Performance Analysis of Induction Motor Drive Fed by VSI for Various Modulation Index

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Abstract: This paper presents the results of an analysis regarding the behavior of three phase induction motor fed by PWM VSI in terms of total harmonic distortion in line and phase voltage of inverter for modulation range 0 < m < 1. For the execution of the proposed drive the MATLAB/SIMULINK software has been used. The analysis of the inverter has been carried out by using the factor total harmonic distortion. The influence of the modulation index on the performance of the inverter has been done in terms of the waveforms for inverter phase voltage and line voltage developed by the motor.

Keywords: Induction Motor Drive, Modulation Index, PWM, Simulation, THD.

Introduction

Induction machines are widely used in the industry, serving as one of the most important roles during the energy conversion between electrical power and mechanical power. Based on the functionality, they are classified into two categories: induction generators and induction motors. Induction generators consume the mechanical energy and produce electrical power, which find the applications in the standing-alone electrical power generations and wind farms. Induction motors produce mechanical power while consuming the electrical power from the grid, which account for more than one half of the total electrical power consumed. Especially the induction machines with squirrel cage rotors are the dominant types due to the simple structures, easy connections, robust to severe operating conditions, low costs, and maintenance free features. They can be found in the applications as the important driving sources where a certain motion is required either linear or rotating ones. They are used to drive fans, pumps, compressors, power tools, mills, elevators, cranes, electrical vehicles, ships, etc.

DC-AC inverters are electronic devices used to produce AC power from low voltage DC energy (from a battery or solar panel). This makes them very suitable for when required to use AC power tools or appliances but the usual AC mains power is not available. Examples include operating appliances in caravans and mobile homes, and also running audio, video and computing equipment in remote areas. Most inverters do their job by performing two main functions: first they convert the incoming DC into AC, and then they set up the resulting AC to mains voltage level using a transformer. And the goal of the designer is to have the inverter perform these functions as efficiently as possible. So that as much as possible of the energy drawn from the battery or solar panel is converted into mains voltage AC, and as little as possible is wasted as heat [1]. Three-phase inverters are used for variable-frequency drive applications. A basic three-phase inverter consists of three single-phase inverter switches each connected to one of the three load terminals [2].

Three Phase SPWM Induction Motor Drive

Of all the modern power electronics converters, the Voltage Source Inverter (VSI), is perhaps the most widely utilized device with 3 power ratings ranging from fractions of a kilowatt to megawatt level. A voltage–fed inverter (VFI) or more generally a voltage–source inverter (VSI) is one in which the dc source has small or negligible impedance. The voltage at the input terminals is constant. A current–source inverter (CSI) is fed with adjustable current from the dc source of high impedance that is from a constant dc source [3], [4], [5]. The VSI consists of six power semiconductor switches with anti-parallel feedback diodes. It converts a fixed DC voltage to three phase AC voltages with controllable frequency and magnitude. Since the VSI has discrete circuit modes for each set of switch states, generating an output voltage with correct frequency and magnitude requires an averaging approach. In the widely utilized Pulse Width Modulation (PWM) methods, the inverter output voltage approximates the reference value through high frequency switching. In AC motor drive applications, typically a rectifier device converts the AC three phase line voltages to DC voltage. Following the rectifier voltage passive filtering stage, the PWM-VSI interfaces the DC source with the AC motor to control the shaft speed/position/torque. Some industrial applications of inverters are for adjustable-speed ac drives, induction heating, standby aircraft power supplies, UPS (uninterruptible power supplies) for computers, HVDC transmission lines, etc [6]. When utilized in such applications, the device is often termed as converter (opposite of inverter), hence PWM-VSC.

