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SHORT WINDING FAULT DETECTION USING PARK'S VECTOR

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Abstract: The subject of on-line detection of short winding fault in three-phase induction motors is discussed, and a noninvasive approach, based on the computer-aided monitoring of the stator current Park's Vector, is introduced. The park's vector representation is obtained using Virtual instrument. The Virtual Instrument is obtained by programming in Labview software. The laboratory tests were conducted on 0.5 hp three phase induction motor. The motor was initially tested under healthy condition and Park's vector representation was plotted. After this, the short winding fault is replicated in the motor. The motor was tested again under faulty condition and Park's vector representation was plotted. Both plots were then compared. It is observed that current park's vector pattern of healthy motor was perfect circle while current park's vector pattern under faulty condition was elliptical in shape. Experimental results, obtained by using a special fault producing test rig, demonstrate the effectiveness of the proposed technique, for detecting the presence of short winding fault in operating three-phase induction machines.

Keyword: Short winding fault, Fast Fourier Transform (FFT), Induction motor, LabVIEW.

1. Introduction

According to the survey, 35-40 % of induction motor failures are related to the stator winding insulation [1]. Moreover, it is generally believed that a large portion of stator winding-related failures are initiated by insulation failures in several turns of a stator coil within one phase. This type of fault is referred as a "stator turn fault" [2]. A stator turn fault in a symmetrical three-phase AC machine causes a large circulating current to flow and subsequently generates excessive heat in the shorted turns. If the heat which is proportional to the square of the circulating current exceeds the limiting value the complete motor failure may occur [3]. However, the worst consequence of a stator turn fault may be a serious accident involving loss of human life. The organic materials used for insulation in electric machines are subjected to deterioration from a combination of thermal overloading and cycling, transient voltage stresses on the insulating material, mechanical stresses, and contaminations. Among the possible causes, thermal stresses are the main reason for the degradation of the stator winding insulation. Stator winding insulation thermal stresses are categorized into three types: aging, overloading, and cycling [4]. Even the best insulation may fail quickly if motor is operated above its temperature

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limit. As a rule of thumb, the life of insulation is reduced by 50 % for every 10^0 *C* increase above the stator winding temperature limit [5]. It is thus necessary to monitor the stator winding temperature so that an electrical machine will not operate beyond its thermal capacity. For this purpose, many techniques have been reported [6]-[8]. However, the inherent limitation of these techniques is their inability to detect a localized hot spot at its initial stage.

A few mechanical problems that accelerate insulation degradation include movement of a coil, vibration resulting from rotor unbalance, loose or worn bearings, airgap eccentricity, and broken rotor bars . The 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. Mechanical faults, such as broken rotor bar, worn bearings, and air-gap eccentricity, may be a reason why the rotor strikes the stator windings. Therefore, such mechanical failures should be detected before they fail the stator winding insulation [9,10]. Contaminations due to foreign materials can lead to adverse effects on the stator winding insulation. The presence of foreign material can lead to a reduction in heat dissipation [11]. It is thus very important to keep the motors clean and dry, especially when the motors operate in a hostile environment.

Regardless of the causes, stator winding-related failures can be divided into the five groups: turn-to-turn, coil-to-coil, line-to-line, line-to-ground, and open-circuit faults. Among the five failure modes, turn-to-turn faults (stator turn fault) have been considered the most challenging one since the other types of failures are usually the consequences of turn faults. Furthermore, turn faults are very difficult to detect at their initial stages. To solve the difficulty in detecting turn faults, many methods have been developed [12]-[14]. In present work, short winding fault is diagnosed with Park's Vector approach.

2. Past studies

Current Park''s vector is an important electrical monitoring technique. The basic idea of current Park's vector is that in three-phase induction motors, the connection to stator windings usually does not use a neutral. For a Y-connection induction motor, the stator current has no zero-sequence component. A two-dimensional representation of the three-phase currents, referred to as current Park's vector, can then be regarded as a description of motor conditions. Under ideal conditions, balanced three phase currents lead to a Park's vector that is a circular pattern centered at the origin of coordinates [15]. Therefore, by monitoring the deviation of current Park's vector, the motor condition can be predicted and the presence of a fault can be detected.

J. Marques Cardoso et. al. [15-16] discussed the subject of on-line detection of airgap eccentricity in three-phase induction motors. Experimental results show that it is possible to detect the presence of airgap static eccentricity in operating three-phase induction motors, by computer-aided monitoring of the stator current Park's Vector. Qualitative information about the

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severity of the fault can be easily obtained by observing the splitting of the current Park's Vector pattern.

