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Comparison of Z-Source EZ-Source and TZ-Source Inverter Systems for Wind Energy Conversion

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ABSTRACT

In this paper, three different impedance source inverters: Z-source inverter, EZ- source inverter, TZ-Source for wind energy conversion system (WECS) were investigated. Total output power and THD of each of these systems are calculated. The proposed system can boost the output voltage effectively when the low output voltage of the generator is available at low wind speed. This system has higher performance, less components, increased efficiency and reduced cost. These features make the proposed TZSI based system suitable for the wind conversion systems. MATLAB simulink model for wind generator system is developed and simulation studies are successfully performed. The simulation is done using MATLAB and the simulation results are presented. This comparison shows that the TZ-source inverter is very promising for wind energy conversion system.

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1. INTRODUCTION

Wind energy is most decisive and crucial source of electrical energy in years to come. Its main mastery come from the authenticity of being a renewable and environmental-neighborly energy. At the opening it was nominal and hefty but the generated power quality was scanty. Most of wind power installations were limited to a few hundred kilowatts connected to distribution grids [1]. Wind turbines and farms vegetates in size and ratio from the few hundred kilowatts to megawatts. The consistent increasing energy demands, tapering sources of fossil fuels or deposit fuels and concern about pollution levels in the environment has been the driving force behind electricity generation using renewable energy sources. Harnessing the energy available from the inexhaustible sources allows the fulfillment of conspicuous contractions in the pollution levels and pessimistic climate changes. On the alternative hand, the opportunity of energy from sustainable sources like wind energy, solar energy, etc. is fickle and is affected by circumstances beyond human control. Accordingly, such renewable energy systems should be backed up by conventional sources of energy or energy storage devices in order to ensure cohesive of the energy supply. This façade leads to the topic of fuzzy controlled TZ-source inverter for wind energy conversion system.

In the early years of the gradual development, fixed speed wind turbines were the most installed wind turbines. They are equipped with an induction generator connected directly to the grid without converter. With this configuration it is not possible to extract all available wind energy. Power electronics makes it possible to apply the variable speed concept. Due to this advantage, power of wind turbines has been increased and variable speed wind turbines became the predominant choice for MW-scale turbines today. In a ordinary voltage source inverter, the two switches of any phase leg cannot be gated at the same time because this may cause a short circuit position and this smash the inverter. In extension, the maximum output voltage cannot outstrip the DC bus voltage. These restrictions in such conventional voltage source inverter can be overcome by using ZSI, EZSI and TZSI [2]. In additional, the ZSI is a power electronic converter with many merits such a buck-boost characteristics, lower price tag and principally higher efficiency compared to traditional converters [3]-[4]. The Z-source inverter consists of "X" Shaped impedance network formed by two similar capacitors and inductors and provides unique distinctive. Furthermore, unlike VSI, the need of dead time would not appear with this topology. Due to these attraction features, the Z-source inverter has found applications in copies industrial processes including variable-speed drives and wind farms [5]-[6]. To bypass using a external LC filter, brand-new concept of Z-source inverter were introduced, this concept is labeled embedded Z-source (EZ-Source) inverter with different topologies that DC sources are added into X-carved impedance [7]-[8]. Multicell TZ source inverters are presented in [9] and [10]. Cascaded TZSI is depicted in [11]. The above mentioned papers do not deal with comparison of ZSI, EZSI and TZSI based AC to AC converters for wind energy conversion. This work proposes TZSI for the WECS.

2. Z-SOURCE INVERTER NETWORK

The Z-source converter (ZSC) is a new topology in power conversion, which has unique features that can overcome the limitations of VSI and CSI. Figure 1 shows the ZSC implemented as a three-phase DC/AC converter (inverter). Although DC/AC conversion is the most common application of the Z-source topology. It can also be applied to AC/DC & AC/AC power conversions. The X-shape impedance is the Z-source network which is composed of two split inductors and two capacitors to provide a coupling between the DC source and the inverter bridge.

The Z-source inverter (ZSI) has the unique back-boost capability which ideally gives an output voltage range from zero to infinity regardless of the input voltage. This is achieved by using a switching state that is not permitted in the VSI which is called the "shoot-through" state.

