

# A Review on Detection and Monitoring of Stator Faults of Induction Motors

Yavuz Bahadır KOCA<sup>1</sup>, Abdurrahman ÜNSAL<sup>2</sup>Lecturer, Department of Electronics and Automation, AfyonKocatepe University, Afyonkarahisar, Turkey<sup>1</sup>Associate Professor, Department of Electrical and Electronics Engineering, Dumlupınar University, Kütahya, Turkey<sup>2</sup>

**ABSTRACT:** Induction motors are the most widely used electric motors in industry due to their simple structure, stable operation and high efficiency. In particular, induction motors are very important in industry due to their smoothly operation under heavy and variable loading conditions. The maintenance and repair costs increase in unexpected faults in operating conditions. The production capacities of industrial facilities also decline due to the failure of induction motors. Therefore, detection of faults of induction motor is quite important for the industry. Thus, various studies have been conducted to find the most effective technique/s for detection of faults. In this study, the **widely-used** methods to detect and monitor the most common stator faults of induction motors are reviewed. The goal is to determine the most effective and user friendly methods for the end-users or field engineers.

**KEYWORDS:** Induction motors, Stator faults, Fault diagnosis, Stator monitoring.

## I. INTRODUCTION

Induction motors are the most preferred electric motors in the industry due to the ease of speed control, low cost, robustness, and reasonable high efficiency, maintenance and repair costs compared to other motors. Motors faults always have been important since the discovery of electric motors. In the past, only the overcurrent protection, voltage protection, etc. methods have been tried by users to protect the induction motors [1]–[3]. Fault detection and prediction methods can be used especially for large and critical induction motors used in industry. This can prevent any fault and reduce the resultant financial losses. This also reduces maintenance and repair costs. At the same time, it is also possible to prevent the production processes that may occur due to induction motor (IM) faults. If these faults are not correctly monitored and diagnosed, they can lead to reduced efficiency, increased energy costs and further all system shutdown [4]. The importance of early diagnosis of faults of induction motors increases accordingly. Some kinds of faults occur slowly and the early diagnosis is very critical. The diagnosis and identification of faults may increase the reliability of the systems. Thus, the early diagnosis of fault is essential for the system's reliability [5]. One of the main reasons of this is the fact that more than 79% of the electromechanical machines are induction motors [6]. Faults in induction motors often arise specifically in ball bearing, stator – winding and rotor. Namely, 40% of the faults arise from the faults of ball bearing. The same rate for stator-winding faults is about 28% to 36%. The rotor faults are about 10% [7]–[11]. Even though smart fault diagnosis methods in induction motors are used in the recent years, the conventional systems are still preferred in industry. The most known method is direct observation. This method requires the continuous monitoring and careful control of the operating processes of the motors. Also, equipment including over current relay, phase protection relay, phase sequence relay and residual current circuit breaker may be used in order to protect the motor. Besides, conventional fault diagnosis methods including bearings and gear box oil analysis are preferred in spite of their high-cost and long time-duration [4]. Smart systems are commonly used for fault diagnosis of induction motors to extract the necessary information without complex mathematical models. Common methods include artificial neural network, genetic algorithms, support vector machine, fuzzy logic, decision-tree and hybrid systems [1], [12], [13]. Each of the motor faults are reviewed below.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 10, May 2017

## II. STATOR FAULTS

The stator faults of induction motors can be categorized as lamination faults and stator winding faults. Stator winding faults occur due to the failure of insulation in the stator of an induction motor [1]. Stator winding faults lead to high line current in induction motors which increases the operating temperature. The increase in the temperature results in failure of stator insulation. Every 10°C increase in temperature (above the operating temperature) decreases the life of the insulation to half. Stator winding faults may be categorized in five groups including coil-to-coil fault, winding-to-winding fault, phase-to-phase fault, broken connection (open circuit), and coil-to-ground fault (Figure 1).

