Comparative Analysis of Improved T-Source Inverter, T-Source Inverter and Z-Source Inverter

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Abstract-

Most of the electrical devices requires converter or inverters in its operation to convert ac to dc voltage and vice-versa. This paper deals with the comparison of Z-source inverter, T-source inverter and improved T-source inverter. This type of inverters has an impedance network after its source unlike traditional voltage and current source inverters which helps in boost capability. They work on two modes of operation - shoot through mode and non-shoot through mode. T-source inverter results in high boost capability than Z-source inverter whereas improved T-source inverter has high boost capability and low current ripple than T-source inverter due to modifications in its topology. Sinusoidal pulse width modulation is used as controller and helps in generation of pulses to the switches. Moreover improved T-source results in less THD and it can be concluded that improved T-source inverter has better characteristics than conventional inverters. This paper presents the operating principles, analysis and simulation results, and compares them with those of the conventional Z-source inverter with T-source and improved T-source inverter. The simulation of various inverter topologies is done in MATLAB and results are shown.

***Keywords*:** Improved T-source inverter, T-source inverter, Z-source inverter, sinusoidal pulse width modulation technique.

I. INTRODUCTION

The Z-source inverter was proposed in order to accomplish single stage power conversion with buck boost abilities. In the Z-source inverter, both of the power switches in a leg can be turned on at the same time, which eliminates dead time and significantly improves the reliability while reducing the output waveform distortion. It has two inductors and two capacitors as shown in fig.1. The Z-source inverter overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source converter and current-source converter and provides a novel power conversion concept. 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, load, or another converter. The dc source/or load can be either a voltage or a current source/or load.

In order to overcome the inconvenience of inrush current suppression at start up of the Z-source inverter quasi-Z-source inverter is proposed which provides continuous input current, reduced passive component count, reduced voltage stress on the capacitors, lower shoot-through current, and lower current stress on inductors and diodes, in comparison to the switched-inductor Z-source inverter for the same input and output voltages. In this two inductors in the impedance Z-network are replaced by a transformer with a turn ratio of 2:1 in order to obtain a high voltage gain with the minimum component count of one capacitor and coupled inductors as shown in fig.2. These are the T-source inverter (TSI) / trans-Z-source. The T-source is extended to various structures in cascade topologies and parallel operations for high power conversion system.

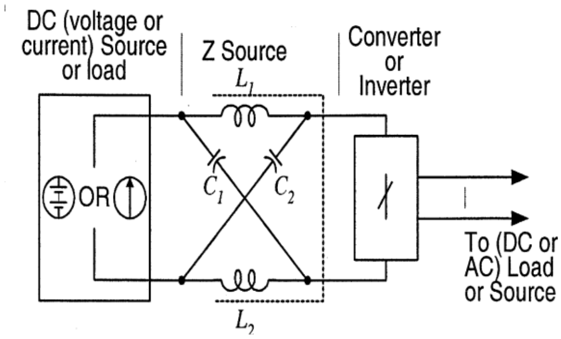


Fig.1 General Structure of Z-source inverter

In order to improve the input current profile, an inductor–capacitor–capacitor–transformer Z-source inverter (LCCT-ZSI) used one more inductor and one more capacitor in comparison with the T-source inverters. This type of inverter topology is called as improve T-source inverter and is shown in fig.3. Like the traditional Z-source inverters, the improved inverter turns on both power switches in a leg to boost the dc bus voltage. The current drawn from the dc source is continuous. In addition, the improved trans-Z-source inverter can suppress resonant current at start up, which might destroy the devices. Both shoot-through states and the transformer turn ratio can be regulated to control the boost voltage gain. Thus, the output voltage can be adjusted over a wide range, and can be boosted to a higher value.

