Diagnosis of the three-phase induction motor using thermal imaging

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Highlights

- Techniques of fault diagnosis of three-phase induction motors are proposed.
- Original method of feature extraction of thermal images called MoASoID is described.
- Three states of the three-phase induction motor are analysed.
- Efficiency of recognition of thermal image is analysed.

Abstract

Three-phase induction motors are used in the industry commonly for example woodworking machines, blowers, pumps, conveyors, elevators, compressors, mining industry, automotive industry, chemical industry and railway applications. Diagnosis of faults is essential for proper maintenance. Faults may damage a motor and damaged motors generate economic losses caused by breakdowns in production lines. In this paper the authors develop fault diagnostic techniques of the three-phase induction motor. The described techniques are based on the analysis of thermal images of three-phase induction motor. The authors analyse thermal images of 3 states of the three-phase induction motor: healthy three-phase induction motor, three-phase induction motor with 2 broken bars, three-phase induction motor with faulty ring of squirrel-cage. In this paper the authors develop an original method of the feature extraction of thermal images MoASoID (Method of Areas Selection of Image Differences). This method compares many training sets together and it selects the areas with the biggest changes for the recognition process. Feature vectors are obtained with the use of mentioned MoASoID and image histogram. Next 3 methods of classification are used: NN (the Nearest Neighbour classifier), K-means, BNN (the back-propagation neural network). The described fault diagnostic techniques are useful for protection of three-phase induction motor and other types of rotating electrical motors such as: DC motors, generators, synchronous motors.

1. Introduction

A number of operating electric motors increases every month [1]. Three-phase induction motors are used in the industry commonly for example woodworking machines, blowers, pumps, conveyors, elevators, compressors, mining industry, automotive industry, chemical industry, railway applications. Often electric motors are required to run continuously without interruption. It is essential in the industry. An early diagnosis of faults prevents financial losses and unplanned breakdowns in production lines. Faults of electrical rotating motors can be listed as: stator faults, rotor electrical faults, rotor mechanical faults [1]. However, techniques of mentioned faults are becoming complex and specific [2].

In the literature, fault diagnostic techniques were developed by scientists [1–27]. The analyses of electric signals, acoustic signals, vibrations, thermal imaging of electrical motors were very popular in the recent literature. Fault diagnostic techniques of electric currents of electrical motors were developed in the literature [3–6]. MCSA (Motor Current Signature Analysis) is simple technique of fault diagnosis. In the literature, MCSA was used for detecting specific electrical and mechanical induction motor faults [2,3,7]. MCSA has many advantages because it is non-intrusive. It needs
the stator winding, not affected by the load or asymmetries. There is also simplicity of installation of current sensors. However it has disadvantages, such as the stator current data should be sampled after motor speed arrives at the steady state [3].

Vibration signals were also very popular for fault diagnosis [8–11]. Techniques based on vibration analysis have the advantage of being more sensitive than the MCSA technique for certain faults [2]. These techniques were used to detect specific faults in motors, for example diagnosis of bearings [9] or gear transmission systems [10]. Techniques based on vibration signals give a fault diagnosis focused on the location of spectral components associated with faults [8]. An article presents a comparative study of different time-frequency analysis methodologies that can be used for detecting faults in induction motors analysing vibration signals during the startup transient. The analysed vibration signals were one broken rotor bar, two broken bars, unbalance, and bearing defects. The methodology proposed in mentioned paper is applicable when it does not have current signals and only has vibration signals [8].

A methodology based on vibration analysis for the diagnosis of different levels of uniform wear in a gearbox and the detection of bearing defect both linked to the same kinematic chain was presented [9]. The vibration analysis results showed that the amplitude increase in the mesh frequency component and its corresponding harmonics were related to the presence of wear in the gearbox. A review of recent progress of diagnosis of hybrid failures in gear transmission systems using vibration sensor signal was presented [10,11].

