Diagnosis of Phase to phase Short Circuit faults in Vector Controlled Permanent Magnet Synchronous Motors

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***Abstract* – Stator turn faults in permanent magnet synchronous motors (PMSMs) are more dangerous than those in induction motors (IMs) because of the presence of spinning rotor magnets that can be turned off at will. Condition monitoring and fault detection and diagnosis of the PMSM have been receiving a growing amount of attention among scientists and engineers in the past few years. This aim of this paper is to present a vector controlled PMSM behaviors under inter-turn short-circuits in two phases. A test bench of a motor producing short circuited turn in stator winding has been built. Results obtained by dynamic model in both healthy and faulty conditions are compared to experimental ones. Thus some signatures of the phase to phase short circuits have been performed for diagnosis purpose.**

I. Introduction

Permanent magnet synchronous motors (PMSM) are becoming highly popular in high performance applications in comparison to other ac motors. The condition monitoring of PMSM drives has become a critical problem for various industrial applications because a sudden drive failure can cause serious damage and economical losses. In such applications it is advantageous to use a drive capable of continuing to operate in the presence of any single point failure [1],[2]. Some of the more frequent faults or high-power density permanent magnet synchronous motor (PMSM) drives are short circuits in stator windings [3], [4]. A stator turn fault in a symmetrical three-phase AC machine, which refers to the insulation failure in several turns of a stator coil within one phase, causes a large circulating current to flow and subsequently generates excessive heat in the shorted turns [5]. The concept of a fault tolerant machine is that it will continue to operate in a satisfactory manner after sustaining a fault. The degree of fault that must be sustainable should be related to the probability of its occurrence. This paper extends the work of authors [3] on vector control of PMSM drives under stator winding inter-turn faults. A dynamic model, sensitive to two phase's short circuits is firstly presented. Thus, an experimental test bench allowing studying this kind of faults is exposed with a brief description of the implemented vector control scheme. Finally, some results are included to show the possible characterisation of the phase to phase short circuits in vector controlled PMSM, simply through the Park's currents.

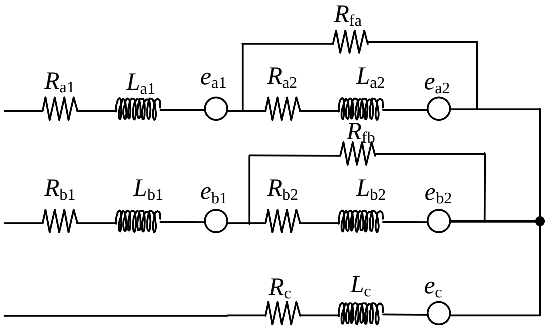

Fig. 1 Equivalent circuit of PMSM with inter turn fault in phases *a* and *b*.

II. Modeling of Two-Phases Winding Turn Faults

As shown in Fig.1 the phases *a* and *b* windings are described with two subwindings a_1, a_2 and b_1, b_2 in series respectively. While subwindings a_2 and b_2 are shorted via the resistors R_{fa} and R_{fb}, to model the short circuit fault, the voltage equation is written as following,

$$v_s = R_s i_s + \frac{d}{dt} L_s i_s + e_s \tag{1}$$

Where,

$$v_s = \begin{bmatrix} v_{a1} & v_{a2} & v_{b1} & v_{b2} & v_c \end{bmatrix}^T$$

$$i_s = \begin{bmatrix} i_{a1} & i_{a2} & i_{b1} & i_{b2} & i_c \end{bmatrix}^T$$

$$e_s = \begin{bmatrix} e_{a1} & e_{a2} & e_{b1} & e_{b2} & e_c \end{bmatrix}^T$$

The resistance and inductance matrices are given as,

$$R_s = \begin{bmatrix} R_{a1} & 0 & 0 & 0 & 0 \\ 0 & R_{a2} & 0 & 0 & 0 \\ 0 & 0 & R_{b1} & 0 & 0 \\ 0 & 0 & 0 & R_{b2} & 0 \\ 0 & 0 & 0 & 0 & R_c \end{bmatrix} \tag{2}$$

$$L_s = \begin{bmatrix} L_{a1} & M_{a1a2} & M_{a1b1} & M_{a1b2} & M_{a1c} \\ M_{a2a1} & L_{a2} & M_{a2b1} & M_{a2b2} & M_{a2c} \\ M_{b1a1} & M_{b1a2} & L_{b1} & M_{b1b2} & M_{b1c} \\ M_{b2a1} & M_{b2a2} & M_{b2b1} & L_{b2} & M_{b2c} \\ M_{ca1} & M_{ca2} & M_{cb1} & M_{cb2} & L_c \end{bmatrix} \tag{3}$$

III. Experimental Setup and Results

An experimental setup was developed to test the validity of the proposed vector control method for PMSM drive. The setup shown in Fig. 2 consists of a 3-pole, 1KW, 3000rpm coupled to a brushless dc motor, an IGBT-based inverter, a dSPACE DS1104 board, and a measurement currents system employing two Hall Effect sensors. The rotor position and speed are measured by an encoder having a resolution of 4096 pulses per mechanical turn. The stator windings was modified by the addition of six connections to the stator coils for two-phases as shown in Fig. 3. To verify the robustness of the drive, experiments have carried out under load and unload conditions. The motor was tested with several numbers of short circuited turns. The Park's modelling approach has been used and seems to be good to be applied on the diagnosis of interturn stator winding short-circuits in PMSMs. In this section, the implemented vector control is firstly explained and its validating results are given in healthy conditions. Afterwards a two-phases short-circuits is simulated when the vector control drive is working.