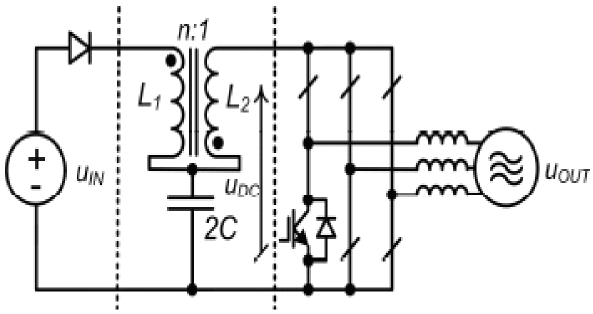


Fig.2 General structure of T-Source inverter

Among all improved T-source inverter has specific characteristics which makes it most efficient than traditional ones. They are 1) the input dc current is continuous; 2) it provides resonant current suppression, unlike the T-source inverter topology , because no current flows to the main circuit at start up; 3) only one inductor and one capacitor are added, and a higher boost factor can be obtained with the same turn ratio and component count.

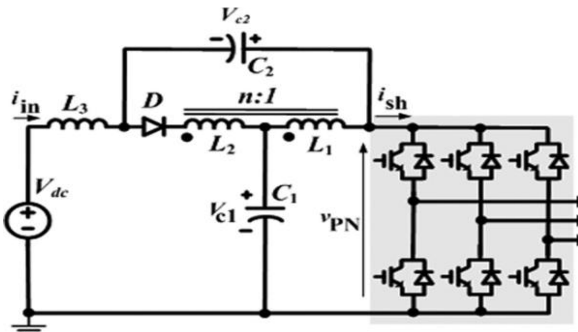


Fig.3 General structure of Improved T-source inverter

All these topologies suit solar cell and fuel cell applications, since they require high voltage gain in order to match the source voltage to the line voltage. These configurations are controlled using sinusoidal pulse width modulation technique. Since these works on shoot through modes an extra pulse is added to shoot through all the three switches.

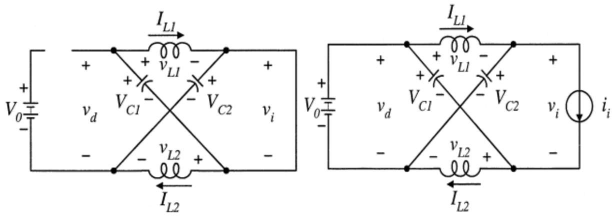
II. PRINCIPLE OF OPERATION OF DIFFERENT INVERTER TOPOLOGIES

The impedance source inverter works in two modes of operation. Impedance network inverter can handle shoot-through states when two switches in same phase leg conduct. T network is used instead of LC network for boosting operation by inserting shoot through states in PWM. The improved inverter has extra shoot-through zero states in addition to the traditional six active and two zero states in a classical Z-source inverter. Thus, the operating principles of all improved inverter are similar to those of the classical Z-source inverters. For the purpose of analysis, the operating states are simplified into shoot-through and non shoot-through states.

The three-phase impedance-source inverter bridge has one extra zero state (or vector) when the load terminals are shorted through both the upper and lower devices of any one phase leg (i.e., both devices are gated on), any two phase legs, or all three phase legs. This shoot-through zero state (or vector) is forbidden in the traditional V-source inverter, because it would cause a shoot-through. We call this third zero state (vector) the shoot-through zero state (or vector), which can be generated by seven different ways: shoot-through via any one phase leg, combinations of any two phase legs, and all three phase legs.

Z-source inverter

The inverter bridge is equivalent to a short circuit when the inverter bridge is in the shoot-through zero state, as shown in Fig. 4(a), whereas the inverter bridge becomes an equivalent current source as shown in Fig. 4(b) when in one of the six active states. Note that the inverter bridge can be also represented by a current source with zero value (i.e., an open circuit) when it is in one of the two traditional zero states. Therefore, Fig.4(b) shows the equivalent circuit of the Z-source inverter viewed from the dc link when the inverter bridge is in one of the eight non shoot-through switching states.