Mendes and Cardoso [17] detected faults in voltage-sourced inverters using the current Park's vector. In similar study, Nejjari and Benbouzid [18] analyzed the deviation in the pattern of current Park's vector to diagnosis the supply voltage unbalance of induction motors. However, this method ignores the non-idealities of electrical machines and inherent unbalance of supply voltages. In addition, it is difficult to isolate different faults using this method alone, since different faults may cause a similar deviation in the current Park's vector.

Douglas et. al. [19] proposed a new technique "Extended park's Vector Approach" (EPVA), which was successfully applied in the steady diagnosis of rotor faults, inter-turn stator faults and unbalanced supply voltage, and mechanical load misalignment. This technique was based on the park's vector approach; however, it provides greater insight into the severity of the faults.

Izzety Onel et. al. [20] investigated the application of induction motor stator current signature analysis (MCSA) using Park's transform for the detection of rolling element bearing damages in three-phase induction motor. This study presents bearing faults and Park's transform and then gives a brief overview of the radial basis function (RBF) neural networks algorithm. Data acquisition and Park's transform algorithm were achieved by using LabVIEW. The neural network algorithm is achieved by using MATLAB programming language. The diagnosis process was tested on a 0.75kW, squirrel-caged induction motor. Experimental results showed that it is possible to detect bearing damage in induction motors using an ANN algorithm. ANN was trained, giving 100% correct prediction for training data. When ANN was presented a set of Park's vector pattern, the diagnosis system was found to provide very good performance.

The research carried out by Szabó Loránd et. al. [21] shows that how the Park's vector approach based method can be used for detecting the rotor faults of the squirrel cage induction machine. The squirrel cage induction machine was tested with two rotors, a healthy one, and one having broken rotor bars. The line currents of the motor were visualized on an oscilloscope using a special electronic circuit which was able to synthesize the two orthogonal components of the current, voltage and flux phasors. Beside this the line currents were acquired by a DAQ board from a PC using advanced virtual instruments (VIs) built up in LabVIEW environment. Several characteristics of the motor under study were plotted. Due to the broken rotor bars, there was significant fluctuation in the torque of the machine, and the amplitude of the line current at the end of the starting period was quite high. The shape of the current's phasor of faulty motor was not of perfect circular shape, which was the clear indication a fault in the squirrel cage induction machine.

Izzet onel and Benbouzid [22] diagnosed the problem of bearing failure in induction motors by using park vector approach. They also compared two fault detection and diagnosis techniques, namely the Park transform approach and the Concordia transform. Experimental tests were carried out on a 0.75 kW two-pole induction motor with artificial bearing damage. The

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Vol. 2 Issue 2 July 2012

results indicate that the Park transform approach has better diagnosis capabilities than the Concordia transform.

3. Detection of faults using Park's vector approach

In three phase induction motors, the connection to the mains does not usually use the neutral. Therefore, the main current has no homopolar component. A two dimensional representation can then be used for describing three phase induction motor phenomena, a suitable one being based on the current Park's vector [15].

As a function of mains phase variable (i_a, i_b, i_c) the current Park's vector components (i_d, i_q) are [16-22]:

$$i_d = \sqrt{\frac{2}{3}} i_a - \frac{1}{\sqrt{6}} i_b - \frac{1}{\sqrt{6}} i_c \quad \text{.....(1)}$$

$$i_q = \frac{1}{\sqrt{2}} i_b - \frac{1}{\sqrt{2}} i_c \quad \text{....(2)}$$

Under ideal conditions, three phase currents lead to a Park's vector with the following components:

$$i_d = \frac{\sqrt{6}}{2} I \sin \omega t \quad \text{....(3)}$$

$$i_q = \frac{\sqrt{6}}{2} I \sin\left(\omega t - \frac{\pi}{2}\right) \quad \text{.....(4)}$$

where

I= maximum value of the supply phase current

ω_s =supply frequency

t =time variable

Its representation is a circular pattern centered at the origin of the coordinators as illustrated by Figure 1. This is very simple reference figure that allows the detection of abnormal conditions by monitoring the deviations of acquired patterns.

