

DESIGN AND ANALYSIS OF VARIOUS INVERTERS USING DIFFERENT PWM TECHNIQUES

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-----ABSTRACT-----

This paper presents the design and analysis of voltage source inverters (VSI) using three different pulse width modulation techniques i.e, sinusoidal pulse width modulation (SPWM), third harmonic injection pulse width modulation (THIPWM) and space vector pulse width modulation (SVPWM). In AC the quality of the sinusoidal waveform is more important than the quantity. In order to achieve that , we need to reduce the harmonic content in the output. For this purpose various pulse width modulation techniques are used. The PWM methods are simulated for various loads and the results are analyzed using FFT analysis for observing the total harmonic distortion (THD). The simulations are performed in MATLAB/SIMULINK environment.

KEYWORDS : Voltage source inverter (VSI), multilevel inverter, SPWM, THIPWM, SVPWM and THD.

1. INTRODUCTION

The main function of the inverter is to convert DC input voltage to a AC output voltage of the desired magnitude. The output voltage waveforms of the ideal inverters should be sinusoidal, however the waveform of the practical inverters are non sinusoidal and contains different harmonics. Square wave or quasi-square-wave voltages are acceptable only for low and medium power applications, but for high power applications low distorted sinusoidal waveforms are required. By using high speed power semi conductor devices and by using different switching techniques we can reduce the harmonic content in output voltage. Inverters are widely used in industrial applications (e.g., variable speed AC motors, induction heating, standby power supplies and uninterruptible power supplies). Inverters are broadly classified in to two types single phase inverters and three phase inverters. Each type can use controlled turn on and turn off devices. These inverters generally use pulse width modulation control signals to provide an AC output signal.

II. PULSE WIDTH MODULATION TECHNIQUES

Switching techniques of pulse width modulation (PWM) have been popular in the area of power electronics and drive systems. PWM is commonly used in applications like motor speed control, converters audio amplifiers etc. PWM is used to adjust voltage applied to the motor [1]. There is no single PWM method which can suite for all applications. As per the advanced technology in solid state power electronic devices and microprocessors, various pulse-width modulation (PWM) techniques have been developed for different industrial applications. For the above reasons, the PWM techniques have been the subject of intensive research since 1970s. The main objective of the PWM is to control the inverter output voltage and to reduce the harmonic content in the output voltage. The pulse width modulation (PWM) techniques are mainly used for voltage control. These techniques are most efficient and they control the drives of the switching devices. The different PWM techniques are Single pulse width modulation, Multiple pulse width modulation, Phase displacement control, Sinusoidal pulse width modulation, Harmonic Injection modulation, Space Vector pulse width modulation, Hysteresis (Delta) pulse width modulation, Selective Harmonic Elimination and Current Controlled pulse width modulation. Hysteresis controller is used for Current source inverter and all the remaining PWM techniques are used for Voltage source inverter. Sinusoidal and Space Vector PWM techniques are most widely used. They control the output voltage as well as reduce the harmonics.

III. SINUSOIDAL PULSE WIDTH MODULATION

The sinusoidal pulse width modulation (SPWM) technique is used to produce the sinusoidal waveform by filtering an output pulse waveform with varying width [2]. A better filtered sinusoidal output waveform can be obtained by using a high switching frequency and by varying the amplitude and frequency of a reference or modulating voltage. In SPWM technique it maintains the pulses in different widths instead of maintaining in equal widths as in multi pulse width modulation where the distortion factor (DF) and lowest order harmonics (LOH) are significantly reduced. The figure 3.1 depicts the six step inverter composed with six switches S_1 to S_6 with each phase connected to the middle of each inverter leg.

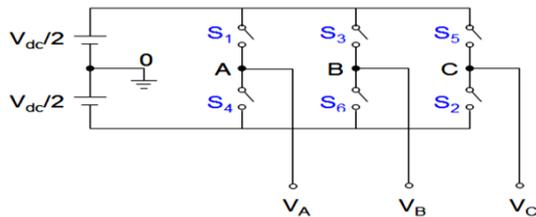


Fig. 3.1: Three Phase Inverter

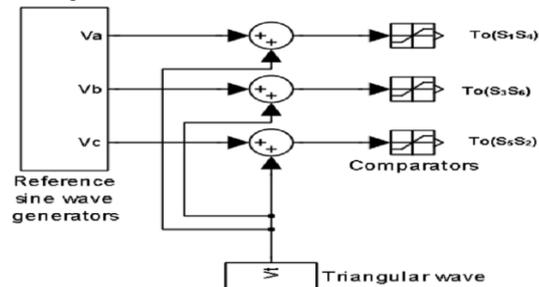


Fig. 3.2: Control signal generator for SPWM

Figure 3.2 represents the control signal generator for SPWM. In this we use triangular wave as carrier signal and sine wave as a reference signal and compare the two waveforms with the help of comparator [3]. The sample output voltage waveforms using sinusoidal pulse width modulation technique along with output voltage per phase to phase and phase to neutral are shown in figure 3.3.

