Switched Reluctance Motor with Parallel Buffer of Energy and Pulse-Width Speed Regulation

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Abstract. Switched Reluctance Motor is the simpler, more technological and cheaper then other known electrical motor. The average values mathematical model for SRM with parallel capacity storage, which give any way to cal–culate its characteristics is proposed in this paper. Com–puter programs for researching electrome–chanical process are described. Examples of calculation SRM’s charac–teristic are presented.

Key words: reluctance motor, parallel capacity stora–ge, mathematical model, electromechanical process

Switched reluctance motors (SRM) it is necessary to reckon to new types of electric machines. Due to high noise immunity and small cost of making, high reliability, possibility of work in aggressive environments, possi–bilities controlled a speed of rotation with the use of noncontact techniques SRM are used in modern cont–rolled electric drives.

Till recently, wide distribution of switched reluc–tance motors restrained by their low-power coefficient, that it is conditioned by the necessity of dispersion of the energy during current commutation in sections stocked in the electromagnetic field by the transistor switches with the purpose of them overvoltage protection. In [1] scheme solutions of the SRM transistor inverters, which allows repeatedly to use this energy for the forced switching-on of current in sections, protecting here power transistors from overvoltage, are offered.

The commutator wuth parallel connection buffer of energy permits to improve power indicator and to dec-rease the current pulsations of SRM’s power supply [2].

The complete principle electric shemes of switched reluctance motors with the parallel buffer of energy is shown in a fig. 1.

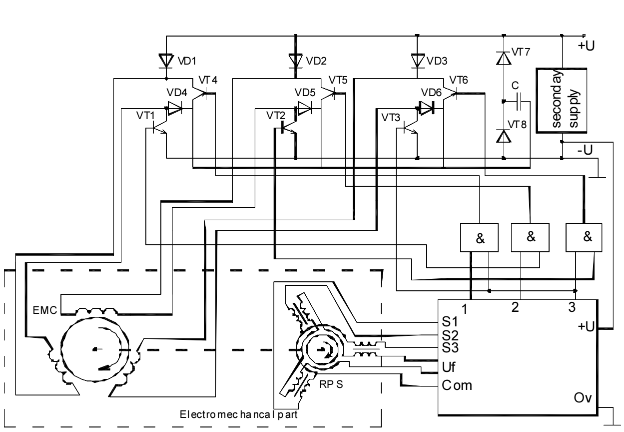

Fig.1. The principle electric schemes of SRM with the parallel buffer of energy.

The successful decision of tasks of analysis of the machine-switches systems largely depends on the presen–ce of adequate mathematical models which described electromechanics in such systems.

Therefore, development of new mathematical mo–dels of the known and re-created switched motors with passive rotors and realization of models by a computer technique is the actual task.

Assumptions were accepted for making of mathe–matical model of SRM with the parallel capacity storage, which allows get simple mathematical depen–dences that adequately represent electromechanics con–version of energy in it [3]. Alternating magnetic stream, which clo–sed on steel core, due to electromotive force, which is the reason of the whirling currents in steel. The last are pre–determined the losses in it. Steel resistance of the whirling currents, with exactness sufficient for engi–neering prac–tice, can be define by formula

$$R_s = \frac{E^2}{\Delta P_s},$$

where $E = 4.44 \cdot f \cdot w_z \cdot B \cdot s$, $\Delta P_s = P_0 \cdot \gamma_s \cdot s \cdot l_m \cdot B^2 \cdot (f / f_0)^2$, from where we will get equation for calculation R_s of section

$$R_s = 4{,}9 \cdot 10^4 \cdot \frac{w_z^2 \cdot S \cdot q}{p_0 \cdot \gamma_s \cdot l_m}, \tag{1}$$

where p0, γs, lm, wz, q - specific losses in steel, density of magnetic core material, length of magnetic force line, number of coils on one teeth, number of stator tooth’s on one section accordingly.

