Performance Analysis of Three-Phase Induction Motor with AC Direct and VFD

Dinesh Kumar

Department of Electrical Engineering, Sekhawati Institute of Engineering and Technology, Sikar

E-mail: saini.dinesh92@gmail.com

Abstract. The electrical machine analysis and performance calculation is a very important aspect of efficient drive system design. The development of power electronics devices and power converters provide smooth speed control of Induction Motors by changing the frequency of input supply. These converters, on one hand are providing a more flexible speed control that also leads to problems of harmonics and their associated ailments like pulsating torque, distorted current and voltage waveforms, increasing losses etc. This paper includes the performance analysis of three phase induction motor with three-phase AC direct and variable frequency drives (VFD). The comparison has been concluded with respect to various parameters. MATLAB-SIMULINK™ is used for the analysis.

1. Introduction
VFD is variable frequency drive. VFD used to control the speed of electric induction motor. Induction motors are fixed speed motors which are used in most industries because of its reduced cost, reliability and rugged nature. The speed of the induction motor can be changed by various methods such as poles changing, voltage changing, connecting the resistance in rotor circuit etc., but the most efficient method is changing the supply frequency and voltage to the motor. Speed is directly proportional to the frequency of supply. The variable frequency drive (VFD) varies the frequency and hence varies the speed or torque of the induction motor as per the requirements of the load. As VFD provides the power efficient operation, smooth speed and torque control but also leads the harmonics in the system. Harmonics are generated due to use of power electronic switching devices. These harmonics affect the performance of the induction motor. This paper describes the effect of harmonics on motor performance and also how to improve the performance of induction motor by using appropriate LC filter with the help of MATLAB/Simulink. This paper has detail study of motor performance with different cases those showing performance of induction motor. First, we study the parameters when three phase induction motor is directly supplied by three phase AC supply. Then these parameters are compared with the parameters those are getting when same three phase induction motor is supplied by VFD without a filter. Then the performance is improved with the injection of LC passive filters in the system.
2. **Three Phase Induction Motor**

Three phase induction motor is widely used in any kind of industry like automobile, cement, fertilizer, chemical, Yarn production etc. because of its simple and rugged construction. A three phase induction motor is singly excited machine. Induction motor works on faraday law of electromagnetic induction. In this paper behaviour of an induction motor is studied when supplied with or without VFD by using MATLAB/Simulink. In this paper studied a three phase induction motor with rated parameters listed in table1. [1]

| S. No. | Parameters                  |
|--------|-----------------------------|
| Power  | 5.4 HP                      |
| Voltage| 400 V                       |
| Frequency| 50 Hz                      |
| Stator resistance and Inductance | 1.405Ω , 0.005839H |
| Rotor resistance and inductance | 1.395Ω, 0.005839H     |
| Mutual inductance      | 0.1722 Ω                  |
| Inertia            | 0.0131kg-m²                |

3. **Induction Motor Supplied from 3-phase AC Direct**

In this paper, the performance analysis of three phases IM is discussed in details. The behaviour of stator current, speed and torque characteristics are explained with respect to time.

Figure 1 Simulation Circuit of Three Phase Induction Motor when Supplied from Three Phase AC Direct
Figure 1 shows simulation model of three phase induction motor which is directly connected to three phase supply. Performance analysis simulation is done using MATLAB/Simulink for a total time of 0.5 sec.

![Simulation Model](image)

Figure 2 (a) Input voltage, input current, stator current, rotor speed, electromagnetic torque waveforms (b) THD of input voltage waveform (c) THD of input current waveform when three phase induction motor is supplied by AC direct

From all curves, the nature of the implemented induction motor is explained in transient as well as steady state condition. The parameter of induction motor is containing in table 1. When this motor is operated at
1 Nm mechanical torque then it draw of 3.72 A per phase at 1496 rpm and develop 1.456 Nm electromagnetic torque on armature conductor. As shown in figure 2 (a) the input voltage and current are sinusoidal in nature. The input current shows some transient effects. The THD in input voltage waveform is 0.09% and in input current waveform is 0.10% which is shown in figure 2(b) and 2(c) respectively. These values of harmonics are too less due to sinusoidal input to the motor. Now motor works more efficiently and give good performance.

