Engineering Universe for scientific Research and management
ISSN (Online): 2319-3069
Vol. 11 Issue IV
April 2019

A NOVEL MECHANISM FOR IDENTIFICATION OF BEARING FAULTS IN THREE PHASE INDUCTION MOTOR

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ABSTRACT

Induction Motor is imperative because of its capability to decrease down-time and manpower required in industry. Moving component bearing faults result in over 40% of all induction motor failure. Vibrational analysis has been used to distinguish bearing faults for quite a long time. Conversely, vibration sensors and master vibration translation are costly. This impediment counteracts across the monitoring of constant bearing conditions in induction motor, which gives better execution contrasted with periodic monitoring, a typical practice for motor bearing support in industry. A strong motivation exists for finding a financially cost-effective approach for the location of bearing faults. Motor terminal signs have pulled in much consideration. In any case, relatively few papers in the literature this issue as it identifies with bearing faults, on account of the troubles in effective detection. In this research, a beginning bearing faults identification strategy for induction motor is proposed in light of the investigation of motor terminal voltages and currents. The essential thought of this technique is to distinguish changes in amplitude modulation between the spatial harmonics caused by bearing faults and the supply principal frequency. This amplitude modulation relationship can be confined utilizing the phase coupling property. An Amplitude Modulation Detector developed from higher prearrange estimation, effectively catches the stage coupling and separates these tweak relationships. In this exploration, in-situ bearing harm tests are directed with the goal that the quickened life traverse of the bearing can be recorded and examined. VSI control schemes, and motor working conditions. Taking the mechanical vibration pointer as a kind of perspective for blame recognition, the proposed technique is shown to be compelling in recognizing nascent bearing faults in induction motors. On the off chance that engines are working at close consistent state conditions the bearing shortcoming recognition.

INTRODUCTION

Induction motors are complex electro-mechanical devices utilized in most industrial applications for the conversion of power from electrical to mechanical form. Induction motors are used worldwide as the workhorse in industrial applications. Such motors are robust machines used not only for general purposes, but also in hazardous locations and severe environments. General purpose applications of induction motors include pumps, conveyors, machine tools, centrifugal machines, presses, elevators, and packaging equipment. On the other hand, applications in hazardous locations include petrochemical and natural gas plants, while severe environment applications for induction motors include grain elevators, shredders, and equipment for coal plants. Additionally, induction motors are highly reliable, require low maintenance, and have relatively high efficiency. Moreover, the wide range of power of induction motors, which is from hundreds of watts to megawatts, satisfies the production needs of most industrial processes. However, induction motors are susceptible to many types of fault in industrial applications. A motor failure that is not identified in an initial stage may become catastrophic and the induction motor may suffer severe damage. Thus, undetected motor faults may cascade into motor failure, which in turn may cause production shutdowns. Such shutdowns are costly in terms of lost production time, maintenance costs, and wasted raw materials.

The motor faults are due to mechanical and electrical stresses. Mechanical stresses are caused by overloads and abrupt load changes, which can produce bearing faults and rotor bar breakage. On the other hand, electrical stresses are usually associated with the power supply. Induction motors can be energized from constant frequency sinusoidal power supplies or from adjustable speed ac drives. However, induction motors are more susceptible to fault when supplied by ac drives. This is due to the extra voltage stress on the stator windings, the high frequency stator current components, and the induced bearing currents, caused by ac drives. In addition, motor over voltages can occur because of the length of cable connections between a motor and an ac drive. This last effect is caused by reflected wave transient voltages [1]. Such electrical stresses may produce stator winding short circuits and result in a complete motor failure.

According to published surveys induction motor failures include bearing failures, inter-turn short circuits in stator windings, and broken rotor bars and end ring faults. Bearing failures are responsible for approximately two-fifths of all faults. Inter-turn short circuits in stator windings represent approximately one-third of the reported faults. Broken rotor bars and end ring faults represent around ten percent of the induction. Several alternatives have been used in industry to prevent severe damage to induction motors from the above mentioned faults and to avoid unexpected production shutdowns. Schedule of frequent maintenance is implemented to verify the integrity of the motors, as well as to verify abnormal vibration, lubrication problems, bearings conditions, and stator windings and rotor cage integrity. Most maintenance must be performed with the induction motor turned off, which also implies production shutdown. Usually, large companies prefer yearly maintenance in which the production is stopped for full maintenance procedures. Redundancy is another way to prevent production shutdowns, but not induction motor failure. Employing redundancy requires two sets of equipment, including induction motors. The first set of equipment operates unless there is a failure, in which case the second set takes over. This solution is not feasible in many industrial applications due to high equipment cost and physical space limitations. Thus, in this thesis an alternative to these approaches is proposed.

