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Performance Analysis of Induction Motor Using Different Pulse Width Modulation Techniques

Swapnik Goud M[1], N Madhuri[2], Kumbam Karthikeyan[3] and Shaik Maheboob[4]

[1] UG Scholar, Department of EEE, Mahatma Gandhi Institute of Technology, Hyderabad, Telangana, India, 500075
[2] Assistant Professor, Department of EEE, Mahatma Gandhi Institute of Technology, Hyderabad, Telangana, India, 500075
[3] UG Scholar, Department of EEE, Mahatma Gandhi Institute of Technology, Hyderabad, Telangana, India, 500075
[4] UG Scholar, Department of EEE, Mahatma Gandhi Institute of Technology, Hyderabad, Telangana, India, 500075

Abstract

Inverters have been most widely used in the field of Power Electronics for different applications. But these inverters have harmonics existence in the output voltage and it led to many research works being conducted. Different topologies were applied to mitigate this inverter drawback, thus improving the efficiency of the inverter. Induction Motors having almost 80% of the industrial share have wider application in the field of Engineering, so if we could incorporate any control strategies for induction motors, we can achieve a full utilization of this Machine. Sinusoidal Pulse Width Modulation (SPWM), Third harmonic injection Pulse Width Modulation (THIPWM) and Modified Sinusoidal Pulse Width Modulation (MSPWM) techniques are applied to the inverter and output is given to the Induction Motor with open loop control has been discussed and implemented in MATLAB/Simulink software.
The objective of this paper is to compare Sinusoidal Pulse Width Modulation(SPWM), Third Harmonic Injection Pulse Width Modulation(THIPWM) and Modified Sinusoidal Pulse Width Modulation(MSPWM) Techniques taking Total Harmonic Distortion(THD) and Performance of Induction Motor (speed, torque) as main parameters. To Simulate the circuit in MATLAB/ Simulink software and tabulate the results. To get a fair idea about different Pulse Width Modulation Techniques and how they work with inverter in producing required output which can be given to any load like induction motor. To incorporate Sinusoidal, Third Harmonic Injection and Modified Sinusoidal Pulse Width Modulation Techniques to a Three Phase Inverter and compare them based on the performance of induction motor which acts as load and THD produced in the inverter output voltage.

Keywords: *Sinusoidal Pulse Width Modulation(SPWM), Third Harmonic Injection Pulse Width Modulation(THIPWM), Modified Sinusoidal Pulse Width Modulation (MSPWM), Speed, Torque, Total Harmonic Distortion (THD), MATLAB.*

1. Introduction

In Power Electronics, especially for inverters, we need to employ different control strategies to control the output AC voltage [2]. This control can be achieved through two modes namely external control and internal control [10]. The external control strategies include the connection of phase controlled rectifiers, AC voltage controllers, choppers etc. But due to this external circuits the overall network becomes bulky and costly, So to avoid this we implement the internal control strategy called the Pulse-Width Modulation (PWM) control/Technique [10].
Pulse Width Modulation is the core for control and has proven effective in driving modern semiconductor power devices. Majority of power electronic circuits are controlled by PWM signals of various forms. Pulse Width Modulation is effective and commonly used as control technique to generate analog signals from a digital device like a micro controller. This Paper will discuss the implementation of different pulse width modulation techniques to a three phase inverter whose output is given to Induction Motor. These PWM techniques are compared base on the two parameters:

1.) Total Harmonic Distortion (THD) in the output voltage of the inverter [1] and
2.) Performance of Induction Motor (Speed, Torque) [9]

Total Harmonic Distortion is a measure of closeness in a shape between the output voltage waveform and it's fundamental component. It is defined as the ratio of RMS value of it's total harmonic component of the output voltage and the RMS value of the fundamental component [8] [10] . It is the total harmonic content present in the output voltage which results in the distortion of the waveform.

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2.Pulse Width Modulation(PWM)

Pulse Width Modulation is the internal control Technique applied for Inverters and it is the most efficient method by which we can control the output voltage of the Inverter [10]. In any Pulse Width Modulation technique applied to an inverter, the reference wave and carrier wave are compared and gate pulses are generated for different switches used in the inverter. This Paper will discuss the following three Pulse Width Modulation(PWM) Techniques applied to three phase inverter [8] [10].

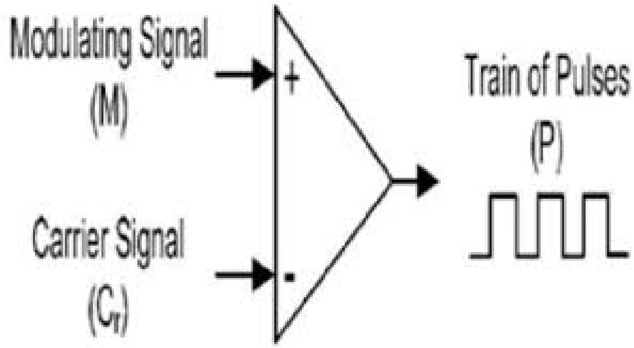

Figure 1: Principle of Pulse Width Modulation [1]

2.1 Sinusoidal Pulse Width Modulation (SPWM)

In Sinusoidal Pulse Width Modulation the reference signal is Sine wave and carrier signal is Triangular wave, whenever the magnitude of reference signal is greater than the magnitude of carrier signal the pulses are generated [1] [4] [7] [8] & [10]. The overall magnitude of carrier signal should be greater than that of reference signal so the modulation index lies below 1 [10].