4. Operating principle and components of VFD
The variable speed drive has a rectifier, inverter, DC link and control components. In VFD a solid state three phase full wave diode rectifier convert three phase 400V 50 Hz supply to DC voltage. This DC output has very high ripples. To minimize these ripples a DC link having low pass filter is connected to get smooth DC output. The harmonic generated are filter out by the low pass filter. After removal of ripple from DC voltage the DC output goes to inverter section of VFD. The inverter converts DC supply to three phase AC supply at any desired frequency with the help of gate pulse to control the speed of three phase induction motor. Inverter consists of power electronics devices like IGBT, Thyristors, MOSFET, power transistors etc. In this paper I use inverter with PWM (Pulse Width Modulation) technique.

5. Induction motor supplied from VFD without filter
The use of power electronics devices in VFD led harmonics in the system. As shown in figure 3 that a three phase induction motor is connected to supply through VFD. In the inverter, the triggering pulse is given by the discrete six pulse generator now the output values are changed as shown in results and waveforms. The resulting torque is decreased from 1.456 Nm to 1.375 Nm due to harmonics effect on induction motor generated by VFD.

![Figure 3 Simulation circuit of three phase induction motor when supplied by VFD without filter](image-url)
Table 2 VFD parameters used in MATLAB/Simulink

| Inverter                  | IGBT           |
|---------------------------|----------------|
| Snubber resistance and capacitance | 1e5,inf        |
| Rectifier                 | Diode bridge   |
| Inductance (DC Link)      | 150e-3         |
| Capacitance (DC Link)     | 100e-6         |
| Initial condition         | 1 0 0 0 0 0 0 0|

Due to the power electronics switching harmonics are increased in the system. The output of an inverter is ac but not sinusoidal due to switching time taken by the Switches [3]. Harmonics are increased in the system so that the motor torque becomes pulsating. These harmonics reduce the performance of three phase induction motor. As a percentage of harmonics increases in the system then distortion of input voltage and input current get increase. This distorted nature of current lead pulsation in torque on rotor of induction motor.

Figure 4 (a) and 4 (b) shows the DC voltage, DC current characteristics of rectifier section and three phase AC voltage output waveforms of inverter section respectively. The ripple from DC supply can be minimised by using an appropriate LC filter after the rectification. This LC filter is known DC link in VFD.
Figure 5(a) Stator current, motor speed and electromagnetic torque waveforms (b) THD in voltage waveform (c) THD in current waveform when motor is supplied by VFD without filter

As shown in figure 5(b) THD in the voltage waveform is 163.96 % and in figure 5(c) THD in the current waveform is 20.19 %. These harmonic inputs decrease the performance of induction motor. Figure 5(a) electromagnetic torque waveform shows the pulsation torque nature even after steady state condition reached.
6. Induction motor supplied from VFD with LC filter
The performance of induction motor can be improved by removing high frequency power signals from the input supply of induction motor.

Figure 6 Simulation circuit of three phase induction motor when supplied by VFD with filter

![Simulation circuit](image)

Figure 7 (a) Rectifier output waveform (b) Inverter output waveform with filter

![Waveform plots](image)
These harmonics can be removed by using an appropriate passive filter after the output of an inverter. The aim of the filter is to ensure sinusoidal stator current and voltage waveforms for the induction motor. In figure 6 a passive filter is connected after the inverter section of VFD. By connecting appropriate inductance and capacitance the inverter output waveforms can be improved.

Figure 8 (a) Stator current, motor speed, electromagnetic torque waveforms (b) THD in voltage waveform (c) THD in current when induction motor is supplied by VFD with filter.
As figure 7 (b) shows the inverter output voltage waveform with minimum harmonics. When this output is supplied to induction motor then the performance of motor improved which is shown in figure 8 (a), 8 (b) and 8 (c). Figure 8 (a) shows improved stator current, motor speed and electromagnetic torque waveform with less harmonic distortion in steady state condition which results less pulsation electromagnetic torque has on the rotor. Now harmonics are reduced as shown in figure 8 (b) and 8 (c) shows that voltage THD is 7.12 % and current THD is 1.23 % respectively which is less than the previous results when the induction motor is supplied by VFD without a filter. This passive filter consists of LC elements with value of L= 25 mH and Qc= 100 Kvar as shown in figure 9. These values are calculated by random variation in values for a specific motor of 5.4 HP, whose parameters are shown in table 1.

7. Conclusion
Operation of three phase induction motor, when connected to three phase ac source is ideally very efficient. The only problem is that speed control is not easily possible. VFD is used for speed control of induction motor however injects harmonics within the circuit and harmonics lead to peaky rotor current, oscillations in torque, which do not die and generate additional heating. When an appropriate LC filter is added after the VFD converter the waveforms of rotor current improve, torque oscillations are damped after initial transients and converter output waveform becomes more sinusoidal.

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