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# Comparative Analysis between Proportional Integral Controller and Wavelet Controller for the Fault Detection in Induction Motor

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***Abstract:*** **Squirrel cage Induction motor is widely used in industries because high efficiency, low cost, and roughest construction. Condition monitoring of induction motor have been a challenging task for the Engineers researchers mainly Industries. This thesis discusses comparative analysis of the fundamental fault in induction motor of PI and wavelet transform analysis. The PI & wavelet transform is considered the most popular fault detection method now a day because it can easy detect the common fault in induction machine such as turn to turn s/c, broken rotor bar, bearing deterioration & open circuit faults etc. The overall problems are subdivided into two key modules, (a) Operation and control, & (b) Fault diagnosis. In this research used the vector control method for speed control. In Induction motor different types of fault are presence and basically divided in to two categories (a) Electrical faults (B) Mechanical faults. There are many condition monitoring methods, including vibration monitoring, thermal monitoring, chemical monitoring, acoustic emission monitoring, but all these monitoring methods required expensive sensors, and specialized tools where current monitoring out of all does not required additional sensors. In asynchronous machine many types of mechanical faults are created like that rotor bar fault, short winding fault, open winding fault, bearing fault, and over load fault. The Discrete Wavelet Transform was used to extract the different harmonics component of stator currents. The key advantage of DWT is local representation (in both Time and frequency domain) of the current signal for normal and faulty modes, and PI controller is provide the variable data by changing the value of Kp and Ki. In these research present two types of faults are consider, a short stator winding fault and another is broken rotor bar fault**

## I. INTRODUCTION

### 1.1 OUTLINE OF THESIS REPORT

The studies of induction motor behavior during abnormal condition due to presence of faults and possibility of diagnose this abnormal condition have been a challenging topic for the many electrical machine researchers. There are many conditions monitoring method including vibration monitoring, thermal monitoring, chemical monitoring acoustic emission, but all these monitoring method required expensive sensor or specialized tools where as current monitoring out of all does not required additional sensors. The first methods utilized to detect motor failures, such as chromatographic analysis, noise analysis, temperature analysis, and vibration analysis have been slowly changing to new on-line monitoring techniques for electrical equipments. The various advanced signal processing techniques such as Fast Fourier Transform, Short Time Fourier Transform, Gabor Transform, and Wavelet Transform are used to diagnose the faults of induction motor. A suitability of the signal for different type of faults is also discussed in detail. FFT is easy to implement but the drawback of this technique is that it is not suitable for analyzing transient signals. Although Short-Time Fourier Transform (STFT) can be used for analyzing transient signals using a time-frequency representation, but it can only analyze the signal with a fixed sized window for all frequencies, which leads to poor frequency resolution. However, Wavelet Transform can overcome this problem by using a variable sized window.

It is important to detect the fault in induction motors in an early stage itself due to the cut-throat competition and stringent reliability standards. As far as the stationary signals are concerned, conventional signal processing techniques such as FFT analysis, cosine transform etc. were used earlier to analysis the fault condition and are proved to be working perfectly. Among the total induction motor faults, around 30-40 % are related to the stator winding insulation and core. It can also be seen that a large portion of stator winding-related faults are initiated by insulation failures in several turns of a stator coil within one phase [1]. Among the possible causes, thermal stresses are the main reason for the degradation of the stator winding insulation. Generally, stator winding solution thermal stresses are categorized into three types: aging, overloading and cycling [2]. The contamination of the insulating materials used in the induction machines, combination of thermal overloading and cycling, transient voltage stresses, mechanical stresses etc. are the other possible reasons for the deterioration of the insulation. Electrical stresses, mainly related to the machine terminal voltages, also cause insulation degradation. Among the various electrical stresses, partial discharges (PDs) in the windings and transient voltages at the machine terminals are considered as the major contributors. Broken rotor bars, vibration resulting from unbalance in rotor, air-gap eccentricity, coil movement, loose bearings, worn bearings, etc. are some of the mechanical reasons, accelerating the insulation degradation [2]. With the increased emphasis on energy conservation and high performance motor control, the use of pulse width-modulated voltage source inverters (PWM-VSIs) has grown at an exponential rate. This has made the stator windings open to higher electrical stresses. High speed PWM operations introduce high rate of rise of transient voltages at the machine terminals. Current in the stator winding produces a force on the coils that is proportional to the square of the current. This force is at its maximum under transient overloads, causing the coils to vibrate at twice the synchronous frequency with movement in both the radial and the tangential direction. This movement weakens the integrity of the insulation system [3]. Contaminations due to foreign materials can lead to adverse effects on the stator winding insulation. Stator winding-related failures can be broadly classified into the following four groups: open-circuit faults, turn-to-turn, line-to-ground, line-to-line, and single or multi-phase winding. Among these four failure modes, turn-to-turn faults (stator turn faults) have been considered as the most challenging one since the other types of failures are usually the consequences of turn faults. It can be seen that among the faults, the inter turn faults are the most difficult fault to detect at an early stage itself. To solve the difficulty in detecting turn faults, several methods have been suggested [3]-[5], [8]. Because of this, remarkable improvements have been achieved in the area of stator turn fault detection. Nevertheless, the question about the delay time between a turn fault and other severe failures still remains to be answered.

The internal asymmetry due to inter turn fault will cause the circulation of extremely high currents in the portion of the winding affected by the fault, thus contributing to the degradation of other portions of the windings. The lead time between the start of the fault and the complete failure of the machine depends on several factors, namely the initial number of shorted turns, winding configuration, rated power, rated voltage, environmental condition etc. [4]. If the fault can be predicted at an early stage, a catastrophic effect can be avoided, the machine can be protected as well as the safety of the working personnel shall be ensured. In the case of a stator turn fault, a large circulating current will be produced, leading to excessive heat generation in the shorted turns. The heat, which is proportional to the square of the circulating current, accelerates the severity of the fault to a destructive level [5]. If this fault is not detected at the early stage it will be propagated and will lead to phase to ground or phase-to-phase fault which in turn may lead to the damage of the machine. As the inter turn fault is one of the major reasons for the machine failure, this paper deals with an early and efficient method for its detection using wavelet based technique. Intensive investigations on stator turn faults revealed that the faults introduce specific changes in the electric properties of the machines. This has created a great deal of scope to develop methods for the detection of a turn fault [3]-[5]. The stator faults and their causes, and detection techniques, latest trends, and diagnosis methods supported by the artificial intelligence, the microprocessor, the computer, and other techniques in monitoring and protection technologies have been proposed. The major intricacy is the lack of an accurate model that describes a fault in the motor. Moreover, experienced Engineers are often called upon to interpret measured and/or observed data that are frequently inconclusive or unconvincing. PI controller is also another method to find out the fault detection in induction motor by using vector controller of speed. Propositional integral is a conventional method but broadly used in field and industries.

### 1.1.1 BACKGROUND OF PROJECT

Induction motor have been widely use in high-performance electrical drive and industries. There are many differences Induction Motor in the market and all with it good and bad attributes. Such bad attribute is the lag of efficiency. In order to overcome this problem fault detection is introduce to the system. There are also many types of fault detector used in the industry; such fault detector is PI fault detector is a generic loop feedback mechanism widely used in industrials system. A PI attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly. PI controller is user friendly, low cost and easy controller that's way we can used the PI controller used in fault detection.

### 1.1.2 OBJECTIVE

The objectives of this project are:

i. To fulfill the requirement for the Engineering Project.
ii. To explorer and apply the knowledge gain in lectures in to practical applications.
iii. To fault diagnosis the fault of Induction motor with PI and comparing with wavelet transform using MATLAB simulation software.
iv. To design the PI and Wavelet transform and tune it using simulation
v. To compare and analyze the result between PI and Wavelet transform simulation result using Induction motor in MATLAB.
vi. This research work is to investigate how the presence of common faults, such as rotor bar fault, short winding fault, air gap eccentricity, bearing fault, load fault, affect on different fault frequencies under different load conditions .
vii. In this research work, condition monitoring and fault detection of induction motors is based on the signal processing techniques. The signal processing techniques have advantages that these are not computationally expensive and these are simple to implement. Therefore, fault detection based on the signal processing techniques is suitable for an automated on-line condition monitoring system. Signal processing techniques usually analyze and compare the magnitude of the fault frequency components, where the magnitude tends to increase as the severity of the fault increase. Therefore, the third aim of this thesis is to utilize the various signal processing techniques for detection of common faults of induction motor.
viii. Signal processing techniques have their limitations. For example, some faults could be not diagnosed using Fast Fourier Transform, if the loading condition is too low or the fault is not too severe. Therefore, the final aim of this thesis is to investigate new features using different techniques such as Wavelet Transform (WT), to find better features for detecting common faults under different loading conditions.

### 1.1.3 SCOPE OF WORK

i. Design and produce the simulation of the PI and Wavelet transform
ii. Simulation and compare between the PI and Wavelet transform with the modeling of the Induction motor.

### 1.1.4 PROBLEM STATEMENT

The problem encounter when dealing with Induction motor with all conversational method is lag of efficiency and losses. In order to eliminate this problem, diagnosis is introduce with the wavelet controller to the system. There's few type of fault detector but in project, PI is chosen as the fault calculator for the Induction motor and make comparing with the Wavelet transform. This is because Wavelet transform helps get the output with eliminated noise, where we want it in a short time with minimal overshoot and little error. We used the white noise for an introduce as error component. Many practical Fault Diagnosis issues (Motor fault detector problems):

- Change in load dynamics
- Noise propagation along a series of unit processes
- Unknown parameters
- Insulation problem
- Temperature effect

Major problems in applying a conventional fault diagnosis in a high speed and they are affected of non-linearity in a Induction motor. The non-linear characteristics of Induction motor such as saturation and friction could degrade the performance conventional method. Many advance method are developed such as Fuzzy Controller, Model reference adoptive controller, have been developed to reduce these effect. However, the performance of these methods depends on the accuracy of system models and parameters. Generally, an accurate non-linear model of an actual Induction motor is difficult to find out, and parameter values obtained from system identification may be only approximate values.

### 1.1.5 METHODS OF FAULTS DETECTION

- Motor current signature analysis

- Park's vector approach
- Fourier transform
- Short time Fourier transform
- Gabor Transform
- Wigner-Ville Distribution
- Artificial intelligent
- Neural network
- Bayesian theorem
- Fuzzy logic controller

**1.2 LITERATURE SURVEY**

As the induction motors form the major work horse in most of the industries, fault detection of it is always indispensable, as far as the reliability of the system is concerned. Due to this, many of the researchers were attracted towards it and a lot of efforts were put to predict the performance of induction machines, using various modeling or simulation techniques and tools. Fault monitoring techniques of induction motors using stator currents is one among them [10]. For the non stationary conditions of the induction motor, one of the possible fault detection methods is by analyzing the power spectral density in wavelet decomposition of stator current waveform [4]. The theory of instantaneous symmetrical components is used for the detection of insulation faults in a three-phase induction motor [5], [6]. The loci of positive and negative sequence components of currents overlap each other under healthy winding conditions as their major and minor axes coincide [6]. When an inter-turn short circuit occurs, these axes do not coincide. But this method didn’t consider the dynamic nature of the loading conditions, which is a major disadvantage. A multiple coupled circuit approach is also proposed for the modeling of induction motor, which is then extended for the stator fault condition. The evolution of an inter-turn short-circuit causes a spectral component in the line current having a frequency thrice the supply frequency and an increase in the amplitude of the principal slot harmonics [7]. The star point voltage of an induction motor with way-connected stator windings shall also be monitored for the stator fault detection [8]. The online current monitoring system that uses both spectrum analysis of machine line current and Extended Park’s Vector Approach techniques for fault detection and diagnosis in the stator and in the rotor is also available [9]. The major limitation of this method is that it does not have inherent ability to discriminate unbalance supply voltage condition and also cannot predict the severity of faults. A simplified mathematical model of the motor in the presence of stator inter-turn short circuit uses the stationary reference frame as well as clockwise and counterclockwise synchronous reference frames [10]. This will allow the extraction and manipulation of the information contained in the motor supply currents in a way that the effects introduced by the fault are easily isolated and measured [8]. The same method is proposed in direct torque controlled (DTC) induction motor drives [7]. The method in [5] suggests that it is possible to acquire the information on online stator winding turn fault by a simple and robust sensor-less technique based on monitoring an off-diagonal term of the sequence component impedance matrix. The major handicap of this method is the difficulty in on line computation of the change in negative sequence impedance. A traditional electrical model of the induction motor is used for predicting the faults of induction motor, where the typical symptom of 100Hz ripple in electromagnetic torque and the speed is employed [11]. In a current monitoring method for the detection of stator turn fault, the stator winding itself is considered as the sensor [12], [20]. A winding-function-based method for modeling poly-phase cage induction motors with inter-turn short circuit in the machine stator winding suggests that no new frequency component will arrive in the current spectra as a consequence of turn fault but some of the existing frequency components dominate under fault conditions [13]. A transient model for an induction machine with stator winding turn faults is derived using reference frame transformation theory [12]. In all these methods of fault detection [3]–[6], conventional and frequency based signal processing techniques were adapted. In detecting faults on a transmission line [18], another algorithm which uses both entropy and energy of the decomposed signals is suggested. Also, for the fault detection of power system applications such as locating and power quality disturbance classification [19], similar method is suggested. Here the current signals are decomposed and the features are extracted using suitable signal processing methods. A similar method has already been used in biomedical applications like analysis of ECG signals for classifying normal and abnormal functioning of human heart [12]. In the method suggested in this paper, advantages of these techniques are used in the fault detection of induction motor, which uses wavelet transform of stator current to extract the features. In the existing scenario, it is evident from the literature that the demand for timely and efficient fault detection scheme is becoming more significant. The electrical faults in the machine can be effectively detected by motor current analysis where as mechanical faults such as bearing faults and rotor eccentricity can be determined by vibration analysis. Due to the increased relevance of diagnosis of stator related faults, which stands in the second place among the various faults of induction motor, stator inter turn fault detection has been considered in this paper. A MATLAB/SIMULINK model is developed for the three phase induction motor with stator inter-turn fault, which is used to extract the features that can be used for the fault detection. PI controller can be assigned to describe the stator current amplitudes by means of corresponding gain functions

