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Fault diagnosis of three-phase induction motor: A review

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Abstract: Now a days the use of Condition Monitoring of electrical machines are increasing due to its potential to reduce operating costs, enhance the reliability of operation and improve service to customers. Different alternatives to detect and diagnose faults in induction machines have been proposed and implemented in the last years. These new alternatives are characterized by an on-line and non-invasive feature, that is to say, the capacity to detect faults while the machine is working and the capacity to work sensor less. These characteristics, obtained by the new techniques, distinguish them from the traditional ones, which, in most cases, need that the machine which is being analyzed is not working to do the diagnosis. The main purpose of this article is to revise the main alternatives in the detection of faults in induction machines and compare their contributions according to the information they require for the diagnosis, the number and relevance of the faults that can be detected, the speed to anticipate a fault and the accuracy in the diagnosis. and to identify various such diagnosis techniques that can be applied for automatic condition monitoring of induction motors and can be extended easily to other electrical machines also.

Keywords: Induction Machines, Fault Detection and Fault Diagnosis

1. Introduction

Induction motor (IM)are the most used in modern industry due to the low cost, strength, and economical maintenance. After review of previous study found that these IM demand around 40- 50% of the total energy generated in a industrial country [1]. The revolution created by IM a in world economy as most of the production processes in a developed country. Although induction motors are reliable we cannot avoid the possibility of failure. These failures may be very harmful to the motor and hence early detection of failure is needed before they affect the whole operational performance. Hence, sudden failures in the IM can be high effect for the processes in which they are involved. This kind of early fault diagnosis can increase machinery availability and performance, reduce consequential damage and breakdown maintenance. To increases the serviceable life and avoid the unwanted shutdown of equipment, one must go for predictive maintenance instead of the conventional time based maintenance. This process reduces the possibility of motor failure during operation. By using this predictive maintenance one can get the higher reliability and low substantial cost. So that seeking more attention from researchers to diagnose the various faults occurring in IM and to develop various monitoring and signal processing techniques that can be applied for diagnosis of IM faults. IM have two types of faults electric and mechanic faults[2,3]. The major faults of IM can broadly be classified as the following:

(1) Stator faults resulting in the opening or shorting of one or more of a stator phase winding;
(2) Abnormal connection of the stator windings;
(3) Shorted rotor field winding;
(4) Broken rotor bar or cracked rotor end rings;
(5) Eccentricity (Static and/or dynamic air gap irregularities);
(6) Bent shaft;
(7) Bearing and gearbox failures.

The percentage of failures in induction motor component is as follows:

(1) Bearing related faults: 40%.
(2) Stator winding faults: 38%
(3) Rotor related faults: 10%
(4) Other faults: 10%

2. Mechanical Fault

This faults contains over 40% of all machine failures. Bearings are common elements of any electrical machines. The rotary motion of shaft is permitted by the bearings. As seen above the bearings are single largest cause of machine failures. Basically bearings consists of two rings which are known as the inner and the outer rings. A set of balls or rolling elements placed in raceways rotate inside these rings. A continuous stress on the bearing results into the fatigue failures. These failures are at inner or outer races of the bearings. This kind of failures results in rough running of bearings which results in detectable vibrations and increased noise levels. Contamination, corrosion, improper lubrication, improper installation and brine ling are the external factors which are also responsible for the bearing fault. Now when flux disturbance like rotor eccentricities occurs, it results in unbalanced shaft voltages and currents which are also the reason for bearing failures. Temperature is also a cause for bearing failure. So it is advisable that the temperature should not exceed beyond its predetermined limits at rated load condition. A fault in bearing imagined as a small hole, a pit or a missing piece of material on the corresponding elements. Now defecting rolling element bearings produces mechanical vibrations at the rotational speeds of each component. Consider the hole on the outer raceway. In this case the rolling element moves over the defect, it will stay in contact with the hole which produces an effect on the machine at a given frequency [18].

