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Comprehensive Review on Fault Detection in Induction Motor

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Abstract
In modern industries Induction Motors plays crucial role. Nowadays every industry move towards zero error products and good revenue. Faults in an induction motor fail the mission such as zero error and revenue. This paper provides a survey on condition monitoring and the methods of detection of faults in induction motor. In This paper comprehensive analysis of various faults of such as stator failure, broken rotor bar, bearing fault and air gap eccentricity are discussed..

Keywords: Induction Motor (IM), mechanical faults, broken rotor bar, Stator faults, Air gap eccentricity, Voltage source inverter (VSI).

Introduction

Induction motor acts as a backbone in many industries because of its low cost, simple and robust structure and ease in control. IM is used in many applications like cement factory, steel mills, elevators, pulping, milling, oil refineries, and packing. Fault in an induction motor causes error in products; it degrades the quality of product. Moreover the failure of an induction motor leads to less productivity and financial loss to the industry. Hence condition monitoring of the induction motors are very much essential. The major faults of an induction machine can broadly be classified as follows:

1) Stator faults resulting in the opening or shorting of the phase winding;
2) Rotor cage failures (broken rotor bars);
3) Air-gap irregularities;
4) Bearing failures.

The failures of the motor are stated in table 1.

Type of fault	Fault percentage
Bearing failures	44%
Stator faults	26%
Rotor faults	8%
Other faults	22%

Induction motor mechanical faults such as broken rotor bar faults and air gap eccentricity are analyzed using motor stator current [1-3]. Mechanical faults are responsible for more than 95% of all failures. In many applications inductions motors are driven by voltage source inverters (VSI). Broken rotor bar faults and air gap eccentricity in an inverter fed induction motor decreases the performance of the inverter and load [4]. Broken rotor bar fault in an induction motor increases the copper loss and the total loss of the machine [5] so this fault decreases the efficiency of the machine. Induction motor stator and rotor parameters are varied during stator and rotor fault. Faults in stator and rotor can be analyzed using stator current [6]. Almost 40%-50% of all failures are caused by bearing fault. In early days bearing fault was analyzed based on vibration. The main thing to be pointed in the analysis is vibration is also caused by motor body. Modern analysis of bearing fault is predicted from the stator current [7].

Classification of faults:

Stator faults:

Approximately 30-40% of faults of induction motors are stator faults. Open circuit / short circuit in the turns of stator winding are the faults in stator.

Various stator faults and causes/stresses leading to these faults are analyzed in [8] with the monitoring techniques. The unbalanced stator resistance fault is analyzed using wavelet decomposition of each phase voltage and current in [9]. Unbalanced voltage effect on induction motor is analyzed using Kalman predictor methods using voltage and current are analyzed in [10]. Sensorless method of online monitoring and classifying of stator turn faults are analyzed in [11].

The various stator faults such as inter turns short circuit, phase to phase and single phase to ground faults are analyzed using symmetrical components of the stator current in [12]. The soft computing technique of fuzzy logic is proposed to monitor the various stator faults like phase-to-phase, turn-to-turn, and turn-to-ground in [13]. Stator current based stator faults are analyzed using adaptive Kalman filter in [14]. Detailed harmonic analysis based induction motor stator fault using stator current spectrum is analyzed in [15].

Rotor faults:

The cracked or broken bar fault constitutes about 5-10% of total induction motor failures and leads to malfunction as well as reduction of the motor's life cycle. Cracked or broken bars in a cast cage rotor cannot be repaired because of their manufacturing characteristics. Broken or cracked bar faults are believed to be caused by a variety of reasons: like thermal, mechanical, magnetic, residual, dynamic, and environmental stresses.

The Kalman predictor based broken rotor bar fault monitoring is analyzed in [10]. The online detection of broken rotor bar faults using generic Neuro fuzzy is analyzed in [16]. The torque signature analysis for the broken rotor bar is discussed in [17]. The broken rotor bar faults in the presence of fluctuation load torque are diagnosed using active and reactive power theory in [18]. The diagnosis of the broken rotor bar during the small interval is analyzed using estimation of signal parameters via rotational invariance technique (ESPRIT) and simulated annealing algorithm (SAA) in [19].

