Comparative Study of Induction Motors Fault Diagnosis Techniques in Industrial Applications

By

Abdelaziz Mohamed Abdelaziz Khedr

A Thesis Submitted To The

Faculty of Engineering at Cairo University

In Partial Fulfillment of the

Requirement of the Degree of

MASTER OF SCIENCE

IN

ELECTRICAL POWER AND MACHINES ENGINEERING

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Prof. Dr. Mahmoud Mohamed Abdel-Hakim

……

Electrical Power and Machines,

Faculty of Engineering, Cairo University

Assoc. Prof. Dr. Hanafy Hassan Hanafy

…….

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Approved By The Examining Committee

Prof. Dr. Mahmoud Mohamed Abdel-Hakim

……..

Assoc. Prof. Dr. Hanafy Hassan Hanafy

……

Prof. Dr. Mouhab Mokhtar Hallouda

……

Prof. Dr. Mohsen Zaki EL Sherif

……

Faculty of Engineering - Cairo University

Giza, Egypt

2016

Engineer: Abdelaziz Mohamed Abdelaziz Khedr

Date of Birth: 7 / 1 / 1988

Nationality: Egyptian

E-mail: EngAziz77@yahoo.com

Phone: 00201020105990

Address: Kallen, Kafrel-Sheikh, Egypt

Registration Date: 1/ 10 / 2011

Awarding Date: / / 2016

Degree: Master of Science

Department: Electrical Power and Machines Engineering

Supervisors:

Prof. Dr. Mahmoud Mohamed Abdel-Hakim

Assoc. Prof. Dr. Hanafy Hassan Hanafy

Examiners:

Prof. Dr. Mahmoud Mohamed Abdel-Hakim

Assoc. Prof. Dr. Hanafy Hassan Hanafy

Prof. Dr. Mohab Mokhtar Hallouda

Prof. Dr. Mohsen Zaky EL Sherif

Title of Thesis: Comparative Study of Induction Motors Fault Diagnosis Techniques in Industrial Applications

Key Words: Motor Current Signature Analysis, Vibration Signature Analysis, Flux Signature Analysis, Induction Motors, Induction Motors Faults

Summary:

Induction motors are considered the main industrial prime mover so their reliability is considered of very high importance. This thesis aims at studying diagnosis of rotor and stator faults of induction motors. Then it investigates three condition monitoring techniques that were used to diagnose motor faults: Motor current, vibration and flux signatures analysis. Finally, comparative study between the detectability of these techniques was done. It proves that current and flux analysis were better in detecting rotor and eccentricity faults while vibration was better in detecting mechanical unbalance, bearing, and misalignment faults.

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To my father in his grave; the man who believed in me more than I do myself and whom I am debited with every good in my life; missing your advice, help, encouragement and enthusiasm; it's all yours my great father.

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List of Symbols

β	Bearing balls contact angle
D_b	Bearing ball diameter
D_c	Bearing pitch diameter
f_s	Fundamental supply frequency
$f_{e_{brb}}$	Characteristic fault frequency accompanying to broken rotor bar fault via MCSA and FSA
$f_{e_{sc}}$	Characteristic fault frequency accompanying to turn to turn short circuit fault via MCSA and FSA
$f_{e_{sph}}$	Characteristic fault frequency accompanying to single phasing fault via MCSA and FSA
f_{ecc}	Characteristic fault frequency accompanying to air gap eccentricity fault via MCSA, VSA and FSA
$f_{i,o}$	Bearing specific component characteristic fault frequencies via MCSA, VSA and FSA
$f_{e_{bng}}$	Characteristic fault frequency for bearing fault via MCSA and FSA
f_i	Inner raceway fault frequency via MCSA
f_o	Outer raceway fault frequency via MCSA
f_{ball}	Ball defect fault frequency via MCSA
f_{cage}	Cage defect fault frequency via MCSA
$f_{e_{mf}}$	Characteristic fault frequency accompanying mechanical faults via MCSA and FSA
f_p	Pole pass frequency
$f_{v_{brb}}$	Characteristic fault frequency accompanying to the broken rotor bar fault via VSA
$f_{v_{sc}}$	Characteristic fault frequency accompanying to stator winding fault via VSA
$f_{v_{sph}}$	Characteristic fault frequency accompanying to single phasing fault via VSA
n_2	Slip speed
n_b	Speed of the backward rotating magnetic field
n_r	Actual rotor speed
n_s	Synchronous speed
N_b	Number of bearing balls
N_r	Number of rotor bars
n_{ecc}	Eccentricity order number
n_{eon}	Order number of stator MMF time harmonic = 1, 3, 5, 7

p	Number of pole pairs
P	Active power
Q	Reactive power
S	Slip
X	Rotation speed frequency in RPS (Motor rotation speed in RPM divided by 60)

List of Abbreviations

ARMA	Autoregressive Moving Averages
CB	Circuit Breaker
CI	Computational Intelligence
DWT	Discrete Wavelet Transform
EMF	Electromotive Force
EPRI	Electric Power Research Institute
FFT	Fast Fourier Transform
FSA	Flux Signature Analysis
FT	Fourier Transform
GT	Gabor Transform
IEEE	Institute of Electrical and Electronic Engineers
IEEE-AIS	IEEE Reliability Working Group
ISO	International Standardization Organization
MCSA	Motor Current Signature Analysis
MLP	Multi-Layer Perceptron
MMF	Magneto-motive Force
MUSIC	Multiple signal classification
STFT	Short Time Fourier Transform
TFDG	Time-frequency distribution of Gabor
TFMS	Time – frequency Morlet Scalogram
TSFEM	Time Stepping Finite-Element Method
UMP	Unbalanced Magnetic Pull
VSA	Vibration Signature Analysis
WT	Wavelet Transform

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Abstract

Induction motors are considered the main industrial prime mover in addition to being the largest energy consumers so their reliability and energy-efficient operation are considered of very high importance. This thesis aims at improving the reliability and efficiency of induction motors through the detection of incipient or premature faults related to induction motors prior to their failures. There are lack of investigations for the failures related to the on-field operating motors so this thesis focus mainly on these motors in order to impact the industrial environment to give real results to help in improving the efficiency and reliability of induction motors.

There are many condition monitoring techniques that are used for monitoring the induction motors using many different quantities as torque, power, current, flux, vibration, noise and temperature. From these techniques, this thesis uses the techniques: motor current signature analysis, vibration signature analysis, and flux signature analysis. It proposes a comparison study for the degree of detectability of each technique for many different faults related to induction motors.

From the multiple number of failures related to induction motors, the thesis investigates the failures that are commonly existed in the industrial life. It deals with electrical failures as broken rotor bar fault, turn to turn short circuit fault and single phasing fault. In addition to that it examines mechanical failures such as bearing faults and air gap eccentricity faults that were explored separately due to their common occurring and high impact. Also other miscellaneous mechanical faults as misalignment fault and mechanical unbalance fault were investigated.

The thesis showed experimentally that each technique has strengths and weaknesses in the detection of induction motor faults. It showed that the motor current signature analysis has the best detectability for turn to turn short circuit faults, air gap eccentricity faults, and broken rotor bars fault for low voltage motors. On the other hand, the vibration signature analysis is better that other techniques in detecting bearing, mechanical unbalance and misalignment faults while the flux signature analysis has the best detectability for broken rotor bar faults and eccentricity faults.