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Induction motor- fault diagnostic system simulation and analysis

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ABSTRACT

Induction motor faults are diagnosed using Motor Current Signature Analysis (MCSA) since the spectrum of the input stator current signals hold the information of the faults present in the motor. Frequency of the fault signals depend on the slip of the induction motor, thus it depends on the actual speed of the rotating part of the motor. It is efficient to rely on this technique to build a tool for finding the faults. Also this follows the IEEE standards, which are the base of this work. Faults of induction motor are diagnosed at the earliest stage possible since, they are the supreme clients of energy in an industry. Almost 50-60% of the total energy consumption is due to induction motors. This work is focused on a virtual fault simulator and a virtual fault analyzing tool developed using LabVIEW, analog output and input cards. Real-time validation has not been done since the limitations of this virtual tool have to be rectified. Motor Current Signature Analysis (MCSA) is suitable method to diagnose most of the faults without any sensors.

Keywords: Induction motor, Faults detection, MCSA, Lab VIEW.

1. INTRODUCTION

In both induction and synchronous motors, the AC power supplied to the motor's stator creates a magnetic field that rotates in time with the AC oscillations. Whereas a synchronous motor's rotor turns at the same rate as the stator field, an induction motor's rotor rotates at a slower speed than the stator field. The induction motor stator's magnetic field is therefore changing or rotating relative to the rotor. This induces an opposing current in the induction motor's rotor, in effect the motor's secondary winding, when the latter is short-circuited or closed through external impedance. The rotating magnetic flux induces currents in the windings of the rotor in a manner similar to currents induced in a transformer's secondary winding. The currents in the rotor windings in turn create magnetic fields in the rotor that react against the stator field. Due to Lenz's Law, the direction of the magnetic field created will be such as to oppose the change in current through the rotor windings. The cause of induced current in the rotor windings is the rotating stator magnetic field, so to oppose the change in rotor-winding currents the rotor will start to rotate in the direction of the rotating stator magnetic field. The rotor accelerates until the magnitude of induced rotor current and torque balances the applied load. Since rotation at synchronous speed would result in no induced rotor current, an induction motor always operates slower than synchronous speed. The difference, or "slip," between actual and synchronous speed varies from about 0.5 to 5.0% for standard Design B torque curve induction motors. The induction machine's essential character is that it is created solely by induction instead of being separately excited as in synchronous or DC machines or being self-magnetized as in permanent magnet motors. For rotor currents to be induced, the speed of the physical rotor must be lower than that of the stator's rotating magnetic field (n_s); otherwise the magnetic field would not be moving relative to the rotor conductors and no currents would be induced. As the speed of the rotor drops below synchronous speed, the rotation rate of the magnetic field in the rotor increases, inducing more current in the windings and creating more torque. The ratio between the rotation rate of the magnetic field induced in the rotor and the rotation rate of the stator's rotating field is called slip. Under load, the speed drops and the slip increases enough to create sufficient torque to turn the load. For this reason, induction motors are sometimes referred to as asynchronous motors. Induction motor can be used as an induction generator, or it can be unrolled to form a linear induction motor which can directly generate linear motion. Induction motor cut way view as shown in Figure No: 1.1

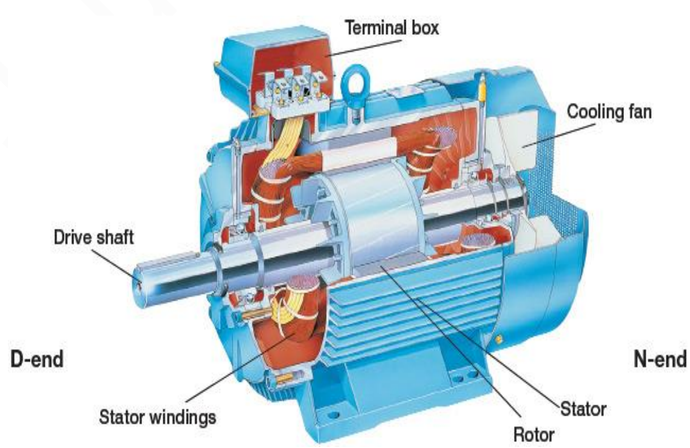


Figure 1.1 Induction Motor Cut Way view

1.1. Synchronous speed

An AC motor's synchronous speed, n_s, is the rotation rate of the stator's magnetic field, which is expressed in revolutions per minute as

$$N_s = 120 \times f / p \quad \text{(Rpm)}$$

Where f is the motor supply's frequency in hertz and p is the number of magnetic poles. That is, for a six-pole three-phase motor with three pole-pairs set 120° apart, p equals 6 and N_s equals 1,000 RPM and 1,200 RPM respectively for 50 Hz and 60 Hz supply systems.

