the coupled inductor , Although this configuration is useful in terms of system monitoring and repair, the partial shading, module mismatch, and dc connection cable losses are inevitable problems and lead to significantly reduced system energy yields.   A zeta converter is a fourth order dc-dc converter capable of amplifying and reducing the input voltage levels without inverting the polarities [10]. The reason being is that it includes two capacitors and two inductors as dynamic storage elements.

2. ZETA CONVERTER

A zeta converter is a fourth order non linear system being that, with regard to energy input, it can seen as buck-boost-buck converter and with regard to the output, it can be seen as boost-buck-boost converter. The ideal switch based realization of zeta converter is depicted.
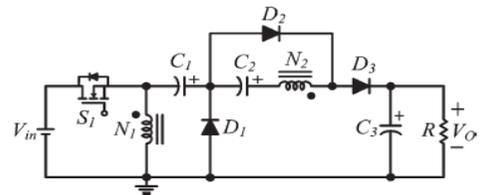

Fig.1 Basic Zeta converter circuit

Although several operating modes are possible for this converter depending on inductance value, load resistance and operating frequency, here only continuous inductor current „iL1" analyzed using the well known state-space averaging method[3] . The analysis uses the following assumptions.

1. Semiconductors switching devices are considered to be ideal.
2. Converter operating in continuous inductor current mode.
3. Line frequency ripple in the dc voltage is neglected.

Basic Five Level Multi string Multi level (MSML) Inverter
The basic five level multi string multi level inverter[10] is shown in Fig.2. and corresponding output voltage waveforms are shown in Fig.3. In this approach, all the six switches are operated with a switching frequency of 50 Hz and the input voltage of Vdc=100V. The symmetrical multilevel approach of the multi string multi level inverter is operated with equal voltage values at the input side of the inverter. These symmetrical multilevel inverters are operated with PWM procedure to generate the gating signals. In a symmetrical multi string multi level inverter, the Seven, Nine, Eleven and Thirteen levels are generated by using 6,8,8,10 switches respectively with repeating sequence as gating signal.
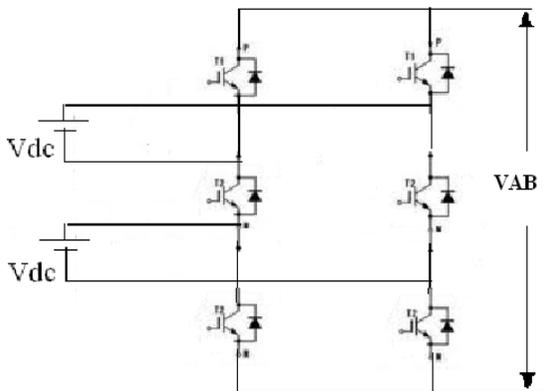
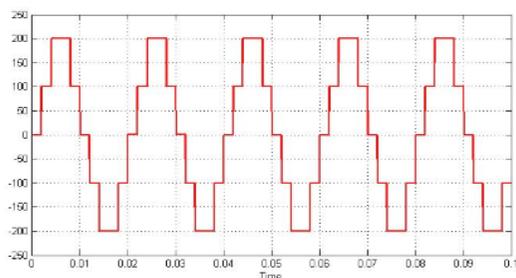**Fig.2. Five level Multi string multi level inverter**

Fig.3.Output voltages of five level MSML Inverter

3. OPERATING PRINCIPLES OF THE PROPOSED ZETA CONVERTER

The simplified circuit model of the proposed converter is shown in Fig.1. The coupled inductor T1 includes a magnetizing inductor Lm, primary and secondary leakage inductorsLk1 and Lk2, and an ideal transformer primary winding N1 and secondary winding N2. To simplify the circuit analysis of the proposed converter, the following assumptions are made.

1) All components are ideal, except for the leakage inductance of coupled inductor T1. The ON-state resistance RDS (ON) and all parasitic capacitances of the main switch S1 are neglected, as are the forward voltage drops of the diodes D1 ~ D3.

2) The capacitors C1 ~ C3 are sufficiently large that the voltages across them are considered to be constant.

3) The ESR of capacitors C1 ~ C3 and the parasitic resistance of coupled-inductor T1 are neglected.

4) The turns ratio n of the coupled inductor T1 winding is equal to N2/N1.

The five operating modes are described as follows.