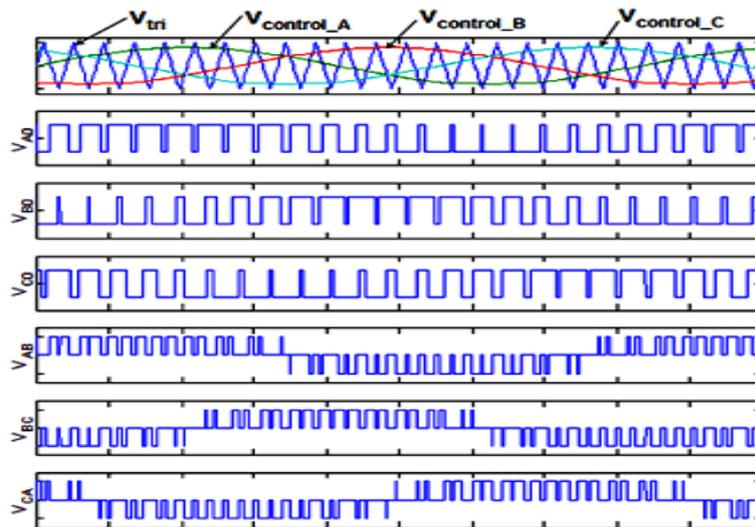


Fig. 3.3: output voltage using SPWM

The modulation ratio can be defined as the ratio of the magnitude of the output voltage generated for SPWM to the fundamental peak value of the maximum square wave.

$$m_a = \frac{V_{PWM}}{V_{max-sixstep}} = \frac{V_{dc}/2}{2V_{dc}/\pi} = \frac{\pi}{4} = 78.55\%$$

Where V_{PWM} the maximum output voltage is generated by a SPWM and $V_{max-sixstep}$ is the fundamental peak value of a square wave. The frequency modulation ratio is defined as the ratio of frequency of the carrier wave to the frequency of the modulating (reference) signal.

$$m_f = \frac{f_c}{f_0}$$

Where f_c the frequency of the carrier is signal and f_0 is the frequency of reference signal, the value of m_f is to be chosen in order to suppress the harmonics.

IV. THIRD HARMONIC INJECTION PULSE WIDTH MODULATION (THIPWM)

In three phase systems the Third harmonic injection PWM is preferred because third harmonic component will not be present in three phase systems. In utilization of DC source the THIPWM is better. Various modulations are used for three phase inverters where space vector pulse width modulation (SVPWM) is extended the linear modulation range 15% more compared with SPWM. The modulation range in THIPWM can be extended by injecting the tripled harmonics.

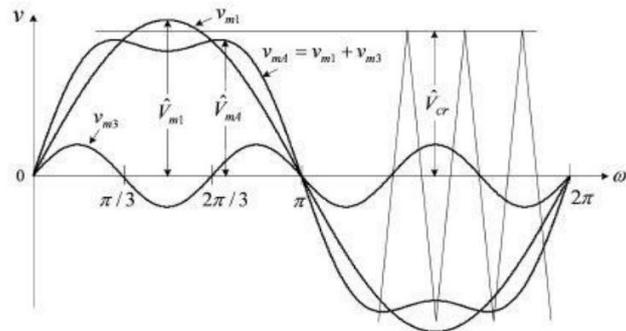


Fig.4.1: Third harmonic injected sine wave

Figure 4.1 shows the modulating signal with third and ninth harmonic injections. The injection of third harmonics do not affect the quality of power since the three phase inverters do not contain tripled harmonics. when the third harmonic component is injected in to 50 Hz fundamental component is given in the following equation:

$$\begin{aligned} V_a &= 1.15\sin\omega t + 0.19\sin3\omega t \\ V_b &= 1.15\sin\left(\omega t - \frac{2}{3}\pi\right) + 0.19\sin3\omega t \\ V_c &= 1.15\sin\left(\omega t - \frac{4}{3}\pi\right) + 0.19\sin3\omega t \end{aligned} \quad (4.1)$$

the equation 4.1 maintains the peak voltage equal to the dc voltage. The carrier signal generation model and THIPWM generation model are explained in [4]. The THPIWM is implemented in the same manner as the SPWM where the reference Waveforms are compared with a triangular waveforms.

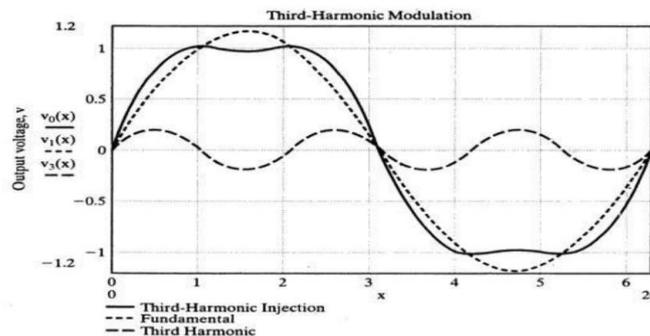


Fig. 4.2: Output waveform for third harmonic PWM

The figure 4.2 represents the output waveform for third harmonic injection PWM. THIPWM reduces the size of the LC filter and complexity of inverter.