1.2 Slip

Slip, is defined as the difference between synchronous speed and operating speed, at the same frequency, expressed in rpm or in percent or ratio of synchronous speed. Thus

$$s = N_s - N_r / N_s$$

where$_{ns}$ is stator electrical speed, $_{nr}$ is rotor mechanical speed. Slip, which varies from zero at synchronous speed and 1 when the rotor is at rest, determines the motor's torque.

Since the short-circuited rotor windings have small resistance, a small slip induces a large current in the rotor and produces large torque. At full rated load, slip varies from more than 5% for small or special purpose motors to less than 1% for large motors. These speed variations can cause load-sharing problems when differently sized motors are mechanically connected. Various methods are available to reduce slip, VFDs often offering the best solution.

2. TYPES OF FAULT IN INDUCTION MOTOR

Faults in induction motor commonly categorized into two types namely electrical and mechanical faults. Electrical fault are occur due to problems occurring in winding and sometimes it related to rotor problems. Mechanical faults are occurring due to air gap eccentricity, shaft misalignment, and load faults. Faults in induction motor commonly due above faults are bearing faults, Air gap eccentricity, Short turn windings, Rotor faults, unbalanced supply voltage, Load torque fluctuation. These faults can analyzed using various techniques such as vibration monitoring ,thermal monitoring, acoustic monitoring but problem defining that it will be working using sensors and it restricted to use real time system due to cost effective of sensors. The above types of faults such as bearing, the stator or armature faults, the broken rotor bar and end ring faults of induction machines and the eccentricity-related faults are the most prevalent ones and thus demand special attention. These faults produce one or more of the symptoms as follows:

- Unbalanced air-gap voltages and line currents;
- Increased torque pulsations;
- Decreased average torque;
- Increased losses and reduction in efficiency;
- Excessive heating.

3. CURRENT SIGNAL ANALYSIS

The 'Current Signature Analysis' is a technique that is based on current monitoring of induction motor ; therefore it is not very expensive. The current signature analysis uses the current spectrum of the machine for locating characteristic fault frequencies. When a fault is present, the frequency spectrum of the line current becomes different from healthy motor. Such a fault modulates the air-gap and produces rotating frequency harmonics in the self and mutual inductances of the machine. Signature analysis is the procedure of acquiring the motor current and voltage signals, performing signal conditioning and analyzing the derived signals to identify the various faults. Motor current acts as an excellent transducer for detecting fault in the motor. Spectrum analysis of the motor's current and voltage signals can hence detect various faults without disturbing its operation.

3.1. Motor Current Signature Analysis

The proposed technique uses the Motor Current Signature Analysis for finding the faults in the induction motors. MCSA involves analysis of the stator current signal of the induction motor and this method is simple and easy since it directly uses the current signal of the motor. In current monitoring, no additional sensors are necessary. This is because the basic electrical quantities associated with electromechanical plants such as currents and voltages are readily measured by tapping into the existing voltage and current transformers that are always installed as part of the protection system.

As a result, current monitoring is non-intrusive and may even be implemented in the motor control center remotely from the motors being monitored. MCSA is the most common form of signal analysis technique used in electric monitoring. In literature review, it has been shown that there is a relationship between the mechanical vibration of a machine and the magnitude of the stator current component at the corresponding harmonics. For increased mechanical vibrations, the magnitude of the corresponding stator current harmonic components also increases. This is because the mechanical vibration modulates the air gap at that particular frequency.

These frequency components then show up in the stator inductance, and finally in the stator current. For this reason, the MCSA can be used to detect rotor and bearing faults. he first step for condition monitoring and fault diagnosis is to develop an analysis technique that can be used to diagnose the observed current signal to get useful information. MCSA detects changes in a machines performance by examining the current signals. It uses the current spectrum of the machine for locating characteristic fault frequencies. The spectrum may be obtained using a Fast Fourier Transformation (FFT) that is performed on the signal under analysis. The fault frequencies that occur in the motor current spectra are unique for different motor faults. This method is the most commonly used method in the detection of common faults of induction motors.