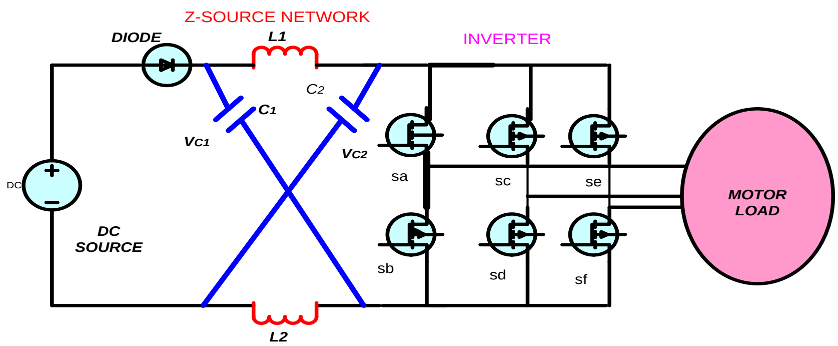

Figure 1. ZSC implemented as a three-phase inverter (ZSI)

3. EZ-SOURCE INVERTER NETWORK

The voltage-type EZ-source inverter show in Figure 2 has its DC sources embedded within the X-shaped LC impedance network with its inductive elements L_1 and L_2 respectively, used for filtering the currents drawn from the two DC sources without using any external LC filter. Quite obviously, the immediate disadvantage shown in Figure 2 is that two DC sources of $V_{dc}/2$, instead of the single DC source shown in Figure 1 are needed for the EZ-source inverter.

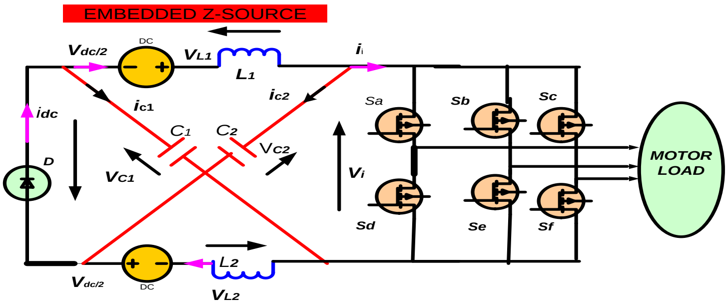

Figure 2. EZSI implemented as a three-phase inverter (EZSI)

Noting that there is again an inductive element placed along all current paths in the DC front-end, the switches from the same phase-leg can as usual be turned on simultaneously to introduce a shoot-through state without damaging semiconductor devices. The resulting equivalent circuit is shown in Figure 3 (a) and (b), where it is shown that when the inverter bridge is shoot-through, the front-end diode D is reverse biased with its blocking – voltage expression and other state equations written as follows.

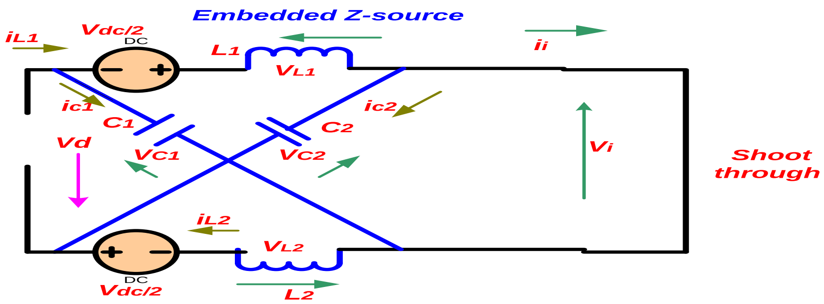

Figure 3(a). Equivalent circuits of the Z-source inverter (Shoot-through conditions)

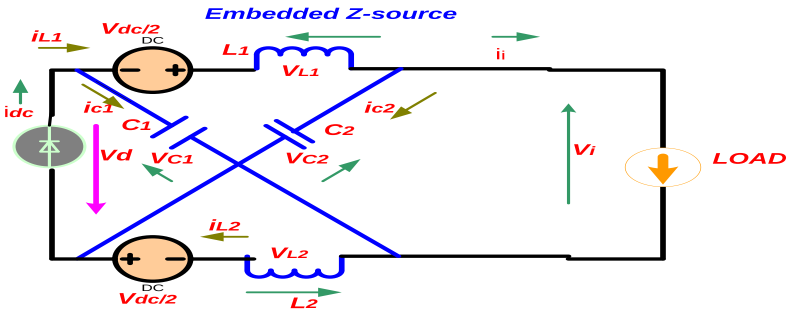

Figure 3(b). Equivalent circuits of the Z-source inverter (Non Shoot-through conditions)

