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ANALYSIS OF ELECTROMECHANICAL CONVERTER ON THE DELPHI PLATFORM

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Abstract: The paper deals with the problem of solving differential equation set for nonlinear electromechanical converter. It is important to present the model which enables to take into account the saturation pheneomenon. Exemplary, the induction motor has been considered.

Keywords: Delphi programming, electromechanical converter, saturation.

1 Introduction

The development of computers software and hardware enable to solve faster and faster problems that were time-consuming previously. Although, the calculation methods have reached the level that enables to present the electromagnetic torque with sufficient accuracy, it is still vital problem to describe the well-known phenomenon that appears in electrical machine – the saturation of magnetic circuit. There are many ways of taking into account this problem [2]. The paper presents way of solution basing on the developed in the recent years numerical platform [1]. The methodology described below leads to the results that coincide well with results presented in [2] and can be compared with [3]. The main virtue of the solution presented there are the both numerical simplicity of the analysis and physical interpretation of the model derived.

2 Induction motor as electromechanical converter

The electromechanical converter is analysed under the given below assumptions. The induction motor is described by circuit voltage equations for machine stator and rotor. The voltage equations take the following form

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$$u_k = R_k i_k + \frac{d\Psi_k}{dt}, \tag{1}$$

where u_k means the supply voltage for k^{th} circuit; $k=1,\ldots, m_s+2\cdot m_r=M$, m_s, m_r denote stator and rotor circuit numbers, respectively (for rotor phase circuit are accepted two equivalent circuit); R_k is circuit resistance; Ψ_k means the magnetic flux coupled with k^{th} circuit. The magnetic circuit is nonlinear. There does not appear the magnetic hysteresis phenomenon. The losses in ferromagnetic regions could be neglected. The magnetic flux coupled with k^{th} circuit is nonlinear function of circuit currents [2]. In these papers are described methods of taking into account the magnetic saturation. In this paper the saturation effect is considered in the following way. There are considered M axes of phase circuit symmetry for those the magnetising currents are defined as follows

$$i_{\mu k} = \sum_{j=1}^{M} i_j \cos(\varphi_{kj}), \tag{2}$$

where i_j mean the phase current for stator circuit ($j=1,\ldots,m_s$) and rotor equivalent currents ($k=m_s+1,\ldots, m_s+2\cdot m_r=M$) ; φ_{kj} denotes the electrical angles between j^{th} and k^{th} axes $\varphi=p\ \varphi_m$ means electrical angle; p is pair-pole number (see Fig.1).

Exemplary, the 1^{st} stator magnetising current is equal to

$$i_{\mu 1} = \sum_{j=1}^{M} i_j \cos(\varphi_{k1}), \tag{3a}$$

which takes the in phase notation (with the help of A, B, C, a, b, c)

$$\begin{aligned} i_{\mu A} &= i_A + i_B \cos(\tfrac{2\pi}{3}) + i_C \cos(\tfrac{4\pi}{3}) + \\ &+ (i_{a1} + i_{a2})\cos(\varphi) + (i_{b1} + i_{b2})\cos(\varphi + \tfrac{2\pi}{3}) + (i_{c1} + i_{c2})\cos(\varphi + \tfrac{4\pi}{3}). \end{aligned} \tag{3b}$$

Exemplary, for the 1^{st} rotor current in phase notation the magnetising current is given by the relation

$$\begin{aligned} i_{\mu a} &= i_A \cos(\varphi) + i_B \cos(\varphi + \tfrac{2\pi}{3}) + i_C \cos(\varphi + \tfrac{4\pi}{3}) + \\ &+ (i_{a1} + i_{a2}) + (i_{b1} + i_{b2})\cos(\tfrac{2\pi}{3}) + (i_{c1} + i_{c2})\cos(\tfrac{4\pi}{3}). \end{aligned} \tag{3c}$$

For the considered electrical machine the currents satisfy the relations

$$i_A + i_B + i_C = 0, \tag{4a}$$

$$(i_{a1} + i_{a2}) + (i_{b1} + i_{b2}) + (i_{c1} + i_{c2}) = 0, \tag{4b}$$

due to the fact the neutral phase is not connected. The Eqns (4a,b) are widely used at formulation of differential state equations - the currents i_C, i_{c1} and i_{c2} are eliminated consequently.