4. FAULTS SIMULATOR

Faults simulator is developed with user inputs such as amplitude and selection of faults [3,4] Addition of user inputs such as amplitude of each faults and peaks detection task is done to enhance the use of the fault simulator. The output of the simulator is fed to the DAQ assistant in LabVIEW. Thus from the card's adapter (wiring board) inputs are taken and fed to analog input card. The communication is initially tested using an oscilloscope such that the signals generated using the simulator is acquired properly. It is first developed with Matlab and reproduced in LabVIEW. The functional block diagram of the simulator developed in Matlab is shown in Figure No.1.2

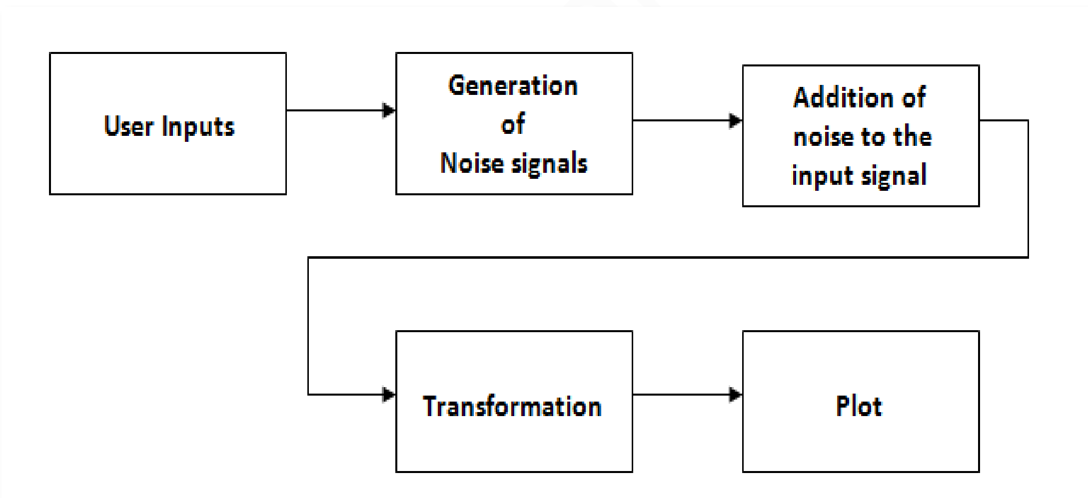


Figure 1.2 Functional block diagram of Simulator

5. FAULTS ANALYZER

Inputs through PCI-1716 are processed to diagnose the fault present in the induction motor. Fault analyzer acquires the signal and performs spectral transformation for the same. After the transformation the significant peaks of the acquired signal is taken as a separate data, which is processed and fed to the fuzzy inference system. Fuzzy inference system analyzes the data according to the rule base and gives the final output based on the fault type. The processing of data is the key part of the fault analyzer after which the fuzzy inference system.

5.1. Fuzzy Logic in Faults Detection

The diagnosis of rotor broken bars when an induction machine is fed or not by an unbalanced line voltage. These signatures are given by the complex spectrum modulus of line current. In order to make the diagnostic, a genetic algorithm was used to keep the amplitude of all faulty lines. A fuzzy logic approach allowed to conclude to the load level operating system and to inform the operator of the rotor fault severity. Several experimental results proved the performance of this method under various load levels and various fault severities. Notwithstanding, this approach requires a steady-state operating condition as shown in Figure No.1.3.The rule base receives two crisp input values from temperature and humidity sensors, divides the universe of discourse into regions with each region containing two fuzzy variables, fires the rules, and gives the output singleton values corresponding to each output variable. Three de-fuzzifiers are used to control the actuators; cooler fan, water pump and room exhaust fan.

