Reduction of Total Harmonic Distortion in Nine Phase Induction Motor Drive with SPWM Technique

Dr. Manjesh, Nilima Siddhartha Dabhade, Hasitha
Associate Professor, Research Scholar, Research Scholar
Department of Electronic Science, Bangalore University, Bangalore, India.

Abstract : Three phase motor drive limit the torque density hence Multiphase motor drives are better solutions for high torque density and heavy loads. In this work a Nine Phase Inverter is designed to drive Nine phase load. The output of the inverter consists of fundamental frequency of of rated voltage with additional harmonics. These harmonics are higher than fundamental frequencies that enhances the Total Harmonic Distortion (THD), results in increase of rms current and generates more heat in the load. Many techniques are used to suppress the harmonics to minimize the heat in the load. A common technique is employed in this work to minimize THD by constructing SPWM (Sinusoidal Pulse Width Modulation) technique to overcome the low performance of a conventional PWM (pulse width modulation) control. In this work, the desired output voltage is achieved by comparing the desired sinusoidal waveform (modulating signal) with a high-frequency triangular waveform (carrier signal). The PWM and SPWM results obtained are compared and presented in this paper using Matlab/Simulink.

Index Terms - **Harmonics, Nine phase Inverter, SPWM Technique, Nine phase Induction Motor, Matlab/Simulink.**

I. Introduction

Three phase drives are generally used for heavy torque loads. If the phases voltages are increased beyond three phase then it is more advantageous. The major advantages of using a multiphase drive machine instead of a three-phase machine are meant for high torque density, reduced torque pulsations, greater fault tolerance, reduction in the required rating per inverter leg, better noise suppression, smoother torque and reduction of the torque ripple magnitude [1]. A nine phase inverter is used to drive the multiphase motor. Inverters overcome the restriction of phase voltage, multiphase drives have major applications in high torque motor drives like ship propulsion, electric aircraft, hybrid electric vehicles, electric traction and battery-powered electric vehicles etc.

An inverter is most commonly used for motor drive applications in industries. The function of the inverter is to convert DC voltage supply to AC voltage supply of desire magnitude and frequency. An inverter is the voltage or current source device. Most of the inverters use power MOSFETs or IGBTs as semiconductor switching devices. An inverter can be constructed with Half or full bridge semiconductor devices. An inverter topology uses two switches connected in series with each inverter leg to perform the ON and OFF operation with upper and lower switch alternatively. The number of inverter leg depends on number of phases. The control signals to the inverter are generated and applied through gates of each semiconductor devices constructed in the 9-phase inverter which controls load operation, the loads used in this work nonlinear in nature.

Nonlinear loads are the major challenge in the field of power electronics. The gradual impact of nonlinear parameters of load generates additional harmonic frequencies which affects the power factor. Harmonics deteriorates the power factor and increases electrical losses in the circuit and device, which intern reduces efficiency of the device and also the equipment failure.

Harmonics are the sinusoidal frequencies of voltage and current that is whole multiples of fundamental power supply frequency (50HZ) which causes distortion and dissipated as heat in the load. The percentage of harmonics in a AC circuit output waveform is called THD (Total Harmonic Distortion). The Percentage of THD can be control through several hardware and software techniques like “Filters”, “modulation”, “multilevel inverter” techniques to overcome harmonics distortion. Modulation of control signals is the most effective technique to reduce harmonics distortion. Sinusoidal signal is the main objective of any modulating technique, which can be achieved by varying amplitude or frequency of the signal. Among all modulating techniques, Pulse Width Modulation (PWM) technique is most commonly used in motor drives where Speed of the motor Drive can be varied by varying width of the duty cycle. Several types of PWM techniques are available with advantages and disadvantages [1-5].

1.1. Carrier based modulation techniques:
- Sinusoidal Pulse Width Modulation (SPWM)
- Modified Pulse Width Modulation (MPWM)
- Random Pulse Width Modulation (RPWM)
- 3rd Harmonic Injection PWM(THIPWM)
- Space Vector Modulation (SVM)

1.2. Carrier less modulation techniques;
- Delta Modulation (DM)
- Specific Harmonic Elimination (SHE)
- Wavelet Modulation (WM).

