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# EXPERIMENTAL ANALYSIS OF TOTAL HARMONIC DISTORTION BY APPLYING VARIOUS PWM TECHNIQUES ON THREE PHASE SQUIRREL CAGE MOTOR

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## Abstract

It has been found that by using Pulse with modulation technique can greatly reduce the harmonics distortions generated by the PV inverter. Harmonics reduction is the main consideration in three phase squirrel cage induction motor. We can improve the performance of the three phase squirrel cage Induction motor by the reduction of THD. In this research work, the harmonic distortion of the three phase induction motor was measured in terms of THD by Simulation model and the results of the Multiple Pulse With Modulation and Sinusoidal Pulse With Modulation inputs were compared to discover the lowest THD value. By using the PWM technique on the Three Phase Induction motor there was reduction in the VTHD by 6.98% and CTHD by 3.12% which in turn reduces the iron, winding and stray losses occurred in three phase squirrel cage induction motor.

**Keywords**: SPWM, MPWM, Simulink, Harmonics, Induction Motor

## 1. Introduction

In many Industrial applications, it is often required to control the output voltage of converters. The most efficient method of controlling the output voltage is to incorporate Pulse width Modulation (PWM) control within the inverters [1-3]. The commonly used techniques are Sinusoidal Pulse Width Modulation (SPWM) and Multi Pulse Width Modulation (MPWM). SPWM is commonly used in industrial application. In this scheme the width of each pulse is varied in proportion to the amplitude of a sine wave evaluated at the centre of same pulse [9-11]. The gating signals are generated by comparing a sinusoidal reference signal with a triangular carrier wave of frequency. The frequency of reference signal determines the inverter output frequency and its peak amplitude controls the modulation index, and then in turn the RMS output voltage [5-6]. The number of pulses per half-cycle depends on the carrier frequency [7-10]. In MPWM, The harmonic content can be reduced by using several pulses in each half cycle of output voltage. The gating signals are produced by comparing reference signal with triangular carrier wave [2-4]. The intersections between the reference voltage waveform and the carrier waveform give the opening and closing times of the switches.PWM is commonly used in applications like motor speed control, converters, audio amplifiers, etc. For example, it is used to reduce the total power delivered to a load without losses, which normally occurs when a power source is limited by a resistive element. PWM is used to adjust the voltage applied to the motor. Changing the duty ratio of the switches changes the speed of the motor. The longer the pulse is closed compared to the opened periods, the higher the power supplied to the load. The change of state between closing (ON) and opening (OFF) is rapid, so that the average power dissipation is very low compared to the power being delivered. Inverters are widely used in drives, UPS. This project presents a comparative study of performance between Sinusoidal Pulse Width Modulation (SPWM) and Multiple Pulse Width Modulation (MPWM) inputs. This technique has been designed and analysed using Mat lab Simulink model. The performance comparison are analysed in terms of THD and Fast Fourier Transformation (FFT).

## 2. Harmonic analysis

Harmonics are integral multiples of some fundamental frequency that, when added together, result in a distorted waveforms.

### *2.1 Sources of Harmonics*

The following sources create the harmonics in electrical circuits.

a. Adjustable speed drives
b. Power supplies
c. Electrical ballets
d. Uninterrupted power supplies
e. Arc Furnaces
f. Welding units and computers

### *2.2 Common Symptoms of Harmonics*

Due to harmonics the following symptoms are observed in electrical equipments.

a. Transformer heating
b. Motor and generator heating and vibrations
c. Neutral heating
d. Nuisance fuse operations
e. Insulation deterioration
f. Electronic control malfunctioning
g. Inconsistent meter reading
h. Voltage regulator mal operations

### *2.3 Total Harmonics Distortion*

The total harmonic distortion was a measurement of the harmonic distortion present and was defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. THD was used to characterize the linearity of audio systems and the power quality of electric power systems. In power systems, lower THD means reduction in peak currents, heating, emissions, and core loss in motors. Total harmonic distortion was measured as the percentage. Lower percentages were better. In reality, total harmonic distortion was hardly perceptible to the human ear.

### *2.4 Voltage THD*

Voltage distortion consists of very sharp notches and spikes in voltage. When applied to the equivalent circuit, that high frequency voltage does not cause much change in the inductive magnetizing current, but causes a change in the load current [8].

### *2.5 Current THD*

Current THD was caused by the motor itself due to non-linearity of the magnetizing current. The current THD will be higher when the motor was unloaded.