Leakage inductance L_σ of whirling currents is insi–gnificant and it is possible to scorn by its size. However, for providing of decision capability of differential equ–ations by numeral methods, the value of l L_σ is offered to accept by $L_\sigma \cong \frac{\Delta t}{12} \cdot R_s$, where Δt is in–tegration step of differential equations.

Each of sections of m-sectional SRM we can examine separately in the electric relation, and to link them only through the electromagnetic moment which was created by it, and which operates on a rotor [3].

The model of the power transistor switches is carried out for assumption, that the transitional processes of their turn-on and turn-off are instantly, resistance of the turn-off switch equals infinity, volt-ampere characteristic of saturated switch is described by equation

$$\Delta U_T = U_{KE} = U_{KE.0} + R_{KE.iac} \cdot i, \qquad (2)$$

where $U_{KE.0}$, $R_{KE.iac}$ determine from a passport oF switch.

The values of the formal coefficients Kj depend on position of rotor and calculate in following commuting function [6]:

$$K_j = 1 \text{ IF } \beta + 2\cdot(N_j - 1)\cdot\pi + (j-1)\cdot 2\cdot\frac{\pi}{m} \langle \theta \le \beta\cdot(N_j - 1)\cdot\pi + \\ +(j-1)\cdot 2\cdot\frac{\pi}{m} + \gamma \qquad (3)$$

$Kj = 0$ for all other values,

where $N_j = \dfrac{\theta + \pi + (j-1)\cdot 2\cdot \dfrac{\pi}{m}}{2\cdot\pi} + 1$ - number of period for the section.

In accordance to principle of motor work, switches VT4 - VT6 will be controlled by any possible law. It is important only, that in the moment of disconnection of current in any of sections switches were turn-off. One of the simplest methods of control by the feeding switches is a method, when control signals are formed by the logical multiplying of contiguous channel RPS signals.

Taking into account the above-mentioned, n.s.d.e., which describes electromechanics processes in SRM with a parallel buffer, it is possible to give by equation (4).

$$\begin{cases} \dfrac{di_j}{dt} = \left[\begin{matrix} u_j + R\cdot i_j + \dfrac{A_j}{L_\sigma} \times \\ \times\left(u_j - R\cdot i_j + R_s\cdot i_{sj}\right) - B_j\cdot\omega \end{matrix} \right] / A_j; \\ \dfrac{di_{sj}}{dt} = -\left(R_s\cdot i_{sj} + u_j - R\cdot i_j\right)/L_\sigma; \\ \dfrac{du_{cj}}{dt} = \left(1 - K_j - K_{j+m}\right)\cdot\dfrac{i_j}{C}; \\ \dfrac{d\omega}{dt} = \left\{ \sum_{j=1}^{m} \left[\begin{matrix} \dfrac{z_r}{2}\cdot\left(i_j + i_{sj}\right)\cdot Cos\theta_{pj} \times \\ \times\psi_y\cdot\left(\begin{matrix} 1 - e^{-a\cdot\left(i_j + i_{sj}\right)\cdot Sin\theta_{pj}} - \\ -\dfrac{\psi_{1t}\cdot\left(i_j + i_{sj}\right)}{2\cdot\psi_y} \end{matrix} \right) \end{matrix} \right] - M_C \right\}\cdot\dfrac{z_r}{J}; \\ \dfrac{d\theta}{dt} = \omega; \\ where \\ u_j = \left(U + \Delta U_D\right)\cdot\left(K_j - K_{j+m}\right) + u_c\cdot\left(K_j + K_{j+m} - 1\right) - \\ -\Delta U_T\cdot\left(K_j + K_{j+m}\right) - \Delta U_D\cdot\left(3 - K_j - K_{j+m}\right); \\ A_j = \psi_{10} - \psi_{1t}\cdot Sin\theta_{pj} + \psi_y\cdot a\cdot Sin^2\theta_{pj} \times \\ \times e^{-a\cdot\left(i_j + i_{sj}\right)\cdot Sin\theta_{pj}}; \\ B_j = \dfrac{Cos\theta_{pj}}{2}\cdot\left[\begin{matrix} \psi_y - \psi_{1t}\cdot(i_j + i_{sj}) - \psi_y \times \\ \times e^{-a\cdot\left(i_j + i_{sj}\right)\cdot Sin\theta_{pj}}\cdot\left(1 - a\cdot(i_j + i_{sj})\cdot Sin\theta_{pj}\right) \end{matrix} \right] \\ \theta_{pj} = \dfrac{\theta}{2} - (j-1)\cdot\dfrac{2\cdot\pi}{m}; \end{cases} \qquad (4)$$