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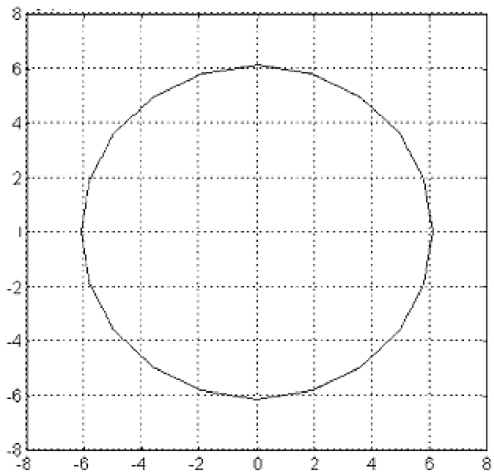

Figure 1: Current Park's vector for ideal condition.

Short winding fault is also diagnosed with Park's vector approach. The analysis of the three-phase induction motor can be simplified using the Park transformation. The method is based on the visualization of the motor current Park's vector representation. If this is a perfect circle the machine can be considered as healthy. If an elliptical pattern is observed for this representation, the machine is faulty. From the characteristics of the ellipse, the fault's type can be established. The ellipticity increases with the severity of the fault.

3.1. Experimental set up

In order to diagnose the fault of induction motor with high accuracy, a modern laboratory test bench was set up. It consists of three phase induction motor coupled with rope brake dynamometer, transformer, NI data acquisition card PCI-6251, data acquisition board ELVIS and Pentium-IV Personnel Computer with software *LabVIEW 8.2.* The rated data of the tested three-phase squirrel cage induction machine were: 0.5 hp, 415V, 1.05 A and 1380(FL) r/min. The parameters of motor used in the experiment are given in Table 1. *LabVIEW 8.2* software is used to analyze the signals. It is easy to take any measurement with NI LabVIEW. The measurements can be automated from several devices and data can be analyzed spontaneously with this software. Data acquisition card PCI-6251 and acquisition board ELVIS are used to acquire the current samples from the motor under load. NI M Series high-speed multifunction data acquisition (DAQ) device can measure the signal with superior accuracy at fast sampling rates. This device has NI-MCal calibration technology for improved measurement accuracy and six DMA channels for high-speed data throughput. It has an onboard NI-PGIA2 amplifier designed for fast settling times at high scanning rates, ensuring 16-bit accuracy even when measuring all channels at maximum speeds. This device has a minimum of 16 analog

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Vol. 2 Issue 2 July 2012

inputs, 24 digital I/O lines, seven programmable input ranges, analog and digital triggering and two counter/timers. . The specifications of the DAQ card are shown in Table 2. The NI ELVIS integrates 12 of the most commonly used instruments – including the oscilloscope, DMM, function generator, and Bode analyzer – into a compact form factor ideal for the hardware lab. based on NI LabVIEW graphical system design software, NI ELVIS offers the flexibility of virtual instrumentation and allows for quick and easy measurement acquisition and display. In the experiment, the speed of the motor is measured by digital tachometer. The virtual instrument (VIs) was built up with programming in LabVIEW 8.2. The VIs was used both for controlling the test measurements and data acquisition, and for the data processing. In order to test the system in practical cases, several measurements were made to read the stator current of a motor.

Table 1: Parameters of experimental induction motor

Parameters	**Data**
Power	0.5 hp
Frequency	50 Hz
Number of phases	3
Speed	1500 r.p.m
Volt	415 V
Current	1.05 Amp
No. of pole pairs	2
Air gap length	2 mm
Number of rotor slots	36
Efficiency(FL)	86%

Table 2: Specification of data acquisition card NI-PCI 6251

Sr. no.	**Specification**	
1	Analog Inputs	16
2	AI Resolution (bits)	16
3	Analog Outputs	2
4	AO Resolution	16
5	Max Update Rate (MS/s)	2.8
6	AO Range (V)	±10, ±5, ±ext ref
7	Digital I/O	24
8	Correlated (clocked) DIO	8, up to 10 MHz

3.2 Data acquisition parameters and LabVIEW programming

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To get the Park's vector pattern, the programming is done with signal processing module of LabVIEW software. The induction motor has been initially tested, in the absence of faults in order to determine the reference current Park's vector pattern corresponding to the supposed healthy motor. Afterward, short circuited motor was tested. A time window of 175ms was used for all data acquisition in order to get simple and sufficient detailed pattern. The sample rate was 2000 sample/second. The number of samples was taken 350.

3.3 Observations and Discussion

Figure 2 shows a Current Park's vector pattern for healthy motor which is a perfect circle where instantaneous magnitude is constant. An unbalance due to short winding faults results in different representation of the park's vector is shown in figure 3. It could be seen that current pattern for faulty motor is clearly different from current pattern of the healthy motor. The shape of the current's phasor in figure 3 is not of perfect circular shape. The elliptical shape of current's phasor indicates short winding fault in the squirrel cage induction machine. Thus, by comparing the current pattern of healthy and faulty motor, the short winding fault can be easily diagnosed.