(a) (b)

Fig.4 (a) Shoot-through mode (b) Non-Shoot through mode of Z-source inverter

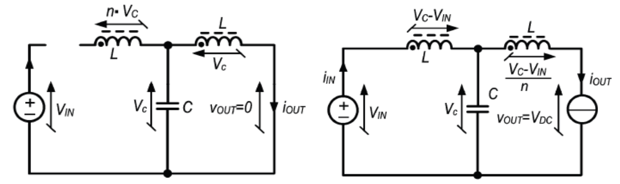
T-source inverter

Fig.5(a) shows the equivalent circuit of shoot through mode of operation of TSI. This shoot through zero is prohibited in traditional voltage source inverter. It can be obtained in three different ways such as shoot through in one leg phase or through combination of two leg phase. At this stage diode D is reverse biased separating DC link from AC line. Both the capacitor voltage and output voltage are the functions of shoot through coefficient $D=T_0/T_s$ where T_s is switching time period. The equation in shoot through mode is given by

$$V_c/V_{in} = T_1/(T_1-n.T_0) = 1-D/(1-(n+1).D)$$

Where D satisfies the condition D<1/ (n+1).

Thus the desired voltage can be obtained by controlling the interval of shoot through mode. TSI improves the reliability of system since it allows across any phase leg and prevents switches from damages.



(a) (b)

Fig.5 (a) Shoot-through mode (b) Non-Shoot through mode of T-source inverter

Fig.5(b) shows the equivalent circuit of Non-shoot through mode of TSI. In this mode, the inverter bridge works in one of the traditional active states, thus act as current source. The diode D is forward biased and hence conducts. It carries the current difference between inductor current and input DC current. As two inductors are coupled both inductors has same current.

The output voltage at the load is given by,

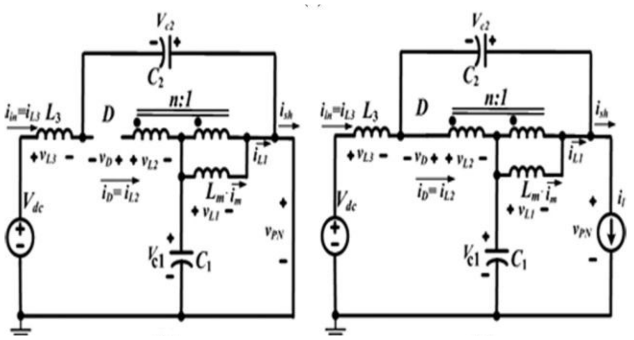
$$V_{dc} = (V_c-V_{in})/ n + V_c$$

As the secondary side inductance of the transformer is not paralleled by any capacitor during non-shoot through mode, the impact of leakage impedance is significant when compared to conventional voltage inverters.

Improved T-source inverter

In the shoot-through state, as shown in Fig. 6(a), the inverter side is shorted by both the upper and lower switching devices of any phase leg. During the shoot-through state, the diode *D* is OFF. We thus obtain the following:

$$v_{L1} = V_{C1}$$
$$v_{L2} = nv_{L1} = nV_{C1}$$
$$v_{L3} = V_{dc} + V_{C2}$$



(a) (b)

Fig.6 (a) Shoot Through state (b) Non-shoot through state of improved T-source inverter

In the non shoot-through state, as shown in Fig.6 (b), the improved inverter has six active states and two zero states of the inverter main circuit. During the non shoot-through state, *D* is on. The corresponding voltages across the primary and secondary windings of the transformers in this state are v_{L1} non and v_{L2} non. We obtain

$$v_{L1\,non} + v_{L2\,non} = -V_{C2}$$
$$v_{L3} = V_{dc} - V_{C1} - v_{L2\,non}$$
$$v_{PN} = V_{C1} - v_{L1\,non}$$

The improved T-source inverter uses a lower transformer turn ratio than the T-source/-quasi-Z source inverter to produce the same boost factor. When *B* = 1/(1 − 2*D*), the improved inverter becomes the classical Z-source inverter. When *n* ≥ 1, the boost ability of the improved T-source inverter is higher than that of the T source, quasi-Z-source, and classical Z-source inverters. On the other hand, the improved inverter uses a smaller shoot-through duty cycle at the same boost factor in comparison with the conventional T-source/-quasi-Z-source inverters. Thus, a higher modulation index is used in the improved inverter to achieve an improvement in the output waveform. When the turn ratio increases, the shoot-through duty cycle used in the improved inverter is close to that used in the conventional T-source/Z-source inverters to produce the same boost factor.