The major objective of the research work is to reduce the Total Harmonics Distortion (THD). The research work in this paper the study is extended to focus on design of Nine Phase Inverter to drive Nine Phase Induction Motor. Control signals are generated with PWM and SPWM modulating techniques using Matlab/Simulink.

II. PWM Technique for Inverters

The Pulse Width Modulation (PWM) technique is characterized by the generation of constant amplitude pulse by modulating the pulse width or duty cycle. In this technique the control signals are applied to the inverter switches are pulse width modulated (PWM) signals. The amplitude of the generated pulse decides the modulation index, the presence of harmonics depends on selection of modulation index. The content of harmonics and THD can be reduced by selecting modulation index to unity.

The in Fig.1.(a) and (b) shows the generation of control signal using PWM technique, carried out by generating one output pulse per half cycle. The output is changed by varying the width of the pulses. The frequency of the two signals is approximately equal, the SPWM technique is obtained by using two types of signals, one is reference sinusoidal signal (fr) with fundamental frequency and the other is carrier triangular wave signal(fc) with high frequency. Carrier signal controls the switching frequency of the inverter and the reference signal controls the output frequency of the inverter. The output frequency(fm) is the ratio of carrier signal(fcr) to the reference signal(fr). The rms output voltage is the ratio of peak amplitude of reference signal (Vr) to the carrier signal (Vc) called modulation index (Ma)[6-8].

$$\text{Ma} = \frac{Vr}{Vc} \tag{1}$$

$$\text{fm} = \frac{fc}{fr} \tag{2}$$

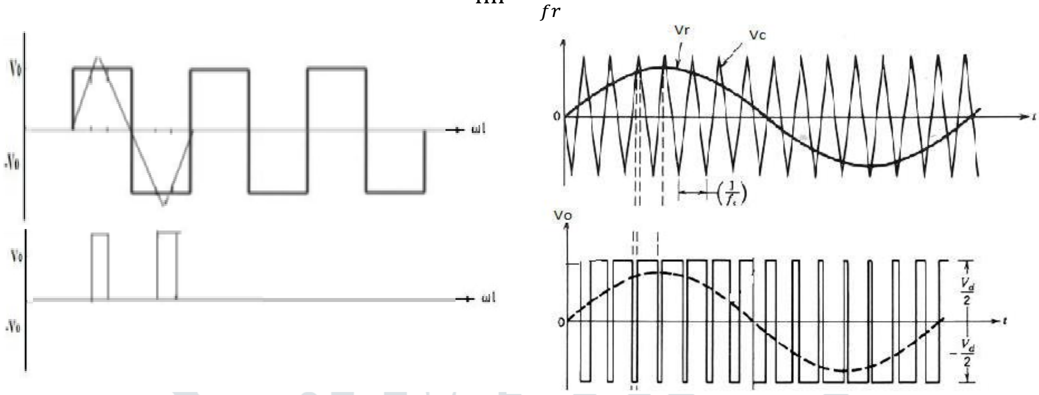

Figure.1. (a)PWM (b)SPWM signal generation

III. NINE PHASE INVERTER DRIVE

N phase inverter drive has "n" number of phase voltages displaced by "360/n" phase. Hence nine phase inverter has nine phases with 40º phase shift. The Fig.2 shows nine phase inverter drive fed by nine phase nonlinear load. There are nine push pull drives, each drive is triggered by SPWPWM control signals. Thus there are nine PWM trigger signals which are 40° out of phase with each other. The PWM 9-phase inverter drive is constructed with IGBT (Insulated-Gate Bipolar Transistor) switches. All the switches conduct for a period of $180^{0.}$ as shown in Fig.3. and Fig.4[9-11].

