Modelling Incipient Inter-Turn Short Circuit Fault in Permanent Magnet Synchronous Motors

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Abstract – The inter-turn short circuit (ITSC) fault in the winding of a 1.7 KW interior permanent magnet synchronous motor (IPMSM) is modelled using a time-stepping finite element analysis (FEA). Conventional FEA normally considers the fault symmetrical, but ITSC faults may initiate in one coil and then expand to other coils. This causes unbalance in flux distribution around the faulty coil, and a full model of the motor is therefore analyzed in FEA. Based on the analyzed results of the IPMSM under incipient ITSC faults, different motor signals are further investigated and processed using Fast Fourier transform (FFT) to find out the best indicator to detect ITSC in an early stage.

A.1 Introduction

Permanent magnet synchronous motors (PMSMs) have become more and more common in industry due to their merits of high efficiency, precise controllability, and high reliability [1–3]. However, PMSMs working in a harsh environment are exposed to electrical, thermal, and mechanical stresses, making the stator insulation continuously degrading, leading to inter-turn short circuit (ITSC) fault. Therefore, understanding the machine behavior under the ITSC fault in early stages is of great importance in preventing a complete machine failure.

In this paper, a 2-D time-stepping finite-element analysis (FEA) is used to model the ITSC fault in the winding of a PMSM. The first objective is to model the fault as close as possible to the real faults in PMSMs. Such a phenomenon cannot be investigated by lumped-circuit models and therefore it is recommended to be modeled using FEA [4]. However, finding a health indicator for a PMSM using signals obtained from FEA is missing in the literature. In this paper, motor signals obtained from the time-stepping FEA, namely torque, currents, instantaneous power of phase-a and input power are transformed into frequency domain using Fast Fourier Transform (FFT), since it is fast and efficient to be implemented [5], to find out which one is better as ITSC fault indicator.

A.2 Modelling of Inter-Turn Fault in IPMSM

To model an ITSC fault, a $1.7kW$ IPMSM is re-designed and implemented. Fig. A.1 shows the motor's structure, whereas its parameters are listed in Table A.1. Since it is an

