ISSN (Print): 0974-6846 ISSN (Online): 0974-5645

# Harmonic Analysis of Inverter-Fed Induction Motor Drive System under Fault Conditions using FFT

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#### **Abstract**

Harmonics are the major issues in Variable Frequency Drive systems. The objective of project is the analysis of harmonics in the signatures of motor current in various fault conditions of Variable Frequency Drive systems. The simulation is done on VSI fed induction motor at constant voltage/frequency and was carried out using MATLAB/ Simulink. Variable Frequency drives commonly uses "Insulated Gate Bipolar Transistor" (IGBT). To get sine wave at required frequency IGBT uses "Pulse Width Modulation" technique for simulation. Simulation of an induction was developed and by observing the current, torque and speed responses, its dynamic response was verified to set up the acceptability of the developed system. Simulation of three various fault conditions were carried out here: one IGBTs gate signal is open circuited, one IGBT in the inverter section is blown off, line to ground fault occurs in one phase of the motor terminal. The technique of frequency domain analysis is used as a method to discriminate various faulty conditions. For various faulted conditions frequency responses characteristics were analyzed and collated to setup the use of Fast Fourier Transform algorithm to distinguish the characteristics of fault. Frequency responses of three various faulty states were emphatically different and were indubitably shown.

Keywords: Fast Fourier Transform, Insulated Gate Bipolar Transistor, Pulse Width Modulation, Variable Frequency Drive

### 1. Introduction

Induction motors are the vital element of any industrial operation and they are regularly integrated for industrial operations and commercial available equipments. Core capabilities often provide by motor-driven equipments are needed for business comfort and equipment and personal safety. They are broadly used motors for industrial control appliances, so they are known as the "workhorse of the motion industry". They are authentic, robust and sturdy. In early periods induction motors constant speed motor and now changed to a "variable speed, variable torque machine". DC motors can be controlled easily at low power applications so it has undergone many evolutions. Induction motors are efficiently used in applications that require huge amounts of torque and power. The use of an induction motor has increased by a large amount with the innovation of "Variable Voltage, Variable Frequency

drives". The speed control of 3-phase squirrel cage IM over a wide range by varying the frequency of stator and are done with Variable frequency VSI's. So the Voltge Source Inverters are commonly preferred for medium power to maximum power variable speed drive systems in industries or driving parallely connected group of motors.

Most advanced variable frequency drives operates with rectifier which converts a  $3\phi$  voltage source to DC. Then a DC bus stores the rectified power. A capacitor is used in the DC link in order to retrieve and stores the power from the rectifier, and the power is fed to the inverter. Transistors are used in inverter for delivering power to the motor. The "Insulated Gate Bipolar Transistor" is generally used in modern VFDs. The IGBT switches on and off several times in a second and indubitably the power is controlled and brought to the motor. The technique of "Pulse Width Modulation" (PWM) is applied here for the

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simulation of a sine wave at the required frequency to the motor.

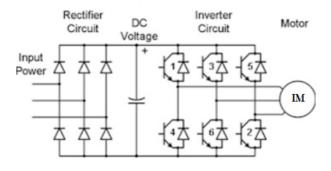
The  $3\Phi$  stator winding of IM is excited by the 6-step VSI .V/f control is used here. Such an induction motor is simulated and its dynamic responses are validated from the current, torque and speed characteristics to make adequacy of the system. Simulations of three different post faults are carried out here: one IGBTs gate signal is open circuited, one IGBT in the inverter section is blown off, line to ground fault occurs in one phase of the motor terminal. Then analyze the frequency domain and time domain under these faulty conditions to discriminate fault types.

## 2. System Configuration

Figure 1 shows the proposed system block diagram. To the VSI fed induction motor a three phase supply is given as input. The rectifier is uncontrolled and is preceded by a dc link capacitor in the first stage. IGBT switches are used in Inverter to controls the Induction motor. The controller used is sinusoidal pulse width modulator (SPWM) which generates the control signals for switches. By adjusting the control parameters the frequency and motor terminal voltage magnitude are adjusted, in order to maintain 'V/f' ratio constant. In this model, the induction motor is applied by a constant torque load.

