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Reduction of Total Harmonic Distortion in Nine Phase Induction Motor Drive with Third Harmonic Injection Pulse Width Modulation Technique

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***Abstract**:Industrial applications demands high torque and long life span motor drives. Three phase motor drives have limited 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 loads used in the industries almost nonlinear loads like motors. Therefore,due to these nonlinear loads additional harmonics induced at the output of the nine phase Inverter Drive with fundamental frequency. These harmonics are higher than fundamental frequencies and cause Total Harmonics Distortion(THD) which increases the 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 new technique is employed in this work to minimize THD by constructing THIPWM (Third Harmonics Injection 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 harmonics and THD obtained using PWM and THIPWM is compared using Matlab/Simulink*

***Keywords**: Harmonics,Matlab/Simulink, Nine phase Inverter, Nine phase Induction Motor,THIPWM Technique.*

I. INTRODUCTION

Three phase drives are generally used for medium torque loads. If the phases are increased beyond three then it is more advantageous, the major advantages of using a multiphase drive motor instead of a three-phase motor are torque density and less harmonics distortion, 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]. 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. There are two types inverter, voltage and current source Inverters, these inverters can be with Half or full bridge constructed using semiconductor devices (MOSFETs or IGBTs). The control signals to the inverter are generated to the 9-Phase inverter drive.

The harmonics generated due to 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 reduces efficiency of the device and the equipment failure.

Harmonics are the sinusoidal component frequencies of voltage and current with 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 Harmonics Distortion). The Percentage of THD can be control through several hardware and software techniques like "Filters", "modulation", "multilevel" techniques to overcome harmonics distortion. Several types of PWM techniques are used to suppress the harmonics at the output of the inverter drive are [1-5].

1) Carrier based modulation techniques;
   - Sinusoidal Pulse Width Modulation (SPWM)
   - Modified Pulse Width Modulation (MPWM)
   - Random Pulse Width Modulation(RPWM)
   - Third Harmonics Injection PWM (THIPWM)
   - Space Vector Modulation (SVM)
2) Carrier Less ModulationTechniques;
   - Delta Modulation(DM)
   - Specific Harmonics Elimination (SHE)
   - Wavelet Modulation (WM).

Hence, Reduction of Total Harmonics Distortion (THD) is the main objective in this research work, therefore THIPWM technique is adopted in this work and Presented with Nine Phase Inverter to drive Nine Phase Induction Motor. Control signals are generated with PWM and THISPWM modulating techniques for the Nine Phase Inverter drive using Matlab/Simulink.

II. PWM TECHNIQUES FOR INVERTER

The inverter is driven with Pulse Width Modulation (PWM) technique to obtain constant amplitude voltage by modulating the pulse width or duty cycle.

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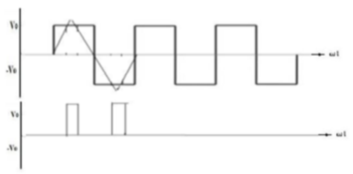
In this technique the control signals to the inverter switches are generated with pulse width modulated (PWM) signals. The amplitude of the generated pulse decides the modulation index. The presence of harmonics depends on selection of modulation index is as shown in Fig.1. (a) and (b).

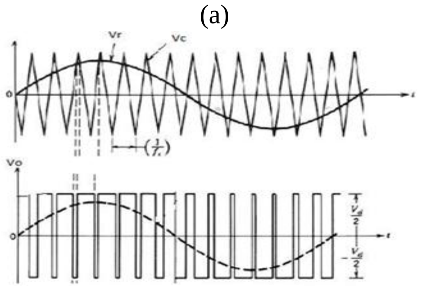
The PWM technique carried out by generating one output pulse per half cycle, the variable output voltage is obtained by varying the width of the pulses. The frequency of the two signals is nearly equal. PWM technique is carried out by using two types of signals, one is reference sinusoidal signal (fr) with fundamental frequency and the other is carrier triangular 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].

$$\text{Ma} = \frac{Vr}{Vc} \quad (1)$$

$$\text{fm} = \frac{fc}{fr} \quad (2)$$



(a)

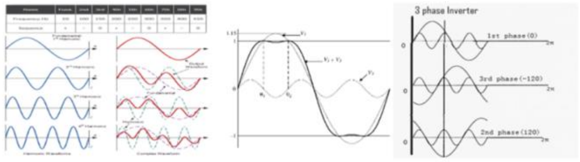


(b)

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

The third harmonic injection technique is as shown in Fig.2. (a), the 3rd order harmonic content refers to a harmonic content having frequency 3 times that of fundamental frequency i.e. for a 50 Hz supply 3rd order content is 3X50=150Hz and magnitude of the harmonics is 34.70% of the fundamental voltage/current is as shown in Fig.2.(c) The injected third harmonics component will not increase the harmonics distortion in the output voltage. Although it appears in the each of the inverter terminal voltages, the third harmonics voltage does not exist in the line to line voltage of three phase inverter because, the reference signal takes two maxima at t=π/3(60°) and t=2π/3(120°) equal to 1. [9-11].

