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Analysis of Three Phase T-Source Inverter with Space Vector PWM Technique

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ABSTRACT: This paper deals with analysis of three phases T-source Inverter with space vector PWM technique. T-source impedance network is developed to overcome the drawbacks of Z-source inverter. The basic topology is known in the literature as a Z-source inverter (ZSI).It has flat reactive components in comparing with conventional ZSI. The T source Network can perform DC to AC power conversion and it provides buck boost operation in a single stage. Space vector pulse width modulation technique is used to produce the output voltage with less harmonics. T-Source inverter implemented with a space vector PWM technique for reducing the harmonics are simulated using MATLAB Simulink.

KEYWORDS: Z-source inverter, T-Source inverter, Space vector pulse width modulation,Total Harmonic Distortion (THD)

I.INTRODUCTION

The inverter is a device which converts direct current to alternating current. It can divide into two traditionally inverters: voltage-source inverter and current-source inverter. In VSI, the output voltage cannot exceed the DC source voltage. So the DC – DC boost converter is utilized when the DC source is limited. The input to the inverter bridge is a constant voltage source.The constant voltage source is found by connecting a large capacitor across the DC source. Dead time is necessary to prevent the short circuit of upper and lower switching devices in each phase leg. In CSI, the output voltage cannot be lower than the DC source. The input to the inverter bridge is a constant current source.A large inductor with the DC source connected in series provide a constant current source.Overlap time between phase legs is necessary to avoid the open circuit of upper or lower switching devices.These drawbacks are overcome in Z- source Inverter.TSI requires a very low leakage inductance transformer with high precision.It makes use of shoot through in the inverter bridge to boost the voltage in the VSI or to buck the voltage in the CSI.The Z-source inverter is a buck–boost inverter. It has more passive components. To overcome this problem in T-source inverter is proposed.

In SVPWM methods, revolving reference vector is used to provide a reference voltage. In the line side, the magnitude and frequency of the fundamental component are controlled by the reference voltage vector magnitude and frequency, respectively. Space vector modulation developsa DC bus voltage and generate less harmonic distortion in a three phase voltage source inverter.

II.T-SOURCE INVERTER

T-source impedance network, is recently introduced to overcome the drawbacks of Z-source inverter. T-Source Inverter is used for high frequency, low leakage inductance transformer and one Capacitance. It has LC components in comparing with conventional ZSI. Due to this, the efficiency significantly increases.The TSI topology requires a very low leakage inductance transformer which should be made with high accuracy. Only the capacitor and the transformer are used by the number of passive elements can be reduced.The TSI topology features a common DC rail between the DC source and inverter, which is unlike traditional ZSI circuits. In addition to use of a transformer with other than a 1:1 transformer ratio allows for a change the output voltage. The modulation index or the shoot-through index is resulted by the Z-source converters, as difference with the voltage .

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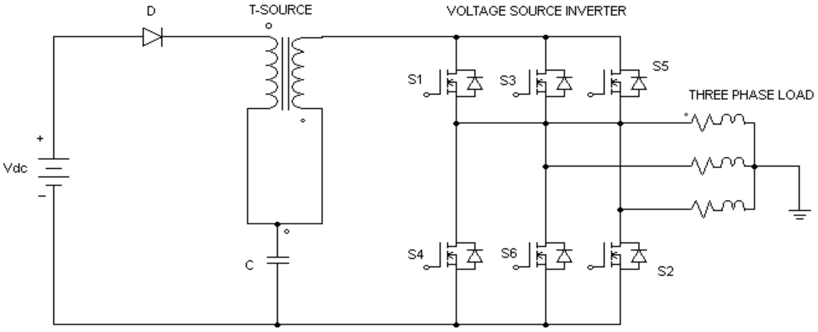

Fig. 1 Circuit Diagram for T-Source Inverter

PRINCIPLE OF OPERATION:

There are two operating mode presents in T-source inverter. One mode is active and the other one is a Shoot-through mode. The T-network can be replaced with the LC-network for boosting the output voltage by inserting shoot through states in the PWM.

(i) Shoot through mode:

During the shoot through state output voltage boosting is involved. During this mode, the inductor is to limit the current ripple.During the shoot through inductor current increases linearly and the voltage across the inductor is same as the voltage across the capacitor. There is no voltage present across the load. Shoot through states are inserted within the zero state without affecting the active states.