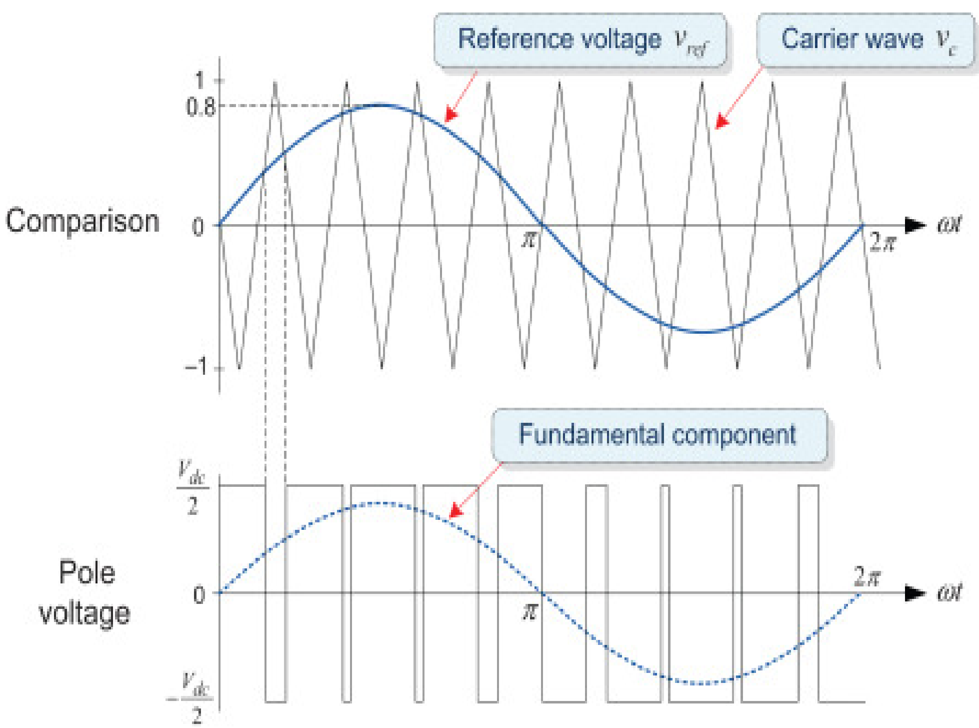

Figure 2: Gate Signal Generation in Sinusoidal Pulse Width Modulation

The RMS output voltage is given by the following equation

$$V_0 = \left(\sum_{m=1}^{2P} \frac{\delta_m}{\pi}\right)^{1/2}$$ ……………………………………………………………………………………Eq 1 [10]

where δ_m is the pulse angle and p is the number of pulses
Fourier coefficient of output voltage is given as

$$B_n = \sum_{m=1}^{2p} \frac{4V_s}{n\pi} \sin n\frac{\delta_m}{2}\left[\sin n\left(\alpha_m + \frac{\delta m}{2}\right)\right]$$ ……………………..……………………………………………………Eq 2 [10]

For n=1,3,5…………∞
This type of modulation eliminates all harmonics less than or equal to 2p - 1.

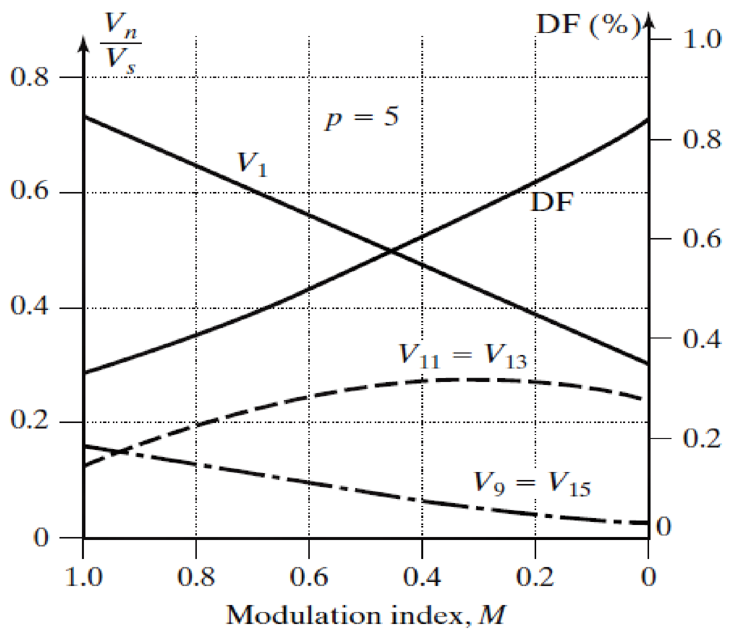

Figure 3: Harmonic profile of sine Pulse Width Modulation [10]

2.2 Third Harmonic Injection Pulse Width Modulation (THIPWM)

In THIPWM the reference signal is the combination of Sine wave and its third harmonic [8] and Carrier signal is triangular wave. These two signals are compared and when the magnitude of reference signal is greater than the magnitude of carrier signal the gate pulses are generated for different switches. The fundamental component of sine wave is $V_1 = V_{1m}$Sinwt and its third harmonic is $V_3 = V_{3m}$Sin3wt, these two are combined to form the reference signal. So for 3 phases the following equations represents the reference signal [1] [8]

V_{1m}Sin(wt) +V_{3m}Sin (3wt) ………………………………………………………………………………………Eq3

V_{1m}Sin(wt-2π/3) +V_{3m}Sin(3wt) ………………………………………………………………………….Eq4

V_{1m}Sin(wt+2π/3) +V_{3m}Sin(3wt)……………………………………………………………………………….Eq5

The sinusoidal PWM is the simplest modulation scheme to understand but it does not fully utilize the available DC bus supply voltage. Due to this problem, the third-harmonic injection pulse-width modulation (THIPWM) technique was developed to improve the inverter performance.