Specifically, this thesis addresses electrically detectable faults that occur in the stator windings and rotor cage, namely inter-turn short circuits in stator windings and broken rotor bars. The methods developed in this thesis detect motor faults without the necessity of invasive tests or process shutdowns. Moreover, the presented methods monitor the operating induction motor continuously, so that human inspection is not required to detect motor faults. Now that the central problem of this thesis has been presented, a literature review about motor fault identification methods including their advantages and disadvantages is made. Induction motors are complex electro-mechanical devices used worldwide in industrial processes to convert electrical energy into mechanical energy. Such motors are widespread because they are robust, easily installed, controlled, and adaptable for many industrial applications, including pumps, fans, air compressors, machine tools, mixers, and conveyor belts, as well as many other industrial applications. Moreover, induction motors may be supplied directly from a constant frequency sinusoidal power supply or by an ac variable frequency drive.

Induction Motor Operation

The operating principle of an induction motor is thus based on the synchronously rotating magnetic field The stator is composed of three windings electrically shifted 120ºe as shown in F The three windings are connected to a three phase ac power supply.

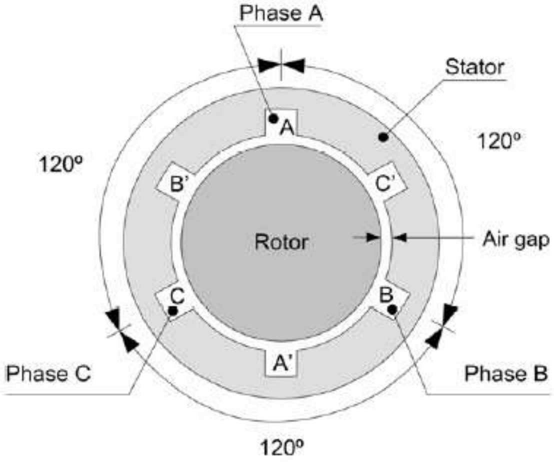

Fig. 1: Two-pole induction motor schematic

AC Drives

The ac drives are electronic devices used to control speed and torque of three-phase induction motors. An induction motor supplied by an ac drive can operate over a wide range of frequency, typically from 0 to 60Hz. This range of frequencies yields rotor speeds from 0 r/min to the rated value. Moreover, the ac drive can produce the rated torque at any frequency within this range from zero to the rated frequency. This is a powerful characteristic for industrial processes that require torque-speed control. Although, the electrical installation of an ac motor-drive system is more expensive than an induction motor with a constant frequency sinusoidal power supply, the ac motor-drive system can control not only the motor speed, but also can control and limit the starting torque and current, can adjust the acceleration and deceleration ramps, can maintain a constant torque for frequencies from zero to the rated frequency, and protect the motor against over voltages and over currents. The ac drives consist of three main parts, namely: three-phase full wave rectifier, dc bus filter, and pulse width modulation (PWM) inverter. The block diagram of the power stage of an AC drive is shown in Fig.

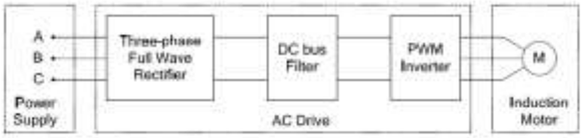

Fig. 2: Functional block diagram of an AC drive

The three-phase full wave rectifier converts the three-phase as voltage of the power supply into dc voltage. Although ac drives are usually supplied by a three-phase power supply, there are also ac drives supplied by single phase ac power supplies to control three-phase induction motors. The power electronic devices used in this portion of the ac drive can be either diodes or SCR (silicon controlled rectifier).

Although the output of a rectifier is dc, it is not ideal, i.e. the dc voltage contains ripples. Thus, a dc bus filter at the second stage is used to reduce the ripple content of the dc bus voltage. The third and last stage is a PWM inverter which converts the dc voltage from the dc bus filter into three-phase balanced ac voltage. The operating frequency and magnitude of this three-phase ac voltage applied to the motor terminals can be controlled in order to maintain the developed torque of the motor constant from zero to rated frequency. The power electronic devices that constitute the switches in a PWM inverter for ac drives are in most cases the so-called IGBT (insulated gate bipolar transistor) due to their high current capability, very low control power, high frequency commutation, and low losses.