**1.3 INDUCTION MOTOR**

Electrical machines are extensively used and core of most engineering system. These machines have been used in all kinds of industries. An induction machine is defined as an asynchronous machine that comprises a magnetic circuit which interlinks with two electric Circuits, rotating with respect to each other and in which power is transferred from one circuit to the other by electromagnetic induction. It is an electromechanical energy conversion device in which the energy converts from electric to mechanical form. The energy conversion depends upon the existence in nature of phenomena interrelating magnetic and electric fields on the one hand, and mechanical force and motion on the other. The rotor winding in induction motors can be squirrel-cage type or wound-rotor type. Thus, the induction motors are classified into two groups.

- Squirrel-cage and
- Wound-rotor induction motors.

Fig 1.3.1 Induction motor overview

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 transformer's secondary windings. These currents 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 windings. The cause of induced current in the rotor is the rotating stator magnetic field, so to oppose this.

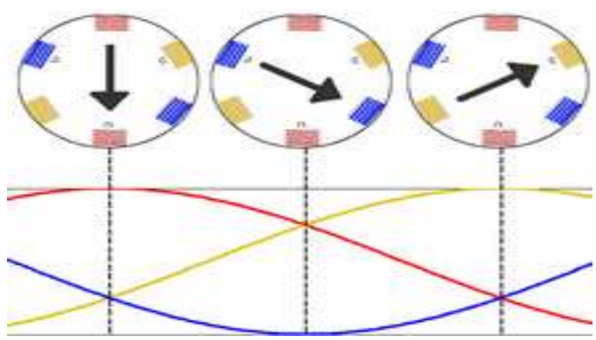

Fig 1.3.2 Current position in IM

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 between actual and synchronous speed and slip varies from about 0.5 to 5% for standard Design B torque curve induction motors. The induction machine's essential characteristic 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 these currents to be induced, the speed of the physical rotor must be lower than that of the stator's rotating magnetic field ($n_s$), or 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 as seen by the rotor (slip speed) 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. An induction motor can be used as an induction generator, or it can be unrolled to form the linear induction motor which can directly generate linear motion. The squirrel cage induction motor consist of conducting bars embedded in slots in the rotor iron and short circuited at each end by conducting end rings.

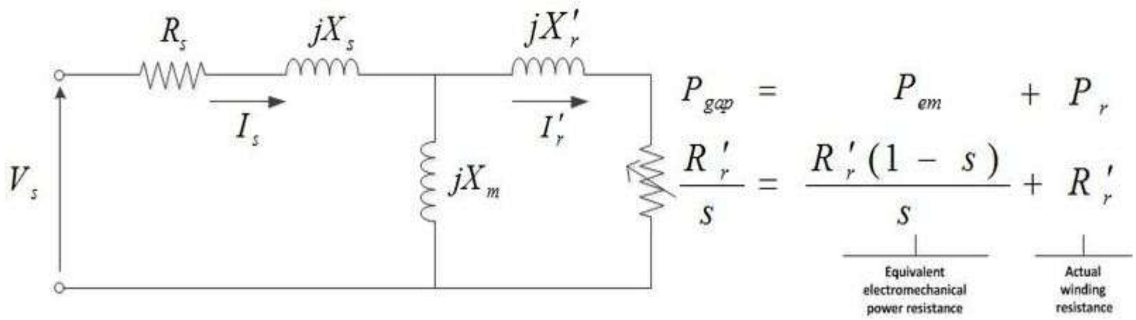


Fig 1.3.3 Modelling of IM

The rotor bars are usually made of copper, aluminum, magnesium or alloy placed in slots. Standard squirrel cage rotors have no insulation since bars carry large currents at low voltages. Another type of rotor, called a form-wound rotor, carries a poly phase winding similar to three phase stator winding. The terminals of the rotor winding are connected to three insulated slip rings mounted on the rotor shaft. In a form-wound rotor, slip rings are connected to an external variable resistance which can limit starting current and associated rotor heating. During start-up, inserting external resistance in the wound-rotor circuit produces a higher starting torque with less starting current than squirrel-cage rotors. This is desirable for motors which must be started often.

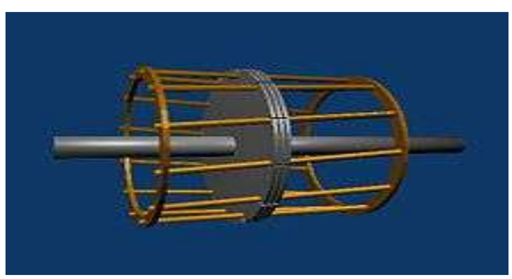

Fig 1.3.4 Squerrial cage IM

The squirrel-cage induction motor is simpler, more economical, and more rugged than the wound-rotor induction motor. A squirrel-cage induction motor is a constant speed motor when connected to a constant voltage and constant frequency power supply. If the load torque increases, the speed drops by a very small amount. It is therefore suitable for use in constant-speed drive systems.

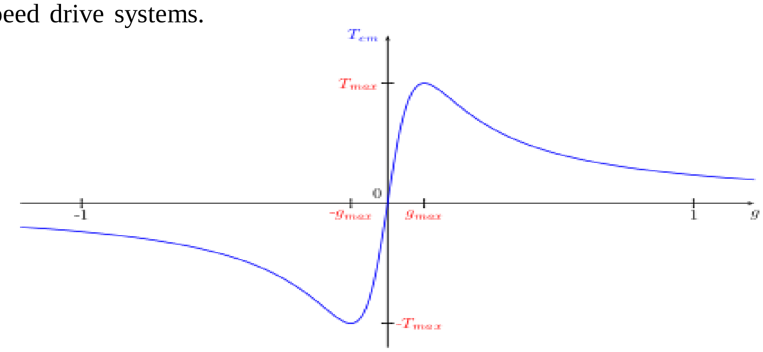

Fig 1.3.5 Charecteristic of IM

On the other hand, many industrial applications require several speeds or a continuously adjustable range of speeds. DC motors are traditionally used in adjustable drive systems. However, since DC motors are expensive, and require frequent maintenance of commutations and brushes. Squirrel-cage induction motors are preferred because they are cheap, rugged, have no commentators, and are suitable for high-speed applications. In addition, the availability of solid state controllers has also made possible to use squirrel-cage induction motors in variable speed drive systems. The squirrel-cage induction motor is widely used in both low performance and high performance drive applications because of its roughness and versatility.

| Major Components | IEEE-IAS % of failures | EPRI % of failures | Allianz % of failures |
|---|---|---|---|
| Bearing related | 44 | 41 | 13 |
| Stator related | 26 | 36 | 66 |
| Rotor related | 8 | 9 | 13 |
| Others | 22 | 14 | 8 |

Table 1.3 Statistics on motor faults/failure modes [11]

Electric machines are frequently exposed to non-ideal or even detrimental operating environments. These circumstances include overload, insufficient lubrication, frequent motor starts/stops, inadequate cooling, etc. Under these conditions, electric motors are subjected to undesirable stresses, which put the motors under risk of faults or failures. There is need to improve the reliability of motors due to their significant positions in applications. According to IEEE Standard 493-1997 [11], the most common faults and their statistical occurrences are listed in Table 1. This table is based on a survey on various motors in industrial applications. According to the table, most faults happen to bearings and windings. A 1985 statistical study by the Electric Power Research Institute (EPRI) provides similar results, i.e., bearing (41%), stator (36%), rotor (9%) and other (14%) [12]. several contributions deal with these faults.

### 1.4 NEED FOR CONDITION MONITORING

Condition monitoring is defined as the continuous evaluation of the health of the plant and equipment throughout its service life. It is important to be able to detect faults while they are still developing. This is called incipient failure detection [1]. The incipient detection of motor failures also provides a safe operating environment. It is becoming increasingly important to use comprehensive condition monitoring schemes for continuous assessment of the electrical condition of electrical machines. By using the condition monitoring, it is possible to provide adequate warning of imminent failure. In addition, it is also possible to schedule future preventive maintenance and repair work. This can result in minimum down time and optimum maintenance schedules [2]. Condition monitoring and fault diagnosis scheme allows the machine operator to have the necessary spare parts before the machine is stripped down, thereby reducing outage times. Therefore, effective condition monitoring of electric machines is critical in improving the reliability, safety, and productivity.

#### 1.4.1 EXISTING CONDITION MONITORING TECHNIQUES

This research is focused on the condition monitoring and fault diagnosis of electric machines. Fault diagnosis is a determination of a specific fault that has occurred in system. Condition monitoring has great significance in the business environment due to following reasons

- To reduce the cost of maintenance
- To predict the equipment failure
- To improve equipment and component reliability
- To optimize the equipment performance
- To improve the accuracy in failure prediction

The condition monitoring of electrical and mechanical devices has been in practice for quite some time now. Several methods have evolved over time but the most prominent techniques are thermal monitoring, vibration monitoring, and electrical monitoring, noise monitoring, torque monitoring and flux monitoring.

### 1.4.2 THERMAL MONITORING

The thermal monitoring of electrical machines is accomplished either by measuring the local or bulk temperatures of the motor, or by parameter estimation. A stator current fault generates excessive heat in the shorted turns, and the heat promulgates the severity of the fault until it reaches a destructive stage. Therefore, some researcher developed thermal model of electric motors. Generally, thermal models of electric machines are classified into two categories [13]:

- Finite element Analysis based model
- Lumped parameter thermal models

FEA based models are more accurate, but highly computational intensive. A lumped parameter thermal model is equivalent to thermal network that is composed of thermal resistances, capacitances, and corresponding power losses. The accuracy of model is generally dependent on the number of thermally homogenous bodies used in model [13-14]. The parameters of lumped parameter model are usually determined in the two ways. The first is by using comprehensive knowledge of the motors, physical dimensions and construction materials. The second is to identify the parameters from extensive temperature measurement at different locations in the motor. Even though an electric machine is made of various materials that have different characteristics, the machine can be assumed to consist of several thermally homogenous lumped bodies. Based on these assumption, simplified model of an induction model and a PMSM consisting of two lumped thermal bodies are proposed in [15], and [16]. Likewise, Milanfar and Lang [17] developed a thermal model of electric machine. This thermal model is used to estimate the temperature of the motor and identify faults. Thermal monitoring can, in general, be used as an indirect method to detect some stator faults (turn-to-turn faults) and bearing faults. In a turn-to-turn fault, the temperature rises in the region of the fault, but this might be too slow to detect the incipient fault before it progresses into a more severe phase-to-phase or phase-to-neutral fault. In the case of detecting bearing faults, the increased bearing wear increases the friction and the temperature in that region of the machine. This increase in temperature of motor can be a detected by thermal monitoring.

### 1.4.3 TORQUE MONITORING

All types of motor faults produce the sidebands at special frequencies in the air gap torque. However, it is not possible to measure the air gap torque directly. The difference between the estimated torques from the model gives an indication of the existence of broken bars. From the input terminals, the instantaneous power includes the charging and discharging energy in the windings. Therefore, the instantaneous power cannot represent the instantaneous torque. From the output terminals, the rotor, shaft, and mechanical load of a rotating machine constitute a tensional spring system that has its own natural frequency. The attenuations of the components of air gap torque transmitted through the torsional spring system are different for different harmonic orders of torque components [18].