About 40-50% of induction motor faults are related to mechanical defects. Classification of these faults includes the following:

1) damage in rolling element bearing;
2) eccentricity

A *Bearing Faults*

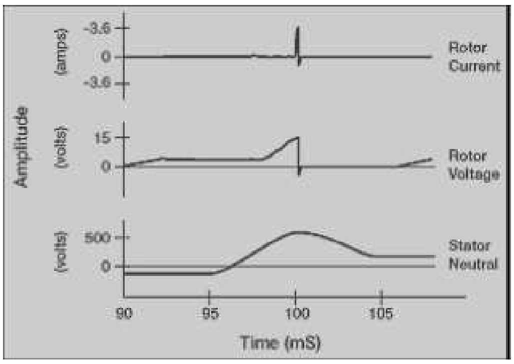

Fig 1. *Time-Vs-Amplitude [4].*

Most electrical machines use either ball or rolling element bearings which consists of outer and inner rings. Balls or rolling elements rotate in tracks inside the rings. Bearing faults may be reflected in defects of outer race, inner race, ball or track. Vibrations, internal stresses, inherent eccentricity, and bearing currents have effective influence on the development of such faults. Taking a step back and looking at the big picture, it is found that motors which were controlled using variable frequency drives tend to show more premature failures. Variable frequency drives (VFDs, or inverters) regulate the speed of motor by converting sinusoidal line AC voltage to DC voltage, and then back to pulse width modulated (PWM) AC voltage of variable frequency. The switching frequency of these pulses ranges from 1 kHz up to 20 kHz and is referred as the "Carrier frequency". The ratio of change of the ΔV/ΔT creates a parasitic capacitance between the motor stator and the rotor, which induces a voltage on the rotor shaft. If this voltage referred as "Shaft voltage", builds up to a sufficient level, it can discharge to ground through the bearings. This current is called as "bearing current". (Fig.1)

The bearing current results from voltage pulse overshoot created by the fast-switching IGBT in the VFD. Other reasons of shaft voltage include non-symmetry of motor's magnetic circuit, supply unbalances, transient conditions and others. Any of these conditions can create bearing currents. Shaft voltage accumulates on the rotor until it exceeds the dielectric capacity of the motor bearing lubricant, then the voltage discharges in a short pulse to ground through the bearing. After discharge, the voltage again accumulates on the shaft and the cycle repeats itself. This random and frequent discharging has an electric discharge machining (EDM) effect, causing pitting of bearings rolling elements and raceways. The first effect of bearing current damage is the audible noise created by rolling elements riding over these pits in the bearing race. This deterioration causes a groove pattern in the bearing race, which indicates that the bearing has sustained severe damage. This can lead to complete bearing failure.

Bearing faults may be reflected in defects of outer race, inner race, ball or track. (Fig.2.) [5]. Fault in the load part of the drive system, load imbalance, shaft misalignment, gearbox faults, or bearing faults, gives rise to a periodic variation of the induction machine load torque. Torque oscillations already exist in a healthy motor owing to space and harmonics of the air-gap field but fault-related torque oscillations are present at particular frequencies often related to the shaft speed. Shaft vibration frequencies associated with different ball-bearing faults were given in [6].

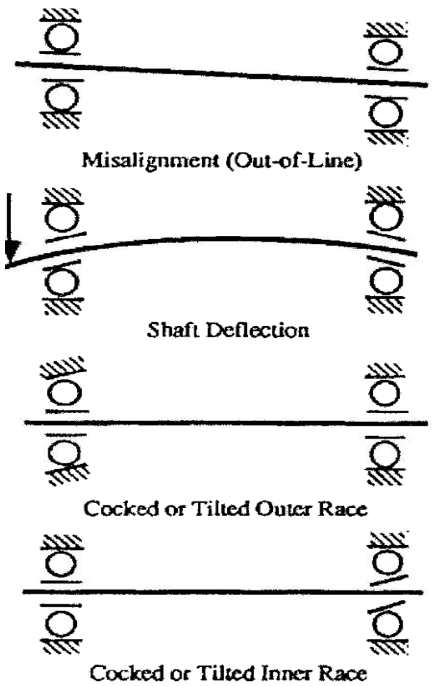

Fig 2. *Four types of rolling –bearing misalignment [5].*

They define cage fault frequency, outer raceway fault frequency, inner raceway fault frequency, ball fault frequency. Typically bearing faults are detected through vibration signals. Internal vibrations are caused by asymmetries and construction details. Vibration and current have different natures. Vibration is acceleration, and is bound to the square of the frequency, while current is a displacement. Hence current is mainly sensitive to low-frequency phenomena. Link between vibration and current component was presented using two different approaches and vibration was seen as a torque component that generates two frequency components in the stator current [7].