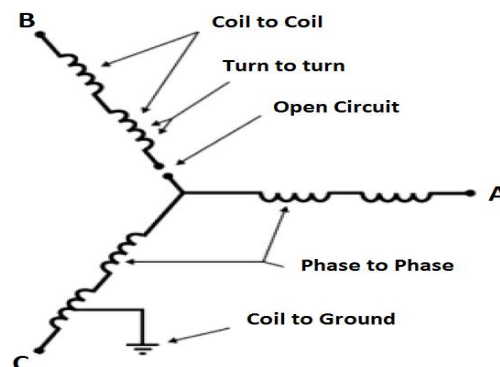


Figure 1. Schematic diagram of the stator faults.

The causes of stator winding faults may be categorized into four groups.

### 2.1 Thermal

Stator winding faults may arise from thermal aging and thermal overloading. The insulation life decreases to half for each increase of 10 °C in temperature. The effect of thermal aging may cause the induction motor defenseless to the other factors which cause failure in the insulation structure. If the insulation system loses its physical integrity, it cannot resist dielectric, mechanical and environmental effects. The effect of temperature on thermal aging can be minimized by decreasing the operating temperature or using high-quality insulation material. Thermal overload may appear depending on the applied voltage [5], [14].

### 2.2 Electrical

Electrical causes of stator winding faults may include dielectric, insulation, corona and temporary voltage rise. The relationship between the insulation life and the effects of the voltage applied to insulation materials should be taken into consideration during the selection of the materials and establishment of the coil design. The electrical stator faults can be categorized as short circuit between phase-to-phase short-circuit, winding-to-winding and ground-to-winding. In an insulation system with over-voltage (higher than the critical voltage) corona and localized discharge may appear. The winding insulation failure may also originate from corrosion and chemical reactions. Transient voltage conditions are another cause of stator winding failure which shortens the life of the winding and leads to failures.

### 2.3 Mechanical

The rotation of rotor or fan which may touch to the stator windings can be considered the main sources of mechanical faults of stator winding faults. The stator current also induces mechanical forces on the stator windings which may lead to winding failures. The cooling-fan of the motor may touch stator windings as a result of bearing failures, shaft deflections, and misalignment. If the cooling-fan touches the stator during the start-up it may cause lamination

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 10, May 2017

damage. This may result in ground faults. On the other hand, if the cooling fan touches the stator during the full-speed operation of the motor, it may cause over-heating and ground faults. Furthermore, faults may appear due to the loose fan blades or any object which may move into the motor via ventilation system [9].

## 2.4 Environmental

Humidity, presence of chemicals, environmental temperature-rise and ventilation problems etc. may cause stator failures of induction motors. Therefore failures due to environmental factors can be reduced by identifying their presence in the work area. The increase in the environmental temperature damages the insulation of windings and failure in windings may occur accordingly. Besides, short-circuit problems originated from humidity may cause important faults in the motors. Depending on the failures in the stator of the induction motors, over-current and mechanical vibration may appear. Over current may increase the temperature and the windings may burn if the motor is not protected against over-temperature [2], [13].

## III. MONITORING METHODS OF STATOR FAULTS

Monitoring of induction motors is very important in order to diagnose faults and prevent the possible failures. In the recent years, various many studies carried out on effective condition monitoring and fault diagnosis methods according to their common presence in the industrial processes [5]. Common methods used in order to monitor and identify the failures in induction motors are grouped under five categories.

### 3.1 Sound and Vibration Analysis

Loose stator windings, variable air gap, voltage unbalance may lead to vibration in induction motors [4], [6]. The resonance between electromagnetic force and stator is the main cause of the noise in the induction motors. Glowacz et al. [15] diagnosed the in stator winding faults by using acoustic signal. This study was done for single phase induction motor. The success rate was 88% in the study. Arrendondo et al. [16] worked on the diagnosis of induction motor faults by using sound and vibration signals. They used complete ensemble empirical mode decomposition (CEEMD) method in this study. Ayaz et al. [17] detected insulation failure of winding of induction motors by using current and vibration signals. The study established a relationship between motor current and vibrations via coherency. Therefore this property is evaluated as an indicator of the stator insulation faults.