The state variables for the electrical converter are chosen as follows

$$\mathbf{I} = [i_A, i_B, i_{a1}, i_{a2}, i_{b1}, i_{b2}]^T, \tag{5a}$$

hence, the Eqs (3a,b,c) leads to the matrix form for magnetising currents as follows

$$\mathbf{I}_\mu = \mathbf{FI}, \tag{5a}$$

where transformation matrix has been defined as given below

$$\mathbf{F}=\begin{bmatrix} \frac{3}{2} & 0 & s(\varphi+\frac{\pi}{3}) & s(\varphi) & s(\varphi+\frac{\pi}{3}) & s(\varphi) \\ 0 & \frac{3}{2} & -s(\varphi) & s(\varphi+\frac{2\pi}{3}) & -s(\varphi) & s(\varphi+\frac{2\pi}{3}) \\ -\frac{3}{2} & -\frac{3}{2} & -s(\varphi+\frac{2\pi}{3}) & -s(\varphi+\frac{\pi}{3}) & -s(\varphi+\frac{2\pi}{3}) & -s(\varphi+\frac{\pi}{3}) \\ s(\varphi+\frac{2\pi}{3}) & s(\varphi) & \frac{3}{2} & 0 & \frac{3}{2} & 0 \\ s(\varphi) & s(\varphi+\frac{\pi}{3}) & 0 & \frac{3}{2} & 0 & \frac{3}{2} \\ s(\varphi+\frac{\pi}{3}) & s(\varphi+\frac{2\pi}{3}) & -\frac{3}{2} & -\frac{3}{2} & -\frac{3}{2} & -\frac{3}{2} \end{bmatrix} \tag{5c}$$

and it is denoted for simplicity $s(x)=\sqrt{3}\sin(x)$ and $c(x)=\sqrt{3}\cos(x)$.

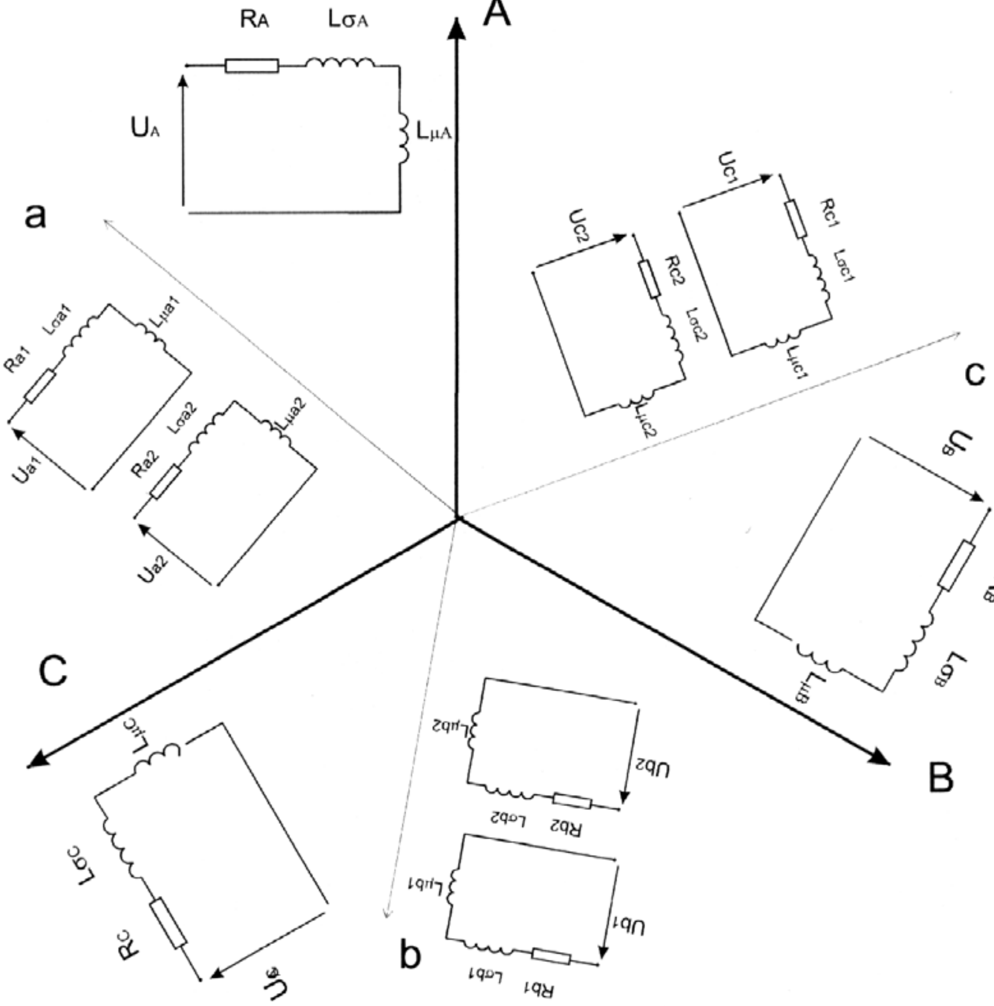

Fig.1 Circuits for considered electromechanical converter

According to the magnetizing currents the values of magnetic fluxes for each circuit can be evaluated. The features of magnetic circuit can be expressed by means of rational function (division of two polynomials) as follows