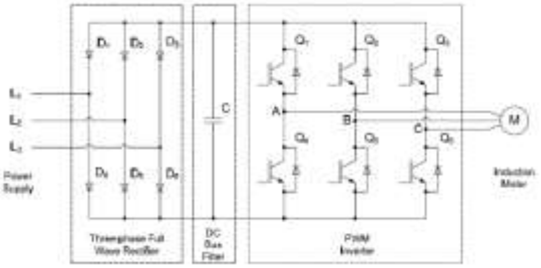

Fig. 3: Circuit diagram of an AC drive

The PWM technique generates rectangular wave forms with modulated width in order to obtain variable voltage and frequency to supply an induction motor. The control stage of an ac drive generates a triangular and a sinusoidal wave as shown in Fig.

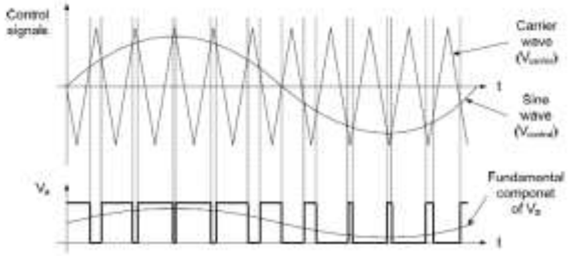

Fig. 4: PWM control signal and phase Va voltage.

Fault Diagnostic Methods

The induction motor fault diagnostic method and the induction motor fault monitoring method are presented.

The diagnostic method classifies two different types of electrically detectable faults in induction motors: broken rotor bars and inter-turn short circuits in stator windings. Additionally, this method identifies the fault severity that is proportional to the number of broken bars or the number or percentage of short circuited turns computed by this method. This method is trained and tested with the datasets experimentally acquired from induction motors. The three-phase stator current envelope is the feature of the induction motors, which is used to build the fault signatures in order to classify the motor operating conditions.

On the other hand, the monitoring method classifies the motor operating conditions of an induction motor as healthy or faulty, in which a faulty condition represents any number of broken rotor bars. The monitoring method is trained with datasets generated using a commercial finite element software package (MAGSOFT) based on Finite Elements (FE) methods, and the monitoring method is tested with datasets experimentally acquired. The air gap torque profile is the feature of an induction motor used to build the signatures of the training and testing stages. This is a robust fault monitoring method because this algorithm is trained with only one dataset generated to a specific motor and it can monitor the fault of other induction motors independently of motor power, number of poles, motor load, and operating frequency. This monitoring method has the following two main advantages:

- The monitoring method is a robust technique to monitor induction motor faults, because this method is trained with datasets generated by FE simulations in order to monitor the operating condition of real motors. Thus, the training and monitoring stages of this method use datasets from different sources. The training stage uses datasets from FE simulations instead of datasets experimentally acquired, while the monitoring stage uses datasets from experimental setups. This characterizes the robustness of this method.

- This monitoring method uses a novel normalization process. This normalization process is used to build fault signatures of the training and monitoring stages with similar amplitude and frequency. Thus, the signatures of the training and monitoring stages are independent of power, number of poles, level of load torque, and operating frequency, or other design characteristics of the motor being monitored. This is the case at least for the two motors subject of this investigation. The monitoring method yields a relatively high degree of motor fault monitoring accuracy.

Additionally, the monitoring method has also the following advantages:

- This monitoring method uses a small training set. The training set consists of two datasets (one for the healthy case and one for the faulty case) generated for only one induction motor simulated by FE methods, and this training set yields signatures that realistically represent the motor operating conditions of any other real induction motor, independent of power, number of poles, level of load torque, and operating frequency. This method yields a relatively high degree of motor fault monitoring accuracy, as will be demonstrated
- This method is quickly trained because only two datasets (healthy and faulty) are needed in the training process instead of large datasets that include every single case related to different motor power, number of poles, motor load, and operating frequency. Accordingly, the small amount of training data needed in this presented method saves considerable time in generating the training set, since an FE simulation and experimentally acquired datasets require considerable time to obtain.
- High costs associated with equipment to emulate the faults through destructive methods to generate datasets to train this method are not involved, since this AI-based method is trained with datasets generated by finite element (FE) methods, instead of datasets experimentally acquired.

This method uses only the three phase stator currents and voltages to build the signatures of the real motor and monitor its operating conditions. Thus, this method does not need complicated mathematical models of induction motors or values of motor parameters that are often difficult to obtain. Even the air gap torque (or developed torque) and the asynchronous speed (rotor speed) needed during the monitoring process are calculated through torque and speed estimators, respectively. These estimators only use experimentally acquired stator currents and voltages in addition to parameters that are commonly available from the nameplate data of motors. Thus, this method constitutes a powerful tool for induction motor fault monitoring. Although, the diagnostic and monitoring methods use different procedures to obtain the training and testing sets, the training and testing stages of these methods are the same. The next section discusses the training and testing stages.

