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High performance operation for a four-leg NPC inverter with two-sample-ahead predictive control strategy

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ABSTRACT

In this paper is proposed a finite control-set model predictive control (FCS-MPC) strategy which uses a two-sample-ahead prediction horizon to achieve high-performance operation for a three-phase four-leg neutral-point-clamped (NPC) inverter with an output LC filter. The control strategy is proposed in order to minimize the error between the output voltages and their references, maintain equal voltage among the dc-link capacitors, and reduce the overall switching frequency of the inverter. One-sample-ahead and two-sample-ahead prediction horizon are evaluated and compared in terms of reference tracking error and THD, under steady-state and transient operating conditions with linear and non-linear loads. The experimental results demonstrate that the proposed two-sample-ahead prediction horizon is more suitable for high power applications where lower switching frequency operation is mandatory.

1. Introduction

The three-level neutral-point-clamped (NPC) inverter is the most widely used configuration in many medium voltage (MV) (from 2.3 to 4.16 kV) industrial applications [1,2]. This power converter has several advantages: (1) high voltage capability, (2) reduced common mode voltages, (3) nearly sinusoidal output voltage, (4) low dv/dt's, which can reduce the electromagnetic interference, and (5) small or even no output filter [3]. Some applications in which an NPC inverter with an output LC filter can be used are uninterruptible power supplies (UPS), off-grid (stand-alone) distributed generation (DG) systems, dynamic voltage restorers (DVRs) and universal power quality conditioners (UPQCs) [4].

Most of the practical UPS, DG, DVR and UPQC systems need to feed unbalanced/nonlinear loads in four-wire systems, and the conventional three-phase NPC is not suitable for this purpose because of: (1) insufficient dc-bus utilization, (2) high ripple on dc-link capacitors, and (3) difficulties in balancing the dc-link capacitor voltages due to low-frequency neutral-point voltage oscillations [5]. A four-leg NPC inverter has been shown to be an effective solution for three-phase four-wire systems because it offers full utilization of the dc-link voltage and reduces the stress on the dc-link capacitors.

Nowadays, with technological advances, the implementation of new and more complex modulation and control strategies is possible. One of the new control schemes for power converters is finite control-set model predictive control (FCS-MPC) as described in [6]. The classical control schemes with PI regulators and pulse width modulation (PWM)/space vector modulation (SVM) assume the power converter as a linear system [7–9], while the FCS-MPC strategy treats the system as nonlinear. The nonlinear nature of the power converter becomes more predominant at lower switching frequency operation, and during such conditions the FCS-MPC strategy provides better steady-state results and a fast transient response. Although predictive control requires a higher amount of calculations than a classic control scheme, with the development of fast microprocessors, its implementation is possible, and this control technique has been applied to wide range of power converters and applications [10–13]. This predictive control technique uses the model of the system, as the name implies, and this requirement has prompted many investigations of the system model used in different applications.

The predictive voltage control with an output LC filter is analyzed for three-leg two-level [14] and four-leg two-level converters [15,16]. This concept has been extended by simulation studies to four-leg NPC converter [17] using the same load model introduced in [14] for the three-wire applications. The predictive

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