Variable Amplitude sinusoidal Pulse Width Modulation for Nine Phase Induction Motor Using Voltage Source Inverter

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Abstract: Motor Drives are predominant on three phase motor drives. Multiphase motor drives are suitable for heavy loads and high torque density. Operation of the load is nonlinear in nature due to impact of additional injection of voltage and current sources with fundamental frequency which dissipated as heat in the load. Impact of additional parameters on fundamental frequency causes harmonics distortion hence, reduction of the Total Harmonics Distortion (THD) is becomes main objective in motor drives. Since variable speed multiphase motor drives requires power converters for their supply hence multiphase Inverters plays major role in the field of motor drives. Suppression of harmonics with variable amplitude sinusoidal pulse width modulation technique by using Voltage Source Inverters (VSI) is the main objective of presented work. In this work, the desired output is achieved by implementing the Simulink model of nine phase VSI to drive nine phase induction motor with Variable Amplitude Sinusoidal Pulse Width Modulation (VASPWM) technique. The Harmonics and THD of VASPWM with and without filter is compared using Matlab/Simulink.

Index Terms— VASPWM, Harmonics, Matlab/Simulink, Nine Phase Inverter, THD.

I. INTRODUCTION

Multiphase motor drives have major applications in Agriculture, aircrafts, Electric vehicles etc. Since variable speed multiphase motor drives requires power converters for their supply hence multiphase Inverters plays major role in the field of motor drives. Multiphase Inverters claims good efficiency and advantage over three phase inverter due to its capability of generating output voltage with extremely low distortion, lower dv/dt, reduced common mode voltage and ability to operate at low switching frequency.

Inverters are the power converters which convert DC supply to AC output supply for desire phases. The topology of multiphase inverters uses number of semiconductor devices (MOSFET's/IGBT's) with respect to number of phases. Switching singles are fed to switching devices trough control generators.

Operation of the load is nonlinear due to gradual impact of nonlinear parameters of load which generates additional harmonic frequencies. Harmonics deteriorates the power factor and increases electrical losses in the circuit and the device, which reduces efficiency of the device results equipment failure.

The percentage of harmonics in AC circuit output is termed as Total Harmonics Distortion (THD). The percentage of THD can be control through several hardware and software techniques, "Filter" technique at the output of the inverter, "Multilevel" Technique and "Modulation" technique at the inverter compartment and switching control of semiconductor devices to overcome the harmonic distortion.

Several modulation techniques are available for the switching operation in the inverters, in order to produce output voltages and current with high qualities for different types of load. Most of the Voltage Source Inverters (VSI) employed with Pulse with Modulation (PWM) technique to drive load depends on shape of the switching signals like square waveform, sinusoidal waveform or triangular (sawtooth) waveform [1-7].

Suppression of harmonics with variable amplitude sinusoidal pulse width modulation technique by using Voltage Source Inverters (VSI) is the main objective of presented work. In this work, the desired output is achieved by implementing the Simulink model of nine phase VSI to drive nine phase induction motor with Variable Amplitude Sinusoidal Pulse Width Modulation (VASPWM) technique. The Harmonics and THD of VASPWM with and without filter is compered using Matlab/Simulink.

II. VASPWM TECHNIQUE

2.1. PWM Switching

The Pulse Width Modulation (PWM) is a technique which is characterized by the generation of constant amplitude pulse by modulating the pulse duration by modulating the duty cycle. Analog PWM control requires the generation of both reference and carrier signals that are feed into the comparator and based on some logical output, the final output is generated. The reference signal is the desired signal output may be sinusoidal or square wave, while the carrier signal is either a sawtooth or triangular wave at a frequency significantly greater than the reference [8]. The amplitude of the generated pulse decides the modulation index (Ma).

