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Analysis of T-Source Inverter with PWM Technique for High Voltage Gain Application

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Abstract

This paper deals with Analysis of T-Source inverter with PWM Technique for high voltage gain application. The T-source impedance network is newly introduced to overcome the problems of Z-source inverter. This T-source inverter is similar to Z-source inverter except the use of high frequency low leakage inductance transformer. It has low reactive components in compare with conventional ZSI. This T-source inverter has an ability to perform dc to ac power conversion and it provides buck -boost operation in a single stage. The traditional inverters cannot provide such feature. Operating principle of T-source inverter is almost same as that of ZSI. All traditional PWM methods can be used to control T-source inverter. The utilization of shoot-through switching state is enhanced in T-source inverter which helps in the unique usage of buck-boost feature to the inverter. It is recommended that to maintain the constant voltage in the input side to get the appropriate output voltage.

Keywords: *Z-source inverter, T-Source inverter, voltage boost, PWM control, shoot-through control.*

1. Introduction

Inverters are the dc to ac converters. The input dc supply is either in the form of voltage or current is converted in to variable output ac voltage [1-4]. The output ac voltage can be controlled by varying input dc supply or by varying the gain of the inverter .There are two types of traditional inverters based on input source used in industries for variable speed drive and many other applications; those are a) Voltage-source inverter and b)Current-source inverter. Traditionally in most of industries these voltage-source inverter and current-source inverter are used in adjustable speed drives. But these traditional inverters have many limitations [4].

The new impedance source power inverter has been invented, eliminates all problems of the traditional V-source and I-source inverters [4]. This impedance network called as Z source inverter. The impedance network consists of two inductors and two capacitors connected to each other [4]. In this design, ZSI provides a single-stage voltage buck-boost operation. It is being used in ac/dc power conversion applications. However in some applications the efficiency of Z-source inverter can be worse than these of conventional two-stage buck-boost systems [3]. Other disadvantage of Z-source inverter is its sensitivity to parasitic inductances of galvanic connections and capacitors of LC impedance network. These inductances cause significant over voltages during switches commutation. Hence over sizing of switches is typically used in Z-source inverters design. Application of additional clamping (snubber) circuits in Z-source inverters is necessary as well.

Another inconvenience of Z-source topology is lack of common point of grounding of primary source, LC network and transistor bridge that is important due to generated EMI disturbances. Finally an inconvenient in some applications feature of Z-source inverter is the discontinuous input current and high values of di/dt that impose the necessity of application of input LC filter. The aim of present paper is to show the possibility of realization of buck-boost inverter similar to Z-source inverter but with use of high frequency (HF) transformer with small leakage inductance. The new impedance-source power inverter has been recently invented, eliminates all problems of the ZSI. This impedance network called as T-source inverter [3].

The TSI topology requires a very low leakage inductance transformer which should be made with high precision [3]. In such a way, the number of passive elements is reduced because only the transformer and the capacitor are needed. By utilizing the T-source inverter,

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the number of switching components and the total volume of the system can be minimized. Thus, the overall cost of the system is minimized. T-source inverter is utilized to realize inversion and boost function in one single stage. As with a conventional ZSI, the TSI can handle shoot through states when both switches in the same phase leg are turned on [5-13]. The T-network is used instead of the LC-network for boosting the output voltage by inserting shoot through states in the PWM. T-Source Inverter operating principle same as that of conventional ZSI. TSI operate in Shoot through mode and Non shoot through mode. In shoot-through mode of operation, the output voltage is boosted [13].

2. Z Source Inverter

2.1. General Description

The new impedance-source power inverter has been recently invented, eliminates all problems of the traditional V-source and I-source inverters [4]. It is being used in ac/dc power conversion applications. Figure 1 shows the general Z-source converter structure. The power source can be either voltage source or current source [2, 4].