Mode I [t_0, t_1]: In this transition interval, the secondary leakage inductor Lk2 is continuously releasing its energy to capacitor C2. The current flow path is shown in Fig. 4(a); as shown, switch S1 and diodes D2 are conducting. The current iLm is descending because source voltage Vin is applied on magnetizing inductor Lm and primary leakage inductor Lk1; meanwhile, Lm is also releasing its energy to the secondary winding, as well as charging capacitor C2 along with the decrease in energy, the charging current iD2 and iC2 are also decreasing. The secondary leakage inductor current iLK2 is declining according to iLm/n. Once the increasing iLk1 equals the decreasing iLm at t = t1, this mode ends

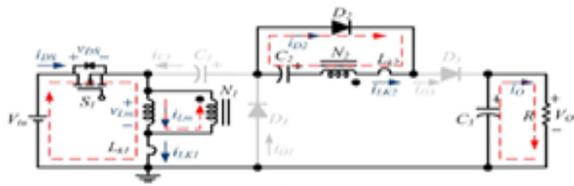**Fig.4 (a) Current flow path during one switching period Mode.1**

$$i_{in}^{I}(t) = i_{DS}^{I}(t) = i_{LK1}^{I}(t) \tag{1}$$

$$\frac{di_{Lm}^{I}(t)}{dt} = \frac{v_{Lm}}{L_m} \tag{2}$$

$$\frac{di_{Lk1}^{I}(t)}{dt} = \frac{V_{in} - v_{Lm}}{L_{k1}} \tag{3}$$

$$i_{Lk2}^{I}(t) = \frac{i_{Lm}^{I}(t) - i_{Lk1}^{I}(t)}{n}. \tag{4}$$

Mode II [t_1, t_2]: During this interval, source energy Vin is series connected with C1, C2, secondary winding N2, and Lk2 to charge output capacitor C3 and load R; meanwhile, magnetizing inductor Lm is also receiving energy from Vin. The current flow path is shown in Fig. 4(b); as illustrated, switch S1 remains on, and only diode D3 is conducting. The iLm, iLk1, and iD3 are increasing because the Vin is crossing Lk1, Lm and primary winding N1; Lm and Lk1 are storing energy from Vin; meanwhile, Vin is also in series with N2 of coupled inductor T1, and capacitors C1 and C2 are discharging their energy to capacitor C3 and load R, which leads to increases in iLm, iLk1,
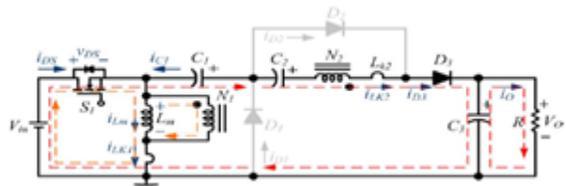

Fig.4 (b) Current flow path during one switching period Mode 2

$$\frac{di_{Lm}^{II}(t)}{dt} = \frac{V_{in}}{L_m} \tag{6}$$

$$i_{in}^{II}(t) = i_{DS}^{II}(t) = i_{Lm}^{II}(t) + (1+n)i_{Lk2}^{II}(t) \tag{7}$$

$$\frac{di_{Lk2}^{II}(t)}{dt} = \frac{di_{D3}^{II}(t)}{dt} = \frac{(1+n)V_{in} + V_{C1} + V_{C2}}{L_{k2}}. \tag{8}$$

Mode III [t_2, t_3]: During this transition interval, secondary leakage inductor Lk2 keeps charging C3 when switch S1 is off. The current flow path is shown in Fig. 4(c), and only diodes D1 and D3 are conducting. The energy stored in leakage inductor Lk1 flows through diode D1 to charge capacitor C1 instantly when S1 turns off. Meanwhile, the Lk2 keeps the same current direction as in the prior mode and is in series with C2 to charge output capacitor C3 and load R. The voltage across S1 is the summation of Vin, VLm, and VLk1. Currents iLk1 and iLk2 are rapidly declining, ut iLm is increasing because Lm is receivingenergy from Lk2. Once current iLk2 drops to zero, this mode ends at t = t3
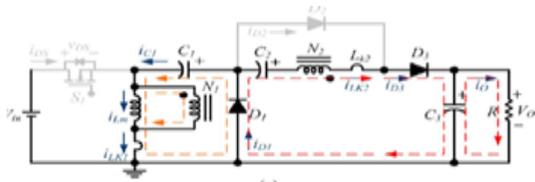
Fig.4 (c) Current flow path during one switching period Mode 3

