Algorithm for Calculating the Parameters of the Starting Rheostat for a Wound-Rotor Induction Motor

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Abstract—A mathematical model has been developed to calculate the starting characteristics and parameters of the starting rheostat for a wound-rotor induction motor, which makes it possible to calculate its parameters while accounting for the electrical energy consumed by the heating of the rheostat elements. The calculation is based on a mathematical model of the induction motor in the form of differential equations of electromagnetic equilibrium, which accounts for magnetic circuit saturation, and a differential method for calculating static characteristics.

Keywords— induction motor, starting rheostat, mathematical modeling, electrical losses, starting characteristics, magnetic circuit saturation

I. Introduction

Despite the transition from rheostat-based speed control of induction motors to frequency-controlled drives, wound-rotor induction motors (WRIM) are still widely used in heavy industry. They are used in crane hoist drives, metallurgical drives, mine hoists, mills, and large pumping stations. These motors are not being replaced because modernizing high-power machines using frequency converters requires enormous capital investment. Rheostat starting remains a reliable and cost-effective solution for harsh operating conditions [1]. Since the rotor winding is connected in series via slip rings to a three-phase rheostat consisting of several sections, the shape of the motor's mechanical characteristic curve depends on the magnitude and variation law of the rheostat resistance in the phase rotor circuit. The purpose of this article is to develop a method and algorithm for calculating the resistance of the starting rheostat and for justifying the selection of the number of sections and their parameters.

II. Mathematical Model of the Motor

The known mathematical models used for rheostat-based control of an asynchronous electric drive are based on classical *T*-shaped equivalent circuits of the motor and the Kloss formula for torque, or modifications thereof. However, they do not provide the necessary calculation accuracy; therefore, the problem of developing methods for studying the operating modes of WRIM remains unresolved to the required extent. The electric drives of many mechanisms operate in a mode of continuous starts (and, accordingly, braking), which consume electrical energy. Therefore, an important task is to optimize the parameters of the additional resistance in the rotor circuit, which would make it possible to achieve the required mechanical characteristics with the lowest possible power consumption. It is evident that reliable results can be obtained only by using a mathematical model of the motor with a high level of accuracy.

The magnetic circuits of modern induction motors have a high saturation level, which causes the flux-current relationships in the circuits to be nonlinear; therefore, mathematical models based on the assumption of their linearity do not allow for the calculation of dynamic modes with the accuracy required for modern engineering practice. Linearizing the electromagnetic relationships in an induction motor does not solve the problem, since in a real motor, saturation varies over a wide range and is determined by the instantaneous values of the currents in all circuits. However, in the technical literature, most algorithms for analyzing operating modes and characteristics in induction motors are based on the classical T-shaped equivalent electrical circuit, whose parameters are generally considered constant or vary according to predetermined laws [2-7]. Furthermore, the flux coupling between circuits is a nonlinear function of all currents, which are variable quantities; consequently, the self-inductance and mutual inductance — which are elements of the equivalent *T*-circuit are also variable.

Notwithstanding the above, various methods for improving equivalent circuits are known, and their number is growing. Their use in numerical calculations does not ensure the necessary accuracy of the results; therefore, they require experimental verification [8]. The main factors causing the nonlinearity of electromagnetic couplings are the saturation of the motor's magnetic circuit and the skin effect, which is significant only in motors with a short-circuited rotor.

The nonlinearity of electromagnetic relationships in the WRIM can be accounted for most accurately using electromagnetic field equations [9]. However, the field model is overly complex and, consequently, requires significant computational resources. Methods based on circuit theory