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Performance Analysis of a Three Phase Induction Motor Fed by Three Phase PWM VSI Using Variable Modulation Index

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Abstract
Today, pulse width modulation technique is one in all the foremost wonderful management methods of speed control of the induction motor. The aim is to regulate effectively the speed and torque. This paper deals with the comprehensive performance analysis of an induction motor (IM) supported by sinusoidal PWM strategy. The PWM method, which involves the modulation of conventional sinusoidal reference signal and a triangular carrier, is used to produce pulse width modulated output only for under modulation index which is fed by voltage source inverter (VSI). For the implementation of the proposed drive the MATLAB/SIMULINK environment has been used. In this paper the impact of the modulation index on the performance of the inverter has been viewed. The whole analysis is done for under modulation (i.e. m_a‹1).

1. Introduction

DC to AC convertors or inverters are electronic devices that are to produce AC voltage from low voltage DC voltage (usually obtained from a battery or solar panel). This makes them suitable for when required to use AC power tools or appliances and the usual AC mains power is not available. Examples include operating appliances in caravans and mobile homes, 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 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. 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 terminal.

2.Three Phase SPWM Induction Motor Drive

Figure 1 shows a three-phase inverter, which the most commonly used topology is in today's motor drives. The control strategy is similar to the control of the single phase inverter except that the reference signals for the different legs have a phase shift of 120°or 180° for the three-phase inverter. Due to this phase shift, the odd triplen harmonics (3rd, 9th, 15th, etc.) of the reference waveform for each leg are eliminated from the line-to-line output voltage. The even-numbered harmonics are canceled as well if the waveforms are pure AC, which is usually the case. The switches of any leg of the inverter (S1 and S4, S3 and S6, or S5 and S2) cannot be switched on simultaneously because this would result in a short circuit across the dc link voltage supply. Similarly, in order to avoid undefined states in the VSI, and thus undefined AC output line voltages, the switches of any leg of the inverter cannot be switched off simultaneously as this will result in voltages that will depend upon the respective line current polarity. Present day drive types are the Induction motor drives with voltage source inverters. Three phase voltage-fed PWM inverters are recently showing rising popularity for multi-megawatt industrial drive applications. The main reasons for this popularity are easy sharing of large voltage between the series devices and the improvement of the harmonic quality at the output as compared to a two level inverter. Today GTO devices are being replaced by IGBTs because of their rapid evolution in voltage and current ratings and higher switching frequency.

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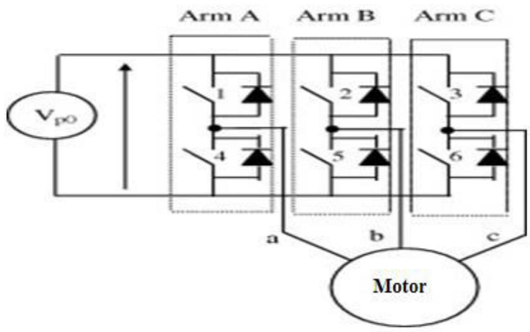

Fig. 1: Topology of a three-phase inverter

end of power, GTO devices are being replaced by IGBTs because of their rapid evolution in voltage and current ratings and higher switching frequency. The Space Vector Pulse Width Modulation of a three level inverter provides the additional advantage of superior harmonic quality and larger under-modulation range that extends the modulation factor to 90.7% from the traditional value of 78.5% in Sinusoidal Pulse Width Modulation.