$$i_{in}^{III}(t) = 0 \tag{9}$$

$$i_{Lm}^{III}(t) = i_{Lk1}^{III}(t) - n i_{Lk2}^{III}(t) \tag{10}$$

$$\frac{di_{Lk1}^{III}(t)}{dt} = \frac{-V_{C1} - v_{Lm}}{L_{k1}} \tag{11}$$

$$\frac{di_{Lk2}^{III}(t)}{dt} = \frac{di_{D3}^{III}(t)}{dt} = \frac{nv_{Lm} + V_{C2} - V_O}{L_{k2}}. \tag{12}$$

Mode IV $[t_3, t_4]$: During this transition interval, the energy stored in magnetizing inductor Lm releases simultaneously to $C1$ and $C2$. The current flow path is shown in Fig. 4(d). Only diodes $D1$ and $D2$ are conducting. Currents $iLk1$ and $iD1$ are persistently decreased because leakage energy still flows through diode $D1$ and continues charging capacitor $C1$. The Lm is delivering its energy through $T1$ and $D2$ to charge capacitor $C2$. The energy stored in capacitors $C3$ is constantly discharged to the load R. The voltage across $S1$ is the same as previous mode. Currents $iLk1$ and iLm are decreasing, but $iD2$ is increasing. This mode ends when current $iLk1$ is zero at $t = t4$
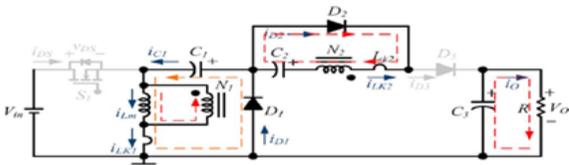

Fig.4 (d) Current flow path during one switching period Mode 4

$$i_{Lm}^{IV}(t) = i_{Lk1}^{IV}(t) - n i_{Lk2}^{IV}(t) \tag{13}$$

$$\frac{di_{Lk1}^{IV}(t)}{dt} = \frac{-V_{C1} - v_{Lm}}{L_{k1}} \tag{14}$$

$$\frac{di_{Lk2}^{IV}(t)}{dt} = \frac{V_{C2} + nv_{Lm}}{L_{k2}}. \tag{15}$$

Mode V $[t_4, t_5]$: During this interval, magnetizing inductor Lm is constantly transferring energy to $C2$. The current flow path is shown in Fig. 4(e), and only diode $D2$ is conducting. The iLm is decreasing due to the magnetizing inductor energy flowing continuously through the coupled inductor $T1$ to secondary winding $N2$ and $D2$ to charge capacitor $C2$. The energy stored in capacitors $C3$ is constantly discharged to the load R. The voltage across $S1$ is the summation of Vin and VLm. This mode ends when switch $S1$ is turned on at the beginning of the next switching period
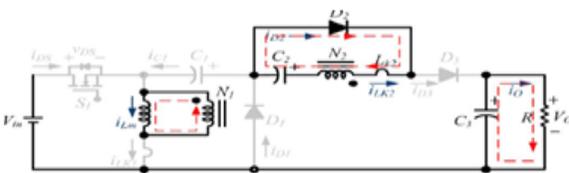