V. SPACE VECTOR PULSE WIDTH MODULATION

Another method to increase the output voltage about that of SPWM technique is the space vector pulse width modulation (SVPWM) technique. This method is used for adjustable speed drives. This technique can increase the fundamental up to 27.3% when compared with SPWM. SVPWM uses the rotating synchronous reference frame [5]. The SVPWM refers to a special switching sequence of the upper three switches of a three

phase inverter. To implement the space vector PWM the voltages in the abc reference frame to be transformed in to the stationary dq reference frame which consists of horizontal and vertical axis shown in figure 5.1.

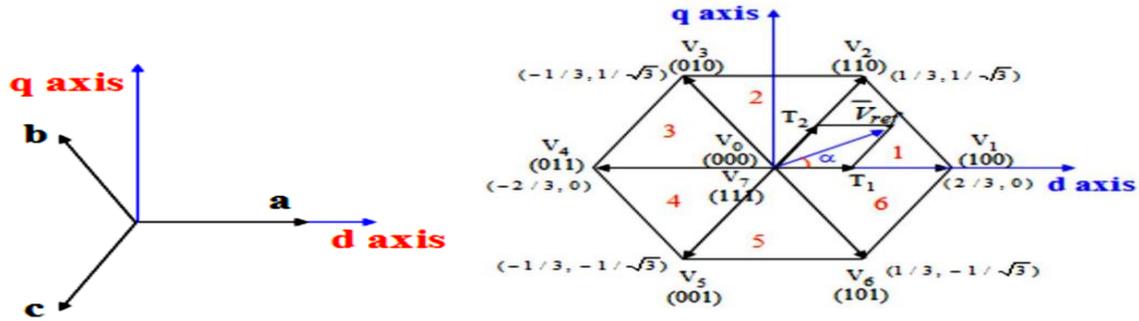


Fig. 5.1: Relation between abc and stationary dq reference frame Fig. 5.2 Basic switching vectors and sectors

The main objective of the SVPWM is to approximate the reference voltage vector V_{ref} by using the eight switching patterns.

In SVPWM by using sectors it can identify the location of reference vector and the switches can be operated as per sectors identified. The switching patterns and sectors are explained in [6]. The voltages in dq reference frame and angle (α) can be given by the following equations

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (5.1)$$

$$|V_{ref}| = \sqrt{V_d^2 + V_q^2} \quad (5.2)$$

$$\alpha = \tan^{-1} \left(\frac{V_q}{V_d} \right) = \omega t = 2\pi f t \quad (5.3)$$

Where f=fundamental frequency.

The SVPWM can also extend to 3 and 5 levels whose space vector representation is shown in the figure below

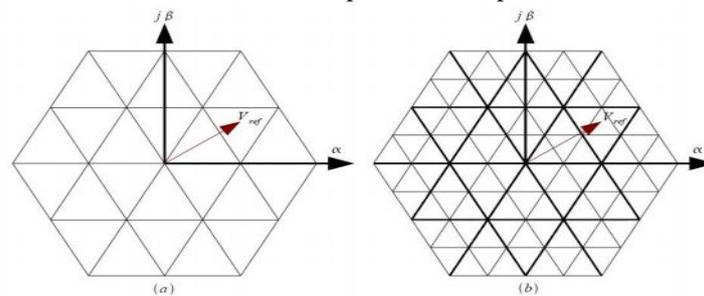


Fig.5.3: space vector representation 3 and 5 level

In this paper we discussed about SVPWM for two level inverter but this can be extend up to three and five levels by using space vectors representation as shown in figure 5.3. But the extending to multilevel may take some complexity in calculating the switching times, sector identification. The SVPWM technique is applicable in many applications like direct torque control and field oriented control of Permanent magnet synchronous motor (PMSM), power factor correction, RFI filters and control of AC drives.

VIII. SIMULINK DESIGNS FOR DIFFERENT INVERTERS

In this paper three separate inverter models are designed for SPWM technique by using the universal bridge from Simulink library. The universal bridge is connected in H-Bridge configuration for two level inverter and for three level it is connected in TWIN bridge configuration. In these models discrete PWM is used to generate pulses and the Simulink block designs are shown in the figures 6.1 to 6.2.

