INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–8

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Influence of magnetic circuit saturation and skin effects on the adjustable induction motor characteristics

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ARTICLE INFO

Article history:
Received 30 May 2017
Received in revised form
22 July 2017
Accepted 28 July 2017
Available online xxx

Keywords:
Induction motor
Frequency control
Saturation
Skin effect
Efficiency
Power factor

ABSTRACT

The aims of this work are to show the influence of saturation and the rotor skin effect current on the characteristics of an adjustable induction motor (AIM). The coefficient of the voltage increase is determined in order to realize the frequency control laws with constant flux. The regulation characteristics of the induction motor are obtained for developed control laws. Great advantages of a first proposed law of frequency control were revealed. The determination of the equivalent scheme parameters taking account the saturation of the magnetic circuit and the skin effect of the rotor current guarantee the accuracy of calculation of the adjustable induction motor energy indices.

As a result of frequency control of the AIM research in a dynamic mode it is established, that while taking into account magnetic conductor saturation and skin effect current in a rotor winding faults while calculating current throws for a control mode U/f = const decreased about 6 compared with 13% without taking into account and, till 3 compared with 17% in a regulation law with a rotor constant flux linkage Ψ_2 = const. Results of mathematical modeling in the course of which power indicators (efficiency and power factor) of the adjustable induction motor defined in transitional regimes at various laws of frequency regulation are experimentally confirmed.

Introduction

The essential power saving in various areas of industry is provided by the use of the adjustable-speed electric drive (ASED). The most widespread is the asynchronous electric drive with frequency control. The series of induction asynchronous motors used in industry and transport are submitted to different operating regimes in accordance to the trained mechanisms.

Using load-adequate induction motors permits rational parameter regulation (speed, torque, etc) power savings by the optimization of the operating conditions of the motor according to its characteristics and those of the trained mechanisms. Conception of the new generation of induction motors, adapted for specific exploitation conditions, isn't

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http://dx.doi.org/10.1016/j.ijhydene.2017.07.221
0360-3199/

Please cite this article in press as: Petrushin V, et al., Influence of magnetic circuit saturation and skin effects on the adjustable induction motor characteristics, International Journal of Hydrogen Energy (2017), http://dx.doi.org/10.1016/j.ijhydene.2017.07.221

feasible without mathematical description of electromagnetic, electromechanical, power, thermal and other processes. Knowing the behavior of the motors in different operation regimes is indispensable to determine the optimal operating conditions.

In this work, we have analyzed the behavior of the adjustable induction motor for different control laws, and we established the influence of the magnetic circuit saturation and the skin effect in the rotoric windings on the characteristics of the adjustable induction motors.

The paper is organized as follows: in Section Methods and results the fundamental relations of the IM in different modes of frequency control obtained using T-type equivalent scheme of a motor are defined, and the obtained simulation and experimental results are presented (temperature variation of the stator winding Θ_{st} stator current, efficiency η and power factor of induction motor in regulation range). Finally, the concluding remarks are given in the Conclusions Section.

Methods and results

Improving of such drive is possible when using laws of high level frequency control [19]. For the first level laws, the ratio of the voltage and frequencies is maintained constants ($U/f = \text{const}$, $U/f^2 = \text{const}$, $U/f^{1/2} = \text{const}$ and others). Laws at which constancy of various magnetic sizes of the induction motor (IM) provided belong to laws of the second level: stator flux linkage Ψ_1 (corresponding to constancy of relation E_1/f), air gap flux Φ_δ (constancy E_{12}/f), rotor flux linkage Ψ_2 (constancy E_2/f). At the last law linear dependence of the electric motor torque, on the frequency of slip is provided and thus quality of ASED control, in static and dynamic modes, significantly increases in comparison with other laws. To number of the second level laws can belong the first time offered law at which constancy of the relation of E_{20}/f, where $\dot{E}_{20} = \dot{E}_2 + \dot{I}_2 R_2^{'}$ is defined taking into account voltage drop at the rotor active resistance. Such law is sufficiently rather effective because it allows to carry out directly power regulation on an engine shaft. With variable frequency control parameters, the fundamental relations of the IM in different modes of frequency control can be obtained using T-type equivalent scheme of a motor (Fig. 1) [6].

