FCS-MPC-Based Current Control of a Five-Phase Induction Motor and its Comparison with PI-PWM Control

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***Abstract*—This paper presents an investigation of the finite-control-set model predictive control (FCS-MPC) of a five-phase induction motor drive. Specifically, performance with regard to different selections of inverter switching states is investigated. The motor is operated under rotor flux orientation, and both flux/torque producing $(d-q)$ and nonflux/torque producing $(x-y)$ currents are included into the quadratic cost function. The performance is evaluated on the basis of the primary plane, secondary plane, and phase (average) current ripples, across the full inverter's linear operating region under constant flux–torque operation. A secondary plane current ripple weighting factor is added in the cost function, and its impact on all the studied schemes is evaluated. Guidelines for the best switching state set and weighting factor selections are thus established. All the considerations are accompanied with both simulation and experimental results, which are further compared with the steady-state and transient performance of a proportional-integral pulsewidth modulation (PI-PWM)-based current control scheme. While a better transient performance is obtained with FCS-MPC, steady-state performance is always superior with PI-PWM control. It is argued that this is inevitable in multiphase drives in general, due to the existence of nonflux/torque producing current components.**

***Index Terms*—Current control, model predictive control (MPC), multiphase inverters, multiphase machines, weighting factor.**

I. Introduction

MULTIPHASE motor drives have received substantial attention during the last decade [1]. The good features of multiphase machines include low torque pulsations, means for inherently fault-tolerant operation, and better power distribution per phase [2]. A unique feature of multiphase machines, when compared with the conventional three-phase counterpart, is a higher number of degrees of freedom in electrical quantities [2].

Manuscript received May 9, 2012; revised August 15, 2012 and October 10, 2012; accepted November 27, 2012. Date of publication February 22, 2013; date of current version July 18, 2013.

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Digital Object Identifier 10.1109/TIE.2013.2248334

In the field of power electronics and drives, model predictive control (MPC) has by now become an established control technique [3]. Previous MPC research in the multiphase drive area predominantly relates to the closed-loop current control of a dual three-phase (asymmetrical six-phase) induction machine with two isolated neutral points. Stationary $(\alpha-\beta-x-y)$ current control, with only switching states that correspond to the largest voltage vectors (and zero vector), was experimentally studied in [4]–[6]. However, the impact of using only the reduced set of switching states is not analyzed in detail. In [7] and [8], pulsewidth modulation (PWM) was integrated into the finite-control-set MPC (FCS-MPC) scheme(s) for the purposes of constant switching frequency and zeroing of average $x-y$ voltages. The same group of switching states, as in [4] and [5], was taken as the MPC's input set. A later work [9] has made an attempt to include all switching states in the MPC's optimization over a long time window. However, in each optimization cycle, a restrained search technique was introduced to enable on-the-fly switching state selection according to the predefined criteria, such as allowing only one commutation per inverter leg and no consecutive commutations in any leg. In other words, not all available switching states were considered by the MPC in each optimization cycle; instead, only 6, 11, or 16 switching states were included, depending on the predefined criteria. The search method reduced significantly the computational time of the FCS-MPC, which is usually high.

FCS-MPC has been also explored to some extent in conjunction with a five-phase induction motor drive. In [10], a predictive torque control algorithm is reported, and performance is experimentally investigated. Next, a synchronous current control scheme with a full set of switching states taken as the control input set of the FCS-MPC was addressed in [11] and [12], using simulation and experiments, respectively. Some other MPC-related works, which used a five-phase RL load, include [13] and [14]. Their focus was on algorithm's feasibility and simplification instead of drive's performance. Another study that used a five-leg inverter investigated the FCS-MPC-based current control of a two-motor three-phase motor drive with a common inverter leg [15]. That topology has the same number of electrical degrees of freedom as the five-phase and dual three-phase motor drives, i.e., four.

A multiphase system, even when supplied from a two-level inverter, is characterized by a high number of switching states. Space vector representation describes the multiphase system using multiple planes, i.e., primary $(\alpha-\beta)$ and secondary $(x-y)$