where j = 1, 2 … m; J – moment of inertia on rotor; Mc - loading moment.

Fourth order Runge-Kutta method with the per–manent step of integration is applied for the decision n.s.d.e.

As angels θ, section current i_j and capacitor vol–tage uc are the functions of time t, then during the integ–ration n.s.d.e. is necessary to apply an iteration me–thods for exact determination of turn-off and – on mo–ments of the power transistor switches, moments, when the cur–rents of sections achieve zero, and also moments, when condense voltage achieve the value of supply voltage. However at the use of higher orders methods of integ–ration, the faithful hit in the moment of commutation is not simple. Most natural is applying method of inver–ting n.s.d.e [4].

The described mathematical model served by basis for creation of the computer-added research system (CARS) of electric drive on the base of explicit-pole SRM with parallel capacity storage which allows to carry out complex researches of characteristics and behavior of SRM in composition of the electromehatronics systems.

The system is realized in the Fortran PowerStation environment; gives to the user wide auxiliary possibilities of work with entrance information, results of calculation, and also visualization of currents, electromagnetic mo–ment, speed of rotation, condenser voltage and others "oscillograms". With the purpose of maximal facilitation of research work entrance information for the CARS is pre–pared by the computer-added design system of SRM [5]; if necessary, a user can set some values of initial con–dition.

The system contains and gives in the interactive mode to the user necessary reference material, creates the proper files of results that allow using the proper prog–rammatic packages for visualization of dependences.

The system consists of the main module, four mo–dules, input data file and files, where results was saving (fig. 2).

Without regard to the necessity of few thousand points calculation for achievement of the steady state, the error of integration does not accumulate because co-ordinates through inverting differential equation were zeroize.

On a fig.3 the example of calculation of three-sectional SRM with the parallel capacity buffer of ener–gy (quasi-steady state values of section currents and condenser voltage).

SRM was designed by the computer-added design system of the SRM and had the following parameters: stator construction – pseudo-U-similar [6]; brand of steel – 2013; diameter of stator – 70 mm; external diameter of stator – 120 mm; axial length of stator – 30 mm; width of stator toothing – 8,2 мм; height of stator to–othing – 17,5мм; number of stator toothing – 12; length of air-gap – 0.20 mm; number of rotor toothing – 10; width of rotor toothing – 8,2 mm; number of coils on one teeth – 85; number of sections – 3; number of spools in a section – 4.

