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Finite Control Set Model Predictive Torque Control of Induction Motors using a Neutral Point Clamped Three-Level Inverter with Computational load Reduction

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Abstract: In this paper, a FCS-MPC strategy for the torque control of 3 phase induction motors using a NPC type 3-level inverter is proposed. It derives a reference state for the given torque reference. Use of a performance index penalizing tracking error for the reference state . Here we propose to confine the evaluation of the performance index to 3 voltage vectors of the 3-level inverter considering the fact that the dynamics of the electrical system is far faster than that of mechanical system. Thus the computational load is not increased compared to earlier FCS-MPC methods based on 2-level inverters. An effective method to maintain the balance of dc capacitors is also proposed. The efficacy of the proposed method is proved simulations.

Keywords: Three-level Inverter, Induction Motors, Torque Control, Finite Control Set MPC, Computational load reduction

1. INTRODUCTION

Finite control set model predictive contro(FCS-MPC) is a class of MPC, which is applicable to systems having finite number of control actions. In the FCS-MPC strategy, use of a performance index is made and the choice of a control action minimizing the performance index is performed at each time step. Recently, application of the FCS-MPC to the torque control of ac-derives draws increasing attention Xia et al. (2014)–Davari et al. (2012). In , the performace index was composed of errors in torque and flux of an induction motor. At each time step, the performance index is evaluated for 6 possible active voltage vectors of a two-level inverter and the one which yields the least performance index is applied to the motor during the sampling period. This control strategy is simple to understand and practical requirements can be taken into account by modifying the performance index. However, the use of constant voltage vector during a sampling period is likely to result in excessive torque ripple. Hence, the sampling rate should be very high in order to reduce the torque ripple of the method .

Attempts to avoid the high torque ripple without increasing the sampling rate were made in Zhang and Yang (2013a)–Davari et al. (2012). In these works, the duration of applying a voltage vector during a sampling period i.e. the modulation factor was adjusted so that the torque ripple should be minimized. In Zhang and Yang (2013a)Zhang and Yang (2013b), the modulation factors were calculated for each possible voltage vectors of a 2-level inverter so that the torque ripple should be minimized. A performance index was evaluated for each voltage vector with corresponding modulation factor and the optimal voltage vector yielding the minimum performance index was applied to the system over the optimal duration for the next sampling period. The performance index was composed of one-step ahead predictions of errors on torque and flux. The choice of weights in the performance index considerably affects the control performance. Thus, the weights on the on the errors of torque and flux should be determined through trail and error efforts.

In Park et al. (2015), another type of performance index was evaluated for active voltage vectors of a 2-level inverter without modulation to choose the minimizing voltage vector. Then a modulation factor for the minimizing voltage vector was computed considering torque ripple and other performance index. Here, a reference state was derived for the given desired values of torque and flux and the performance index was defined using this reference state. A systematic method to determine a weighting matrix for this performance index was provided.

Above studies considered the use of 2-level inverters for the application of FCS-MPC strategy to induction motors. Use of multi-level inverters and multi-phase induction motors draw increasing attention for large-scale motor drive and high-efficiency operation, respectively. One of the obstacles in the use of multi-level inverters or multi-phase motors for FCS-MPC applications are large computational burden. Multi-level inverters have much

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more active voltage vectors than 2-level inverters. Thus the computational load to compare performance indices increases as much. Current control of 5-phase induction motor using 2-level inverter was considered in Perez et al. (2014). In the case of 5-phase induction motor, number of feasible control input is 32.

Torque control of induction motors using a multi-level inverter was reported in Lim et al. (2014). The multi-level inverter used in Lim et al. (2014) was composed of h-bridges and it has 27 feasible voltage vector vectors. Performance indices of Perez et al. (2014) and Lim et al. (2014) were evaluated for every possible control vectors. Thus both of the methods are likely to require much more computation than Zhang and Yang (2013a)–Park et al. (2015). On the other hand, balancing of 2 dc capacitors should be considered for Neutral Point Clamped(NPC) type 3-level inverters, which requires extra compuatation. In the case of mismatching voltage of these 2 dc capacitors, output voltage vectors of NPC type three-level inverter are are corrupted.