Fig.4 (e) Current flow path during one switching period Mode 5

$$\frac{di_{Lm}^{V}(t)}{dt} = \frac{v_{Lm}}{L_m} \tag{16}$$

$$i_{Lk1}^{V}(t) = 0 \tag{17}$$

$$\frac{di_{Lk2}^{V}(t)}{dt} = \frac{nv_{Lm} + V_{C2}}{L_{k2}}. \tag{18}$$

3.2 Basic Five Level Zeta Converter fed Multi string Multi level Inverter (MSMLI)

The basic five level Zeta Converter fed multi string multi level inverter is shown in Fig.5. and corresponding output voltage waveforms are shown. In this approach, all the six switches are operated with a switching frequency of 50 Hz and the input voltage of Vdc=100V. The symmetrical multilevel approach of the multi string multi level inverter is operated with equal voltage values at the input side of the inverter. These symmetrical multilevel inverters are operated with PWM procedure to generate the gating signals. In a symmetrical multi string multi level inverter, the Seven, Nine, Eleven and Thirteen levels are generated by using 6,8,8,10 switches respectively with repeating sequence as gating signal.
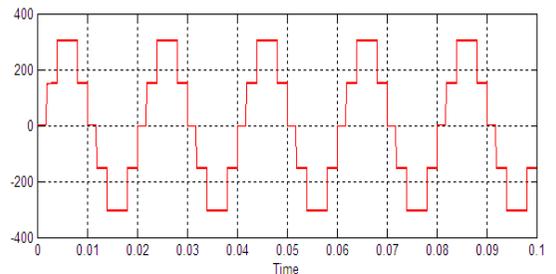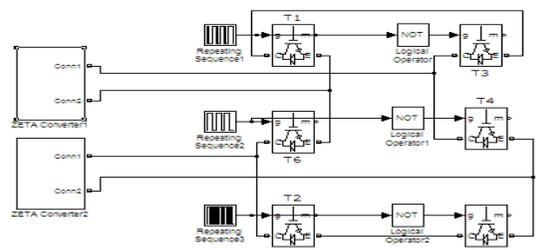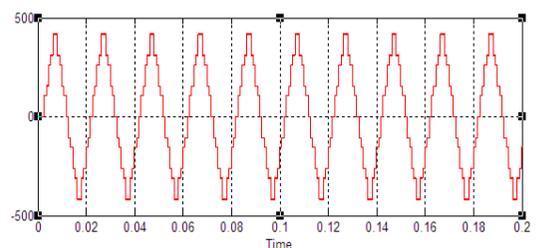

Fig 5: Zeta Converter fed Multi String Multi Level Inverter and Output voltage Wave forms.

3.2 Eleven level (ELI) Zeta Converter fed Multi String Multi level inverter:

The proposed Eleven Level Zeta Converter fed Multi String Multi level inverter[10] circuit is shown in Fig.6 in an asymmetrical approach with an input voltages of 80V, 160V, 160V and corresponding output voltage waveforms are shown in Fig.8. It requires 8 switches to get eleven level of output voltage. The Table.4 shows the operation of switches at different levels of voltages.
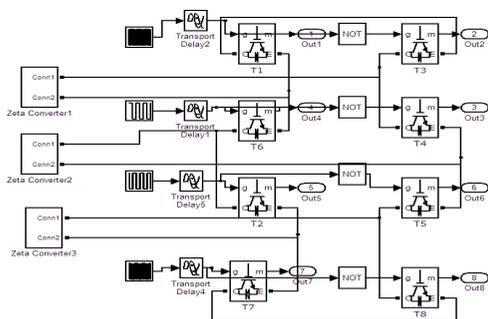
Fig.6 Eleven level Zeta Converter fed Multi String Multi level inverter and Output Voltage waveforms.

Output Voltage, Vac	Swiches in eleven level MSMLI							
	S1	S2	S3	S4	S5	S6	S7	S8
+5Vs	0	1	0	1	1	0	1	0
+4Vs	1	1	0	1	0	0	1	0
+3Vs	0	1	0	0	1	0	1	1
+2Vs	1	1	0	0	0	0	1	1
+Vs	0	1	1	1	1	0	0	0
0	1	1	1	1	0	0	0	0
-Vs	1	0	0	0	0	1	1	1
-2Vs	0	0	1	1	1	1	0	0
-3Vs	1	0	1	1	0	1	0	0
-4Vs	0	0	1	0	1	1	0	1
-5Vs	1	0	1	0	0	1	0	1

Table.1 consists of list of switching combinations that generate the required eleven level output voltage signals.

The corresponding mode of operations of the Zeta Converter fed Multi string multilevel inverter stages are described as follows

a) Maximum positive output voltage (+5Vs): Active switches S2,S4,S5 and S7 are kept ON and inverter output voltage is 5Vs.

b) positive output voltage (+4Vs): Active switches S1,S2,S4 and S7 are kept ON and inverter output voltage is 4Vs.

c) positive output voltage (+3Vs): Active switches S2,S5,S7 and S8 are kept ON and inverter output voltage is 3Vs.

d) positive output voltage (+2Vs): Active switches S1,S2,S7 and S8 are kept ON and inverter output voltage is 2Vs.

e) positive output voltage (+Vs): Active switches S2,S3,S4 and S5 are kept ON and inverter output voltage is Vs.