3.1. Shoot-through

$$s_x = s_x = on$$

$$x = A, B, (\mathrm{or})\, C, D = \mathrm{OFF}\ ,\ V_L = V_C + V_{dc}/2\ ,\ V_i = 0\ ,\ V_d = V_D = -2V_C\ ,\ i_L = -i_C$$

$$i_i = i_L - i_c\ ,\ i_{dc} = 0$$

Assuming now that the inverter returns back to its non shoot through active (or) null state, the re-drawn equivalent circuit is shown in Figure 3(b) with diode D conducting and the inverter bridge and external (usually inductive) load replaced by a current source, whose value is non zero for active state.

3.2. Non shoot-through

$$s_x \neq s_{x;} x = A, B, (or) C, D = ON \, , V_L = V_{dc}/2 - V_C \, , V_i = 2V_C$$

$$V_d = V_D = 0 \, , i_{dc} = i_L + i_c \, , i_i = i_L \, , i_{dc} \neq 0$$

When compared with Z inverter [9], clearly shows that both Z and EZ source inverters produce the same transfer gain even through the EZ-source inverter has its DC sources embedded within the impedance network for achieving inherent filtering.

$$\vec{V} = \frac{V_{dc}}{1 - 2T_0/T} = BV_{dc} \, , \quad \vec{V}_x = M\vec{V}_i = B(M\frac{V_{dc}}{2}) \, , \quad V_D = -V_{dc}/(1 - 2T_0/T)$$

Inductor voltage

$$V_L = V_{dc}\frac{(1 - T_0/T)}{(1 - 2T_0/T)}$$ During shoot-through

$$V_L = -V_{dc}\frac{(T_0)}{(1 - 2T_0/T)}$$ During Non shoot-through

4. TZ-SOURCE INVERTER NETWORK

In the trans-Z-source inverters, high gain is obtained by increasing their common transformer turns ratio γTZ, which is in agreement with classical transformer theories. Depending on the eventual voltage gain demanded, the raised γTZ might at times be excessive for realization. Because of this, T-Z-source inverters shown in Figure 4 are proposed for wind energy conversion. The proposed inverters use the same components as the trans-Z-source inverters, but with different transformer placement. This difference causes the T-Z-source gain to be raised by lowering, and not increasing, the transformer turns ratio γTZ. The general structure of three phase T- Z-source inverter is shown in Figure 4.

It basically has an impedance network that couple the converter main circuit to be power source. This addition of impedance network introduce a unique feature that cannot be used for the traditional three phase voltage source inverter and three phase current source inverter. The limitations for the traditional inverter are being solved in the TZ-source inverter. The TZ-source also can be used for all DC-DC, AC-AC, AC-DC and DC-AC power combinations. The analysis is as follows.