III. SINUSOIDAL PULSE WIDTH MODULATION TECHNIQUE

In the most straight forward implementation, generation of the desired output voltage is achieved by comparing the desired reference waveform (modulating signal) with a high frequency triangular carrier wave as depicted schematically in Fig.7. Depending on whether the signal voltage is larger or smaller than the carrier waveform, either the positive or negative dc bus voltage is applied at the output. Note that over the period of one triangle wave, the average voltage applied to the load is proportional to the amplitude of the signal (assumed constant) during this period. The resulting chopped square waveform contains a replica of the desired waveform in its low frequency components, with the higher frequency components being at frequencies of an close to the carrier frequency. Notice that the root mean square value of the ac voltage waveform is still equal to the dc bus voltage, and hence the total harmonic distortion is not affected by the PWM process.

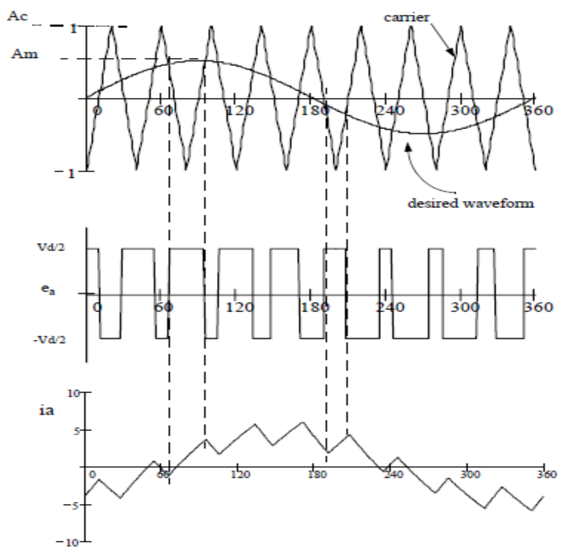


Fig.7 Pulses produced by sinusoidal PWM

The harmonic components are merely shifted into the higher frequency range and are automatically filtered due to inductances in the ac system. When the modulating signal is a sinusoid of amplitude Am. and the amplitude of the triangular carrier is Ac, the ratio m=Am/Ac is known as the modulation index. Note that controlling the modulation index therefore controls the amplitude of the applied output voltage. With a sufficiently high carrier frequency, the high frequency components do not propagate significantly in the ac network (or load) due to the presence of the inductive elements. However, a higher carrier frequency does result in a larger number of switchings per cycle and hence in an increased power loss. Typically switching frequencies in the 2-15 kHz range are considered adequate for power systems applications. Also in three-phase systems it is advisable to use fc/fm=3k, so that all three waveforms are symmetric. Note that the process works well for .For, there are periods of the triangle wave in which there is no intersection of the carrier and the signal as in Fig.9. However, a certain amount of this ―over modulation‖ is often allowed in the interest of obtaining a larger ac voltage magnitude even though the spectral content of the voltage is rendered somewhat poorer. Note that with an odd ratio for fc/fm, the waveform is anti-symmetric over a 360 degree cycle. With an even number, there are harmonics of even order, but in particular also a small dc component. Hence an even number is not recommended for single phase inverters, particularly for small ratios of fc/fm.