Industrial systems are however, still based on vibration signals as they are the only reliable media. However, use of electrical signals is, preferable in many applications. Extensive research activity focuses on bearing fault detection based on current Signals. Current signals can be used for bearing fault detection only in the case of large failures where it is desirable to detect incipient faults that quickly degenerate into other defects. There are a number of papers dealing with the detection and diagnosis of faults in rolling-element bearing based on the analysis of current [8],[9]. It was shown that mechanically induced speed oscillations give rise to sidebands components of the fundamental stator current frequency. It was also demonstrated that shaft misalignment causes modulation of current by the shaft rotational frequency. The use of dedicated signal processing techniques is therefore essential to extract the fault signature from current efficiently.

B *Eccentricity Faults*

Unequal air gap that exist between stator and rotor is known as machine eccentricity. When the eccentricity becomes larger, the resulting unbalanced radial forces can cause stator and rotor rub, and this can result in stator and rotor core damage. The eccentricity is divided into two parts: (1) Static eccentricity and (2) Dynamic eccentricity. In the case of static eccentricity the position of the minimal radial air gap length is fixed in space. Incorrect positioning of the stator or rotor core at the commissioning stage results into static eccentricity. [16,17] In the case of dynamic eccentricity, the centre of the rotor is not at the centre of the rotation and the position of minimum air gap rotates with the rotor. This misalignment caused due to the several factors such as bent rotor shaft, bearing wear or misalignment etc. An air gap eccentricity is permissible upto10%. An inherent level of static eccentricity exists even in newly manufactured machines due to manufacturing and assembly methods. The eccentricity of a cylinder rotating around an air gap can be classified as static, dynamic, or mixed eccentricity (Fig.3.)[10]. Air gap eccentricity is one of the common failure conditions in an induction motor. For static eccentricity the centre of rotation is displaced from the original centre, for dynamic eccentricity, the centre of rotation is at origin while the cylinder is displaced. Finally, for mixed eccentricity, both the cylinder and centre of rotation are displaced from their respective origin. An eccentricity may be caused by many problems such as bad bearing positioning during the motor assembly, worn bearings, bent rotor shaft or operation under a critical speed creating rotor whirl [11]. The eccentricity causes extensive stressing on the machine and greatly increases the bearing wear. Also, the radial magnetic field owing to the eccentricity can act on the stator core exposing the stator windings to potentially harmful vibrations. More recently, the rotor eccentricity was evaluated through different signal analysis such as vibration, flux and current [12], [13].

Where s is the machine slip. Since the frequencies related to the eccentricity and to the load torque overlap on the current sidebands, the frequencies provided by are no longer enough for the diagnosis [14], [15].

The model of eccentricity using both analytical and finite element (FE) approach is still investigated so that it can be improved.

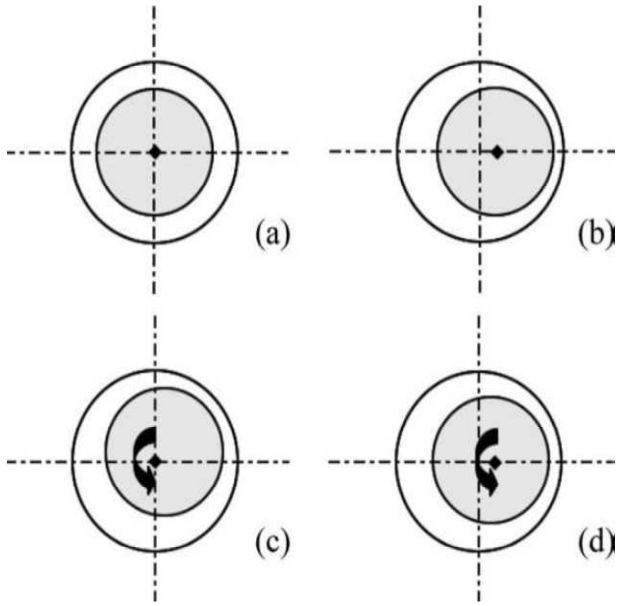

Fig 3. *(a) Without eccentricity (b) Static eccentricity (c) Dynamic eccentricity (d) Mixed eccentricity [10].*

3. Electrical Fault

3.1. A. Stator Faults

In induction motor the stator faults are occurs mainly due to inter turn winding faults caused by insulation breakdown. They are generally known as phase-to-ground or phase-to-phase faults. Almost 30%-40% faults are stator faults. It is very important to detect them in time because they can lead to the total destruction of the motor. Now a days stator current signal analysis is a popular tool to find out stator winding faults due to the advantage of cheap cost, operation and multifunction. Due to the faults in the induction motor the magnetic field in the air gap of the machine will be no uniform and results in harmonics in the stator current which can be signatures of several faults[19].

