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Effect of Carrier Frequency on the Performance of Three Phase SPWM Inverter

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***Abstract*—Inverter has wide number of industrial applications. The Sinusoidal Pulse Width Modulation (SPWM) technique is one of the most popular PWM techniques for controlling and harmonic reduction of inverter. Recent developments in power electronics and semiconductor technology have lead use of high carrier frequency in SPWM inverter.In this paper, the performance of three phase inverter is checked with different carrier frequency. Three phase induction motor is used as load to inverter. The simulation results have been shown before and after harmonic reduction using a passive filter at different carrier frequency**

***Keywords*—Carrier frequency, SPWM, Voltage Source Inverte, MATLAB.**

I. INTRODUCTION

The use of inverter is significant in hybrid power system and micro grid system. Moreover in industrial applications, such as single phase and three phase induction motor, other rotating machines requires variable frequency, variable voltage supply.To vary the supply frequency and supply voltage, voltage source inverter (VSI) is used. Thus, VSI is used extensively for AC motor drive. Three phase induction motor drives are most widely used in industry industrial control and automation.

There are different switching techniques are used for controlling and harmonic reduction of inverter. Each techniquehas some advantages and disadvantages. Pulse Width Modulation (PWM) technique is the best one out of them, but the most widely used switching techniques are the Sinusoidal PWM (SPWM) and the Space Vector PWM (SVPWM).The number of industry applications in which induction motors are fed by Sinusoidal Pulse Width Modulation inverter is growing fast. It provides many benefits to their users such as simplicity of circuit, improved control of processes, reduced energy consumption andalso it is compatible with today's digital microprocessors as well as analog circuits. Despite such benefits, it can be also used to drive low voltageinduction motor.In this paper three phase voltage source inverter is presented. Later the SPWM technique with guidelines for selection of carrier frequency is described. Then last part gives the simulation results of proposed system with different carrier frequency.

II. THREE PHASE VOLTAGE SOURCE INVERTER

The voltage source inverter (VSI) gives controlled AC output voltage waveform and behaves as a voltage source formany industrial applications [1]. The output voltage waveform of VSI is unaffected by the load. Due to this property, it is used in many industrial applications such as Un-interruptible power supply (UPS), Industrial (induction motor) drives, Traction, HVDC, etc. Three single phase half bridge inverters need to be connected in parallel to form a three phaseVSI as shown in fig. 1. It employs three legs each comprising two power semiconductors and two freewheeling diodes. The inverter is fed by a fixed, ripple freeDC voltage source.The DC input to inverter may be battery, fuel cell, solar cells or other DC sources [5].

PowerMOSFET and insulated-gate bipolar transistor (IGBT) are largely used power semiconductor devicesfor inverters [1].

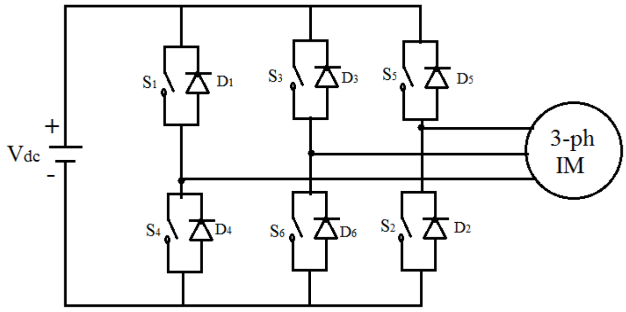

Fig.1 Three-phase voltage source inverter

III. SPWM TECHNIQUE

In SPWM a high frequency triangular carrier wave is compared with the low frequency sinusoidal reference wave which determines the switching instants of control switches. The switching signal is generated by comparing the sinusoidal waves with the triangular wave as shown in fig. 2. The comparator gives a pulse when sine wave voltage is greater than the triangular wave voltage and this pulse is used to trigger the respective inverter switches.