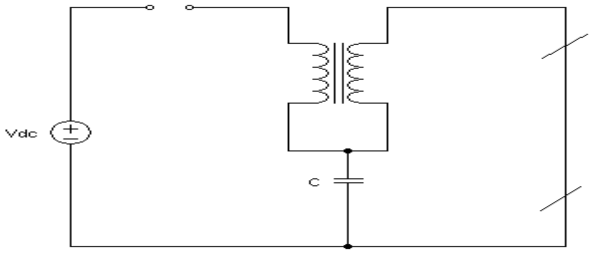

Fig. 2 Equivalent Circuit of shoot through state

(ii) Non shoot through mode:

During the traditional mode of operation the input voltage appearing across the capacitor, no voltage appears across the inductors; only a pure DC current flow through the inductors. During active mode, the voltage getsimpressed across the load. The diode conducts and carries the current difference between theinductor current and input DC current. Both the inductors have an equal current because of coupled inductors.

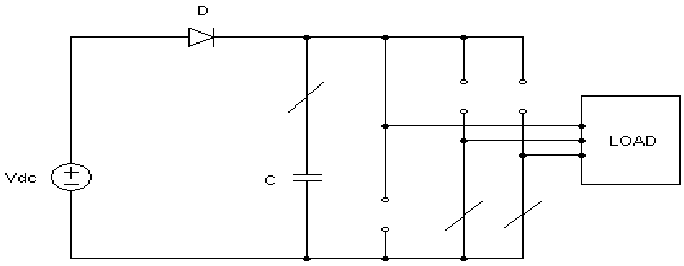

Fig. 3 Equivalent Circuit of non-shoot through the state

(iii) Mathematical modelling:

By using Kirchhoff's laws and voltage averaging can be developed by TSI governing equations.For the switching time period T, the average voltage through the transformer inductances should be equal to zero.

$$V_1 = \left[T_{0.}V_c + T_1.(V_{in} - V_c)/n\right]T = 0$$

(1)

Both output voltage $V_{out}$and capacitor voltage V_c are functions of the shoot-through coefficient

$D=(T_0/T)$

(2)

$$V_C \ / V_{in} \ = \frac{(T_1 - D)}{\left[1 - (n+1).D\right]}$$

(3)

Where D satisfies a condition D<1/ (n+1). Therefore, the maximum value of D for TSI n>1is smaller than the Z-source. The same output voltage can be obtained by achieving a smaller time period of short circuits transistor current from the TSI in n>1in comparison with ZSI. Using the amplitude of voltage Vdc in non-shoot-through states can find from:

$$V_{dc} = V_{in} / \left[1 - (n+1).D\right]$$

(4)

Actually, the influence of leakage on inductance in the transformer is very important. In T source inverter, the leakage inductance is very less because both the primary winding and secondary winding are placed in a single iron core. The performance of TSI depends on the accuracy of the transformer design.

The peak dc link voltage across the inverter is expressed as,

$$V_{dc} = \frac{T}{T_1} - T_0$$

(5)

Where,

$$B = \frac{T}{T_1} - T_0 \geq 1$$

(6)

B is the Boost factor resulting in the shoot through state

T0 is the shoot through time period in sec

T1 is the non-shoot through time period in sec

The inverter can be expressed by the output peak phase voltage ,

$$V_{dc} = M.V_{dc} / 2$$

(7)

Where M is the modulation index.

Using the above equations the output peak voltage can be expressed as,

$$V_{ac} = M.B.V_{dc} / 2$$

(8)

Thus the output voltage can be stepped up and down by choosing an suitable Buck-Boost factor BB.

$$B_B = M \times B_{(X)}$$

(9)

The modulation index (M) and boost factor (B) can be determined from the buck-boost factor (BB).The duty cycle of the shoot through state over the non shoot through states of the inverter can be controlled from the boost factor.

IV. PWM TECHNIQUES

The power electronics and drive systems are popular inSwitching techniques of pulse width modulation (PWM). PWM is most commonly used in applications like motor speed control, converters audio amplifiers, etc.. The main aim of the PWM is to control the inverter output voltage and reduce the harmonic content in the output voltage. The pulse width modulation (PWM) techniques are mainly used for voltage control. These techniques are more efficient and they control the drive of the switching devices. The different PWM techniques are used in T-source inverter.In this paper, Space Vector pulse width modulation technique is used.Space Vector PWM techniqueis used to control the output voltage as well as reduce the harmonics.