### *2.6 THD Analysis*

The THD was the means to express the distortion affecting a current or voltage flowing at a given point as a single number. THD analysis was done according to the standard IEC 61000-2-2.

### *2.7 IEEE 519-1992 Standards for Harmonics*

The following Table 1 and 2 shows IEEE 519-1992 standard for voltage and current THD.

**Table 1 IEEE 519-1992 Standard for Voltage THD**

| S.No | Maximum Harmonic Voltage Distortion | | |
|---|---|---|---|
| | Bus Voltage at PCC | Individual harmonic voltage distortion | Total Voltage Harmonic Distortion (THD) |
| 1 | $V \leq 69$ KV | 3.0 | 5.0 |
| 2 | 69 KV < $V \leq 161$ KV | 1.5 | 2.5 |
| 3 | V > 161 KV | 1.0 | 1.5 |

**Table 2 IEEE 519-1992 Standard for Current THD**

| S.No. | Maximum Harmonic current distortion in % of $I_L$ | | | | | |
|---|---|---|---|---|---|---|
| | $I_{SC} / I_L$ | <11 | 11≤h<17 | 17≤h23 | 23≤h<35 | TDD |
| 1 | <20 | 4.0 | 2.0 | 1.5 | 0.6 | 5.0 |
| 2 | 20 - 50 | 7.0 | 3.5 | 2.5 | 1.0 | 8.0 |
| 3 | 50 – 100 | 10.0 | 4.5 | 4.0 | 1.5 | 12.0 |
| 4 | 100 - 1000 | 12.0 | 5.0 | 5.0 | 2.0 | 15.0 |
| 5 | >1000 | 15.0 | 7.0 | 6.0 | 2.5 | 20.0 |

## 3. Proposed Work

In this research work THD was analyzed on three phase squirrel cage induction motor. Sinusoidal Pulse Width Modulation (SPWM) and Multi Pulse Width Modulation (MPWM) techniques are used to reduce the THD value produced in the Inverter circuit. The performance comparison are analysed in terms of THD and Fast Fourier Transformation. Here, the SPWM and MPWM techniques are analysed and the reduced THD values are discovered at SPWM technique.

## 4. Development of Inverter with Pulse Width Modulation Technique

The various methods of Pulse Width Modulation techniques are given below,

a. Delta Modulation PWM control
b. Delta-Sigma Modulation PWM control
c. Multiple Pulse Width Modulation (MPWM)
d. Sinusoidal Pulse Width Modulation (SPWM)
e. Third Harmonic Injection Pulse Width Modulation (THIPWM)
f. Space Vector Pulse Width Modulation (SVPWM)

The sinusoidal pulse-width modulation (SPWM) technique produces a sinusoidal waveform by filtering an output pulse waveform with varying width. A high switching frequency leads to a better filtered sinusoidal output waveform. The desired output voltage is achieved by varying the frequency and amplitude of a reference or modulating voltage. The variations in the amplitude and frequency of the reference voltage change the pulse-width patterns of the output voltage but keep the sinusoidal modulation.

The following Figure1 shows the simulation model of three phase Squirrel Cage Induction motor, in this the output from the Sinusoidal Pulse Width Modulation Inverter is given to the motor.

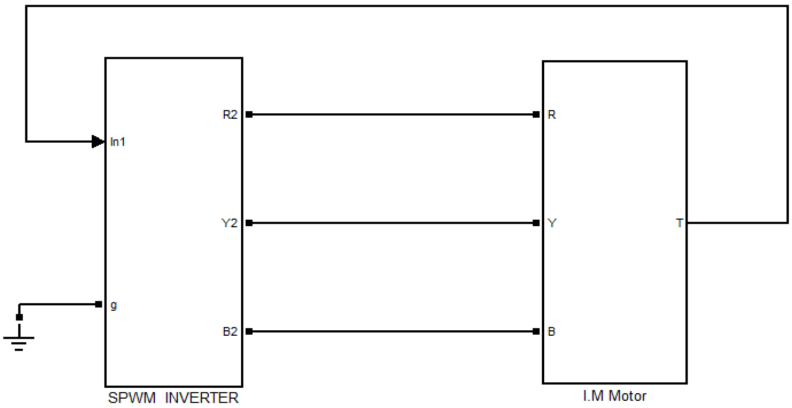


**Figure 1 Simulink model for SPWM technique**

The following Figure 2 shows the simulation model Inverter Circuit diagram. In this Inverter, unidirectional triangular carrier wave is compared with absolute value of reference sinusoidal wave. This output after comparison is then multiplied to 50% duty cycle signal.