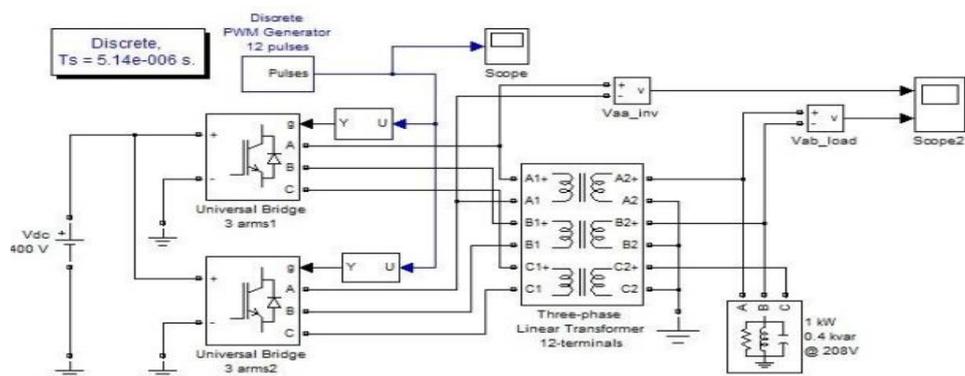


Fig. 6.1 Three phase two level double bridge.

As shown in figure 6.1 the three phase two level single bridge is loaded with RLC parameters and the outputs are observed with SPWM.

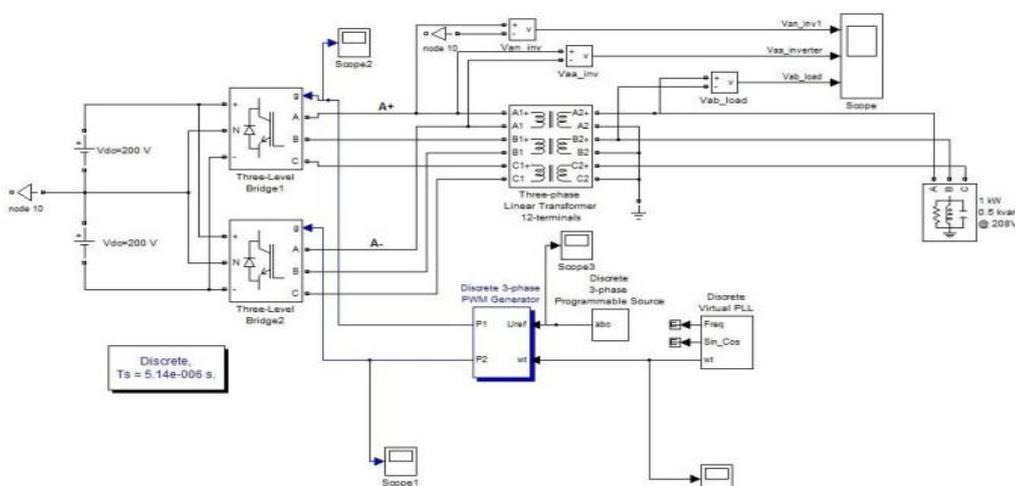


Fig. 6.2 Three Phase Three Level Twin Bridge

The Simulink model for THIPWM is shown in figure 6.3 and in this technique closed loop control is used instead of open loop as in the SPWM technique. In this model PMSM acts as a load to the PWM inverter which acts as the generator of third The Simulink model for THIPWM is shown in figure 6.3 and in this technique closed loop control is used instead of open loop as in the SPWM technique. In this model PMSM acts as a load to the PWM inverter which acts as the generator of third harmonics. The third harmonic currents are taken from the three phase motor through PMSM and the feedback to the THIPWM generator to produce triggering pulses.

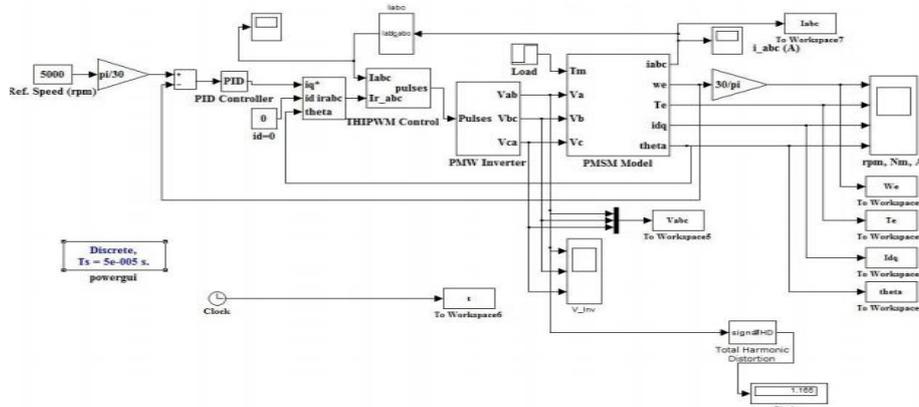


Fig. 6.3 Third Harmonic Injection PWM

By using SVPWM technique two inverters are designed with different load conditions i.e, RLC load and induction motor load and their performances are observed as shown in figure6.4 and 6.5. In the three phase two level double inverter the induction motor load has considered and SVPWM generator is used to generate the pulses and the speed of the induction motor is controlled by the constant V/f block and a load torque of 11.9 N-m is applied to the shaft of the induction motor.