### 3.2 Air Gap Torque Analysis

Air gap torque appeared during the start-up of the induction motors is sensitive to the unbalanced in supply voltage, cracked rotor bars or asymmetrical stator windings [18]. When the motor is subject to an unbalanced supply voltage harmonics appear in the air gap torque [19]. The eccentricity in the air gap causes fluctuating torque, unbalanced magnetic flux and reduces the power factor. This causes speed pulsations, vibration, acoustic noise, bearing and rotor damage. This may cause deterioration in conductors and insulation [20]. Filho et al. [21] used magnetic flux and vibration signals of induction motors to monitor and diagnose stator faults. They found that short-circuit faults windings can be diagnosed by using magnetic flux and vibration signals.

### 3.3 Current Analysis

Induction motor faults mainly reflect into the stator current as harmonics. The analysis of stator current is mainly known as current signature analysis method (MCSA). Since stator current is always available when the motor is running it is easier to perform current signature analysis than other methods. Therefore this method is often preferred because of its convenience. However, load factor of motor and the signal to noise ratio affect the accuracy of this method. [5], [18].

Lee et al. [22] used stator current information to detect induction motor faults. In this study, the most reliable phase current among 3-phase current information was selected by fuzzy entropy method. It was then trained with artificial neural networks. The faults were investigated by Fourier and wavelet transforms and classified into six categories. Jimenez et al. [23] have offered an online method to identify faults of induction motors. In this method, steady state stator current and axial flux signal analysis information is used. In order to improve the accuracy

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 10, May 2017

the signal is subjected to Hilbert transformation and wavelet analysis, respectively. Then, error thresholds were determined by statistical analysis. Thus the faults which may be at the initial stage are detected successfully. Allal and Chatete have suggested an approach called Park Vector Product Approach (PVPA) for cases where rotor or stator faults exist. In this study, the classical methods such as motor current signature analysis (MCSA) are compared with recent methods such as motor square current signature analysis, Park's vector square modules, Park-Hilbert techniques [24].

### 3.4 Temperature

Overheating in an induction motor is also considered as one of the main causes of a fault [25]. The industry usually uses equipment such as fuses, thermal magnetic switches and overcurrent relays for thermal protection purposes. However, these devices cannot provide complete protection. [26]. Stator failure detection of an induction motor is normally performed by measuring the temperature change of the motor [14]. Temperature is observed through sensors installed on the motor [26]. The detection of stator fault by analysis of temperature is based on stator resistance and thermal models. Other factors such as ambient temperature and cooling should be considered in these models [5]. Rajagopal et al. [27] studied a two-dimensional transient analysis method by using heat transfer coefficients of an induction motor. Transient thermal behaviour study is useful for determining the causes of failure in induction machines. Glowacz and Glowacz have studied thermal image analysis for fault diagnosis in a single-phase induction motor. Thermal images are analysed by a method called MoASoS (Method of Area Selection of States). In this method, MoASoS and an image histogram were used to construct feature vectors. The classification of the obtained vectors was performed with NN (Nearest Neighbour Classification) and Gaussian Karna Models (GMM) [28]. Baneira et al. [29] have proposed a method based on dc signal injection for stator winding temperature estimation in dual three-phase induction motors. The proposed method is verified experimentally. In another study, Ramirez et al. [30] have proposed a method based on thermographic image segmentation for fault detection of induction motors. This method is also based on the repercussion of errors along the kinematic chain.

### 3.5 Magnetic Flux

The air gap flux changes sinusoidally if an induction motor operates under normal conditions. However, stator faults can cause changes in air gap flux distribution. Depending on the stator faults, any deterioration in the air gap flux density will create an axial homopolar flux. This flux flows along a shaft which can be detected by a search coil installed around the shaft. It is better to detect signal variations using an external flux detection sensor. The air gap flux can also be detected by sensing the voltage in two uniformly positioned motor windings [5], [18]. The flux signal is analysed by various methods to extract the required information as an indicator of stator faults of induction motors.