In all cases, power flow is controlled by the inverter switching device gate signals in a manner to obtain high performance, improved efficiency, and reliable operation. Although its main circuit topology is quite simple, a modern PWM-VSI drive involves an overwhelming level of technology and intelligence. From the semiconductor power switching devices such as Insulated Gate Bipolar Transistors (IGBTs) operating at frequencies as high as many tens of kilohertz to the microcontrollers and Digital Signal Processors (DSPs) that process the control signals at speeds beyond many tens of megahertz, most components of a state of the art PWM-VSI drive involve advanced technologies. The costumer's increasing demand for multifunctionality, precision performance, efficiency, and reliability and user friendliness has motivated engineers to build a significant amount of intelligence into the microcontrollers and DSPs of the PWM-VSI drives. Load parameter estimation, fault diagnostics, high performance vector control, observer based shaft encoder less speed control, energy efficiency optimization etc. algorithms have been developed and built into the modern PWM-VSI drives. With their global production rate above millions per year, the power ratings ranging from fractions of a kilowatt to megawatts, and the applications ranging from simple house appliances such as air-conditioning units to heavy industries such as steel mills, PWM-VSI drives are modern technology devices which have been experiencing a rapid progress over the last three decades. This rapid progress is partially due to the great effort of many academic and industrial researchers' attempts to respond to the costumers demand for increasing efficiency, reliability, and enhanced performance. And, it is partially due to the substantial progress in the enabling technologies, such as the semiconductor micro and macro electronics technology.

Voltage Source Inverters are one in which the DC source has small or negligible impedance. In Other words VSI has stiff DC voltage source at its input terminals. A current source inverter is fed with adjustable current from a DC source of high impedance, i.e. from a stiff DC current source. In a CSI fed with stiff current source, output current waves are not affected by the load. It is the first and foremost requirement that the output of three phase inverter should be purely sinusoidal. However the waveforms of the practical inverter are non-sinusoidal and contain certain harmonics. These harmonics are generated by the semiconductor devices used in implementing three phase inverter is in the generation of harmonics. The power electronics devices when used in practical circuits like converter/controller circuits generate harmonics in the output voltage supply. The harmonics generate undesirable effects in power supply circuits like generation of humming noises, derating of the machines and torque pulsations which make the operation of the machine pulsating [7]. The following are the important parameters which measure the quality of the inverter output voltage are

- ➢ Harmonic Factor
- ➢ Total Harmonic Distortion
- ➢ Distortion Factor
- ➢ Lowest Order Harmonic

But in this paper, a technique is used to tolerate the fault in the inverter section of a three phase VSI fed induction motor drive. A standard three-phase voltage source inverter, fed from a three-phase mains supply, through a three-phase uncontrolled rectifier circuit, usually supplies the induction motor used in this AC drives category Figure 1.
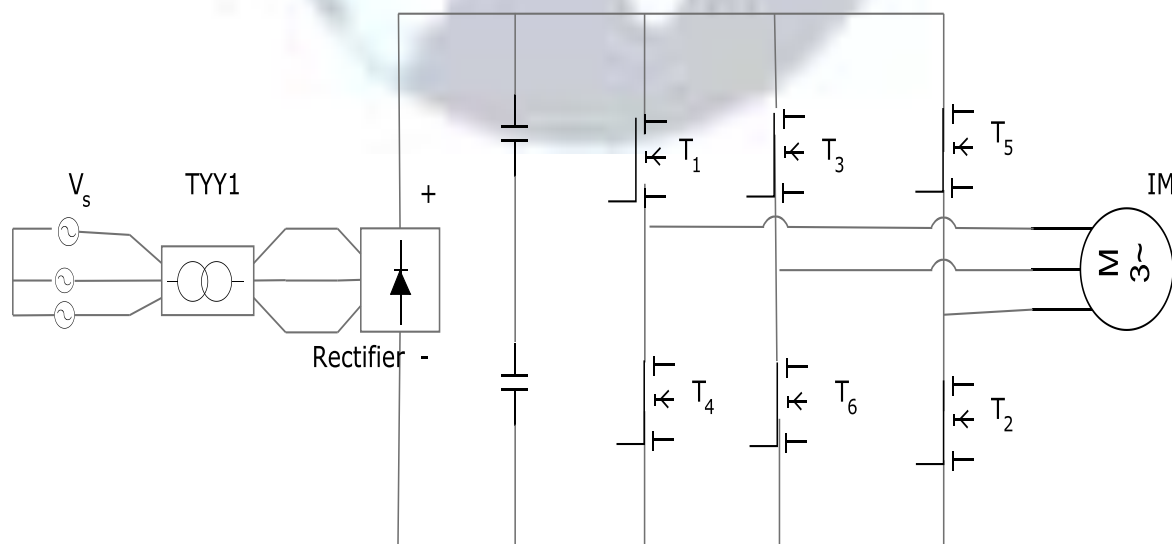

Figure 1.   Typical induction motor drive structure based on a voltage source inverter

Techniques Used to Implement Inverter

Formerly 180^0 conduction mode full bridge type inverter were used so as to produce three phase output voltage waveform. The output voltage is available in the form of discrete pulses displaced from each other by an angle of 1200. However the harmonics contents are more. Inverter gain is less and the output voltage regulation is poor [8]. To satisfy the constant voltage and frequency requirement is also difficult.