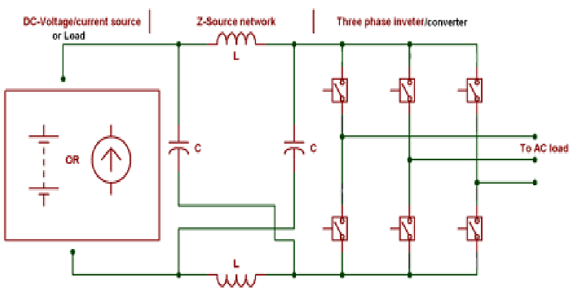

Figure 1. Z-Source Inverter Structure

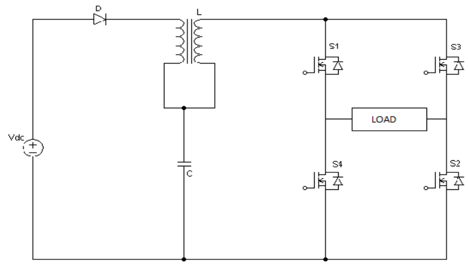

Figure 2. New type T – Source inverter

ZSI provides a single-stage voltage buck-boost operation. Unique LC impedance network significantly improves the performance of the inverter. It allows shoot-through states of the inverter legs during boost operation as well open circuits of inverter legs during normal (buck) operation. In steady state, the capacitor voltage, the d.c.-link voltage and the output a.c. peak phase voltage of the ZSI are given by [4]:

$$Vc = Vin / (1-Do) \quad (1)$$

$$Vi = B.Vin = Vin / (1-2Do) \quad (2)$$

$$Vac = \mathrm{M}.\frac{\mathrm{Vi}}{2} = \mathrm{M.B}\frac{\mathrm{Vin}}{2} \quad (3)$$

Where, Do=To/Ts is the ST duty ratio, To is the ST time per the switching period Ts

B=1/ (1-2Do)

B= Boost Factor
M= Modulation Index

From (3), the peak a.c output phase voltage can be controlled both by adjusting the modulation index or ST time, and it can be larger than the input dc Voltage by adjust the ST Time. This is the main Advantage of the ZSI [4].

2.2. Drawbacks of ZSI Network

The unique operation principle makes the osses evaluation of the ZSI is complex and different from that of the VSI, and different ST boost control methods have a great influence on the losses evaluation [3]. When The ZSI is operating in buck mode, it operates like a VSI and the losses of the IGBTs and the freewheeling diodes (FWDs) are calculated in the same way as the VSI. Going into the boost mode, the ST states are required to boost the input voltage.

During the ST state all six IGBTs (for simple, maximum and constant maximum ST boost control methods) or two IGBTs (for modified space vector modulation ST boost control method) are conducting simultaneously and the d.c.-link is short circuited.

Above features ensure robustness of the inverter during incorrect turn on of transistors or during appearance of external EMI disturbances. Moreover Z-source inverter characterizes attenuating of common mode and differential disturbances on DC side (depending on coupling of inductors within the impedance network).

However in some applications the efficiency of Z-source inverter can be worse than these of conventional two-stage buck-boost systems. Other disadvantage of Z-source inverter is its sensitivity to parasitic inductances of galvanic connections and capacitors of LC impedance network. These inductances cause significant over voltages during switches commutation. Hence over sizing of switches is typically used in Z-source inverters design. Application of additional clamping (snubber) circuits in Z-source inverters is necessary as well.

Another inconvenience of Z-source topology is lack of common point of grounding of primary source, LC network and transistor bridge that is important due to generated EMI disturbances.

Finally an inconvenient in some applications feature of Z-source inverter is the discontinuous input current and high values of di/dt that impose the necessity of application of input LC filter. The aim of present paper is to show the possibility of realization of buck-boost inverter similar to Z-source inverter but with use of high frequency (HF) transformer with small leakage inductance. For minimization of the negative impact of transformer leakage inductance on the inverter performance two clamping circuits are proposed: an active snubber and a passive snubber [3].

