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Research Article

Harmonic reduction of Direct Torque Control of six-phase induction motor

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ABSTRACT

In this paper, a new switching method in Direct Torque Control (DTC) of a six-phase induction machine for reduction of current harmonics is introduced. Selecting a suitable vector in each sampling period is an ordinal method in the ST-DTC drive of a six-phase induction machine. The six-phase induction machine has 64 voltage vectors and divided further into four groups. In the proposed DTC method, the suitable voltage vectors are selected from two vector groups. By a suitable selection of two vectors in each sampling period, the harmonic amplitude is decreased more, in and various comparison to that of the ST-DTC drive. The harmonics loss is greater reduced, while the electromechanical energy is decreased with switching loss showing a little increase. Spectrum analysis of the phase current in the standard and new switching table DTC of the six-phase induction machine and determination for the amplitude of each harmonics is proposed in this paper. The proposed method has a less sampling time in comparison to the ordinary method. The Harmonic analyses of the current in the low and high speed shows the performance of the presented method. The simplicity of the proposed method and its implementation without any extra hardware is other advantages of the proposed method. The simulation and experimental results show the preference of the proposed method.

1. Introduction

The multi-phase machines for different structures are used in many projects. The multi-phase machines have some advantages like lower torque pulsations, higher reliability, lower current per phase and etc., [1–5]. The 6-phase induction machine is one of the familiar types of these machines [1]. The 6-phase induction machines are named and used in the previous papers as Dual Three Phase Machine (DTPM), Dual Stator Winding Induction Machine (DSWIM), and six-phase induction machine. The six-phase induction machine has the same stator parameters in two three-phase stator winding groups. The DTPM has various stator windings parameters and the same stator windings. The DSWIM has various parameters with different stator windings.

The speed control of the six-phase induction machine is experimented by the FOC and the DTC method in [1]. The DTC method is a suitable method used in many ac drive applications. The DTC technique has fast torque response and its robustness against the parameter variations have been put to test and therefore approved. In the ordinal DTC technique, the hysteresis comparators for the torque and flux are used with the flux section is calculated by the flux amplitude in the $(\alpha-\beta)$ subspace. An appropriate vector of the switching table is selected from the switching table [4,6]. The proposed method in [5] needs a great time to proceed therefore requiring a large sampling time. Besides, the algorithm is complex and difficult to implement. A complex algorithm to drive a symmetrical six-phase induction machine is presented in [7]. Although the phase currents distortion problem has not been solved completely, the flux and torque performance is improved in [7].

The efficiency improvement of the DTC of the six-phase induction machine is presented in [8,9]. Also, efficiency improvement of FOC of machine is reported in [10–11]. The Kalman filter modeling of machine is presented in [12]. Modified DTC of multi-phase machine are reported in [13–17]. Current harmonics elimination control method for six-phase PM synchronous motor in [18] and sliding mode control of 5-phase machine in [19]. Fault diagnosis and fault-tolerant finite control set-model predictive control of a multiphase machine is discussed in [20].

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The six-phase inverter used to drive the machine has 64 switching states [21] which are mapped to three subspaces. The first subspace $(\alpha-\beta)$ consists of the electromechanical energy conversion and must be larger than the others. The fundamental component of the machine and the harmonics of the order $12n\pm1$ $(n=1, 2, 3 \ldots)$ are mapped to match this subspace. The second subspace (z_1-z_2), consisting of harmonics by the order of $6n\pm1$ $(n=1, 3, 5 \ldots)$, produces loss and has to be reduced so as to improve the efficiency. The third subspace (o_1-o_2) including $3n$ $(n=1,2,3, \ldots)$ harmonics also produces loss and will become zero by isolating the neutral points of two three-phase windings. The space voltage vector in the largest group is employed so as to start the motor and builds the stator flux within a short period of time. The voltage vectors in the other two groups do not affect the flux amplitude as significantly as the ones in the first group. Therefore, they can be utilized for a finer adjustment of the stator flux when the motor runs at the steady state [21].

The main purpose of this paper is to improve the ST-DTC of the Six-phase induction machine for reducing the harmonic of the order fifth and seventh. Increasing number of the voltage vectors causes great flexibility in selection of the inverter states; thereby it achieves more precise control of the stator flux and torque in the six-phase induction drives. The large number of inverter switching states means that a more elaborate and complex selection criterion is needed. The efficiency improvement of a machine is performed by: First, a change in the machine structure, like such as varied magnetic materials and windings or a change in control method. Second, a change in the drive control method [22–24]. This technique does not require any alterations in the machine structure and hence specified in any machine [10–12].

The six-phase induction machine with a suitable Switching Tables (ST) is presented in this paper to reduce stator current harmonic. Improving the ST-DTC of the six-phase induction machine to reduce harmonic of the order fifth and seventh is given

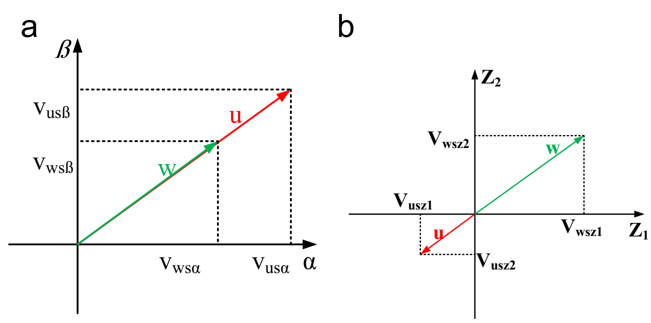

Fig. 1. Selected vectors in (a) $(\alpha-\beta)$ subspace and (b) (z_1-z_2) subspace.

Table 1
Number of switching and voltage array numbers in group one (in hex).

U0	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12
0,07,38, 3F	39	34	18	2C	1E	0D	06	0B	27	13	21	32

Table 2
Number of switching and voltage array numbers in group two (in hex).

W0	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
0,07,38, 3F	3C	07	30	0E	33	1C	03	38	0F	31	0C	23

Table 3
Switching table in DTC method

ΔT	$\Delta\Psi$	Time	Selected vector
1	1	AT_s	U_{k+1}
1	1	$(1-A)T_s$	V_{k+1}
1	0	AT_s	U_{k+4}
1	0	$(1-A)T_s$	V_{k+4}
0	1	AT_s	U_0
0	1	$(1-A)T_s$	V_0
0	0	AT_s	U_0
0	0	$(1-A)T_s$	V_0
−1	1	AT_s	U_0
−1	1	$(1-A)T_s$	V_0
−1	0	AT_s	U_0
−1	0	$(1-A)T_s$	V_0