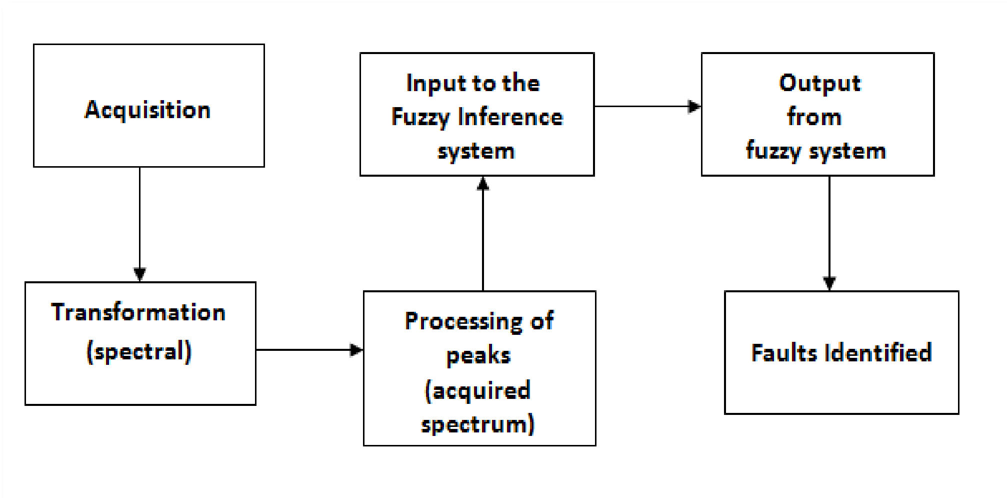


Figure 1.3 Fault Analyzer Processes

A system based on fuzzy logic allows the transformation of heuristic and linguistic terms into numerical values via fuzzy rules and membership functions and is able to approximate the complex relationships related to a diagnostic task. To develop a specific example, the detection of broken rotor bars fault severity is considered by utilizing Mamdani-type fuzzy inference and using as input variables the fault components and at frequencies provided into the FS by the expert system. A model-based analysis, previously performed on the 500-W test motor, gives the guidelines for the choice of the linguistic variables to evaluate the fault components severity.The simulated data suggest considering “small” to amplitude up to 50 dB, both “small” and “medium” up to 40 dB, etc., until 30 dB that can be considered “large.” By selecting generalized bell-shaped membership functions with suitable parameters, it is possible to obtain the membership functions for the two fault components. At this stage, the output fuzzy set related to the broken bars must be defined.

6. INSTALLATION AND INTERFACING OF DAQ CARDS

The driver software is installed first to the system before installation of the cards into the system. This is followed by the installation of supporting drivers for LabVIEW and the data acquisition cards. After these installations the cards are inserted into the system as shown in the Figure No.1.4.After the successful installation of the DAQ cards they are tested for the proper communication using ‘Advantech navigator’ proprietary software developed for the testing of their device. This may be also called as device manager for the Advantech cards. This is done by making proper connection using the wiring boards, function generator and oscilloscope.

The connections are made using recommended adapters and wiring boards. As they are the vital parts for the working of the system they are set properly without any errors. These wiring boards are connected to each other such that the output from one card could be given as an input to the other. Data acquisition is another major part of the system, as the major part of system could be completed only by setting proper communication between the faults simulator and the controller. This could be done by proper selection of the card that is compatible with the software tool that is chosen for the development of the system. This can be done according the system requirements and the application specified.

Major factor that is to be considered is the type of signal to be transmitted or received. There are number of data acquisition cards available for serving this purpose. It is important to choose the card before the selection of tool, as the tool compatibility issues could be avoided by following this procedure shown in figure 4.1. The cards such as PCL-726, PCI-1710 are available commercially for serving this purpose. But they are found with some compatibility limitations.

Figure 1.4. Installation of DAQ cards

6.1. PCL-726

The PCL-726 provides 6-channel analog outputs, 16-channel digital inputs and 16-channel digital outputs add-on card for the IBM Personal Computer and compatible computers. It is designed for industrial control applications requiring analog outputs voltage and current with 12-bit resolution in rugged environment. In addition to the 6 analog outputs, the PCL-726 has 16 digital inputs and 16 digital outputs, all of the digital channels are TTL compatible. The PCLD-782 (16-bit Isolation digital input board) and PCLD-785 (16-bit relay output board) are designed for going with the digital input and output connection.

6.2. PCI-1710

The PCI-1710/1710HG features an automatic channel/gain scanning circuit. The circuit uses software, controls multiplexer switching during sampling. The on-board SRAM stores different gain values and configuration for each channel. This design lets you perform multi-channel high-speed sampling (up to 100 kHz) with different gains for each channel with free combination of single-ended and differential inputs. The PCI-1710/1710HG has an on-board FIFO buffer which can store up to 4K A/D samples. The PCI-1710/1710HG generates an interrupt when the FIFO is half full. This feature provides continuous high- speed data transfer and more predictable performance on Windows systems. The PCI-1710/1710HG provides a programmable counter for generating a pacer trigger for the A/D conversion. The counter chip is an 82C54 or equivalent, which includes three 16-bit counters on a 10 MHz clock. One counter is used as an event counter for counting events coming from the input channels. The other two are cascaded together to make a 32-bit timer for a pacer trigger as shown in Figure No.1.5 and 1.6

Figure 1.5 Hardware Module

Figure 1.6 DAC Interfacing

7. FUZZY INFERENCE SYSTEM

Fuzzy inference system is another important part of this fault analyzer. The data acquire has to be processed according to the requirements of the inference system. The number of input variables and their membership functions are taken according to the data collected for individual faults using separate simulators.