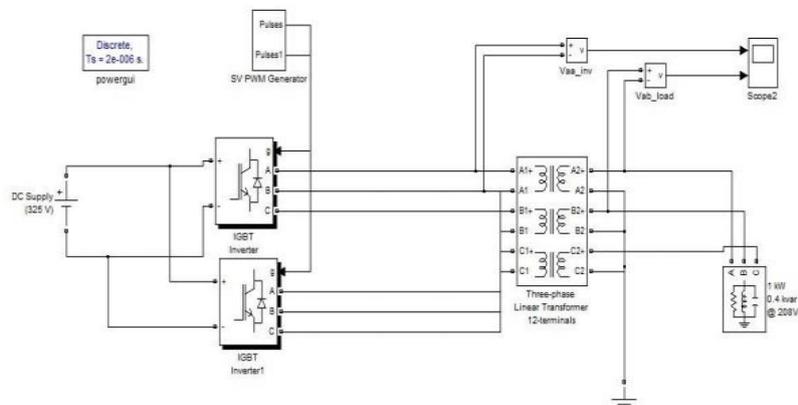


Fig.6.4 Three phase two level double bridge with RLC load

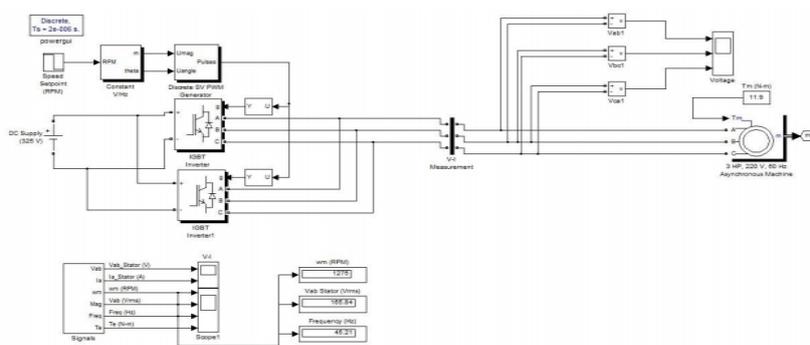


Fig. 6.5 Three phase two level double bridge with I/M load

The simulation results are shown for inverters with SPWM technique and THIPWM technique and also with SVPWM technique with different load conditions are analyzed and the wave forms are shown in figures 6.6 to 6.12

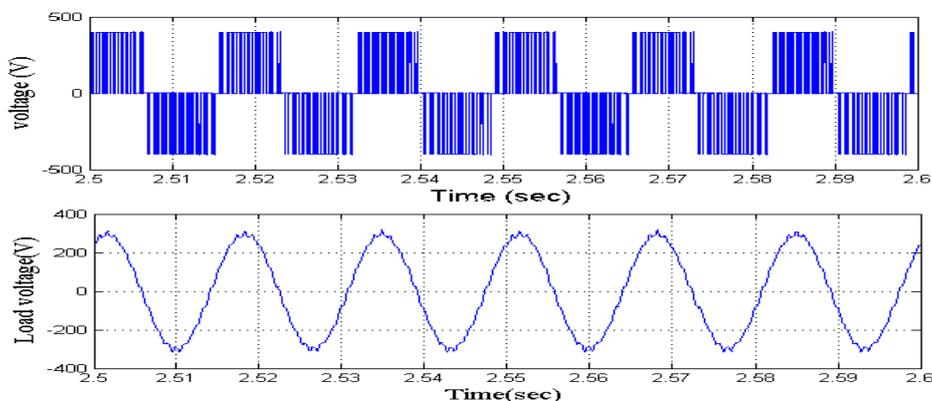


Fig. 6.6 Phase-phase and load voltage of 2level double bridge SPWM inverter

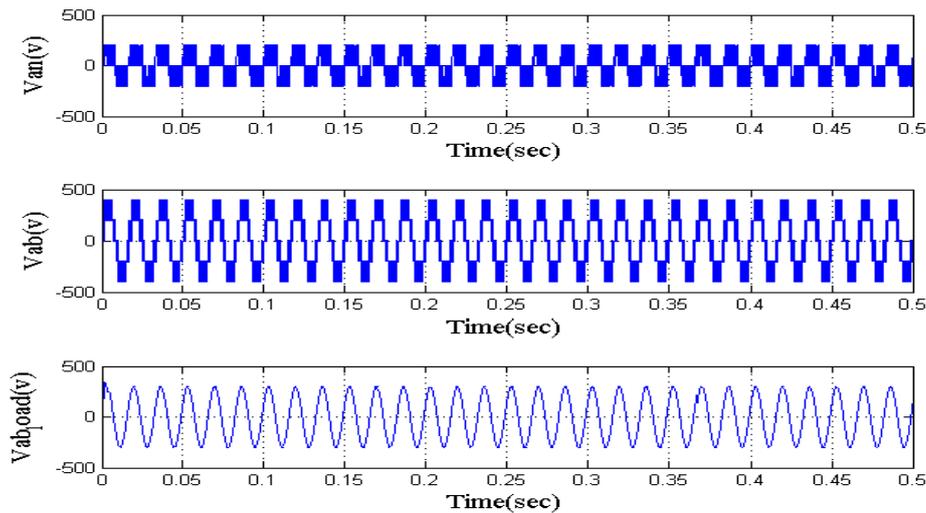


Fig. 6.7 Phase-neutral, Phase-Phase and load voltages of 3level twin SPWM inverter