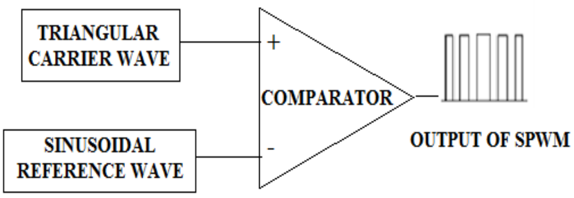

Fig. 2 Sinusoidal Pulse width modulation

SPWM technique is characterized by constant amplitude pulses with different duty cycles for each period. The width of these pulses are modulated to obtain inverter output voltage control and to reduce its harmonic content [2]. This technique directly controls the inverter output voltage and frequency according to the reference sine function.Fundamental frequency of output voltage is controlled by the frequency of reference sinusoidal waveform.

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A.Modulation index:

It is also known as amplitude modulation index. Suppose the amplitude of sinusoidal reference wave is A_m, and the amplitude of triangular carrier wave is A_c, then the ratio $m=A_m/A_c$, is known as the modulation index. It is to be noted that the amplitude of applied output voltage can be controlled by controlling the amplitude modulation index [3].When m is greater than one, lower order harmonics will be appeared in the inverter output, therefore mshould be less than one.

B.Frequency modulation ratio (m_f):

It is the ratio of frequency of the triangular carrier waveform (f_c) to the frequency of sinusoidal reference waveform (f_s). It controls harmonics in the output voltage.

C.Selection of "m_f" :

1.For an odd integer value ofm_f: For minimization of harmonics, carrier wave should be synchronized with the reference wave means.Thus carrier wave frequency f_c is an integer multiple of the reference sinusoidal wave frequency f_s. That is, the pulse number $n = f_c/f_s$ must be an exact integer. If m_f is not an integer, there may exist sub harmonics at the inverter output voltage [4].

The SPWM waveform has harmonics of several orders in the phase voltage waveform, the dominant ones are the fundamental and other of order of n and n±2. Thus m_f should bean odd integer to reduce even harmonics. Thus, if m_f is not odd, DC component may exist and even harmonics are present at output voltage [4].

2. Form_f as a multiple of 3: To reduce triplen harmonics of three-phase PWM inverter,m_f should be multiple of 3.

Choosing a multiple of 3 is also convenient as then the same triangular waveform can be used as the carrier in all three phases, leading to some simplification in hardware [5].

3. For highm_f :PWM pushes the harmonics into the high frequency range around the carrier frequency and its multiples. Harmonic content at inverter output is reduced with lager number of pulses that is with high value of m_f or f_c [5]. However, a higher carrier frequency does result in alarger number of switching per cycle and hence in an increased power loss. Typically switchingfrequencies in the 2-15 kHz range are considered adequate for different power systems applications [7].

SPWM for three phase inverter requires three reference sine waves which are 120° shifted with each other and a common high frequency triangular carrier wave to generate the modulating signals for the three phases.

IV. SIMULATION STUDY

A. Generation of SPWM Switching Signal

SIMULINK block diagram of SPWM control is shown in fig 3. For the generation of control or switching signal for three phase SPWM inverter, first step is to generate three phase sine waves. Sine wave generator is used to generate sinusoidal waves of selected amplitude and frequency so as to give required output voltage of inverter. These sine waves then compared with a common carrier triangular wave; generated by triangle generator. It generates triangular wave of selected carrier frequency with fix amplitude of one. A high carrier frequency will results in low harmonics in output of inverter. The high carrier frequency switching scheme enables to design a low pass smoothing filter for harmonic elimination resulting a reduction in Total Harmonic Distortion (THD) with small sized inductors and capacitors. Fig.4 shows generated gate signals which are then used to trigger the respective inverter switches.

