Configuration Impacts on Eccentricity Fault Detection in Permanent Magnet Synchronous Motors

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Abstract — Among different structures of permanent magnet motors, surface permanent magnet (SPM) motors and interior permanent magnet (IPM) motors are widely used in different industries. In this paper, effects of these structures on the eccentricity fault detection strategies are analyzed in details. Albeit, four indices have been so far proposed for eccentricity fault recognition in SPM motors, no index has been introduced for IPM motors. Hence, the possibility of using published indices for SPM motors is investigated for IPM motors. Since proposed indices for fault diagnosis in SPM motors have been extracted from spectra of the stator current, and the developed torque, spectra of these signals in the SPM and IPM motor are compared with each other. Then, necessary modifications are applied to these indices for employing to identify eccentricity in IPM motors. Due to essential influence of motor modeling on the accuracy results, tow and three-dimensional time stepping finite element method is used to simulate healthy and faulty SPM and IPM motors. Effects of fault extension and load variation on the used indices in SPM motors and modified indices in IPM motors are scrutinized from different aspects. The simulation results are verified by the experimental results.

I. Introduction

Structures of permanent magnet motors have perceptible effects on their performance in different cases. Eccentricity fault is one of these cases and relation between different types of these structures and accurate fault detection should be inspected. In [1, 2], a surface permanent magnet (SPM) motor and an interior permanent magnet (IPM) motor under static eccentricity fault have been compared via analysis of magnetic flux density, cogging torque, radial force and electromagnetic torque. They have demonstrated that variation rate of the magnetic flux density and cogging torque in the faulty IPM motor is more than that SPM motor. Meanwhile, they have illustrated that radial force in the IPM motor under static eccentricity is larger than that SPM motor and electromagnetic torque decreases in the faulty IPM motor. In [3, 4], magnitude of the side-band component at frequency $(1/P)f_s$ as a criterion has been proposed for dynamic eccentricity in the permanent magnet synchronous motors (PMSMs). It has been emphasized that criterion cannot be utilized for static eccentricity fault diagnosis in PMSMs In [5, 6], amplitude of the side-band components at frequencies $(1\pm(2k-1)/p)f_s$ as an index has been introduced for static and dynamic eccentricity fault recognition in PMSMs. It has been shown that static and dynamic eccentricities and their expansion increase the amplitude of the side-band components at frequencies $(1\pm(2k-1)/p)f_s$ which have been used to diagnose the degree of the eccentricity fault.

II. 2D Finite Element Method

Magnetic field distribution within the motor can be obtained by FEM. Current, torque and speed of the motor can be then determined using other specifications of the motor. A 2D scheme of the simulated SPM and IPM has been displayed in Fig. 1. Since in this approach, spatial distribution of the stator windings, non-linear characteristics of the ferromagnetic and PM materials, geometrical and physical characteristics of the stator slots and permanent magnets (PMs) are taken in to account, it has been used to model and analyze the healthy and faulty PMSM under different types of eccentricity. In this modeling, non-uniformity of the air-gap due to static, dynamic and mixed eccentricities in different degrees are modeled. In the static eccentricity case, the rotor from the center of the stator and rotor is rotated around its own center. Albeit in the dynamic eccentricity fault, the rotor is moved from the center of the stator, rotor is rotated around the center of the stator. In the mixed eccentricity fault, stator and rotor are displaced from the rotor rotation center. Hence, transient analysis of rotating machines (RM) is employed for modeling and analyzing the SPM and IPM with mechanical coupling. The RM Program is a transient eddy current solver, extended to include the effects of rigid body (rotating) motion [6]. The solver also provides for the use of external circuits and coupling to mechanical equations. In the modeling of the SPM and IPM under eccentricity fault, three-phase sinusoidal voltages are applied to the motor terminals as inputs, magnetic flux density, stator current and torque are predicted as the selected signals for processing and feature extraction. In this simulation, electrical equations due to the external circuits which exhibit supply and electrical circuits are combined with magnetic field equation in FEM and motion equations due to the mechanical coupling.