harmonics. The third harmonic currents are taken from the three phase motor through PMSM and the feedback to the THIPWM generator to produce triggering pulses.

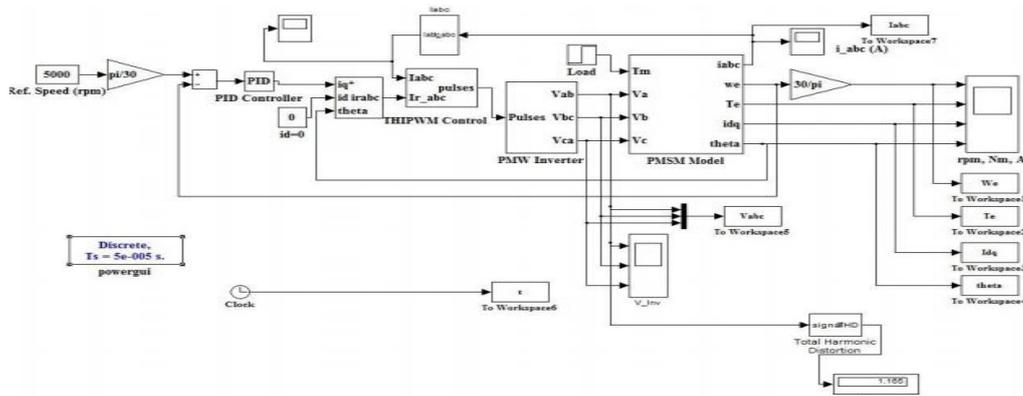


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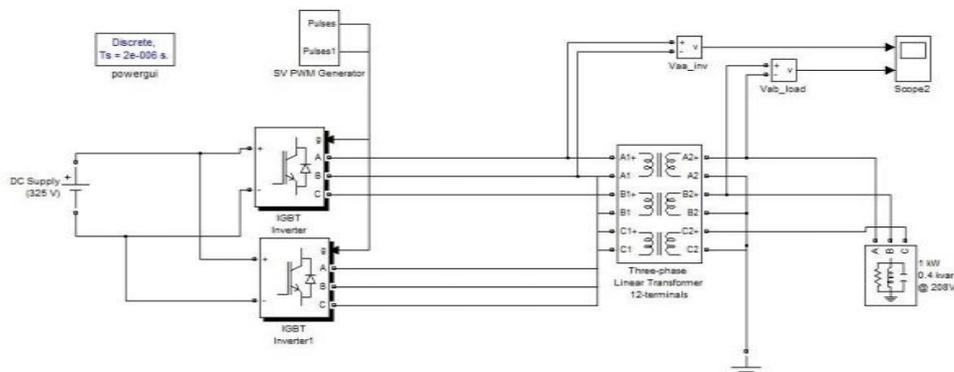


Fig.6.4 Three phase two level double bridge with RLC load

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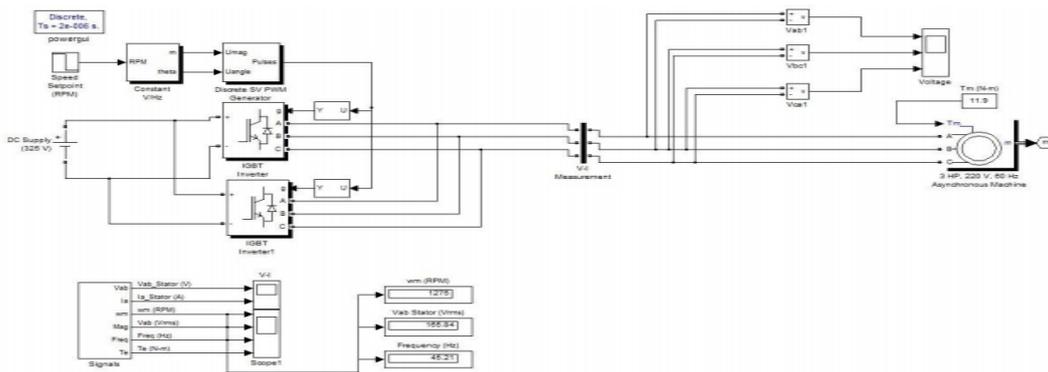