#### 2.1 Substantiation of the Simulation Model

After simulating the model, by analyzing the dynamic response of the motor drive system such as rotor current, speed, torque, the reliability and performance of the model have been verified. Figure 2 shows Rotor current v/s Time characteristics, Figure 3 shows Speed v/s Time characteristics and Figure 4 shows Torque v/s Time characteristics.



**Figure 1.** Induction Motor Drive System.

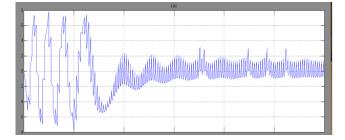


Figure 2. Rotor Current v/s Time.

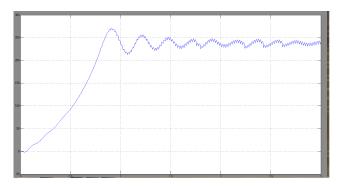
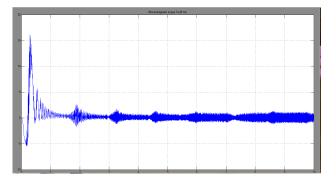


Figure 3. Speed v/s Time.



**Figure 4.** Torque v/s Time.

By analyzing the above profiles it can be finalize that the model is crystal clear.

### 2.2 Conditions under Study

Simulation studies were done on a  $3\Phi$  IM. Different faulty conditions were created in the simulated model by the three different ways.

- 1. One IGBT's gate signal is open circuited
- 2. One IGBT in the inverter section is blown off
- 3. One phase of the motor terminal is given a line to ground fault.

## 3. Results of Simulation

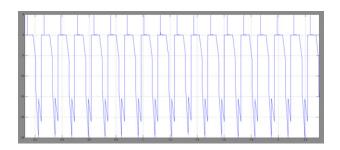
# 3.1 One IGBTs Gate Terminal is Open Circuited

In this case, phase A's upper IGBT is grounded for obtaining the simulation in the specified condition. Motor-current signatures of phases A and B are displayed. Figure 5 shows the A phase motor current signature and Figure 6 shows the B and C phase Motor-current signatures with Fault at IGBT gate terminal in phase A.

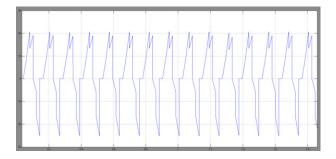
Figure 7. Shows FFT of A phase motor-current signature at the condition of the motor working at a speed of 314 rpm and Figure 8. Shows the FFT of A phase motor-current signature at the condition of the motor working at a speed of 376 rpm.

Figure 9. shows FFT of B and C phase motor-current signature at the condition of the motor working at a speed of 314 rpm and Figure 10. shows the FFT of B and C phase motor-current signature at the condition of the motor working at a speed of 376 rpm.

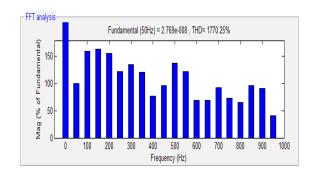
From Figure 7 and Figure 9, it is obvious that the FFT signatures of the phase-A and the salutary motor FFT signature are not matching.



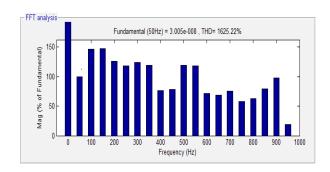
**Figure 5.** A phase Motor-current signature with Fault at IGBT gate terminal in phase A.



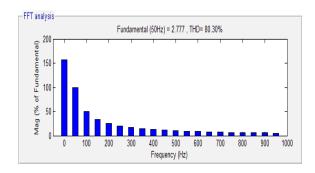
**Figure 6.** B and C phase Motor-current signature with Fault at IGBT gate terminal in phase A.