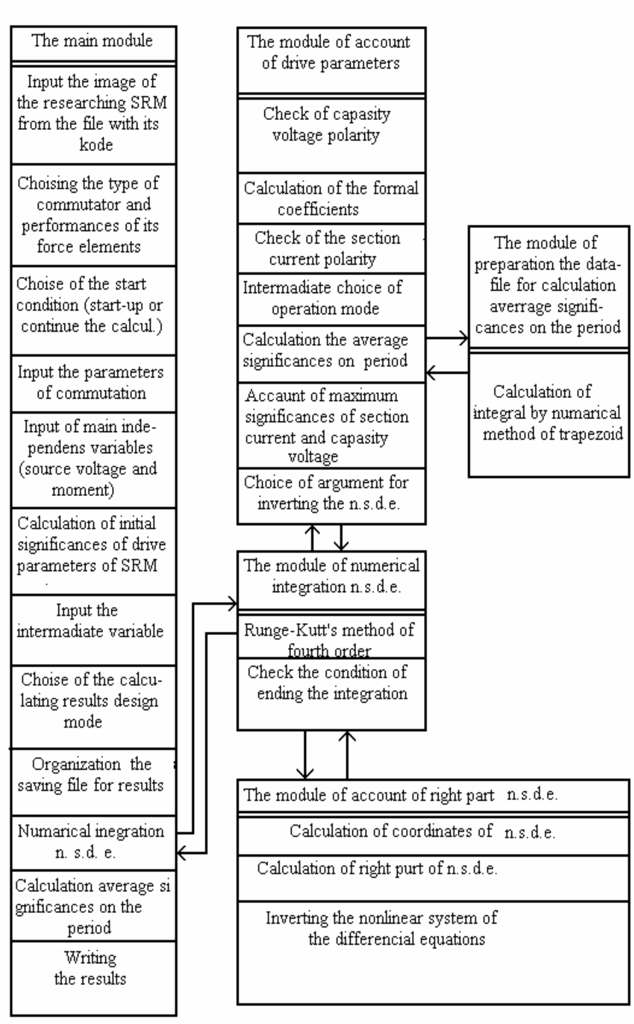

Fig. 2. A structure of a computer-added research system of switched reluctance motors

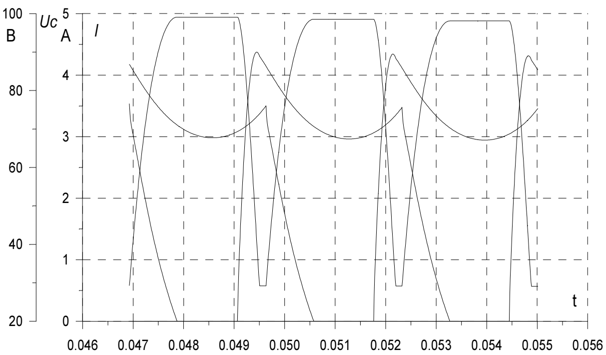

Fig. 3. Quasi-steady calculation values of sections currents and condenser voltage of SRM with parallel capacity storage

On fig. 4 the example of calculation of transitional process in starting of 3-sectional SRM with the parallel buffer of energy (current of one sections, electromag–netic moment, and speed of rotation) is given.

Application of commutator with the parallel buffer of energy enables to improve power coefficients and decrease the current pulsations in power supply of the SRM.

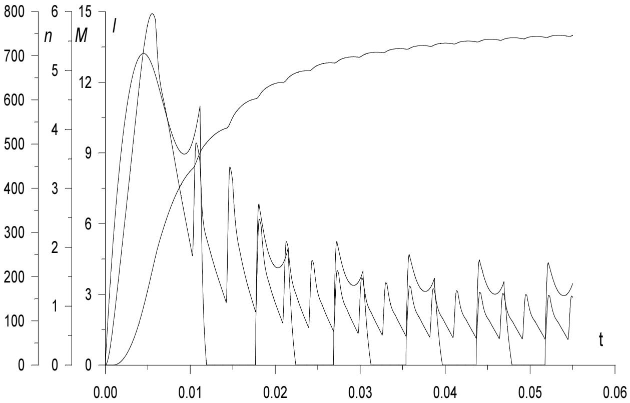

Fig. 4 Calculation values of section current, electro–magnetic moment and speed of rotation 3-sectional SRM with the parallel buffer of energy

The analysis of simulated results shows that an electromagnetic moment at start-up time equal 5,5 Nm and with decreasing of current diminishes to the level 1, 5 Nm. Then, with starting to work of capacity storage, moment to increase again. This change of electromag–netic moment predetermines character of speed change of the SRM's rotor: it equals a zero, while an electro–magnetic moment will not attain the value of the loading moment; the further takes place acceleration of rotor with considerable acceleration to the set value of speed of rotation.

Comparison of output and experimental oscillograms for the prototype SRM with nominal torque rating from 0.05 to 20 Nm, show that divergence is not over (5-7) %. That testifies to adequacy of mathematical model to the physical prototype.

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