SPACE VECTOR PULSE WIDTH MODULATION

Principle of Space vector pulse width modulation

Six non-zero vectors are (V_1,V_2,V_3,V_4,V_5,V_6)sharp the axes of a hexagon and supplies power to the load. The angle between anytwo adjacent non-zero vectoris 60 degrees.The two zero vectors(V_0 and V_7) and are at the origin and apply zero voltage to the load. The eight vectors are denoted by (V_0, V_1, V_2, V_3, V_4, V_5, V_6, V_7) are called the basic space vectors. The same transformation can be applied to the desired output voltage to get the desired reference voltage vector,V_{ref} in the d-q plane. By using the eight switching patterns,SVPWM technique is to estimate the reference voltage vector V_{ref}.One simple method of approximation is generatedif the small period T is equal to V_{ref} in the same period such that the average output of the inverter is obtained.

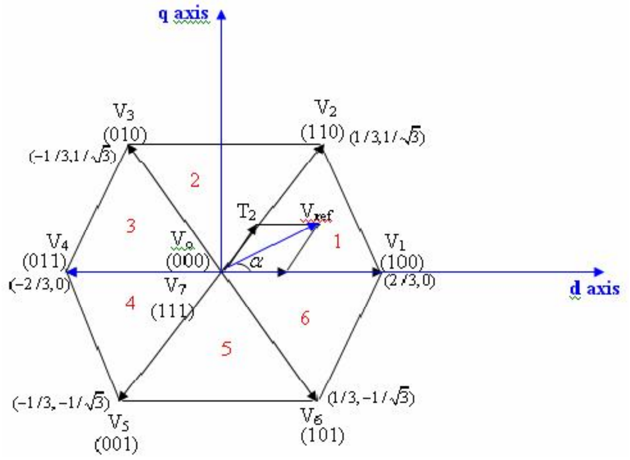

Fig. 4 Basic switching, vectors and sectors.

SWITCHING STATES

For 180° mode of operation, there are six switching states and additionally two more states, which make all three switches of either upper arms or lower arms ON. It is required to have three bits($2^3 = 8$),to code these eight states in binary (one-zero representation) since the upper and lower switches are represented in complementary fashion, it is enough to represent either the upper or lower arm switches. The status of upper bridge switches will be represented and the lower switches with its complementary. Let "1" denotes that the switch is ON and "0" denotes that the switch in OFF. Table-1 gives the details of different phase and line voltages for the eight states.

Table.1 Switching patterns and output vectors.

Voltage vectors	Switching vectors			Line to neutral Voltage			Line to Line voltage		
	A	B	C	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_0
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V_2	1	1	0	1/3	1/3	-2/3	0	1	-1
V_3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V_4	0	1	1	-2/3	1/3	1/3	-1	0	1
V_5	0	0	1	-1/3	1/3	2/3	0	-1	1
V_6	1	0	1	1/3	-2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

Realization of Space Vector PWM

Space vector PWM can be implemented by the following steps:

Step-1: Determine V_{d}, V_{q}, Vref, and angle (α).

Step-2: Determine the time duration, T_1, T_2, and T_0.

Step-3: Determine the switching time of each transistor (S_1 to S_6)

Step-1: Determine V_{d}, V_{q}, Vref, and angle (α)

V_{d}, V_{q}, Vref and angle (α) can be found as follows:

$$V_d = V_{an} - \frac{1}{2}.V_{bn} - \frac{1}{2}.V_{cn}$$

(10)

$$V_q = V_{an} + \frac{\sqrt{3}}{2}.\cos 30^0 - \frac{\sqrt{3}}{2}.\cos 30^0$$

(11)

$$\therefore \begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3}.\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}$$