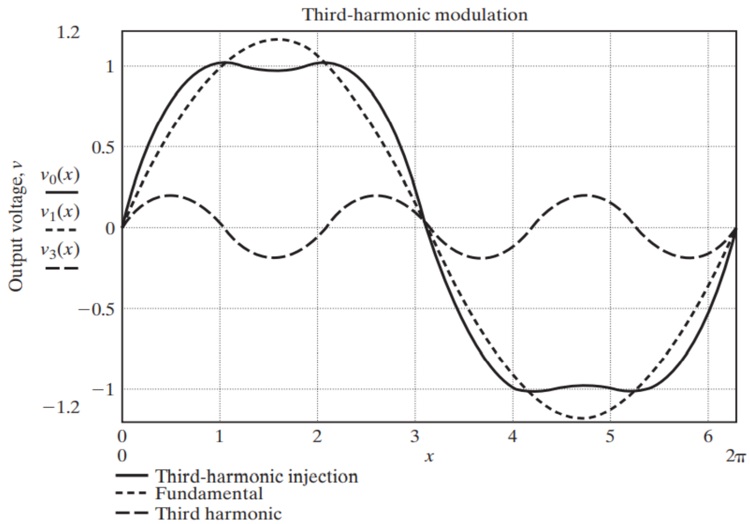

Figure 4: Third Harmonic Modulation

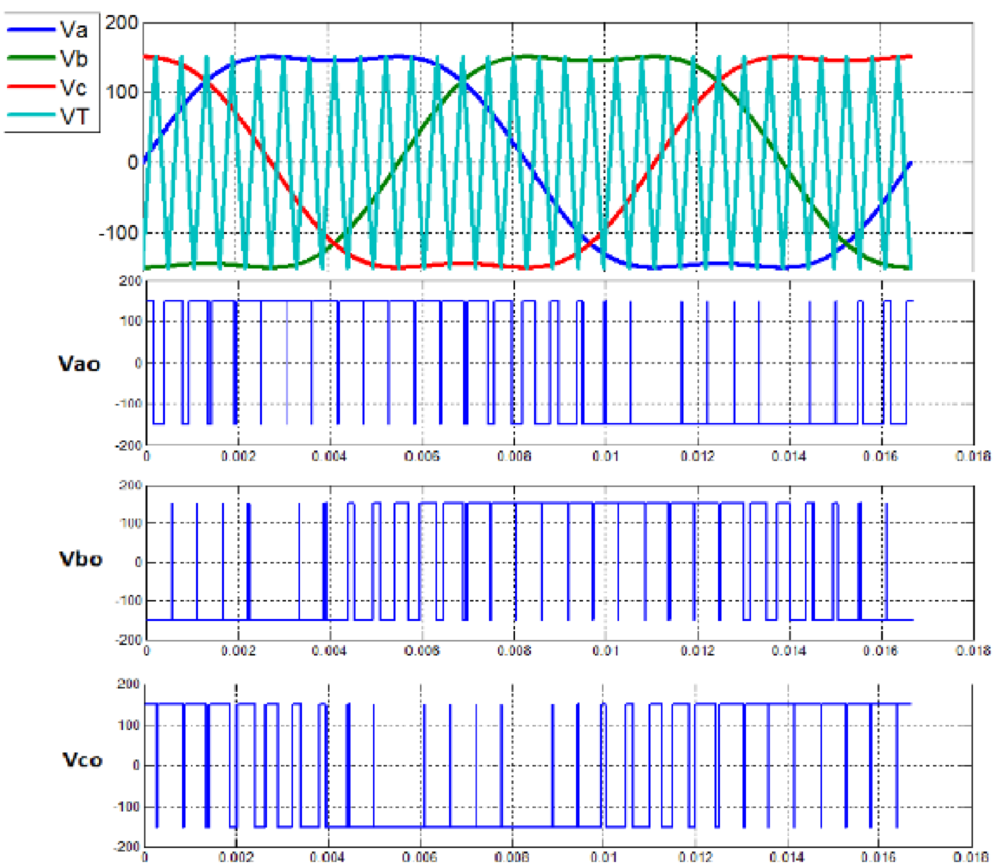

Figure 5: Gate Signal generation in Third Harmonic Injection Pulse Width Modulation

2.3 Modified Sinusoidal Pulse Width Modulation (MSPWM)

In Modified Sinusoidal Pulse Width Modulation the reference signal and carrier signal are same as SPWM but in MSPWM the reference and carrier signals are compared on for first 60^0 and last 60^0 of every half cycle [1] and gate signals are generated using same logic accordingly [1] [8] [3].

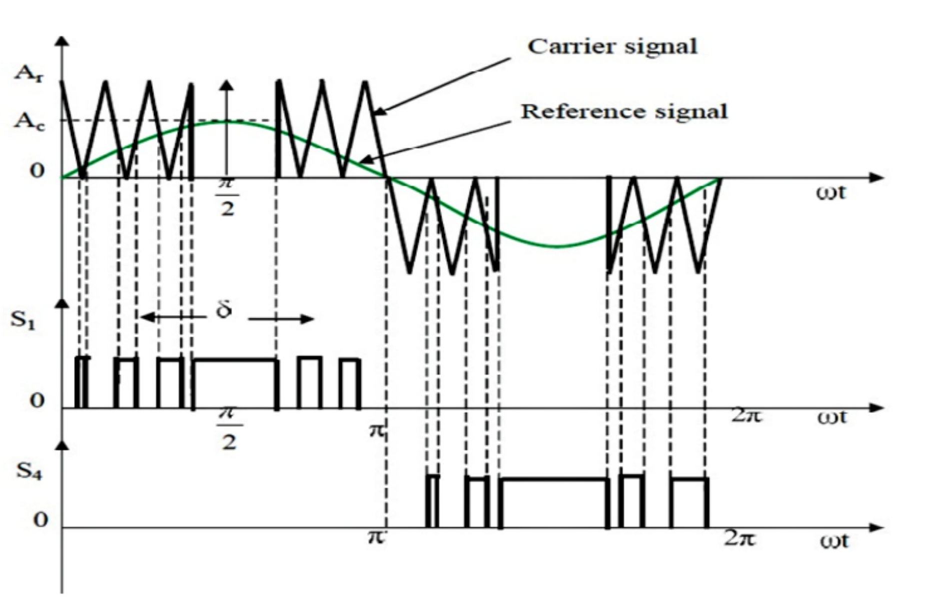

Figure 6: Gate signal generation using Modified Sinusoidal Pulse Width Modulation [1]