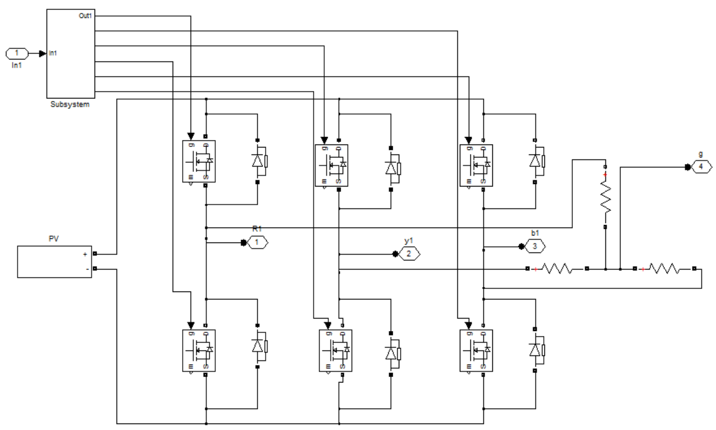

**Figure 2 Three Phase Sinusoidal PWM Inverter**

The following Figure 3 shows the simulation model of three Phase Squirrel Cage Induction motor. In the Inverter circuit diagram MOSFET are mainly used. The output from the inverter is given to the input of the motor.

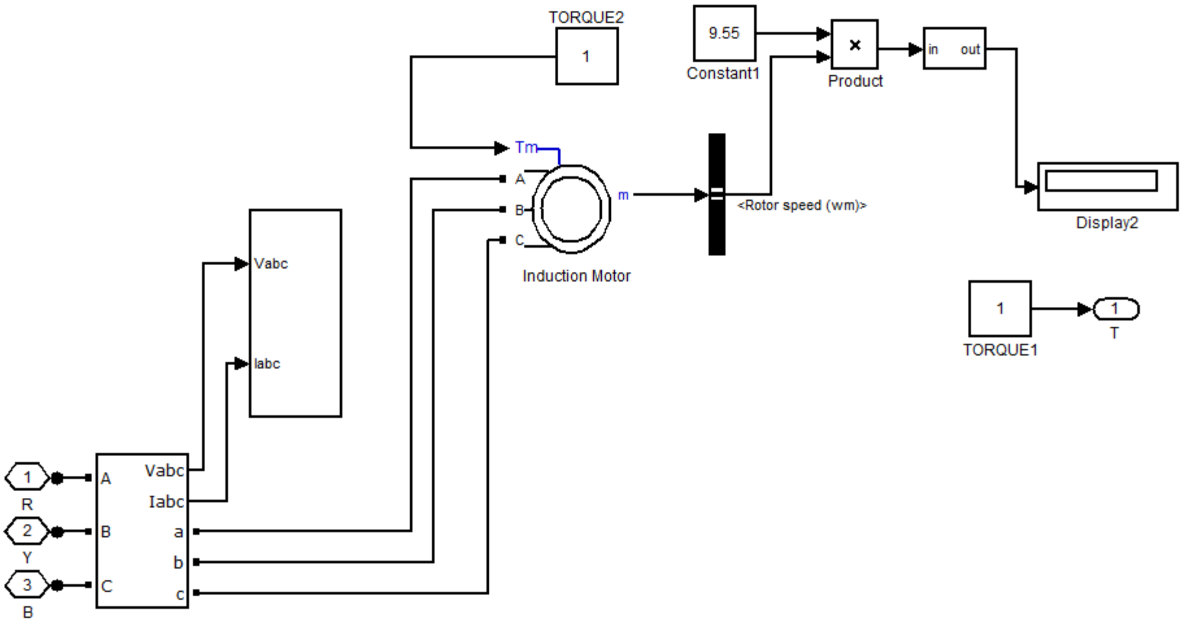


**Figure 3 Simulink model of three Phase Induction Motor**

## 5. Experimental Analysis of SPWM and MPWM Techniques

The frequency of reference signal determines the Inverter output frequency and its peak amplitude controls the modulation Index. The modulation Index value of the reference signal and frequency of the triangular carrier signal are varied to find out the different VTHD and CTHD values.