The detection of broken rotor bar fault based on a synchronous reference frame and on Steinmetz's phasors are presented in [20]. The discrete wavelet transform is utilized to find the rotor fault in double cage induction motor in [21]. The ESPRIT based frequency extraction to find the broken rotor bar is analyzed in [22]. In this paper amplitude of fault harmonics is estimated using least square method. In [23] the ambiguities of line-current noise or sensor-resolution errors and operating-point-dependent threshold issues are effectively utilized to find the broken rotor bar faults. In this paper DSP based hardware is implemented to validate the simulation.

The conventional Hilbert method of broken rotor bar fault is improved with a combination of ESPRIT in [24]. It is analyzed for small motors. High resolution stator current spectral estimation improves the conventional MUSIC algorithm. It is effectively utilized to find the broken rotor bar faults in [25]. Identification of broken rotor bar faults based on FFT analysis of Stator current is discussed in [26]. An air-gap torque profile in conjunction with a Bayesian classifier is used to detect the broken rotor bar faults in [27]. Small and large motor rotor failures are identified using discrete wavelet transform in [28]. The broken rotor bar fault detection using variation in axial flux density is discussed in [29].

Discrete Wavelet analysis of stator current space-vector magnitude and the instantaneous magnitude of the stator current signal to detect the broken rotor bar fault is presented in [30]. The simple method of current spectrum analysis, such as reference frame theory is discussed in [31] for broken rotor bar fault detection. The single phase rotation test is analyzed in [33] to find the rotor problems such as broken bar.

Eccentricity faults:

Eccentricity is the Non uniform air-gap in motors. Unbalanced rotor shaft, awful manufacturing tolerances and weak bearing are the core causes of eccentricity. Effects of Eccentricity are the unbalanced magnetic pull, vibration and harmonics in current signal. Depends on rotor motion Eccentricity is classified into two types such as, static eccentricity and dynamic eccentricity as shown in figure 1. Static Eccentricity is stated as if the rotor rotation center is removed for a faraway place which is parallel to stator center. Dynamic Eccentricity is stated as Rotor rotates around stator center, but it does not rotate around its center.

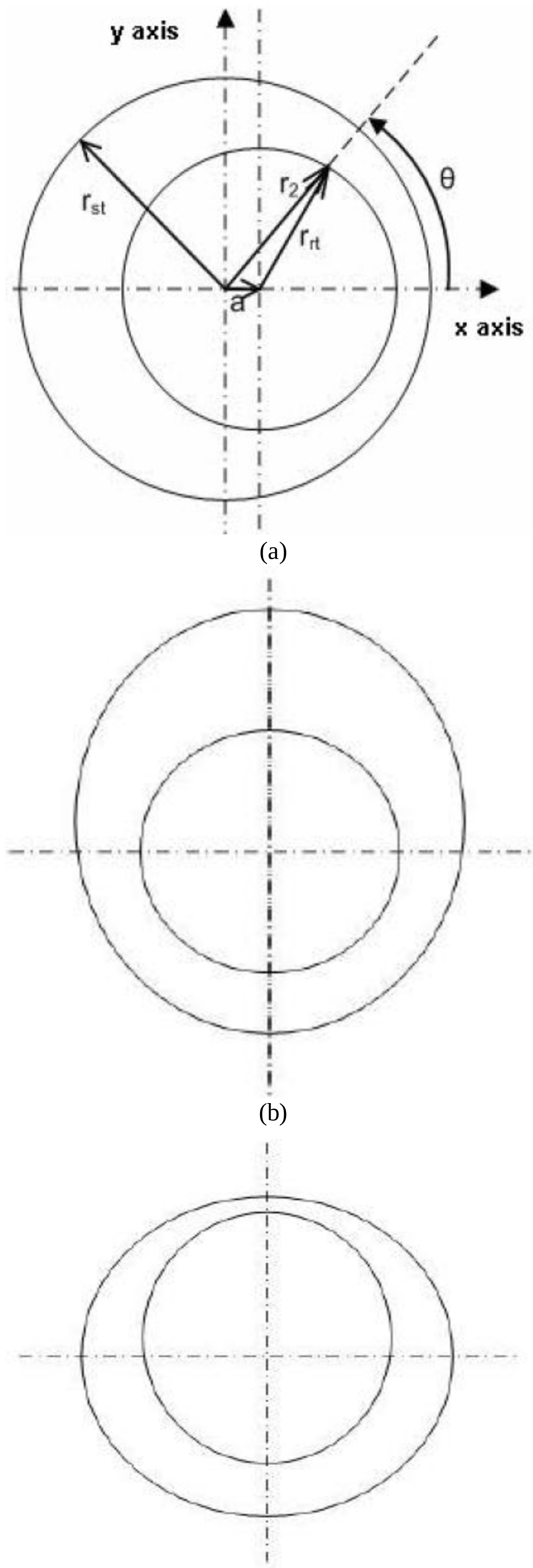
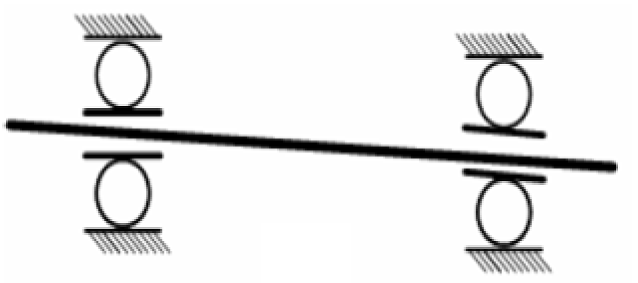