Various causes/stresses leading to stator faults can be classified into four main types as: [22]

1) Thermal stress:

For every 10 C rise in temperature, the insulation life gets halved due to thermal aging. If operating temperature becomes extremely high, the insulation becomes vulnerable to other influencing factors or stresses that can cause failure [23]. If insulation loses its physical integrity, its resistance to other dielectric, mechanical and environmental stress reduces. By reducing the operating temperature, or by increasing the grade of insulating material used, thermal aging can be minimized.

During start-up, stator current is five to eight times more than the actual normal current; therefore if the motor is subjected to repeated start-ups, the winding temperature will rapidly increase. Also voltage imbalance per phase causes winding temperature to increase with large currents [23]. It has been estimated that the winding temperature also increases with load. Therefore to operate the motor at a specific load, insulation system should be selected accordingly, to meet a rating that is well above the operating temperature.

2) Electrical stresses:

The relation between voltage stresses generated in a motor and its insulation life must be considered while selecting the insulating material. Transient voltages result in reduced winding life or premature failure. These conditions can be caused due to insulation failure, variable frequency drives, opening and closing of circuit breakers, current-limiting fuses, capacitor switching, three-phase faults, line-to-line, line-to-ground, multiphase line-to-ground faults.

3) Mechanical stresses:

These stresses may be due to rotor striking the stator, caused due to shaft deflection, misalignment, bearing failures...If the rotor strikes the stator, while the motor is running; it results in premature grounding of the coil in the stator slot caused by excessive heat generated at the point of contact. If the strike is during start-up, the stator lamination causes puncturing of coil insulation, resulting in grounding of coil. There can be other factors also, which can cause winding failures like: loose nuts and bolts, rotor fan blades, striking the stator or foreign particles striking the stator, causing the stator to overheat and fail.

4) Environmental stresses/contaminations:

Presence of foreign particles could cause various ill effects on the function of motor like premature bearing failure, breakdown of insulation system caused due to reduction in heat dissipation. So steps should be taken to prevent the foreign particles from interacting with motor surface.

To summarize, all the factors responsible for stator winding failure, can be minimized by carefully designing the induction machine and carrying out proper maintenance. Since some of the phenomena are random and uncontrollable, early diagnosis of an induction motor can be more helpful to record these failures and prevent complete failure of the machine.

From the view-point of signal processing and data clustering, researchers view stator winding failures accounting to: 1) stator winding open-phase failure; 2) stator winding short-circuit failure. Open-phase failure allows the machine to operate with a reduced torque while short-circuit failure leads to complete failure of the machine in a short time. A short circuit is the most difficult failure to detect. If left undetected the motor might keep on running, and heating in the shorted turns would cause critical insulation breakdown.

The analysis of turn-to-turn short-circuit in a stator winding can be made by different models. Four main approaches used, in the event of shorted turns are: 1) Analysis of Magneto motive forces (MMF); 2) Finite element (FE) approach; 3) Winding function approach; 4) Dynamic mesh reluctance approach.

Abnormal frequencies, which appear in the stator current, are functions of a number of variables due to MMF distribution and the presence-wave representation of the air gap. These abnormal harmonic frequencies can be made independent of the type of drive-systems or control techniques, by using MCSA as the online motor diagnosis technique. The short-circuit current flowing in the interterm short circuit winding initiates a negative MMF, which reduces the net MMF of the motor phase , therefore waveform of airgap flux, which is changed by the distortion of MMF, induces harmonic frequencies in stator-winding currents as [24].

Dynamic mesh reluctance approach is used to estimate the time available to shut down the machine after a short-circuit event. The worst case is when the number of shorted turns are small, for which lead time is around a few seconds. The lead time can however be slightly increased, weakening the magnetizing field.