### *5.1 Multiple Pulse Width Modulation*

MPWM is used various applications. In this scheme the width of each pulse is varied in proportional to the amplitude of a square wave evaluated at the same pulse. The Ramp carrier signals are used in MPWM technique.

#### *5.1.1 Ramp carrier signal*

The following Table 3 shows the THD analysis of MPWM with Ramp carrier signal by applying various Modulation Index value and Frequency. The modulation Index value of the reference signal and frequency of the ramp carrier signal are varied to find out the different VTHD and CTHD values.

**Table 3 THD analysis of MPWM with Ramp carrier signal**

| Frequency | Modulation Index=0.9 | | Modulation Index=0.8 | | Modulation Index=0.7 | | Modulation Index=0.6 | | Modulation Index=0.5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | VTHD (%) | CTHD (%) | VTHD (%) | VTHD (%) | CTHD (%) | CTHD (%) | VTHD (%) | CTHD (%) | VTHD (%) | CTHD (%) |
| 500 | 40.33 | 80.23 | 48.54 | 95.08 | 55.44 | 86.65 | 68.02 | 112.41 | 84.78 | 132.05 |
| 1000 | 43.39 | 71.09 | 54.31 | 83.86 | 64.95 | 89.7 | 77.9 | 96.74 | 92.27 | 96.75 |
| 3000 | 31.2 | 74.51 | 31.38 | 72.27 | 31.59 | 69.51 | 31.24 | 73.19 | 32.04 | 68.38 |
| 5000 | 41.64 | 71.05 | 51.43 | 70.16 | 62.26 | 66.73 | 74.35 | 73.66 | 89.69 | 71.66 |
| 7000 | 31.50 | 74.03 | 31.69 | 71.11 | 31.50 | 66.78 | 32.71 | 67.95 | 33.46 | 70.46 |

The following Figure 4 shows the PWM pulse generation for MPWM with ramp carrier signal technique. Here, square reference signal and ramp carrier signal provides PWM pulses. Gate signal waveforms of MPWM with Ramp carrier signal technique are shown in Figure 5.

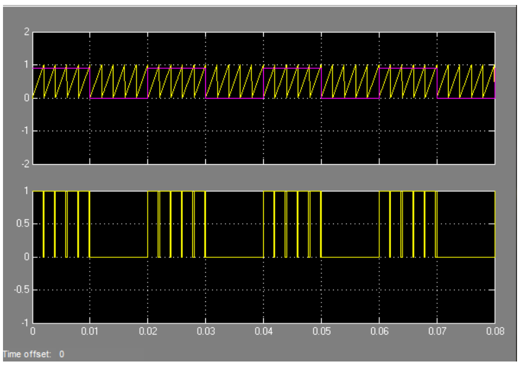

**Figure 4 PWM pulse generation for MPWM with Ramp carrier signal Technique**

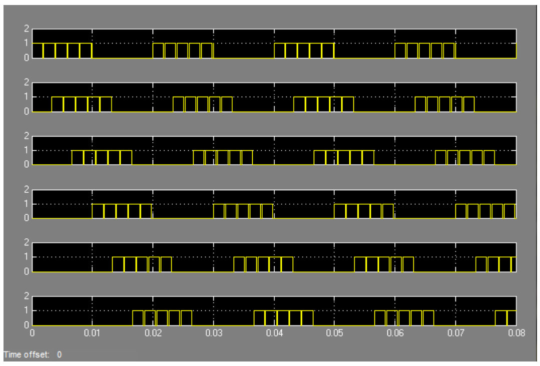

**Figure 5 Gate signal waveform of MPWM with Ramp carrier signal**

The following Figure 6 and 7 shows the voltage and current THD of the MPWM with Ramp carrier signal. The gating signals are generated by comparing a square reference signal with a ramp carrier wave of frequency. The frequency of reference signal determines the Inverter output frequency and its peak amplitude controls the modulation Index. The number of pulses per half cycle depends on the carrier frequency.