3. Block Diagram

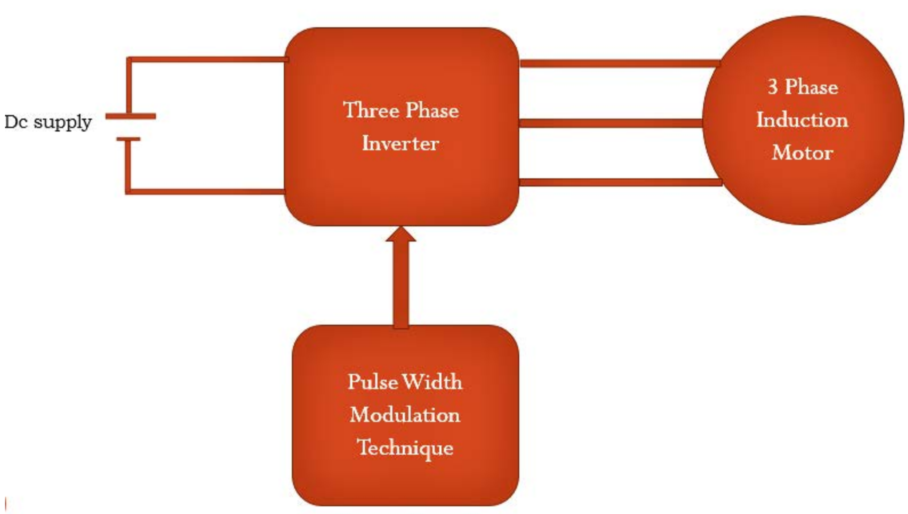

Figure 7: Block Diagram

As shown in figure 7 dc supply is given to the three phase inverter and the output voltage of the inverter is given to three phase induction motor. Open loop control technique is applied as Pulse Width Modulation (PWM) to the three phase inverter thus controlling the output voltage of inverter in turn the motor performance (Speed, Torque) [9].

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4. Implementation and Results

The Model building and simulation of results are done in MATLAB / Simulink software.

4.1 Implementation

All the models are built in Simulink Software as shown in below figures. In all those figures the left most part represents logic part and right part represents the three phase inverter and induction motor. For logic implementation reference signal, carrier signal, relational block, logic gates, from and goto blocks are used. Comparison is done with relational operator, when the magnitude of reference signal is greater than carrier signal then the gate signal is given to positive group of switches and when the condition is opposite the signal is given to negative group of switches through NOT gate.

Motor Rating :- 5HP, 4KW, 400V, 1430RPM.