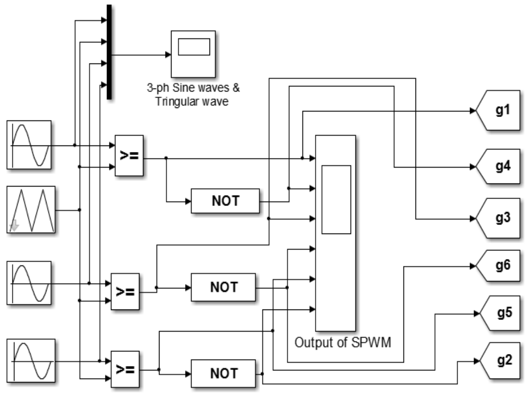

Fig. 3SIMULINK block diagram of SPWM control

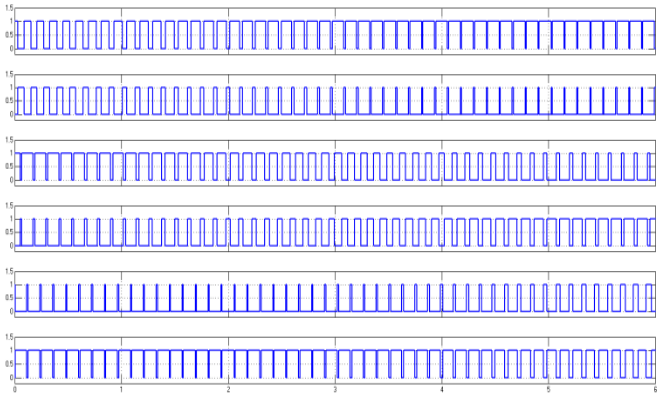

Fig.4 Gate signals

B. Simulation model of Three Phase VSI

A three phase VSI is developedin SIMULINK as shown in fig. 5. Switching signals generated by SPWM technique are given to respective inverter switches. Three phase induction motor rated 0.33 HP, 48 V, 50 Hzis connected to output of inverter as a load to inverter. The inverter is modeled using IGBT switches and the motor by the "Asynchronous Machine" block. A system in which Inverter drives induction motor, Inverter gives modulated output voltage and sinusoidal current (with small ripples) before filtering. A second order LC filter is connected at the output of inverter as shown in fig. 6so as to get sinusoidal output. The designed filter values are L=0.5mH and C= 2200µF [6].

C. Simulation with different carrier frequency

Proposed inverter is simulated for different carrier frequency f_c. This f_c is selected for lower, middle and higher value of m_f with a constant value of f_s=50Hz. Inverter output is checked before and after filtering at different carrier frequency as shown in fig. 7 to fig. 12.

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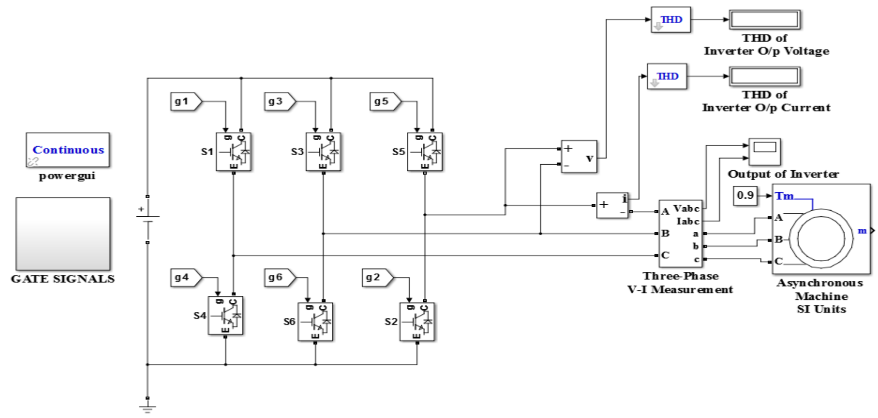