7.1. Frequency Analysis

7.1.1. Peak Frequency

For every 1 percent change in slip, the difference between the lower and higher frequency of peaks changes as shown in Figure No.1.7.

Faults		Difference Change(HZ)	Range(HZ)
Rotor Bar		4	4-40
Load Torque		0.5	45-49.5
Short Run		0.5	22.5-24.75
Air Gap		0.005	0.45-0.495
Bearing	Outer	0.016	1.44-1.584
	Inner	0.024	2.16-2.376

Figure 1.7 Frequency Changes for faults

7.1.2. Analyzing Faults Frequency Range for Induction Motor

The peaks are obtained for each of the induction motor faults that are generated using the simulator. The spectrum differs for each faults of air gap eccentricity, bearing fault, short turn fault thus it is possible to diagnosis the faults in induction motorand the healthy motor frequency should follow as mentioned below

- Frequency range for air gap is22.5-24.75 HZ
- Frequency range for short turn is 0.45-0.495HZ
- Frequency range bearing
- outer : 44-1.584 HZ
- inner :2.16-2.376HZ

AIR GAP WAVE FORM

a.healthy Motor Graph **b.unhealthy Motor Graph**

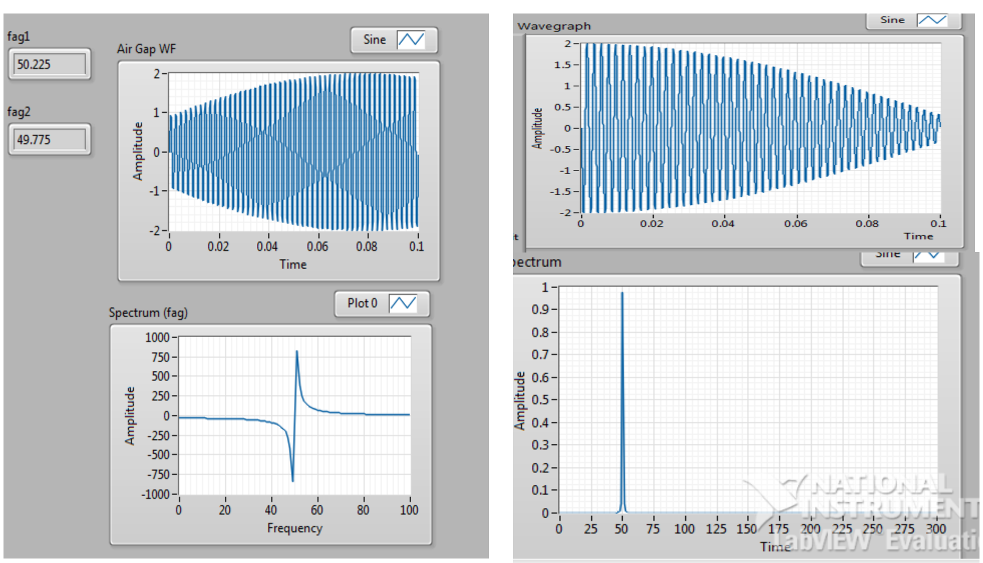
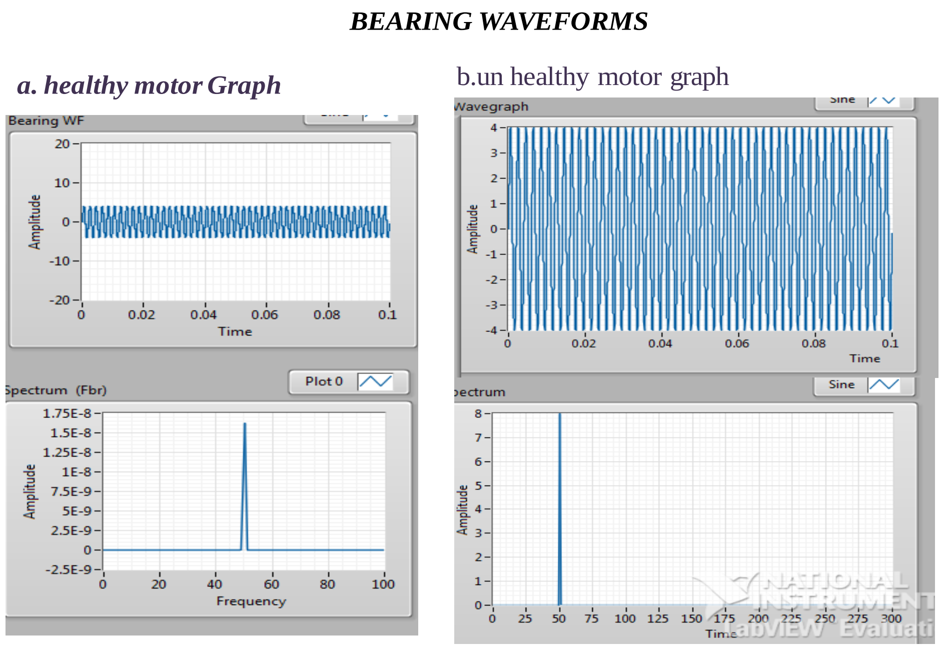