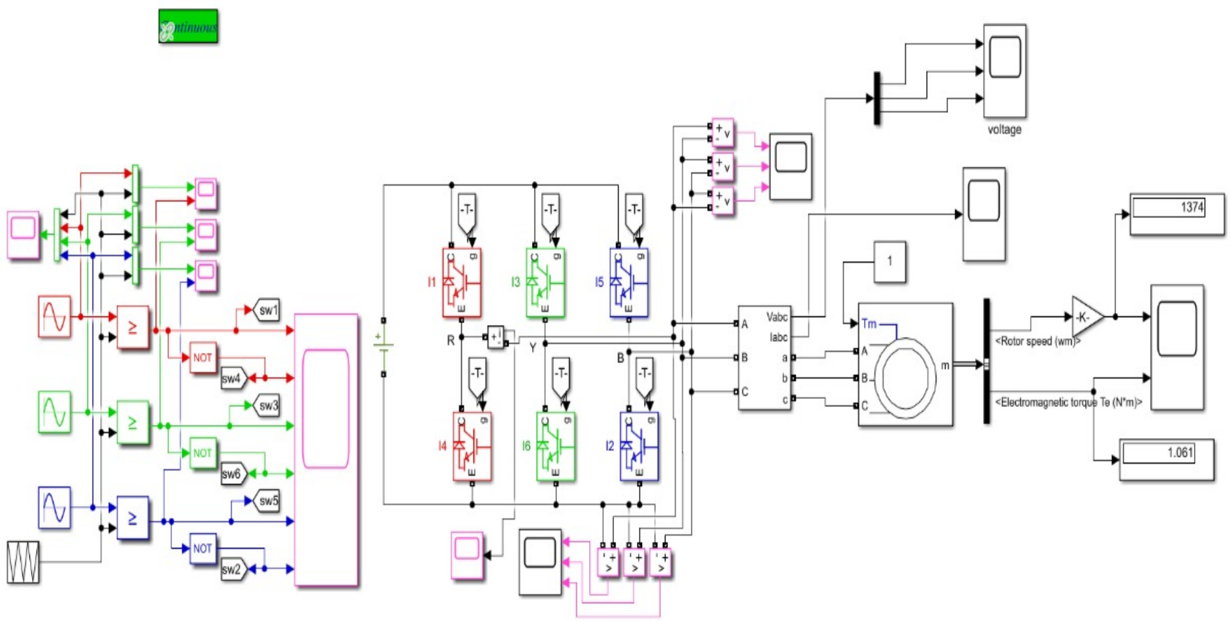

Figure 8: MATLAB / Simulink model of Sinusoidal Pulse Width Modulation

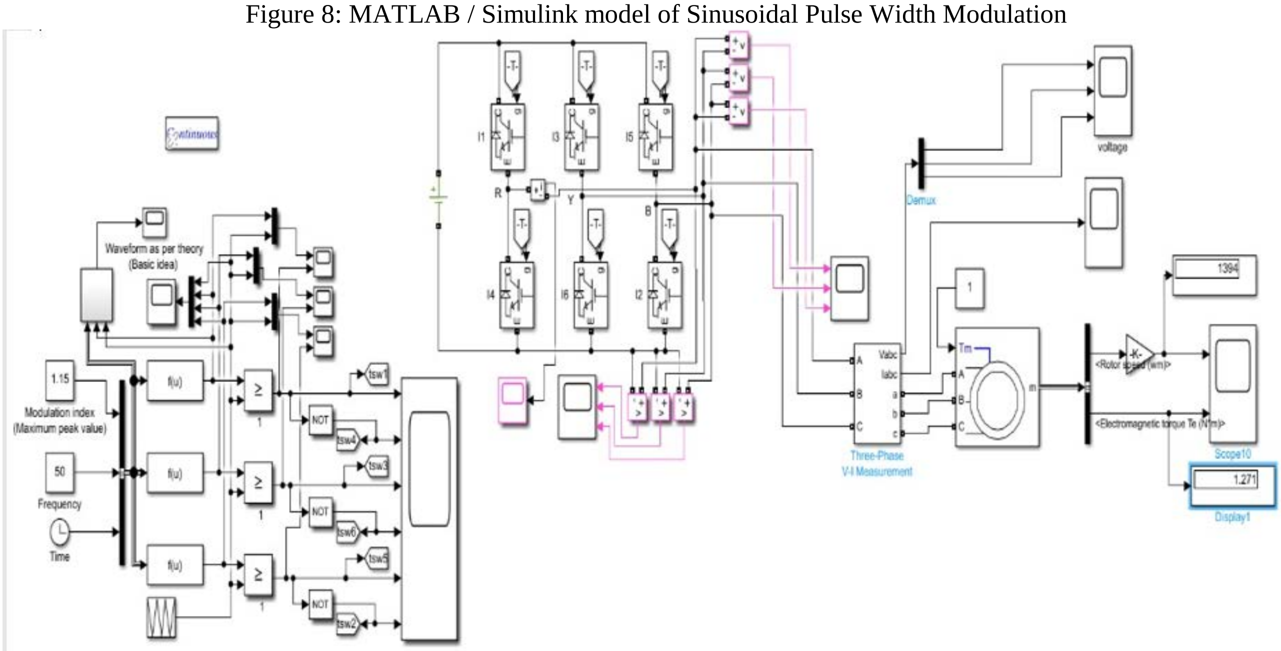

Figure 9 :- MATLAB / Simulink model of Third Harmonic Injection Pulse Width Pulse Width Modulation

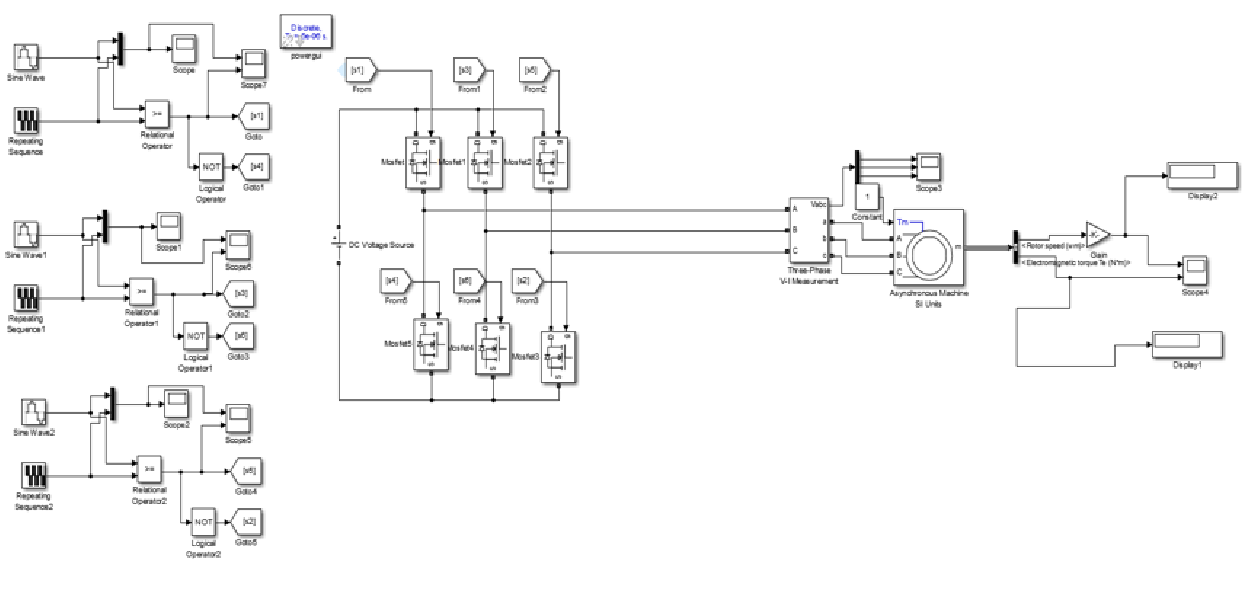

Figure 10 :- MATLAB / Simulink model of Modified Sinusoidal Pulse Width Pulse Width Modulation

4.2 Results

Scope from Simulink Library is used for observing the output waveforms where we get to see the magnitude of parameter with respect to time. The main parameters that is Speed and Torque of induction motor are observed in scope with respect to time. Total Harmonic Distortion(THD) [1] [8] [10]is calculated using FFT analysis [8] [10] tool from Powergui block in Simulink.