### 1.4.4 NOISE MONITORING

Noise monitoring is done by measuring and analyzing the acoustic noise spectrum. Acoustic noise from air gap eccentricity in induction motors can be used for fault detection. However, the application of noise measurements in a plant is not practical because of the noisy background from other machines operating in the vicinity. This noise reduces the accuracy of fault detection using this method. Ellison and Yang [19] were detected the air gap eccentricity using this method. They verified from a test carried out in an anechoic chamber that slot harmonics in the acoustic noise spectra from a small power induction motor were functions of static eccentricity.

### 1.4.5 VIBRATION MONITORING

All electric machines generate noise and vibration, and the analysis of the produced noise and vibration can be used to give information on the condition of the machine. Even very small amplitude of vibration of machine frame can produce high noise. Noise and vibration in electric machines are caused by forces which are of magnetic, mechanical and aerodynamic origin [20]. The largest sources of vibration and noise in electric machines are the radial forces due to the air gap field. Since the air gap flux density distribution is product of the resultant mmf. wave and total presence wave.

### 1.4.6 ELECTRICAL MONITORING

Current Park's vector, zero-sequence and negative-sequence current monitoring, and current signature analysis, all fall under the category of electrical monitoring. These methods are used stator current to detect various kinds of machine and inverter faults. In most applications, the stator current of an induction motor is readily available since it is used to protect machines from destructive over-currents, ground current, etc. Therefore, current monitoring is a sensor-less detection method that can be implemented without any extra hardware.

### 1.5 FAULTS IN INDUCTION MOTOR

The detection of common faults of induction motor with help of signal processing techniques is main focus of this research. A variety of faults can occur within three phase induction motor during the course of normal operation. These faults can lead to a potentially catastrophic failure if undetected. Consequently, a variety of conditions monitoring techniques have been developed for the analysis of abnormal condition. Signal processing techniques are also very effective for fault detection. Due to continuous advancement of signal processing techniques and related instruments, online monitoring with signal processing techniques has become very efficient and reliable for electrical machines. The objective of this chapter is to present the classification of three phase induction motor faults and various advanced signal processing techniques for fault diagnosis of electric machines. Short turn winding faults, rotor faults, bearing faults, gear fault and misalignment are common internal faults of induction motor. The common internal faults can be mainly categorized into two groups [1, 2]:

- Electrical faults
- Mechanical faults

Electrical faults include faults caused by winding insulation problems, and some of the rotor faults. Mechanical faults include bearing faults, air gap eccentricity, load faults and misalignment of shaft.

### 1.5.1 ELECTRICAL FAULTS

The following electrical faults are very common in three phase induction motor while operating in industries.

- ❖ BROKEN ROTOR BAR FAULTS
- ❖ SHORT STATOR WINDING FAULTS

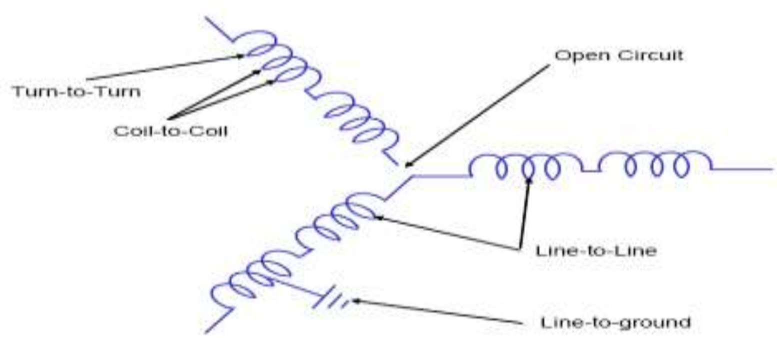


Fig 1.5.1 Types of Fault

### 1.5.2 MECHANICAL FAULTS

Common mechanical faults found in three phase induction motor are discussed below:

- **AIR GAPE ECCENTRICITY**

There are three types of air gap eccentricity [1, 2,]:

- Static eccentricity
- Dynamic eccentricity
- Mixed eccentricity

Static eccentricity is a steady pull in one direction which creates UMP. It is difficult to detect unless special equipment used. A dynamic eccentricity on the other hand produces a UMP that rotates at the rotational speed of the motor and acts directly on the rotor. This makes the UMP in a dynamic eccentricity easier to detect by vibration or current monitoring. Actually, static and dynamic eccentricities tend to coexist. Ideal centric conditions can never be assumed. Therefore, an inherent grade of eccentricity is implied for any real machine. The combined static and dynamic eccentricity is called mixed eccentricity.

### 1.5.3 BEARING FAULTS

Bearings are common elements of electrical machine. They are employed to permit rotary motion of the shafts. In fact, bearings are single largest cause of machine failures. According to some statistical data, bearing fault account for over 41% of all motor failures [12]. Bearing consists of two rings called the inner and the outer rings. A set of balls or rolling elements placed in raceways rotate inside these rings. A continued stress on the bearings causes fatigue failures, usually at the inner or outer races of the bearings. Small pieces break loose from the bearing, called flaking or spelling. These failures result in rough running of the bearings that generates detectable vibrations and increased noise levels. This process is helped by other external sources, including contamination, corrosion, improper lubrication, improper installation, and brinelling. The shaft voltages and currents are also sources for bearing failures. These shaft voltages and currents result from flux disturbances such as rotor eccentricities [9]. High bearing temperature is another reason for bearing failure. Bearing temperature should not exceed certain levels at rated condition. For example, in the petroleum and chemical industry, the IEEE 841 standard specifies that the stabilized bearing temperature rise at rated load should not exceed 45 degree. The bearing temperature rise can be caused by degradation of the grease or the bearing. The factors that can cause the bearing temperature rise include winding temperature rise, motor operating speed, temperature distribution within motor, etc. Therefore, the bearing temperature measurement can provide useful information about the machine health and bearing health [2, 9]. A fault in bearing could be imagined as a small hole, a pit or a missing piece of material on the corresponding elements. Under normal operating conditions of balanced load and a good alignment, fatigue failure begins with small fissures, located between the surface of the raceway and rolling elements, which gradually propagate to the surface generating detectable vibrations and increasing noise levels [19].

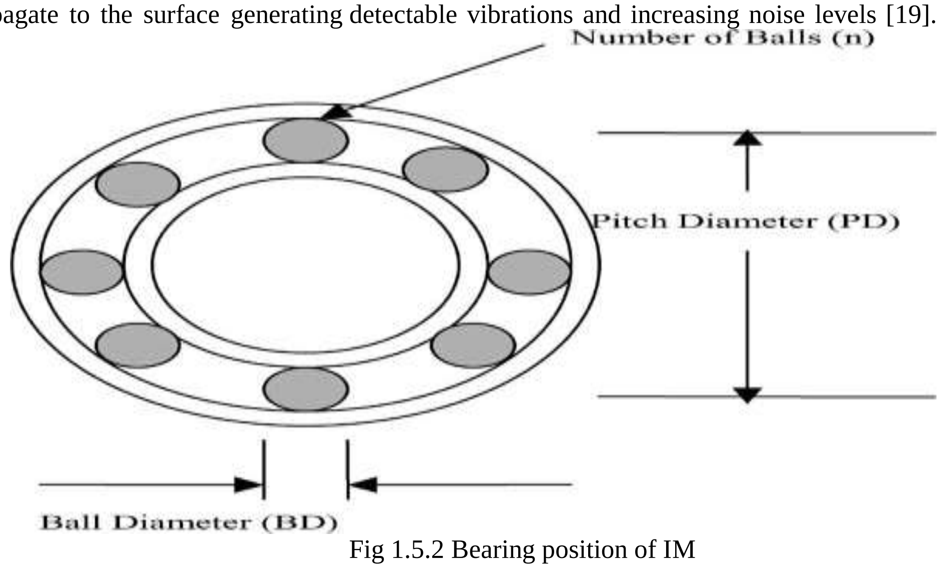


Fig 1.5.2 Bearing position of IM

### 1.5.4 LOAD FAULTS

In some applications such as aircrafts, the reliability of gears may be critical in safeguarding human lives. For this reason, the detection of load faults (especially related to gears) has been an important research area in mechanical engineering for some time. Motors are often coupled to mechanical loads and gears. Several faults can occur in this mechanical arrangement. Examples of such faults are coupling misalignments and faulty gear systems that couple a load to the motor [10].

### 1.6 SIGNAL PROCESSING TECHNIQUES FOR FAULT DETECTION IN INDUCTION MOTOR

The 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. There are several signal processing techniques which are very useful for fault diagnosis purpose. These are classified below [6, 12, and 13]:

1. Frequency domain

   Fast Fourier Transform (FFT)

2. Time-Frequency techniques
   a) Short Time Fourier Transform (STFT)
   b) Gabor Transform (GT)
   c) Cohen class distribution
      i) Wigner –Ville distribution (WVD)
      ii) Choi-Williams distribution
      iii) Cone shaped distribution
3. Wavelet Transform (WT)
4. Time series methods
   a) Spectral estimation through ARMA models
   b) Welch method
   c) Periodogram
5. Fuzzy logic
6. Artificial Intelligent
7. Neural network
8. PI controller

## II. FAULT DETECTION STRATEGY FOR THE PROPORTIONAL INTEGRAL CONTROLLER AND WAVELET CONTROLLER

### 2.1 FAULT DETECTION STRATEGY FOR THE PI CONTROLLER

Proportional integral is used as fault detection in induction motor. In this method we can find out the characteristic of torque and speed after that decided the fault is presence in motor. For integral control action the actuating single consists of proportional error signal added with integral of the error single. Therefore, the actuating signal for integral control action is give by, Definition of the integral feedback is

$$u = K_I \int e \, d\tau \qquad \text{…………….2.1}$$

In the PI controller we have a combination of P and I control i.e.

$$u = K_p e + K_I \int e \, d\tau$$

$$u = K_p e + \frac{1}{\tau_I} \int e \, d\tau$$

$$u = K_p \left( e + \frac{1}{\tau_N} \int e \, d\tau \right) \qquad \text{...........2.2}$$

Where $\tau_I$ = "Integration time" [s]
$\tau_N$ = "Reset time" [s] Where Ki is the integration gain factor and Kp is the proportional gain factor.

### 2.1.1 INTEGRAL GAIN FACTOR

Ensures that under study state condition the motor speed (almost) exactly match the set point speed. A low gain can make the controller slow to push the speed to the set point but excessive gain can cause hunting around the set point. In lass extreme case it can cause overshoot whereby the speed passes through the set point and then approaches the required speed from the opposite direction. Unfortunately sufficient gain to quickly achieve the set point speed can cause overshoot and even oscillation but the other term can be used to damp this out.

### 2.1.2 PROPORTIONAL GAIN FACTOR

Given fast response to sudden load change and can reduce instability caused by high integral gain. This gain is typically many times higher than the integral gain so that relatively small aviation in speed is corrected while the integral gain slowly moves the speed to the set point. Like integral gain set to high, proportional gain can cause a hard oscillation of a few hertz in motor speed

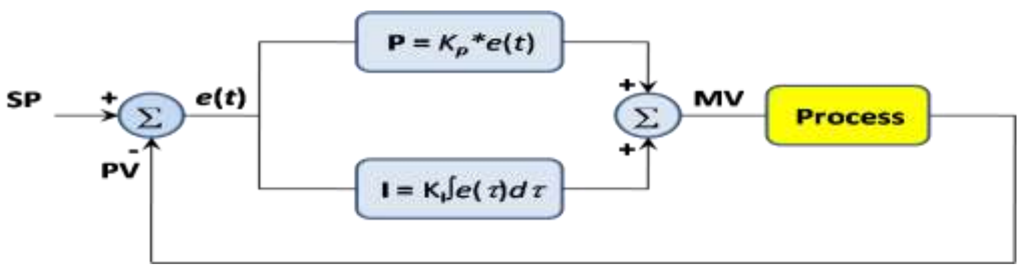

Fig 2.1.1 Block Diagram of PI Gain Factor

### 2.1.3 BASIC CONSIDERATION

The main PI controller was designed to be fairly general purpose and hence modular. Whilst here it is used to control an IM, it could be re-deployed to other situations where some parameter has to be controlled to a set value under varying conditions. The actual control software is located in a single function and its major inputs and output are held in a structure. Although it was designed originally for a specific job it is really intended as an example of the basic techniques involved and to allow those with no control system knowledge to experiment with a simple PI system. The PI controller calculation (algorithm) involves two separate parameter: the Proportional, and Integral value. The Proportional value determined the reaction to the current error and the integral determine the reaction based on the sum of recent error and the output of this port is give to next PI Controller proportional value is the previous output and Integral input is the reaction of rate at which the error has been changing. The weighted sums of these two actions are used to adjust the process via a control element such as the position of a control value, the power supply of an element.

### 2.1.4 DESIGNING THE PI CONTROLLER ROUTINE:

The PI control problem has to be converted form a theoretical continuous process into a real "discrete" system running on a microcontroller. What this mean in practice is that the measuring of the set point and motor speed and the calculation of the output is only performed a regular interval. In the context of a microcontroller, this is might correspond to some code run from a timer interrupt.