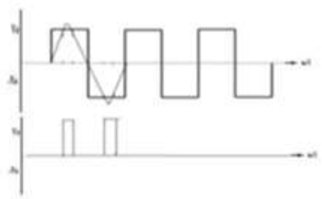


Figure.1. PWM signal generation

2.2. SPWM Switching

The SPWM technique is illustrated in Fig.2. The switching signals of SPWM are created by comparing a sinusoidal waveform (fr) with a triangular carrier waveform (fc). Reference frequency signal defines the inverter output frequency, with its peak amplitude and control the modulation ratio (Ma). The carrier frequency determines the number of pulses per half-cycle where, width of the pulses are changed in ratio to the amplitude of a reference signal estimated at the centre of the same pulse[2]. SPWM inverter has a constant DC input for generating sinusoidal shape at a certain frequency. The output frequency (fm) is the ratio of carrier triangular waveform (fc) to the reference sinusoidal waveform (fr). The rms output voltage is the ratio of peak amplitude of reference waveform (Vr) to the carrier waveform (Vc) called modulation index (Ma) is defined as in Equation (1) and (2) [9-11]. There are two SPWM techniques for VSI SPWM with unipolar switching and SPWM with bipolar switching.

$$\mathrm{Ma} = \frac{Vr}{Vc} \qquad (1)$$

$$\mathrm{fm} = \frac{fc}{fr} \qquad (2)$$

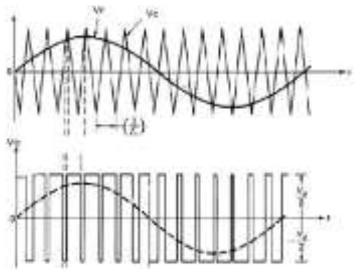


Figure.2. SPWM control signal

2.3. VASPWM control signal

The proposed method of Variable Amplitude sinusoidal Pulse width Modulation(VASPWM) is an extension of SPWM technique. As plotted in Fig.3.The technique derived from the integral of triangular carrier signal (A_c) in such a way that the peak value of the triangular carrier signal attenuates and become equal to the instantaneous magnitude of reference sinusoidal signal (V_r) at that instant. The amplitude and width of the carrier signal varies with respect to reference signal without over modulation, hence it is termed as Variable Amplitude Sinusoidal Pulse Width Modulation (VASPWM). The amplitude of each triangle can be calculated using equation (3) where 'V_{mi}' is the amplitude of the 'i^{th}' triangle and 'mf' is the frequency modulation index [12-13].

$$V_{mi} = \sum_{i=0}^{m_f-1} \sin\left(\frac{\pi}{m_f}\left(\frac{1}{2}+i\right)\right) \qquad (3)$$

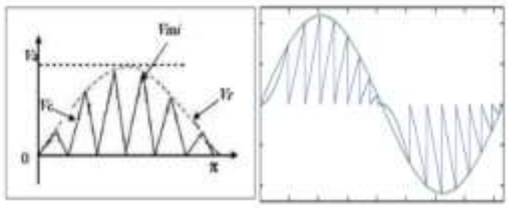


Figure.3. VASPWM control signal

III. TOPOLOGY OF NINE PHASE VSI

Topology of a Nine Phase Voltage Source Inverter (VSI), is shown in Fig.4. Each switch in the circuit consists of two power semiconductor devices (MOSFET'S/IGBT'S), connected complimentary to each other. Nine phase inverter is energized by a fixed DC voltage and constructed with nine legs (**V_A-V_I**) and eighteen switches to control the output of the Nine Phase Induction Motor (**e_a - e_i**). There are nine push pull drives, each drive is triggered by PWM signal, there are eighteen PWM trigger signals which are 40° out of phase with each other, is as shown in Fig.4. all the switches in the inverter conduct for the period of 180^0 [14-17].