3. T- SOURCE Network

3.1. General Description

The New type T - source inverter (TSI) overcome the limitation of traditional voltage source inverter and current source inverter [3]. With use of TSI, the inversion and also the boost function is accomplished in a single stage. TSI has fewer components. Due to these reason, the efficiency appreciably increase. Unlike the traditional inverter, TSI utilizes a unique impedance network that links the inverter main circuit with the DC source. The TSI 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 [1, 3].

The DC voltage is fed as input to the impedance network of TSI which helps to achieve voltage buck and boost properties. Then the output of the impedance network is applied to the inverter main circuit which consists of four switches. The voltage boost capability of TSI is facilitated by turning ON both the switches in the same phase leg simultaneously. Voltage boost capability of TSI is due the energy transfer from capacitors to inductors, during the shoot through state. Since, the capacitors may be charged to higher voltages than the source voltage, the diode ‘D’ prevents discharging of capacitors through the source [13].

The features of T – Source inverter are as follows:

a) Low reactive components in compare with conventional Z-source inverter.
b) Use of a common voltage source of the passive arrangement.
c) Minimize the number of switching devices.
d) No needs of dead time.
e) Inductor decreases the inrush current and harmonics in the inrush current.

3.2. Principle of Operation

As with a conventional ZSI, the TSI can handle shoot through states when both switches in the same phase leg are turned on. The T-network is used instead of the LC-network for boosting the output voltage by inserting shoot through states in the PWM. T – Source

Inverter operating principle same as that of conventional ZSI [2]. The T-network is used instead of the LC-network for boosting the output voltage by inserting shoot through states in the PWM. TSI operate in two modes: a) Shoot through, b) Non shoot through mode

a) Shoot through mode:

Figure 3 shows the equivalent circuit of T – Source Inverter in Shoot through mode operation. This shoot through zero state prohibited in traditional voltage source inverter. It can be obtained in three different ways such as shoot through via any one phase leg or combination of two phase leg. During this mode, Diode is reverse biased, separating DC link from the AC line.

A desired voltage can be maintained at the output by controlling the interval of shoot through state. Thus the T – Source inverter highly improves the reliability of the inverter since short circuit across any phase leg is allowed and it cannot destroy the switches in the inverter [13, 14].

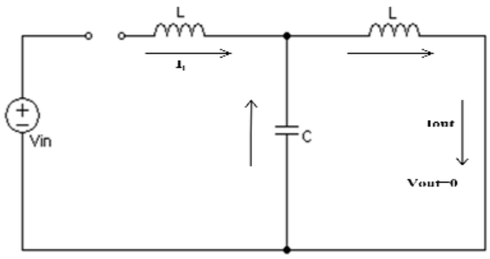

Figure 3. Shoot through Mode

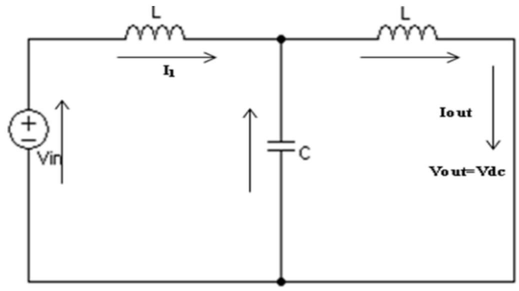

Figure 4. Non Shoot through Mode

b) Non – shoot through mode:

Fig 4 shows the equivalent circuit of TSI in Non – shoot through mode operation. In this mode, the inverter bridge operate in one of traditional active states, thus acting as a current source when viewed from T – source circuit. During active state, the voltage impressed across load. The diode conduct and carry current difference between the inductor current and input DC current. Note that both the inductors have an identical current because of coupled inductors.