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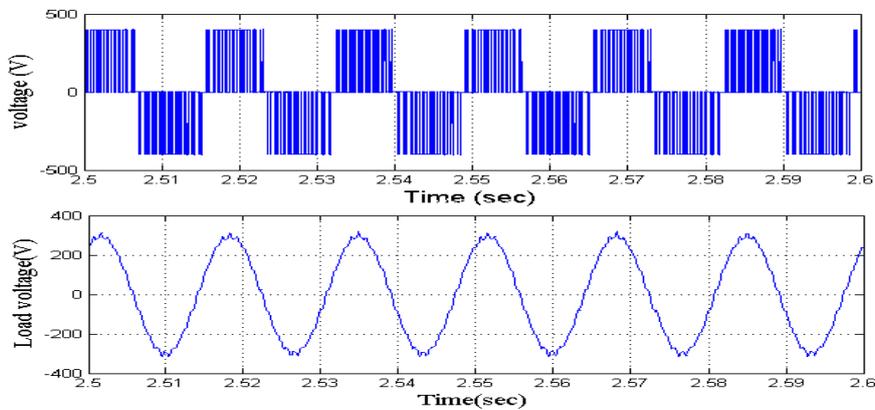


Fig. 6.6 Phase-phase and load voltage of 2level double bridge SPWM inverter

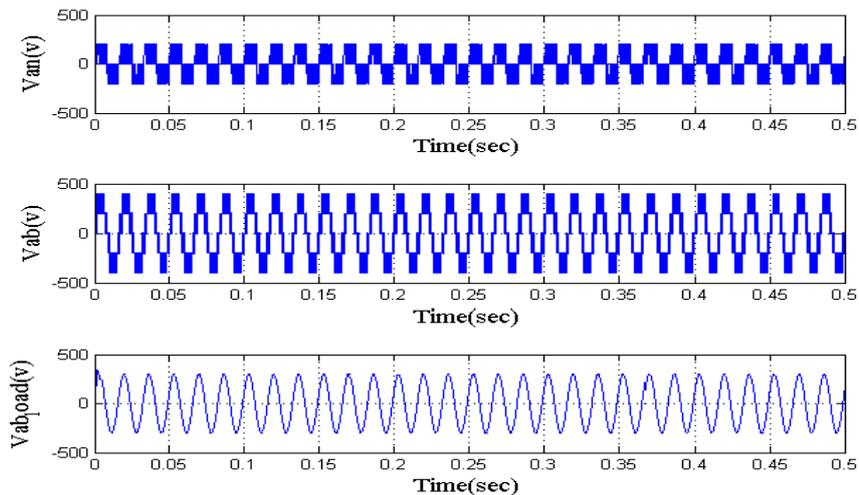


Fig. 6.7 Phase-neutral, Phase-Phase and load voltages of 3level twin SPWM inverter

The figure 6.8 and 6.9 shows the voltage waveforms are of inverter by using THIPWM technique and the motor currents which are also third harmonic currents injected from PMSM motor to the system respectively.

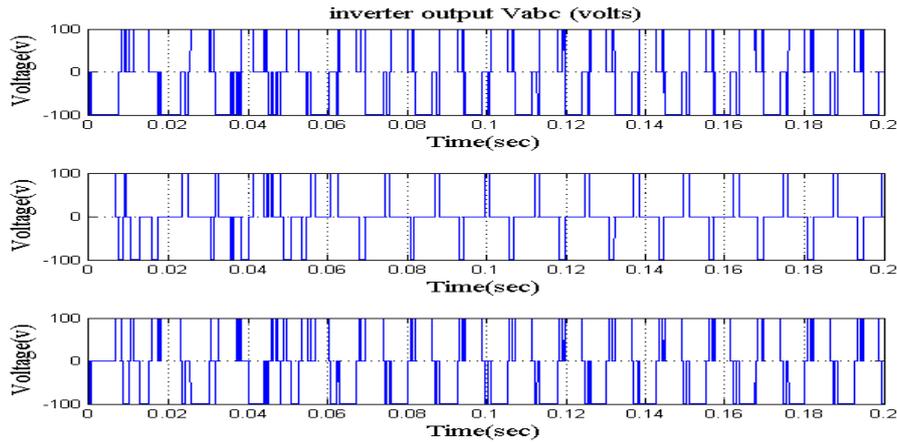


Fig. 6.8 Voltages across the THIPWM inverter

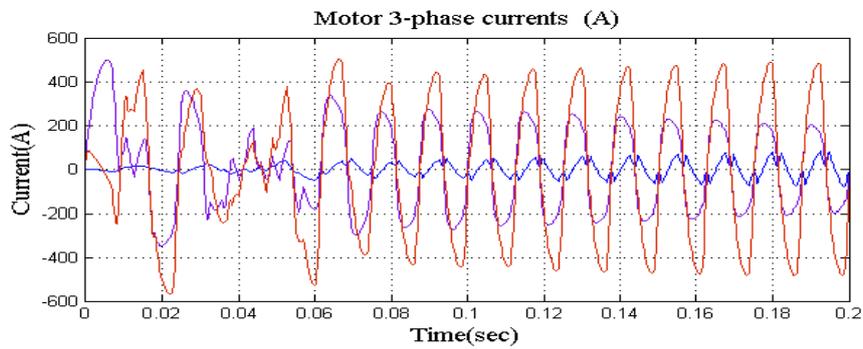


Fig. 6.9 Three-phase motor currents

We observed the voltages of inverter and load voltage for various configurations of inverters using SPWM and THIPWM technique for different load conditions. Similarly the inverter with SVPWM technique produced waveforms for RLC load and induction motor load as shown in figure 6.10 and 6.11 respectively.