The PI controller can thus be expressed as: Output = Proportional Gain*(error_speed) + Integral Gain*S (previous_error_speed_) and **Final output** = [{(Output) or Proportional Gain*(error_speed) + Integral Gain*S (previous_error_speed_)} – (last_error_speed)]

### 2.1.5 PI CONTROL

The PI controller algorithm is the most common control algorithm used in industry for the speed control but in this research work PI used as a fault diagnosis in IM. When using PI control we must specify a process variable and a set point. The process variable is the system parameter we want to control and compare the referenced speed. We can used the PI (toolbox) block in SIMULATION function in MATLAB software (7.10.0 R2010a)

### 2.1.6 PI ERROR CALCULATION:

The PI controller compares the set point (SP) to the process variable (PV) or mean variable (MV) to obtain the error e, as follows:

$$e = SP - PV \quad \text{……….2.3}$$

Then the PI controller calculated the control action, u (t), as follows. In this equation, Kp is the process gain.

$$u = K_p e + \frac{1}{\tau_I}\int e \, d\tau \quad \text{……………2.4}$$

Where $\tau_I$ = "Integration time"
The above following formula represents the proportional gain.

$$Up\,(t) = Kp\,(e) \quad \text{……………2.5}$$

### 2.1.7 IMPLEMENTING THE PI ALGORITHM WITH THE PI FUNCTIONS:

This section describes how the PI control toolbox function implements the PI algorithm. The PI algorithm used in the PI control toolbox

- **ERROR CALCULATION**

The following formula represents the current error used in calculating proportional, integral, where PV is the filtered process variable.

$$e\,(k) = SP - PV \quad \text{………………2.6}$$

- **PROPORTIONAL ACTION**

Proportional action is the controller gains times the error, as show the following formula:

$$Up\ (k) = K_p * e\ (k) \quad \ldots\ldots\ldots\ldots\ldots..2.7$$

- **TRAPEZOIDAL INTEGRATION**

Trapezoidal Integration is used to avoid sharp changes in integral action when there is a sudden change in the PV or SV. Use nonlinear adjustment of the integral action to counteract overshoot. The following formula represents the trapezoidal integration action.

$$Ui\ (k) = Kp/Ti * \{[e\ (i) + e\ (i-1)]/2\}\ \Delta t \quad \ldots\ldots\ldots\ldots\ldots.2.8$$

Where i = 1, 2, 3 …k

- **CONTROLLED OUTPUT**

Controller output is the summations of the Proportional, and integral action, as show in following formula

$$U\ (k) = Up\ (k) + Ui\ (k) \quad \ldots\ldots\ldots\ldots\ldots\ldots.2.9$$

- **OUTPUT LIMIT**

The actual controlled output is limited to the range specified for control output as follows:

If U (k) ≥ Umax then U (k) = Umax

And

If U (k) ≤ Umin then U (k) = Umin

The following formula shown the practical model of PI controller.

$$U\ (t) = Kp\ [(SP-PV) + \frac{1}{T_i}\int_0^t (SP - PV)\, dt] \quad \ldots\ldots\ldots\ldots\ldots..2.10$$

The PI function uses an integral sum correction algorithm that facilitates anti-windup & bumpless manual-to-automatic transfers. Windup occures at the upper limit of the controller output, for example, 100% when the error (e) decreases the controlled output is decreases, moving out of the windup area. The integral sum correction algorithm prevents abrupt controller parameters. The default range for the SP, PV and output parameter corresponds to percentage value; adjust the corresponding range accordingly.

- **ERROR CALCULATION**

The current error used in calculating integral action for the precise PI algorithm is shown the following formula:

$$e\ (k) = (SP-PV_f)\ (L+(1-L)*\frac{|SP - PV_f|}{SP_{range}}) \ldots\ldots\ldots\ldots\ldots\ldots..2.11$$

Where SP range is the range of the SP and L is the linearity factor that produces a nonlinear gain term in which the controller gain increase with the magnitude of the error. If L is 1, the controller is linear. A valve of 0.1 makes the minimum gain of the controller 10% Kp. Use of a nonlinear gain term is referred to as a precise PI algorithm.

### 2.1.8 BLOCK DIAGRAM AND FLOW CHART OF PI CONTROLLER

The PI controller can use the following types of PI algorithm to determine the controlled output.

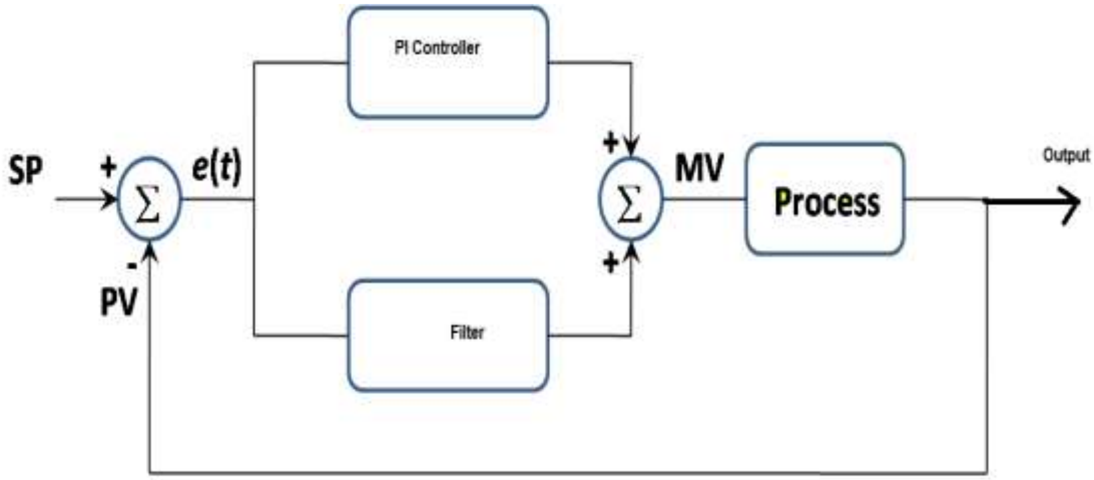


Fig 2.1.2 Block diagram of PI controller

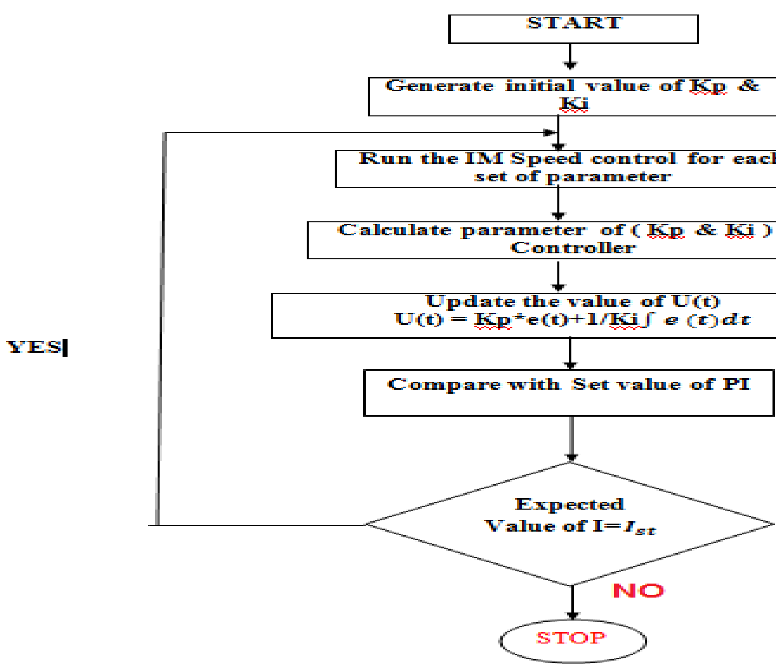


Fig 2.1.3 Flow chart of PI controller for fault detection in IM

### 2.2 FAULT DETECTION STRATEGY USING WAVELET CONTROLLER

A wavelet is a waveform of effectively limited duration that has an average value of zero.

### 2.2.1 DISCRETE WAVELET TRANSFORM FOR FAULT DETECTION

Wavelet technique is an emerging field of error finding. It is capable of extracting information in reference to time and class of the occurring fault. This technique provides a sensitive method for the judgment of the fault relative to other signal processing such as Fourier transforms, including the disadvantages of using a single window function in all the frequency components, and held the linear resolution of the entire frequency range. The condition - based maintenance approach is used to conduct a review and diagnosis of machine [14].

Fault diagnosis is conducted on two levels:

- Traditional control
- Fault diagnosis based on knowledge

The techniques of fault diagnosis consist of wavelet or extraction component, feature cluster component, and the fault decision component In order to diagnose the fault in stator short circuit, Motor Current Signature Analysis or (MCSA) is utilized. When talking about fault diagnosis regarding wavelets, one of the useful characteristics seen is that of localization of good time and multi-resolution analysis. Techniques of signal processing such as the FFT are formed on the basis of load, fundamental frequency of constant stator, assumption on sufficient load and the speed of motor. There are various kinds of wavelet transformation. Only the important kinds will be discussed in this chapter such as:

- Wavelet packet decomposition transformation
- Discrete wavelet transformation
- Continuous wavelet transformation

There are two main groups of the wavelet. The following equation presents the first group of Wavelet known as discrete wavelet transformation:

$$\text{DWT}(m,k) = \frac{1}{\sqrt{m_0^m}} \sum x(n)\, g\left(\frac{k - n b_0 a_0^m}{a_0^m}\right) \quad \ldots\ldots\ldots\ldots\ldots 2.12$$

g(*n*,)(x*n)* is considered to be the mother wavelet while the other is considered to be input signal respectively. The scaling parameters "*a*" and the translation parameters "*b*"are integer parameter's '*m*' functionality [69]. The second group of wavelet is known as continuous wavelet transformation or CWT which is depicted using the following equation:

$$\omega(m,n) = \int_{-\infty}^{\infty} f(t)\, \Psi_{m,n}(t)\, dt \quad \ldots\ldots\ldots\ldots\ldots\ldots 2.13$$

Complex conjugate is denoted by * where waveform signal is denoted by *f (t)* and wavelet by *(t).*

$$\Psi_{m,n}(t) = 2^{\frac{-1}{2}} \Psi(2^{-m} t - n) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.14$$

"*m*" and "*n*" are denoting the wavelet dilation and translation respectively used to transform the old signal in a new signal according to the components of high frequency with small scales. The relation is only valid for the wavelet transform based on orthogonal (*a*=2 and *b*=1). As such in the continuous wavelet transformation, scale parameter and time parameter are denoted by "*a*" and "*b*".

$$\omega_{a,b}(t) = |a|^{\frac{-1}{2}} \Psi\left(\frac{t-b}{a}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.15$$

As observed in Table 5.1 and Table 5.2, CWT is divided in two groups: real wavelet and complex wavelet respectively.

| | |
|---|---|
| Beta Wavelet | $\Psi_{beta}(t\vert\alpha,\beta) = (-1)dp(t\vert\alpha,\beta)\vert dt$ |
| Harmitian Wavelet | $\Psi_n(t) = (2n)^{\frac{-n}{2}} C_n H_n\left(\frac{t}{\sqrt{2}}\right) e^{\left(\frac{-1}{2n}\right)} t^2$ |
| Mex.hat Wavelet | $\Psi(t) = \left(\frac{2}{\sqrt{3\sigma \Pi^{\frac{1}{4}}}}\right)\left(1 - \frac{t^2}{\sigma^2}\right) e^{\left(\frac{-t^2}{2\sigma^2}\right)}$ |
| Shannon Wavelet | $\Psi(t) = 2\sin(2t) - \text{sinc}(t)$ |

Table 2.1

| | |
|---|---|
| Mexican | $\Psi(t)=\frac{2}{\sqrt{3}}\Pi^{-0.25}\{\sqrt{\Pi(-t^2)e^{-0.5t^2}-\sqrt{\{2it\}\sqrt{\Pi erf\left\{\frac{i}{\sqrt{2}}t\right\}(1-t^2)e^{-0.5t^2}}}}\}$ |
| Morlet Wavelet | $\Psi(t)=(C\Pi^{\left\{\frac{-1}{4}\right\}}e^{\frac{-1}{4}t^2}(e^{it}-k)$ |
| Shannon Wavelet | $\Psi(t)=\text{sinc}(t)e^{-j\Pi t}$ |
| Modified Morlet Wavelet | $\Psi(t)=C_\Psi cos(\omega_0 t)\text{sech}(t)$ |

Table 2.2

Discrete wavelet transformation is a better choice for digital computers where the mother wavelet is scaled on a power of 2 [7]. As depicted in Table 1, the development of continuous wavelet transformation was an alternative approach to deal with the problem of resolution [7].