3.3. Design of T – Source Inverter

During the design of TSI the most challenging is the estimation of values of the reactive components of the impedance network. The component values should be evaluated for the minimum input voltage of the converter, where the boost factor and the current stresses of the components become maximal. Calculation of the average current of an inductor [13, 14].

$$I_L = \frac{P}{V_{DC}} \quad (1)$$

The maximum current through the inductor occurs when the maximum shoot-through happens, which causes maximum ripple current. In our design, 60% peak-to-peak current ripple through the Z-source inductor during maximum power operation was chosen. Therefore, the allowed ripple current is ΔI_L, and the maximum current through the inductor is I_{Lmax}:

$$I_{L\max} = I_L + \Delta I_L \qquad I_{L\min} = I_L - \Delta I_L$$
$$\Delta I_L = I_{L\max} - I_{L\min} \quad (2)$$

The boost factor of the input voltage is:

$$B = \frac{1}{1 - 2D_Z} \tag{3}$$

Where D_0 is the shoot-through duty cycle:

$$D_z = \frac{B - 1}{2B} \tag{4}$$

Calculation of required inductance of Z-source inductors:

$$L = \frac{T_O.V_C}{\Delta I_L} \tag{5}$$

Where, T_0 - is the shoot-through period per switching cycle.
Calculation of required capacitance of Z-source capacitors:

$$C = \frac{I_L.T_z}{\Delta V_C} \tag{6}$$

4. Pulse Width Modulation Technique

With the introduction and wide acceptance of TSI as an alternative for traditional voltage source and current source inverters (VSI/CSI), the modified switching schemes from the traditional schemes has reached the point where the further improvements in firing the switches and inserting the shoot through states bring crucial benefits [14]. In addition to the six active switching states for the VSI, ZSI has seven shoot-through zero states, when the positive and negative switches of a same phase leg are simultaneously switched on. This shoot-through state is harmful in VSI/CSI and can result short circuiting and damaging of entire application.

Due to the capability of buck-boost and wide range of operating points, TSI is suitable for the applications with unstable power supply such as fuel cell, wind power, photovoltaic etc. Same pulse width modulation (PWM) logics and methods of VSIs can be adapted to a switch a TSI with a slight modifications. The distribution of the shoot-through in the switching waveforms of the traditional PWM concept is the key factor to control the TSI. The DC link voltage boost(diagonal capacitor voltage), controllable range of ac output voltage, voltage stress across the switching devices and harmonic profile of the ac output parameters are purely based [14].

4.1. Types of PWM Techniques

There are number of control methods have been presented in recent years that include sinusoidal pulse that include [16]:

a) Sinusoidal Pulse Width Modulation (SPWM) Techniques
b) Modified Space Vector Modulation (MSVPWM) Techniques.

The various PWM control algorithms are:

a) Simple Boost Control (SBC)
b) Maximum Boost Control (MBC)
c) Maximum Constant Boost Control (MCBC)
d) Traditional Space Vector Modulation (TSVPWM)
e) Modified Space Vector Modulation (MSVPWM) [16]

5. Exitsting Method

In this performance analysis and simulation of maximum constant boost control with third harmonic injection methods for the Z-source inverter, which can obtain maximum voltage boost for a fixed modulation index [4]. The Z-source inverter is very advantageous over traditional inverters and it can be employed in all ac and dc power conversion applications. All traditional PWM methods can be used to control Z-source inverter. Maximum constant boost control methods eliminates the low-frequency ripples in the inductor current and capacitor voltage by maintaining the shoot through duty cycle constant, and minimize the voltage stresses of switching devices at the same time. The Maximum boost control method is suitable for relatively high output frequency only, but in the maximum constant boost control method the Z-source network design is independent of the output frequency and determined only by the switching frequency [4].

5.1. Maximum Constant Boost PWM with Third Harmonic in Control Method

The maximum constant boost control achieves the maximum voltage gain while always keeping the shoot-through duty ratio constant [4]. Maximum Constant boost control with third harmonic injection method is devised to produce the maximum constant boost while minimizing the voltage stress. Shoot-through pulses are generated as shown in Figure 5. These shoot-through pulses can be generated by using triangular waveform generator and comparator. Shoot-through time is decided by the two reference levels called shoot-through level. When triangular carrier wave exceeds above upper shoot-through level or below lower shoot-through level a shoot-through pulse is generated [4].