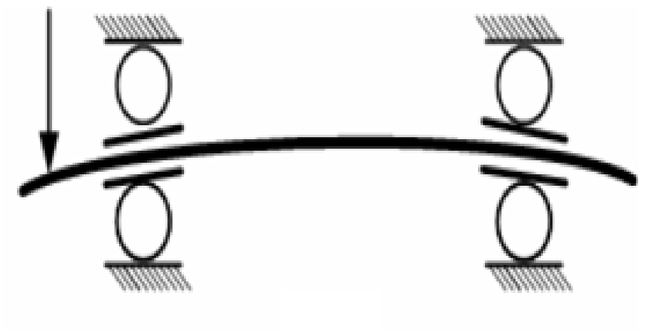
Fig. 1: (a) Static eccentricity, (b) Oval stator, (c) Oval rotor.

The modified MUSIC algorithm using High resolution stator current spectral estimation is used to find the air gap eccentricity faults in [25]. Detection of air gap eccentricity faults based on FFT analysis of Stator current is discussed in [26]. Variation in axial flux density is utilized to detect the air gap eccentricity in [29]. The simple method of current spectrum analysis, such as reference frame theory is discussed in [31] for eccentricity fault detection. Complex apparent power signature analysis is discussed in [32] to find air gap fault. The single phase rotation test is analyzed in [33] to find the rotor problems such as eccentricity. Offline detection of eccentricity faults in large induction motors using name plate detail is discussed in [34]. Classification of various faults and detection of eccentricity of inverter fed induction motor is analyzed in [35] using inverter input current. Finite element method on line current spectrum is analyzed in [36] to diagnose mixed eccentricity faults. Magnetic flux density in the air gap caused by fault current is analyzed in [37] to detect the eccentricity fault.

Bearing faults:
In general balls or rollers in bearing rotate between two rings named as inner raceway and outer raceway. Faults may occur in a raceway or balls as shown in figure 2 and it is classified as cyclic and non cyclic faults. Once a fault is produced, the affected area expands rapidly contaminating the lubricant and causing localized overloading over the entire circumference of the raceway. Apart from of the failure mechanism, defective rolling element bearings generate mechanical vibrations at the rotational speeds of each component.



(a)



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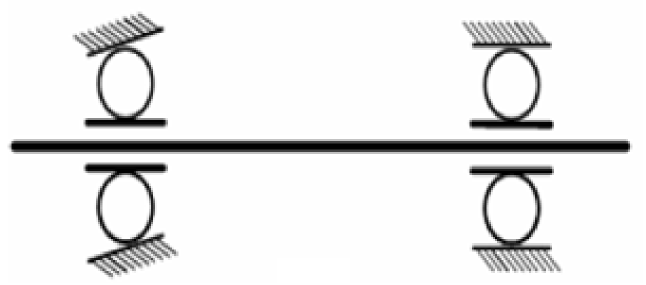
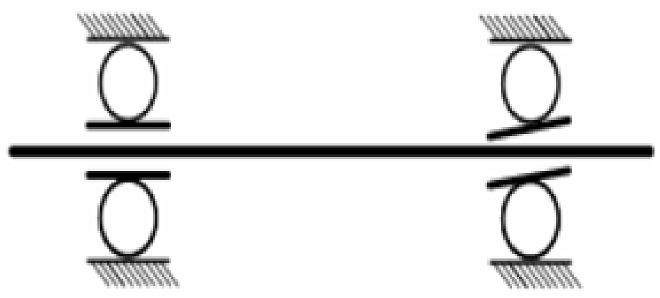


(c)



(d)

Fig. 2: (a) Misalignment (out-of-line), (b) Shaft deflection, (c) crooked or tilted outer race, (d) Crooked or tilted inner race.