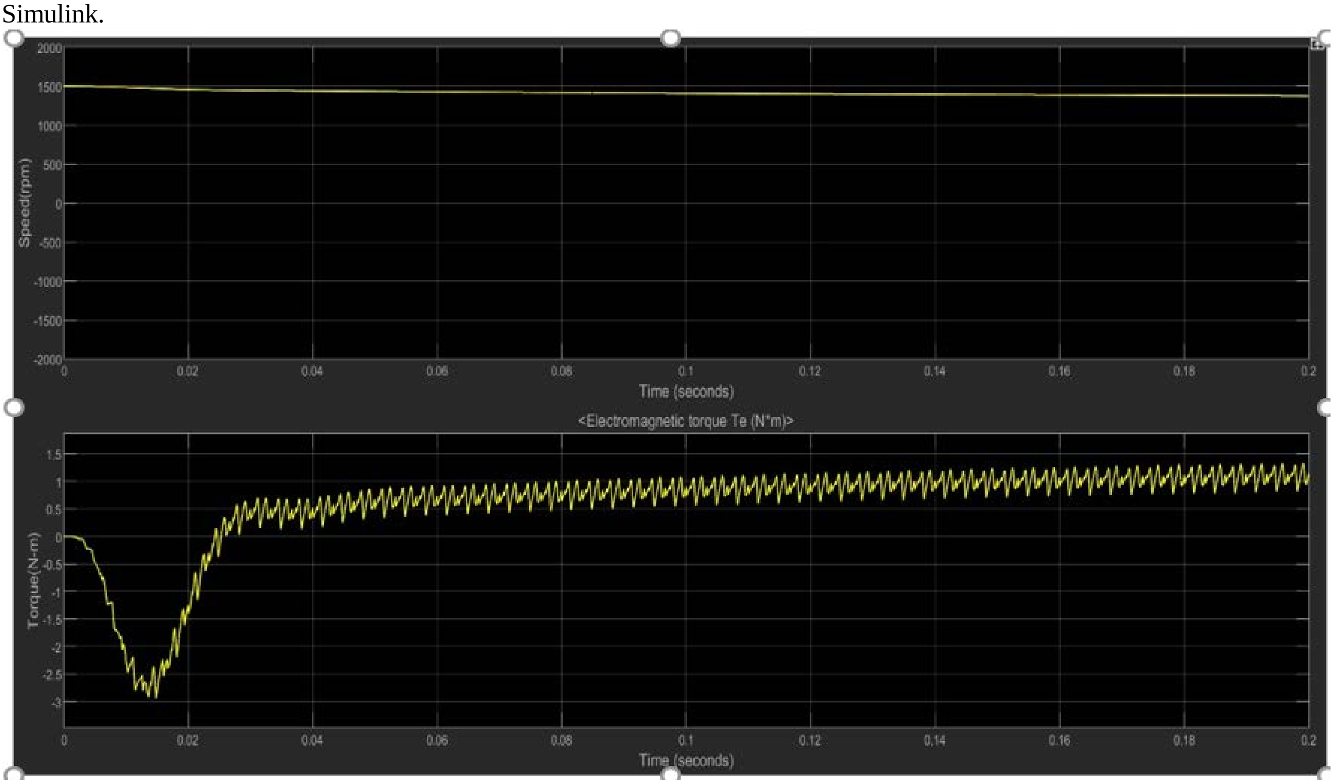

Figure 11:- Motor Performance with Sinusoidal Pulse Width Modulation

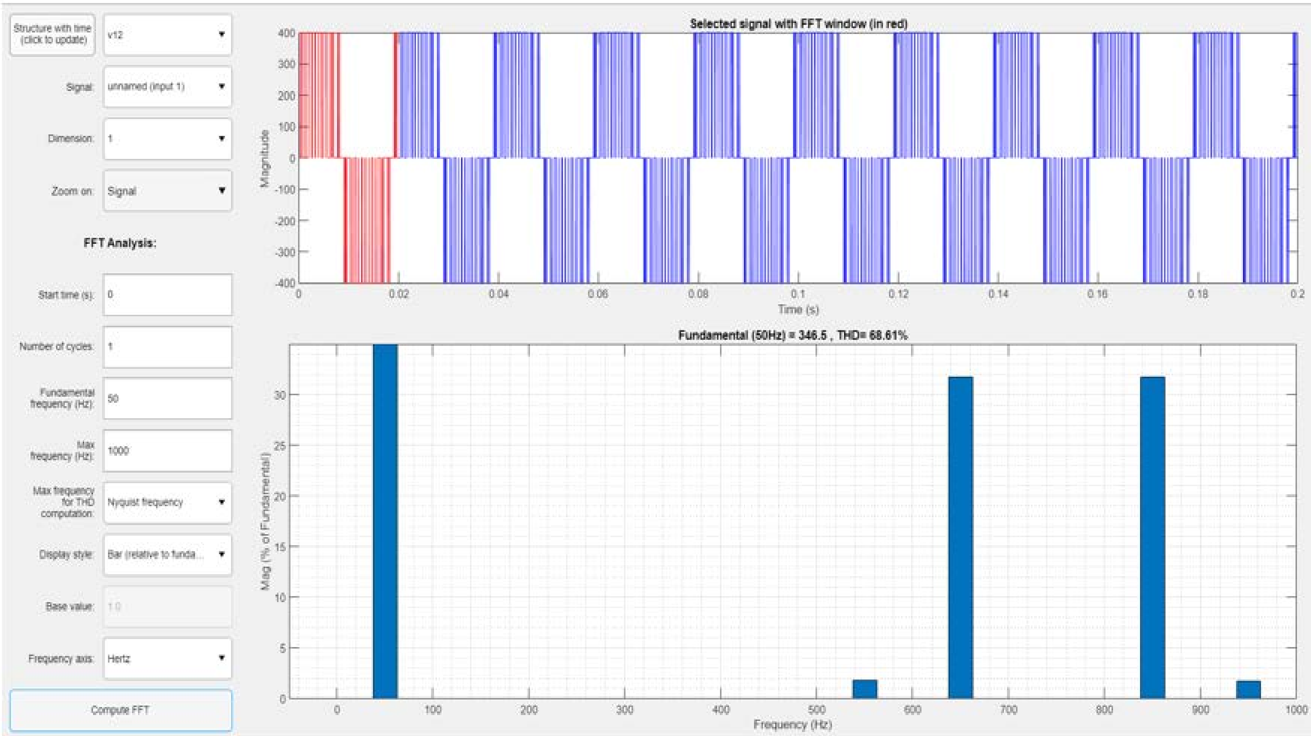

Figure 12:- Total Harmonic Distortion in output voltage of Inverter with Sinusoidal Pulse Width Modulation