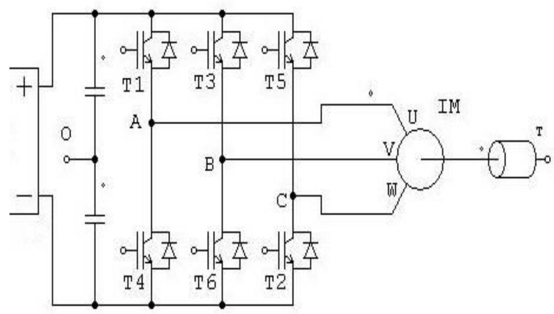

Fig. 2: Three Phase PWM inverter fed induction motor

In most variable speed drives pulse width modulation (PWM) voltage source inverters are used. Usually machine design tools only consider the fundamental harmonic of the stator voltage when calculating the losses. These losses are caused by harmonics of the voltage and the current due to the PWM. A number of algorithms for PWM voltage generation are available. Some well known techniques are unipolar voltage switching and bipolar voltage switching, harmonic elimination and space vector PWM.

3. 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 120^0. However the harmonics contents are more. Inverter gain is less and the output voltage regulation is poor.

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:

1. Single Pulse Width Modulation
2. Multiple Pulse Width Modulation
3. 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.

4. Matlab Based Analysis of Three Phase Sinuosoidal Pulse Width Modulated Inverter

Simulation is done on a three phase induction motor fed by a PWM inverter developed in MATLAB/SIMULINK environment. The figure 3 shows the SIMULINK diagram of the developed model. For the simulation purpose, the tool box used is the Sim-power system tool box. 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.

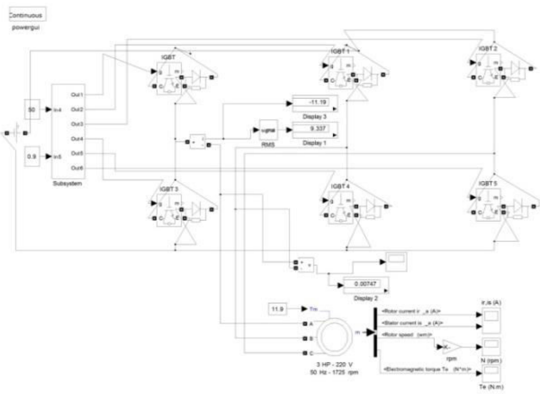

Fig. 3: Circuit diagram of PWM based VSI fed three phase induction motor

Voltage source pulse width modulated inverter is made up of six IGBTs switches in a bridge form and fed by a dc voltage source. IGBT switches have 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 connected to the three phases a, b, c, on the stator side of three phase induction motor.

5.Simulation Results of The SPWM Fed Induction Motor Drive

Results are obtained by simulating the circuit. Here we analyze the inverter and motor performance for under modulation range i.e. for the value of m < 1. Amplitude Modulation index is defined as the ratio of control signal amplitude and carrier signal amplitude i.e. $m_a=A_r/A_c$.

5.1 For modulation index m_a=0.7

First of all the inverter is operated in the under modulation range i.e. the value of m_a =0.7 is maintained. Figure 4 shows the waveform for the phase "a" current. Form the waveform it is clear that the part of the wave form present before the time 0.2 sec is the transient part and after that it acquires it steady state value.

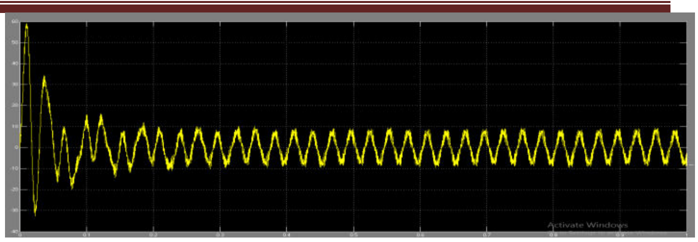

Fig 4: Phase 'a' current waveform for m_a=0.7

The 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}. Form the waveform it is clear that the output waveform is pulse width modulated wave.