So as to fulfill above mentioned requirements, the most efficient technique used to implement the three phase inverter is the Pulse Width Modulation Technique. The inverter so fabricated is called PWM Inverter. In this technique, the width of each pulse is varied on per half cycle basis. This variation of the pulse width in each half cycle enables us to control output voltage in an efficient manner and eliminate the particular harmonic component from output voltage waveform. The commonly used PWM techniques used for implementing three phase inverter are

➢ Single Pulse width modulation

➢ Multiple Pulse Width Modulation

➢ Sinusoidal pulse Width Modulation

By using the number of pulses and modulating the width of these pulses in each half cycle rather than using a single pulse, the harmonic contents can be further reduced. This analogy can be implemented by using Multiple Pulse Width Modulation and Sinusoidal pulse Width Modulation techniques [9, 10].

Analysis of Three Phase SPWM Voltage Source Inverter

Simulation is done on a three phase induction motor fed by a PWM inverter developed in Matlab/Simulink environment. The Figure 2 shows the Simulink diagram of the developed model. For the simulation purpose, the tool box used is the Sim-power system tool box. The basic circuit of the proposed scheme consists of a three phase induction motor as squirrel-cage rotor type having ratings as 5.4 HP, 400V, 50 Hz, 1430 RPM. The three phase induction motor drive is fed by a three phase PWM VSI inverter. The modulation technique used for the generation of three phase balanced output from the inverter is the sinusoidal pulse width modulation technique.
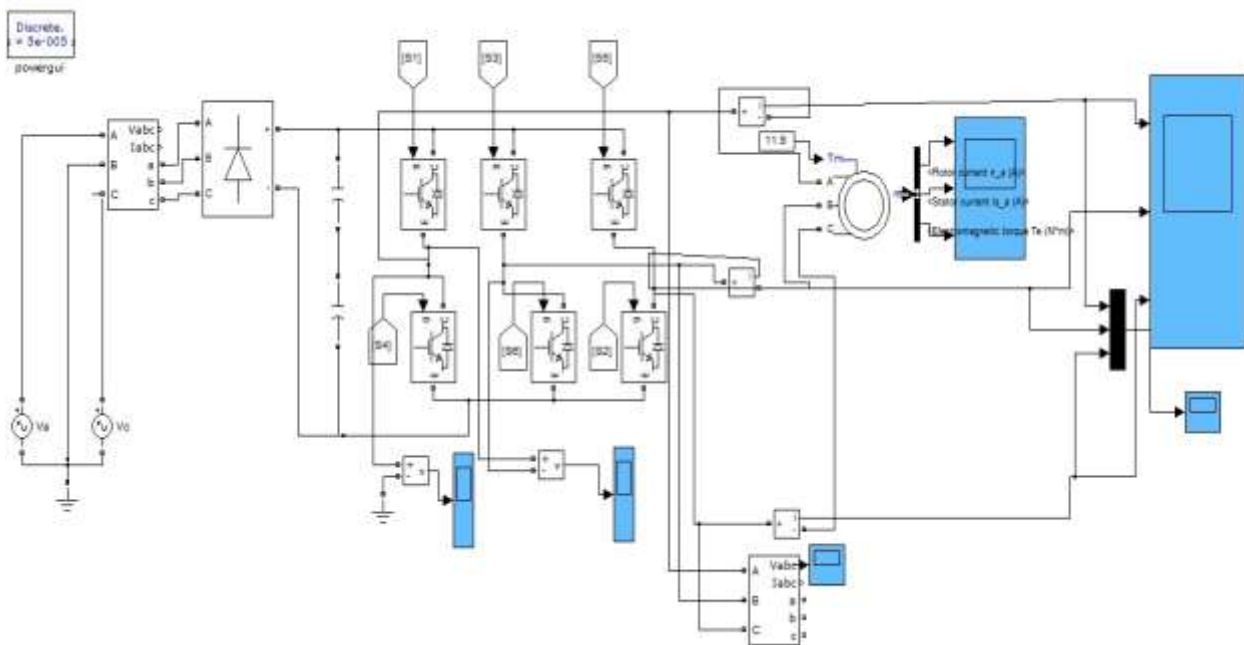

Figure 2.   Circuit diagram of PWM based VSI fed induction motor

Voltage source pulse width modulated inverter is made up of six IGBTs switches in a bridge form. IGBT switches has been used because of the number of advantages offered them for switching purpose. Three phase output is taken from the of three arms of bridge circuit designated as a, b, c , which is tconnected to the three phases a, b, c, on the stator side of three phase induction motor. The harmonics present in the output voltage and the load current has also been measured. The evolution of the harmonic contents has been carried out by its THD and the harmonics spectrum has been extracted using the FFT analysis.