III. Stator Currents

A. *SPM Motor*

Fig. 2 depicts the stator current of the faulty SPM under

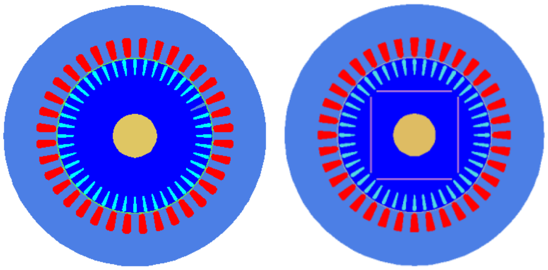

Fig.1 Cross section of the motors, (right) SPM and (left) IPM

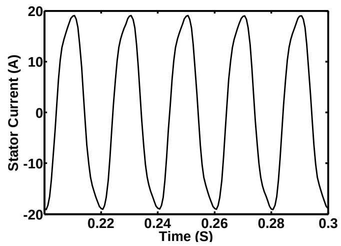

Fig. 2. Stator current waveform of SPM motor with 10% static eccentricity

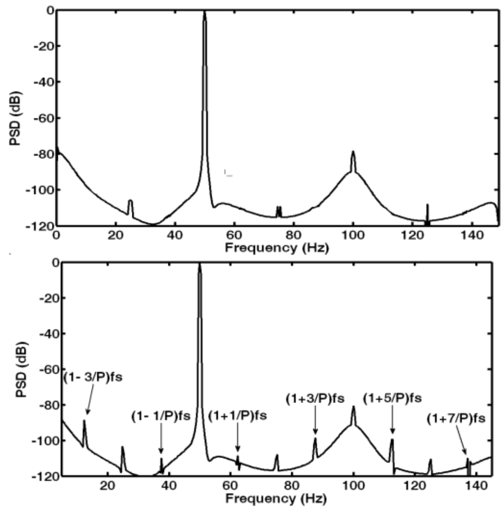

Fig. 3. Normalized line current spectra of the SPM motor in (top) healthy, (bottom) with 10% static eccentricity

static eccentricity. According to Fig. 2, static eccentricity distorts the stator current waveform. Thus, it is concluded that new harmonics have been generated in the stator current signal. Hence, spectrum of the stator current can be utilized for non-invasive eccentricity fault diagnosis. Fig. 3 demonstrates the spectrum of the stator current in the healthy case and 10% static eccentricity. It is seen that static and dynamic eccentricity increase the amplitude of side-band components at frequencies $(1\pm(2k-1)/p)f_s$ can be employed as a competent index for eccentricity fault detection and in SPM motors. The noticeable difference between the amplitude of side-band components at aforementioned frequencies at different eccentricity degrees can be used to determine the percentage of eccentricity fault precisely. Meanwhile, the perceptible difference between amplitude of side-band components at frequencies $(1\pm(2k-1)/p)f_s$ in the same eccentricity degree in the static and dynamic cases can be utilized for eccentricity type recognition.

A. *IPM Motor*

Fig. 4 illustrates the stator current of the faulty IPM motor

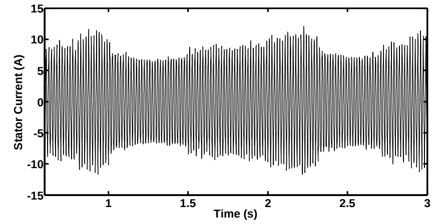

Fig. 4. Stator current waveform of SPM motor with 10% static eccentricity

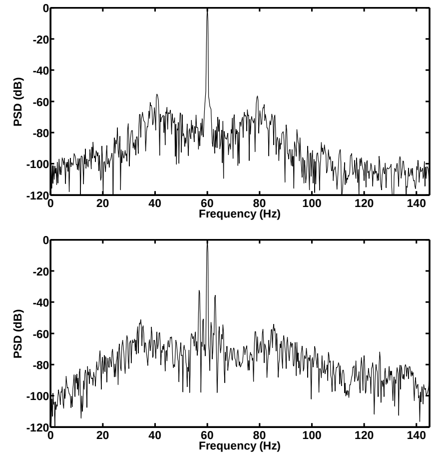

Fig. 5. Normalized line current spectra of the IPM motor in (top) healthy, (bottom) with 10% static eccentricity

under static eccentricity. It is seen that the stator current has been unbalanced due to fault. Fig. 5 reveals the spectrum of the stator current of the IPM motor in the healthy and faulty cases. Comparison between Fig. 3 and Fig. 5 exhibits that generated side-bands in the stator currents spectra of the SPM motor are not seen in the IPM motor. However, number of generated side-bands in the spectra of the SPM motor is less than that IPM. It is due to rotor slots in the IPM motor which generate considerable spatial harmonics in the stator currents spectra.

IV. References

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