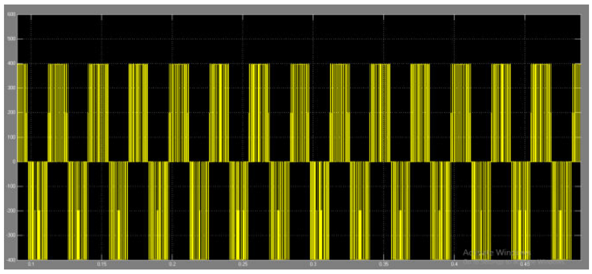

Fig 5: Waveform of line voltage V_{ab} for m_a=0.7

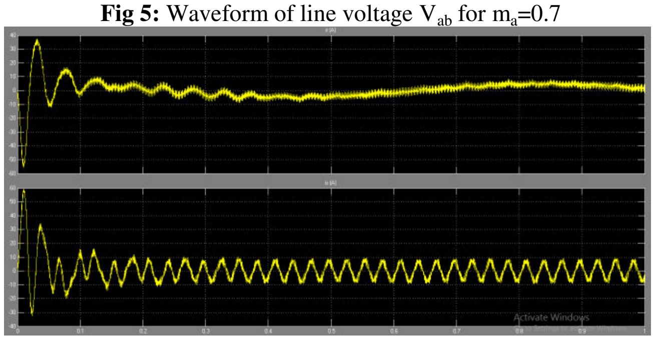

Fig 6: Waveforms of rotor and stator current of three phase induction motor for m_a=0.7

The variation of rotor and stator current i.e. I_r and I_s of phase 'a' of motor with respect to time is shown in Fig 6. The rotor current has transient time of 0.2 Sec and stator current has 0.5 Sec.

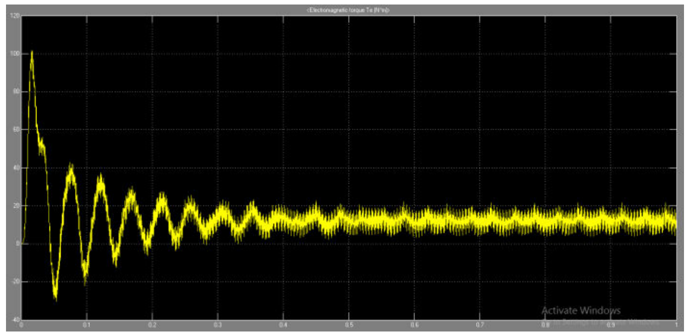

Fig 7: Waveform for the developed electromagnetic torque for m_a=0.7

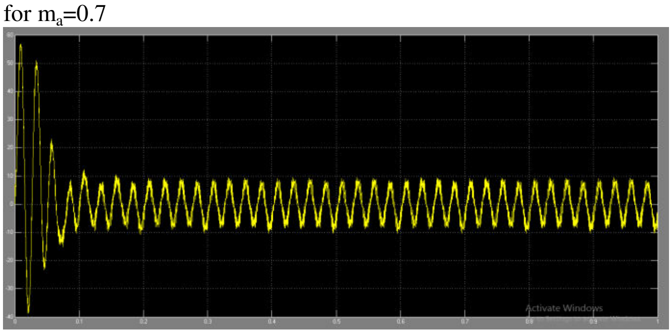

Fig 8: Phase 'a' current waveform for m_a=0.8

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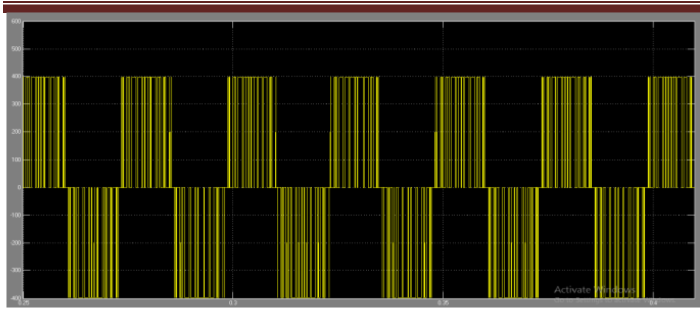