Generation of Gating Pulses

The gating pulses for the six IGBTs of three legs are generated. The generation of these pulses is carried out by Sinusoidal Pulse Width Modulation technique. A number of algorithms for PWM voltage generation are available. Some well-known techniques are unipolar voltage switching and bipolar voltage switching. In this work the unipolar switching scheme has been used.
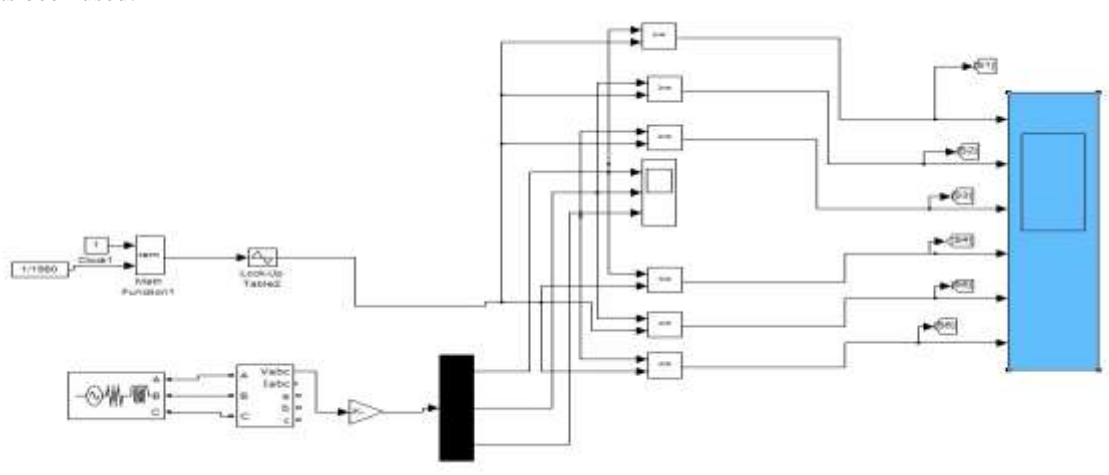

Figure 3.   Drive circuit of IGBTs

Simulation Results

Results are obtained by simulating the circuit. Here we analyze the inverter and motor performance for modulation range between 0 and 1 i.e. $0 < m < 1$. Amplitude Modulation index is defined as the ratio of control signal amplitude and carrier signal amplitude i.e. $m_a = A_r/A_c$. The number of pulses per half cycle depends upon the value of the frequency modulation index mf defined by the relation $mf = f_c/(2f)$, where f_c = frequency of the carrier signal and f = frequency of the modulating signal.

A.   For Modulation Index $m_a = 0.7$

First of all the inverter is operated in the modulation index i.e. the value of $m_a = 0.7$ is maintained. The generated pulses are applied to the gate circuit of the six IGBTs which in turn produce the balanced pulse width modulated three phase output voltages.
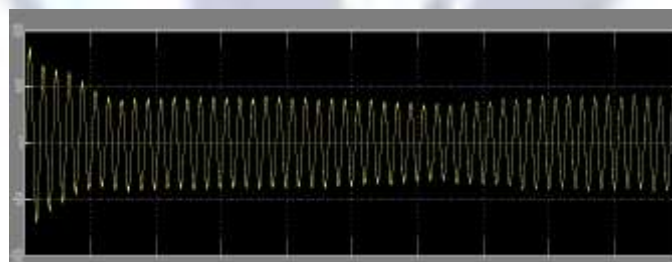