An insightful comparative analysis of the four approaches is still under discussion. One of the simplest but most efficient methods is the continuous monitoring of the negative sequence of the stator current, which helps in the detection of electrical or magnetic non-rotational asymmetry of induction machine or an asymmetry in the supply voltage. Many proposals have been presented for use of negative sequence of stator current that is sensitive to different phenomena beyond stator asymmetry [25]. An effective diagnostic procedure should distinguish between negative sequence caused by short-circuit that must be linked to few fundamental parameters of the machine; and the negative sequence caused by unbalanced voltages, saturation winding asymmetries, and eccentricity.

In order to take into account the effects of unbalanced voltages, both current and voltage signals are acquired and a procedure is proposed to disconnect the machine before a complete failure. By means of current and voltage signals, the negative sequence impedance is computed, which is quiet constant unless a failure occurs in the machine. using negative sequence of stator current it is also possible to compute the cross-admittance between voltages and current sequences and their variation with machine load.

In summary, extensive research is focused on stator fault detection with special reference to short circuits. Fault detection and periodic monitoring of stator turn-to-turn insulation is the most effective method. The surge test and the offline partial discharge (PD) test are the most common techniques gaining popularity for assessing turn-to-turn insulation.

B. Rotor Faults

From the survey it has been showed that 10% faults of total induction motor failures are caused by rotor winding. Induction motor rotor faults are mainly broken rotor bars because of pulsating load and direct on line starting. It results into fluctuation of speed, torque pulsation, vibration, overheating, arcing in the rotor and damaged rotor laminations [19].

Cage rotors are classified in two parts: cast and fabricated. Cast rotors were only used in small machines, but now a days due to the development of casting technology it can be used for the rotors of machines in the range of 3000 kW. While fabricated rotors are generally used in special application machines[20]. The reasons for rotor bar and end ring breakage are as following:

1 Thermal stresses
2 Magnetic stresses
3 Residual stresses
4 Dynamic stresses
5 Environmental stresses
6 Mechanical stresses[21].

The two different types of squirrel-cage rotors exist in induction motors: 1) cast; and 2) fabricated. Fabricated cages are used for higher ratings and special application machines where possible failure events occur on bars and end-ring segments. Cast rotors are almost impossible to repair after bar breakage or cracks. In the event of cracked bar, current in the rotor bars adjacent to the faulty bar increases up to 50% of rated current. An accurate detection of rotor faults may lead to a complete diagnosis process. Motor current signature analysis (MCSA) has been extensively used to detect broken rotor bars and end-ring faults in induction machines. The detection of rotor bar failures relies on the analysis of current demanded by the machine. This is a non-invasive way (i.e. without interfering with the normal operation of the machine) and the equipment needed for its registration and processing is rather simple. The rotating field theory states any rotor asymmetry generates a component (1-2s) f in the stator current spectrum when it rotates at a constant speed and infinite inertia. Against, the aforesaid conditions, a component at (1+2s) f appears in the current spectrum.

Where, s = slip.

This conventional approach though robust, has important limitations. To overcome these drawbacks, some authors have proposed, analysis of current demanded by the machine during transient operation (Transient motor current signature analysis). In this regard, methods based on stator start-up current have been recently introduced.

4. Various Techniques of Condition Monitoring

1 *Thermal Monitoring*

The thermal monitoring of electrical machines can be completed by measuring local temperature of the motor or by the estimation of the parameter. Due to the shorted turns in the stator winding the value of stator current will be very high and hence it produces excessive heat if proper action would not be taken and results into the destruction of motor. So some researchers have introduced thermal model of electric motor. Basically this model is classified into two parts:

(1) Finite Element Analysis based model
(2) Lumped parameter based model

FEA model is more accurate than the second model but it is a highly computational method and also time consuming. A lumped parameter based model is equivalent to the thermal network and made from thermal resistances, capacitances and corresponding power losses. 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 faults [31] .

2 *Air gap torque monitoring*

The airgap torque is produced by the flux linkage and the currents of a rotating machine. It is very sensitive to any unbalance created due to defects as well as by the unbalanced voltages. If the harmonic contains zero frequency that means the motor is operating in normal condition. The forward stator rotating field produces a constant while the backward stator field produces a harmonic torque. If we consider the speed of forward and backward rotating field as +ωs, -ωs, the speed of rotor as ωs(1-s), and speed of rotor magnetic field as s ωs then the value of the frequency will be -2 ωs. Hence it indicates the gap in the stator winding and voltage.