Fig. 5 SIMULINK block diagram of VSI fed 3-ph IM

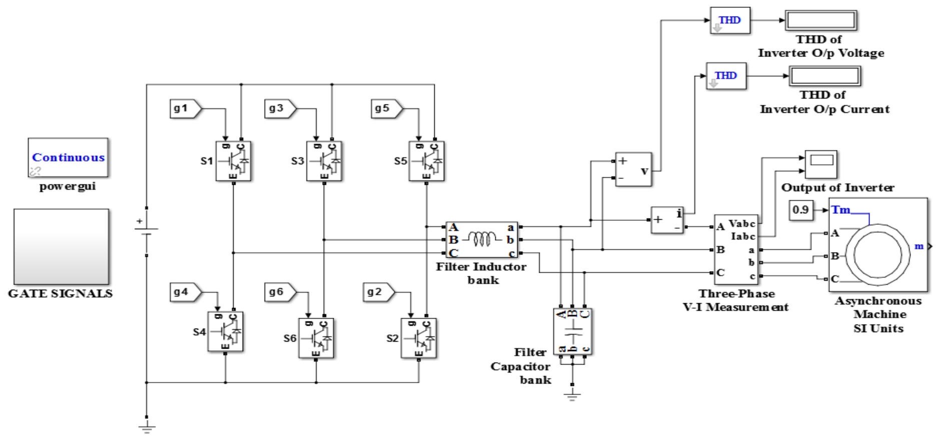

Fig. 6 SIMULINK block diagram of VSI fed 3-ph IM with filter

D. Simulation results at different carrier frequency

1. For m_f=21 and f_c=1.05kHz:

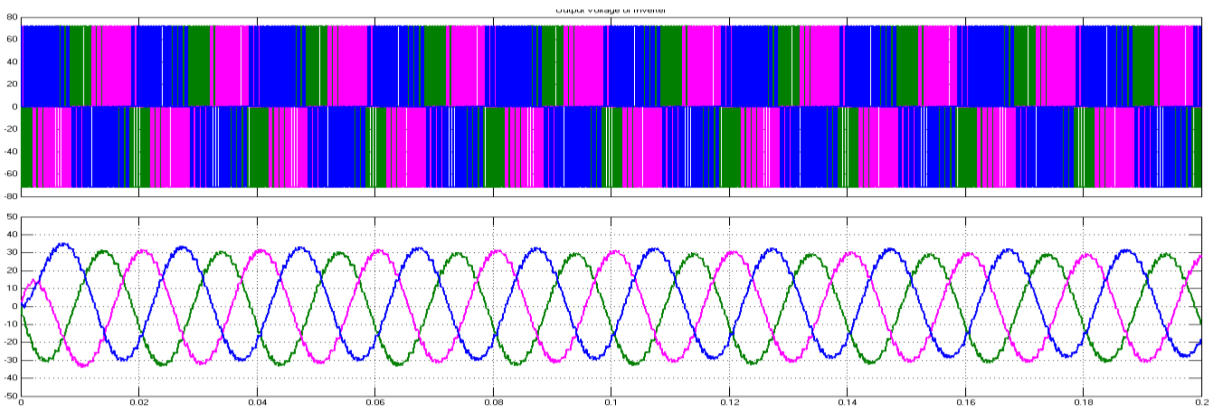

Fig.7Voltage and Current output respectively of Proposed 3-ph Inverter at 1.05 kHz Carrier Frequency before filtering

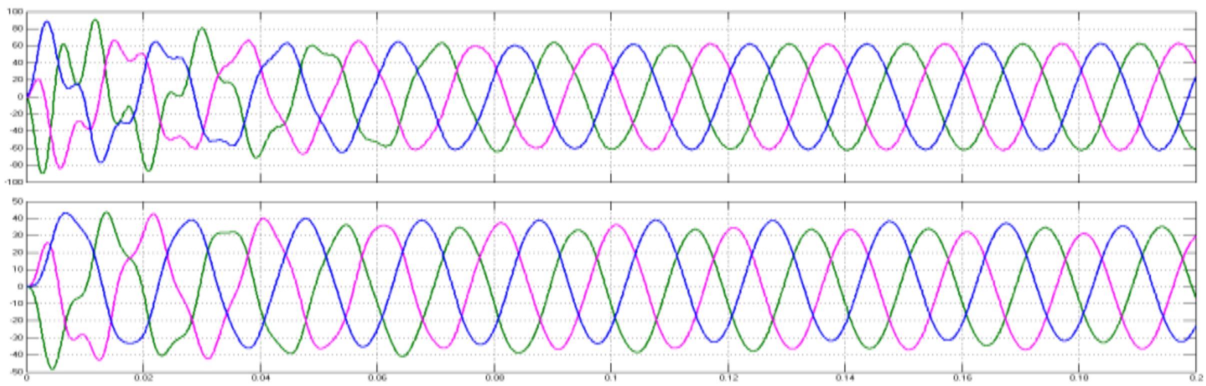

Fig.8Voltage and Current output respectively of Proposed 3-ph Inverter at 1.05 kHz Carrier Frequencyafter filtering