f) Zero Output, (0): Active switches S1,S2,S3 and S4 are kept ON and inverter output voltage is 0.

g) negative output voltage (-Vs): Active switches S1,S6,S7 and S8 are kept ON and inverter output voltage is -Vs.

h) negative output voltage (-2Vs): Active switches S3,S4,S5 and S6 are kept ON and inverter output voltage is -2Vs

i) negative output voltage (-3Vs): Active switches S1,S3,S4 and S6 are kept ON and inverter output voltage is -3Vs.

j) negative output voltage (-4Vs): Active switches S3,S5,S6 and S8 are kept ON and inverter output voltage is -4Vs.

k) Maximum negative output voltage (-5Vs): Active switches S1,S3,S6 and S8 are kept ON and inverter output voltage is -5Vs.

4 Eleven Level Asymmetrical ZETA Converter based Multi String Multi Level Inverter fed Three Phase Induction Motor Drive

The proposed Asymmetrical configuration with Eleven Level Asymmetrical ZETA Converter based Multi String Multi Level Inverter fed Three Phase Induction Motor Drive (IMD) is shown in Fig.8. In this approach, Asymmetrical voltages are applied to the inverter and corresponding three phase generated output voltages are given to the induction motor drive. The performance factors are analyzed at both transient and steady state operating conditions with usage of minimum number of switches so that switching losses can be reduced effectively with Zeta

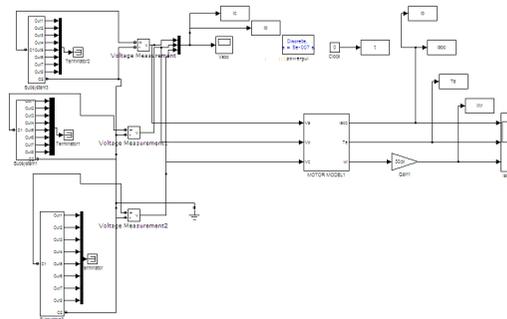Converter fed multi string multi level approach when compared to the multi string multi level inverter.

Fig.7. Eleven Level Asymmetrical ZETA Converter based Multi String Multi Level Inverter fed Three Phase Induction Motor Drive

5. Simulation results and Discussions

To validate the proposed topologies, numerical simulation studies have been carried out by using Matlab-Simulink. For the simulation studies the dc link voltage is taken as 400V.The parameters of the induction motor used in this paper are Rs =1.57ohm, Rr=1.21ohm, Lm=0.165H, Ls=0.17H, Lr=0.17H and J=0.089Kg-m2. The simulation results of proposed topologies are shown from Fig.8 – Fig12.
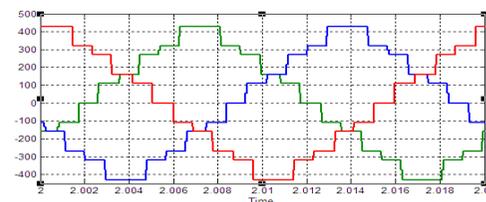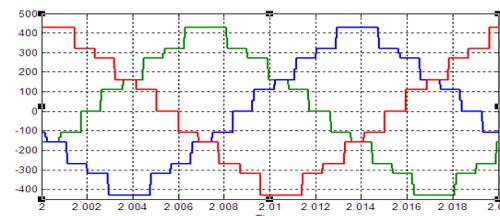

Fig:8(a)

Fig.8(b)

Fig. 8(a) & Fig8(b): Three phase Eleven level Output Voltage waveforms Multi string multi level and Zeta Converter based Multi string multi level inverters respectively.
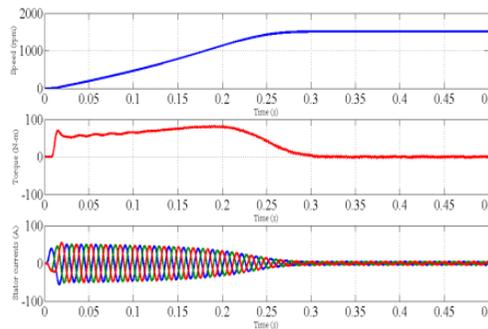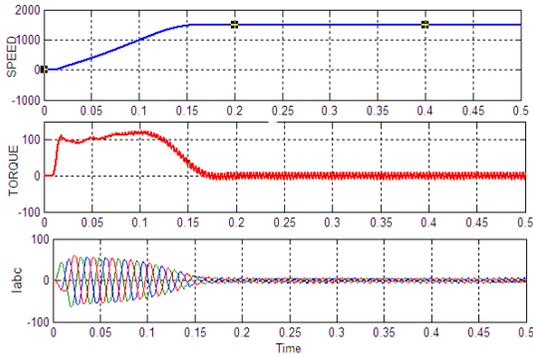