PROPOSED BEARING FAULT DETECTION METHOD

One of the most fundamental and useful tools in digital signal processing has been the estimation of the power spectra density (PSD) of discrete-time deterministic and stochastic processes. The available power spectrum estimation techniques may be considered in a number of separate classes, namely, conventional (or ”Fourier type”) methods, maximum-likelihood method of Capon with its modifications, maximum entropy and minimum-cross-entropy methods, minimum energy, methods based on autoregressive (AR), moving average (MA) and ARMA models, and harmonic decomposition methods such as Prony, Pisarenko, MUSIC, and Singular Value Decomposition. multi-dimensional, multi-channel, and array processing problems. Each one of the aforementioned techniques has certain advantages, and limitations not only in terms of estimation performance, but also in terms of computational complexity. Therefore, depending on the signal environment, one has to choose the most appropriate method in power spectrum estimation, the process under consideration is treated as a superposition of statistically uncorrelated harmonic components and the distribution of power among these frequency components is then estimated. Only linear mechanisms governing the process are investigated because phase relationships between frequency components are suppressed. The information contained in the power spectrum is essentially present in the autocorrelation sequence. This is sufficient for the complete statistical description of a Gaussian process of known mean. However, there are practical situations where one must look beyond the power spectrum (autocorre1ation) to obtain information regarding deviations from Gaussian's and presence of nonlinearities in the system that generates the signals. Higher order spectra (also known as poly-spectra), defined in terms of higher order cumulates of the process, do contain such information Particular cases of higher order spectra are the third-order spectrum also called the bi-spectrum which is, by definition, the Fourier transform of the third-order cumulate sequence, and the tri-spectrum (fourth-order spectrum), which is the Fourier transform of the fourth-order cumulate sequence of a stationary random process. The power spectrum is, in fact, a member of the class of higher order spectra, i.e., it is the second-order spectrum.

The general motivation behind the use of higher order spectra in signal processing is threefold:

1) To extract information due to deviations from Gaussian's,
2) To estimate the phase of non-Gaussian parametric signals,
3) To detect and characterize the nonlinear properties of mechanisms that generates time-series via phase relationships of their harmonic components.

The motivation for using higher order spectra is based on the fact that the nonlinear properties of mechanisms can be characterized via phase relationships of their harmonic components. Using the phase relation information between harmonic components, some motor faults can be detected. The amplitude modulation detector is developed from the concept of the bi-spectrum. In the following section, the bi-spectrum estimation is reviewed.

Effect of Bearing Faults on Motor Efficiency

When the bearing is damaged, the motor losses caused by the increased friction will be larger. This decreases the motor efficiency. The gearbox test-bed is used to conduct an efficiency experiment. The motor torque is measured by an AC100V Torque Detector, and the motor speed is measured by a MP981 encoder. The experiment procedure of the efficiency experiment is the same with the closed-loop experiment procedures listed The vibration indicator and the AMD indicator for this experiment are shown in The motor efficiency is shown in Figure. It can be seen that the motor efficiency decreases from around 79.8% in healthy condition, to around 76.5%in faulty condition. The experimental results are shown in this chapter. These experiments are based on:

- Different power supplies, supply mains, and VSI;
- Different VSI control methods, open-loop, and closed-loop controls;
- Different motor operation conditions, steady state, and transient operations;
- Different fault indicators, electrical AMD indicators, and mechanical vibration indicators.

The mechanical vibration indicator can effectively detect mechanical faults of induction motors. It is used as the fault detection capability reference for the electrical AMD indicators. Experimental results show that electrical AMD indicators developed in this research can effectively detect incipient bearing faults in motors with a constant load level. When motors are operating at steady state, experimental results show that the fault detection rate is 100%.

RESULTS

Results are presented to test the effect of the shaft currents on the electrical indicator performance; to the effect of different load levels on the indicators. bearing are the variations of the. Bearing damage for motors energized by power supply mains and VSI are respectively. Finally, the effect of bearing faults on motor conversion efficiency A. Effect of Shaft Currents on Indicator Performance the motor load-side bearing is damaged using injected shaft currents. The effect of shaft currents on the indicator has to be investigated since this is a large current, around compared with the motor stator current. However, it is difficult to exactly identify the effects of the shaft currents on the motor magnetic field. With shaft currents and without shaft currents are so that the effect of shaft currents on the fault indicator can be identified. Moreover, this work is focused on the early stage of bearing damage because we are interested in detecting incipient are conducted.

