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Calculation of The Rotor Bars Current in The Squirrel Cage Induction Motor in The Rotor Eccentricity Condition Using the Multiple Coupled Circuit Model

Hamed Shadfar [1], Hamid Reza Izadfar [1,*]

[1]*Faculty of Electrical and Computer Engineering, Semnan University, Semnan, Iran*
**Corresponding author: hrizadfar@semnan.ac.ir*

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Abstract

Rotor eccentricity (RE) is one of the common faults in induction motors (IMs). We will calculate the rotor bar current (RBC) in this condition. This helps to the precision modeling of motors under fault conditions. Besides, the dynamic behavior of the IM under dynamic eccentricity (DE) and static eccentricity (SE) will be analyzed. To monitor the condition of electric machines to prevent unexpected failure, we need accurate modeling of motor behavior and performance in different operating conditions. The multiple coupled circuit (MCC) model is one of the powerful methods for modeling and analyzing electric machines in healthy and faulty conditions, including RE faults, which have been widely used in recent years. This paper calculates the RBC under RE conditions on a 2-pole squirrel cage induction motor (SCIM) with a nominal specification of 1.1 kW, 220/380 V, and 50 Hz, using an MCC model based on the winding function theory (WFT) and the stator data. Also, the behavior of other motor characteristics is evaluated. This paper presents a new method for calculating the RBC of an IM. This method is analytical and can be used to model the IM precisely. The results enable us to calculate and compare the primary parameters of IMs for both healthy and faulty conditions, including losses, efficiency, and torque ripple.

Keywords

Multiple coupled circuit model (MCC); Rotor bar; Rotor eccentricity (RE); Squirrel cage induction motor (SCIM); Winding function theory (WFT).

1. Introduction

Squirrel-cage induction motors (SCIMs) are considered the most widely used electrical machines in industrial and domestic applications due to their simplicity, low maintenance costs, ease of starting, and other favorable characteristics [1]. A common mechanical fault in induction motors (IMs) is rotor eccentricity (RE), which occurs due to non-uniformity in the air gap between the stator and the rotor. This non-uniformity can stem from various factors, including improper bearing placement during installation and commissioning, wear of mechanical components under stress, misalignment between the load axis and the rotor axis, relative misalignment between the stator and the rotor during installation, mechanical resonance at critical speeds, unbalanced loading, or deflection of the rotor shaft [2-3]. Given the significance of IMs in various industrial processes, the implementation of fault detection strategies—integrated with a maintenance program—can help minimize unplanned downtime and the associated costs [4-5]. To monitor and evaluate motor performance, it is essential to develop accurate mathematical models, which allow for the simulation of motor behavior under diverse operating conditions [6-7]. Modeling methods for IMs can be classified into four general categories:

1) Coupled Circuit Models (MCC) [8-9],
2) d-q Models [10-11],
3) Magnetic Equivalent Circuit (MEC) Models [12-13], and
4) Finite Element Method (FEM) Models [14-15].

The objective of this paper is to calculate the rotor bar condition (RBC) of a squirrel-cage induction motor (SCIM) under rotor eccentricity (RE) conditions, using a proposed algorithm based on motor current signature analysis (MCSA) and stator data. To this end, static eccentricity (SE) and dynamic eccentricity (DE) faults are introduced into a two-pole SCIM (rated at 1.1 kW, 220/380 V, 50 Hz); subsequently, various motor parameters—including the RBC—are calculated and evaluated using the proposed algorithm.

2. Rotor bar flow calculation process

Various methods can be used for this purpose. In the proposed model, a relatively simple approach is presented. Assuming that the simulation time step (Δt) is chosen to be sufficiently small, these equations can be effectively approximated as differential equations, as follows:

$$[\Lambda_s]_i = \{[V_S]_i - [R_S][I_S]_{i-1}\}\Delta t + [\Lambda_s]_{i-1} \quad (1)$$

$$[\Lambda_r]_i = -[R_S][I_S]_{i-1}\Delta t + [\Lambda_r]_{i-1} \quad (2)$$

$$\omega_i = \frac{1}{J}(\mathrm{T}_{e.i-1} - \mathrm{T}_{L.i})\Delta t + \omega_{i-1} \quad (3)$$

$$\theta_{r.i} = \omega_i \Delta t + \theta_{r.i-1} \quad (4)$$

In the proposed model, the rotor bar currents under various operating conditions can be calculated using stator data and the motor's nameplate specifications, through an iterative numerical method implemented in the MATLAB programming environment. This model offers superior convergence speed and accuracy compared to the conventional MCC method. To calculate the Rotor Bar Current (RBC) under the specified conditions, one must first determine the stator data along with other motor nameplate specifications, such as the number of poles, load torque, rotor bar skew angle, and the SE (Stator End) and DE (Drive End) coefficients. Subsequently, the rotor inductance and resistance matrices are calculated. Then, through an iterative process involving the stator currents, the mutual inductance matrices between the rotor bars and the stator windings, and ultimately the rotor bar currents—are computed. This iterative process continues until the end of the simulation duration.