In [23] the ambiguities of line-current noise or sensor-resolution errors and operating-point-dependent threshold issues are effectively utilized to find the bearing faults. Frequency analysis of stator current is analyzed to detect the bearing faults in [37]. In this paper sudden eccentricity faults are simulated to analyze the bearing damage. The neural network is implemented in [38] to classify the various bearing faults such as single point balls, raceways faults and distributed defects like roughness. Motor stator current spectral analysis (MCSA) and vibration analysis are discussed in [39] to detect the outer raceway bearing faults in small induction motors. Various bearing detects like crack in the outer race, hole in the outer race, deformation of the seal, and corrosion are experimentally analyzed in [40].

Conclusion:
This paper provides a comprehensive survey on various faults of an induction motor. This study provides a survey on small, medium and large induction motor faults in aspect of simulation as well as experiment

References

[1] Zhongming Ye., Bin Wu and Alireza Sadeghian., 2003. Current Signature Analysis of Induction Motor Mechanical Faults by Wavelet Packet Decomposition. IEEE Transactions on Industrial Electronics, 50(6): 1217-1228.

[2] Liang. B., B. S. Payne., A. D. Ball and S. D. Iwnicki., 2002. Simulation and fault detection of

three-phase induction motors. Mathematics and Computers in Simulation, 61: 1-15.

[3] Shahin Hedayati Kia., Humberto Henao and Gérard-André Capolino., 2009. Diagnosis of Broken-Bar Fault in Induction Machines Using Discrete Wavelet Transform Without Slip Estimation. IEEE Transactions On Industry Applications, 45: 1395-1404.

[4] Ilias P. Georgakopoulos., Epaminondas D. Mitronikas and Athanasios N. Safacas., 2011. Detection of Induction Motor Faults in Inverter Drives Using Inverter Input Current Analysis. IEEE Transactions On Industrial Electronics, 58(9): 4365-4373.

[5] Bashir Mahdi Ebrahimi, Amir Masoud Takbash and Jawad Faiz., 2013. Losses Calculation in Line-Start and Inverter-Fed Induction Motors Under Broken Bar Fault. IEEE Transactions on Instrumentation And Measurement, 62(1): 140-152.

[6] Smail Bachir., Slim Tnani., Jean-Claude Trigeassou and Gérard Champenois., 2006. Diagnosis by Parameter Estimation of Stator and Rotor Faults Occurring in Induction Machines. IEEE Transactions On Industrial Electronics, 53(3): 963-973.

[7] Lucia Frosini and Ezio Bassi., 2010. Stator Current and Motor Efficiency as Indicators for Different Types of Bearing Faults in Induction Motors. IEEE Transactions on Industrial Electronics, 57(1): 244-251.

[8] Arfat Siddique, G. S. Yadava, and Bhim Singh, 2005, "A Review of Stator Fault Monitoring Techniques of Induction Motors", IEEE Transactions On Energy Conversion, Vol. 20, No. 1, pp. 106-114.

[9] Erick Schmitt, Peter Idowu, Aldo Morales, 2010, "applications of wavelets in induction machine fault detection applications de wavelets en la detección de fall as de máquinas de inducción", Ingeniare Revista chilena de ingeniería, vol. 18 No. 2, pp. 158-164.

[10] Olivier Ondel, Emmanuel Boutleux, Eric Blanco, and Guy Clerc, 2012, "Coupling Pattern Recognition With State Estimation Using Kalman Filter for Fault Diagnosis", IEEE Transactions On Industrial Electronics, Vol. 59, No. 11, Pp. 4293-4300.

[11] Jangho Yun, Kwanghwan Lee, Kwang-Woon Lee, Sang Bin Lee and Ji-Yoon Yoo, 2009, "Detection and Classification of Stator Turn Faults and High-Resistance Electrical Connections for Induction Machines", IEEE Transactions On Industry Applications, Vol. 45, No. 2, pp. 666-675.