There are two characteristics of wavelet:

1. A finite energy signal can be reconstructed when the admissibility condition is satisfied by the Type equation here. Wavelet without any need of decomposition values. As a result, the equation of admissibility equation is presented as follows:

$$\int \frac{|\Psi(\omega)|^2}{|\omega|} d\omega < +\infty \qquad \text{………………………2.16}$$

The Fourier transform is denoted by $\Psi(\boldsymbol{\omega})$ while the wavelet function is denoted by $\Psi$(t). The fourier transform is used to analysis the wavelet signals as well as reconstruct them without any information loss. The Fourier transform will be zero according to the admissibility condition which is given by the equation:

$$|\Psi(\omega)|^2 = 0 \qquad \text{…………………..2.17}$$

The second important characteristic of the wavelet is:

$$\int \Psi(\omega) = 0 \qquad \text{……………………2.18}$$

2. A limited number of regularity conditions are been imposed in order to resolve the squared relationship that exists between wavelet transform's time bandwidth and the input signal which will then ensure a concentrated and smooth wavelet function in the domains of frequency and time.

Down-sampling and filtering can be used to implement decomposition which can be iterated with success as presented in [7]. The total levels of decomposition denoted by (*L*) will be calculated based on the following equation:

$$L \geq \frac{\log\left(\frac{Fs}{f}\right)}{\log(2)} + 1 \qquad \text{………………2.19}$$

Until a new acquisition is made based on different frequency sampling, the bands cannot be changed. This complicates any detection of fault using DWT specifically in condition of changing time

A six level decomposition is seen when equation (5.9) is applied at a 1KHz frequency.

$$L = \frac{\log\left(\frac{1000}{50}\right)}{\log(2)} + 1 \qquad \text{……………2.20}$$

The frequency bands for every wavelet signal are presented in Table 2.3

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| Approximation<$a_j$> | Frequency bands(Hz) | Details | Frequency bands(Hz) |
|---|---|---|---|
| $a_6$ | [0-16.125] | $d_6$ | [16.125-32.25] |
| $a_5$ | [0-32.25] | $d_5$ | [32.250-64.5] |
| $a_4$ | 0-64.50] | $d_4$ | [64.50-125.0] |
| $a_3$ | [0-125.0] | $d_3$ | [125.0-250] |
| $a_2$ | [0-250.0] | $d_2$ | [250-500] |
| $a_1$ | [0-500] | $d_1$ | [500.0-1000.0] |

Table 2.3

The analysis of signal require data which is dependent of resolution (R) and sampling frequency (*fs*) as shown in equation.

$$D_{required} = \frac{f_s}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.21$$

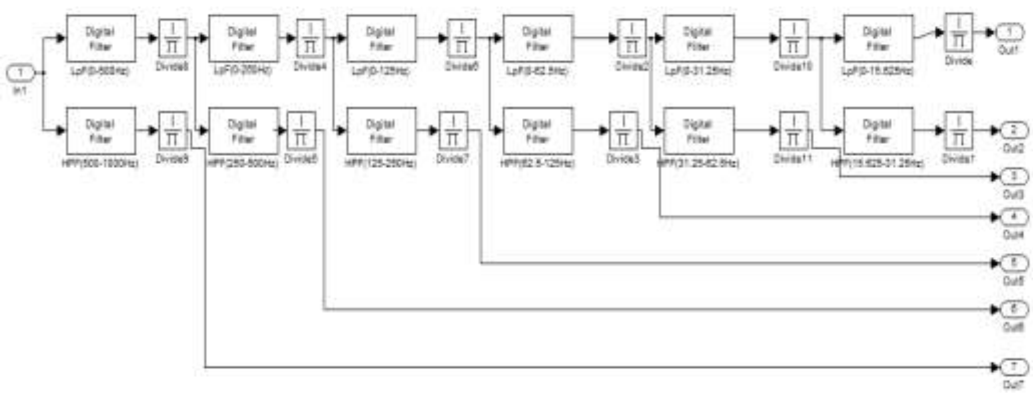


Fig 2.2.1 DWT filter bank

An alternative way to performing the same task is through the DWT dyadic filter from MATLAB/Simulink. Although for this method, the wavelet coefficients may need to be calculated using the following MATLAB instruction:

[Lo_D, Hi_D, Lo_R, Hi_R] = wfilters ('db10')

Where Lo_D,Hi_D,Lo_R,Hi_R represent low pass filter decomposition,high pass filter decomposition ,low pass filter reconstruction and high pass filter reconstruction respectively. The decomposition of the wavelets was impemented using the above relation as can be seen in Fig.7. The above two circuits are exactly the same. A wavelet-transform-based method was developed for diagnosis and protection the induction motor against broken rotor bar and short stator windings. Detailed information is obtained from the high pass filters and the approximation information is obtained from low pass filter. Daubechies wavelet (db10) is used to analayze stator current as in Fig8. The construction of DWT is followed by implementing the criterion of fault detection of induction motor faults. The criteria used to detect the induction motor faults depend on the relationship between maximum detail energy (d6) and the original stator current (Ia)

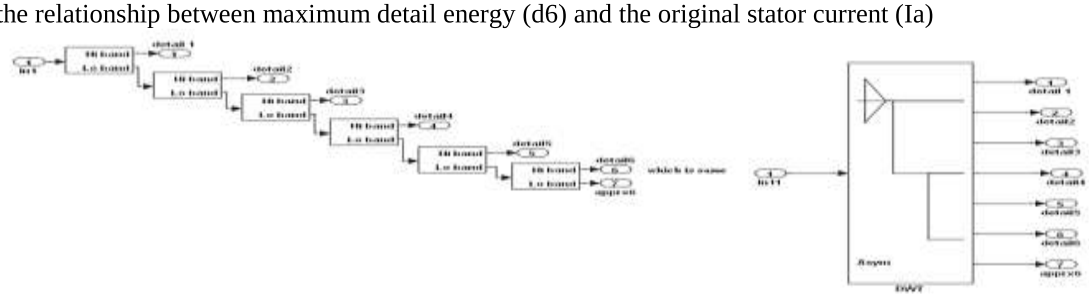


Fig 2.2.2 DWT filter bank

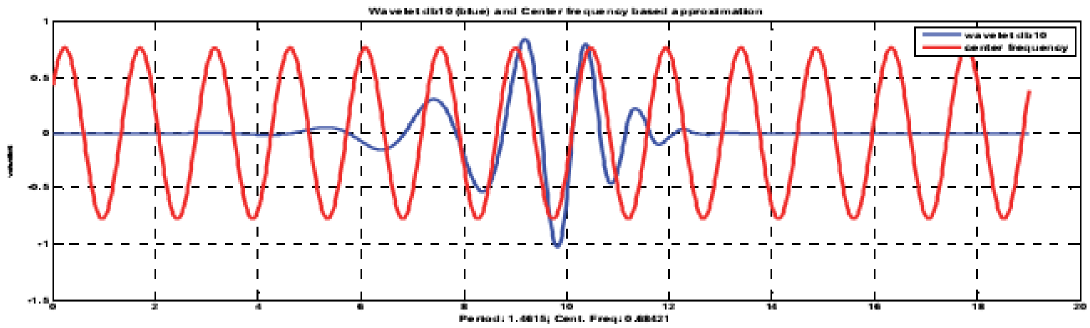


Fig 2.2.3 DWT Fiter bank Waveform

Offline calculations of maximum energy were done using MATLAB instructions as in the following wavelet program:

```
load Ia
[C, L] = wavedec (Ia, 6,'db10');
[Ea, Ed] = wenergy(C, L)
```

Ea is the percentage of energy correspondingto the approximation, Ed is the vector containing the percentages of energy corresponding to the details, C is the wavelet decomposition vector and L is the bookkeeping vector.

Ea = 99.5370(a6)

Ed =0.0000(d1) 0.0000(d2) 0.0000(d3) 0.0001(d4) 0.0010(d5) 0.4619(d6)

The Wavelet coefficients, the energy of the details of any signal at level j can be expressed as (M. Sabarimalai Manikandan, and S. Dandapat, 2007):

$$E_j = \sum d_{j,k}^2 \qquad \ldots\ldots\ldots 2.22$$

$$d_{j,k} = \langle x(t), \psi_{j,k} \rangle = \frac{1}{\sqrt{2^j}} \int x(t)\psi(2^j t - k)dt \qquad \ldots\ldots\ldots 2.23$$

**2.2.2 APPLICATION OF WAVELET**

Wavelets are a powerful statistical tool which can be used for a wide range of applications, namely

- Signal processing
- Data compression
- Smoothing and image denoising
- Fingerprint verification
- Biology for cell membrane recognition, to distinguish the normal from the pathological membranes
- DNA analysis, protein analysis
- Blood-pressure, heart-rate and ECG analyses
- Finance (which is more surprising), for detecting the properties of quick variation of values
- In Internet traffic description, for designing the services size
- Industrial supervision of gear-wheel
- Speech recognition
- Computer graphics and multifractal analysis
- Many areas of physics have seen this paradigm shift, including molecular dynamics, astrophysics, optics, turbulence and quantum mechanics.

**2.2.3 ADVANTAGE OF WAVELET CONTROLLER**

The Fourier transform is less useful in analyzing non-stationary signal (non-stationary signal is a signal where there is change in the properties of signal) Wavelet transforms allow the components of a non-stationary signal to be analyzed. Wavelets also allow filters to be constructed for stationary and non-stationary signals

## III. RESULT DISCUSSION AND CONCLUSION

### 3.1 DEVELOPMENT OF SIMULATION SETUP AND RESULTS

An Induction motor rating is 5 hp, 50 Hz, 440 volt phase voltage is used in following simulation. The parameter values associated with the motor are discussed in chapter of IM. Those values are same for the PI controller and wavelet controller both. This simulation block for fault detection in Induction motor by using PI controller. Total capacity of 5 hp motor is 5*746 = 3730 watts, (3.730kw) power factor is 0.8 lagging & motor is drawn maximum 16 amps current. In this block we can use the two PI controllers for fault diagnosis. The PI controller rating is (Proportional gain) is Kp = 13 and (Integral gain) is Ki = 26

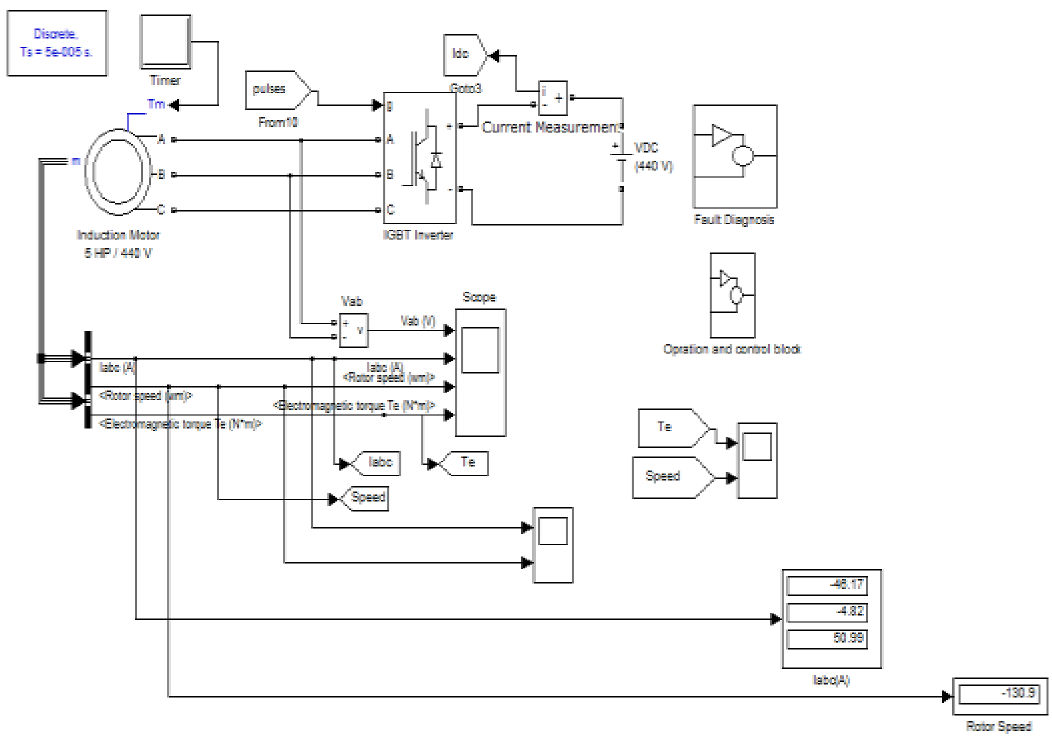



Fig: 3.1.1 Fault detection in IM by using PI controller

This block display shown the three phase's current. Phase R (Ia) is 6.097amp, phase Y is -29.41 amp. and phase B is 23.31 amp. and rotor speed is negative -137.8 rpm. This data is abnormal motor data, if motor is healthy so three phase current are balance and the rotor speed is positive.