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2. For m_f= 165 and f_c= 8.25 kHz:

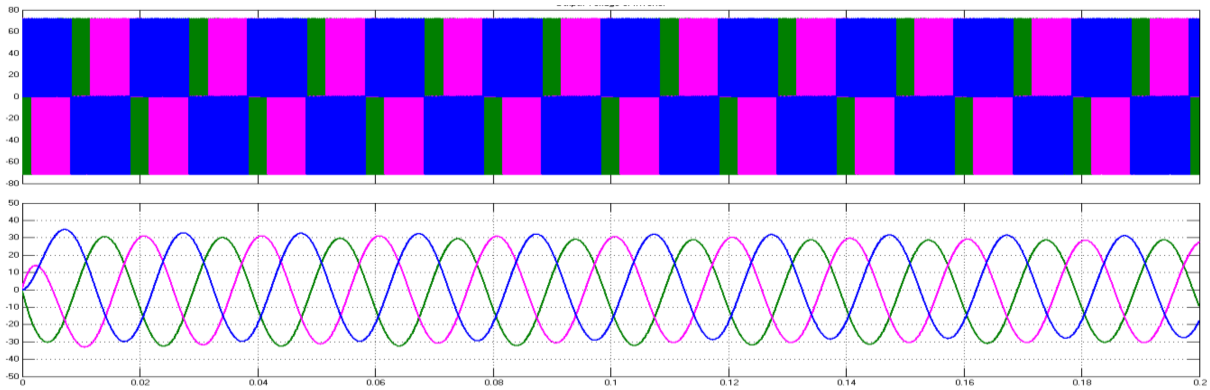

Fig.9Voltage and Current output respectively of Proposed 3-ph Inverter at 8.25 kHz Carrier Frequency before filtering

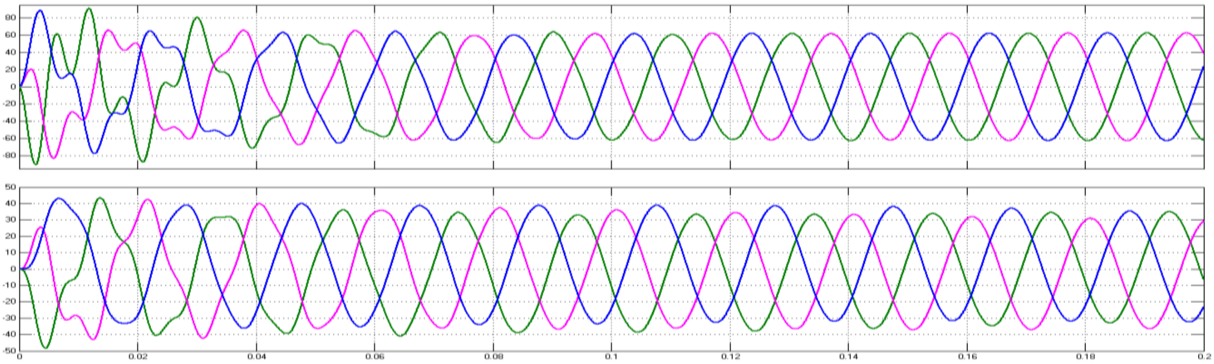

Fig.10Voltage and Current output respectively of Proposed 3-ph Inverter at 8.25 kHz Carrier Frequencyafter filtering