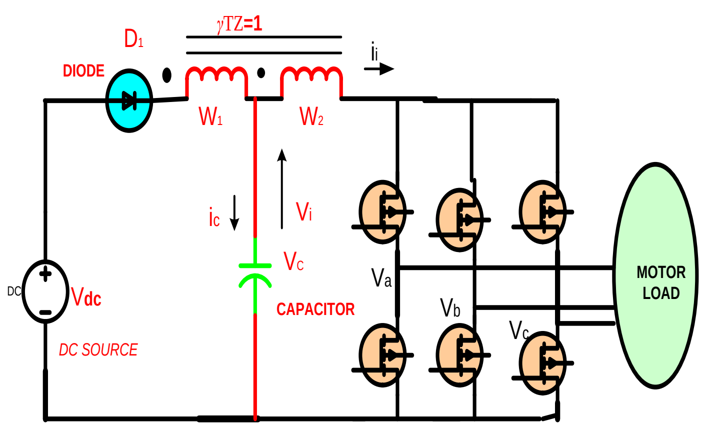

Figure 4. General structure of TZ-source inverter

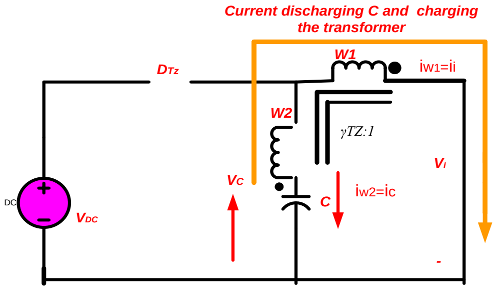

Figure 5(a). Shoot-through conditions

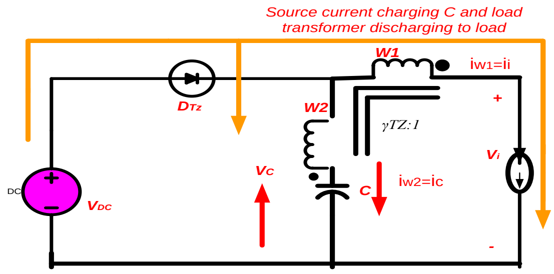

Figure 5(b). Non-shoot-through states.

5. SIMULATION STUDIES OF Z-SOURCE INVERTER NETWORK

The simulation of ZSI system is done using the MATLAB software. Wind energy conversion system feeding a RL load is considered. The Z-network is used to boost the output of WECS to the required level.

The Figure 6(a) shows the simulink diagram of Z-source inverter based system. Scopes are connected to measure three phase voltages and currents. The output power is shown in Figure 6(b) and its value is 230 watts. The frequency spectrum is shown in Figure 6(c). The THD is 19.8 %.