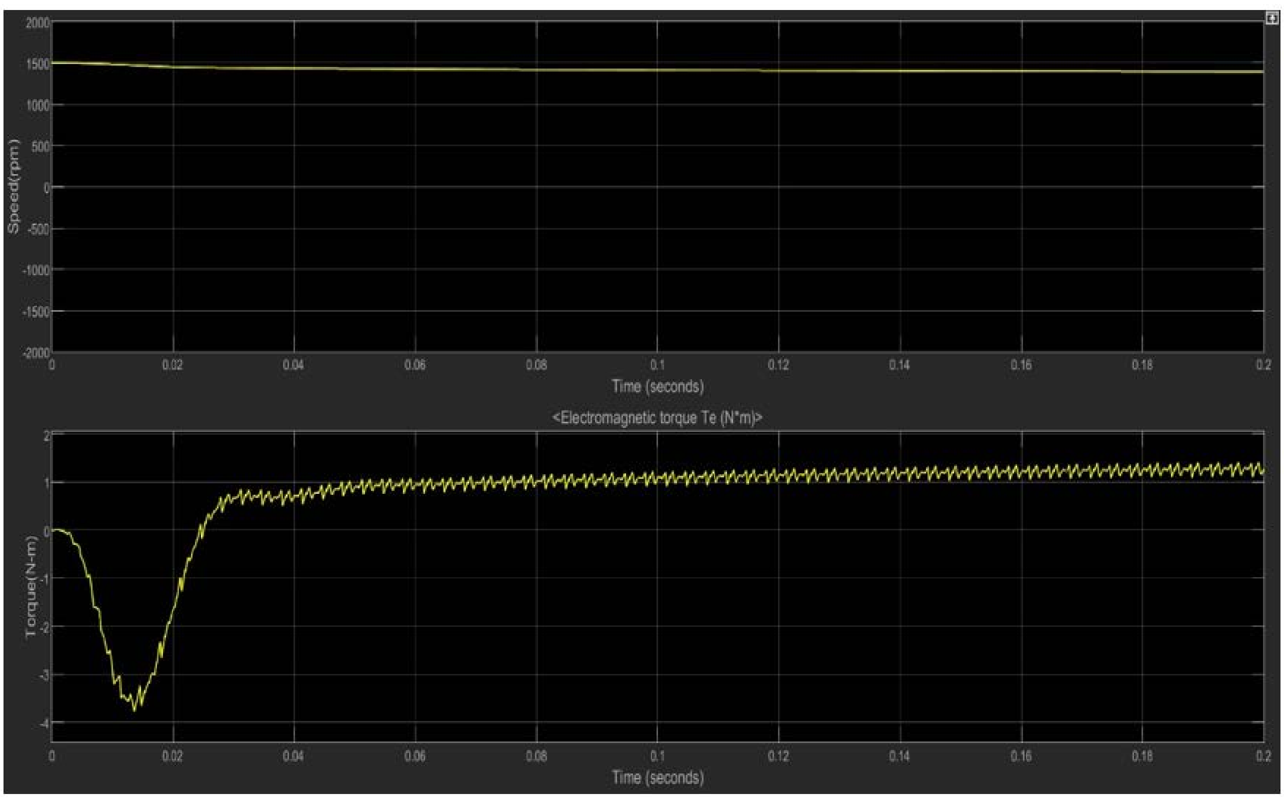

Figure 13:- Motor Performance with Third Harmonic Injection Pulse Width Modulation

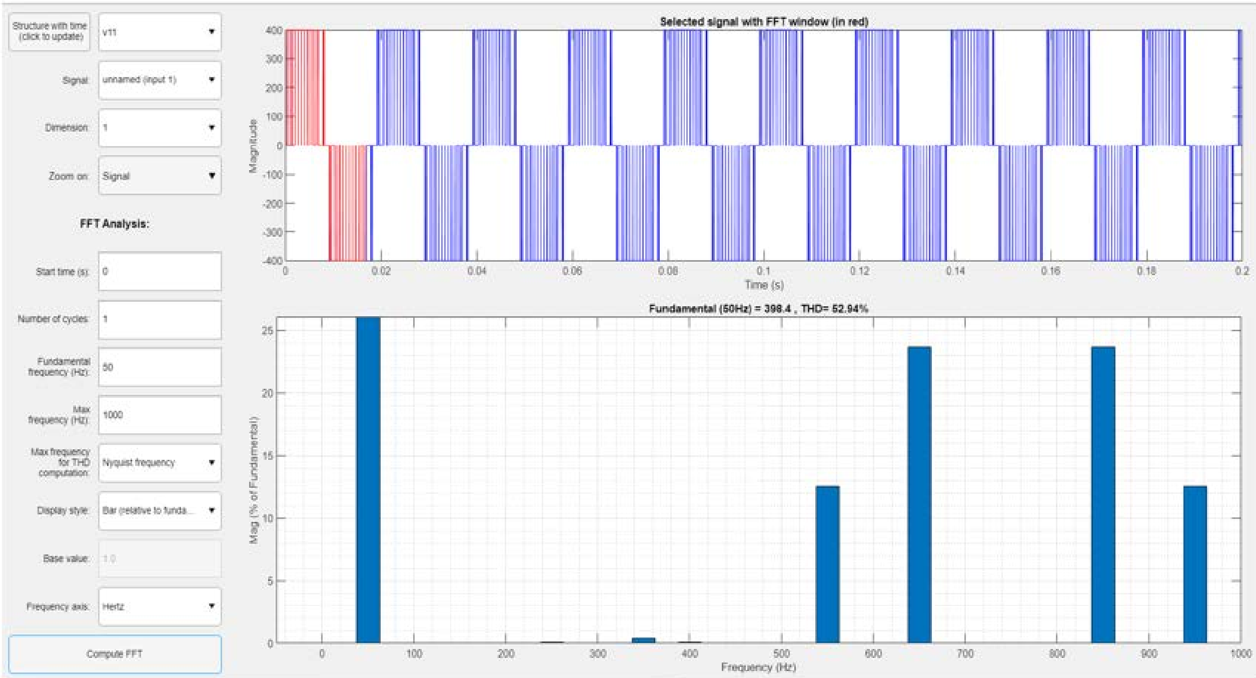

Figure 14:- Total Harmonic Distortion in inverter output voltage with Third Harmonic Injection Pulse Width Modulation