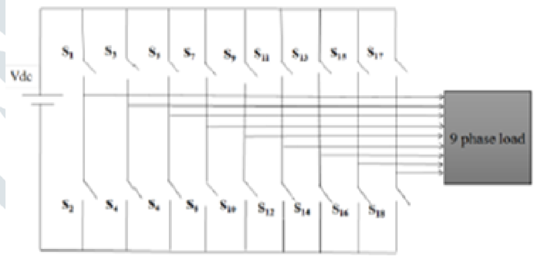

Figure.2. Topology of Nine Phase Inverter drive with non linear load

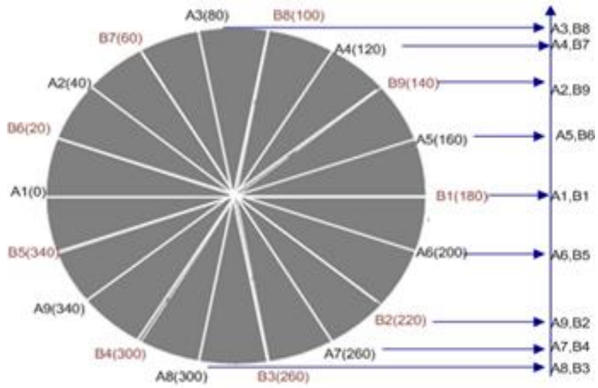

Figure.3. Switching Cycle of Inverter legs with $180^{0.}$ Conduction mode

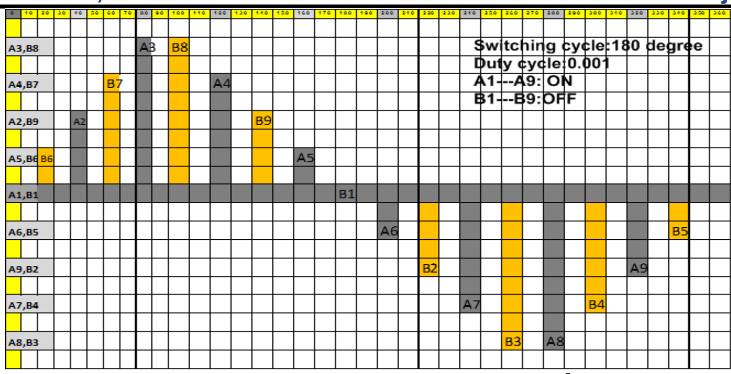

Figure.4. Switching Sequence of Inverter legs with 180^{0}. Conduction mode

IV. Nine Phase PWM Inverter constructed With simulink/matlab:

The Fig.5. shows the Nine phase inverter. A Nine phase inverter is fed by a fixed DC voltage and constructed with nine legs and eighteen switches to control the output of the Nine phase Inverter drive. IGBT's are used as a semiconductor switching devices. In PWM technique, gate of semiconductor device is controlled by PWM control singles [12-15].

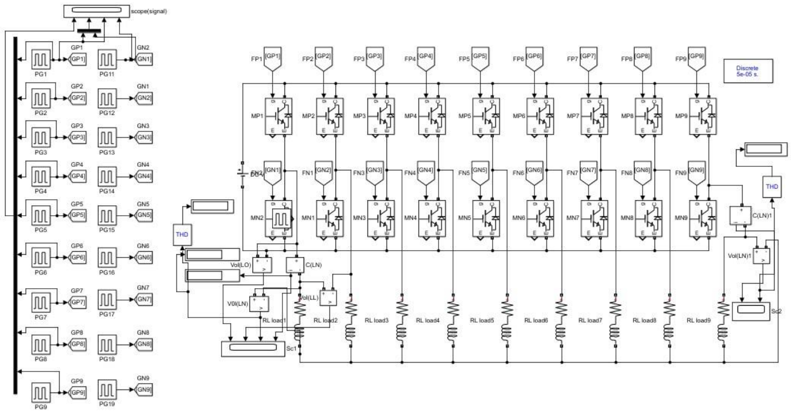

Figure.5. Construction of Nine Phase Inverter with PWM Technique by Simulink/Matlab

The Design of nine phase PWM control signals are applied to each phase leg of the 9-phase inverter with 40° out of phase with each other. The switching pulses of all the legs of the switching devices are monitored using a scope. All the control signals are arranged in such a way that alternate switching of positive and negative signal are provided to each switch at a regular interval of time, the complete circuit setup is shown in Fig.6.