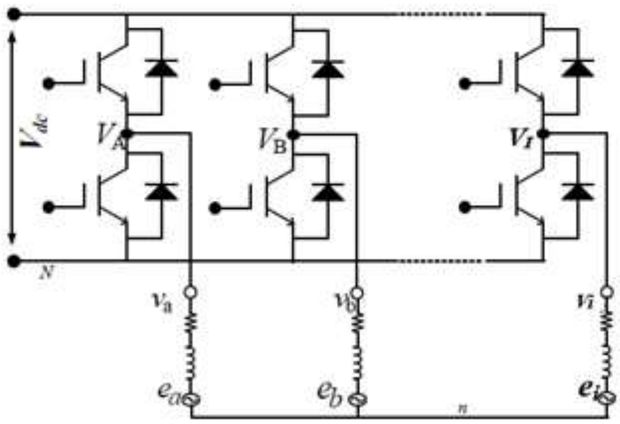


Figure.4. Topology of Nine Phase VSI

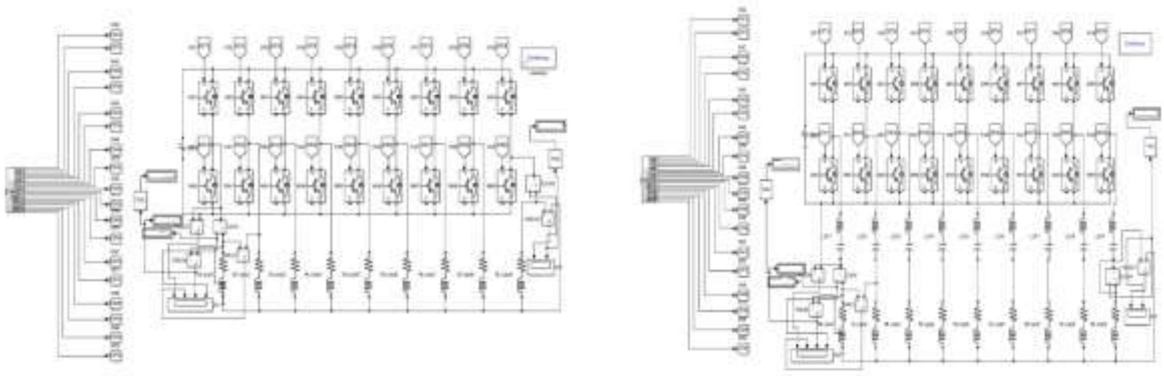
Phase-to-neutral voltages of the star connected load are obtained by defining a voltage difference between the star point *n* of the load and the negative rail of the dc bus *N* is as shown in equation (4) and (5).

$$V_A = V_a + V_{nN} \ldots\ldots\ldots\ldots V_I = V_i + V_{nN} \qquad (4)$$

$$V_{nN} = (1/9)(V_A + V_B + \ldots\ldots\ldots V_I) \qquad (5)$$

IV. SIMULINK MODEL OF VASPWM FOR NINE PHASE VSI

The simulink model of VASPWM is illustrated in Fig.5 (a)without filter and (b)with filter. Simulink model of VASPWM switching for nine phase VSI with and without filter constructed with the nine pair and eighteen switches of MOSFET's which are complimentary with each other for the conduction period of 180°. Each Nine phases are 40° out of phase with each other. Fig.6. shows the switching signals for nine phase VSI Introducing VASPWM signals, the switches of the inverter are obtained by comparison of a sinusoidal modulating reference signal with variable amplitude triangular carrier signal. Modulated signals of upper switch and lower switch are complimentary to each other and amplitude varies in between neutral to phase.



(a) (b)

Figure.5. Simulink model of VASPWM for nine phase VSI (a)without filter (b) with filter

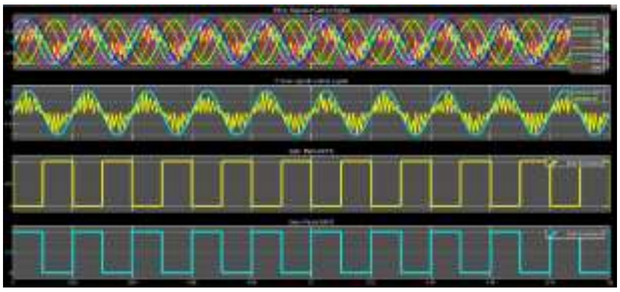
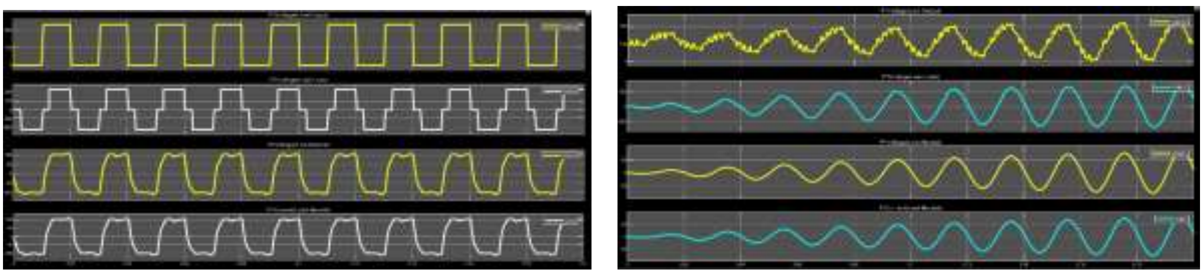