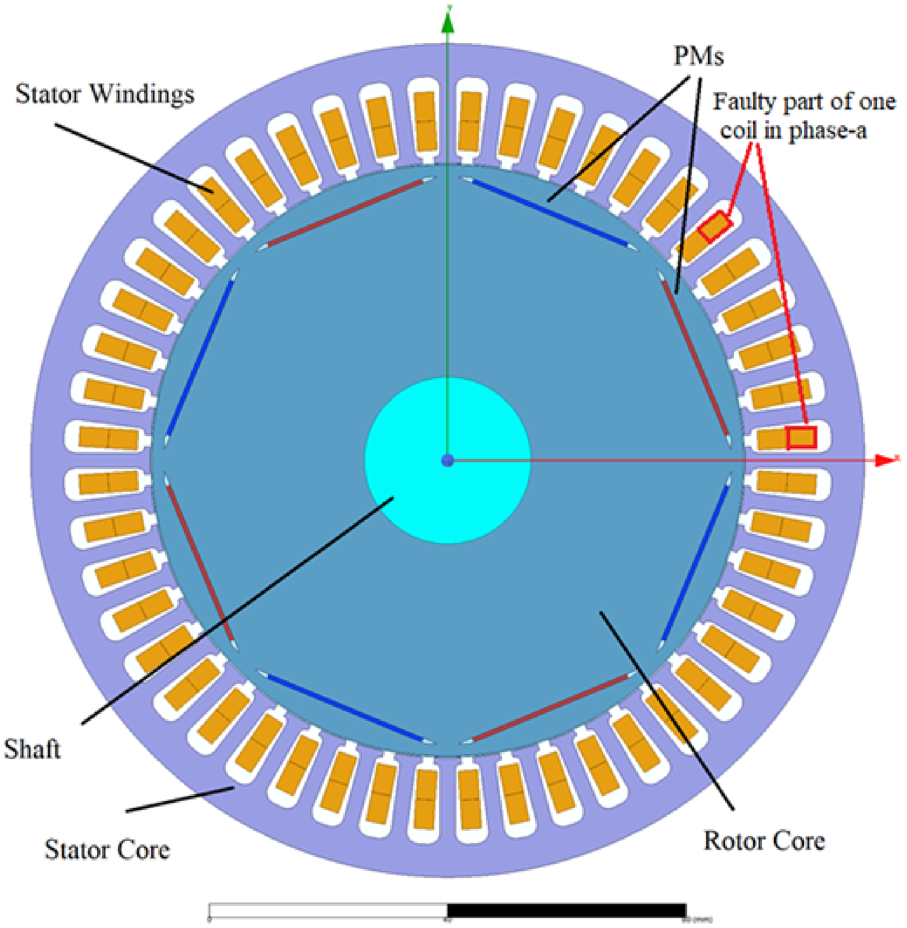

Figure A.1: 2-D model of an 8-pole permanent magnet synchronous motor.

8-pole motor with $q = 2$ (slots per pole per phase), each phase consists of 8 coils connected in series.

An ITSC fault usually starts with a few short turns, and then propagates to the whole coil, leading to phase-to-phase or phase-to-ground faults as well. Here, it is assumed that half of one coil in phase-a, marked in Fig. A.1, is short circuited. Since 8 coils are in series in each phase, 6.25% or 1/16 of phase-a is considered to be short circuited.

A 2-D time-stepping FEA has been performed on the aforementioned PMSM with a time-step of $100\mu s$. Fig. A.2 shows the flux distribution inside the cores of the motor stator and rotor. It is obvious that even a small ITSC fault creates unbalance in flux distribution under the faulty coil. In addition, numerical data of three-phase currents, instantaneous powers, input power, and electromagnetic torque are extracted and analyzed by FFT. In Fig. A.3 and Fig. A.4, FFT analysis reveals that the 3rd and 9th harmonics appear in spectrum of the phase-a current (Ia) and 4th harmonic in phase-a instantaneous power (Pa) under the ITSC fault condition. FFT analysis of input power (Pin) and torque (Te) shows that 2nd, 4th, 8th and 10th harmonics are generated in the presence of ITSC fault as shown in Fig. A.5 and Fig. A.6.

Current signals are a common index and widely investigated in literature due to simplicity of measurement. However, as shown in Fig. A.3, the difference of the 3rd harmonic between faulty and healthy cases is rather small and inconsistent at other harmonics, and

Table A.1: Parameters of the PMSM

Symbol	Parameter	Value	Unit
V_s	Rated voltage	300	V
P_{out}	Output power	1.75	A
T_{out}	Output torque	14.0	$N.m$
n_s	Rated speed	1200	rpm
P	Number of poles	8	
S	Number of slots	48	