(12)

$$\therefore |\overline{V_{ref}}| = \sqrt{V_d^2} + \sqrt{V_q^2}$$

(13)

$$\alpha = \tan^{-1\left(\frac{V_d}{V_q}\right)} = wt = 2\pi ft$$

Where f = fundamental frequency

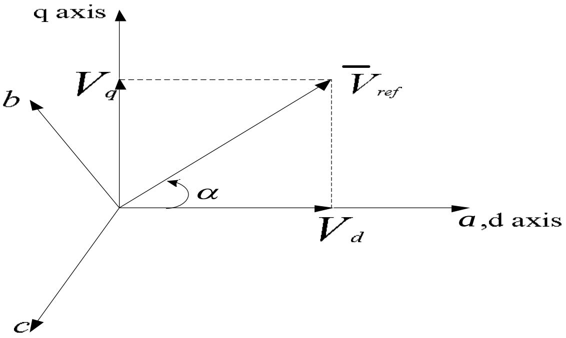

Fig. 5 Voltage space vector and its component in (d,q)

Step-2: Determine the time duration, T_1, T_2 , and T_0

The switching time duration can be determined as follows:

- Switching time duration at Sector 1

$$\int_0^{T_1}\overline{V_{ref}} = \int_0^{T_1}\overline{V_1}dt + \int_{T_1}^{T_1+T_2}\overline{V_2}dt + \int_{T_1+T_2}^{T_z}\overline{V_0}$$

(14)

$$\int_0^{T_Z}\overline{V_{ref}} = \int_0^{T_1}\overline{V_1}dt + \int_{T_1}^{T_1+T_2}\overline{V_2}dt + \int_{T_1+T_2}^{T_Z}\overline{V_0}$$

(15)

$$T_Z.|\overline{V_{ref}}|.\begin{bmatrix}\cos(\alpha)\\ \sin(\alpha)\end{bmatrix} = T_1.\frac{2}{3}.V_{dc}.\begin{bmatrix}1\\ 0\end{bmatrix} + T_2.\frac{2}{3}.V_{dc}.\begin{bmatrix}\cos(\frac{\pi}{3})\\ \sin(\frac{\pi}{3})\end{bmatrix}$$

(16)

$$\therefore T_1 = T_z.a.\frac{\sin\left(\frac{\pi}{3}-\alpha\right)}{\sin\left(\frac{\pi}{3}\right)}$$

(17)

$$\therefore T_2 = T_z.a.\frac{\sin(\alpha)}{\sin\left(\frac{\pi}{3}\right)}$$

(18)

- Switching time duration at any sector

$$T_0 = \frac{\sqrt{3}}{V_{dc}}T_Z.|\overline{V_{ref}}|.\sin\left(\frac{n}{3}\pi-\alpha\right)$$

(19)

$$T_2 = \frac{\sqrt{3}}{V_{dc}}T_Z.|\overline{V_{ref}}|.\left(\sin\frac{n-1}{3}\pi.\cos\alpha - \cos\frac{n-1}{3}\pi.\sin\alpha\right)$$

$$\therefore T_0 = T_Z - T_1 - T_2$$

(20)
(21)

Where,n=1 through 6 (that is sector 1 to 6), $0 \le \alpha \le 60^\circ$

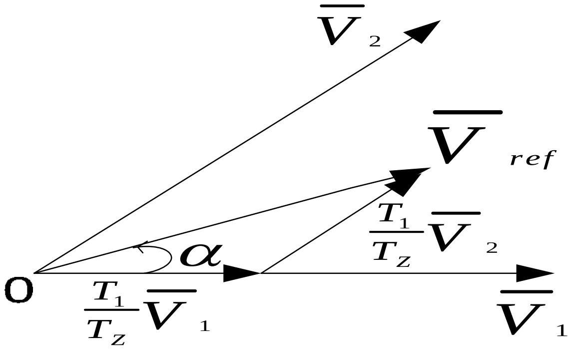

Fig. 6 Reference vector as a combination of adjacent vectors at sector-1.

Step 3: Determine the switching time of each transistor (S_1 to S_6)