The third Harmonics Injection Pulse Width Modulation (THIPWM) technique carried by injecting the 3rd harmonic sinusoidal signal(V3) to the sinusoidal reference signal(V1) is as shown in Fig.2 (b). where, amplitude of third harmonic signal is smaller than the first harmonic reference signal. which increase the voltage reference signal(V) frequency without causing over modulation. The Dr.amplitude of the third harmonic signal generated is equal to the amplitude of the first harmonic reference signal which make the output signal flattened on the top, as a result, the peak fundamental component can be higher than the peak triangular carrier which boosts the fundamental voltage level.



(a) (b) (c)

Fig.2. (a)Fundamental of 3rd harmonics (b)3rd harmonics injection (c) Each phase reference signal generation.

The first and third harmonic equations are given by;

V1=V1maxsint (3)

V3=V3maxsin3t (4)

Therefore;

When t=π/3, the first harmonics of the output (line to neutral) takes the value Vbus/2. By substituting in Equation [5],

Vbus/2 = V1maxsin (π/3) (5)

V1max= Vbus/1.732 (6)

For each phase reference, the third harmonics injected is equal to;

V (1st phase)=V1maxSin (wt) +V3maxsin (3wt) (7)

V(2nd phase)=V1maxSin (wt-2π/3) +V3maxsin (3wt) (8)

V(3rd phase)=V1maxSin (wt+2π/3) +V3maxsin (3wt) (9)

III. NINE PHASE INDUCTION MOTOR DRIVE

A nine phase induction motor has been constructed ,with the nine stator windings with phase shift by 40° is provided to inverter with short circuit dead time. Rotor windings are squirrel cage. The nine phase induction motor drive fed by nine phase inverters is as shown in Fig.4. There are nine push pull drives. Each drive is triggered by PWM signal. Thus, there are nine PWM control signals are generated with 40° out of phase with each other. The switches used in the 9-phase inverter conduct for a period of 1800. As shown in Fig.4. and Fig.5[9-11].

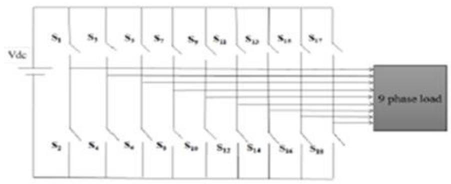


Fig.3. Topology of Nine Phase Induction Motor feed by Nine Phase Inverter

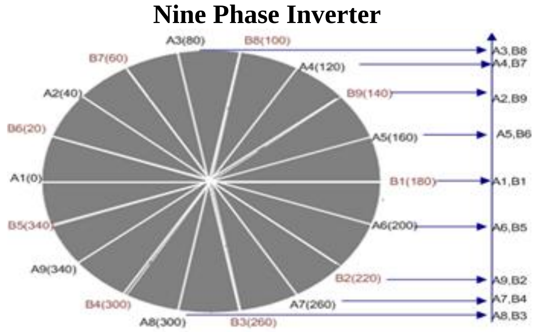


Fig.4. Switching Cycle of Inverter legs with 180⁰ Conduction mode

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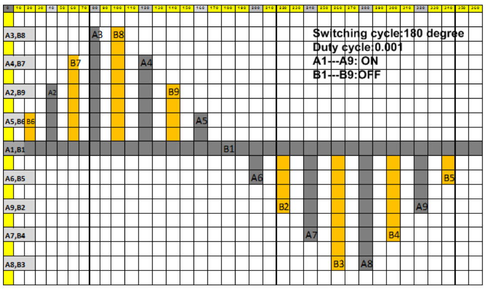


Fig.5. Switching Sequence of Inverter legs with 180$^{0.}$ Conduction mode

IV. NINE PHASE PWM INVERTERS

The Fig.6. 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 Induction Motor. IGBT's are used as a semiconductor switching devices. In PWM technique, gate of semiconductor device is controlled by PWM control signals [12-18].