## IV. CONCLUSION

In this study, common stator faults of induction motors and detection methods have been reviewed. Monitoring and diagnostic methods have also been discussed briefly. The study summarizes the most effective and user friendly methods for the end-users or field engineers. The study also provides a list of recent publications on the stator faults of induction motors for the interested researchers who may be interested in certain methods.

## REFERENCES

- [1] S. Nandi, H. A. Toliyat, and X. Li, "Condition monitoring and fault diagnosis of electrical motors-a review," *IEEE Trans. energy Convers.*, vol. 20, no. 4, pp. 719-729, 2005.
- [2] T. Doğruer, M. Akar, G. Üniversitesi, and G. Üniversitesi, "İndüksiyon Motorlarında Durağan Olmayan Çalışma Şartlarında Kırık Rotor Çubuğu Arızasının Tespiti Mekatronik Mühendisliği Bölümü," pp. 11-13, 2016.
- [3] A. ÜNSAL and A. KABUL, "Asenkron Motor Rotor Arızalarının İstatiksel Analiz Yöntemi ile Değerlendirilmesi, sayfa: 283-289," *Politek. Derg.*, vol. 20, no. 2, 2017.
- [4] H. Çalış and K. Kayaalp, "Asenkron Motor Hata Teşhisinde Modern Metotlar," *Makine Teknol. Elektron. Derg.*, vol. 2007, no. 2, pp. 49-57, 2007.
- [5] A. Siddique, G. S. Yadava, and B. Singh, "A review of stator fault monitoring techniques of induction motors," *IEEE Trans. Energy Convers.*, vol. 20, no. 1, pp. 106-114, 2005.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 10, May 2017