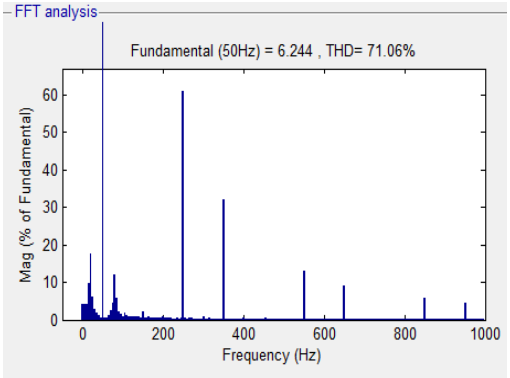


**Figure 6 Current THD - FFT analysis of the MPWM with ramp signal**

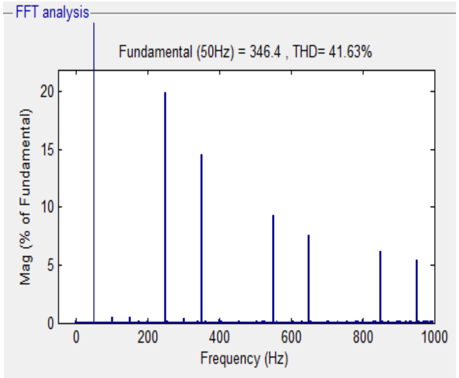


**Figure 7 Voltage THD - FFT analysis of the MPWM with Ramp signal**

### *5.2 Sinusoidal Pulse Width Modulation (SPWM)*

In this scheme the width of each pulse is varied in proportional to the amplitude of a sine wave evaluated at the centre of same pulse. The following two carrier signals are used in SPWM technique.

#### *5.2.1 Ramp carrier signal*

The following Table 4 shows the THD analysis of SPWM with Ramp carrier signal by applying various Modulation Index value and Frequency. The modulation Index value of the reference signal and frequency of the triangular carrier signal are varied to find out the different VTHD and CTHD values. The reduced THD values are observed at the frequency rate of 7000 Hz and value of modulation index is 1.

**Table 4 THD analysis of SPWM with Ramp carrier signal**

| Frequency | Modulation Index=1.0 | | Modulation Index=0.9 | | Modulation Index=0.8 | | Modulation Index=0.7 | | Modulation Index=0.6 | | Modulation Index=0.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | VTHD (%) | CTHD (%) | VTHD (%) | CTHD (%) | VTHD (%) | CTHD (%) | VTHD (%) | CTHD (%) | VTHD (%) | CTHD (%) | VTHD (%) | CTHD (%) |
| 500 | 40.06 | 49.85 | 45.78 | 67.75 | 55.71 | 76.47 | 67.28 | 73.87 | 79.45 | 98.09 | 92.59 | 90.25 |
| 1000 | 43.07 | 27.09 | 51.15 | 34.38 | 59.09 | 41.64 | 70.67 | 44.2 | 80.91 | 50.68 | 92.46 | 50.54 |
| 1500 | 24.91 | 11.93 | 36.9 | 17.59 | 49.48 | 23.67 | 62.59 | 31.33 | 75.64 | 38.47 | 90.16 | 39.09 |
| 2000 | 42.86 | 13.55 | 51.11 | 15.91 | 59.82 | 18.7 | 71.53 | 21.11 | 81.68 | 24.11 | 92.79 | 24.03 |
| 3000 | 14.14 | 3.94 | 20.87 | 5.42 | 29.23 | 7.27 | 37.42 | 9.7 | 45.27 | 11.47 | 52.38 | 11.64 |
| 4000 | 43.17 | 7.64 | 50.66 | 8.36 | 58.89 | 9.88 | 68.02 | 10.11 | 79.08 | 13.19 | 89.52 | 13.08 |
| 5000 | 41.52 | 5.79 | 49.94 | 6.67 | 59.32 | 7.86 | 71.27 | 9.3 | 82.31 | 11.38 | 92.85 | 10.72 |
| 6000 | 13.16 | 2.88 | 18.18 | 3.52 | 21.6 | 3.66 | 21.67 | 3.54 | 22.31 | 3.56 | 31.04 | 3.92 |
| 7000 | 6.79 | 3.12 | 8.37 | 5.37 | 9.42 | 2.96 | 10.94 | 3.49 | 13.25 | 3.95 | 16.1 | 7.28 |
| 8000 | 40.47 | 4.3 | 49.42 | 4.58 | 58.27 | 5.39 | 69.74 | 9.34 | 82.52 | 8.97 | 92.84 | 8.39 |

The following Figure 8 shows the PWM pulse generation for SPWM with Ramp carrier signal technique. Here, sinusoidal reference signal and ramp triangular carrier signal provides PWM pulses.  Figure 9 shows the gate signal waveform of SPWM with Ramp carrier signal technique.

