IECMA 2024 Conference
The 2nd International Electronic Conference on Machines and Applications
18–20 June 2024 | Online
MDPI

Effective Strategies for Early Detection of Inter-Turn Short-Circuit Faults in Line-Start Permanent Magnet Synchronous Motors

Maria Teresa Santos, Khaled Laadjal, Antonio J. Marques Cardoso
CISE - Electromechatronic Systems Research Centre
University of Beira Interior, Calçada Fonte do Lameiro, P – 6201-001 Covilhã, Portugal
(email: maria.teresa.rei.santos@ubi.pt; khaled.laadjal@ubi.pt; ajmcardoso@ieee.org)

INTRODUCTION & AIM

- Line-Start Permanent Magnet Synchronous Motors (LS PMSMs) have emerged in response to strict efficiency goals [1], [2], [3].
- Capable of starting directly connected to the grid, LS PMSMs are highly recommended for replacing older induction motors and have been the target of significant technological advances [2], [3].
- Combining features of permanent magnet synchronous motors and induction motors, LS PMSMs include rotors with permanent magnets and a squirrel cage. They operate as PMSMs at steady state and start like mains-fed induction motors without needing a power electronics converter [3].
- The increasing importance of LS-PMSMs in modern industry necessitates the development of effective fault diagnostics to prevent unexpected breakdowns, which could lead to catastrophic economic losses and human casualties [4].
- Previous research has focused mainly on demagnetization and rotor faults. However, stator winding faults, often due to aging, represent a significant portion of faults in three-phase AC motors (21%-37%). Literature addresses modeling and online detection of interturn short circuits faults (ITSCFs) in both induction motors and PMSMs, with several techniques proving effective under constant load and balanced voltage conditions [5], [6].
- This study presents an intelligent technique for online detection of ITSCFs in LS-PMSM stator windings, involving real-time estimation of Impedance Symmetrical Components (ISCFs) using the Short Time Least Square Prony's Technique (STLSP). To validate the efficacy of the proposed technique, extensive testing of LS PMSMs have been conducted under diverse operating conditions, including varying fault severities, load variations.

PROPOSED METHOD

- The proposed indicators are extracted from the monitored system, based on the online measurements of stator currents and voltages, using the STLSP algorithm to obtain their spectrum, only the fundamental component of each signal is taken into consideration [7], [8].
- Calculation of the Fortescue symmetrical components related to the stator winding voltages and impedances:

$$\begin{cases} ZVF = \dfrac{|V_0|}{|V_P|} = \dfrac{V_m}{3}\left(v_{m-sc}^{a} - v_{m-sc}^{b}\right) \\ NCF = \dfrac{|I_N|}{|I_P|} \end{cases} \quad and \quad \left\{ Z_{1fs}^{P} = \frac{V_{1fs}^{P}}{I_{1fs}^{P}}, Z_{1fs}^{N} = \frac{V_{1fs}^{N}}{I_{1fs}^{N}}, Z_{1fs}^{0} = \frac{V_{1fs}^{0}}{I_{1fs}^{0}} \right\} \quad (1)$$

ZVF: Zero Voltage Factor; **NCF:** Negative Current Factor; **ZP, ZN, Z0:** Positive, Negative and Zero sequence of the impedances.