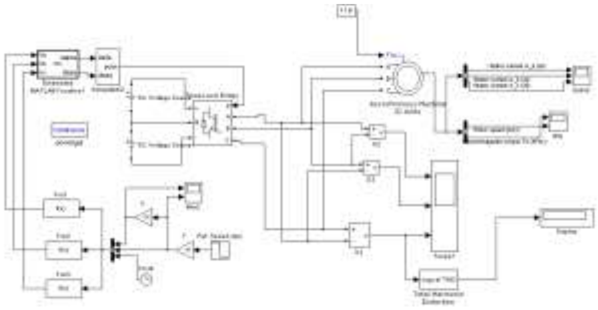

Fig. 5: Simulation Circuit Diagram of New techniques for identifying bearing faults in 3-Phase induction motor

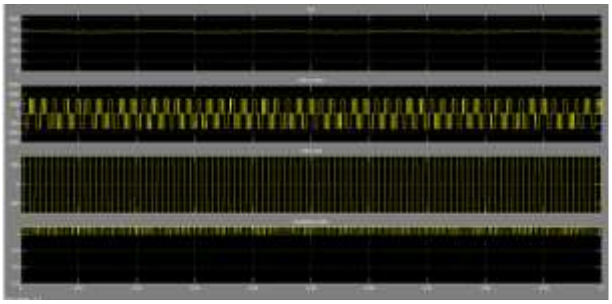

Fig. 6: Simulation Result VDC,Vab Inv, after LC Filter

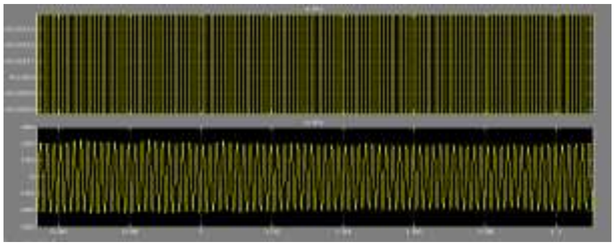

Fig. 7: Simulation Result Rotor current ir_a (A), Stator current is_a (A)

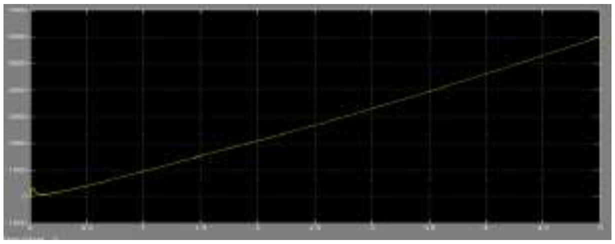

Fig. 8: Simulation Result Rotor speed (wm)

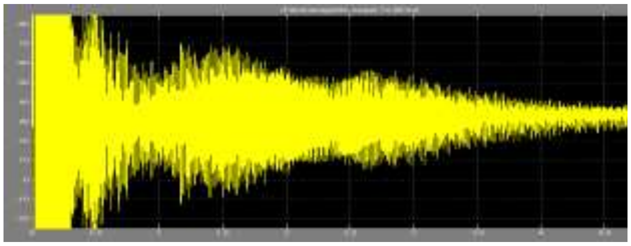

Fig. 9: Simulation Result Electromagnetic torque Te (N*m)

CONCLUSION

The bearing fault detection of induction motors energized by power supply mains and VSI type drives. In the proposed method, only motor terminal voltages and currents are utilized for fault detection purposes. To develop a bearing fault detection scheme, bearing faults are often staged in an off-line manner. That is, disassembling the bearing, damaging it separately and then assembling the machine. The act of disassembling, reassembling, remounting, and realigning the test motor significantly alters the current and vibration characteristics of the machine, which is one of the difficulties in developing a bearing fault monitoring scheme. In this research, in-situ bearing damage experiments are conducted so that the life span of the bearing can be simulated in an accelerated manner and a bearing fault detection scheme can be developed and tested. Bearing faults can be categorized into single point defects and generalized roughness defects. In both single point defect and generalized roughness bearing faults, the damaged bearing leads to radial motion between the stator and the rotor. This kind of motion varies the air gap of the machine, so that the original amplitude modulation relationships in the healthy motor are changed when bearings are damaged. In single point defect bearing defects, the fault related frequencies can be determined using the bearing geometric dimensions, while in generalized roughness bearing defects.

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