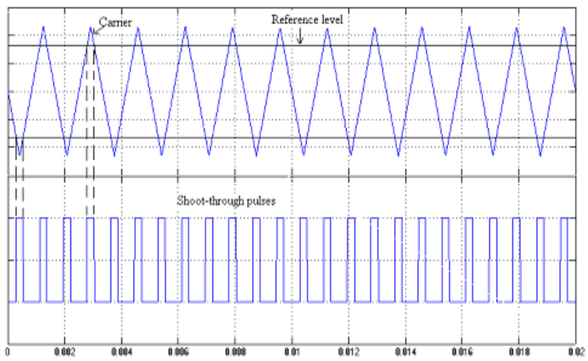

Figure 5. Shoot-through Pulses [4]

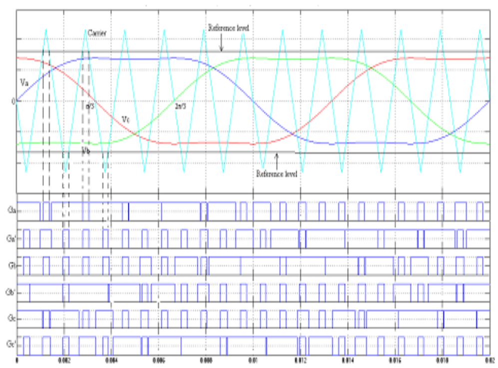

Figure 6. Maximum constant boost control with third harmonic injection-PWM waveform [4]

Figure 5 shows third harmonic injected PWM with shoot-through and the control method is referred as maximum constant boost control with third harmonic injection. The third and higher harmonic component can be injected into fundamental to reduce harmonic distortion in the output waveform. The third harmonic component with 16.6% of the fundamental component is injected into the modulating signals [10, 11].

As shown in Figure 6, at an angle of π/3 of modulating signal the third harmonic component crosses zero and then increases towards negative peak [4]. Therefore at π/3 Va reaches its peak value (√3/2)M while Vb is at its minimum value -(√3/2)M. In this method only two straight lines are needed to control the shoot-through time with the third harmonic injection [4, 11].

The component values of Z-source inverter depends on switching frequency only. These component values are L1 = L2 = 4mH and C1 = C2 = 1000uF. The purpose of the system is to produce 230Vrms line to line voltage. For PWM generation the carrier frequency is set to 10 KHz and modulating reference signal frequency is set to 50Hz. The modulation index is 0.8 and the input DC voltage is 188V [4].

5.2. Results and Output Waveforms

Input dc voltage applied to Z-source inverter is 188V [4]. The capacitor voltage is the average dc link voltage remains almost constant about 337V as shown in Figure 8 Thus the input voltage (188V) is boosted (337V) and applied as dc link voltage. The peak value of this dc link voltage appears as input voltage across the main inverter circuit.

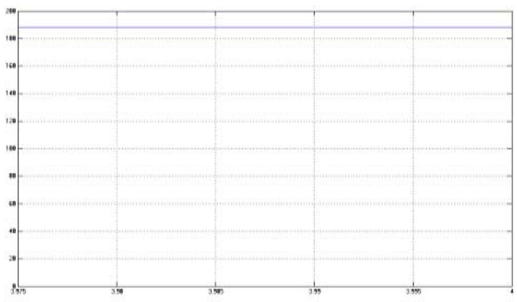

Figure 7. Input DC Voltage = 188V [4]

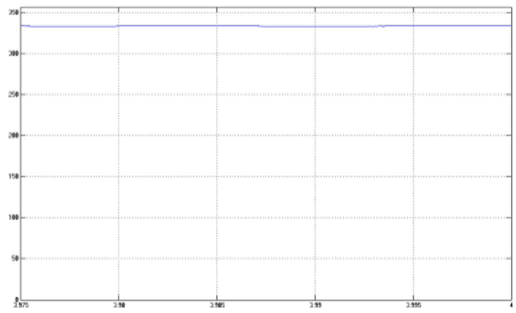

Figure 8. Capacitor Voltage = 337V [4]

The output dc link voltage across Inverter Bridge appears as shown in the Figure 9 The peak dc link voltage remains almost constant about 480V. It is observed that during shoot-through state dc link voltage becomes zero since all devices in main inverter are switched on simultaneously, short circuiting the dc link.