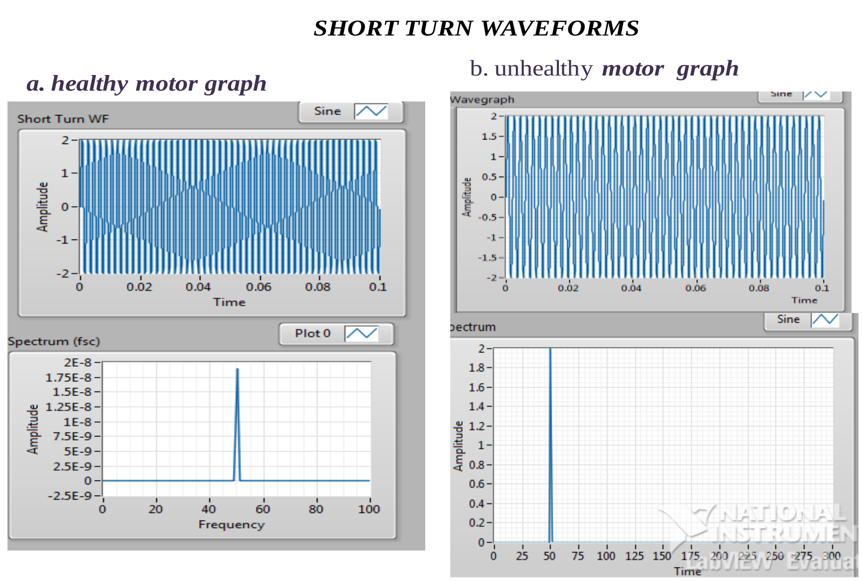
Figure 1.8 Air Gap Eccentricity Fault; a. without fault waveform for Air Gap Eccentricity b. with fault waveform for Air Gap Eccentricity

Figure 1.9 Bearing Fault



a. Without fault waveform for Bearing; b. With fault waveform for Bearing

Figure 1.10 Short Turn Faults



a. without fault waveform for short turn; b. with fault waveform for short turn

8. WORKING OF SYSTEM TO DIAGNOSIS OF ROTOR BAR FAULT, LOAD TORQUE FLUCTUATION AND UNBALANCED SUPPLY VOLTAGE

The system was designed for a slip range of about 1-10%. On testing the system responded with some good results even beyond this limit. The Figure No 1.12 shows the faults, combinations of faults and their limits of slip to which the system responds well. Unbalanced supply voltage could be detected for all possible slip, as there are no characteristic frequency bands for that. The frequency or the peak to indicate its presence will be in multiples of fifty. These results are inferred using the faults simulator and tabulated in Figure No 1.11. The front panel has indicators to show the fault detected and an array to show the peaks that are detected in the spectrum for the acquired signal. There are indicators to show the status of acquisition and idle condition. The stop button will shut down the whole system when pressed. The dial helps in setting the threshold to make the peak detector to detect peaks above certain amplitude level.