Sector	Upper (S1,S3,S5)	Lower (S4,S6,S2)
1	S1= T1 + T2+T0/2 S3= T2 + T0/2 S5 = T0/2 -T	S4=T0/2 S6=T1 + T0/2 + T S2 = T1 + T2 + T0/2 + 2T
2	S1= T1 +T0/2 S3= T1 + T2 + T0/2 S5 = T0/2 -T	S4=T2 + T0/2 + T S6=T0/2 S2 = T1 + T2 + T0/2 + 2T
3	S1= T0/2 - T S3= T1 + T2 + T0/2 + T S5 = T2 +T0/2	S4=T1 + T2 + T0/2 +2T S6=T0/2 S2 = T1+ T0/2 + T
4	S1=T0/2 - T S3= T1 + T0/2 S5 = T1 + T2 + T0/2 +T	S4=T1 + T2 +T0/2 + 2T S6=T2+ T0/2 + T S2 = T0/2
5	S1= T2+T0/2 S3= T0/2 - T S5 = T1 + T2 +T0/2 +T	S4=T1 + T0/2 + T S6=T1 + T2 +T0/2 + 2T S2 =T0/2
6	S1= T1 + T2+T0/2 + T S3= T0/2 - T S5 = T1 + T0/2	S4=T0/2 S6=T1 + T2 +T0/2 + 2T S2 =T2 + T0/2 + T

V.SIMULATION RESULTS

Table 2 shows the system parameters used for simulation. The performance of the T-source inverter was tested under space vector modulation technique. Fig 7, represents the simulation model for the generation of PWM pulses for TSI by using SVPWM technique.

Table- 2. Parameters used for simulation

S.NO	Parameters	Values of simulation
1	DC supply voltage (V_{dc})	200V
2	Capacitance (C)	218×10^{-3} F
3	Inductance (L)	20×10^{-6} H
4	Switching frequency	50 HZ
5	Snubber Resistance (R_s)	$1 \times 10^{5}\Omega$
6	Diode Resistance (R_d)	0.01Ω
7	Output voltage	400V

The Line current is shown in fig. 7.The Line voltage and current is shown in fig. 8. Harmonic spectrum of the output current is shown in fig. 9.

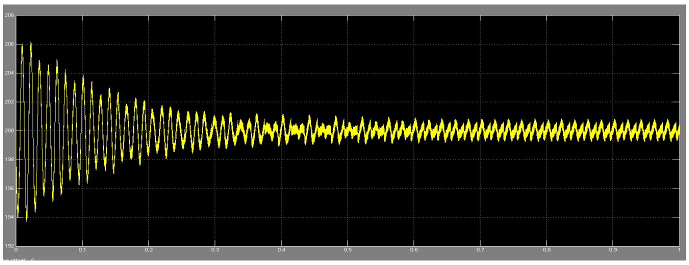

Fig. 7 Line current in svpwm

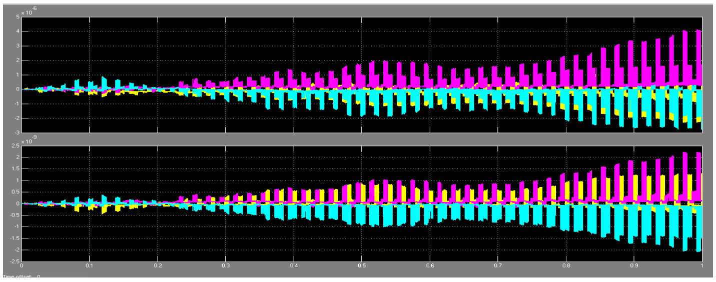

Fig. 8 Line voltage and current in svpwm

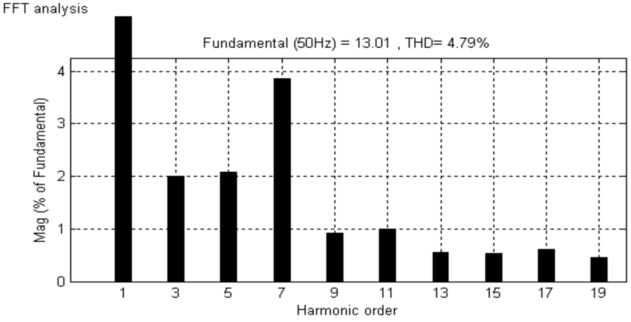

Fig. 9 Harmonic spectrum of the output current

VI.CONCLUSION

This research deals with the Analysis of T-source inverter with Space vector pulse width modulation technique.The T-source impedance network provide the output voltage larger than the input voltage by proper maintaining the duty ratio of shoot-through state, voltage-source inverter and current-source inverter can't be provide these advantages..All Pulse Width Modulation methods can be used to control T-source inverter. The THD obtained for 4.79% for SVPWM. In this paper using space vector PWM technique for boosting the voltage and reducing low harmonics in T-source inverter.

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