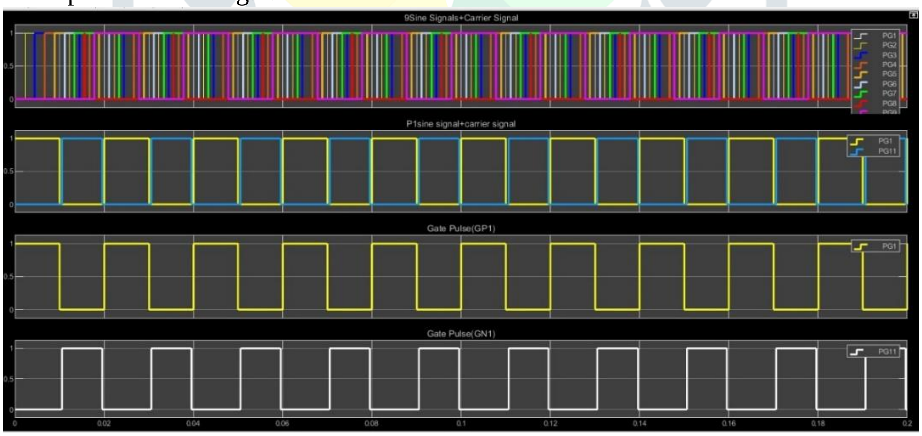

Figure.6. Nine phase PWM signal generation with square waveform

V. SPWM Technique For Nine Phase Inverters

The complete setup of SPWM nine phase inverter drive is shown in Fig.7. A Nine phase design includes Nine PWM trigger signals which are 40° out of phase with each other. These Nine sinusoidal waveforms are compared with a positive and a negative carrier waveform to generate positive and negative SPWM pulses for the inverter, the same signal applied to the switches used in the nine phase inverter drive. The sinusoidal reference waveforms with triangular carrier waveforms are shown in Fig.7. The Nine phase consist of three different positive and negative pulses which should be provided to the Nine different legs of the switching devices. The switching pulses of all the legs of the switching devices are monitored using a scope. All the switching signals are arranged in such a way that alternate switching of positive and negative signal are provided to each switch at a regular interval of time.

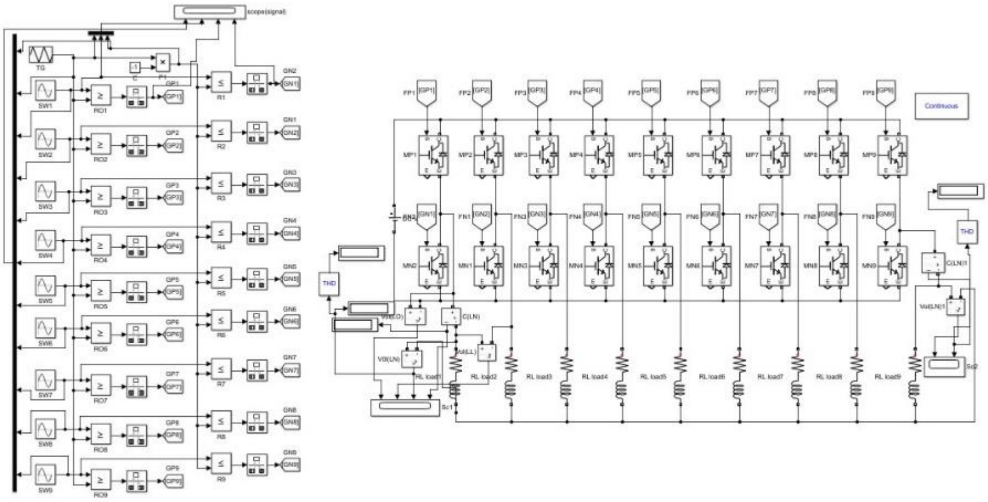

Figure.6. Construction of Nine Phase Inverter Drive with SPWM Technique

The SPWM control signals generated for nine phase inverter drive is as shown in Fig.7. The switches of the inverter are controlled by designing SPWM signals by the comparison of a sinusoidal modulating signal with triangular carrier signal. The sinusoidal modulating signal determines the desired fundamental frequency of the inverter output, while the triangular carrier signal decides the switching frequency of the inverter. The frequency ratio of the triangular carrier signal to the sinusoidal modulating signal is referred to as the modulation frequency ratio.