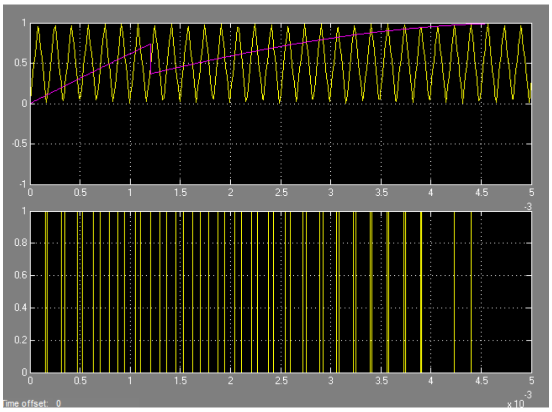

**Figure 8 PWM pulse generation for SPWM with Ramp carrier signal**

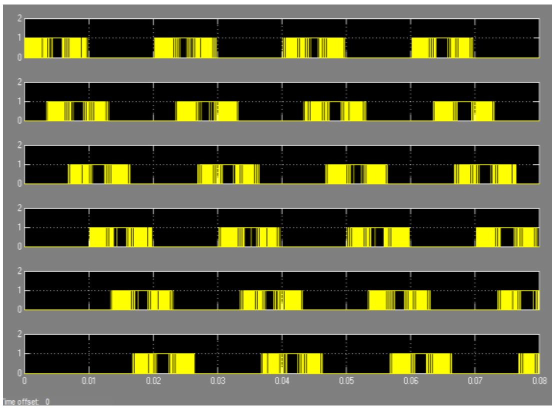

**Figure 9 Gate Signal waveform of SPWM with Ramp carrier Signal**

The following figure 10 and 11 shows the voltage and current THD of the SPWM with Ramp carrier signal. The gating signals are generated by comparing a sinusoidal reference signal with a ramp carrier wave of frequency. The frequency of reference signal determines the Inverter output frequency and its peak amplitude controls the modulation Index. The number of pulses per half cycle depends on the carrier frequency.

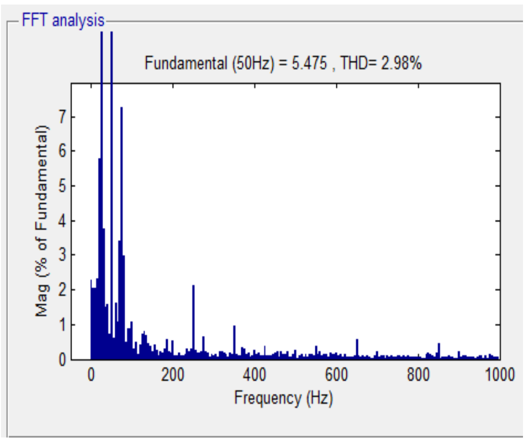


**Figure 10 Current THD - FFT analysis of the SPWM with Ramp signal**

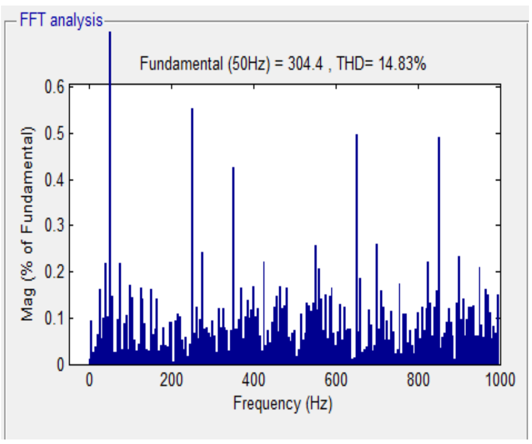


**Figure 11 Voltage THD-FFT Analysis of the SPWM with Ramp Signal**

### *5.2.2 Triangular carrier signal*

The following Table 5 shows the THD analysis of SPWM with triangular carrier signal by applying various Modulation Index value and Frequency. The modulation Index value of the reference signal and frequency of the triangular carrier signal are varied to find out the different VTHD and CTHD values. The reduced THD values are observed at the frequency rate of 7000 Hz and value of modulation index is 1.

