

Effects of Inter-Turn Faults in Induction Motors on Phase Currents: A Continuous Wavelet Transform Approach

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Inter-turn faults in the stator winding represent a critical failure in induction motors, significantly affecting their reliability and efficiency. Although extant studies mainly focus on faults within a single phase, there is a paucity of publications presenting the results of simulation calculations or measurements of inter-winding faults in more phases of the stator winding. The present study aims to address this lacuna by presenting the results of a continuous wavelet transform of the stator winding current waveform, with consideration of inter-turn short circuits in all three phases. The results obtained provide insights into the complex fault dynamics and their impact on machine performance, thus forming the basis for improved diagnostic techniques and deepening the understanding of fault mechanisms in induction motors.

Index Terms—Induction motors, Multiphase inter-turn short circuits, Wavelet transform, Fault diagnostics.

I. INTRODUCTION

Induction motors are widely used in industrial systems due to their robustness and efficiency [1]. However, one of the most critical faults affecting their operation is the occurrence of inter-turn short circuits in the stator windings. These faults compromise motor reliability and efficiency, often leading to unplanned downtime and costly maintenance. While traditional diagnostic methods are effective for detecting single-phase faults, they often fail to capture the complex dynamics of inter-turn short circuits, particularly under multiphase configurations.

Although prior studies have extensively analysed inter-turn short circuits within a single phase [2], there is a notable gap in understanding their phenomena when multiple phases are affected. Multiphase inter-turn short circuits pose a significant diagnostic challenge, as they introduce complex asymmetries and transient effects that are difficult to analyse using conventional techniques.

This study introduces a novel methodology to address these challenges by employing wavelet transform techniques on current waveforms. The time-frequency capabilities of wavelet transform allow for the identification of critical fault dynamics, providing a deeper understanding of fault mechanisms. The results confirm the suitability of wavelet analysis for the comprehensive examination of multiphase inter-turn short circuits in induction motors. These findings not only contribute to the advancement of diagnostic methodologies but also lay the groundwork for real-time monitoring systems capable of early fault detection, ultimately enhancing the operational reliability of induction motors.

II. CALCULATING THE PHASE CURRENT WAVEFORMS OF A FAULTY MOTOR

A. The equivalent diagram of the stator winding with inter-turn short circuits

The present article has two principal aims. Firstly, it seeks to present the effects of inter-turn short circuits on the phase current waveforms of the stator winding of a squirrel-cage induction motor. Secondly, it considers the occurrence of inter-turn short circuits in all phases of the winding. As illustrated in Figure 1, the equivalent circuit diagram of the stator winding incorporates the consideration of inter-turn short circuits.

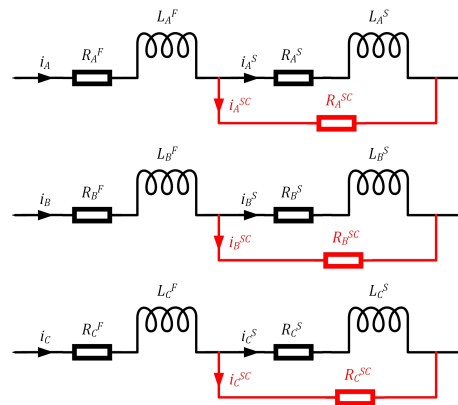


Fig. 1. Inter-turn short-circuits in all phases of stator winding

One of the consequences of a short circuit of the winding appearing in the stator winding is its division into two parts: the faulty part (parameters marked with superscript ^F) and the shorted part (parameters marked with superscript ^S). For the purpose of further analysis,

the number of turns in the faulty part of the i -th phase winding is designated as N_i^F , and the number of shorted turns in the same phase is denoted as N_i^S . The numbers of shorted turns in the individual windings are independent of each other. The equivalent diagram is presented for all phases of the stator winding, with the resistance R_i^{SC} of the shorting circuit. In the majority of studies, the assumption is made that the short circuit is galvanic, leading to the simplification of $R_i^{SC} = 0$.

B. Stator current waveform simulation calculations

The method presented was utilized to calculate the current waveforms of the stator windings. In the motor under consideration, the phase winding consists of 180 turns. The calculations took into account the variation of the number of shorted turns from 0 (undamaged machine) to 10 turns per one phase winding. Therefore, a small number of shorted turns was considered in comparison to the total number of turns in the phase winding. The stator current waveforms were calculated using a developed numerical model of a squirrel cage induction motor with the following parameters: power of 3 kW, speed of 1415 rpm. The developed model of a squirrel-cage induction machine was employed for simulation calculations in ANSYS/Maxwell.

III. SELECTED RESULTS OF THE CONTINUOUS WAVELET TRANSFORM OF THE PHASE CURRENT WAVEFORMS

As illustrated in Figure 2, the results of the continuous wavelet transform ($CWT(I(t))$) of the stator winding currents are labelled $CWT(I_A(t))$, $CWT(I_B(t))$ and $CWT(I_C(t))$, for the following number of shorted turns $N_A^S = 1$, $N_B^S = 2$, $N_C^S = 10$. The analysis of these wavelet spectrograms can facilitate the discernment of inter-turn short circuits by means of an examination of alterations in frequency content over time.

Interpretation of the CWT Spectrograms:

- The presence of fundamental and harmonic frequency components in the stator currents is indicated by the strong alternating red-blue patterns at the top of each plot. The periodicity observed in the high-frequency range (approximately scale index 50) is likely to correspond to the fundamental frequency of the phase currents.
- In the event of an inter-turn short circuit, disparities may be discerned amongst the three spectrograms. These disparities may assume the form of localised distortions, alterations in intensity, or the propagation of frequency components. The presence of additional frequency components within the mid-to-low frequency range can be attributed to an imbalanced phase current.

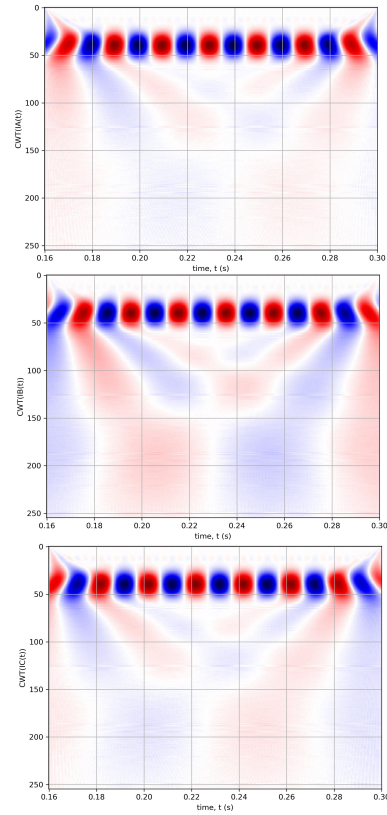


Fig. 2. Continuous wavelet transform of phase currents: (a) $CWT(I_A(t))$, (b) $CWT(I_B(t))$, (c) $CWT(I_C(t))$

IV. SUMMARY AND CONCLUSIONS

The present study was concerned with the diagnosis of inter-turn short circuits in the stator windings of induction motors. It was observed that traditional diagnostic methods have difficulty in capturing such faults due to their complex dynamics. To address this, the study introduced a wavelet transform approach to analyse phase current waveforms to detect fault dynamics and provide insight into fault mechanisms. The outcomes of the study demonstrate the efficacy of the proposed approach in identifying and diagnosing faults in a multiphase system, thus providing a foundation for real-time monitoring and enhancing motor reliability.

REFERENCES

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