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Detection of Stator Shorted-Turns Faults in Induction Machine using DC-Centered Periodogram

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***Abstract*—The detection and diagnosis of stator winding shorted turns faults of in induction machine is essential for reliable and economical operations in industries. The problem of detecting shorted turns faults in stator windings has been difficult. The risk of the failure or the breaking down of this machine can be circumvented provided there is a proper way to detect the shorted turns faults. From literature, there are many methods of faults detection and diagnosis of the machine, however, DC-centered periodogram has not really been applied to detect and diagnose a fault in electrical machine. This paper describes stator winding shorted-turn fault detection of induction machine using DC-centered periodogram. Codes to analyses the DC-centered periodogram for both induction Machine under Healthy and shorted fault conditions were written from the general algorithm of periodogram. It is observed that the abnormality showed from the stator current signals for each condition corresponds to the plots generated by the DC-centered periodogram.**

***Index Terms*—Faults detection, Induction machine, Periodogram, Shorted-turn.**

I. Introduction

THERE have been many researchers focusing on the new fault diagnosis and condition monitoring techniques for an electrical machine, especially induction machine for the past 40 years. Undoubtedly, one of the major parts of the industries that cannot be replaced is induction machine. The machine is considered very important because they are extensively used not only in the industries where it is the core of most of the engineering processes but also in many home appliances. Therefore, it is very crucial that the machine does not break down, particularly for process chains continuity and productions in many industries. The risk of the failure or the breaking down of this machine can be circumvented provided there is a proper diagnostic technique. The technique in question is required to detect coming failure/faults at an early stage. This will prevent production shutdowns, huge financial loss, sudden disruption of the machine and personal injuries if these faults are detected at the incipient stage. From literature, there are many methods for fault detection and diagnosis of the machine, however, DC-centered periodogram has not really been applied to detect and diagnose faults in electrical machine[1], [2], [3]. This paper, section II explains what shorted turns fault and section III discusses a brief experiment to capture data from both Healthy and Induction machines with shorted-turns fault. Section IV gives the definition of periodogram and also describes how DC-centered periodogram can be used to detect stator shorted turns fault in an induction machine.

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II. Shorted-Turn Faults

The stator winding faults often initiated with inter-turn or shorted-turn which short circuits the few nearby turns of a phase winding. The shorted turn fault is caused by insulation failure between the turns of the individual windings in either stator of the machine[4]. As the machine continues to operate, the current circulating within the shorted-turns generates heat and temperature increases in the affected area. The rise in temperature leads to further destruction in the insulation of the affected area and this can lead to a short circuit between coils of the same phase. This is a more severe fault. However, the machine could still be in operation and increase the severity of the faults into, phase to ground, phase to phase or Open-circuit (in a phase) faults. At this stage, the protective equipment may disconnect the machine from the supply. The general opinion of the users and manufacturers is that there is a longer lead-time between the inception of shorted turns up to failure in the winding. Even if there is no enough knowledge about the time interval from the shorted-turns fault to insulation failure, but it is clear that transition and its rate depend on the severity of the fault. In other words, the number of the shorted-turns has gradual and slow increases to insulation failure. Thus, the earlier the shorted-turn faults are detected the better for the machine.

Figures 1(a) and (b) shows winding shorted turn-to-turn and winding with shorted coils faults respectively. Shorted turn forms the genesis and elementary of winding faults in the electrical machine. It can be seen from figure 1(b) that the fault is becoming more severe and this could damage the machine if it continues to operate. As the unit on the machine ages, shorted-turn problems are more likely to be experienced. The stresses involved in each stop-start cycle play an important role in the development of shorted turns faults. The major stresses that caused shouted turns faults are Thermal, Mechanical, Environmental and Electrical[5].

(a) Winding shorted turn-to-turn

(b) Winding with shorted-coil

Fig. 1. Stator winding faults in electrical machine.