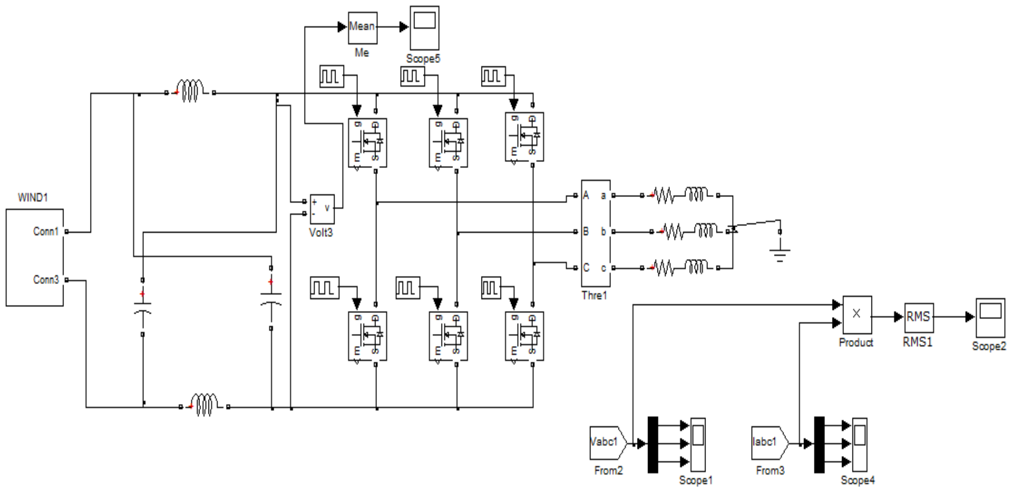

Figure 6(a). Simulink diagram of Z-Source inverter system

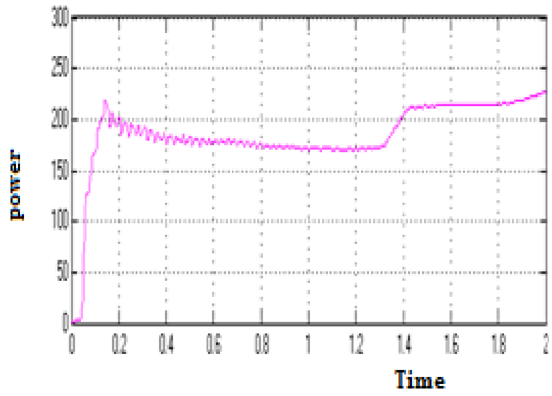

Figure 6(b). Output Power of ZSI system

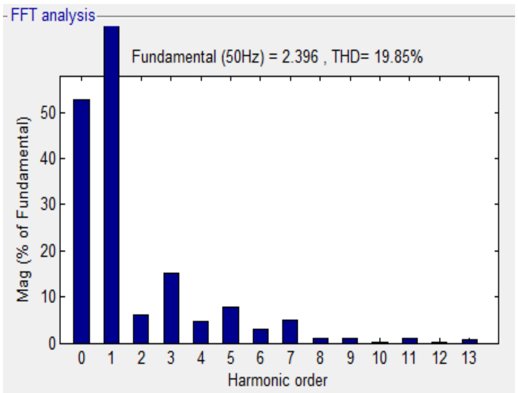

Figure 6(c). THD value of ZSI system

6. SIMULATION STUDIES OF EZ-SOURCE INVERTER SYSTEM

EZSI system is capable of reducing the ripple. Therefore EZSI based conversion system is also simulated using MATLAB. The Figure 7(a) shows the simulink diagram of EZ-source inverter based system. Scopes are connected to measure three phase voltages and currents. The output power is shown in Figure 7(b) and its value is 450 watts. The frequency spectrum shown in Figure 7(c). The THD is 12.8 %.