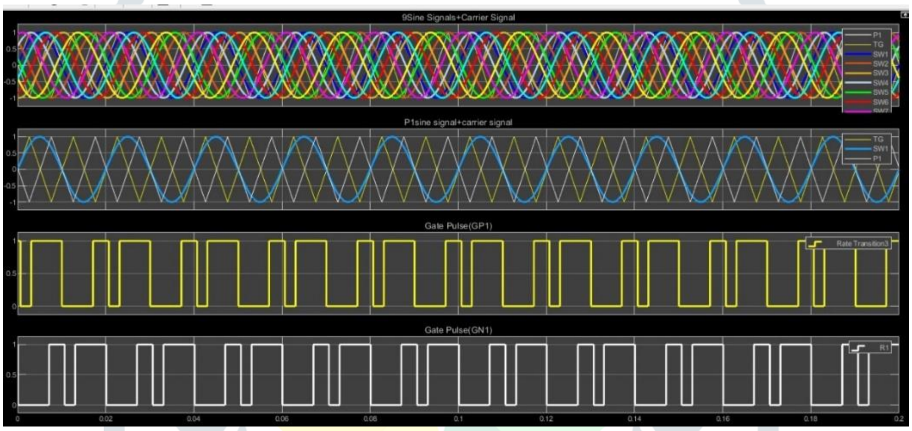

Figure.7. Nine phase SPWM signal generation with sinusoidal and triangular waveform

VI. Simulation Results

The results obtained using nine phase inverter drive with PWM and SPWM technique are as shown in Fig.8. and Fig.9. Waveforms are generated for line voltage and line current. Simulation work has been done for nine phase PWM and SPWM inverter Drive. The nine phase inverter drives are studied and simulated with RL load for the rated frequency of 50Hz and dc voltage(Vdc) of 230v. Parameters used for the SPWM Inverter are the Carrier wave with triangular frequency (Fcr) and Modulating frequency (Fm) and modulation index (m). The results obtained are analyzed for harmonics and (THD). Each output waveform is generated at the different stage of the modulation index.

Figure.8. (a)Load-Output (b)Load-Load voltage c) Load-neutral Voltage and (d)Load-neutral Current waveforms with PWM Inverter

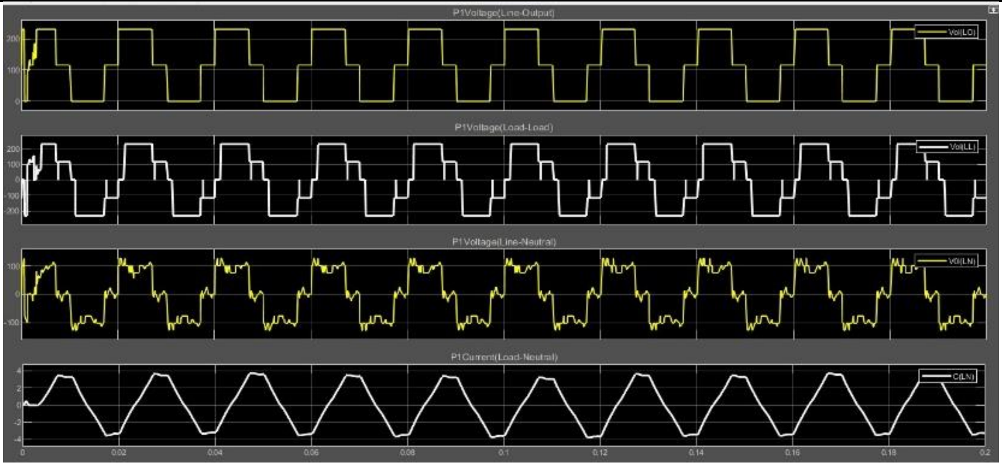

Figure.9. (a)Load-Output (b)Load-Load voltage (c)Load-neutral Voltage and (d)Load-neutral Current waveforms with SPWM Inverter

FFT analysis has been done to obtain the voltage and current THD using Simulink/Matlab and the results are compared with PWM and SPWM inverter drive is depicted in Fig.10. and Fig.11. shows FFT analysis of nine phase Inverter drive with PWM and SPWM Inverter Drive for 50Hz respectively.