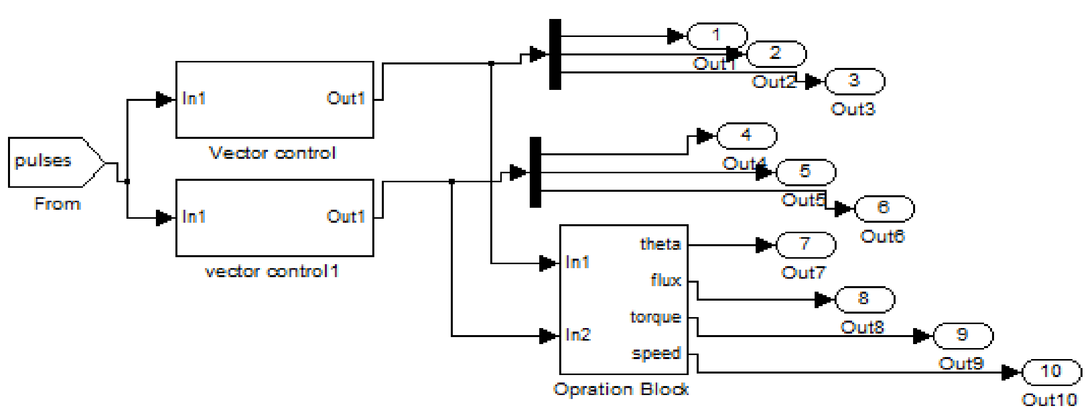



Fig: 3.1.2 Operations and Control Block for PI Controller

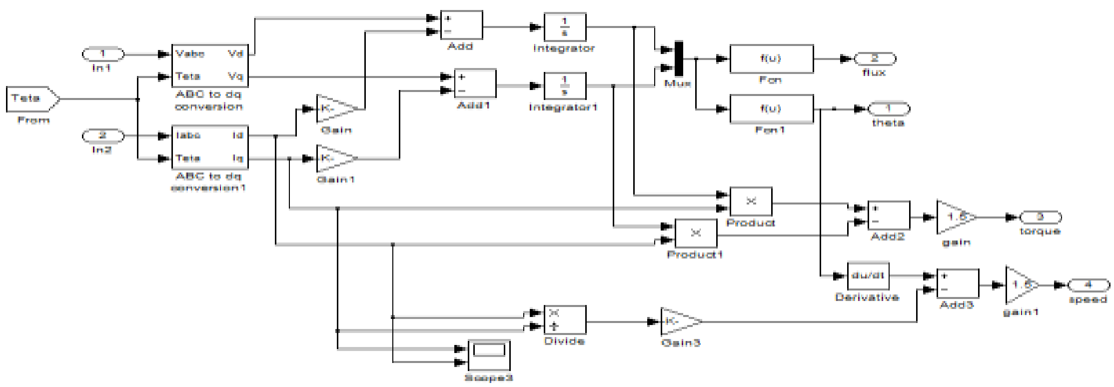


Fig: 3.1.3 Operation Block for PI Controller

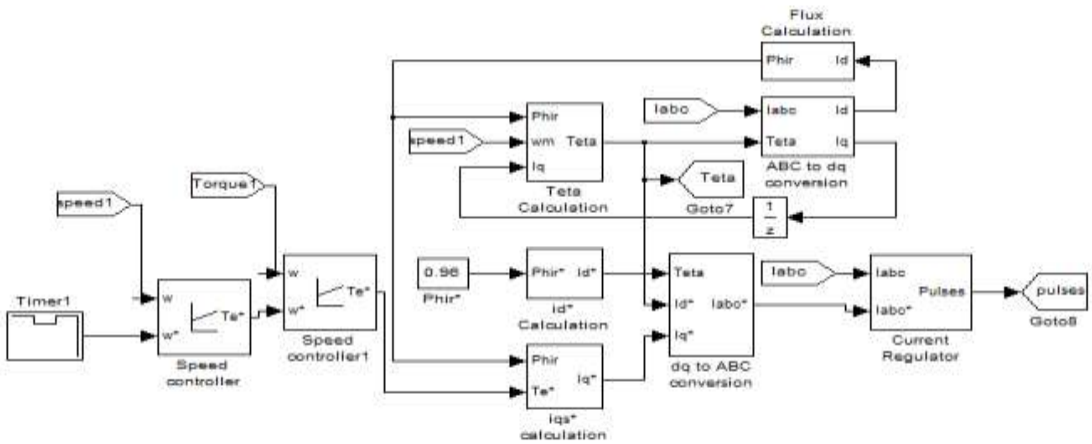


Fig: 3.1.4 Fault Detection Block for PI Controller

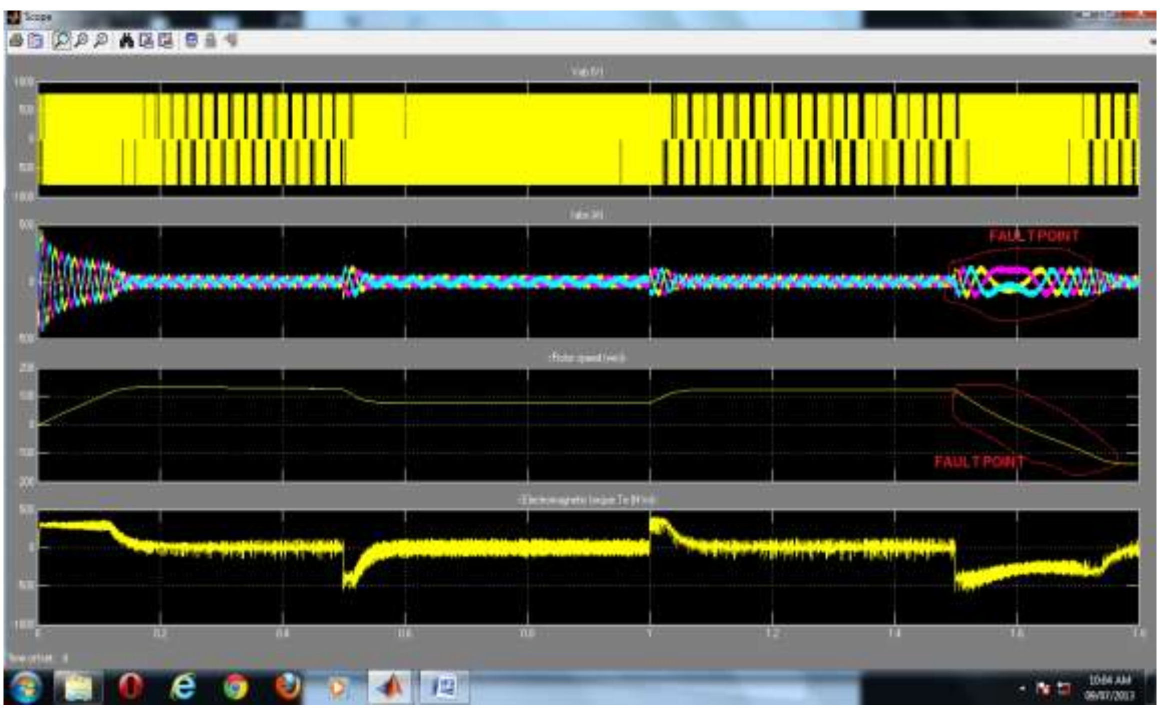



Fig: 3.1.5 Simulation Results

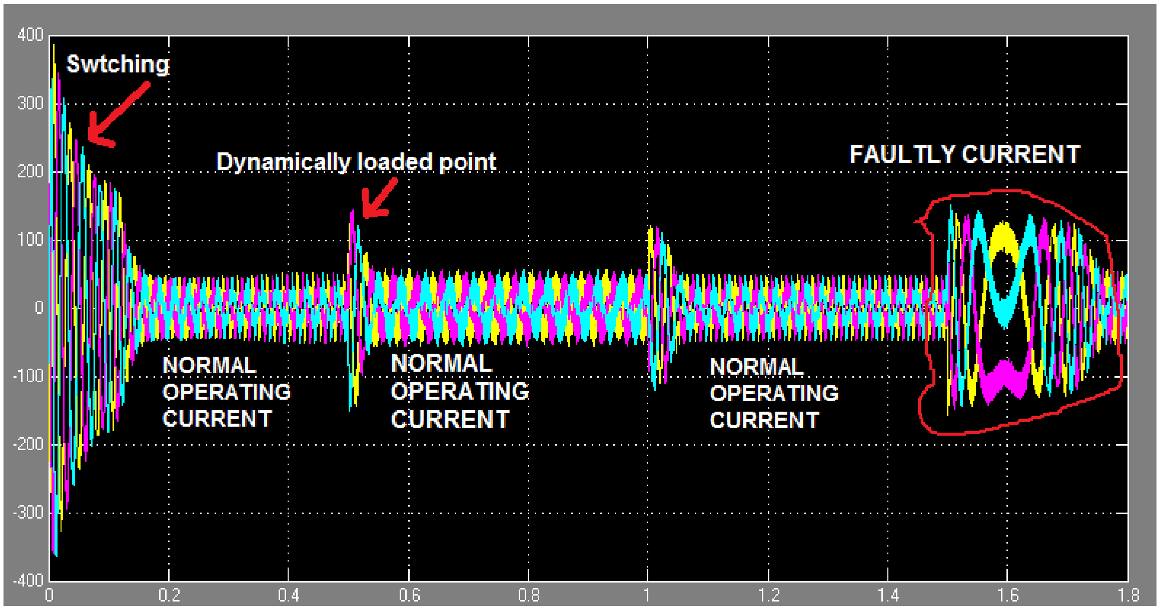


Fig: 3.1.6 Simulation Result for Different Condition

Basic difference between PI & Wavelet is that when, fault detection in Induction motor by using PI controller we cannot define which fault is create but by using Wavelet Index we can define which fault is presence.