Figure 10 shows the simulation and experimental results of diode voltage and inductor current. The diode is reverse biased by capacitor voltage during shoot-through when all the six switches are turned on, blocking the reverse flow of current. Also, we can see that during the shoot-through period, the capacitor voltage becomes equal to the inductor voltage. The capacitor charges the inductor so that the inductor current increases during this time and releases its energy during active state [4].

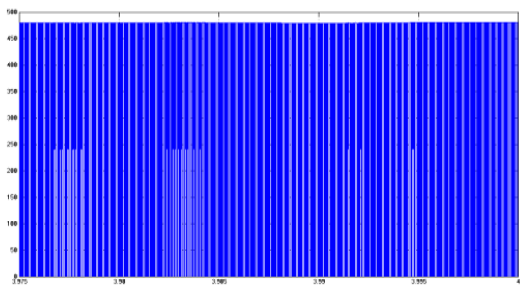

Figure 9. Peak dc Link Voltage across Inverter Bridge = 480V [4]

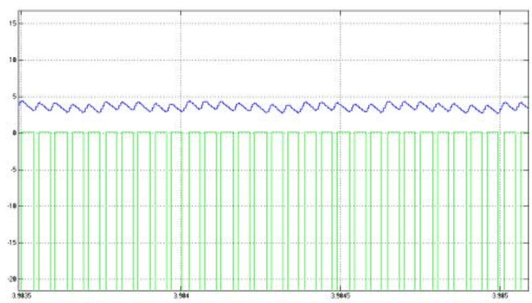

Figure 10. Diode Voltage and Inductor Current [4]

6. Proposed Method

In this paper performance analysis and simulation of Simple Boost Control method for the T-source inverter [14]. The T-source inverter is very advantageous over Z-source inverter and it can be employed in all ac and dc power conversion applications. All traditional PWM methods can be used to control T-source inverter. The simple boost control method is simple to control T-source impedance network.

6.1. Simple Boost Control

In simple boost control, the shoot-through periods are fabricated by two straight lines which are equal or greater than the (maximum and minimum) peak values of the modulation reference sinusoidal signal. Figure 11 shows the complete implementation block diagram of the SBC technique. Shoot through switching pulses are generated by comparing the dc signal (with equal or greater than the peak of triangular signal) with the high frequency triangular carrier signal.

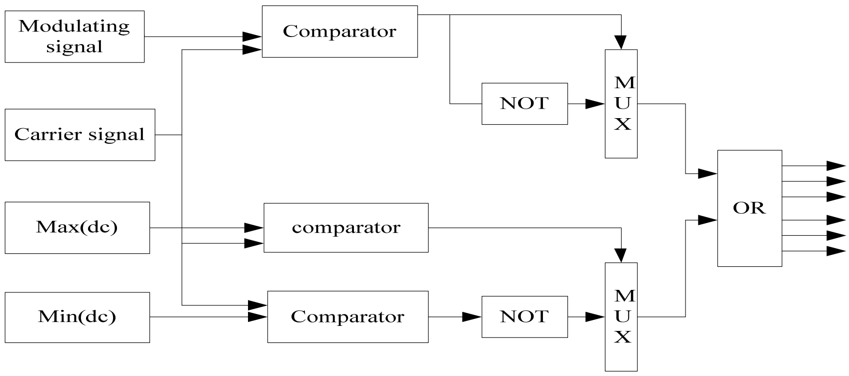

Figure 11. Block Diagram of Simple Boost Control

Major expressions of SBC method are outlined here,
Modulation index:

$$M = \frac{V_{ref}}{Vcar}$$

Shoot through duty ratio:

$$D_O = 1 - M$$

Gain factor:

$$G = \frac{M}{1 - 2D_O}$$

Boost factor:

$$B = \frac{G}{M}$$

In order to produce the output voltage that requires a high voltage gain, a small modulation index has to be used. However, small modulation indexes result in greater voltage stress on the devices. Using this control method, the voltage stress across the switches is quite high, which will restrict the obtainable voltage gain because of the limitation of device voltage rating. [14]