Figure 1.11 Slip observed

Fault(s)	Maximum slip (%)	Minimum slip (%)
Rotor bar	10.466	0.866
Load torque fluctuation	12	0.1
Unbalanced supply voltage	∞	∞
Rotor bar, Load torque Fluctuation	10.2	0.866
Rotor bar, unbalanced supply voltage	10.466	0.933
Load torque, unbalanced supply	11.933	0.01
Rotor bar fault, load torque, unbalanced supply	10.133	0.933

The system is developed for a working slip range of 1 to 10%. The number of faults is limited to three. Only threshold is used for limiting the noise amplitude and considerations should be made for some other noise reducing techniques. There is a slight delay in the settling of the system after start-up, this can be minimized by evaluation using the data stored in the buffer of the analog input card. But the system works well for faults with severity higher than certain limit (this is known when tested with real-time current signals).

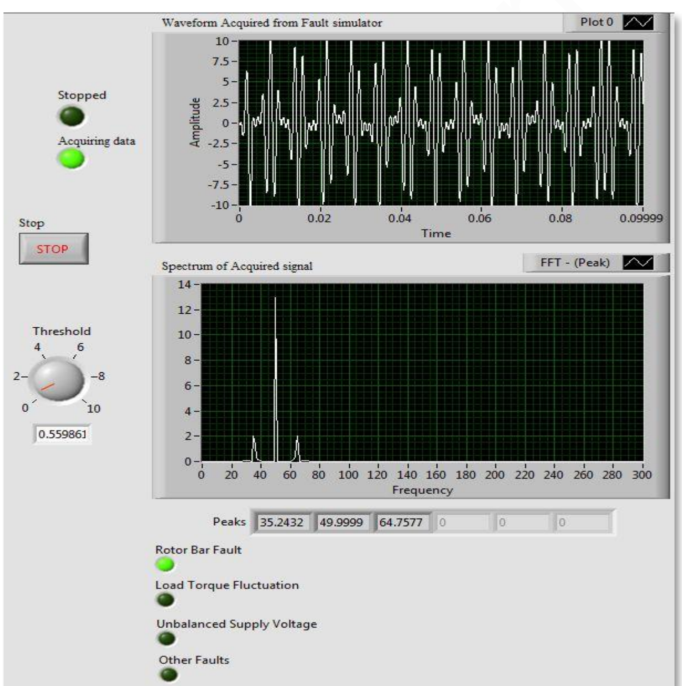


Figure 1.12 Rotor Bar Fault

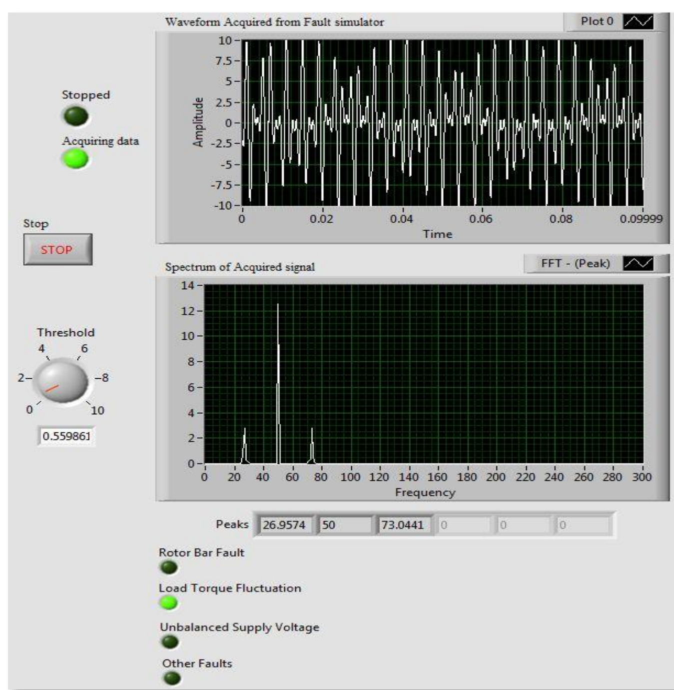


Figure 1.13 Load Torque Fluctuation

The fault simulator is fed with the frequency spectrum expressions of the major faults of induction motor, which is the basic step for the development of simulator. The principle behind this simulator is that, it generates noise signals using the spectrum expressions. This is then added to the input signal, thus the signals of induction motor faults are created. These signals are subjected to fast Fourier transform and spectral outputs of the faults are taken as output of the simulator. The fault analyzer consists of three different parts in the sequence of its operation. Initially acquire the signal from the DAQ card and it wills analysis the spectral transformation and peak detection. Then a peak acquired is to be processed so that it is used in the conditional statements. The fault analyzer is tested using the virtual fault simulator. The input for the system is from DAQ assisted in Lab view, which is then communicating with card PCI-1716.As communication carries, some noise amplitude. The peak detector detects number of peaks occurring. Thus to limit the amplitude, threshold is used, So that the peaks occurring over certain value of the amplitude can be detected. Thus the significant peaks are separated and used for further processing. There is a need for better filtering to get rid of the noise that may occur when tested using real time signal. But this works well when the faults are severe occurring. Based on the current work the following faults from the induction motor such as rotor bar faults, load torque fluctuation and unbalanced supply voltage have been obtained as shown in Figure No.1.12, 1.13 and 1.14.