[12] Monia Ben Khader Bouzid, Gérard Champenois, 2011, "New Expressions of Symmetrical Components of the Induction Motor under Stator Faults", IEEE.

[13] Vinoth Kumar. K, S. Suresh Kumar and Badugu Praveena, 2010, "Soft Computing Based Fault Diagnosis", International Journal of Computer and Electrical Engineering, Vol. 2, No. 4, pp. 1793-8163.

[14] F. Bagheri, H. Khaloozadeh and K. Abbaszadeh, 2007, "Stator Fault Detection in Induction Machines by Parameter Estimation Using Adaptive Kalman Filter", Iranian Journal of Electrical & Electronic Engineering, Vol. 3, pp. 73-82.

[15] Gojko M. Joksimovic, Jakša Riger, Thomas M. Wolbank, Nedjeljko Peric, Mario Vašak, 2011, "Stator Current Spectrum Signature of a Healthy Cage Rotor Induction Machines", IEEE, pp. 1-9.

[16] Woei Wan Tan and Hong Huo, 2005, "A Generic Neurofuzzy Model-Based Approach for Detecting Faults in Induction Motors", IEEE Transactions On Industrial Electronics, Vol. 52, No. 5, PP. 1420-1427.

[17] Konstantinos N. Gyftakis, Dionysios V. Spyropoulos, Joya C. Kappatou and Epaminondas D. Mitronikas, 2013, "A Novel Approach for Broken Bar Fault Diagnosis in Induction Motors Through Torque Monitoring", IEEE Transactions On Energy Conversion, pp. 1-11.

[18] Sergio M. A. Cruz, 2012, "An Active-Reactive Power Method for the Diagnosis of Rotor Faults in Three-Phase Induction Motors Operating Under Time-Varying Load Conditions", IEEE Transactions On Energy Conversion, Vol. 27, No. 1, pp. 71-84.

[19] Boqiang Xu, Liling Sun, Lie Xu and Guoyi Xu, 2012, "An ESPRIT-SAA-Based Detection Method for Broken Rotor Bar Fault in Induction Motors", IEEE Transactions On Energy Conversion, Vol. 27, No. 3, pp. 654-660.

[20] C. Concari, G. Franceschini, C. Tassoni and A. Toscani, 2011, "Validation of a Faulted Rotor Induction Machine Model with an Insightful Geometrical Interpretation of Physical Quantities", IEEE.

[21] Jose Antonino-Daviu, Martin Riera-Guasp, Joan Pons-Llinares, Jongbin Park, Sang Bin Lee, Jiyoon Yoo and Christian Kral, 2012, "Detection of Broken Outer-Cage Bars for Double-Cage Induction Motors Under the Startup Transient", IEEE Transactions On Industry Applications, Vol. 48, No. 5, pp. 1539-1548.

[22] Yong-Hwa Kim, Member, Young-Woo Youn, Don-Ha Hwang, Jong-Ho Sun, and Dong-Sik Kang, 2011, " High-Resolution Parameter Estimation Method to Identify Broken Rotor Bar Faults in Induction Motors", IEEE. pp. 1-14.

[23] Seungdeog Choi, Bilal Akin, Mina M. Rahimian and Hamid A. Toliyat, 2011, "Implementation of a Fault-Diagnosis Algorithm for Induction Machines Based on Advanced Digital-Signal-Processing Techniques", IEEE Transactions on Industrial Electronics, Vol. 58, No. 3, pp. 937-948.

[24] Boqiang Xu, Liling Sun, Lie Xu and Guoyi Xu, 2013, "Improvement of the Hilbert Method via ESPRIT for Detecting Rotor Fault in Induction Motors at Low Slip", IEEE Transactions on Energy Conversion, Vol. 28, No. 1, pp. 225-233.

[25] El Houssin El Bouchikhi, Vincent Choqueuse, Mohamed Benbouzid and Jean Frederic Charpentier, 2012, "Induction Machine Fault Detection Enhancement Using a Stator Current High Resolution Spectrum", IEEE, pp. 3913-3918.