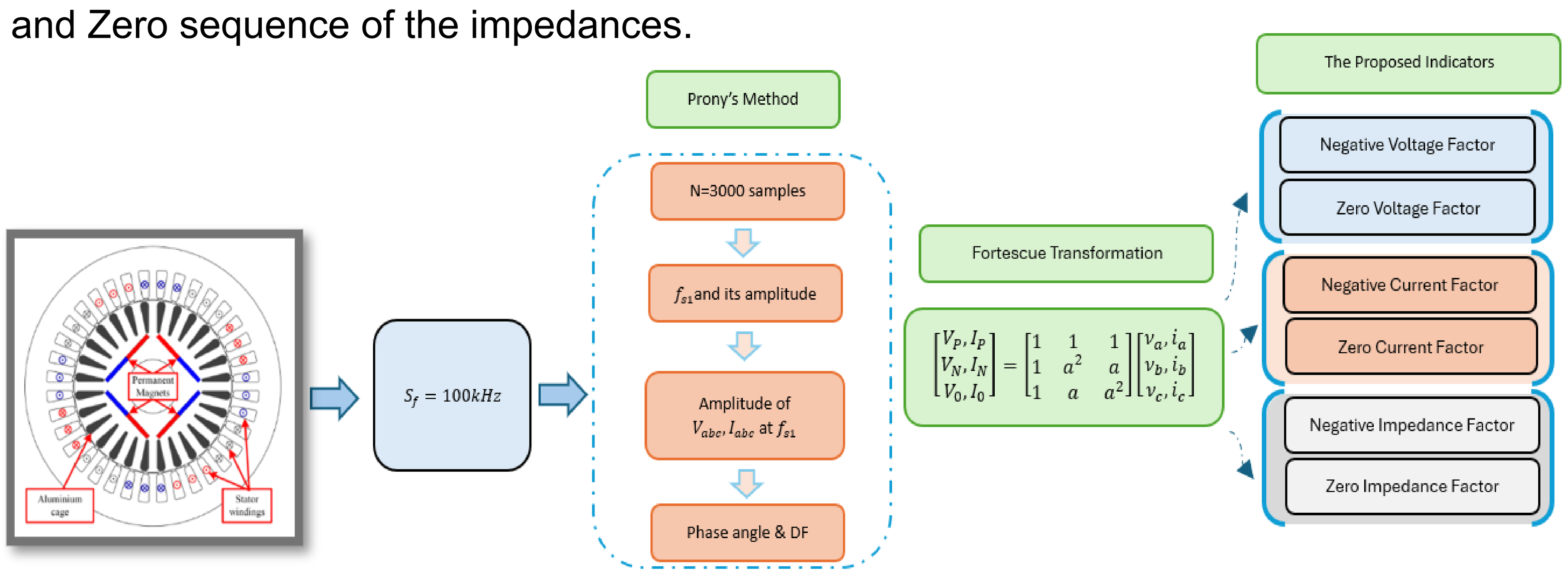

Figure 1. Description of the proposed method and its strategy for indicator extraction.

RESULTS & DISCUSSION

Table 1. Quantitive values of the proposed indicators with 0 Nm.

	Healthy	7 turns	14 turns	30 turns	Rate of variation (%)		
					7 turns	14 turns	30 turns
ZVF	0,000000306	0,002938	0,007879	0,01423	>> 1000 %	>> 1000 %	>> 1000 %
NCF	0,000008228	0,04392	0,1072	0,1814	>> 1000 %	>> 1000 %	>> 1000 %
ZA	125,7	98,15	82,9	72,8	-16%	-21%	-20%
ZB	125,7	105,2	99,84	100,4	-22%	-34%	42%
ZC	125,8	105,1	94,38	81,95	-16%	-35%	-35%

RESULTS & DISCUSSION

Table 2. Quantitive values of the proposed indicators with 7 Nm.

	Healthy	7 turns	14 turns	30 turns	Rate of variation (%)		
					7 turns	14 turns	30 turns
ZVF	0,0000000492	0,002938	0,007879	0,01423	>> 1000 %	>> 1000 %	>> 1000 %
NCF	0,00004747	0,04392	0,1072	0,1814	>> 1000 %	>> 1000 %	>> 1000 %
ZA	94,56	98,15	82,9	72,8	4%	-12%	-23%
ZB	94,49	105,2	99,84	100,4	11%	6%	6%
ZC	94,58	105,1	94,38	81,95	11%	0,2%	-13%

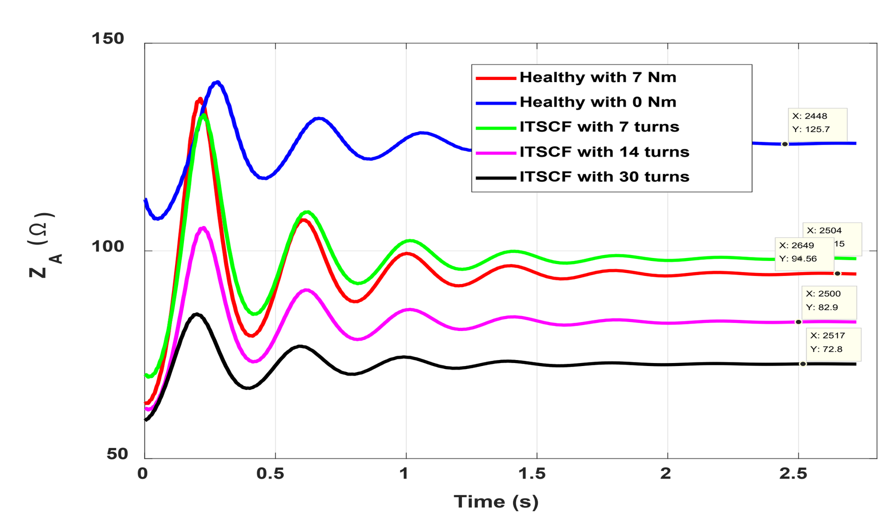

Figure 2. Z_A indicator, assessed for healthy state and in the presence of ITSCF with different severities.

