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Voltage source inverter driven multi-phase induction machine

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Abstract

Multi-phase (more than three phases) drives possess several advantages over conventional three-phase drives such as: reducing the amplitude and increasing the frequency of torque pulsations, reducing the rotor harmonic currents, reducing the current per phase without increasing the voltage per phase, lowering the dc link current harmonics and higher reliability. By increasing the number of phases it is also possible to increase the power/torque per rms ampere for the same volume machine. This paper, therefore, presents a simple *d–q* model of a multi-phase induction machine suitable for analyzing the transient, steady state and dynamic behavior of the machine under balanced operating condition. In the analytical model, the effects of common mutual leakage reactance between the two three-phase winding sets have been included. The model has been developed in general reference frame and is suitable for analysis of the machine behavior with an arbitrary angle of displacement.

Keywords: Analysis; Induction machine; Multi-phase; Modeling; Simulation

1. Introduction

The voltage source inverter fed induction machine drive systems have many advantages such as a rugged and low cost rotor structure, capability of high waveform fidelity with PWM operation, reasonably high performance, etc. However, their applications are still limited to the lower end of the high-power range due to the limitations on the ratings of the gate-turn-off type semiconductor power devices. To achieve high-power rating in such systems, multi-level inverters have been developed in the past decade as a promising approach. Another strong contender in achieving high power is the multi-phase inverter fed multi-phase (in excess of three) induction machine drive

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Nomenclature

T_l	load torque
P	number of poles
J	moment of inertia
ω_b	base speed
ω_k	speed of the reference frame
ω_r	speed of the rotor
p	differentiation w.r.t. time
v_{q1}, v_{d1}	q- and d-axis voltages of stator winding set I
v_{q2}, v_{d2}	q- and d-axis voltages of stator winding set II
$\lambda_{q1}, \lambda_{d1}$	q- and d-axis stator flux linkages of set I
$\lambda_{q2}, \lambda_{d2}$	q- and d-axis stator flux linkages of set II
$\lambda'_{qr}, \lambda'_{dr}$	q- and d-axis rotor flux linkages referred to stator
i_{q1}, i_{d1}	q- and d-axis currents of stator winding set I
i_{q2}, i_{d2}	q- and d-axis currents of stator winding set II
r_1	stator per phase resistance of set I
r_2	stator per phase resistance of set II
r'_r	rotor per phase resistance referred to stator
L'_{lm}	common mutual leakage inductance between the two stator winding sets
L_m	mutual inductance between stator and rotor
L_{l1}	leakage inductance per phase of stator winding set I
L_{l2}	leakage inductance per phase of stator winding set II
L'_{lr}	leakage inductance per phase of rotor winding referred to stator
x'_{lm}	common mutual leakage reactance between the two stator winding sets
x_m	mutual reactance between stator and rotor
x_{l1}	leakage reactance per phase of stator winding set I
x_{l2}	leakage reactance per phase of stator winding set II
x'_{lr}	leakage reactance per phase of rotor winding referred to stator
L'_{ldq}	mutual between the d- and q-axis circuit of the stator windings
v'_{qr}, v'_{dr}	q- and d-axis rotor voltages referred to stator

system. In addition to enhancing the power rating, a multi-phase system also has the merit of high reliability at the system level [1–4]. In particular, with loss of one or more of stator winding excitation sets, a multi-phase induction machine can continue to be operated with an asymmetrical winding structure and unbalanced excitation.

It is well known that the d–q–o reference frame transformation has long been used successfully in the analysis and control of three-phase electric machines. In this approach, the original three-dimensional vector space is decomposed into direct sum of a d–q subspace and a zero sequence subspace, which is orthogonal to d–q. By virtue of this decomposition, the components, which produce rotating m.m.f, and the components of zero sequence are totally decoupled, and thus the analysis and control of machine is simplified.