**Table 5 THD analysis of SPWM with Triangular carrier signal**

| Frequency | Modulation Index=1.0 | | Modulation Index=0.9 | | Modulation Index=0.8 | | Modulation Index=0.7 | | Modulation Index=0.6 | | Modulation Index=0.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | VTHD (%) | CTHD (%) | VTHD (%) | CTHD (%) | VTHD (%) | CTHD (%) | VTHD (%) | CTHD (%) | VTHD (%) | CTHD (%) | VTHD (%) | CTHD (%) |
| 500 | 39.41 | 49.85 | 45.78 | 67.75 | 55.71 | 76.47 | 67.28 | 73.87 | 79.45 | 98.09 | 92.59 | 90.25 |
| 1000 | 43.07 | 27.09 | 51.15 | 34.38 | 59.09 | 41.64 | 70.67 | 44.2 | 80.91 | 50.68 | 92.46 | 50.54 |
| 1500 | 24.91 | 11.93 | 36.9 | 17.59 | 49.48 | 23.67 | 62.59 | 31.33 | 75.64 | 38.47 | 90.16 | 39.09 |
| 2000 | 42.86 | 13.55 | 51.11 | 15.91 | 59.82 | 18.7 | 71.53 | 21.11 | 81.68 | 24.11 | 92.79 | 24.03 |
| 3000 | 14.14 | 3.94 | 20.87 | 5.42 | 29.23 | 7.27 | 37.42 | 9.7 | 45.27 | 11.47 | 52.38 | 11.64 |
| 4000 | 43.17 | 7.64 | 50.66 | 8.36 | 58.89 | 9.88 | 68.02 | 10.11 | 79.08 | 13.19 | 89.52 | 13.08 |
| 5000 | 41.52 | 5.79 | 49.94 | 6.67 | 59.32 | 7.86 | 71.27 | 9.3 | 82.31 | 11.38 | 92.85 | 10.72 |
| 6000 | 13.16 | 2.88 | 18.18 | 3.52 | 21.6 | 3.66 | 21.67 | 3.54 | 22.31 | 3.56 | 31.04 | 3.92 |
| 7000 | 6.79 | 3.12 | 8.37 | 5.37 | 9.42 | 2.96 | 10.94 | 3.49 | 13.25 | 3.95 | 16.1 | 7.28 |
| 8000 | 40.47 | 4.3 | 49.42 | 4.58 | 58.27 | 5.39 | 69.74 | 9.34 | 82.52 | 8.97 | 92.84 | 8.39 |

The following Figure 12 shows the PWM pulse generation for SPWM with triangular carrier signal technique. Here, sinusoidal reference signal and triangular carrier signal provides PWM pulses. Figure 13 shows the gate signal waveform of SPWM with triangular carrier signal technique.

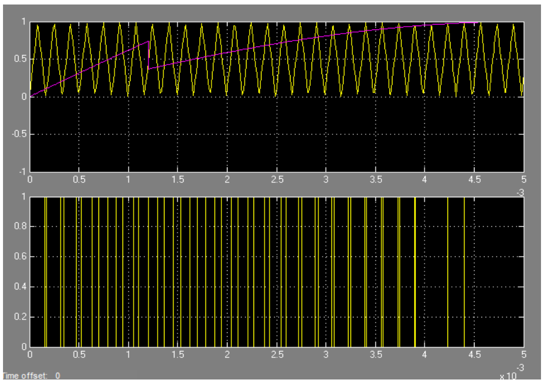

**Figure 12 SPWM pulse generation for SPWM with Triangular carrier signal**

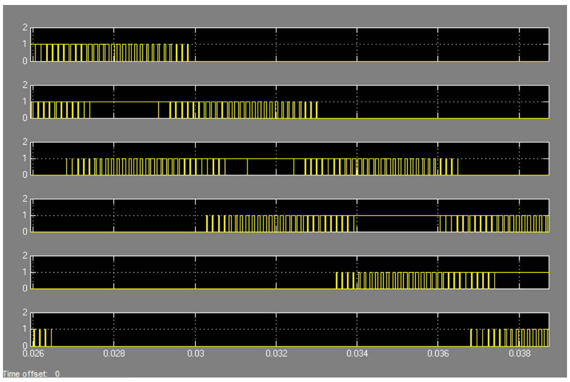

**Figure 13 Gate signal wave form of SPWM with with Triangular signal**

The following Figure 14 and 15 shows the measurement of Current THD and Voltage THD at Inverter.