Figure.6. Switching singles of VASPWM for nine phase VSI

V. SIMULATION RESULTS

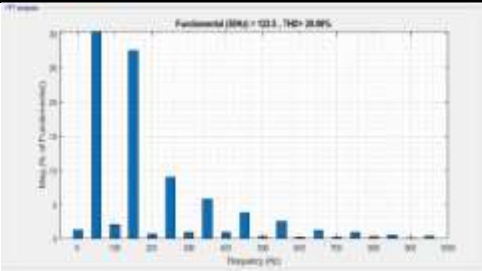
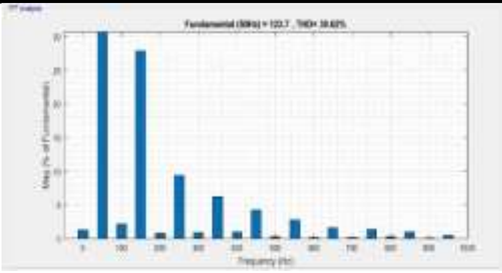
Simulation Results of VASPWM switching for nine phase VSI with and without filter is as shown in Fig.7. (a) and (b) where waveforms are generated for line voltage and line current. The Nine Phase Inverter Drive is studied and simulated with RL load for rated frequency of 50Hz and dc voltage (Vdc) of 230v. The results obtained are analyzed for harmonics and (THD).



(a) (b)

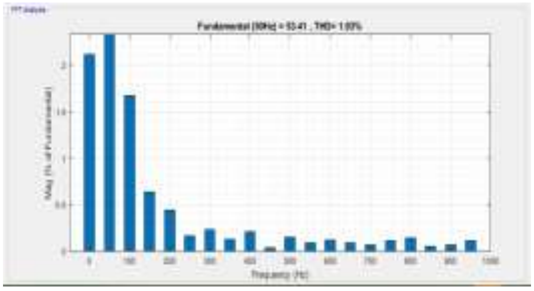
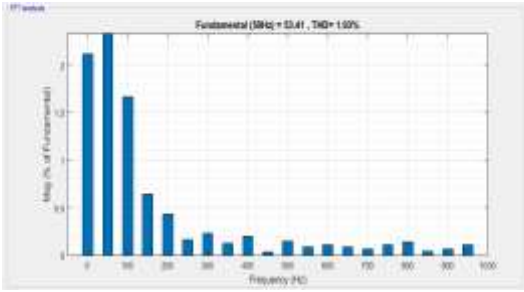
Figure.7. VASPWM-Load-Output, Load-Load, Load-neutral Voltage and Load-neutral Current signals (a)without filter (b)with filter

The voltage and current THD are presented in Fig.8. and Fig.9. The FFT analysis has been done to Nine Phase VSI drive using VASPWM control signals with and without filter for 50Hz and 230v respectively. FFT analysis has been done to obtain voltage and current THD using Simulink and the results of VASPWM are compared with and without filter. Table.I. shows the comparison of % of reduction in THD using VASPWM with and without filter.

(a) (b)

Figure.8. (a) VTHD (b) ITHD for VASPWM VSI without Filter(50Hz)

(a) (b)

Figure.9. (a) VTHD (b) ITHD for VASPWM VSI with Filter(50Hz)

Table- I: THD comparison of VASPWM VSI with and without Filter

V_{dc}= 230v, f= 50 Hz, fc=1khz, L=100mH, C= 100µF		
VASPWM switching	***V-THD%***	***I-THD%***
Without Filter	29.98%	30.62%
With Filter	1.93%	1.93%

VI. CONCLUSION

A Nine phase Inverter drive is constructed with with Simulink/Matlab for the study of THD at the ouput of the nine phase inverter using VASPWM control signals. The Analysis of proposed work has been studied. The results are obtained and compared with and without filter. It is concluded that the extension of the PWM technique with variable amplitude sinusoidal signal (VASPWM) removes the harmonics components from line voltage and current drastically.

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