3. Conclusions

In this paper, the authors present an efficient method for calculating the Residual Braking Component (RBC) under both Static Eccentricity (SE) and Dynamic Eccentricity (DE) conditions. The proposed method is based on the Wavelet Fourier Transform (WFT), which facilitates a comprehensive analysis of the impact of Rotor Eccentricity (RE) on motor performance parameters. Furthermore, it provides significant insights into the performance characteristics of motors subjected to varying levels of RE. Specifically, under a 50% static eccentricity condition, a substantial decline in motor efficiency and speed—approximately 57% and 21%, respectively—was observed. Concurrently, stator currents exhibited an increase of about 40%. These findings underscore the detrimental effects of SE on motor performance and highlight the necessity for effective monitoring and surveillance strategies.

Additionally, the authors' analysis extends to a 50% dynamic eccentricity scenario, in which motor efficiency and speed experience reductions of 46% and 12%, respectively.

In conclusion, this research emphasizes the critical importance of understanding the impact of RE on motor performance. By utilizing the WFT, we provide a robust framework for calculating the RBC, thereby enabling more precise evaluations of motor efficiency and performance under various RE conditions. This insight is essential for the development of advanced motor designs and maintenance practices aimed at mitigating the adverse effects of RE.

References

[1] Maghsoodi, Saeed, Yusef Kazemi-Sanji, Mohammad Farhadi-Kangarlu, and Sadjad Galvani. "Comprehensive Modeling of Induction Motor Imbalance Condition to Precise Assessment of Steady State Performance Based on Complex Current Unbalance Factor." Journal of Modeling in Engineering 19, no. 66 (2021): 65-78. (in Persian)

[2] Goroshko, Andrii, and Maryna Zembytska. "Study on the Eccentric Rotor Dynamics in A Three-Phase Induction Motor with Squirrel Cage Rotor under Unbalanced Magnetic Field." 2024.

[3] Zhou, ZiWei, ZaiGang Chen, and WanMing Zhai. "Dynamics modeling and electromechanical coupling characteristics analysis of cage induction motors." Science China Technological Sciences 67, no. 3 (2024): 709-724.

[4] Nasiri, Ahmad, Akbar Rahideh, Gholam Reza Agah, and Shahin Hedayati Kia. "Ball-bearing fault detection of squirrel-cage induction motors based on single-phase stator current using wavelet packet decomposition and statistical features." IEEE Transactions on Energy Conversion, 2024.

[5] Goroshko, Andrii, and Maryna Zembytska. "Study on the Eccentric Rotor Dynamics in A Three-Phase Induction Motor with Squirrel Cage Rotor under Unbalanced Magnetic Field." 2024.

[6] Sarac, Vasilija. "Impact of core saturation on operating characteristics of three-phase squirrel cage motor." (2024): 84-92.

[7] Bahgat, Bahgat Hafez, Enas A. Elhay, Tole Sutikno, and Mahmoud M. Elkholy. "Revolutionizing motor maintenance: a comprehensive survey of state-of-the-art fault detection in three-phase induction motors." International Journal of Power Electronics and Drive Systems 15, no. 3 (2024): 1968-1989.

[8] Zhou, ZiWei, ZaiGang Chen, and WanMing Zhai. "Dynamics modeling and electromechanical coupling characteristics analysis of cage induction motors." Science China Technological Sciences 67, no. 3 (2024): 709-724.

[9] Huang, Liangyuan, Niaoqing Hu, Yi Yang, Ling Chen, Jihong Wen, and Guoji Shen. "Study on electromagnetic–dynamic coupled modeling method—detection by stator current of the induction motors with bearing faults." Machines 10, no. 8 (2022): 682.

[10] Rodriguez-Blanco, Marco Antonio, Victor Golikov, René Osorio-Sánchez, Oleg Samovarov, Gerardo Ortiz-Torres, Rafael Sanchez-Lara, and Jose Luis Vazquez-Avila. "Fault diagnosis of induction motor using DQ simplified model and parity equations." Energies 15, no. 22 (2022): 8372.

[11] El-Faouri, Fares S., Omar Mohamed, and Wejdan Abu Elhaija. "DQ model and control of a three-phase induction motor considering mutual flux saturation effect." In 2017 10th Jordanian International Electrical and Electronics Engineering Conference (JIEEEC), pp. 1-6. IEEE, 2017.

[12] Wang, Yewei, Zhike Xu, Long Jin, Hongbin Zhang, and Jun Hong. "Magnetic Equivalent Circuit Modeling of Permanent Magnet Synchronous Motor with External Rotor." In Frontier Academic Forum of Electrical Engineering, pp. 659-668. Singapore: Springer Nature Singapore, 2024.

[13] Korman, Oğuz, Mauro Di Nardo, Jacopo Riccio, Mukhammed Murataliyev, Michele Degano, and Chris Gerada."Distributed Magnetic Equivalent Circuit Modelling of Synchronous Machines." IEEE Transactions on Industry Applications,2024.

[14] Fantin Irudaya Raj, E., and M. Appadurai. "Static 2D-finite element analysis of eccentricity fault in induction motor." In Smart Technologies for Energy, Environment and Sustainable Development, Vol 1: Select Proceedings of ICSTEESD 2020,pp. 409-422. Singapore: Springer Nature Singapore, 2022.

[15] Prasad, Kapu V. Sri Ram, K. Dhananjay Rao, and Faisal Alsaif. "Induction motor structure design to reduce vibrations with numerical (FEA) and experimental (VA) techniques." IEEE Access 12 (2024): 40894-40904.