Figure 4. Phase A current waveform for $m_a = 0.7$

Figure 4 shows the waveform for the phase "A" current. From the waveform it is clear that the part of the wave form present before the time 0.33 sec is the transient part and after that it acquires it steady state value of x amperes.
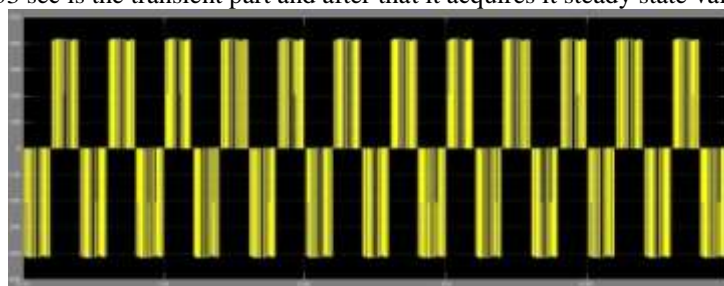

Figure 5. Waveform of line voltage V_{ab} for m = 0.7

Figure 5. shows the waveform of line voltage V_{ab}. Similar waveforms can be obtained for the other line voltages V_{bc} and V_{ca}. From the waveform it is clear that the output waveform is PWM wave and the frequency of the output voltage wave is 50 Hz and its amplitude is 220V.
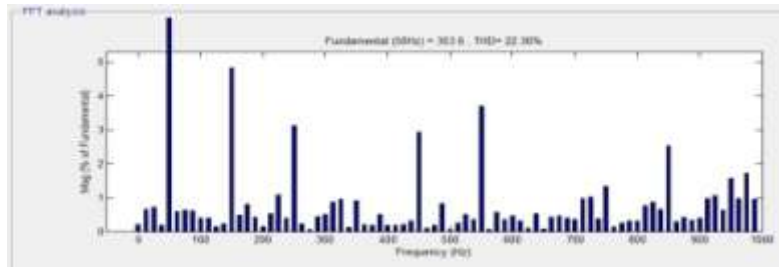

Figure 6. FFT analysis in line voltage V_{ab} for $m_a = 0.7$

Figure 6 shows the frequency spectrum of the line voltage. The value of the THD is 22.36% for the value of $M_a= 0.7$. From the waveforms it is clear that the dominant harmonic is the third harmonic.
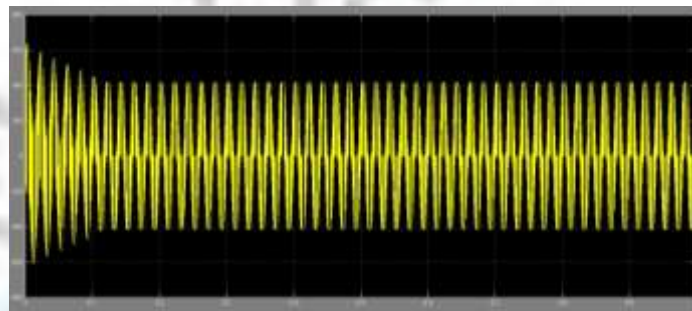
Figure 7. Phase A voltage waveform for $m_a = 0.7$
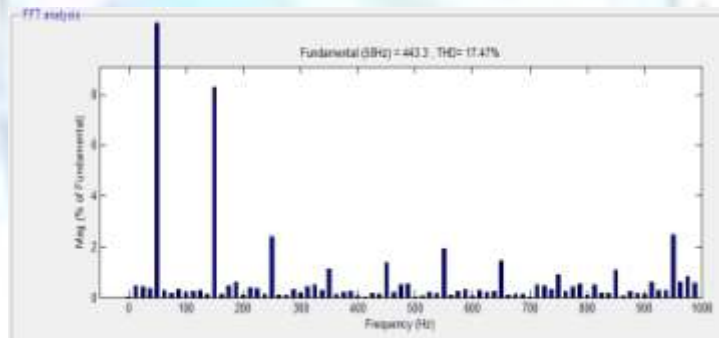
Figure 8. FFT analysis in phase voltage A for $m_a = 0.7$

Figure 7 shows the waveform and Figure 8 shows frequency spectrum of the phase voltage for $m_a= 0.7$. It shows THD of 17.47%.