III. Experiment to Capture Data of Induction Machine

Laboratory experiments were carried out on 1.5kW, 380V/220V,50Hz, 4-pole induction machine as shown in figure 2. The detail parameters of the machine is given are appendix A Switches are connected to the stator winding on phase A on the machine to create a shorted-turns fault in the winding faults on the phase. The data obtained during healthy(normal) and shorted-turns fault conditions are captured by the HIOKI 3197-Power Quality Analyser measuring device. These data captured are interfaced with the computer for application of DC-centered periodogram. When the machine is in operation, data capture from the HIOKI Power Quality Analyser is recorded and this represents the data for the induction machine healthy state. However, when the switch for shorted-turn faulty state is on, a shorted-turn fault is created. The data is captured by the HIOKI represent data for induction machine with a stator shorted-turns fault conditions. Figure 3 shows the comparison of the phase-A current of both healthy and faulty conditions on the machine. A close look at healthy and shorted-turn fault condition is in agreement with similar comparison published paper in [6]. From the figure 3, the peak value of current for healthy condition is 2.32A. However, the peak of stator currents for shorted-turns faults is 3.48A. There is an increment of about 50% for shorted-turns. This abnormality is observed and it could grow into more severe winding faults could destroy the machine if it continue to run. Section IV discusses the analysis of each signal captured using DC-centered periodogram.

Fig. 2. Experimental Set-up for 1.5kW Induction Motor for data capturing

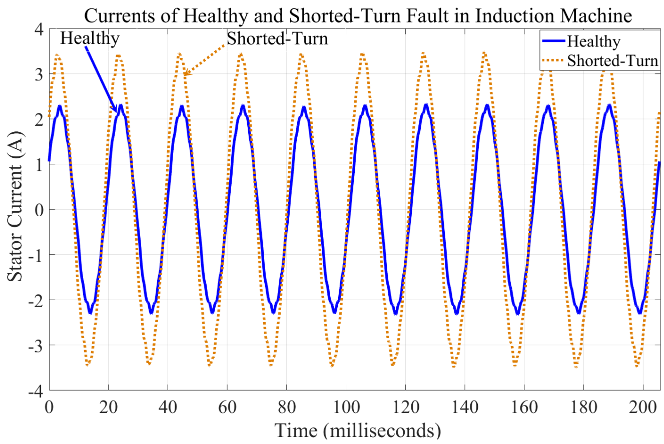

Fig. 3. Comparison of Stator Currents of Healthy and shorted turns fault Induction Machine

IV. Periodogram Algorithm

The periodogram is a nonparametric estimate of the power spectral density (PSD) of an input signal. The periodogram is the Fourier transform of the biased estimate of the autocorrelation sequence. There are various forms depending on the algorithm that will analyse the signal features in a better way. The forms are; Periodogram Using Default Inputs, Modified Periodogram with Hamming Window, DFT Length Equal to Signal Length, Periodogram of Relative Numbers, Periodogram at a Given Set of Normalized Frequencies, Periodogram PSD Estimate of a Multichannel Signal, Reassigned Periodogram and DC-Centered Periodogram [7], [8], [9]. However, a general algorithm for periodogram is described equation 1

For a signal, y_n, sampled at f_s samples per unit time, the periodogram is defined as:

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$$\hat{P}(f) = \frac{\Delta t}{N}\left|\sum_{n=0}^{N-1} y_n e^{-i2\pi fn}\right|^2, \frac{-1}{2\Delta t} < f < \frac{1}{2\Delta t} \quad (1)$$

where Δt is the sampling interval. For a one-sided periodogram, the values at all frequencies except 0 and the Nyquist, 1/2Δt, are multiplied by 2 so that the total power is conserved. If the frequencies are in radians/sample, the periodogram is defined as:

$$\hat{P}(f) = \frac{1}{2\pi N}\left|\sum_{n=0}^{N-1} y_n e^{-i\omega n}\right|^2, \pi < \omega < \pi. \quad (2)$$

The frequency range in the equations 2, has variations depending on the value of the input sampling rate argument. The integral of the true PSD, P(f), over one period, 1/Δt for cyclical frequency and 2π for normalised frequency, is equal to the variance of the signal in equation 3.

$$\sigma^2 = \int_{\frac{-1}{2\Delta t}}^{\frac{1}{2\Delta t}} P(f)df \quad (3)$$

If the normalised frequencies are required for equation 3, the limits of integration are replaced appropriately in a similar way to equation 2.