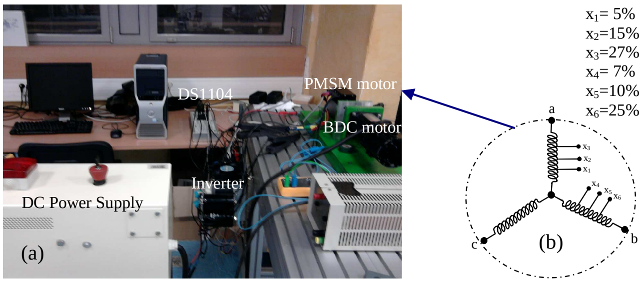

Fig. 2. Experimental setup: (a) photograph of the experimental setup, (b) stator winding configuration of the PMSM under test

A. *Vector controlled PMSM in healthy conditions*

Fig.3 shows the implemented program in Dspace board for the real time drive of the studied PMSM. The control d-q reference farm is fixed to the rotor flux position which is defined by the rotor mechanical angle. The motor is fed by a current-controlled three phase inverter. The mechanical speed and stator currents are regulated by IP regulators to generate the references of the PWM bloc. The operator may supervise the test bench through Controldesk software specially dedicated to Dspace device.

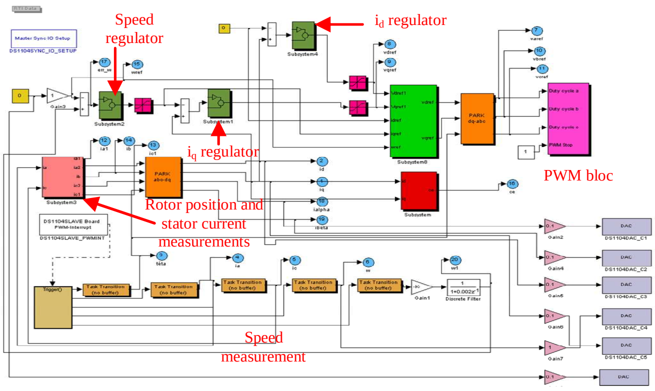

Fig. 3. Implemented vector control scheme in DSPACE board

Fig. 4 shows the current Park's representation of healthy operating mode for both unload and load conditions. It is clearly seen that under load healthy conditions, the space vector representation of the current is a circular locus, while it looks like a triangular ring, under unload conditions.

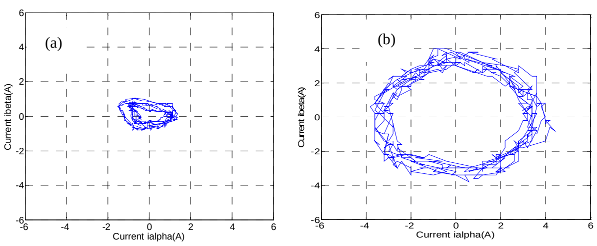

Fig. 4 Experiment Locus of α β current in healthy operating mode. (a) Unload conditions. (b) Load conditions

B. *Vector controlled PMSM in two-phases short-circuit*

After analyzing the stator currents in healthy mode, a phase to phase short circuit fault was simulated. The fault has been performed between phases 'a' and 'b' with 15% turns of phase 'a' and 10% turns of phase 'b' short circuited. In these faulty conditions, the current space vector representations are elliptical pattern as shown in Figs. 5a and 5b. The ellipticity increases with the severity of the fault and the major axis orientation depends on faulty phase.

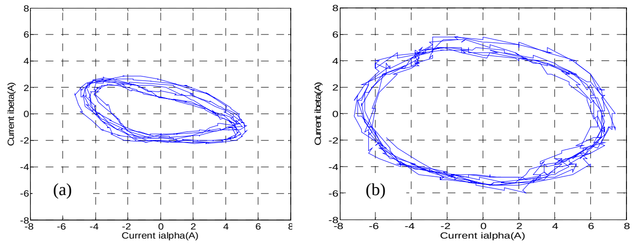

Fig. 4 Experiment Locus of α β current in faulty operating mode "x2=15% and x_5=10%": (a) Unload conditions. (b) Load conditions.

IV. Conclusion

In this paper the behaviour of vector controlled PMSM has been studied regarding to two-phase partial short-circuits. The measurements highlight that the locus of α β current characterises very well this kind of fault. Indeed, the obtained line varies from circular to elliptical shape when short-circuit occurs. The major axis of the measured ellipse magnitude and position traduce the fault severity in each of the two phases. In the full paper more explanations will be given on the model developing and identifying. The experimental measurements of time variations of currents, speed, and torque in faulty conditions, will be compared to the simulation results.

V. Acknowledgment

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VI. References

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