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Starting torque of synchronous motor with a capacitor in the excitation winding circuit

Abstract *The problem of computation of starting conditions of synchronous motors with a capacitor in the excitation winding circuit has been discussed. A technique of investigating the effect of capacitance value on the starting torque of the motor has been proposed.*

Streszczenie *Rozpatrzono problem analizy stanów rozruchowych silników synchronicznych z kondensatorem w uzwojeniu wzbudzenia. Zaproponowano metodę badania odziaływania pojemności kondensatora na moment rozruchowy silnika.*

Keywords: synchronous motor, starting torque, capacitor, boundary value problem.
Słowa kluczowe: silnik synchoniczny, stan rozruchowy, kondensator, problem krajowy.

With high-power electric drives, salient-pole synchronous motors (SM) are used, which have several advantages comparing to asynchronous ones. The main problem of their work in these drives is difficult starting conditions, and therefore it is necessary to provide an increased starting torque. The problem of reliable start-up is usually resolved by overpowering the driving motor.

One way to solve the problem of the asynchronous starting of SM is to increase starting torque at the expense of switching on capacitors into the excitation winding [1]. However, studies of the problems occurring for such starting modes were conducted on a simplified mathematical model. Therefore, it is necessary to verify the obtained results experimentally. Capacitors can damage the excitation winding. Consequently, the problem of investigation of processes in SM, while using starting capacitors, has an important practical significance. It can be solved with high credibility only if it was based on using mathematical models of the motor that allow computing the magnetic flux linkage of circuits considering saturation.

The system of differential equations (DE) of the power balance of SM with capacitors in the excitation winding circuit and two equivalent circuits of the starting windings in axes d, q has the following form:

$$\frac{d\psi_d}{dt} = \omega\psi_q - ri_d + u_d\,;\; \frac{d\psi_q}{dt} = -\omega\psi_d - ri_q + u_d\,;$$

$$(1) \qquad \frac{d\psi_f}{dt} = -r_f i_f + u_c\,;\quad \frac{d\psi_D}{dt} = -r_D i_D\,;$$

$$\frac{d\psi_Q}{dt} = -r_Q i_Q\,;\quad \frac{du_c}{dt} = \frac{i_f}{C}\,,$$

where $\psi_k, i_k, r_k\ (k = d, q, D, Q, f)$ – magnetic flux linkages, currents and active resistances of relevant circuits of the motor; $u_d = U_m \sin\theta$, $u_q = U_m \cos\theta$ – voltage applied to the stator circuits; θ – rotor rundown angle; u_c – voltage of capacitor in the excitation winding; $\omega = \omega_c(1-s)$ – rotation frequency of the rotor, which is connected with mechanical rotation speed ω_r of rotor by the dependence $\omega = p_0\omega_r$, where p_0 – number of poles pairs; ω_c – frequency of feeding voltage; s – sliding.

The system (1) in the vector form has the following appearance:

$$(2) \qquad \frac{d\vec{y}(\vec{x},t)}{dt} + \vec{z}(\vec{y},\vec{x},t) = 0\,.$$

In the asynchronous mode with the constant sliding *s*, angle θ changes with the period *2π/s*, which means the asynchronous mode is periodic, and all coordinates are changing with the time period $T = 2\pi/(s\omega_c)$. Thus, solution of the system of equations (2) is *T*-periodic dependences of components of the vector $\vec{x}(t) = \vec{x}(t+T)$.

The article proposes a method of studying the influence of the capacitance value of the capacitors switched into the excitation winding circuit by solving the boundary value problem for system (2) of DE of the first order with periodic boundary conditions. The method is based on the use of cubic splines [2], and makes it possible not only to compute default asynchronous mode, but also investigate the impact of the capacitance value on the starting torque of the SM.

For this, each of the DE of system (2) has to be approximated on the grid of knots of the period *T* with system of *n* algebraic equations in accordance with [2]. This results in a system of nonlinear algebraic equations of the form:

$$(3) \qquad S\vec{Y} + \vec{Z} = 0\,,$$

where S – square transformation matrix of continuous changing of the coordinates to their nodal values for the variables approximated by cubic splines, the elements of which are determined only by inter-nodal distance; $\vec{Y}$, $\vec{Z}$ – vectors components of which are the nodal values of vectors $\vec{y}_j$ and $\vec{z}_j$ respectively. The received system of algebraic equations (3) is a discrete counterpart of the nonlinear system of DE (2). The solution of system (3) is the vector $\vec{X}$ of nodal values of the coordinates, which can be found by one of the iteration methods, particularly by Newton method.

Equation (3) allows investigating the impact of capacitance change on the operating mode of the SM, including the possibility of resonance. For this, it is necessary to differentiate system (3) and then to integrate it by the value of capacity C. The result is the below DE:

$$(4) \qquad J\frac{d\vec{X}}{dC} = \frac{\partial\vec{Z}}{\partial C}\,,$$

where *J* – Jacobi matrix, which allows studying the impact of changing capacity on the processes in the motor, including the possibility of resonance.

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