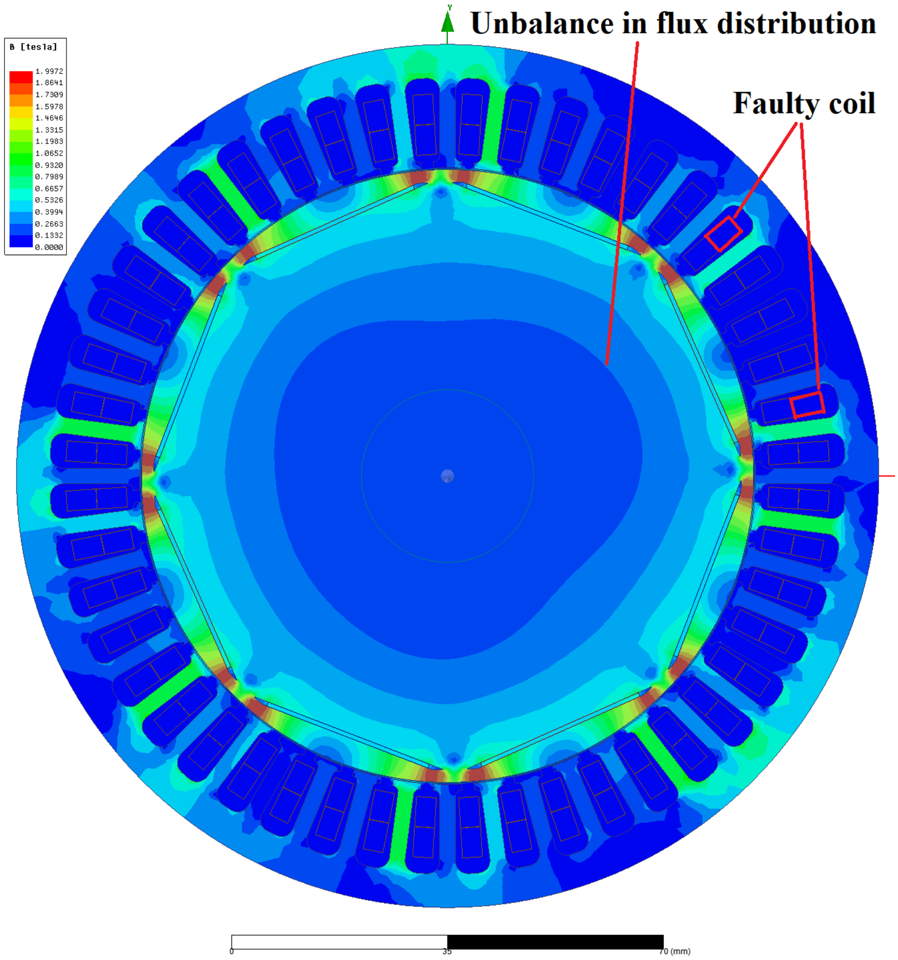

Figure A.2: Flux distribution in the motor.

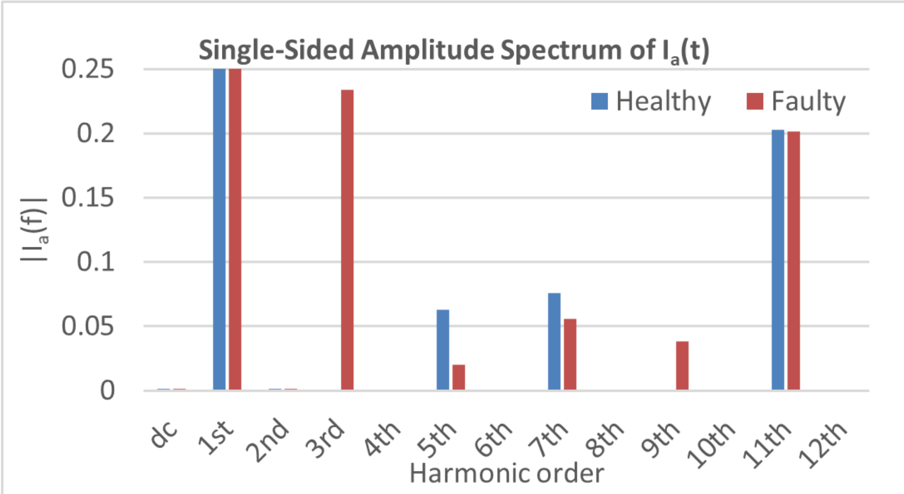

Figure A.3: Comparison of spectrum of I_a in healthy and faulty condition.

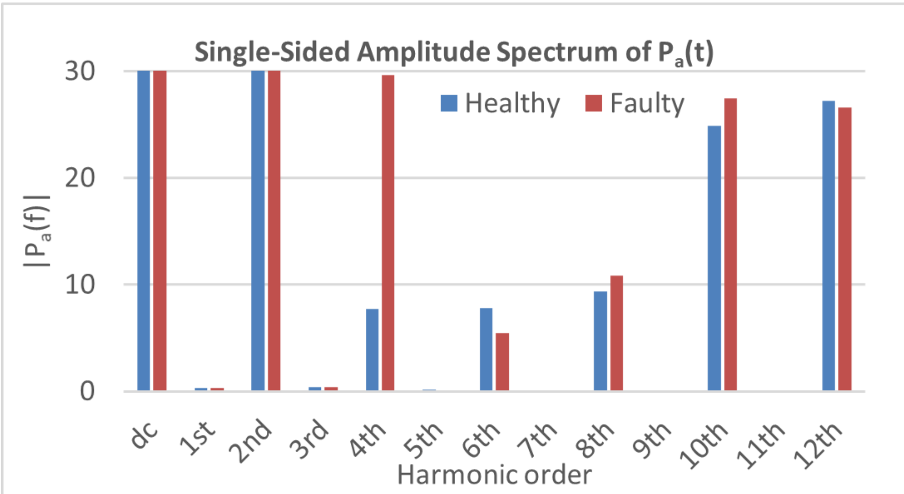

Figure A.4: Comparison of spectrum of P_a in healthy and faulty condition.