3 *Noise Monitoring*

By measuring and analyzing the noise spectrum we are able to do noise monitoring. Due to the air gap eccentricity the noise is produced. This noise is used for fault detection in induction motor. However it is not the accurate way to detect the fault by noise monitoring because of the noisy background from the other machines. Ventilation noise is associated with air turbulence, which is produced by periodic disturbances in the air pressure due to rotating parts. The noise is due to the Maxwell's stresses that act on the iron surfaces. These forces are responsible for producing the noise in the stator structure [31].

4 *Vibration Monitoring*

The vibrations are produced mainly due to the interturn winding faults, single phasing and supply voltage unbalance. It is also a parameter which is very useful for monitoring the health of induction motor. Vibrations in electric machines are caused by forces which are of magnetic, mechanical and aerodynamic origin.

5 *Motor Current Signature Analysis*

MCSA is a non-invasive, online monitoring technique for the diagnosis of problem in induction motor. A full mathematical analysis(with experimental verification) of a three phase induction motor operating with broken rotor bars was published by Williamson and Smith (1982)- this gives an excellent in-depth analysis. It is well known that a three phase symmetrical stator winding fed from a symmetrical supply will produce a resultant forward rotating magnetic field at synchronous speed, and, if exact symmetry exists, there will be no resultant backward rotating field. In most applications stator current is monitored for diagnosis of different faults of induction motor. [32] The MCSA utilizes the results of spectral analysis of the stator current for the detection of air gap eccentricity, broken rotor bars and bearing damage. It is based on the behavior of the current at the side band associated with the fault. For that the intimate knowledge of the machine construction is required. It is known that when the load torque varies with the rotor position, the current will contain spectral components, which coincides with those caused by the fault condition. Researchers conclude that Fourier analysis is very useful for many applications where the signals are stationary. Any asymmetry of the supply or stator winding impedances will cause a resultant backward rotating field from the stator winding. Now apply the same rotating magnetic field fundamentals to the rotor winding the difference is that the frequency of the induced voltage and current in rotor winding is at slip frequency and not at the supply frequency and is given by f2=sf1, where f2 is the rotor current frequency and f1 is the supply frequency [32].

6 *Partial Discharge*

Partial discharge can be described as an electrical pulse or discharge in a gas filled void or on a dielectric surface of a solid or liquid insulation system. This theory involves an analysis of materials, electric fields, arcing characteristics, pulse wave propagation and attenuation, sensor spatial sensitivity, noise and data interpretation. This is a small electric discharge, which occurs due to insulation imperfection. One of the main factor of partial discharge is poor manufacturing which results into voids or air pockets, which get discharged. A deteriorated winding has a PD activity approximately 30 times or even higher than a winding in good condition. So this is a very useful technique to monitor the effectiveness of the winding and also the health of the motor[30].

7 *Wavelet Analysis*

Wavelets are functions that can be used to decompose signals, similar to how to use complex sinusoids in Fourier Transform to decompose signals. The wavelet transforms computes the inner products of the analyzed signal and family of wavelet. In general terms, mathematical transformations are applied to signals to obtain further information from that signal that is not readily available in the unprocessed signal. Most of the signals in practice are time domain signals. That is, whatever that signal is measuring, is a function of time. The frequency spectrum of a signal is basically the frequency components of that signal. It indicates what frequencies exist in the signal. [31]

Several transformations can be applied, but all amongst them the Fourier transformation is a best option and most popular one for signal decomposition. Although this transformation is widely used, it has some disadvantages. The Fourier transforms gives the frequency information of the signal, but it does not mark when in time these frequency components exist. [31] This method works on principle that all signals can be reconstructed from the sets of local signals of varying scale and amplitude, but constant shape. In contrast with sinusoids, wavelets are localized in both the time and frequency domains, so wavelet signal processing is suitable for those signals, whose spectral content changes over time. Wavelet signal processing is different from other signal processing methods because of the unique properties of wavelets. For example, wavelets are irregular in shape and finite in length. The decomposition of the signal into different frequency bands is simply obtained by successive high pass and low pass filtering of the time domain signal. The original signal x[n] is first passed through a half band high pass filter g[n] and a low pass filter h[n] as shown in Fig. 4.