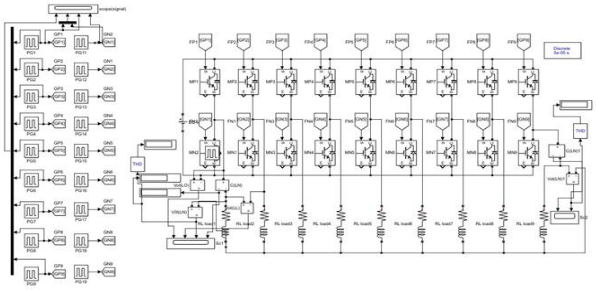


Fig.6. Construction of Nine Phase Inverter with PWM Technique

The Nine signals generated is applied to the 9-Phase inverter drive. 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.

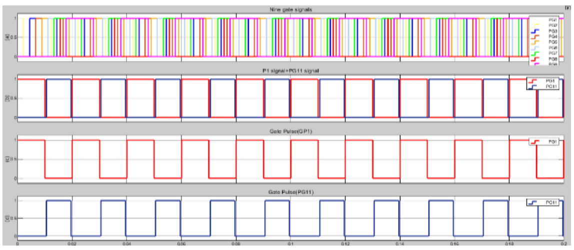


Fig.7. Nine phase PWM signal generation with square waveform

V. THIPWM TECHNIQUE FOR NINE PHASE INVERTERS

The complete setup of Third Harmonic Injection technique for Nine Phase Inverter is shown in Fig.8. A Nine phase inverter is design with Nine PWM control 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 PWM pulses for the inverter. The sinusoidal reference waveforms with triangular carrier waveforms are shown in Fig.1(b). The Nine phase consist of nine different positive and negative pulses which are provided to the Nine different legs of the switching devices.

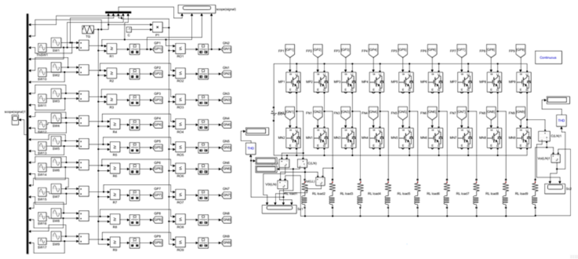


Fig.8.Construction of Nine Phase Inverter Drive with SPWM Technique

The Fig.9. shows the control signals for nine phase inverter Introducing third harmonic with PWM signals, the switches of the inverter are controlled by comparison of a sinusoidal modulating reference signal, triangular carrier signal and third harmonics modulating 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. The Fundamental frequency of 3rd harmonics is 150hz and signals are 40^{o} out of phase hence, all multiple 40^{o} phases of nine phase inverter are in phase with 3rd harmonics signal.

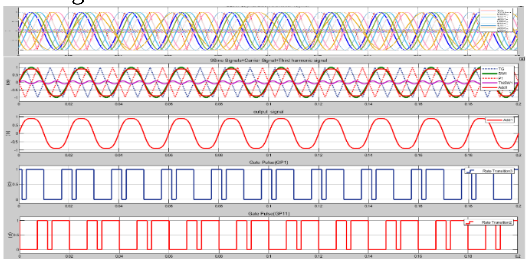


Fig.9. Nine phase THIPWM signal generation with sinusoidal and triangular waveform

VI. SIMULATION RESULTS

The results obtained using nine phase inverter drive with PWM and SPWM technique are as shown in Fig.10. and Fig.11. Waveforms are generated for line voltage and line current. Simulation work has been done for nine phase PWM drive and THIPWM inverter drive. The Nine Phase Inverter Drive is studied and simulated with RL load for rated frequency of 50Hz and dc voltage(Vdc) of 230v. Parameters used for the THIPWM Inverter are carrier triangular frequency(Fcr), Modulating frequency(Fm),3rd harmonics frequency(Fthi) 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.

