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ORIGINAL ARTICLE

Improved flux pattern by third harmonic injection for multiphase induction machines using neural network

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Abstract This paper presents a modified V/f control strategy using neural network with an improved flux pattern using third harmonic injection for multiphase induction machines. The control objective is to generate a nearly rectangular air–gap flux, resulting in an improved machine power density for the required speed range. If just a proportional relation is used between the third harmonic and fundamental plane voltage magnitudes with zero phase shift, variable misalignment between fundamental and third air–gap flux components occurs with varying mechanical loading as a result of stator voltage drop. Due to this misalignment, saturation may take place which affects the total flux and increases machine iron losses. Neural network is used to obtain the required injected voltage phasors magnitudes and angles to ensure that the air–gap flux is near rectangular with a maximum value of 1 pu for all loading conditions. Simulations are carried out on an eleven-phase induction machine to validate the proposed controller using MATLAB/Simulink.

1. Introduction

Many applications, such as electric ship propulsion, aircraft drives, locomotive traction and high power industrial plants, require high power ratings for both the motor and its converter. However, converter ratings cannot be accordingly increased due to power rating limitations of semiconductor devices [1]. A multiphase machine fed from a multiphase inverter [2] could be a suitable candidate for this task [3]. It has less current per phase or can be designed with a lower voltage for the same power. A detailed review on multiphase machines has been presented in [1]. Many references have covered various multiphase machine topics such as modeling [4,5], applications [1], performance with different control techniques [6,7], and advantages [8]. One major advantage of multiphase machines is the additional degrees of freedom offered for new applications

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with high torque density by current harmonic injection into concentrated machine windings [9]. Harmonic injection provides torque enhancement and can also produces more robust control [10]. Speed control strategies for multiphase induction machines are similar to those for the three-phase induction machine. Conventional constant V/f control has been employed for the multiphase variable-speed induction motor drive at steady state [11,12]. Torque enhancement at steady state was the main task of [12]. An optimization technique is used to find the suitable values for both fundamental and third harmonic flux components to obtain a near rectangular flux distribution. Consequently the magnetizing current component corresponding to each plane is calculated. Based on the steady state model, the corresponding stator voltage components are calculated. Since the conventional scalar V/f control is used, the stator voltage sequence components are assumed in phase. With mechanical loading, there is a change in the circuit impedance for each plane and the corresponding stator voltage angle changes. These assumptions yield to unequal flux tips which increases with the mechanical loading.

In this paper, a modified V/f controller is presented which gives a near flat flux pattern irrespective of mechanical loading. Neural network is used to find suitable values for both fundamental and third harmonic stator voltage space phasor components. The neural network determines the magnitude and angle of each space phasor, namely $\overline{V}_{s1}$ and $\overline{V}_{s3}$ which ensure equal flux tips at all mechanical loading levels. The required training data for the neural network are obtained from the steady state machine model in both sequence planes. The parameters of a prototype eleven-phase induction machine presented in [13] are used for the simulation study.

2. Problem description and conventional control

To obtain a nearly trapezoidal air–gap flux distribution a third harmonic component with a certain magnitude [14] is required to be in phase with the fundamental component of the air–gap flux. The desired air–gap flux distribution is shown in Fig. 1a, where both the fundamental and third harmonic space phasors are aligned. The ideal distribution has two peaks of 1 pu at 60° and 120° [14]. The V/f controller employed in [12] applies in phase stator voltage sequence components to the machine stator terminals. Due to the stator voltage drop, which is different in both fundamental and third plane, the corresponding induced EMF sequence components are not completely aligned. At no-load, the stator voltage drop may be neglected which yields approximately aligned air–gap flux components. However, as the machine is loaded the stator voltage drop results in unequal flux tips caused by the misalignment of the two components of the induced EMF space phasor. Fig. 1b illustrates this case assuming a 10° misalignment between the two space phasors due to a certain mechanical loading. It is shown that the first peak at 60° exceeds 1 pu and the second peak is less than 1 pu. If saturation is not considered, there is no effect since the two curves have the same area; hence, the total flux is not affected. However, if saturation occurs, the total flux and saturation will increase the machine iron losses. The severity of this problem will be dependent on the stator voltage drop which is different depending on the machine rating.

To overcome this problem the angle between the two components of the applied stator voltage components should be selected variable, not zero as in [12], to ensure aligned components of the internally induced EMF. In this paper, the steady state model is used to find the required phase angle of the two components of the applied stator voltage for different loading conditions.

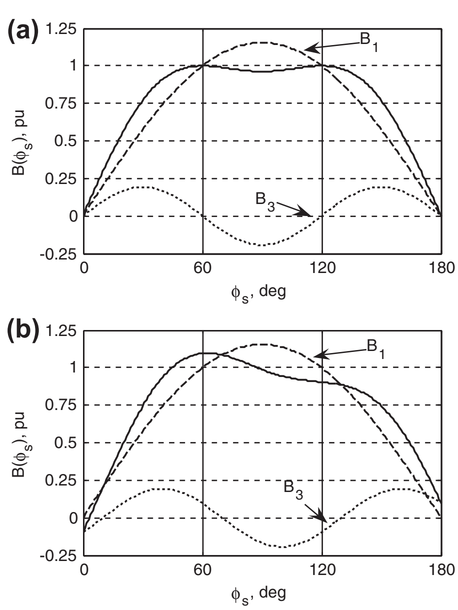

Figure 1 Flux density distribution and its components (a) aligned and (b) misaligned.

3. Steady state model

The multiphase machine steady state model and the equivalent circuit for any sequence k, shown in Fig. 2, are given in [13].

To maintain a quasi-trapezoidal air–gap flux density distribution, the optimum air–gap flux distribution, for maximum fundamental air–gap flux density, is given in pu by [13,14]

$$B(\phi_s) = B_1(\sin\phi_s + k_3 \sin 3\phi_s) \tag{1}$$

where

$$B_1 = 1.15 \text{ pu}, \quad k_3 = \frac{1}{6}$$

and ϕ_s is the stator periphery angle.

This flux density induces a voltage with the same waveform shape and can be composed from two components E_{m1} and E_{m3}, which represents the internal induced voltages in both sequence circuits.

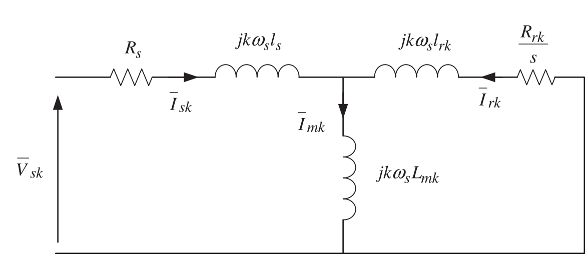

Figure 2 Steady-state equivalent circuit for any sequence k.