Using frequency converter, the applied voltage is considered as a relative regulating parameter $\gamma_i = U_1/U_{1\text{rated}}$ –Ratio of applied voltage to nominal one of the motor power supply, where i is the law number. Using current –source frequency converter [20]; the stator current varies with the frequency variations according to a well defined way. The regulating parameter $\gamma_i = I_1/I_{1\text{rated}}$ is a ratio of actual current I_1 to nominal $I_{1\text{rated}}$ values of the converter. In this equivalent scheme, except stator and rotor active resistances respectively r1 and r2, all the other resistances vary proportionally with the parameter $\alpha = f_1/f_{1\text{rated}}$, where f_1 and $f_{1\text{rated}}$ are actual and nominal values of converter's frequencies. The equivalent resistance, represents a load at motor's shaft, depends on the regulation parameter α and absolute slip parameter $\beta = f_2/f_{1н} = \alpha\cdot s$, where f_2 – rotor frequency, s – motor slip. The measured voltage varies proportionally with the parameter $\gamma = U_1/U_{1\text{rated}}$, where U_1 and $U_{1\text{rated}}$ are actual and nominal values of the converter's voltage. The control voltage and frequency of the converter, while using first level laws is defined by: $\alpha = \gamma$, if $U/f = \text{const}$, $\alpha = \gamma^2$, if $U/f^2 = \text{constant}$ *etc.* [1].

Second level frequency control laws propose to increase the motor supply voltage in order to ensure the compensation of the voltage drop in different parts of equivalent circuit. This voltage increase can be taken in account by means of the factor $\gamma_i = U_1/U_{1\text{rated}}$, depending on γ.

As an example we will consider the first law of the second level, in which constancy of the stator flux Ψ_1 is provided, i.e. at voltage drop compensation in the stator active resistance, the ratio E_1/f must remain constant. In such a regulation, stator current may be the expression that we have developed:

$$\dot{I}_1 = \dot{U}_{rat}\gamma \frac{r_0 + \frac{r_2'}{\beta} + j(x_0 + x_2')}{jx_1\alpha\cdot\left(r_0 + jx_0 + \frac{r_2'}{\beta} + jx_2'\right) + \left(\frac{r_2'}{\beta} + jx_2'\right)(\alpha r_0 + j\alpha x_0)} \quad (1)$$

Then the circuit input voltage U_1 must be greater than the EMF and the voltage drop can be written as follows:

$$\begin{aligned}\dot{U}_1 &= \dot{U}_{rat}\gamma + \dot{I}_1 r_1 \\ &= \dot{U}_{rat}\gamma\left[1 + r_1\cdot\frac{r_0 + \frac{r_2'}{\beta} + j(x_0 + x_2')}{jx_1\alpha\cdot\left(r_0 + jx_0 + \frac{r_2'}{\beta} + jx_2'\right) + \left(\frac{r_2'}{\beta} + jx_2'\right)(\alpha r_0 + j\alpha x_0)}\right]\end{aligned} \quad (2)$$

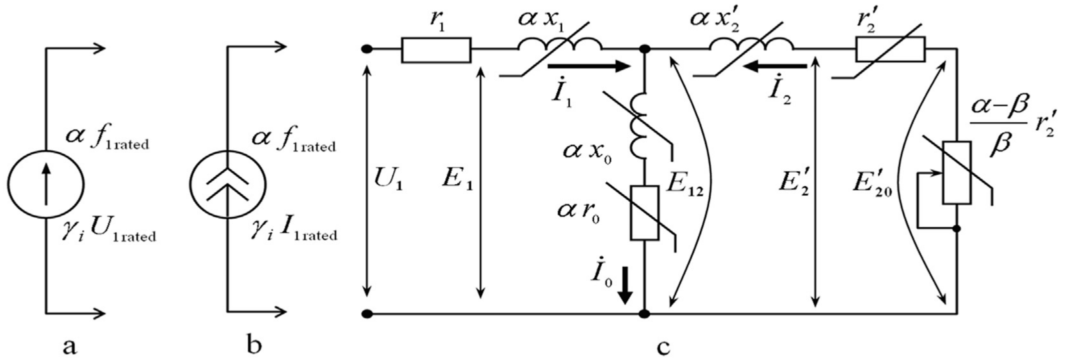

Fig. 1 – T-type equivalent scheme of induction motor when its parameters vary in frequency control: a – voltage source, b – current source, c – replacement scheme.

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