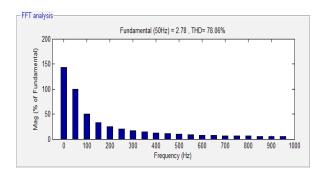
**Figure 7.** FFT of A phase motor current signature when motor is at a speed of 376 rpm



**Figure 8.** FFT of A phase motor current signature when motor is at a speed of 314 rpm



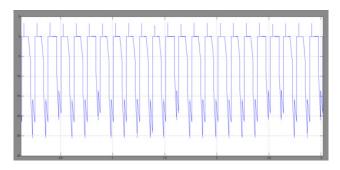
**Figure 9.** FFT of B and C phase motor current signature the motor is at a speed of 314 rpm



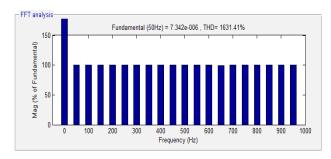
**Figure 10.** FFT of B and C phase motor current when signature when the motor is at a speed of 376 rpm

# 3.2 One IGBT in the Inverter Section is Blown Off

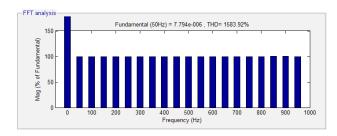
The IGBT in the upper section of phase A was replaced and a high resistance is introduced for the simulation of the condition in the system. This condition in simulation can be done by the addition of the high resistance along with one of the six IGBTs. The motor -current signatures are displayed and FFT profiles are obtained for analyzing and comparing with the salutary motor drive system. The current-signatures of the motor are shown in Figure 11 and corresponding FFT profile with motor working at a speed of 314 rpm and 376 rpm are showed in the Figure 12 and Figure 13 respectively.



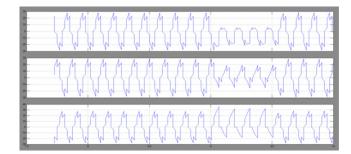
**Figure 11.** Current-profile of motor in phase A when one IGBT is blown.



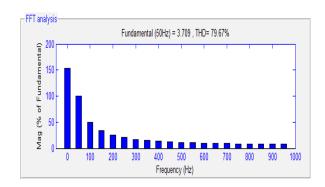
**Figure 12.** FFTs of Motor-current signature of phase A when the motor is at speed 314 rpm



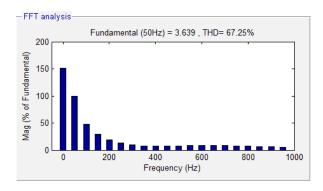
**Figure 13.** FFTs of Motor-current signature of phase A when the motor is at speed 376 rpm



**Figure 14.** Current profiles of motor in phase A, Band C when line to ground fault occurs in phase A



**Figure 15.** FFT of motor-current profile of phase A when line to ground fault occur in phase A, the motor is at speed 314 rpm.



**Figure 16.** FFT of motor-current profile of phase A ground fault occur in phase A, the motor is at a speed of 376 rpm.

# 3.3 Line to Ground Fault Occurs at the Motor Terminal's One Phase

A switch is introduced in the phase A for this type of simulation. At first open condition is made in the switch, i.e. phase-A is a healthy. A fault of line to ground is created at Phase-C. Here the fault is occurred in the period from 9s to 9.5s .The motor-current profiles are displayed. To the motor current signatures, FFT is applied to obtain frequency domain. Frequency domain of three phases of

current signatures of motor are shown in the Figure 14 Figure 15 shows the FFT of motor current profile at phase A when line to ground fault occur in phase A and the motor is at speed 314 rpm and Figure 16 shows the FFTs of motor current profile of phase-A when line to ground fault occur in phase A and the motor is at speed 376 rpm.

### 4. Conclusion

In order to discriminate various fault states, frequency domain analysis technique was used. The frequency responses for various faultly conditions were analysed and their FFTs were compared to distinguish the fault's nature. Frequency responses of the three disparate faulty conditions, one of the six IGBT's gate signal is open circuited, one IGBT in the inverter section is blown off, line to ground fault occurs at the motor terminal's one phase, are distinctly different. Hence, by analyzing FFT profiles, we can identify which type of fault is occurred.

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