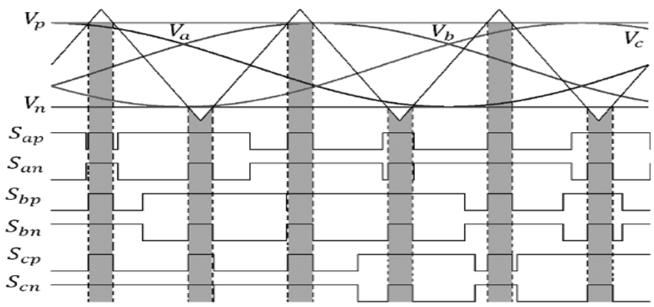

Figure 12. Simple Boost Control Method Waveforms [16]

This method, uses two straight lines equal to or greater than the peak value of the three phase references to control the ST duty ratio in a traditional sinusoidal PWM,as shown in Figure 12 When the triangular waveform is greater than the upper line, Vp, or lower than the bottom line Vn, the circuit turns into ST state. Otherwise it operates just as traditional carrier based PWM. This method is very straight forward however, the resulting voltage stress across the switches is relatively high because some traditional zero states are not utilized [16].

6.2. Simulation Diagram

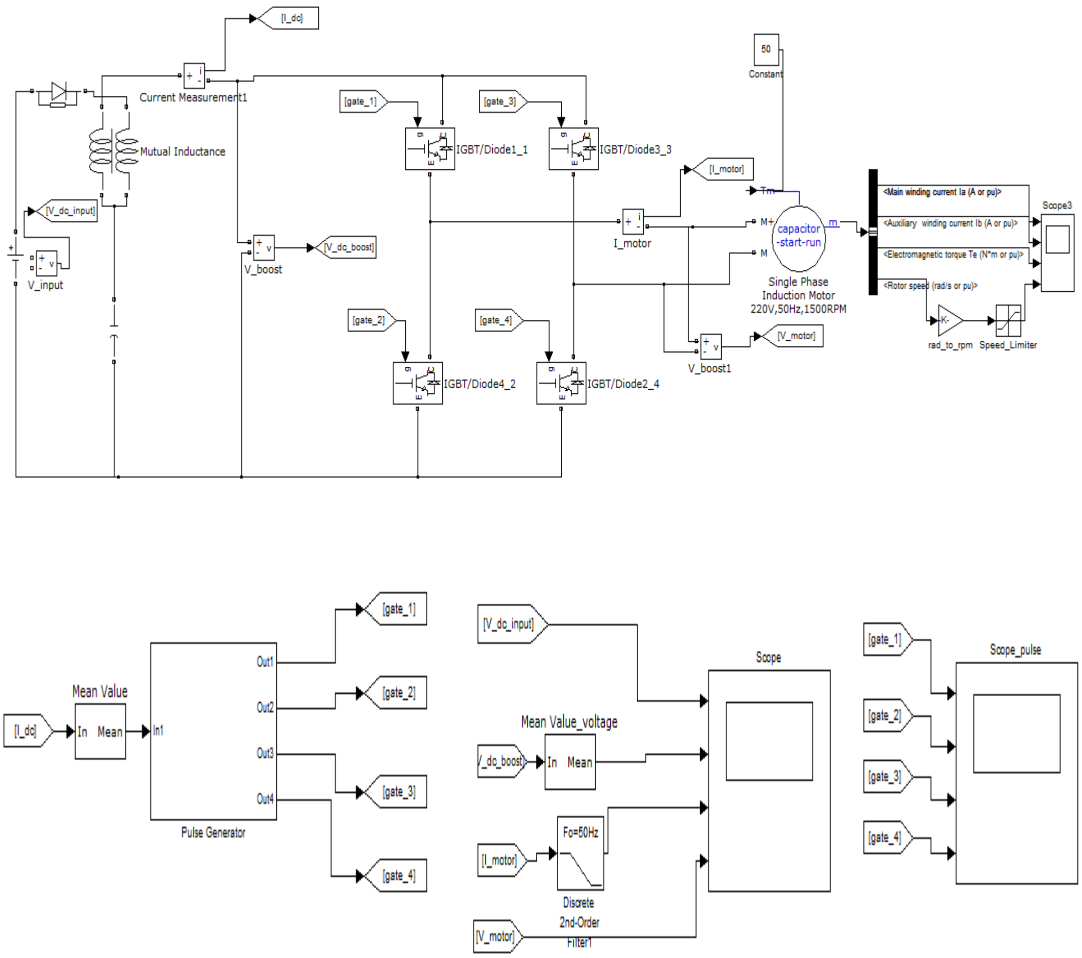

Figure 13. Simulation Diagram of Proposed System

7. Experimental Results

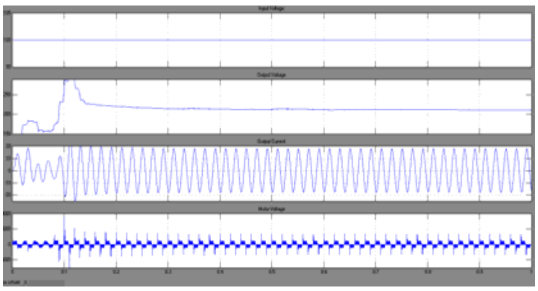

Figure14. Input and Output Waveform

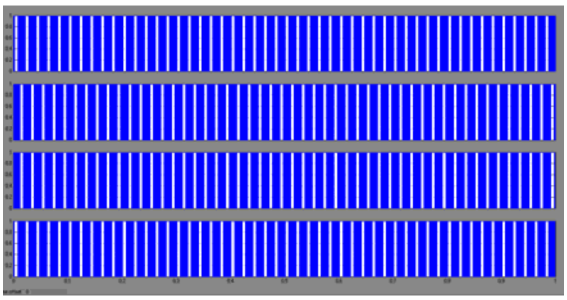

Figure15. Input Pulses of TSI

Simulation model for single phase T-source inverter was designed by using MATLAB/ SIMULINK. Figure 14 shows the output voltage and current waveform of T-source inverter with simple boost control technique. Here, the input voltage is 100V. The output voltage is boosted up to 220V by shoot through duty ratio.