3. For m_f= 255 and f_c= 12.75 kHz:

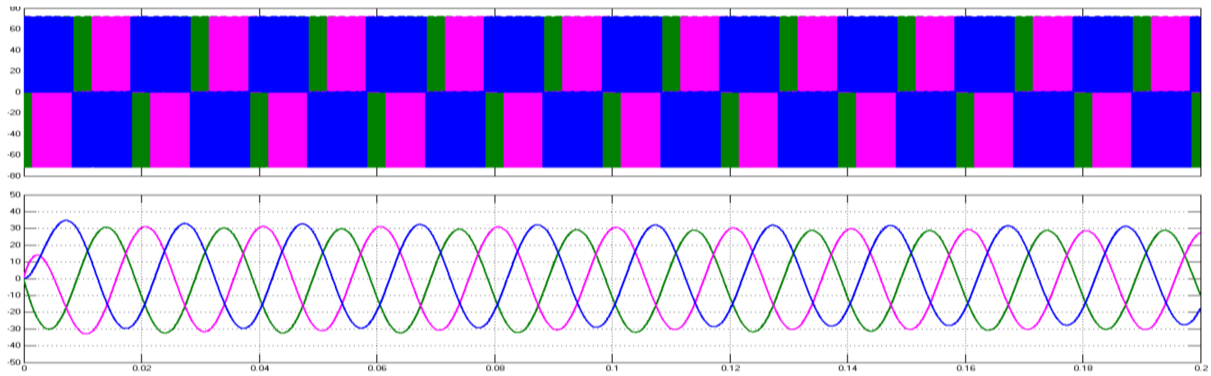

Fig.11Voltage and Current output respectively of Proposed 3-ph Inverter at 12.75 kHz Carrier Frequencybefore filtering

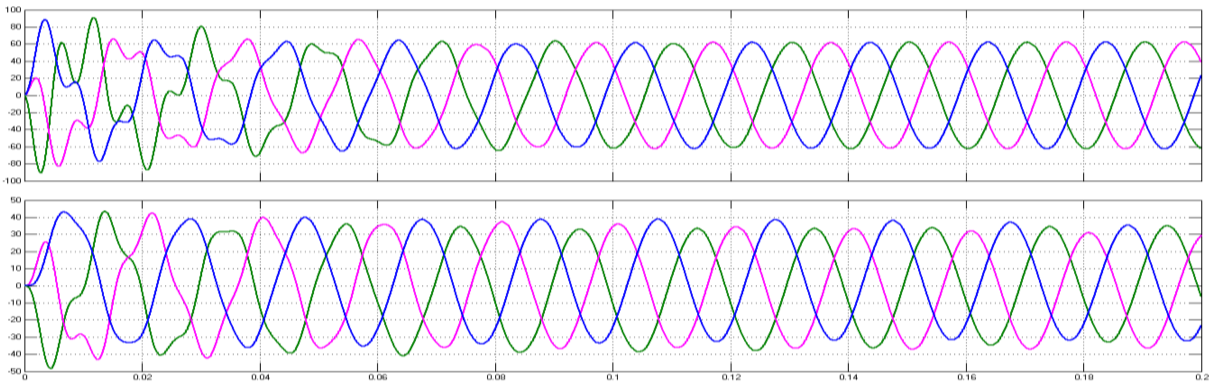

Fig.12Voltage and Current output respectively of Proposed 3-ph Inverter at 12.75 kHz Carrier Frequencyafter filtering

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Carrier Frequency in kHz	THD of Voltage (%)		THD of Current (%)	
	Before Filtering	After Filtering	Before Filtering	After Filtering
1.05	90.39	0.84	10.28	0.40
8.25	90.33	0.042	1.35	0.12
12.75	90.33	0.041	0.91	0.12

Table 1: Carrier frequency and its effects on Performance on proposed Inverter in terms of THD

V. CONCLUSION

In this paper, Simulink model for Sinusoidal PWM three-phase VSI with three phase induction motor as a load has been developed and tested in the MATLAB/Simulink at different career frequencies.The simulation results proved that THD for the output current decreaseswith increase in the carrier frequency without connecting filter at inverter output. When filter is connected to the output of inverter, the output will go into transient state, for initial few cycles after that steady state will be achieved and THD for the output voltage also decreaseswith increase in the carrier frequency.Means it has been clearly shown by varying carrier frequency from low tohigh value we can minimize the THD of phasecurrents and voltages.

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