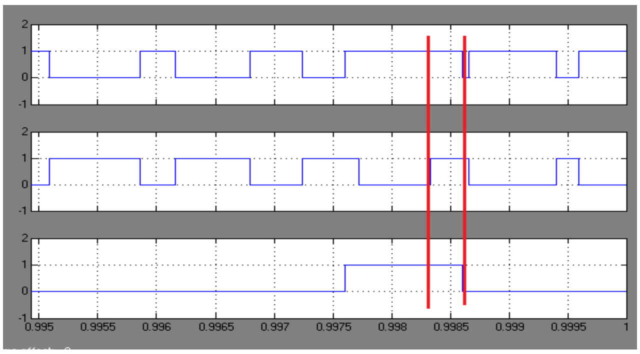
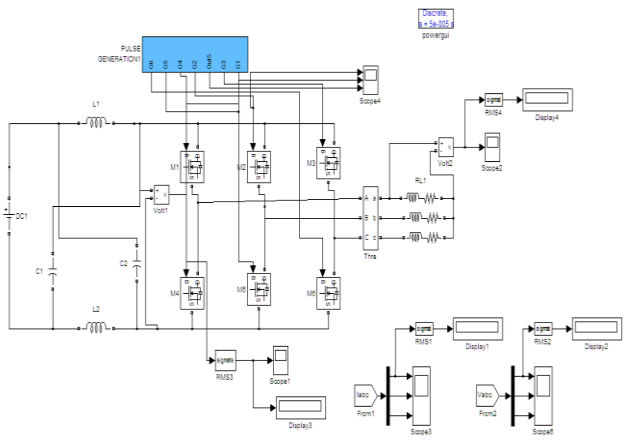


Fig.8 Triggering pulses at S2,S5 and shoot through period of the inverter

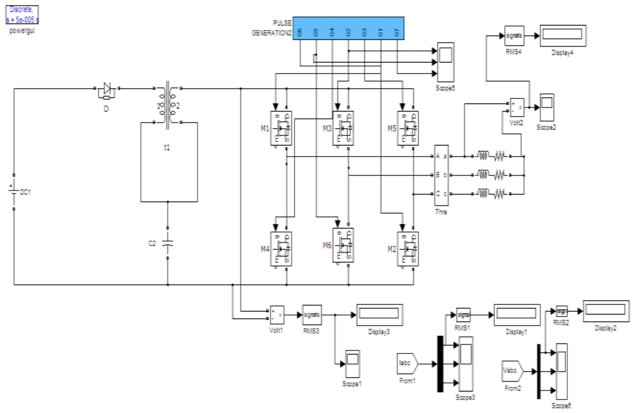
The impedance source inverter works on two modes of operation- shoot through mode and non-shoot through mode. In order to allow shoot through stage, switches at all the three wings are made to turn on by giving on pulses at the same time. Thus all the three switches turn on and results in high boost capability. This extra pulse is added to the reference pulses. Fig.8 shows the triggering pulses to switches S2 and S5 and shoot through period of the inverter.

IV. SIMULATION AND RESULTS

A dc source with the input voltage of 100V is given to various inverter topologies. The ac output is connected to RL load. Fig.9 shows the simulink model of Z-source, T-source and improved T source inverter. Z-source inverter has two inductors and two capacitors of 500uH and 1000uF respectively as shown in Fig.9 (a). The T network has two coupled inductors which acts as transformer and a capacitor of 1000uF as shown in Fig.9 (b). Improved T-source inverter has a inductor and capacitor connected in series across the source to have high current and voltage gain as shown in Fig.9 (c). The pulses are given using sinusoidal pulse width modulation technique which results in reduced THD. Six MOSFETs are used as switches which helps in conversion from dc to ac voltage. The diode at the source helps in prevention of inrush current back to the source and thus avoids the device from damage.



(a)