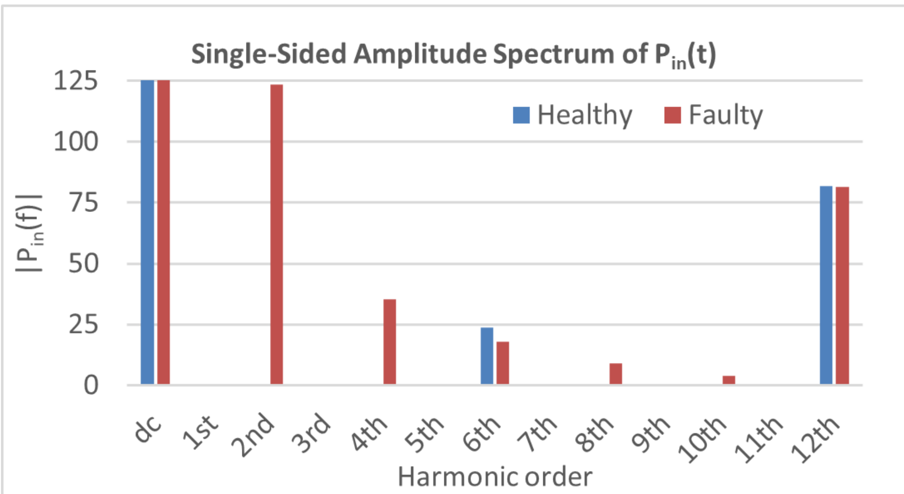

Figure A.5: Comparison of spectrum of P_{in} in healthy and faulty condition.

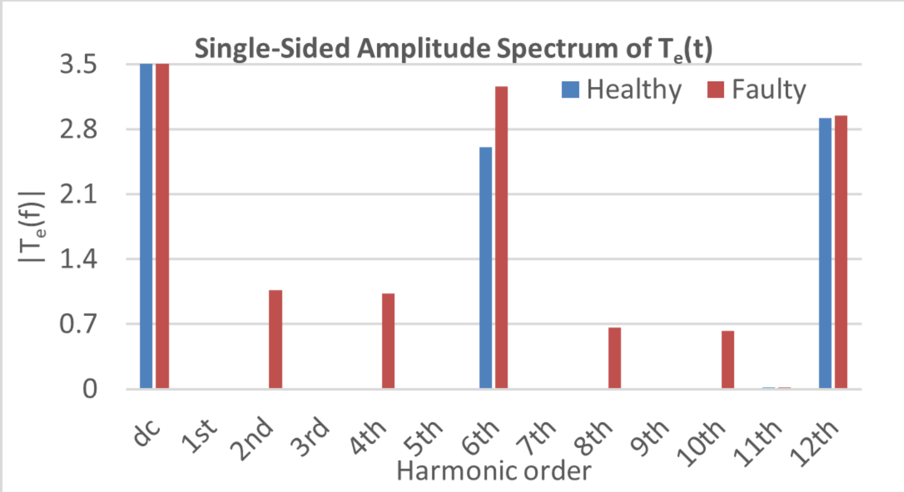

Figure A.6: Comparison of spectrum of T_{out} in healthy and faulty condition.

can hence easily be affected by noise.

Although the torque is a feasible fault indicator, cost of a torque transducer, load dependency and measurement complexity make it less interesting to be considered. Instantaneous power of phase-a seems to be a promising fault indicator compared to both torque and current, since the difference between healthy and faulty components is noticeable. Nevertheless, input power shows better indication of ITSC fault since it contains the information of all the three-phase currents and voltages. Not only are more harmonic components influenced by the fault, but also the difference between healthy and faulty components, especially in 2nd and 4th, are high enough not to be influenced by noise. Furthermore, it can be used for ITSC fault in other phases as well.

A.3 Conclusion

A 2-D time stepping finite element analysis has been performed on an 8-pole IPMSM both in healthy condition and under an ITSC fault in the stator winding. Initial analysis of transform currents, phase-a instantaneous powers, and torque, signals using FFT shows that certain harmonics due to an ITSC fault can be observed in spectra. However, these components in faulty case can be affected either by load change and noise or are inconsistent at higher frequencies and that is why authors recommend using input power as the ITSC fault indicator instead. All in all, using input power as fault indicator brings about a low-cost, fast, efficient, and effective ITSC fault detection method which can be used in various industrial applications.

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