B. For Modulation Index $m_a = 0.8$

For modulation index $m_a= 0.8$, the waveform of line voltage V_{ab} of inverter is shown in Figure 9. Similar waveforms can be obtained for the other line voltages V_{bc} and V_{ca}. From the waveform it is clear that the output waveform is PWM wave and the frequency of the output voltage wave is 50 Hz and its amplitude is 220V.
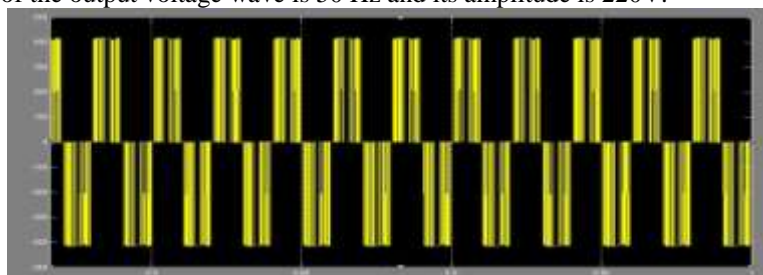

Figure 9. Waveform of line voltage V_{ab} for $m = 0.8$
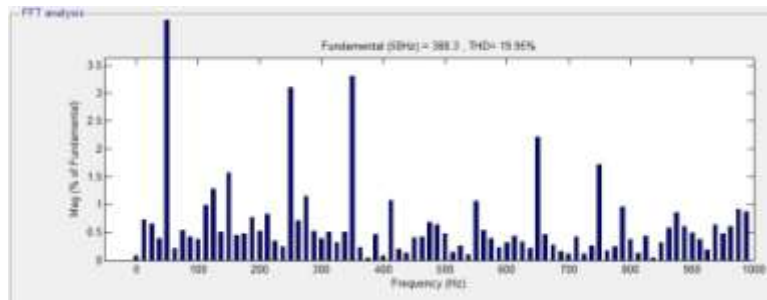
Figure 10.   FFT analysis in line voltage V_{ab} for $m_a = 0.8$

Figure 10 shows the frequency spectrum of the line voltage. The value of the THD is 19.95% for the value of $M_a = 0.8$. From the waveforms it is clear that the dominant harmonic is the third harmonic.
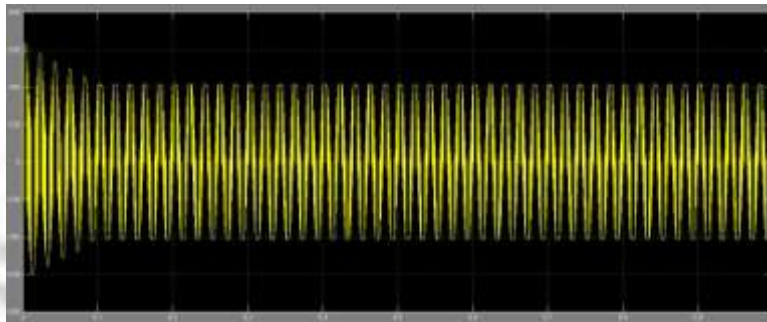

Figure 11.   Phase A voltage waveform for $m_a = 0.8$
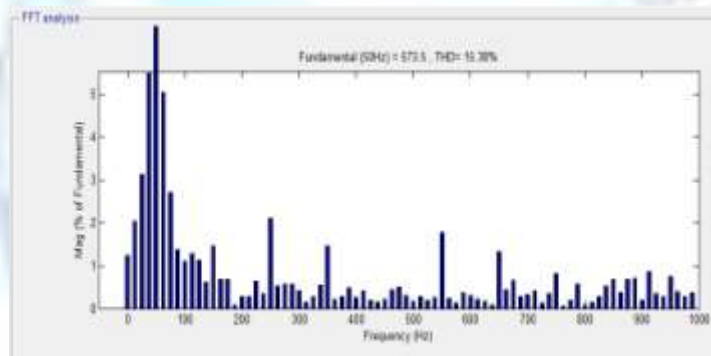

Figure 12.   FFT analysis in phase voltage A for $m_a = 0.8$

Figure 11 shows the waveform and Figure 12 shows frequency spectrum of the phase voltage for $m_a = 0.8$. It shows THD of 15.38%.