Fig:9(a)

Fig:9(b)

Fig.9(a) & 9(b): Starting Transients of Eleven level Multi string multi level a ZETA Converter based Multi String Multi Level Inverter fed Three Phase Induction Motor Drive respectively.
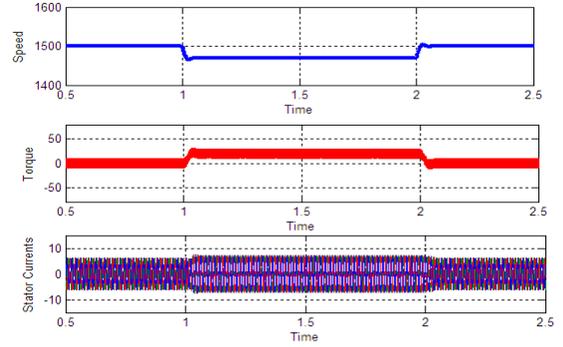

Fig.10(a)

Fig.10(b)

Fig.10(a)&10(b): Steady state Performance of Eleven level Multi string multi level a ZETA Converter based Multi String Multi Level Inverter fed Three Phase Induction Motor Drive respectively.

Fig11(a)

Fig.11(b)

Fig. 11: Performance during sudden change in load torque of Eleven level Multi string multi level and Eleven level (ELI) a ZETA Converter based Multi String Multi Level Inverter fed Three Phase Induction Motor Drive respectively.
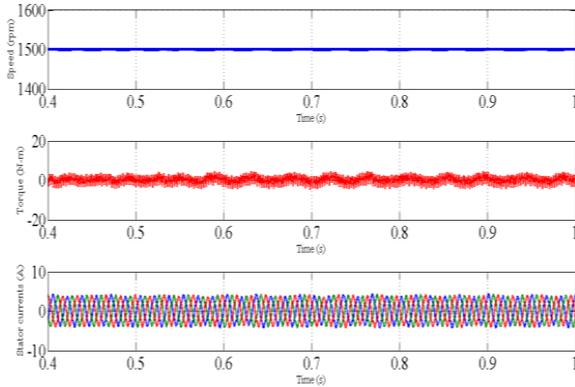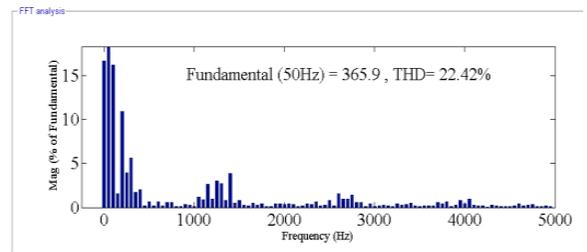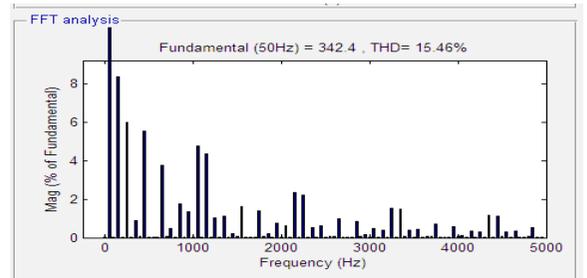

Fig.12 (a)

Fig.12 (b)