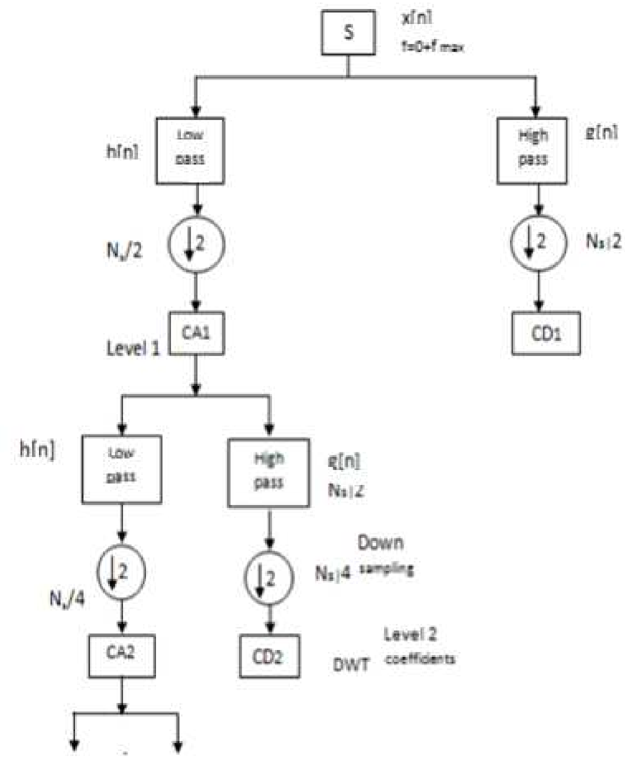

Fig 4. *DWT decomposition of signal [33].*

After the filtering, half of the samples can be eliminated according to SyQuest's rule. Simply discarding every other sample will subsample the signal by two, and signal will then have half the number of points. The scale of the signal is now doubled. Note that the filtering removes a part of the frequency information, but leaves the scale unchanged. Only the sub sampling processes change the scale [29].

8 *Expert Systems*

It is a computer program for performing a suitable data acquisition and a FFT is to be activated for stating the stationary condition of the machine. By using this technique the harmonic contents are eliminated and perform the reduction of the large amount of spectral information to a sutable level. The system can detect the health of the motor by using signature extraction and fault identification from the various harmonic component and from the condition of the motor [26].

9 *Fuzzy Logic System*

For induction motor fault detection, the machine condition is described by linguistic variables. Basic tools of fuzzy logic are linguistic variables. Their values are words or sentences in a natural or artificial language, providing a means of systematic manipulation of vague and imprecise concepts. Fuzzy subsets and the corresponding membership function is constructed for any one parameter for example stator current amplitude. A knowledge base consisting of rule and databases is formed to support the fuzzy inference

10 *Artificial Neural Network*

The architecture of the neural network indicates the arrangement of the neural connection as well as type of units characterized by an activation function. The processing algorithm specifies how the neuron calculates the output vector for any input vector and for a given set of weights. The adjustment of weights is basically known as the training of the neural network. The fault severity evaluation can be done by the supervised neural network, which can synthesize the relationship between the different variables. The neural network can acquire knowledge through the training algorithm and store the knowledge in syneptic weights. The objective of training the network is to adjust the weights so that application of a set of inputs produces the desired set of outputs. [26,27]

11 *Neural Fuzzy System*

By combining ANN techniques and fuzzy logic, a neural-fuzzy system is created. The neural-fuzzy is an ANN structured upon fuzzy logic principles, which enables this system to provide qualitative description about the machine condition and the fault detection process. Fuzzy parameters of membership functions and fuzzy rules provide the knowledge.

5. Conclusion

Fault diagnosis of an induction motor is a still a challenging task for researchers and academicians. Motor current signature analysis is still an open topic of research. As reported by included references, a large majority of research was oriented to induction machines, often with constant speed. Attempts are being made to design artificial intelligence systems using fuzzy logic, neural networks, and genetic algorithm. Making use of digital signal processors for effective monitoring and diagnosis have given appreciable results, but still a lot of work has to be done in the near future to deal with induction motors with adjustable speed drives. The papers published in the past years reflect experimental results obtained from lab set-up using small induction machines. But dealing with large induction machines in field still produces new challenges. Eventually in the near future the reliability and efficiency of diagnostic techniques will improve and may lead to the design of fault tolerant drives.

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