$$\Psi(I)=\frac{a_1 I + a_3 I^3 + a_5 I^5 + a_7 I^7}{1 + a_2 I^2 + a_4 I^4 + a_6 I^6}, \tag{6}$$

where the coefficients $a_1,\ldots a_7$ are calculated with the help of procedure PSEROZ ([1] pp.61-69) basing on obtained magnetizing curve [2]. This procedure bases on minimalization of differences vector. The norm of the differences vector is minimalised.

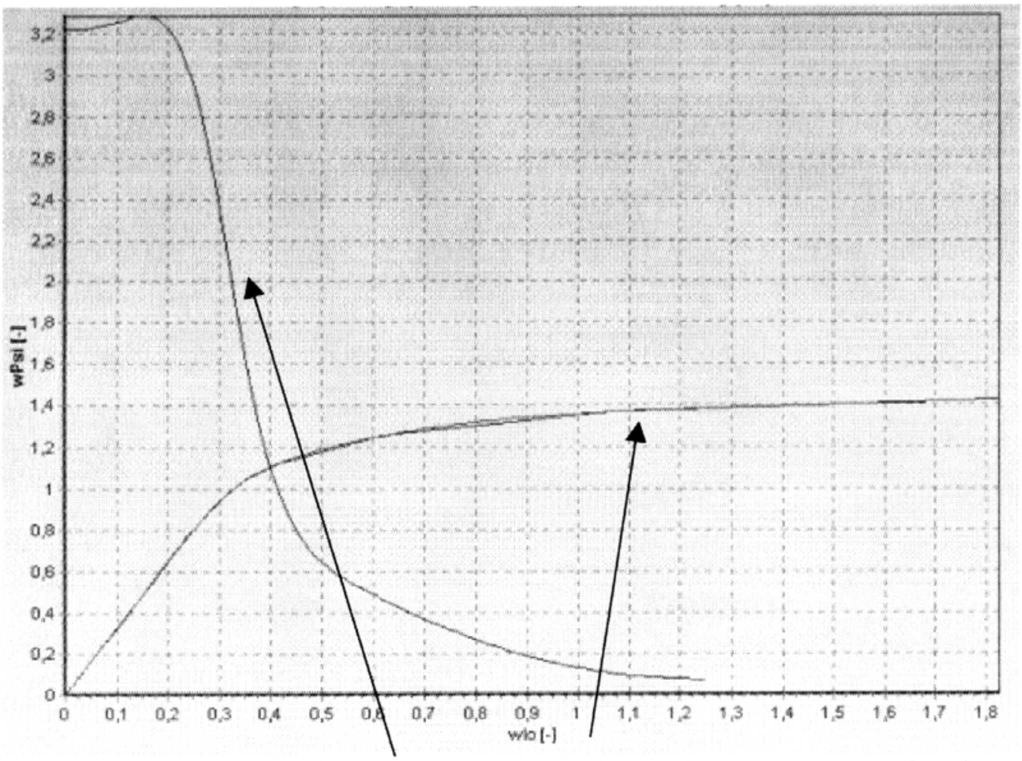

Fig.2. Magnetising function and its approximation for magnetic circuits of electrical machine and the derivative thereof

The magnetising currents defined are considered as arguments for magnetic fluxes coupled with phase circuit

$$\Psi_k = \Psi(i_{\mu k}) + L_{\sigma k} i_{\mu k} \tag{7a}$$

where $\Psi(\ )$ means the function which describes the saturation effect for magnetic circuit of electrical machine, $L_{\sigma k}$ denotes the leakage inductance for k^{th} circuit. Exemplary, for circuit k=1 (phase A) the given below relation has the form

$$\Psi_{\mu A} = \Psi(i_{\mu A}) + L_{\sigma A} i_{\mu A} \square . \tag{7b}$$

The magnetising function $\Psi(\ )$ depends on stator and rotor material B-H curves. For the numerical analyses carried out below the following magnetising function has been brought (Fig.2).

The theoretical analysis will be continued in part II of this paper.

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