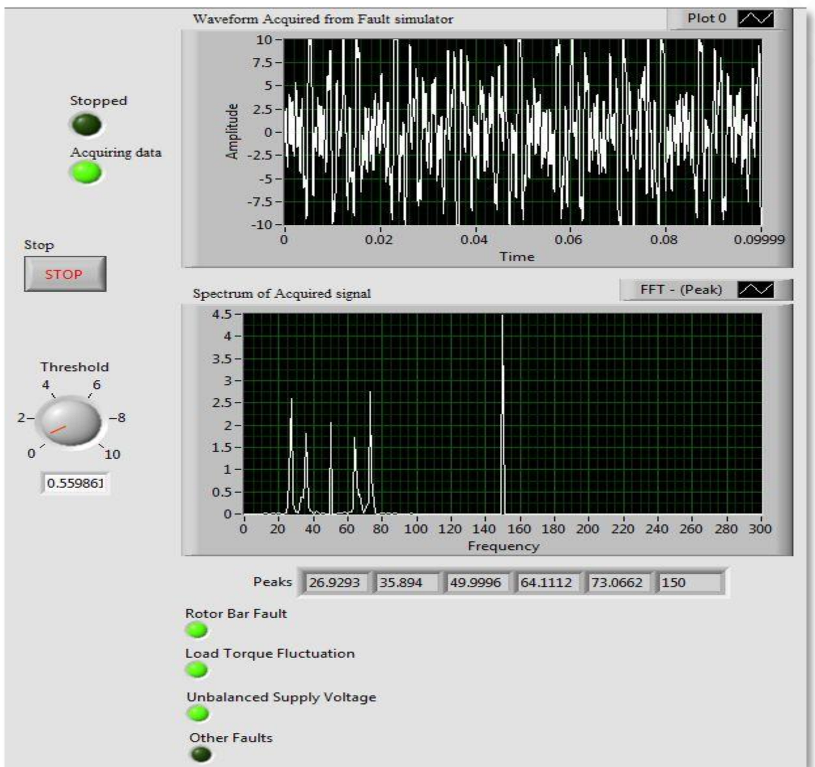


Figure 1.14 Unbalanced Supply Voltage

9. FUTURE SCOPE

Though the system works well for the detection of faults within the specified limits, considerations have to be made in the introduction of special filtering techniques in order to remove the frequency components that may arise due to external factors. The limitations of the system proposed was discussed with some scope that may help in enhancing the work in future. This has to be done before the development of the system for online monitoring. All possible faults should be made available to enhance the novelty of the system. Techniques should be modified to overcome the interference between the frequency components of the faults. Communication between the simulator and the controller should be made possible which could be achieved only by finding a data acquisition card. The controller has to be designed for analyzing the input data with the predefined data set by the user. The controller performs this analysis to diagnose the faults in induction motor. The proposed instrument has a display, a keypad for making some user inputs and interfaced with fault simulator. Thus, it will work as standalone device.

10. CONCLUSION

A new logical approach for the detection of induction motor faults was presented. Systematic flow of the approach was explained with data collected using virtual simulator developed for individual faults of induction motor. Results showed that the system could work well for faults with the specified limitations. Based on this systematic approach the fault such as air gap eccentricity fault, bearing fault , short turn fault ,rotor bar fault , load torque fluctuation, unbalanced supply voltage were diagnoized and compared with the standard analysis. This system found to work even beyond limits for certain faults provided they are not affected by some other factors such as load and noise. As the faults were simulated virtually the developed system provided better results while testing.

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