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Instantaneous power factor signature analysis for efficient fault diagnosis in inverter fed three phased induction motors

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ABSTRACT

Majority of the electricity used in the industry is consumed by induction motors. Early detection of abnormal cases that occur at the electrical and mechanical parts of these motors is very important for the safe operation of industrial facilities and the decrease of economic losses. In this presented study, the detection of parallel, angular and mixed misalignment fault in inverter fed induction motors has been carried out via the harmonic analysis of the instantaneous power factor signal. Results obtained from experimental studies carried out under different speed and loads indicated that the detection of misalignment fault can be carried out successfully. The presented method can be used effectively without any additional cost since inverter fed motors have both voltage and current sensors. Also online monitoring of induction motors with the suggested method not only improves the motor's performance and longevity but also its efficiency. The main innovative parts of this study is that instantaneous power factor signal was used at the first time for detection of misalignment faults.

Introduction

Manufacturers try to decrease costs while at the same time facing increasing production demands in the competitive business environment and energy costs. Unplanned production stops are among the most frequent reasons that decrease efficiency. Stopping of production and unexpected faults of electrical motors are always among undesired issues. This may result in production losses and expensive repairs at places where production is critical [1,2]. The fundamental philosophy of predictive maintenance of electrical motors is to continuously monitor the characteristic signals to the motor and to analyze the acquired signals.

Inverter use has increased especially in systems that require adjustable speed after realizing the fact that electrical motors may reimburse themselves in a short amount of time thanks to the energy saving they make. They have been used in many vital control applications such as rolling mills, variable speed compressors, pumps and fans. Despite the advantages they bring forth, they also cause heating and noisily working problems in electrical motors due to the high frequency harmonics they inject to the motor voltage and current.

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Because of the widespread usage of induction motors, the regular operation of these motors has great importance in terms of efficient usage of energy and not to be interrupted in the course of industrial production processes. Motor monitoring and fault detection methods for predicting possible fault conditions that can occur with the significant functions of induction motors have become important and conspicuous subjects. When the fault types of induction motors are examined, it can be seen that there are mechanical faults such as bearing fault, eccentricity fault and misalignment fault in addition to electrical faults such as stator winding faults, rotor bar and end-ring fault. Many signals such as current, torque, vibration, airgap flux are monitored for the detection of electromechanical faults and methods such as spectral analysis, wavelet transformation, time–frequency analysis, Wigner–-Ville distribution, stator current analysis, order analysis etc. have been used for years for the analysis of these signals [3–10].

Misalignment fault is the early stage for mechanical faults. Misalignment is defined as the deviation of the axes that rotate in an interconnected manner on the same line. In general, parallel, angular and mixed misalignment faults are frequently seen in electrical motors. This fault generates vibrations at certain frequencies in the motor shaft, bearing and core depending on the rotor speed. If this fault is not detected at early stages, it can cause new faults in the motor such as bearing faults and eccentricity.

Obaid et al. have demonstrated faulty axial states (angular and radial) which is one of the mechanical failures on induction motors, together with imbalances in various load cases. They investigated the vibration and current signals in low frequency ranges and compared them with the load cases. With the help of these comparisons, they have indicated what type of faulty motor is misalignment with the figures. As the load percentage increases, it becomes more difficult to diagnose faults between balanced and unbalanced conditions, and both vibration and current signals are more successfully detected in low percentage loads [6]. Chaudhury and Gupta have studied the detection of misalignment in induction motors by the help of signal analysis and K-means clustering method [11]. They gave information about the dynamic effects of misalignment and motor vibration. In their analysis, they indicated the items of high speed, low memory requirement, and simplicity as the reasons of their K-means clustering method algorithm usage. A motor drive with an induction motor, generator for the load case and Hall sensors for motor control was used as test setup. The motor was operated under 0%, 33%, 66% and 100% load and it is misaligned in parallel with 0.5 mm, 0.75 mm, 1 mm and angularly 0.5 mm from the front and rear sides. In this case, misalignments are interpreted by the frequency spectrum analysis of the received vibration signal [11]. Bossio et al. investigated the angular misaligned state of the induction motors connected with the flexible coupling by using motor electromagnetic torque, instantaneous power and current values. They obtained the equations necessary for the calculation of speed and torque relations together with modeling of the system in the axial state. Then, they investigated the effects of torque, instantaneous power and current values on misalignment. As the fault severity increased, they made comments on the values in the frequency components. In the study carried out, the state of the fault in different load values was examined and it was observed which frequency components constitute harmonics for which misalignment [12]. Behera et al. created a virtual fault simulation by using the vibration signal and its harmonics for misalignments in the motors. After giving information on angular and parallel misalignment, they explained about the simulation on parallel misalignment. In the angular misalignment, it is shown that the maximum harmonic rotor frequency in the vibration analysis is in the 1× frequency component and the parallel misalignment is in the 2× frequency component. Information on the reasons for misalignment is given. Later, parallel misalignment gave preliminary information about the simulator operation, allowing the user to select different values for misaligned and speed values. It is observed that emitted values are in the same direction as the harmonic components in the vibration analysis [13]. In their study, Abusaad et al. performed fault detection by monitoring current and torque signals of an induction motor driven by using a sensorless variable speed drive. They compared different misaligned states (0.5 mm, 0.7 mm, 1.0 mm, 1.30 mm raised) with different load cases. After comparison of these four cases where the fault has been generated and the current and torque data received from the healthy state, the information about the fault condition was given. In the same way, they observed the current information and the frequency spectrum values and investigated the fault condition [14]. Vibration based fault diagnosis is very expensive and requires special sensors, data acquisition and signal processing hardware. Although motor current monitoring is the most popular technique, it contains supply frequency harmonics and its multiples. This makes difficult to robust fault diagnosis without filtering these harmonics. The most advantage of instantaneous power factor signal monitoring is that only fault frequency and its multiples are present in the frequency spectrum because of cleaned from any fundamental component.

In this study, a new approach is presented for the detection of misalignment fault in three phase induction motors based on the monitoring of instantaneous power factor signal and harmonic analysis. Instantaneous power factor signal has been used for the first time for detection of misalignment fault. Misalignment fault is presented in the second section of the study and its effect on the instantaneous power factor is presented in the third section. Whereas the experimental study and the results obtained are presented respectively in the fourth and fifth sections, the obtained results are evaluated in the final section.

Misalignment faults in induction motors

Misalignment has a very wide potential for the faults in power transmission. Misalignment is one of the most important reasons for machinery faults, early wear in parts, system faults and expensive repairs. Misalignment is defined as the deviation of axes rotating on the same line. It generally results from two conditions. These are parallel and angular conditions as shown in Fig. 1. In real applications, alignments with parallel and angular faults are generally together and hence this relationship makes measurements more complicated [15].