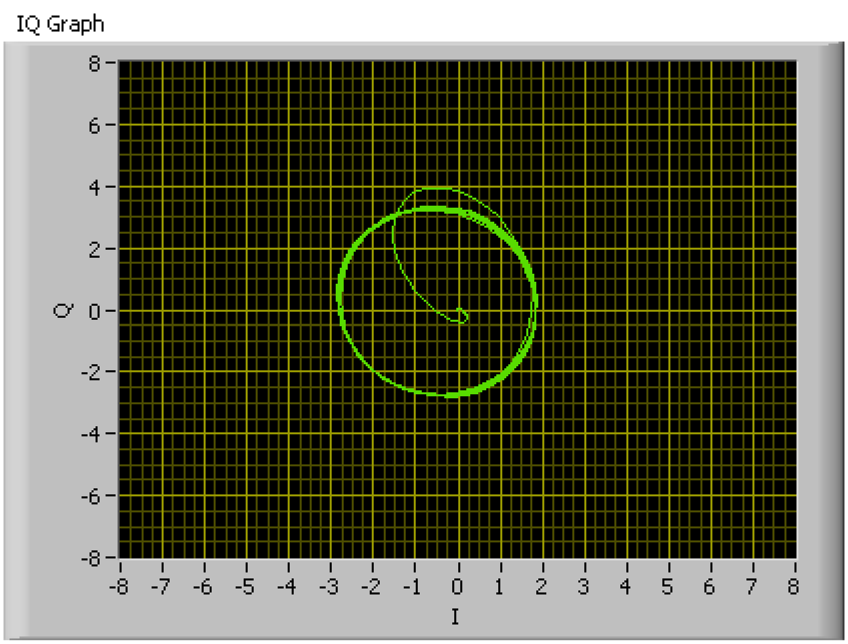

Figure 2: Current Park's vector pattern for healthy motor

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Vol. 2 Issue 2 July 2012

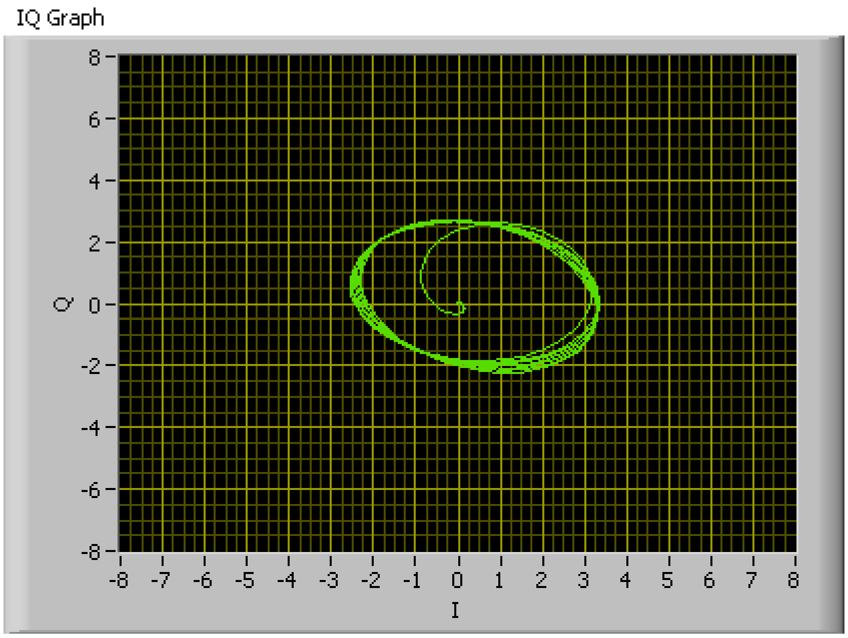

Figure 3: Current Park's Vector pattern for short circuited motor

4. Conclusion

This paper has proposed a methodology by which induction motors electrical faults can be diagnosed by monitoring the stator current by computer. The proposed methodology was based on the so-called Park's vector approach. In fact, stator current Park's vector patterns used to discern between 'healthy' and 'faulty' induction motor. The results obtained from the experiment show that current park's vector pattern of healthy motor was perfect circle while current park's vector pattern under faulty condition was elliptical in shape. In this way, the short winding fault of induction motor can be easily diagnosed by comparing the Park's vector representations. Thus, the laboratory experiment proves the effectiveness of this technique in area of computer aided condition monitoring of induction machines.

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