Comparison of conventional and unconventional 5-phase PM motor structures for naval applications

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Abstract: - Multi-phase motors are widely used in marine propulsion. In this paper, a Multi-machine modeling of Surface Mounted PM motors is presented and applied to a 5-phase machine. The latter is proved to be equivalent to a set of two-phase fictitious machines each ones being characterized by a set of specific harmonic ranks. A simple control consists of supplying each fictitious machine with a current which contains only one harmonic. A five phase machine is then supplied by currents with only first and third harmonics. Considering this kind of control, it is shown that for a given stator resistance and average torque the Joule losses and the torque ripple are minimized if a simple criterion on the harmonics of electromotive force at constant speed is fullfilled. Different structures of rotor are then compared to examine numerically which improvements can be practically obtained.

Key-Words: - marine application, multi-phase PM motor, multi-machine, design.

1 Introduction

Electric marine propulsion widely uses multi-phase motors because of reliability, smooth torque and partition of power. Usually supplied by Pulse Amplitude Modulation Current Source Inverter (PAM CSI), these motors can nowadays be controlled by Voltage Source Inverter (VSI) thanks to advances in power semiconductors (IGBT, IGCT) and Digital Signal Processor (DSP)[1,2,3]. This kind of supply increases the flexibility of control. Studies [4,5,6,7] exhibit potential improvements on multi-phase induction motors. Multi-phase PM synchronous motor are also used [2,8,9]. The permanent excitation due to permanent magnets gives another design freedom degree. To find control laws [10], and also criteria of drive design, a vectorial multi-machine model of multi-phase motor is presented [11]: a multi-phase machine is equivalent to a set of 1-phase and 2-phase machines. In the paper, this approach enables, for a chosen supply strategy and a chosen stator, the definition of a criterion for the design of PM motor rotor with minimum Joule losses, under constraint of given average torque value. This criterion is used to find unconventional motor structures which can be very advantageous for this kind of application.

2 Multi-machine modeling of a multi-phase machine

2.1 Assumptions and notations

Usual assumptions are used to model the machine:

- All phases are identical and regularly shifted by an angle:

$$\alpha = \frac{2\pi}{n} \quad (1)$$

- Effects of saturation and damper windings are neglected;

All quantities relating to the phase k are written x_k.

The n-phase machine is described in figure 1.

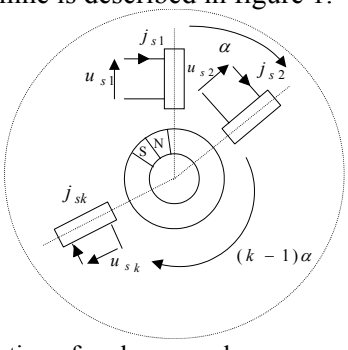

Fig.1: Presentation of *n*-phase synchronous machine

2.2 Usual modeling in a natural base

In the usual matricial approach of n-phase electric machines, a vector n-space is implicitly considered since vectors with n lines are defined. This space is provided with an orthonormal base $B_n = \left\{\overrightarrow{x_1^n}, \overrightarrow{x_2^n}, ..., \overrightarrow{x_n^n}\right\}$ that can be called "natural" since the coordinates of a vector in this base are the measurable values relative to each phase.

Next a second kind of rotor is considered. This unconventional machine is supplied using the strategy presented at paragraph 3.1. The corresponding Joule losses, currents value and EM torque ripple values are given also in Table 5. It is noted that the Joule losses have been reduced by about 20%. The EM torque ripples have also been widely reduced : the 7^{th} and 9^{th} harmonics of the EMF are very small, so the pulsating torques related to these harmonics has been reduced.
So the presented unconventional structure of machine associated with a multi-machine feeding current strategy seems to be a very interesting solution in terms of minimization of the Joule losses and torque ripple.

Rotor type	Feeding current strategy	Joule losses	EM torque ripple	Current first harmonic (RMS)	Current third harmonic (RMS)
Conventional (radial magnetization)	H1 only	63,0 W	4,3 N.m	3,25 A	0,00 A
	H1 and H3 (&3,1)	58,7 W	5,6 N.m	3,01 A	0,84 A
Unconventional (3 magnets/pole)	H1 and H3 (&3,1)	50,3 W	1,2 N.m	2,76 A	0,88A

Table 5: Results for a required torque of 60N.m

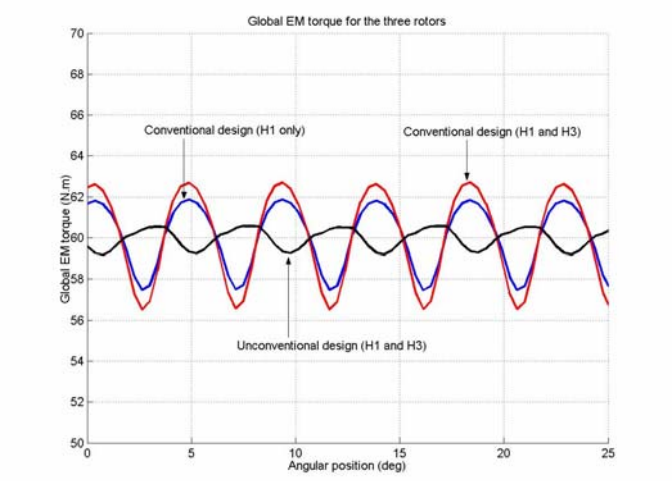

Fig.4: Global EM Torque for the 3 cases (60 N.m required)

4 Conclusion

In this paper several design configurations of Surface Mounted PM 5 phase motors fed by a PMW voltage inverter are studied using the association of a multi-machine modeling and a 2D Finite Difference field calculation software. This approach enables the determination of a design criterion to minimize the Joule's losses for a given performance in terms of torque. For a given common set of parameters and a given performance specifications, some conventional and unconventional structures of rotor are compared. This study shows that the choice of unconventional rotor configurations can be a very interesting choice to improve performances of multiphase SMPM machines.

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