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A Vectorial modeling for the pentaphase Permanent Magnet Synchronous Machine based on multimachine approach

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Abstract

The polyphase [1] machines are developed mainly in the field of variable speed drives of high power because increasing the number of phases on the one hand allows to reduce the dimensions of the components in power modulators energy and secondly to improve the operating safety. By a vector approach (vector space), it is possible to find a set of single-phase machine and / or two-phase fictitious equivalent to polyphase synchronous machine.These fictitious machines are coupled electrically and mechanically but decoupled magnetically. This approach leads to introduce the concept of the equivalent machine (multimachine multiconverter system MMS) which aims to analyze systems composed of multiple machines (or multiple converters) in electric drives. A first classification multimachine multiconverter system follows naturally from MMS formalism. We present an example of a synchronous machine pent phase.

Keywords

Polyphase machines, multimachine concept, vector space, eigenvectors, eigenvalues, pentaphase machine

1. Introduction

Through the many advances in technology, the power applications high and average at speed variable are increasingly made on the based on the whole electrical machinery-static converters. For applications of high power density, low rotor losses and reduced inertia, the permanent magnet synchronous machines [1] are best suited. However with the traditional structures of static converters and high power machines, the power transmitted between the power source and the mechanically receiver can not be treated appropriately. The use of current switches associated with machine double-star [2] on the one hand allows to reduce the power transmitted by each converter and, secondly, to reduce the torque ripple of the machine. Despite this improvement, the torque ripples are important, especially for low [3] speeds. Despite this improvement, the torque ripples are important, especially for low speeds. The polyphase machines are an interesting alternative to reducing constraints applied to the switches and coils. Indeed, the increase in the number of phases allows a fractionated of power, and therefore a reduction in switched voltages at a given current. In addition, these machines can reduce [4] the amplitude and increasing the frequency of the torque ripple, which allows at the mechanical loading of filter them more easily. Finally, increasing the number of phases [5] provides increased reliability by allowing run, one or more faulted phases. The polyphase machines are found in areas such as marine, railway, petrochemical industry, avionics, automotive, etc.

2. Pentaphase machine application

2.1 presentation of the machine

We model, for the application, a synchronous machine with permanent [3] magnets pentaphase. This machine is represented symbolically in Fig. 1

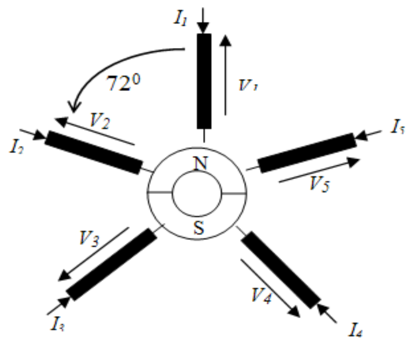

Fig. 1: Representation of the pentaphase machine

2.2 Modelling of the machine in the natural basis

We associate the five phases a Euclidean vector space E^5 of dimension 5.

We write in an orthonormal base B^5 the voltage equation of the machine:

$$\vec{v} = R_s \cdot \vec{i} + \left[\frac{d\overrightarrow{\Phi_s}}{dt} \right]_{/B^n} + \vec{e} \qquad (1)$$

$$B^5 = \left\{ \overrightarrow{x_1},\ \overrightarrow{x_2},\ \overrightarrow{x_3},\ \overrightarrow{x_4},\ \overrightarrow{x_5} \right\} \qquad \text{Orthonormal basis}$$

In linear mode, there exists morphism between vectors stator flux and current, such as:

$$\overrightarrow{\Phi_s} = \lambda(\vec{i}) \quad (2)$$

$$[L_s^n] = \begin{pmatrix} L & M_1 & M_2 & M_2 & M_1 \\ M_1 & L & M_1 & M_2 & M_2 \\ M_2 & M_1 & L & M_1 & M_2 \\ M_2 & M_2 & M_1 & L & M_1 \\ M_1 & M_2 & M_2 & M_1 & L \end{pmatrix} \quad (3)$$

With:

- L the inductance of a phase $(L = L_p + l_f)$;
- M_1 The mutual inductance between two phases shifted from $\pm\frac{2\pi}{5}$;
- M_2 The mutual inductance between two phases shifted from $\pm\frac{4\pi}{5}$.