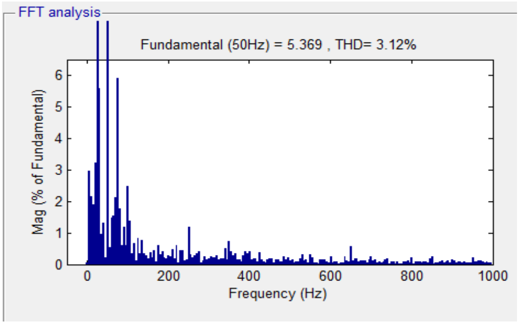


**Figure 14 Current THD - FFT analysis of the SPWM with Triangular carrier signal**

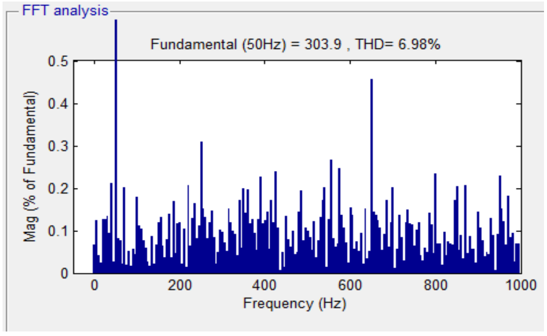


**Figure 15 Voltage THD – FFT analysis of the SPWM with Triangular carrier signal**

## 6. Acknowledgement

Thank God and His almighty power to finish His research work by using me, my friend and my Students for His ultimate work.

## 7. Conclusions

The following observations were clear as per this study:

There was reduction of VTHD by 6. 98% and CTHD by 3.12% by using Sinusoidal Pulse Width Modulation technique, which in turn reduces the iron, winding and stray losses occurred in three phase squirrel cage induction motor.

## REFERENCES

[1] Yang Du, Dylan Dah-Chuan Lu, Geoffery James, David J.Cornforth, "Modelling and analysis of Current harmonic distortion from grid connected PV inverters under different operating conditions", Elsevier Science direct, pp.183-194, 2013.

[2] Abeyasekera. T, Johnson.C.M, Atkinson D.J, Armstrong M, "Suppression of line voltage related distortion in current controlled grid connected inverters", IEEE Trans. Power Electron 20 (6), pp.1393- 1401, 2005.

[3] Armstrong. M, Atkinson. D.J, Johnson. C.M, Abeyasekera. T.D, " Loe order harmonic cancellation in a grid connected multiple inverter system via current control parameter randomation", IEEE Trans.Power Electron 20(4),pp. 885-892, 2005.

[4] Bennett. T, Zilouchian. A, Messenger. R, "Photovoltaic model and converter topology considerations for MPPT purposes", Solar Energy, 86(7), pp.2029-2040, 2010.

[5] Beser. E, Arifoglu. B, Camur. S, Beser. E.K, "A grid connected photovoltaic power conversion system with Single phase multilevel inverter" Solar Energy 84 (12), pp.2056–2067, 2010.

[6] Brinkman. G, Denholm. P, Drury. E, Margolis. R, Mowers. M, "Toward a solar powered grid", IEEE Power Energy Mag., 9 (3), pp.24–32, 2011.

[7] Chicco. G, Schlabbach. J, Spertino.F.,"Experimantal assessment of the waveform distortion in grid connected photovoltaic installation", Solar Energy 83 (7), pp.1026–1039, 2009.

[8] Lieutenant Ganesan. J, Jeyadevi.S. Dr, and Edison Selvaraj. D "Analysis of Harmonics and Electromagnetic Interference in Single Phase Induction Motor Coated with $Al_2O_3$ Nano filler Mixed Enamel" ACEEE Advances in Engineering and Technology Series Journal, pp.6-10, 2013.

[9] K.Gurumoorthy, D.Prince Winston and Lieutenant.J.Ganesan, "Reduction of Harmonic Distortion by applying various PWM and Neural Network Techniques in Grid connected Photovoltaic Systems" in

International Journal of Research in Computer Applications and Robotics, Vol.1,Issue 8, pp.25- 29, 2013.

[10] A.Mahendran, K.Muthulakshmi, D.Edison Selvaraj and Lieutenant.J.Ganesan, "Design and Implementation of a Fuzzy Logic Controller for Multilevel Inverter Topology" in International Journal of Research in Computer Applications and Robotics, Vol.1,Issue 9, pp.109-116, 2013.

[11] K.Gurumoorthy, D.Prince Winston, D.Edison Selvaraj and Lieutenant.J.Ganesan, "Reduction of Harmonic Distortion by applying various PWM and Neural Network Techniques in Grid connected Photovoltaic Systems " in International Journal Advanced Research in Electrical, Electronics and Instrumentation Engineering,Vol.2,Issue 12,pp.5892-5899, 2013.