Current Control Methods for an Asymmetrical Six-Phase Induction Motor Drive

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***Abstract*—Using the vector space decomposition approach, the currents in a multiphase machine with distributed winding can be decoupled into the flux and torque producing α–β components, and the loss-producing *x–y* and zero-sequence components. While the control of α–β currents is crucial for flux and torque regulation, control of *x–y* currents is important for machine/converter asymmetry and dead-time effect compensation. In this paper, an attempt is made to provide a physically meaningful insight into current control of a six-phase machine, by showing that the fictitious *x–y* currents can be physically interpreted as the circulating currents between the two three-phase windings. Using this interpretation, the characteristics of *x–y* currents due to the machine/converter asymmetry can be analyzed. The use of different types of *x–y* current controllers for asymmetry compensation and suppression of dead-time-induced harmonics is then discussed. Experimental results are provided throughout the paper, to underpin the theoretical considerations, using tests on a prototype asymmetrical six-phase induction machine.**

***Index Terms*—Current control, induction motor drives, multiphase systems.**

I. INTRODUCTION

USING the vector space decomposition (VSD) approach, an n-phase machine can be represented using $n/2$ [or $(n-1)/2$ for machines with an odd number of phases] orthogonal subspaces, which include one α–β subspace and several *x–y* subspaces, and the zero-sequence components [1]. For a machine with sinusoidal magnetomotive force distribution, only the α–β components contribute to useful electromechanical energy conversion, while *x–y* and zero-sequence components only produce losses. In most cases, zero-sequence components can be neglected, since the neutral point of the machine is usually isolated so that the zero-sequence currents cannot flow. Due to the existence of additional degrees of freedom, controlling only the torque and flux producing α–β currents is insufficient and additional controllers are necessary to nullify the *x–y* currents that may flow due to the machine/converter asymmetry and the inverter dead-time effect [2].

Among the multiphase machines, those with multiple three-phase windings (such as 6-phase, 9-phase or 18-phase machine) are most frequently discussed. While having the benefits of a multiphase machine, the modular three-phase structures allow the use of the well-established three-phase technology. This study hence focuses on the discussion of *x–y* current control for an asymmetrical six-phase machine (30° spatial shift between the two three-phase stator windings) with isolated neutral points.

Unlike in multiphase machines with a prime number of phases, where *x–y* currents are fictitious, the *x–y* currents in a six-phase machine can have more meaningful physical interpretation. As will be shown in Section II, the *x–y* currents can be interpreted as the circulating currents between the two three-phase windings in a six-phase machine. Using this concept, the control of *x–y* currents can be analyzed.

This paper is organized as follows. Section II establishes the physical interpretation of the *x–y* currents, based on the VSD and double-*dq* machine models. Section III discusses the two roles of the *x–y* current controllers: asymmetry compensation and dead-time effect compensation. Next, experimental results are given in Section IV, where the performance of several different types of *x–y* current controllers is compared, in order to validate the analysis of Section III. Finally, conclusions of the work are summarized in Section V.

II. INTERPRETATION OF THE $X-Y$ CURRENTS USING VSD AND DOUBLE-DQ MODELING APPROACHES

In the early studies of the asymmetrical six-phase machines, a double-*dq* or double-stator modeling approach has been utilized to aid the understanding of the machine's operation [3], [4]. Using this model, the two three-phase windings in a six-phase machine are treated separately. Two three-phase decoupling (Clarke) transformations are applied separately on the phase variables for each three-phase winding. This transforms the six-phase variables into two sets of stationary reference frame variables, denoted as $\alpha1$–$\beta1$ and $\alpha2$–$\beta2$ components, for windings 1 and 2, respectively:

$$[\,f_{\alpha1} \quad f_{\beta1}\,]^T = [T_{\alpha\beta1}][\,f_{a1} \quad f_{b1} \quad f_{c1}\,]^T \tag{1}$$

$$[\,f_{\alpha2} \quad f_{\beta2}\,]^T = [T_{\alpha\beta2}][\,f_{a2} \quad f_{b2} \quad f_{c2}\,]^T. \tag{2}$$

Symbol f represents arbitrary machine variables (voltage, current, or flux). The spatial 30° displacement between the two

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