The electromotive force emf vector :

$$\vec{e} = e_1 \cdot \overrightarrow{x_1} + e_2 \cdot \overrightarrow{x_2} + e_3 \cdot \overrightarrow{x_3} + e_4 \cdot \overrightarrow{x_4} + e_5 \cdot \overrightarrow{x_5}$$

$E^{\max} = k_{fem} \cdot \Omega$ Is the maximum value of emf with k_{fem} emf coefficient and Ω the rotational speed of the rotor.

2.3 Modelling in a base decoupling

There exists an orthonormal basis $B^d = \{\overrightarrow{x_z}, \overrightarrow{x_{p\alpha}}, \overrightarrow{x_{p\beta}}, \overrightarrow{x_{s\alpha}}, \overrightarrow{x_{s\beta}}\}$ in which the inductance matrix is diagonal:

$$[L_s^d] = \begin{pmatrix} \Lambda_1 & 0 & 0 & 0 & 0 \\ 0 & \Lambda_2 & 0 & 0 & 0 \\ 0 & 0 & \Lambda_5 & 0 & 0 \\ 0 & 0 & 0 & \Lambda_3 & 0 \\ 0 & 0 & 0 & 0 & \Lambda_4 \end{pmatrix} \quad (4)$$

It appears then double values:

$$\Lambda_1 = L + 2(M_1 + M_2)$$

$$\Lambda_2 = \Lambda_5 = L - 2 \cdot \left(M_1 \cdot \cos\left(\frac{3\pi}{5}\right) + M_2 \cdot \cos\left(\frac{\pi}{5}\right) \right)$$

$$\Lambda_3 = \Lambda_4 = L - 2 \cdot \left(M_1 \cdot \cos\left(\frac{\pi}{5}\right) + M_2 \cdot \cos\left(\frac{3\pi}{5}\right) \right)$$

Inductors are associated with eigenvectors.

There is a single eigenvalue and two double eigenvalues. This property allows us to decompose the vector space E^5 at three orthogonal subspaces, namely:

- A subspace E^z generated by the eigenvector $(\overrightarrow{x_z})$ associated with the eigenvalue $\Lambda_z = \Lambda_1$.

This subspace is a straight line called homopolar

- A subspace E^p generated by the eigenvectors $(\overrightarrow{x_{p\alpha}}, \overrightarrow{x_{p\beta}})$ associated to the eigenvalue: $\Lambda_p = \Lambda_2 = \Lambda_5$.

This subspace is called the principal plan.

- A subspace E^s generated by the eigenvectors $(\overrightarrow{x_{s\alpha}}, \overrightarrow{x_{s\beta}})$ associated with the eigenvalue $\Lambda_s = \Lambda_3 = \Lambda_4$. This subspace is called the secondary plan.

the vector $\vec{g} = \overrightarrow{g_z} + \overrightarrow{g_p} + \overrightarrow{g_s}$

2.4 Equivalence between real and fictitious machine

A fictive machine may be associated with each subspaces, respectively [6]

- A machine associated with the two-phase principal plan possessing the time constant and emf induced the most important; electrical
- A machine associated with the plan secondary at two-phase possessing the electrical constant time lowest and emf induced the less important;
- A machine phase associated with the straight line with the homopolar electric time constant and emf induced weaker.

2.5 Simulation of the pentaphase machine

We implement the model of the machine on the software numerical simulation Matlab Simulink. we apply a load resistant (C_r=2N.m) at t=0.1s we take the speed loop fixed to the rated speed 157 rad / s.

$$e_k = E_{\max} \sin(\omega t - \frac{2(k-1)\pi}{5}), k = 1,...,5$$

The currents are sinusoidal and in phase with the emf:

$$i_k = I_{\max} \sin(\omega t - \frac{2(k-1)\pi}{5}), k = 1,...,5$$

K means the number of the phase. For our machine there are 5 phases (k phases).