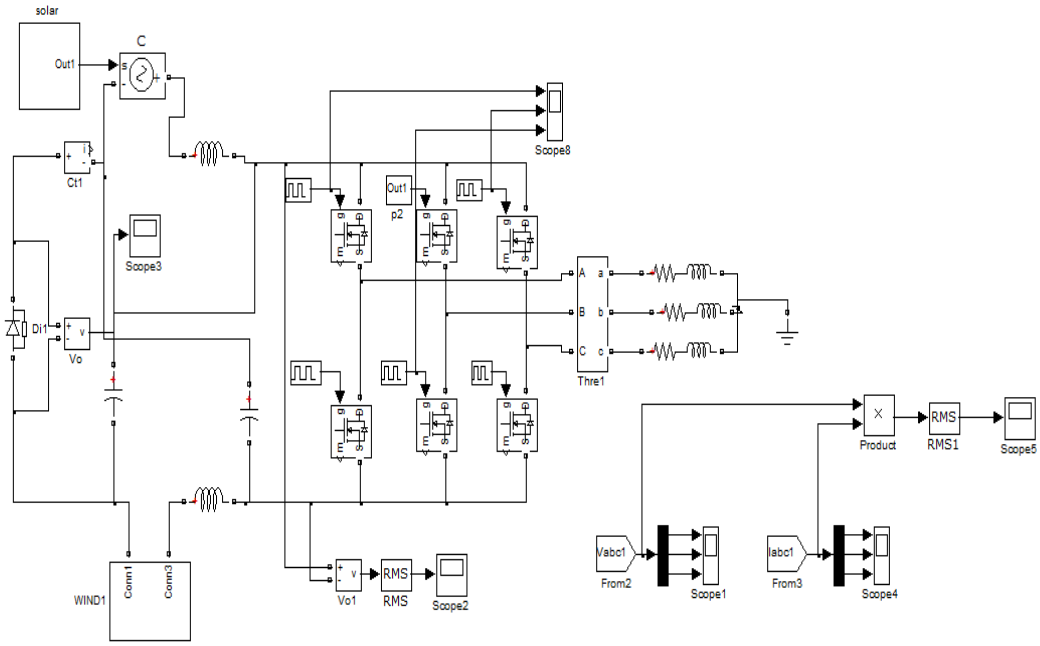

Figure 7(a). Simulink diagram of EZ-Source inverter system

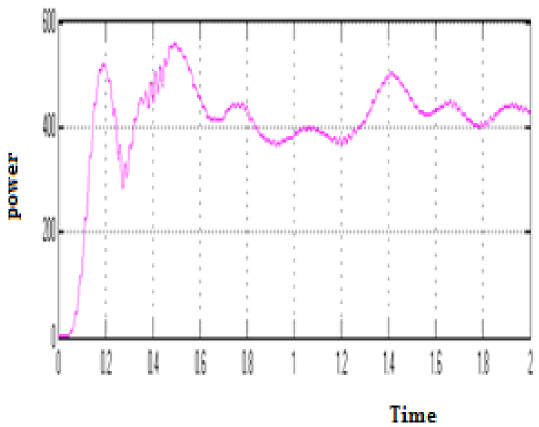

Figure 7(b). Output Power of EZSI system

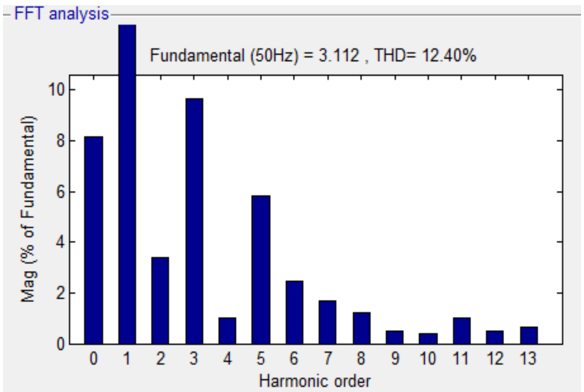

Figure 7(c). THD value of EZSI system

7. SIMULATION STUDIES OF TZ-SOURCE SYSTEM

The Figure 8(a) shows the simulink diagram of TZ-source inverter based system. Scopes are connected to measure three phase voltages and three currents. The output power is shown in Figure 8(b) and its value is 500 watts. The frequency spectrum is shown in Figure 8(c). The THD is 10.36 %.