Fig 9: Waveform of line voltage V_{ab} for m_a=0.8

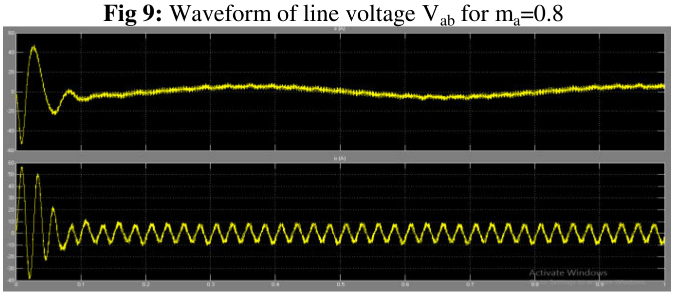

Fig 10: Waveforms of rotor I_r and stator current I_s of phase 'a' three phase induction motor for m_a=0.8

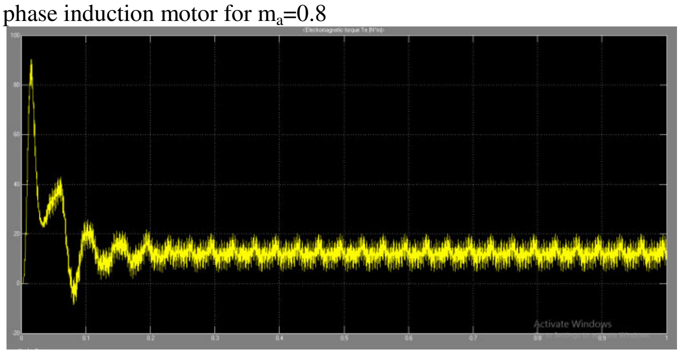

Fig 11: Electromagnetic torque at m_a =0.8

The variation of electromagnetic torque is shown in figure 7. From the figure it is clear that the initial response of the motor if highly oscillatory. But after a time of 0.35 sec the electromagnetic torque developed by the motor acquires a steady state value of 10.2 N-m.

5.2 For Modulation Index m_a=0.8

For modulation index m_a = 0.8, the waveform of phase current I_a and line voltage V_{ab} is shown in Fig 8 and 9 observed that the phase current I_a has transient time 0.18 sec which is smaller as compared to the transient time obtained when m_a =0.7.

Fig 10 shows the rotor and stator current of phase "a" at modulation index 0.8. From the variation of electromagnetic torque shown in Fig 11, it is clear that the initial response of the motor is again highly oscillatory. But after a time of 0.14 sec the electromagnetic torque developed by the motor acquires a steady state value of 9 N-m, which is equal to load torque.

6. Comparision of Line and Phase Voltage for Different Modulation Index

Amplitude of various parameters of three phase induction motor during under modulation condition at different modulation index:

Sr. No	Parameter	Modulation Index m_a= 0.7	Modulation Index m_a= 0.8
1	Rotor current	0.5 sec	0.12 sec
2	Stator current	0.2 sec	0.18 sec
3	Rotor speed	0.4 sec	0.2 sec
4	Electromagnetic torque	0.35 sec	0.14 sec

Settling time of various parameters of three phase induction motor during under modulation condition at different modulation index:

Sr. No	Parameter	Modulation Index m_a= 0.7	Modulation Index m_a= 0.8
1	Rotor current	40A	46A
2	Stator current	60A	56A
3	Rotor speed	1010 rpm	1150 rpm
4	Electromagnetic torque	102 N-m	90 N-m

7. Conclusions

The paper presents performance analysis of three phase induction motor fed by PWM voltage source inverter in under modulation range. For this purpose the MATLAB/SIMULINK approach has been used for the implementation of the proposed drive. The switching devices used are the power IGBTs. The three phase balanced output is then used to drive an induction motor.

Initially the electromagnetic torque developed by the motor is highly oscillatory and after the transient time it settles down to the vale which is equals to the load torque.

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