2.5.1 Current in machines phases real:

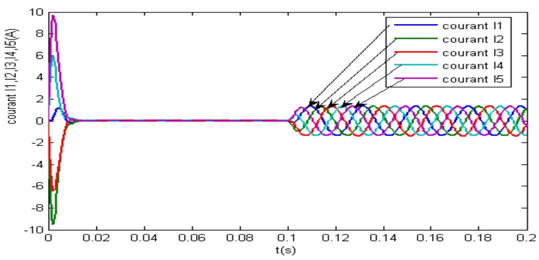

Fig. 2: current real machine

2.5.2 Currents in the fictitious machines

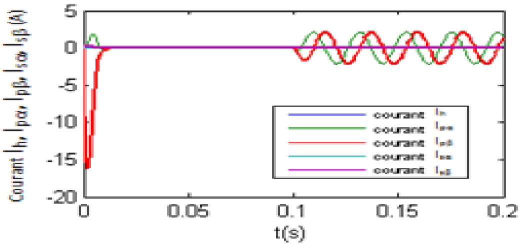

Fig. 3: Current in the fictitious machines

- Current in the principal machine :

$$i_{\alpha p} = \sqrt{5/2} I_{\max} \sin(\omega t)$$

$$i_{\beta p} = -\sqrt{5/2} I_{\max} \cos(\omega t)$$

- Current in the secondary machine:

$$i_{\alpha s} = 0 \text{ et } i_{\beta s} = 0$$

- Current in the homopolar machine :

$$i_z = 0$$

2.5.3 The electromagnetic torque

$$C_n = \frac{1}{\Omega}(e_z i_z + \overrightarrow{e_{\alpha\beta p} i_{\alpha\beta p}} + \overrightarrow{e_{\alpha\beta p} i_{\alpha\beta p}})$$

$$C_n = \frac{5}{2}\frac{E_{\max} I_{\max}}{\Omega} = \frac{5}{2} k I_{\max}$$

$$k = \frac{E_{\max e}}{\Omega}$$

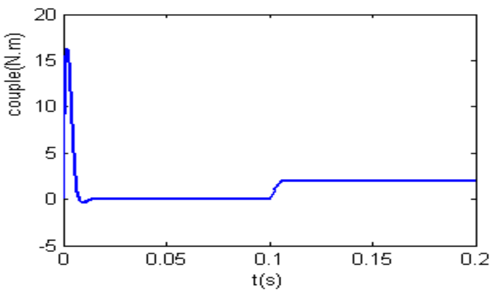

Fig. 4 : electromagnetic torque

2.5.4 The speed of the pentaphase machine

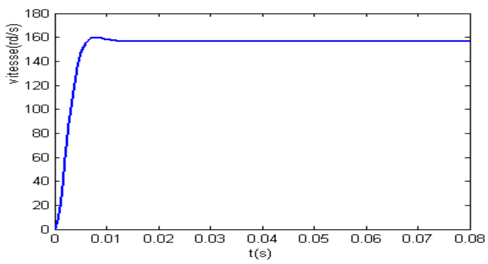

Fig. 5: The speed of the pentaphase machine

3. Interpretation of the simulation

The simulation shows that the fictitious machines secondary and homopolar not work in a given torque nonzero for a sinusoidal balanced. During a load operation, the principal machine alone produces the electromagnetic torque.

4. Conclusion

A polyphase machine is composed of 5 windings spatially *2π/5* and powered by the voltage phase-shifted temporally *2π/5*. These machines are characterized by a magnetic coupling between phases. The generalization of the method of space vector allows defining a base change of dimension 5**,** implying a simplification of the study of the machine by Diagonalization of the matrix inductance. This change leads to subspaces orthogonal base of dimension 2 and 1. Each subspace is independent. The notion of machine fictive dimensions 1 and 2 is then introduced.Conversion of magnetic coupling binding and difficult to manage electrical and mechanical couplings simple. Association vector concept multimachine modelling allows us to consider a pentaphase machine as equivalent to a set of fictitious machines at one-phase and two-phase mechanically coupled. The study of a complex pentaphasé machine turns into studies of simple 2 machines.

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