[26] Seungdeog Choi, Bilal Akin, Mina M. Rahimian and Hamid A. Toliyat, 2012, "Performance-Oriented Electric Motors Diagnostics in Modern Energy Conversion Systems", IEEE Transactions On Industrial Electronics, Vol. 59, No. 2, pp. 1266-1277.

[27] Aderiano M. da Silva, Richard J. Povinelli and Nabeel A. O. Demerdash, 2013, "Rotor Bar Fault Monitoring Method Based on Analysis of Air-gap Torques of Induction Motors", IEEE, pp. 1-10.

[28] Jose Antonino-Daviu, Selin Aviyente, Elias G. Strangas and Martin Riera-Guasp, 2013, "Scale Invariant Feature Extraction Algorithm for the Automatic Diagnosis of Rotor Asymmetries in Induction Motors", IEEE Transactions On Industrial Informatics, Vol. 9, No. 1, pp. 100-108.

[29] Andrian Ceban, Remus Pusca, and Raphaël Romary, 2012, "Study of Rotor Faults in Induction Motors Using External Magnetic Field Analysis", IEEE Transactions on Industrial Electronics, Vol. 59, No. 5, pp. 2082-2093.

[30] Shahin Hedayati Kia, Humberto Henao and Gérard-André Capolino, 2009, "Diagnosis of Broken-Bar Fault in Induction Machines Using Discrete Wavelet Transform Without Slip Estimation", IEEE Transactions On Industry Applications, Vol. 45, No. 4, pp. 1395-1404.

[31] Bilal Akin, Seungdeog Choi, Umut Orguner and Hamid A. Toliyat, 2011, "A Simple Real-Time Fault Signature Monitoring Tool for Motor-Drive-Embedded Fault Diagnosis Systems", IEEE Transactions On Industrial Electronics, Vol. 58, No. 5, pp. 1990-2001.

[32] M'hamed Drif, A. J. Marques Cardoso, 2006, "Airgap Eccentricity Fault Diagnosis, in Three-Phase Induction Motors, by the Complex Apparent Power Signature Analysis", International Symposium on Power Electronics, Electrical Drives, Automation and Motion, pp. 18-22.

[33] Doosoo Hyun, Sungho Lee Jongman Hong, Sang Bin Lee and Subhasis Nandi, 2012, "Detection of Airgap Eccentricity for Induction Motors Using the Single-Phase Rotation Test", IEEE Transactions On Energy Conversion, VOL. 27, NO. 3, pp-689-696.

[34] Subhasis Nandi, Thirumarai Chelvan Ilamparithi, Sang Bin Lee and Doosoo Hyun, 2011, "Detection of Eccentricity Faults in Induction", IEEE Transactions on Industrial Electronics, Vol. 58, No. 5, pp. 1673-1683.

[35] Ilias P. Georgakopoulos, Epaminondas D. Mitronikas and Athanasios N. Safacas, 2011, "Detection of Induction Motor Faults in Inverter Drives Using Inverter Input Current Analysis", IEEE Transactions On Industrial Electronics, VOL. 58, NO. 9, pp. 4365-4373.

[36] Jawad Faiz, Bashir Mahdi Ebrahimi, Bilal Akin and Hamid A. Toliyat, 2008, "Finite-Element Transient Analysis of Induction Motors under Mixed Eccentricity Fault", IEEE TRANSACTIONS ON MAGNETICS, VOL. 44, NO. 1, pp. 66-74.

[37] Ilker Ozelgin, 2008, "Analysis of magnetic flux density for air gap eccentricity and bearing faults", International Journal of Systems Applications, engineering & development No. 4, Vol. 2, pp. 162-169.

[38] Miguel Delgado, Giansalvo Cirrincione, Antonio Garcia Espinosa, Juan Antonio Ortega and Humberto Henao, 2011, "Bearing Faults Detection by a Novel Condition Monitoring Scheme based on Statistical-Time Features and Neural Networks", IEEE.

[39] Zzet YO Nel, K Burak Dalci and Ibrahim Senol, 2005, "Detection of outer raceway bearing defects in small Induction motors using stator current analysis", Sadhana Vol. 30, No. 6, December 2005, pp. 713-722.

[40] Lucia Frosini, and Ezio Bassi, 2010, "Stator Current and Motor Efficiency as Indicators for Different Types of Bearing Faults in Induction Motors", IEEE Transactions on Industrial Electronics, Vol. 57, NO. 1, pp. 244-251.