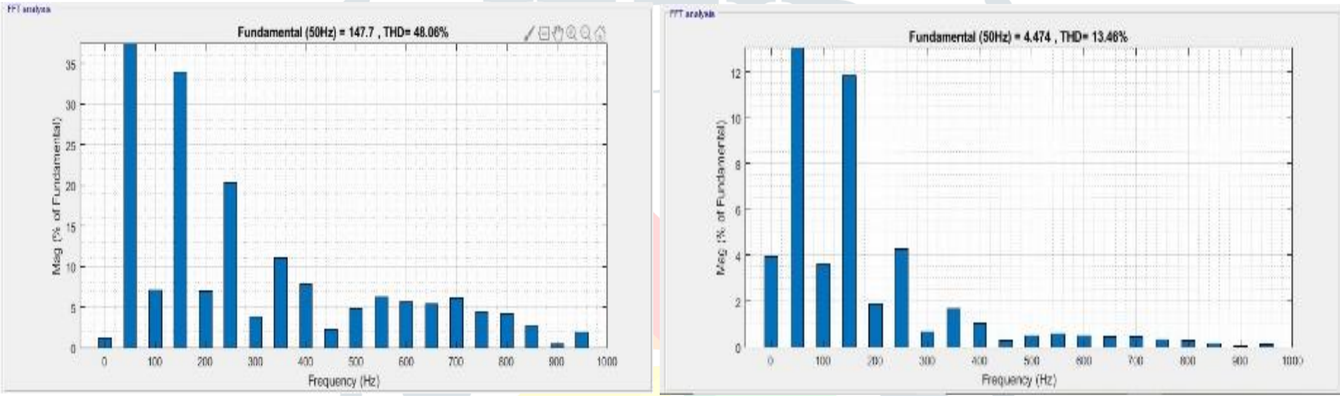

Figure.10. FFT analysis with PWM Inverter with voltage and current harmonics for 50 Hz

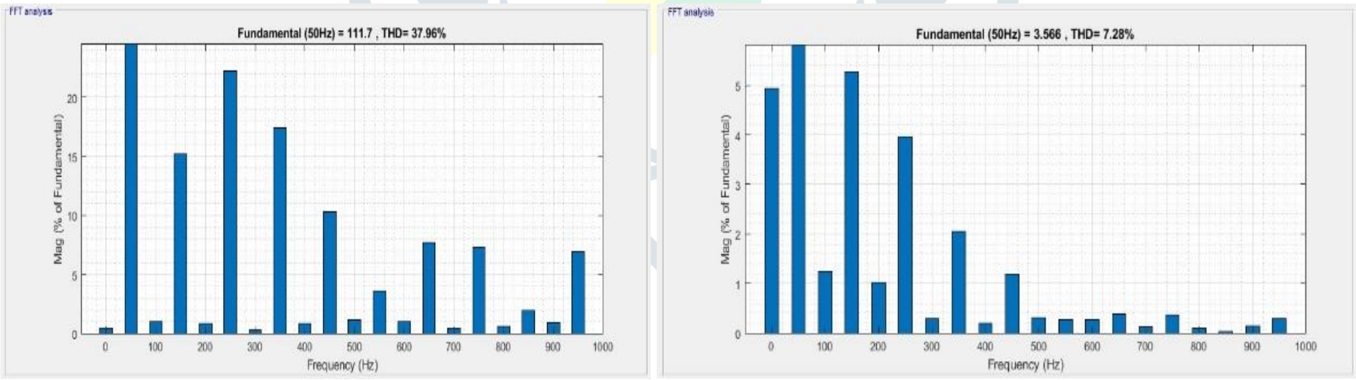

Figure.11. FFT analysis with SPWM Inverter with voltage and current for 50 Hz

Table.1. shows the comparison of % of reduction in THD with PWM and SPWM Inverter drive.
At fundamental frequency f= 50 Hz, V_{dc}= 230v, Fcr=100Hz, Fm=50Hz, m=1 THD % is as shown in table 1.

Table 1. Overall THD comparison with PWM and SPWM Inverter for frequency 50 Hz

Modes	V-THD %	I-THD%
PWM Inverter	48.06%	13.46%
SPWM Inverter	37.96.03%	7.82%

VII. Conclusion

A nine phase inverter drive is constructed using simulink/Matlab to study the voltage/current harmonics and THD at the output of the inverter with nonlinear load and the results obtained are compared with PWM and SPWM nine phase inverter drive. It is observed that the percentage of THD at the output of the SPWM inverter is found to be less than the THD obtained at the output of the PWM inverter drive. Therefore, it is concluded that the efficiency of nine phase inverter drive is excellent with SPWM control drive than PWM control drive.

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