- [6] S. Ergin, A. Uzuntas, and M. B. Gulmezoglu, "Procedia Engineering Detection of Stator , Bearing and Rotor Faults in Induction Motors," vol. 30, no. 2011, pp. 1103–1109, 2012.
- [7] M. O. Mustafa, D. Varagnolo, G. Nikolakopoulos, and T. Gustafsson, "Detecting broken rotor bars in induction motors with model-based support vector classifiers," *Control Eng. Pract.*, vol. 52, pp. 15–23, 2016.
- [8] W. Zhou, T. G. Habetler, R. G. Harley, and B. Lu, "Incipient Bearing Fault Detection via Stator Current Noise Cancellation using Wiener Filter," *2007 IEEE Int. Symp. Diagnostics Electr. Mach. Power Electron. Drives*, pp. 11–16, 2007.
- [9] A. Ünsal and O. Karakaya, "Asenkron Motor Rotor Arızalarının Analizi," 2015.
- [10] E. Cabal-Yepez *et al.*, "FPGA-based entropy neural processor for online detection of multiple combined faults on induction motors," *Mech. Syst. Signal Process.*, vol. 30, pp. 123–130, 2012.
- [11] M. Akar and M. Soyaslan, "Asenkron Motorlarda Rotor Çubuğu Kırık Arızasının Elektromanyetik Tork ile Tespiti," no. May, pp. 16–18, 2011.
- [12] G. H. Bazan, P. R. Scalassara, W. Endo, A. Goedel, W. F. Godoy, and R. H. C. Palácios, "Stator fault analysis of three-phase induction motors using information measures and artificial neural networks," *Electr. Power Syst. Res.*, vol. 143, pp. 347–356, 2017.
- [13] S. Nandi and H. A. Toliyat, "Fault diagnosis of electrical machines-a review," *IEEE Int. Electr. Mach. Drives Conf. IEMDC 1999 - Proc.*, pp. 219–221, 1999.
- [14] S. Karmakar, S. Chattopadhyay, M. Mitra, and S. Sengupta, *Induction Motor Fault Diagnosis*. 2016.
- [15] A. Glowacz and Z. Glowacz, "Diagnostics of stator faults of the single-phase induction motor using thermal images, MoASoS and selected classifiers," *Meas. J. Int. Meas. Confed.*, vol. 93, pp. 86–93, 2016.
- [16] P. A. Delgado-Arredondo, D. Morinigo-Sotelo, R. A. Osornio-Rios, J. G. Avina-Cervantes, H. Rostro-Gonzalez, and R. de J. Romero-Troncoso, "Methodology for fault detection in induction motors via sound and vibration signals," *Mech. Syst. Signal Process.*, vol. 83, pp. 1–22, 2016.
- [17] E. Ayaz, M. Ucar, S. Seker, and B. R. Upadhyaya, "Signal based fault detection for stator insulation in electric motors," in *Universities Power Engineering Conference, 2008. UPEC 2008. 43rd International*, 2008, pp. 1–4.
- [18] M. Eftekhari, M. Moallem, S. Sadri, and A. Shojaei, "Review of induction motor testing and monitoring methods for inter-turn stator winding faults," *2013 21st Iran. Conf. Electr. Eng. ICEE 2013*, pp. 13–18, 2013.
- [19] M. Seera, C. P. Lim, S. Nahavandi, and C. K. Loo, "Condition monitoring of induction motors: A review and an application of an ensemble of hybrid intelligent models," *Expert Syst. Appl.*, vol. 41, no. 10, pp. 4891–4903, 2014.
- [20] H. Vishwanath and G. S. Maruthi, "Experimental investigation on detection of air gap eccentricity in induction motors by current and vibration signature analysis using non-invasive sensors," *Energy Procedia*, vol. 14, pp. 1047–1052, 2012.
- [21] P. C. M. Lamim Filho, R. Pederiva, and J. N. Brito, "Detection of stator winding faults in induction machines using flux and vibration analysis," *Mech. Syst. Signal Process.*, vol. 42, no. 1–2, pp. 377–387, 2014.
- [22] S. Lee, Y. Wang, J. Song, L. E. E. Sang-hyuk, W. Yi-qi, and S. Jung-il, "Fourier and wavelet transformations application to fault detection of induction motor with stator current," *J. Cent. South Univ. Technol.*, vol. 17, no. 1, pp. 93–101, 2010.
- [23] G. A. Jiménez, A. O. Muñoz, and M. A. Duarte-Mermoud, "Fault detection in induction motors using Hilbert and Wavelet transforms," *Electr. Eng.*, vol. 89, no. 3, pp. 205–220, 2007.
- [24] A. Allal and B. Chetate, "A new and best approach for early detection of rotor and stator faults in induction motors coupled to variable loads," *Front. Energy*, vol. 10, no. 2, pp. 176–191, 2016.
- [25] M. Ojaghi, M. Sabouri, and J. Faiz, "Diagnosis methods for stator winding faults in three-phase squirrel-cage induction motors," no. June 2013, pp. 891–912, 2014.
- [26] R. M. Tallam *et al.*, "A survey of methods for detection of stator-related faults in induction machines," *IEEE Trans. Ind. Appl.*, vol. 43, no. 4, pp. 920–933, 2007.
- [27] M. S. Rajagopal, K. N. Seetharamu, and P. A. Ashwathnarayana, "Transient thermal analysis of induction motors," in *Power Electronics, Drives and Energy Systems for Industrial Growth, 1996., Proceedings of the 1996 International Conference on*, 1996, vol. 2, pp. 932–939.
- [28] A. Glowacz and Z. Glowacz, "Diagnostics of stator faults of the single-phase induction motor using thermal images, MoASoS and selected classifiers," *Meas. J. Int. Meas. Confed.*, vol. 93, pp. 86–93, 2016.
- [29] F. Baneira, A. G. Yepes, Ó. López, and J. Doval-Gandoy, "Estimation Method of Stator Winding Temperature for Dual Three-Phase Machines Based on DC-Signal Injection," *IEEE Transactions on Power Electronics*, vol. 31, no. 7, pp. 5141–5148, 2016.
- [30] A. G. Garcia-Ramirez, L. A. Morales-Hernandez, R. A. Osornio-Rios, J. P. Benitez-Rangel, A. Garcia-Perez, and R. D. J. Romero-Troncoso, "Fault detection in induction motors and the impact on the kinematic chain through thermographic analysis," *Electr. Power Syst. Res.*, vol. 114, pp. 1–9, 2014.