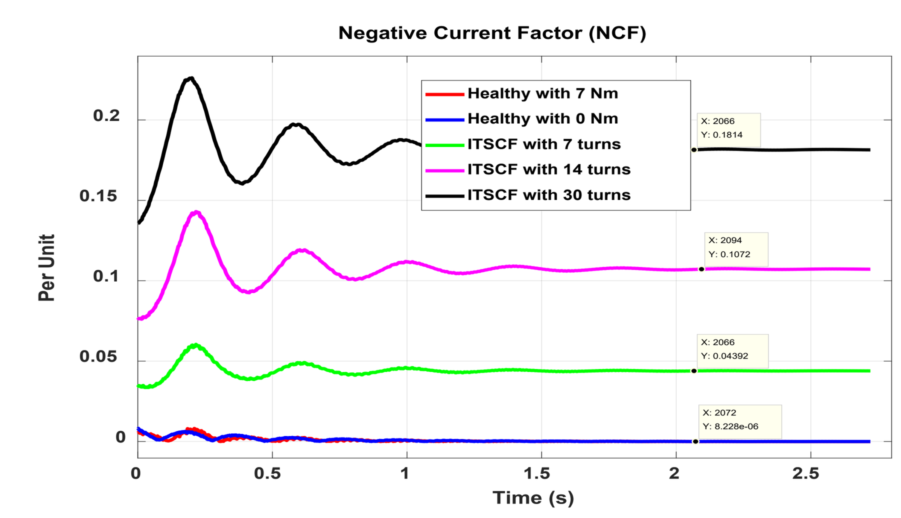

Figure 3. **NCF** indicator, assessed for healthy state and in the presence of ITSCF with different severities.

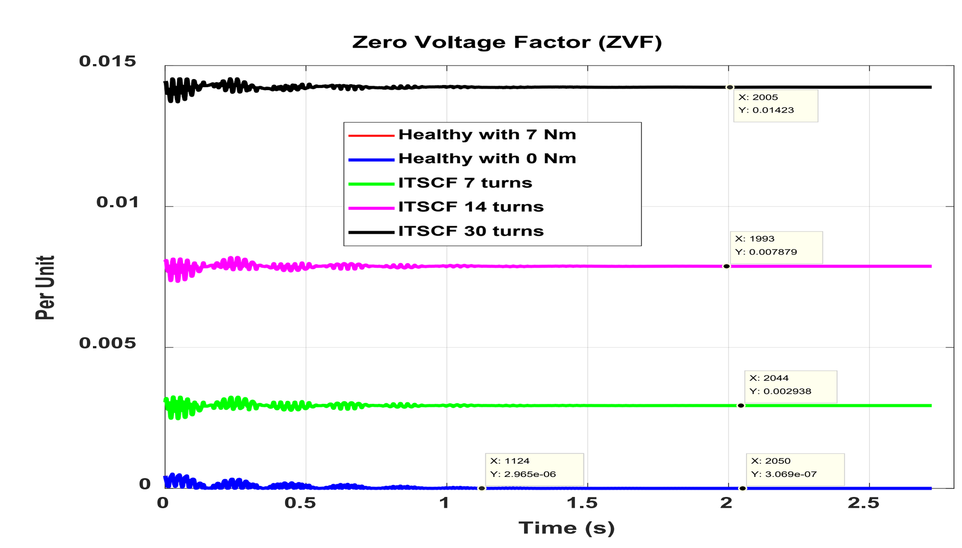

Figure 4. **ZVF** indicator, assessed for healthy state and in the presence of ITSCF with different severities.

CONCLUSIONS & FUTURE WORK

- This research presents a new real-time system for diagnosing ITSFs in LS-PMSMs.
- The STLSP method computes the proposed indicators (ZVF, NCF) for identifying incipient ITSC faults in LS-PMSMs.
- The effectiveness of the indicators, ZVF and NCF, in detecting the occurrence of an interturn short circuit is evident from the variation in values corresponding to different fault severities. This demonstrates efficacy of the indicators in accurately identifying fault conditions.
- Table 1 and Table 2 indicate that there are no significant variations under different load conditions. This confirms the robustness of the technique against load variation.
- The obtained findings support the method's reliability, accuracy, and adaptability for detecting ITSC faults.
- In the coming stages, the primary objective is to experimentally validate the results presented by the approach.

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Acknowledgments: This work was supported by the Portuguese Foundation for Science and Technology (FCT) under Projects UIDB/04131/2020 and UIDP/04131/2020.