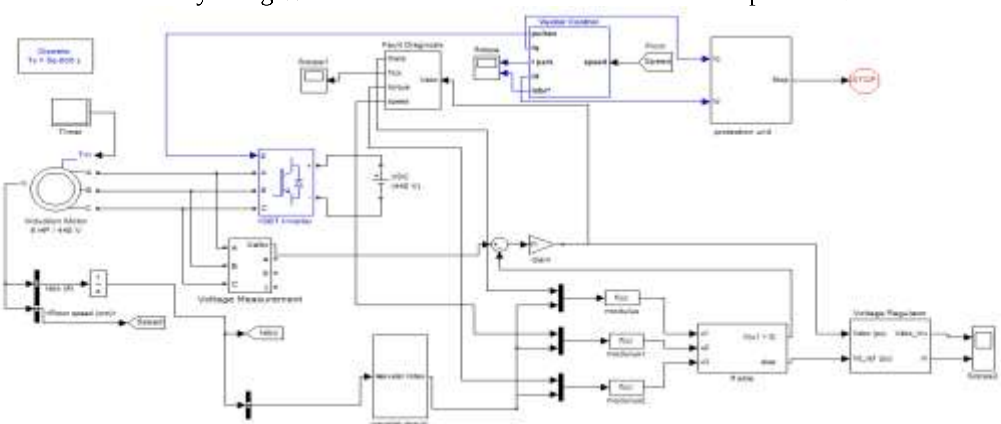


Fig: 3.1.7 Fault Detection Block in Induction Motor by using wavelet

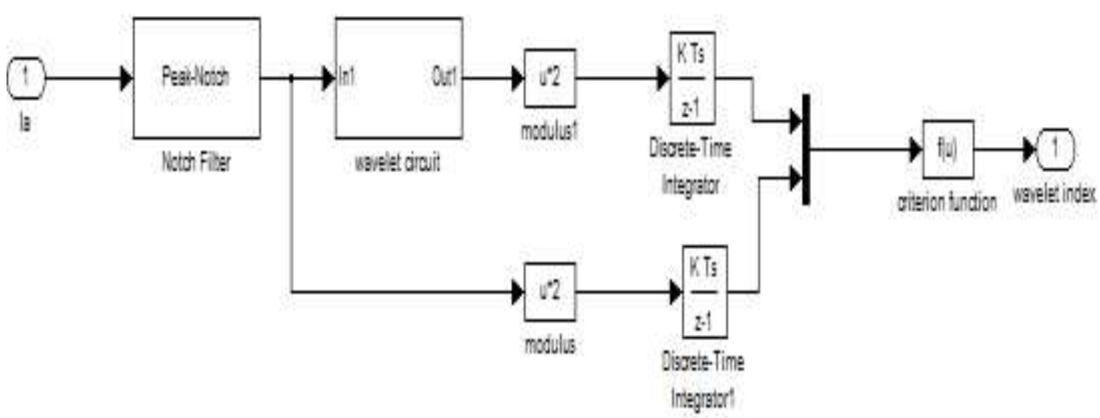


Fig: 3.1.8 Wavelet Index Subsystems

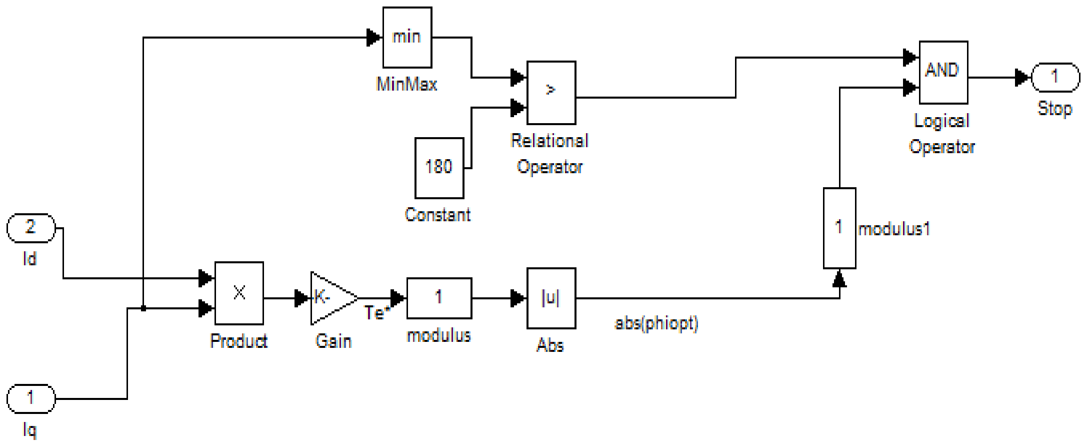



Fig: 3.1.9 Protection Subsystems

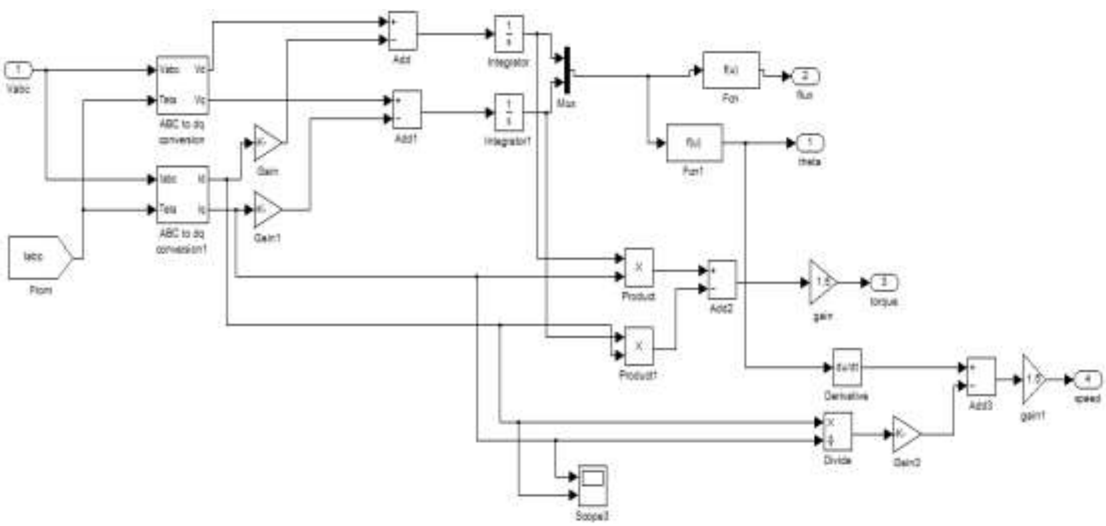
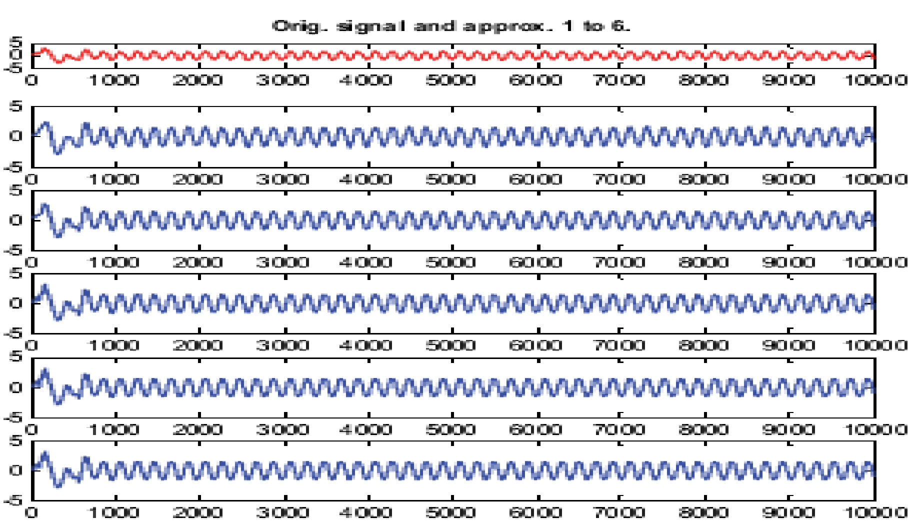


Fig: 3.1.10 Fault Detection Block



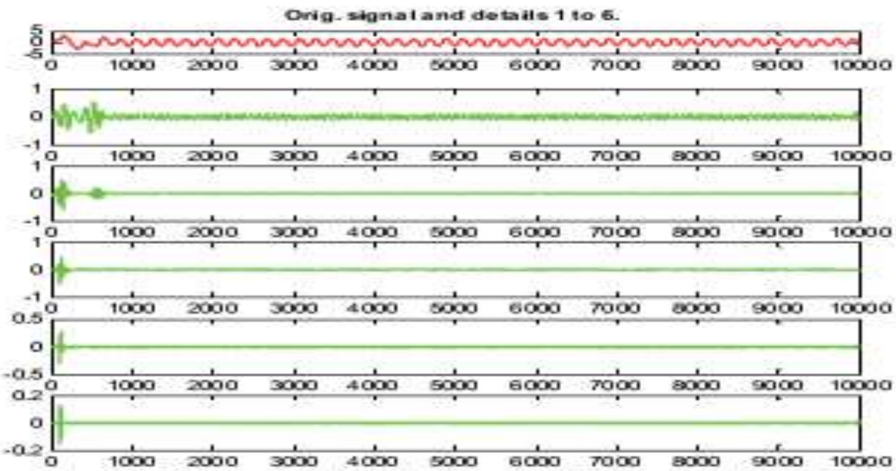



Fig: 3.1.11 Approximation and detailes signal in healthy motor

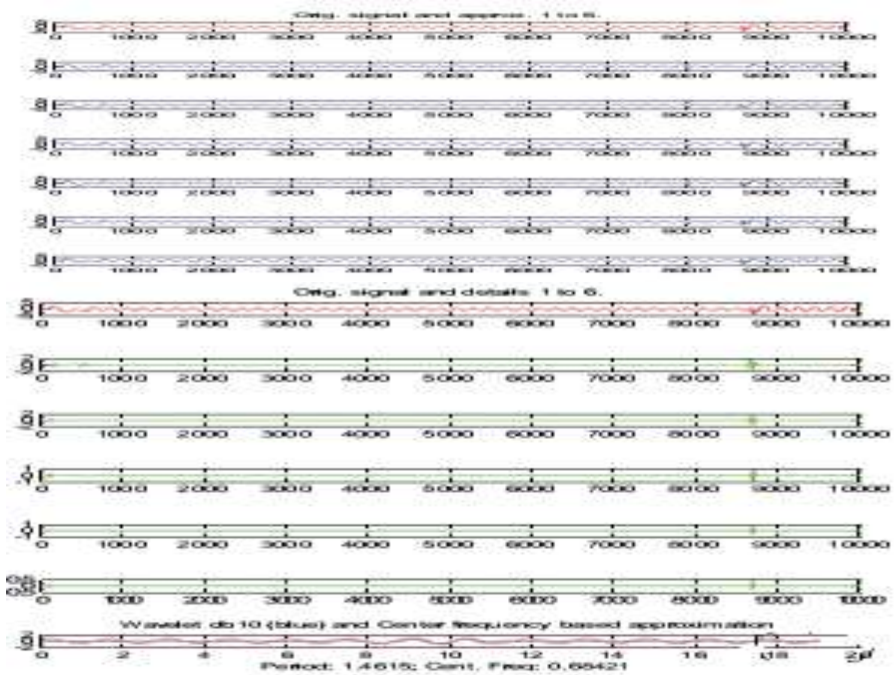



Fig: 3.1.12 Approximation and detailes signal in Broken Rotor Bar Fault

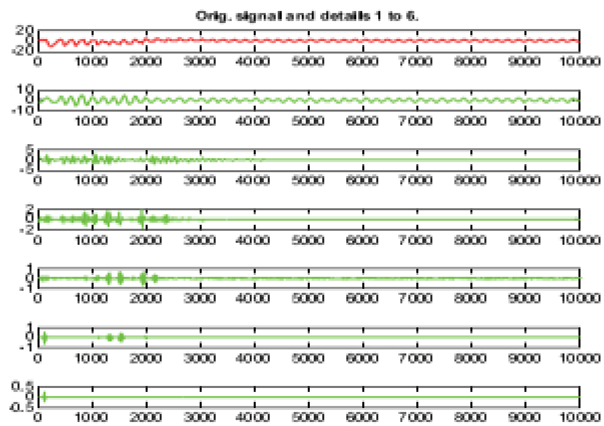


Fig: 3.1.13 Approximation and detail signal in Short Stator Winding Fault

This wavelet is also used as fault indicator or wave index as is shown in Fig

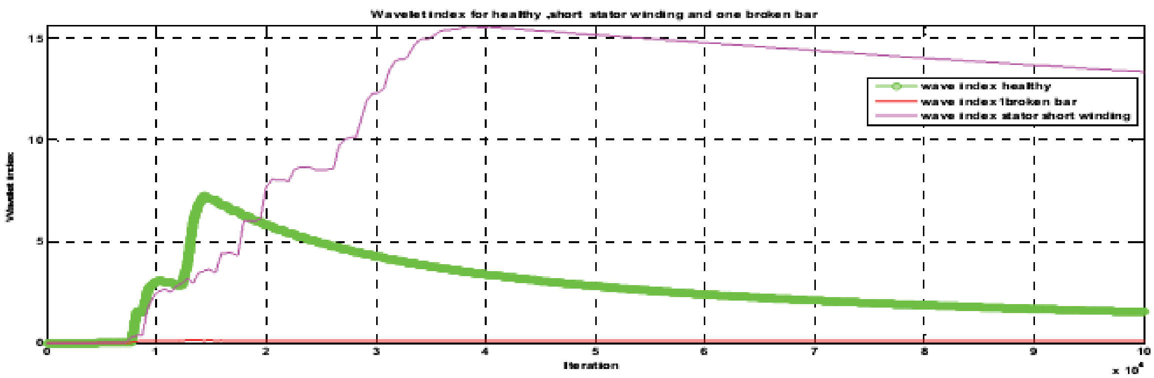


Fig: 3.1.14 Wavelet Index for fault detection

- **Broken rotor bar**

Key reasons for a broken rotor bar are (Ahmed Y. Ben Sasi et al, 2006):
1. Direct on line starting which leads to excessive heating and mechanical problems.
2. Variable mechanical load.
3. Unsatisfactory rotor cage manufacturing.

Broken rotor bar faults can be simulated by connecting three resistances with the rotor resistance so that by increasing one of the rotor phase resistances, the broken rotor bar equivalent resistance can be computed as in (24).

$$R_{brk} \cong (0.33/4) R_r z_{nb} / N^2_s$$

……………….3.1

The external added resistances are changed in 0.0833Ω steps, which represents the difference between the reference rotor resistance and the original rotor resistance for one broken rotor bar .Reference rotor resistance depends on the number of broken bars and the total number of rotor bars (Hakan Calıs& Abdulkadir Cakır, 2007). The resistance of induction motor rotor bar is assumed to be high. (Levent Eren, & Michael J. Devaney, 2004), presented the bearing fault defects of the induction motor WPT decomposition of 1 Hp induction motor stator current through the test of RMS for both healthy and faulty bearings.