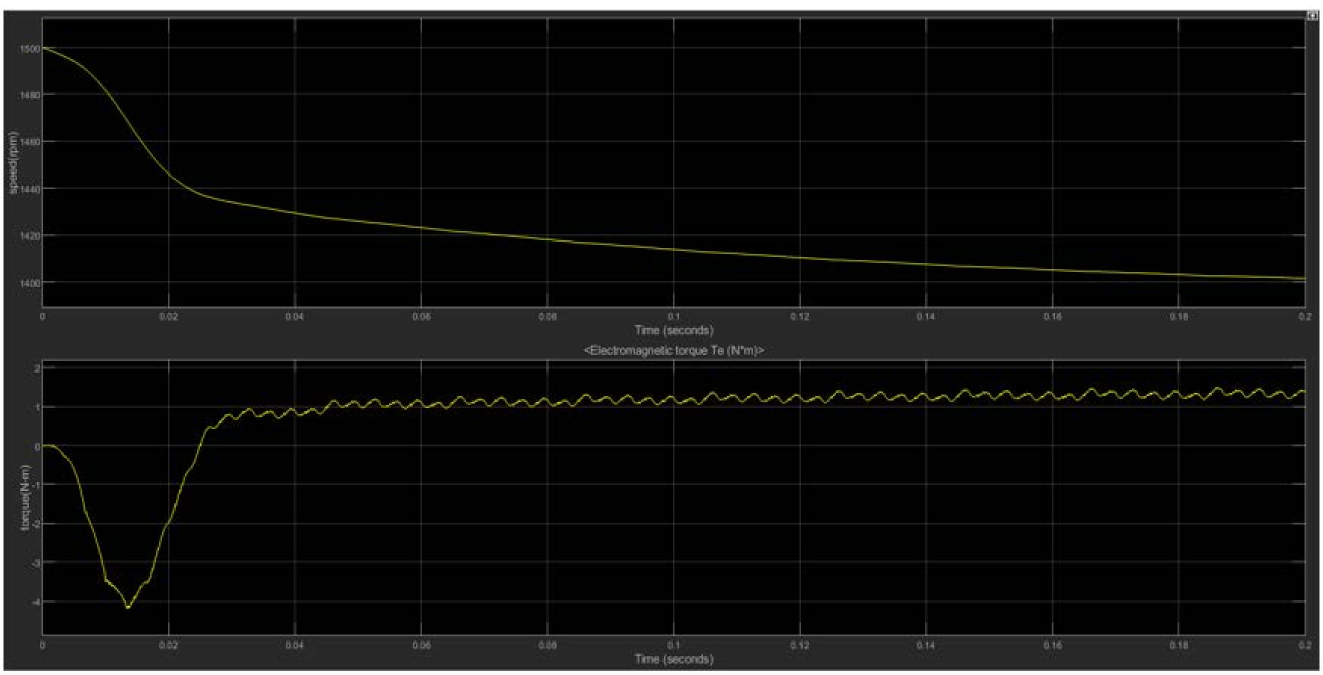

Figure 15:- Motor Performance with Modified Sinusoidal Pulse Width Modulation

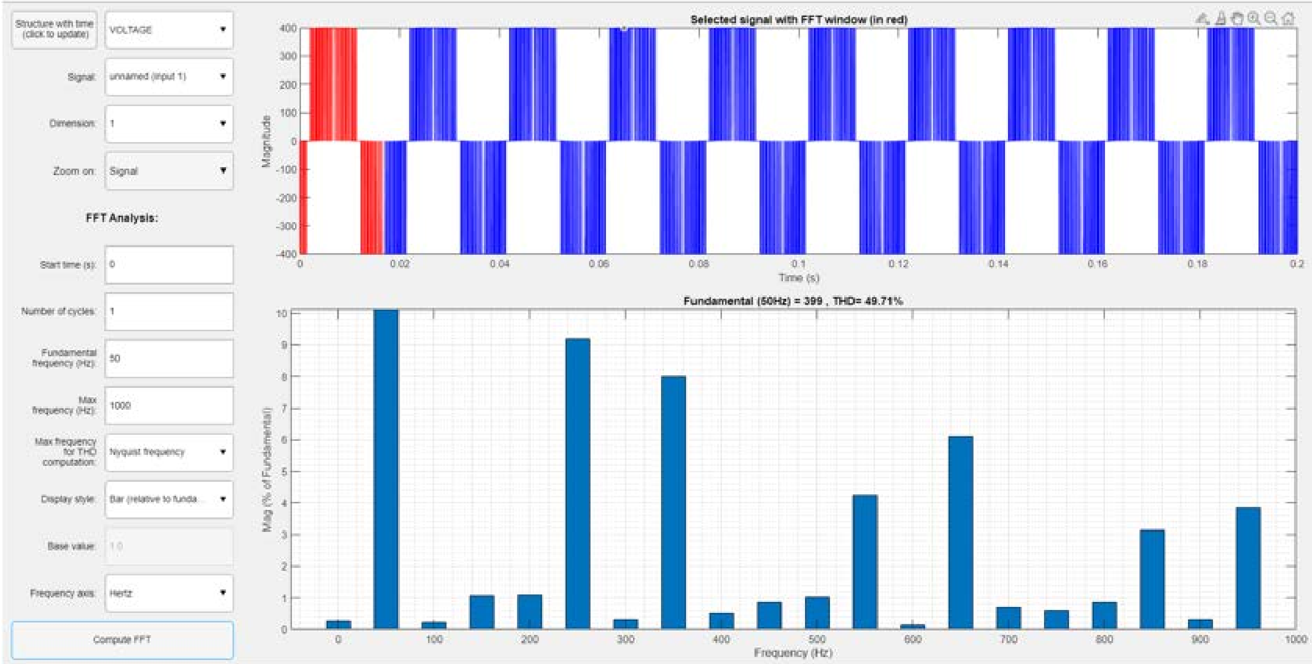

Figure 16:- Total Harmonic Distortion in inverter output voltage with Modified Sinusoidal Pulse Width Modulation

5.Conclusion

PWM TECHNIQUE	TOTAL HARMONIC DISTORTION(%)
Modified Sinusoidal Pulse Width Modulation(MSPWM)	49.71
Third Harmonic Injection Pulse Width Modulation(THIPWM)	52.94
Sinusoidal Pulse Width Modulation(SPWM)	68.60

Table 1 :- Total Harmonic Distortion With Different Pulse Width Modulation Techniques

PWM TECHNIQUE	SPEED (RPM)	Torque (N-m)
Modified Sinusoidal Pulse Width Modulation(MSPWM)	1403	1.245
Third Harmonic Injection Pulse Width Modulation(THIPWM)	1394	1.271
Sinusoidal Pulse Width Modulation(SPWM)	1374	1.061

Table 2 :- Motor Performance with different Pulse Width Modulations

The Three Pulse Width Modulation Techniques are compared with respect to THD and Motor Performance. In terms of Total Harmonic Distortion(THD), Modified Sine Pulse Width Modulation has given the better results and also when we look at Motor Performance Modified Sinusoidal Pulse Width Modulation Technique gave better results but Torque of MSPWM is less compared to torque of THIPWM but the difference is very negligible when we observe Table 2, so we can conclude that MSPWM has given good results in terms of reduction in THD and as well as in achieving desired Speed and Torque of Induction Motor when compared to the other two PWM Techniques, also the torque is smooth with MSPWM. As a result MSPWM is widely used Technique. The Pulse Width Modulation Techniques help us to reduce the voltage and current harmonics and provide a smooth operation of the Machines. By adding the filters we get even more reduced Total Harmonic Distortion and the Torque and Speed ripples are eliminated giving smooth operation of the Motor throughout the operating characteristics.

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