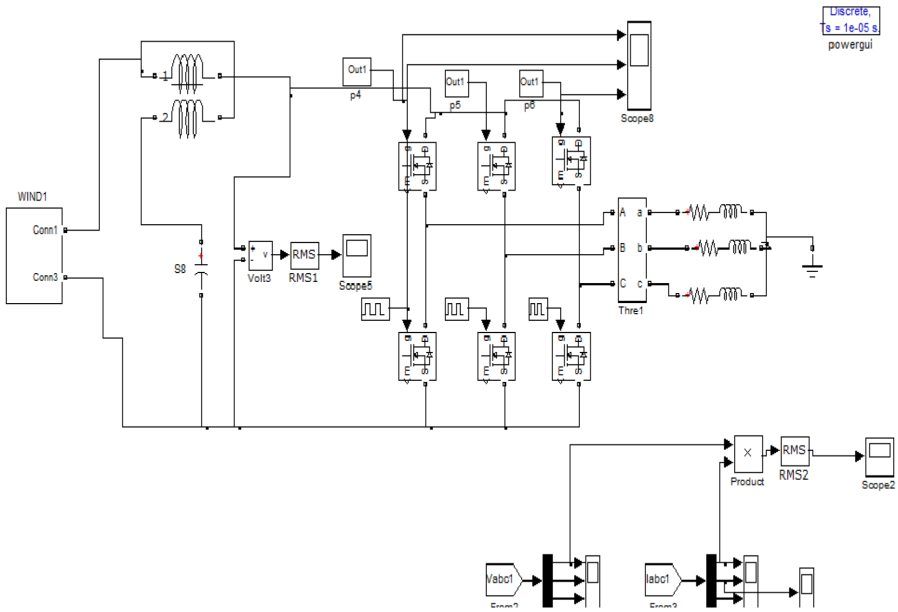

Figure 8(a). Simulink diagram of TZ-Source inverter system

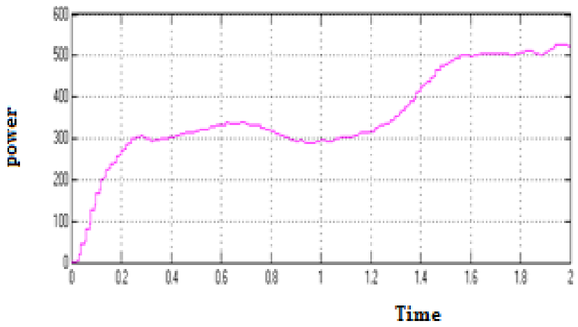

Figure 8(b). Output Power of TZSI system

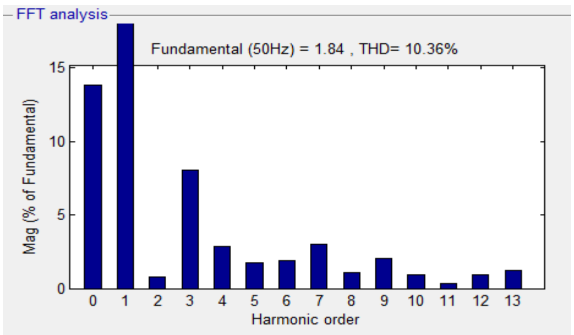

Figure 8(c). THD value of TZSI system

8. EXPERIMENTAL RESULTS OF TZ-SOURCE

A prototype hardware for TZSI based system is fabricated and tested. The snap shot of the hardware is shown in Figure 9(a). The hardware consists of control board and power board. The output voltage of wind generator is shown in Figure 9(b). Output voltage of TZ network is shown in Figure 9(c). Phase voltage and line to line voltages are shown in Figures 9(d) and 9(e) respectively. PIC is used to generate pulses for MOSFETs. The 480LCR digital multimeter and DSO is used to measure the hardware output voltage.

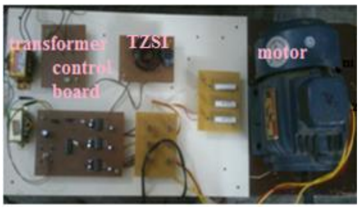

Figure 9(a). Hardware snap shot

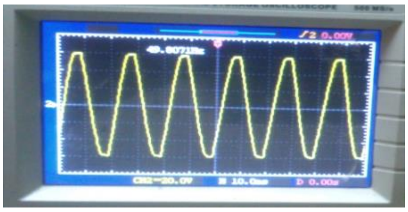

Figure 9(b). Output voltage

Figure 9(c). T-Z source output voltage

Figure 9(d). Line to neutral voltage

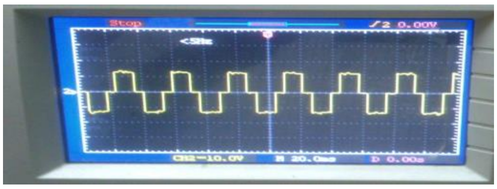

Figure 9(e). Line to line voltage

9. SUMMARY OF RESULTS

The Table 1 Summaries the output power and THD for various of types inverter systems. It can be seen that TZ-source based inverter system gives higher output power with least harmonic distortion in the output. Above analysis, proved that T-ZSI is superior than rest of two impedance source network. So hardware was build up for T-ZSI alone. It was good boosting capability than ZSI and EZSI. The Table 2 contains hardware specifications of TZSI.

Table 1. Summary of output power and THD values (Simulations)

System	Output power in Watts	THD
Z-source	230	19.85%
EZ-source	450	12.40%
TZ-source	500	10.36%

Table 2. Hardware Specifications for T-ZSI

Components	Ratings
MOSFET	IRF 840, I_D=0.8A
Diode	ING007, V_D=0.9V, V_G=10V
PIC	16F84A, 18-Pin, 1A, 230V
Driver	IR2110, 14-Pin
L_1.L_2	5mH , 2A
C_1,C_2	2200µF, 63V
Regulators	7812,7805
Motor	0.5HP,15RPM,2A, Induction motor,
DSO	100-240V, 45-440HZ, 30Watts
DMM	450 LCR

The experimental values are slightly less than that of simulation value. This is due to the drops in devices, resistance of the choke and equivalent series resistance of capacitor. The comparison between simulation and experimental results is given in Table 3. The comparison is done by considering similar voltage and load conditions.

Table 3. Comparison of Simulation and Experimental Results

Outputs	Simulation value	Experimental value
DC Input to TZ-Source	48volts	48volts
Output of TZ-Source	96volts	90volts
Load voltage per phase	130 volts	120 volts

9. CONCLUSION

This paper has presented the comparison between ZSI, EZSI and TZSI based wind energy conversion systems. From the results it is concluded that TZSI based wind energy conversion system is viable alternative to the existing converters applied to wind energy conversion system. Since it delivers higher power with reduced THD. The TZSI based WECS has advantages like reduced hardware and low THD. The disadvantage of TZSI system is that it requires a coupled inductor. The present work deals with comparison of open loop controlled systems. The comparison of closed loop systems will be done in future.

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