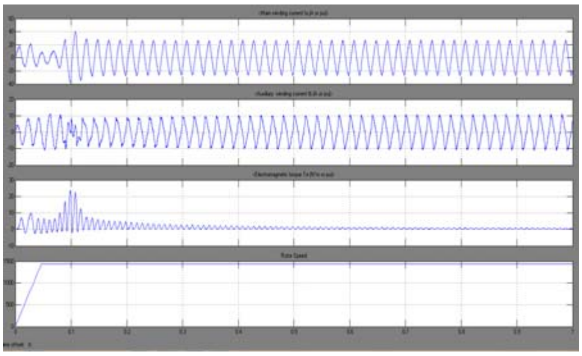

Figure 16. Motor Output

Figure 16 shows the motor output and it consist of auxiliary current, main winding current, torque and speed variation.

8. Conclusion

This thesis deals with the Analysis of T-source inverter with PWM technique for high voltage gain application. The T-source inverter overcomes the problems of the Z-source inverter and provides buck-boost operation in a single stage. The T-source inverter system can produce an output voltage greater than the dc input voltage by controlling the shoot-through duty ratio, which is impossible for the traditional voltage-source inverter and current-source inverter. The T-source inverter has low reactive components in compare with ZSI. All traditional PWM methods can be used to control T-source inverter. In this paper Simple boost control method is used to control the T-source inverter. The output of the T-source inverter is given to the induction motor. The output voltage can be varied by varying the DC input voltage.

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