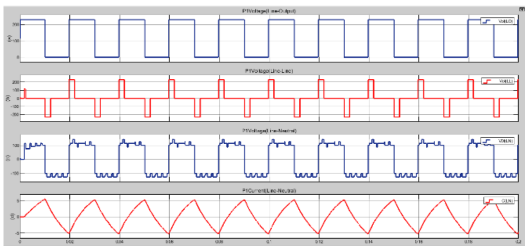


Fig.10.(a)Load-Output(b)Load-Load (c)Load-neutral Voltage and (d)Load-neutral Current waveforms with PWM Inverter

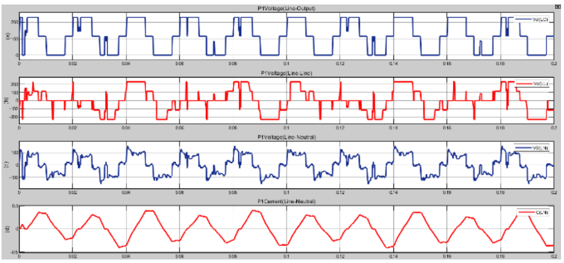
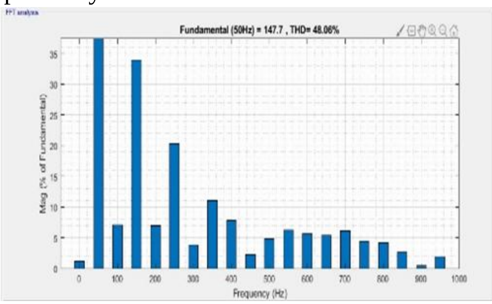
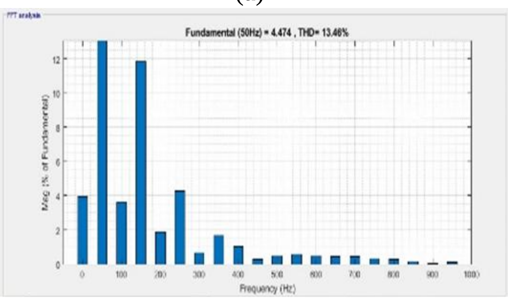


Fig.11. (a)Load-Output (b)Load-Load (c)Load-neutral Voltage and (d)Load-neutral Current waveforms with THIPWM Inverter

FFT analysis has been done to obtain voltage and current THD using Simulink and the results are compared with PWM and THIPWM inverter drive. Is as presented in Fig.12. and Fig.13. The FFT analysis has been done to Nine Phase Inverter drive with PWM and THIPWM Inverter Drive for 50Hz respectively.

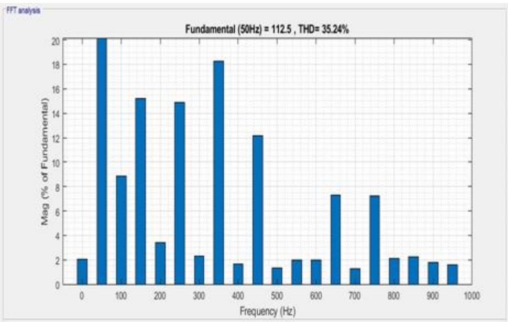


(a)

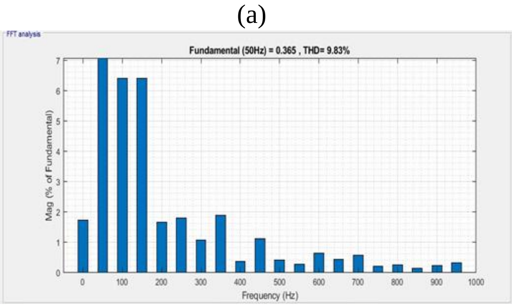


(b)

Fig.12.(a)v-THD(b)I-THD with PWM Inverter for 50 Hz



(a)



(b)

Fig.13.(a)V-THD (b)I-THD with THIPWM Inverter for 50 Hz

Table.1. shows the comparison of % of reduction in THD with PWM and THIPWM Inverter drive.

At fundamental frequency f= 50 Hz, V_{dc}= 230v, Fcr=100Hz, Fm=50Hz, m=1, F(thi)=150Hz THD% is as shown in table I.

Table I.Overall THD comparison with PWMandTHIPWM Inverter for frequency 50 Hz

Modes	V-THD %	I-THD%
PWM Inverter	48.06%	13.46%
THIPWM Inverter	35.24%	9.83%

VII. CONCLUSION

A nine phase Inverter drive is constructed using simulink/Matlab to study the harmonics and THD at the output of the inverter and compared the results obtained using PWM and THIPWM of Nine Phase Inverter Drive. It is observed that the percentage in THD at the output of the THIPWM inverter is found to be less than PWM Inverter Drive. Therefore, it is concluded that the reduction of harmonics is favor to reduce the heat produced due to motor loads used in the industry. The same work is extended to study the temperature analysis of Nine phase Induction motor.

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