Condition Monitoring of Electrical Machines

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Abstract- All machines, no matter how well they are designed, calculated or produced have the tendency to fail at some point of their existence. If the condition of the machines in use is not monitored in any way and the maintenance is forgotten, the resulting failures may pose a large economic and safety risk. Even the small and at first not important faults can end in catastrophic measures. This paper describes the main faults that occur in electrical machines and the diagnostic methods that can be used to detect these faults.

I. INTRODUCTION

In nowadays world, the number of electrical machines and their responsible tasks is continuously growing. This means that their reliability has to be a priority for all the producers and users of electrical machines.

There are a vast number of different faults that can pose danger for the reliability of electrical machines. Most of those faults start as a small declination from the normal operating conditions. The problem with those faults is that if they are not treated at an early stage, they can grow to catastrophic measures. One possible solution for the early detection of faults in electrical machines is condition monitoring.

Condition monitoring of electrical machines can be used for different reasons. These include [1]:

1) Preventing catastrophic failures and significant damage of the machines;
2) Avoiding loss of life, environmental harm and economic losses;
3) Stopping unscheduled outages;
4) Optimization of machine performance;
5) Reducing repair time and spare parts inventory;
6) Lengthening of the maintenance cycle;
7) Reducing price and raw material consumption;
8) Increasing product quality.

In other words, the reasons can be safety (1, 2), production assurance (3, 4), predictive maintenance (5, 6) and quality control (7, 8) [1].

Possible features to be monitored in the diagnostic purposes can include vibration, noise, heat, power consumption, displacement, rotation speed, different electric parameters (such as voltage, current, frequency, resistance, etc.). The list is long and growing.

This is also one of the reasons why condition monitoring can be used in very different industries. These industries include power generation, oil and gas industry, petrochemical industry, pipelines, refineries, waste water treatment, food and pharmaceutical industries, marine propulsion, metal and mining industry, transportation, etc.

II. MAIN FAULTS IN ELECTRICAL MACHINES

Electrical machines are critical components in many commercially available equipment and industrial processes. Furthermore, they are often used in critical duty drives where sudden failures can cause safety risks and large economic expenses. Different failures can occur in electrical machines, some of which are listed below.

A. Rotor Bar Faults

One of the most common rotor faults in induction motors is the breaking of the rotor bars. Fig. 1. shows broken rotor bars due to heavy duty operation.

Fig. 1. Broken rotor bars due to heavy duty operation. [2]

The main reasons for such faults is poor manufacturing, such as defective casting and poor jointing. Another common reason is over current e.g. due to jam condition of the rotor [3], but there can be various reasons that will lead to cracking or broken rotor bars [4]:

1) Thermal stress due to over-load, non-uniform heat distribution, hot spot and arc;
2) Magnetic stresses due to electromagnetic forces, magnetic asymmetry forces, noises and electromagnetic vibrations;
3) Residual stress from the fabrication process;
4) Dynamic stress due to rotor axial torque and centrifugal forces;
5) Circumferential stress due to wearing and pollution of rotor material by chemical materials and humidity;
6) Mechanical stress due to mechanical fatigue of different parts, bearing damage, loosened laminations etc.
When a rotor bar is cracked or broken, resistance in this bar rises. This stops the current flow in broken bar and additional current starts flowing in the bars next to the broken bars, which means that thermal stress in those bars rises and they are likely to break when this fault is not dealt with. If such rotor is not fixed, the fault propagates until the whole rotor cage is damaged.

B. Bearing Faults

Damage of bearings is the most common cause of failures in squirrel-cage induction motors. Fig. 2 shows a typical bearing fault of an induction motor. Two types of bearing faults are usually distinguished. The first are single point defects and the second is generalized roughness [5].

Fig. 2. Flaking of the bearing. [3]

In case of single point defects, the characteristic spectral components in vibration signal can be predicted for inner ring, outer ring, rolling element and cage fault. These frequencies can also appear in stator current around the fundamental harmonic [6]. Although they are usually clearly visible using vibration analysis, in case of stator current it is difficult to observe them due to their low amplitude and noise disturbance [7].

In contrary to single point defects, generalized roughness does not produce characteristic frequency, but rather specific frequency bands. Therefore, methods for diagnosing generalized roughness problems are usually based on removing the non-bearing faults components from diagnostic signal and utilizing the residuum or on seeking and utilizing the frequency bands with high probability of presence of bearing faults components. Since the generalized roughness is the most often type of bearing fault these methods are hardly investigated [5].

C. Air-gap Eccentricity

Air-gap eccentricity can be introduced due to manufacturing imperfections or during operation and the inherent level of static or dynamic eccentricity is typically within 10% of the air-gap [8-9].

Static eccentricity is a condition where the position of the minimum radial air-gap is fixed [10]. It can be caused by stator core ovality, or incorrect positioning of stator core or bearing at commissioning or following a repair, and its level usually does not change over time [8].