Fig.12(a) & Fig.12(b): Total Harmonic Distortion of Output Voltage waveforms with Eleven level Multi string multi level and Zeta converter based Multi string multi level inverters respectively.
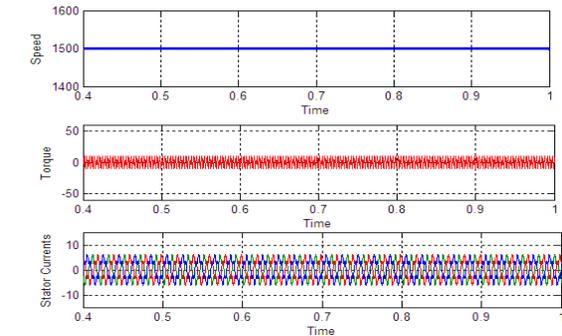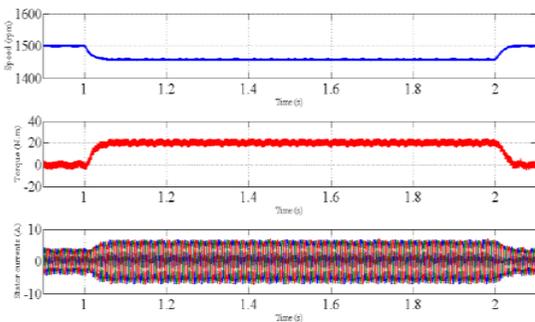
6. Conclusion

In this paper, a Zeta Converter based Multi string multi level inverter topology is proposed to offer strong advantages like an improved output waveforms, smaller filter size, and lower electromagnetic interference. The proposed converter employs the turns ratio of the coupled inductor to achieve high step-up voltage gain; based on the floating switch structure of the Zeta converter. Here an asymmetrical configuration with Eleven-level(ELI) Zeta Converter based Multi String Multi Level inverter fed Three Phase Induction Motor Drive performance is analyzed and compared with conventional Multi string multi level inverter. Fast dynamic response is obtained The analysis of performance factors at both transient and steady state operating conditions are satisfactory. Hence the switching losses can be reduced effectively with multi string multi level approach by using of minimum number of switches.

REFERENCE

[1] Y. Li, D. M. Vilathgamuwa, and P. C. Loh, Design, analysis, and real time testing of a controller for multi bus micro grid system, IEEE Trans. Power Electronics, vol. 19, no. 5, pp. 1195-1204, Sept. 2004. | [2] G. Ceglia, V. Guzman, C. Sanchez, F. Ibanez, J. Walter, and M. I. Gimenez, A new simplified multilevel inverter topology for DC-AC conversion, IEEE Trans. Power Electronics, vol. 21, no. 5, pp. 1311- 1319, Sep. 2006 | [3] M. J. Bonato, F. T. Wakabayashi, and C. A. Canesin, "A novel voltage step-down/up ZCS-PWM Zeta converter," in Conf. Rec. IEEE IAS Annu. Meeting, 2000, pp. 2448–2454 | [4] B. R. Lin and F. Y. Hsieh, "Soft-switching Zeta-flyback converter with a buck-boost type of active clamp," IEEE Trans. Ind. Electron., vol. 54, no. 5, pp. 2813–2822, Oct. 2007. | [5] T. F. Wu, S. A. Liang, and Y. M. Chen, "Design optimization for asymmetrical ZVS-PWM Zeta converter," IEEE Trans. Aerosp. Electron. Syst., vol. 39, no. 2, pp. 521–532, Apr. 2003. | [6] M. J. Bonato, F. T. Wakabayashi, and C. A. Canesin, "A novel voltage step-down/up ZCS-PWM Zeta converter," in Conf. Rec. IEEE IAS Annu.Meeting, 2000, pp. 2448–2454. | [7] L. S. Yang, T. J. Liang, and J. F. Chen, "Transformerless dc-dc converters with high step-up voltage gain," IEEE Trans. Ind. Electron., vol. 56, no. 8,pp. 3144–3152, Aug. 2009. | [8] M. J. Bonato, F. T. Wakabayashi, and C. A. Canesin, "A novel voltage step-down/up ZCS-PWM Zeta converter," in Conf. Rec. IEEE IAS Annu.Meeting, 2000, pp. 2448–2454. | [9] G. Zhu and A. Ioinovici, "Switched-capacitor power supplies: dc voltage ratio, efficiency, ripple, regulation," in Proc. IEEE ISCAS, 1996, pp. 553–556 | [10] Ms Ch.V.V.Manga Lakshmi, Mr.B.Ramesh, Dr.K.Satyanarayana, " Performance Analysis of Eleven Level Asymmetrical Multi String Multi Level Inverter fed Three Phase Induction Motor Drive"., International Journal of Advances in Science and Technology, Vol. 7, No.6, 2013 December Issue Page No:37 - 46 ISSN 2229 5216 | |