C. **For Modulation Index $m_a = 0.9$**

For modulation index $m_a = 0.9$, the waveform of line voltage V_{ab} of inverter is shown in Figure 13. Similar waveforms can be obtained for the other line voltages V_{bc} and V_{ca}. From the waveform it is clear that the output waveform is PWM wave and the frequency of the output voltage wave is 50 Hz and its amplitude is 220V.
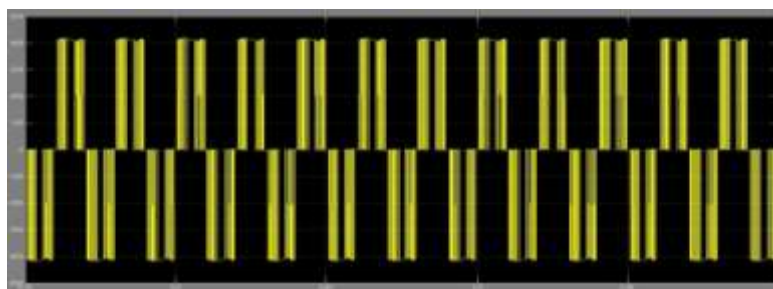

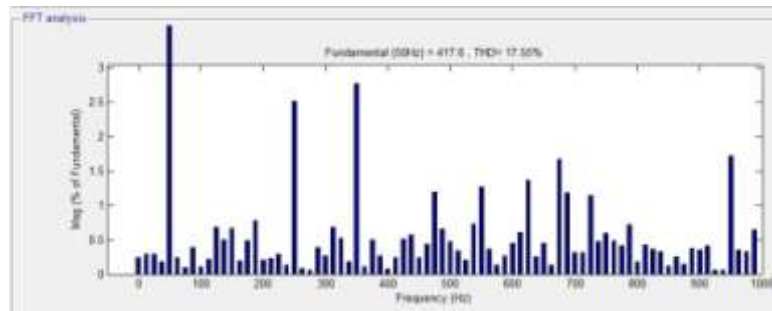Figure 13.   Waveform of line voltage V_{ab} for $m = 0.9$

Figure 14.   FFT analysis in line voltage A for m_a = 0.9

Figure 14 shows the frequency spectrum of the line voltage. The value of the THD is 17.55% for the value of M_a= 0.9. From the waveforms it is clear that the dominant harmonic is the third harmonic.
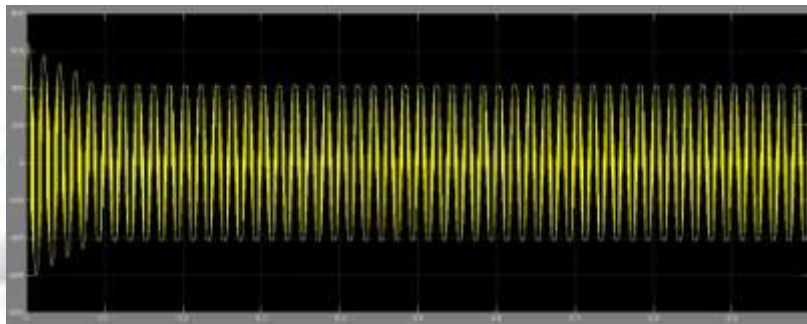

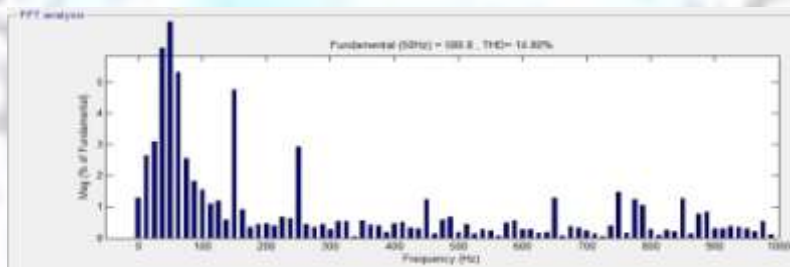Figure 15.   Phase A voltage waveform for m_a = 0.9

Figure 16.   FFT analysis in phase voltage A for m_a = 0.9

Figure 15 shows the waveform and Figure 16 shows frequency spectrum of the phase voltage for m_a= 0.9. It shows THD of 14.80%.

Conclusion

The paper presents performance analysis of three phase induction motor fed by PWM voltage source inverter in under modulation range. The analysis has been carried in the modulation range 0 to 1. The effect the modulation index on the motor performance in terms of the line voltage and phase voltage has been carried out. Its impact on the on the performance on the motor in terms of the transients and steady state response has been presented. The main advantage of this approach is that it shows the performance of the motor as well as of the voltage source three phase inverter for the entire range of under modulation index. There is appreciable improvement in THD in inverter line and phase voltage as the modulation index is increased and close to unity. Total harmonic distortion THD in line and phase voltage deceases as the value of modulation index increased.

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