Dynamic eccentricity is a condition where the center of the rotor is not at the center of rotation, and the position of the minimum radial air-gap rotates with the rotor [10]. This can be produced by worn bearings, a bent shaft, asymmetric thermal expansion of the rotor, or by high level of static eccentricity [8-9].

Eccentricity causes unbalanced magnetic pull which results in vibration, acoustic noise, bearing wear, and/or rotor deflection. This increases the risk of stator-rotor rub, which can cause serious damage in the motor, stator or rotor core, and/or insulation. [10]

D. Stator Faults

Winding turn faults are one of the most common problems that arise in stator. Fig. 3. shows such a fault. Other common group of stator faults is the interlaminar short circuits.

Fig. 3. Short-circuited stator windings.

Stator winding failure usually starts with a short circuit between the adjacent turns in the stator windings [11]. Winding insulation damages may cause faults which in turn produce high currents and winding overheating. This overheating can quickly result in severe faults between windings of different phases or between winding and ground, producing then permanent and irreversible damages both in windings and stator core. [12]

Early detection of such winding faults is needed to prevent serious damage for the motor. The use of variable-speed drives increases these problems due to the high rates of voltage changes produced by inverter switching [13].

III. DIAGNOSTIC METHODS FOR ELECTRICAL MACHINES

In developed countries today there are more than 3 kW of electric motors per person and most of it is from induction motors [14]. During the past few decades there has been a continually increasing interest and investigation into fault detection, condition monitoring and diagnosis of electrical machines. As this interest has grown, the literature has also grown [15]. Many different techniques can be found for the fault diagnostics and condition monitoring of induction
motors. An incomplete, but quite common list of most used methods for induction motor rotor diagnostics via stator signals is brought below.

A. Fast Fourier Transformation

Fourier analysis is very useful for many applications where the signals are stationary, as in diagnostic faults of electrical machines [16].

Its purpose is to monitor a single-phase stator current. This is accomplished by removing the 50 Hz excitation component through low-pass filtering and sampling the resulting signal. Single-phase current is sensed by a current transformer and sent to a 50 Hz notch filter where the fundamental component is reduced. Analog signal is then amplified and low-pass filtered. Filtering removes the undesirable high-frequency components that produce aliasing of the sampled signal while the amplification maximizes the use of the analog-to-digital converter input range. Analog-to-digital converter samples the filtered current signal at a predetermined sampling rate that is an integer multiple of 50 Hz. This is continued over a sampling period that is sufficient to achieve the required fast Fourier transform. [17]

Fast Fourier transform is however not always the best solution for condition monitoring of an electric motor. As the properties vary with the time-varying normal operating conditions of the motor, it can be difficult to differentiate fault conditions from the normal operating conditions of the motor using only fast Fourier analysis.

B. Wavelet Analysis

To overcome the problems, described in the last paragraph, wavelet analysis can be used. Wavelet is a time frequency analysis tool originated from seismic signal analysis, which uses narrow windows for high frequency component [18].

Continuous wavelet transforms (CWTs) have constant frequency to bandwidth ratio analysis and therefore, CWTs provide powerful multi-resolution in time-frequency analysis for characterizing the transitory features of non-stationary signals [19]. Wavelet analysis can be used for localized analysis in the time-frequency or time scale domain, which makes it a powerful tool for condition monitoring and fault diagnosis [16].

C. Park (Clarke) Transformation

A two-dimensional representation can be used for describing three-phase induction motor phenomena. This transformation can be made using Park transformation (or Clarke transformation)

\[
\begin{align*}
  i_\alpha &= i_a, \\
  i_\beta &= \sqrt{2/3}(i_b + i_c),
\end{align*}
\]

(1)

where \(i_a\), \(i_b\), and \(i_c\) are phase currents, \(i_\alpha\) and \(i_\beta\) are alpha and beta components of the current.

Its representation is a circular pattern centered at the origin of the coordinates. This is a very simple reference figure, which allows the detection of an abnormal condition due to any fault of the machine by observing the deviations of the acquired picture from the reference pattern [20].

The same transformation can be made using voltage instead of current [21]. The usage of voltage can prove to be a better method, because voltage is not influenced by torque. Both open loop and closed loop motor diagnostics is possible with using stator voltage for the reference pattern of this method. Figs. 4 and 5 show the stator voltage patterns of healthy and faulty rotors.
IV. CONCLUSION

Using of different condition monitoring devices and techniques is becoming increasingly important as the number of different machines performing very responsible tasks is continuously growing. Different faults, even the smallest ones, in machines and drives have to be detected in a very early stage. If those faults are not dealt with the earliest as possible, propagation of the fault can lead to catastrophic outcomes.

In general it is possible to decide on the motor state using the described condition monitoring and diagnostic methods. Choosing of a certain method or a set of methods and also the parameters, which will be used for diagnostics, depends highly on the properties and peculiarities of the machine and the setup which has to be monitored.

Condition monitoring and diagnostic of electrical machines plays a huge role in prolonging the lifetime of the machines.

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REFERENCES