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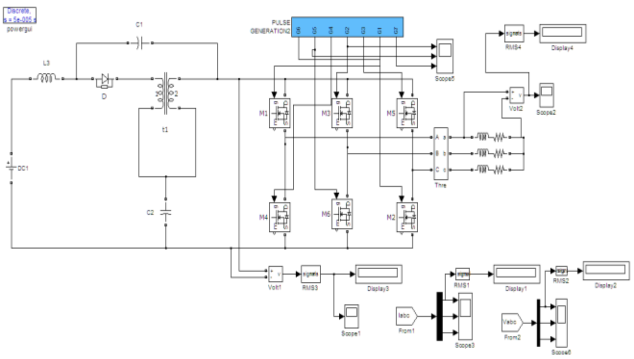
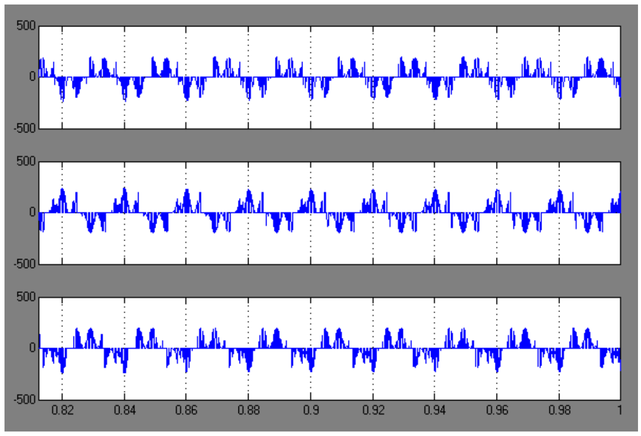


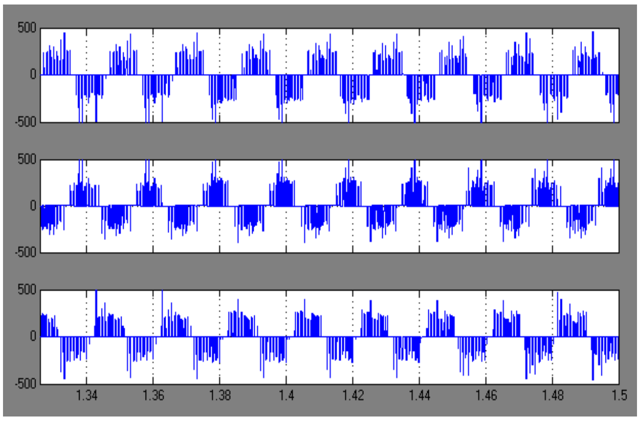
(c)

Fig.9 Simulink model of (a) Z-source inverter (b) T-source inverter (c) Improved T-source inverter.

The impedance network boosts the input voltage to certain higher voltage. The output at the impedance network of Z-source, T-source and improved T-source inverter are 121V, 166V and 195 V respectively.



(a)



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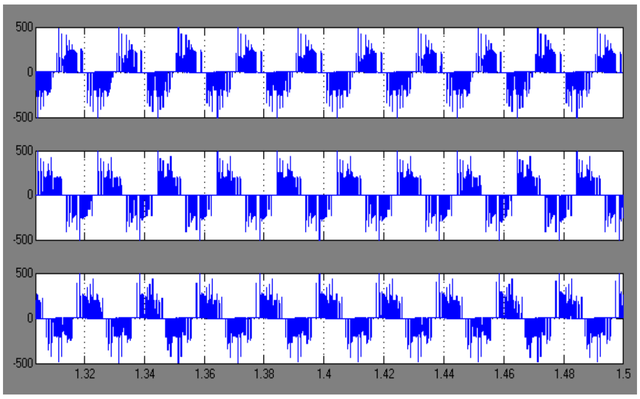
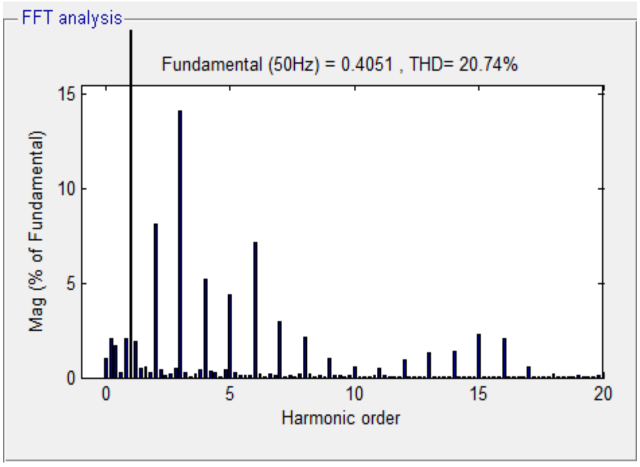