The researchers used also acoustic signals for fault diagnosis of machines [12–17]. Techniques based on acoustic signal analysis have the advantage of being cheaper than the other methods. A condenser microphone costs about 30€. It is also non-invasive. However it has disadvantage. When the induction motor is running a variety of acoustic signals mix together. Reflected and interferenced waves are mixed together. Unfortunately it is very difficult to processing. To solve this problem some feature extraction methods were developed: such as MSAF, MSAF-RATIO, SMOFS and modifications of these methods [12,13]. The results of these methods were similar. Mentioned methods MSAF, SMOFS are good for small training set. For bigger training set it is better to use modifications of these methods: MSAF-RATIO30-MULTIEXPANDED, SMOFS-25-EXPANDED. Another approach for identifying technical condition of combustion engine was described [14,15]. The authors of these papers proposed decision method for identifying engine failure based on sound emission spectral characteristics. It allows fast identification of specific engine damage. Methodology for fault detection in induction motors via sound and vibration signals was showed [16]. The authors of this paper demonstrated the feasibility of detecting faults, such as broken rotor bars, defects in bearings or mechanical unbalance, in induction motors operating at steady-state by analysing acoustic sound signals. The proposed methodology could be used to identify other types of faults in induction motors and in any equipment in which the sound and vibrations were emitted as an unequivocal consequence of malfunctioning. However, the proposed methodology had some limitations. The localization of fault frequencies depended on the knowledge of the motor speed [16]. A bearing fault diagnosis using acoustic emission sensors was presented [17]. The presented technique was validated using the acoustic signals of seeded fault steel bearings on a bearing test rig. The presented approach can be utilized to effectively extract condition indicators to diagnose all four bearing fault types at multiple low shaft speeds below 10 Hz.

Recently fault diagnostic techniques based on thermal imaging gained noticeable attention [18–27]. Thermal imaging is considered for improving the monitoring of induction motors with the advantage of being a non-invasive technique [7]. It can be noticed that thermal images are related with faults for example short-circuit of stator coils. The analysis of thermal images can be difficult. It is caused by many problems such as: access to many electrical motors, many different parameters of machines (power, size, rotor speed), cooperation with the industry and machine operators, database of thermal images. The researchers should know how to select faults of machine. Moreover long durations of shorted coils can cause permanent damage to the analysed machine. The average time to heat up stator coils is about 1–3 min. Sometimes after such duration stator (rotor) coils can be damaged permanently. For these reasons, the authors decided to analyse fault diagnostic technique of three-phase induction motors (Fig. 1).

In the literature there are not many analyses of early fault diagnostic techniques based on thermal imaging. Diagnostics of electric equipments by means of thermovision was developed [18]. The authors of this paper compared the results of calculated and measured values of breakers in electric switchgear. An analysis of thermal imaging for bearing fault detection of induction motors was also conducted [19]. It was conducted that a faulty bearing of induction motor can be detected using a low-cost camera. It was necessary to consider ambient temperature because absolute thermogram was not enough to determine a faulty state. A detection of induction motor inter turn fault using infrared thermographic analysis was presented [20]. The proposed method used transient thermal monitoring during the start of motor. Next it applied pseudo colouring technique on infrared image of the motor, after it reached a thermal steady state. The monitoring system for three phase induction motor using thermal imaging was implemented [21]. The colour based segmentation technique was used to identify abnormal hot regions in the thermal image. A changing red colour intensity method was implemented to recognise the hot spots. The NSCT-based (nonsubsampled contourlet transform) infrared image enhancement method for rotating machinery fault diagnosis was developed [22]. The method was experimentally validated in the analysis of rotor test stand in the laboratory. The results of image recognition were in the rage of 83–92%. 3D temperature field analysis of the induction motors with broken bar fault was discussed [23]. The paper dealt with 3D temperature estimation for totally enclosed fan cooled (TEFC) induction motor. The authors of this paper analysed the influence of the broken bar number on the motor thermal field. Unsupervised sparse pattern diagnostic of defects with thermography imaging system was developed [24]. The method was based on a thermal mechanism with signal processing-based pattern extraction algorithm using sparse greedy-based principal component analysis (SGPCA). Man-made and natural defects from industry were analysed by the proposed method.

![Fig. 1. Four three-phase induction motors (healthy motor, motor with 2 broken coils, motor with faulty ring of squirrel-cage).](image-url)
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