A. DC-Centered Periodogram Application

The measuring device (HIOKI 3197-Power Quality Analyser) that is used the experiment of section III that captures all the signals required before and after the fault conditions. Sampling frequency, f_s of the captured signals is very important for the analysis. In this case, the number data captured for samples for 50Hz (i.e 20ms/cycle) is 2056 samples/sec based on the findings from the device manual (10cycle/sec). The frequency is measured in cycles/second, or with a more common name, in "Hertz". For example, the electric power we use in our daily life in the South Africa 50 Hz. This means that if you try to plot the electric current, it will be a sine wave passing through the same point 50 times in 1 second.

Therefore, the DC-centered periodogram of both Healthy and Shorted-turns signals is obtained according to the codes in appendix B. The 'centered' option in the codes is used to obtain the DC-centered periodogram for each condition. Figure 4 shows the plot the results. The peak of the healthy electrical machine at DC($0Hz$) is $0dB/Hz$, however, the peak of the machine with stator shorted-turn fault at DC($0Hz$) shoot above $0dB/Hz$. It is about $4.545dB/Hz$ above $0dB/Hz$. This implies that an abnormality noted in figure 3 correspond to the $4.545dB/Hz$ above $0dB/Hz$ in figure 4

V. Conclusion

This paper describes induction machine stator winding shorted-turn fault detection using DC-centered periodogram. A brief definition of shorted-turn faults was discussed. Then an experiment to capture data of induction machine under healthy and shorted fault condition was set up. A brief algorithm of the process of the periodogram was also discussed. From the algorithm, codes to analyses the DC-centered periodogram for each condition were written in Matlab From figure 4, the peak of the healthy electrical machine at DC($0Hz$) is $0dB/Hz$, however, the peak of the machine with stator shorted-turn fault at DC($0Hz$) is about $4.545dB/Hz$ above $0dB/Hz$. This implies that an abnormality noted in figure 3 correspond to the $4.545dB/Hz$ above $0dB/Hz$ in figure 4.

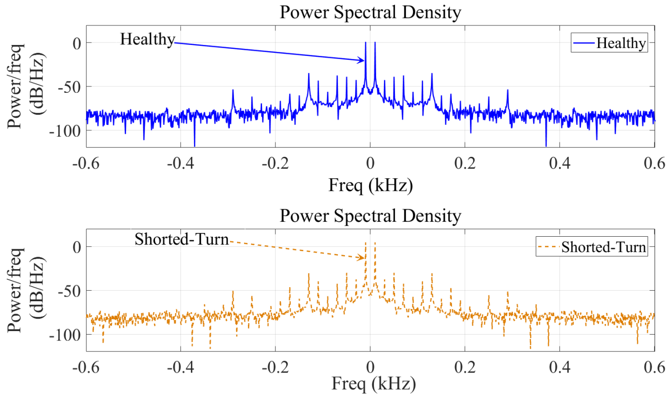

Fig. 4. DC-centered periodogram plot for Induction Machine under Healthy and shorted fault Conditions

Appendix A
Induction Machine Parameters

TABLE I
NAMEPLATE INFORMATION

Parameters	Rated Values	Remarks
Voltage [V]	380	Y-Connection
Current [A]	3.7	
Power [kW]	1.5	
Power Factor [-]	0.79	
Speed [rev/min]	1500	
Frequency [Hz]	50	
Number of poles [-]	4	

Appendix B
Matlab Codes

```
f_s = 2056 ; % Number of samples/sec
load( 'I_healthy.mat') % Load Healthy Current
I_Norm=I_1a; %Phase A Current of the healthy Machine
subplot (2, 1, 1)
periodogram(I_Norm ,[],length((I_Norm),f_s, 'centered') %
DC-centered periodogram plot for healthy currents
subplot (2, 1, 2)
load('I_Shorted.mat') % Load Shorted turn Current
I_Shorted=I_2a; %Phase A Current of the Machine with
shorted turn fault
periodogram(I_Shorted,[],length(I_Shorted),f_s,'centered')
% DC-centered periodogram plot for Machine with shorted
turn fault
```

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