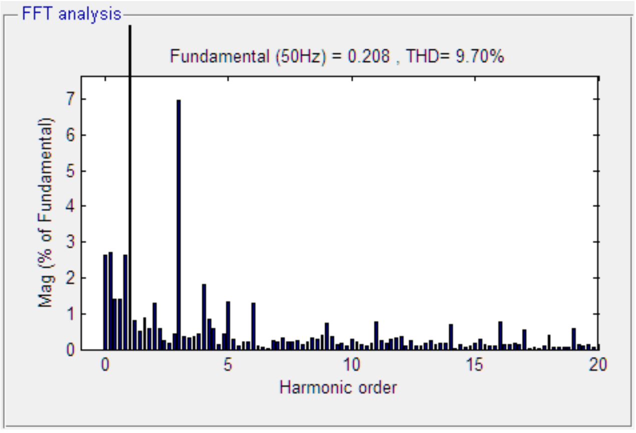
(c)

Fig.10 Output phase to phase voltage of (a) Z-source inverter (b) T-source inverter (c) Improved T-source inverter.

The output voltage after inversion is ac voltage. It is done using six MOSFET switches which helps in inversion of dc to ac voltage. The output phase to phase voltage at the inverter is shown in fig.10. In order to estimate the total harmonics distortion present in the output FFT analysis is done and its output are shown in fig.11. Improved T-source inverter has less THD than Z-source and T-source inverter. The THD values obtained are 20.74%, 9.7% and 9.4% respectively for Z-source, T-source and improved T-source inverter.



(a)



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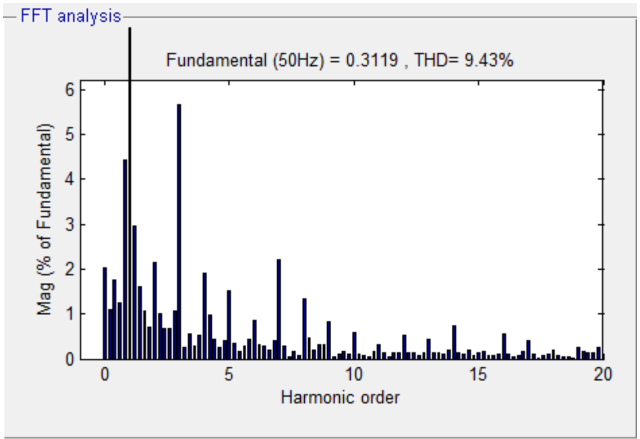

(c)

Fig.11 FFT analysis of (a) Z-source inverter (b) T-source inverter (c) Improved T-source inverter.

All the output results are compared and results are tabulated in table.1. It was seen that improved T-source inverter has better output characteristics than conventional impedance source inverters.

Table.1 Comparison of parameters of different impedance source inverters

Parameters	Z-source	T-source	Improved T-source
Input voltage	100V	100V	100V
Impedance network	121V	166V	195V
Output current (RMS)	0.27A	0.33A	0.35A
Output voltage (Ph-N RMS)	35.7V	47.8V	54V
Output voltage (Ph-Ph RMS)	66.1V	74.53V	106V
Output peak voltage	93.4V	105.38V	150V
THD	20.74%	9.7%	9.4%

V. CONCLUSION

Thus various topologies of impedance source inverters were analysed and results were stimulated using matlab. It was seen that improved T-source inverter has higher boost capability than traditional inverter. It also has many other advantages like continuous input current resonance suppression at start up and reduced THD which results in less ripples in the current. Thus the improved inverter can be applicable to fuel cells or photovoltaic applications where a low input voltage must be inverted to a high ac output voltage. It can also be used to drive various motor because of its low ripples. Thus improving the efficiency of performance of drives. Further investigations can be made to develop impedance topology with variations of components which helps in better boost capability than these improved T-source inverter.

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