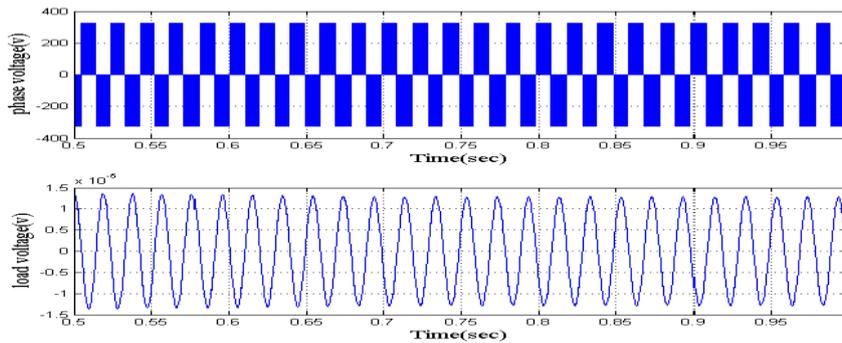


Fig. 6.10. Phase-phase and load voltage of SVPWM inverter with RLC load

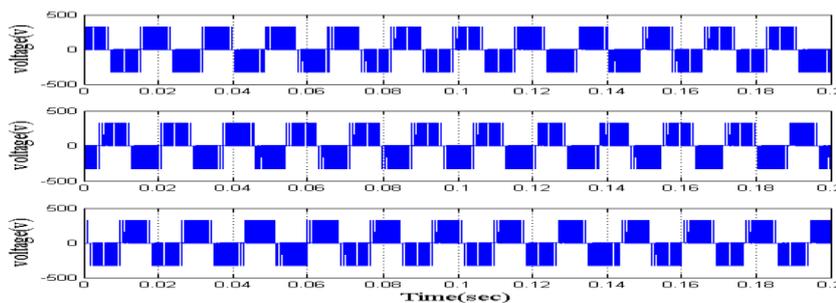


Fig. 6.11 Phase-phase voltages of SVPWM inverter with I/M load

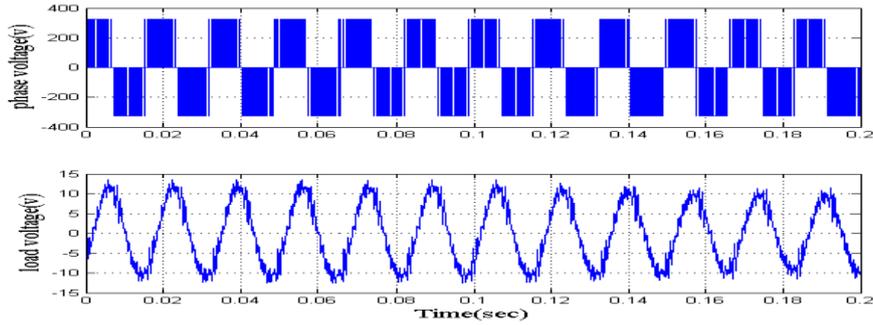


Fig. 6.12 Voltage and current across stator of Induction motor

The inverter voltages with different PWM technique have been implemented and the results are analyzed in Fast Fourier Transform (FFT) analysis to find the fundamental component and the harmonic component presented. The different voltages with different PWM technique are tabulated in the table 6.1.

TYPE OF INVERTERS	FUNDAMENTAL	THD(%)
Two level single bridge inverter (using SPWM)	292.8	85.49
Two level double bridge inverter (using SPWM)	337.7	70.43
three level twin bridge inverter using SPWM)	335.5	36.75
THIPWM inverter	110	51.22
SVPWM inverter with RLC load	301.8	47.15
SVPWM inverter with I/M load	301.4	33.02

Table. 6.1 FFT analysis of Inverters

VII. CONCLUSION

In this paper we discussed about types of various types of inverters with different PWM techniques are analyzed. The THD value is reduced to 33.02% with induction motor load for SVPWM technique when compared with RLC load which is having THD value of 47.15%. The THD value is reduced to 36.75% for three level twin bridge inverter when compared to two level twin bridge inverter with THD value of 70.43% while using SPWM technique. As seen from the above results the SVPWM technique is a better option for the application of inverters with different industrial loads.

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