- **Stator shorting the winding**

More than 30% of all motor faults are caused by failure of the motor winding due to insulation problems. For the stator short circuit winding fault, the stator resistance of the induction motor is connected to the parallel variable resistance which is reduced according to the following formula:

$$R_{sh} = 0.1 R_{org} \qquad \text{…………..3.2}$$

The majority of induction motor winding failures proceeds gradually from lower short circuit current to a higher level and finally break as can be seen in (Dimas et al, 2010). To check the validity of the wavelet fault detection of both stator winding and broken rotor bar units as well as when the motor is in a healthy condition ,MATLAB/Simulink‘s Predicted Model Block (PED) is used to verify the wavelet detection units as is shown in subsequent figures. In the healthy induction motor, transfer function of the wavelet unit (interval test) is:

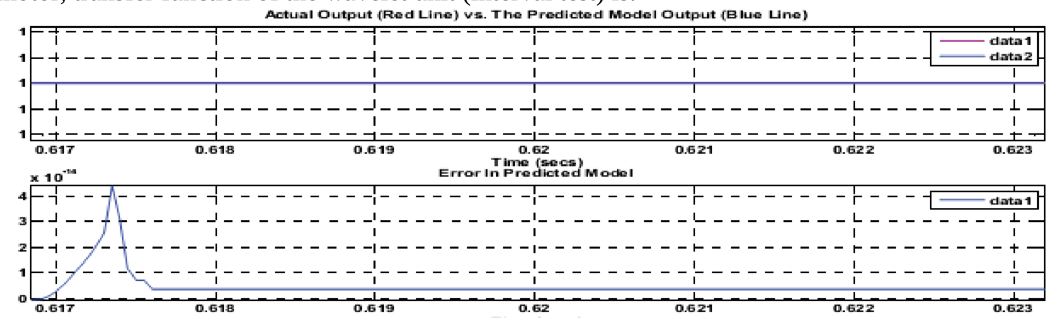



Fig: 3.1.15 Predicted model output and its noise model for wavelet detection in the healthy case

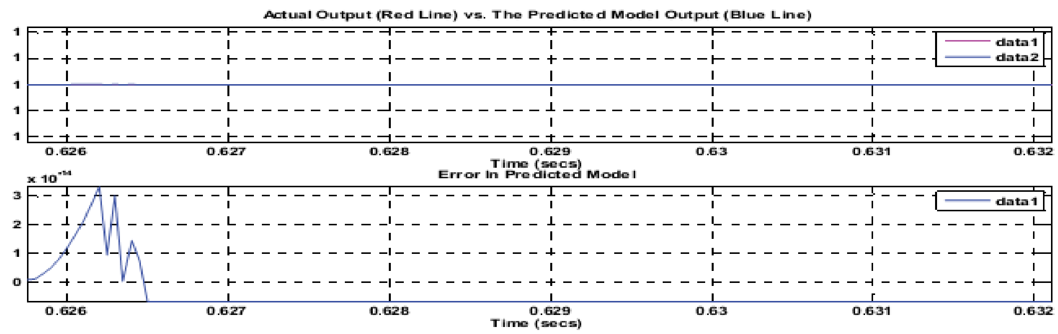



Fig: 3.1.16 Predicted model output and its noise model for wavelet detection in the short stator winding fault

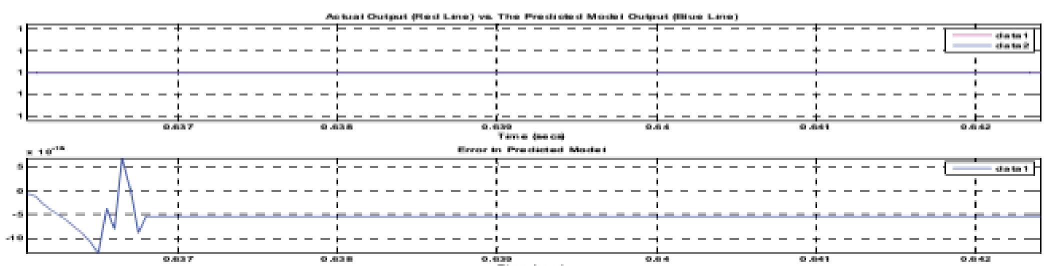


Fig: 3.1.17 Predicted model output and its noise model for wavelet detection in broken rotor bar

**3.2 DISCUSSION**

In the protection stage of the induction motor, there are many steps to perform exact or optimal protection of the circuit like: condition monitoring which is the process of monitoring a parameter of condition in machinery, such that a significant change is indicative of a developing failure. Many condition-monitoring methods, which monitor the motor’s condition using only the currents and voltages of the motor, are preferred due to their low cost and non-intrusiveness (Zhang etal, 2011). For reliable operation of adjustable speed drive systems, the vulnerable components of the power converter, cable, and motor must be monitored, since failure of a single component can result in a forced outage of the entire system (Lee, et al, 2011). In this chapter, two approaches are used to treat the faults mentioned above. First, voltage regulation with automatic gain control (AGC) is used to control the voltage after the occurrence of fault and hence the speed to maintain the operation of the induction motor

$$AGC = reciprocal(mean(real(f_{vd})^2 + real(f_{vq})^2)$$
…………3.3

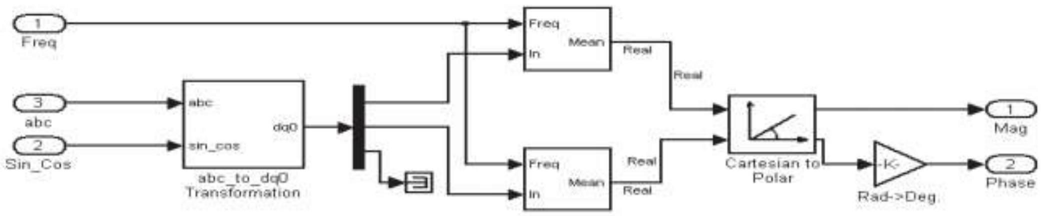



Fig: 3.1.18Automatic Gain Control Circuit

The fault diagnosis condition depends also upon an optimization technique of induction motor flux.

$$\varphi_{optimal} = | T_e * \sqrt{R_r / (3/2 * p)} |$$
………………..3.4

The proposed circuit of the wavelet fault diagnosis is shown in Fig10. The last stage of the protection is to stop the motor operation when the fault severity becomes high and cannot be controlled according to the following criteria.

$$if \max(Iq) > 180 \ \& bad\ flux\ due to bad\ torque \quad then\ stop the\ operation$$

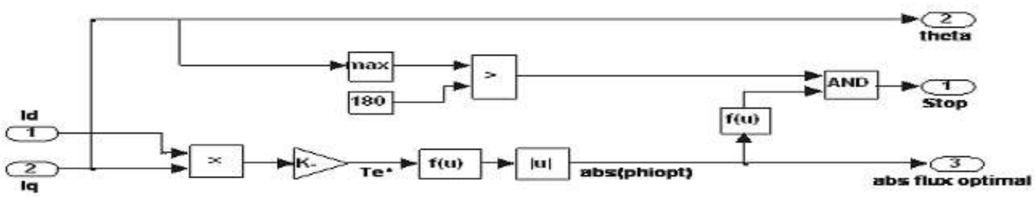



Fig 3.1.19 Protection and Chacking of the optimal flux

3.3 **CONCLUSION**

A Squirrel cage Induction motor 5 hp 440 volts 50 Hz input supply fully loaded condition checked out the fault by using wavelet transform & PI controller. When we apply the PI controller (conventional method) & checked out the results so scope is shown large distortion in current. Due to faults change the nature of current and as well as speed. An Induction motor apply the PI controller easily find out the fault point but we cannot decide which fault is create. When we apply the modern signal processing technique (Wavelet) and find out faults. In these methods we can easily decide which fault is created. An Induction motor applies the discrete wavelet transform and finds out two faults separately (1) Broken rotor bar faults, (2) Short stator winding fault. The wavelet is considered as powerful tools in the fault detection and diagnosis of induction motors as compare to PI controller. Many wavelet classes can be generated by different kinds of mother wavelets and can be constructed by filters banks. The improvement of fault detection and diagnosis can be exploiting the wavelet properties to get high detection and diagnostics effectiveness.

**3.4 FUTUR SCOPE**

In this model we apply the PI controller and find out the fault, but we cannot decide which fault is created. In this model by connecting the resistance in power supply then set the value of all three resistance and if change the value of any resistance (increase) that case decided the open winding faults

## REFERENCES

[1] T. A. Kawady, A. A. Afify, A. M. Osheiba, A. I. Taalab, "Modeling and Experimental Investigation of Stator Winding Faults in Induction Motors " , Electric Power Components and Systems, Volume 33, October 2008, pp.599-611.

[2] M. S. Ballal , H. M. Suryawanshi , Mahesh K. Mishra , "Stator Winding Inter-turn Insulation Fault Detection in Induction Motors by Symmetrical Components Method ", *Electric Power Components and Systems*, *36*: July 2008, pp.741–753.

[3] A.H. Bonnett, G.C.Soukup, "Cause and Analysis of Stator and Rotor Failures in Three- Phase Squirrel-Cage Induction Motors," *IEEE Transactions on Industry Applications, vol. 28 No. 4*, July/August 1992**,** pp.921-937.

[4] Jordi Cusido, Luis Romeral, J A Ortega, J A Rosero and A G Espinosa, "Fault Detection in Induction Machines Using Power Spectral Density in Wavelet Decomposition", *IEEE Transactions on Industrial Electronics, Vol.55, N0.2*, February 2008, pp 633-643.

[5] B.Liang, B.S.Payne, A.D.Ball and S.D.Iwnicki, "Simulation and fault detection of three-phase induction motors", *Journal in Mathematics and Computers in Simulation 61* (2002) 1–15.

[6] Arfat Siddique, G. S. Yadava, and Bhim Singh, "A Review of Stator Fault Monitoring Techniques of Induction Motors", *IEEE Transactions on Energy conversions, Vol. 20, No. 1*, March 2005, pp.106-114.

[7] Sergio M. A. Cruz and A. J. Marques Cardoso, "Diagnosis of Stator Inter-Turn Short Circuits in DTC Induction Motor Drives", *IEEE Transactions on Industry Applications, Vol. 40*, September/October 2004, pp.349-1360.

[8] S. B. Lee, R. M. Tallam, and T. G. Habetler, "A robust, on-line turn-fault detection technique for induction machines based on monitoring the sequence component impedance matrix," *IEEE Transactions Power Electronics, Vol. 18, No. 3*, May 2003, pp. 865-872

[9] M. Sahraoui, A. Ghoggal, S. E. Zouzou, A. Aboubou and H. Razik, "Modelling and Detection of Inter-Turn Short Circuits in Stator Windings of Induction Motor", *IEEE Industrial Electronics, IECON 2006-32 Annual Conference of IEEE, 6-10*,Nov 2006, pp.4981-4986.

[10] G.G. Acosta, C.J. Verucchi and E.R. Gelso, "Current Monitoring System for Diagnosing Electrical Failures in Induction Motors", *Journal in Mechanical Systems and Signal Processing 20* (2006), pp.953–965.

[11] Jesper S. Thomsen and Carsten S. Kallesøe, "Stator Fault Modelling of Induction Motors", SPEEDAM 2006, *International Symposium on Power Electronics, Electrical Drives, Automation and Motion*, S9, pp.6-11. *nd*

[12] Sergio M. A. Cruz and A. J. Marques Cardoso, "Multiple Reference Frames Theory: A New Method for the Diagnosis of Stator Faults in Three-Phase Induction Motors", *IEEE Transactions on Energy conversions, Vol. 20, No. 3*, September 2005.

[13] Xu Bo-qiang, LI He-mhg, SUN Li-hg, "Detection of Stator Winding Inter-turn Short Circuit Fault in Induction Motors", *2004 International Conference on Power System Technology - POWERCON 2004 Singapore*, 21-24 November 2004, pp.1005-1009.

[14] Andreas Stavrou, Howard G. Sedding, and James Penman, "Current Monitoring for Detecting Inter-Turn Short Circuits in Induction Motors", *IEEE Transactions on Energy Conversion, Vol.16, No: 1*, pp.32-37, March 2001.

[15] Mehrdad Heidari, Davar Mirabbasi, S. Ghodrattollah Seifossadat, Reza Kianinezhad, "Comparison and Detection of Abnormal Conditions in Induction Motors", *International Review of Electrical Engineering*, Vol. 3. n. 5, October 2010 (part A), pp. 803-808

[16] Gojko M. Joksimovic and Jim Penman, "The Detection of Inter-Turn Short Circuits in the Stator Windings of Operating Motors", *IEEE Transactions on Industrial Electronics, VOL. 47, NO. 5*, October 2000, pp.10781084.

[17] R. M. Tallam, T. G. Habetler, and R. G. Harley, "Transient model for induction machines with stator winding turn faults," *IEEE Transactions on Industry Application, Vol. 38*, May/June 2002, pp. 304-309.

[18] Sami Ekici, Selcuk Yildirim and Mustafa Poyraz, "Energy and entropy-based feature extraction for locating fault on transmission lines by using neural network and wavelet packet decomposition", *Journal on Expert Systems with Applications 34* (2008), pp. 2937–2944.

[19]. YE Zhongming and WU Bin, Ryerson, *A Review on Induction Motor Online Fault Diagnosis*, Proceedings of third international conference on Power Electronics and Motion Control, 2000.

[20]. M.E.H. Benbouzid, H. Nejjari, University of Picardie, France, *A Simple Fuzzy Logic Approach for Induction Motors Stator Condition Monitoring*, IEEE International Electric Machines and Drives Conference, pp. 634 – 639, 2001.