In this paper, a FCS-MPC strategy for the torque control of 3 phase induction motors using a NPC type 3-level inverter is proposed. It adopts the performance index and cost weights of Park et al. (2015). Here we propose to confine the evaluation of the performance index to 3 voltage vectors of the 3-level inverter considering the fact that the dynamics of the electrical system is far faster than that of mechanical system. Thus the computational load is not increased compared to Zhang and Yang (2013a) and Park et al. (2015), which are based on 2-level inverters. An effective method to maintain the balance of dc capacitors is also proposed. The efficacy of the proposed method is proved simulations and experiments.

2. SYSTEM DESCRIPTION

2.1 Induction Motor

The dynamics of an induction motor can be modeled as follows in the stationary coordinates. The stator voltage equation is given as:

$$v_{abcs} = R_s i_{abcs} + \frac{d}{dt}\lambda_{abcs}, \tag{1}$$

where v_{abcs}, i_{abcs}, λ_{abcs}, and R_s represent stator voltage, stator current, stator flux, and stator resistance, respectively. The rotor voltage equation is described as:

$$0 = R_r i_{abcr} + \frac{d}{dt}\lambda_{abcr} \tag{2}$$

where i_{abcr}, λ_{abcr}, and R_r represent rotor current, current flux, and rotor resistance, respectively. The flux equation is given as:

$$\lambda_{abcs} = L_s i_{abcs} + L_m i_{abcr} \tag{3}$$

$$\lambda_{abcr} = L_r i_{abcr} + L_m i_{abcs}, \tag{4}$$

where L_s, L_r, and L_m are stator inductance, rotor inductance and mutual inductance, respectively. Equations (1) – (4) can be transformed as follows in the rotating dq-axis:

$$v_{dqs} = R_s i_{dqs} + \frac{d}{dt}\lambda_{dqs} + j\omega_e \lambda_{dqs} \tag{5}$$

$$0 = R_r i_{dqr} + \frac{d}{dt}\lambda_{dqr} + j(\omega_e - \omega_r)\lambda_{dqr} \tag{6}$$

$$\lambda_{dqs} = L_s i_{dqs} + L_m i_{dqr} \tag{7}$$

$$\lambda_{dqr} = L_r i_{dqr} + L_m i_{dqs}, \tag{8}$$

where ω_e and ω_r are the rotational speeds of the stator current and rotor, respectively. The relations between the values of a stationary frame and rotating dq-frame are as follows:

$$v_{dqs} = T(\theta_e)v_{abcs},\ i_{dqs} = T(\theta_e)i_{abcs},\ \lambda_{dqs} = T(\theta_e)\lambda_{abcs} \tag{9}$$

$$\lambda_{dqr} = T(\theta_e)\lambda_{abcs},\ i_{dqs} = T(\theta_e)i_{dqr} \tag{10}$$

$$T(\theta_e) := \begin{bmatrix} cos\theta_e & cos(\theta_e - 2\pi/3) & cos(\theta_e + 2\pi/3) \\ -sin\theta_2 & -sin(\theta_2 - 2\pi/3) & -sin(\theta_2 + 2\pi/3) \end{bmatrix},$$

where θ_e represents the rotational angle of the stator current. Equations (5) – (8) can be rewritten as the following continuous time state space equations:

$$\dot{x}(t) = A_c x(t) + B_c u(t) \tag{11}$$

$$A_c := \begin{bmatrix} -\frac{1}{\alpha}(R_s + \beta^2 R_r) - j\omega_e & \frac{\beta R_r}{\alpha L_r} - j\frac{\beta}{\alpha}\omega_r \\ \beta R_r & -\frac{R_r}{L_r} - j(\omega_e - \omega_r) \end{bmatrix},$$

$$B_c := \begin{bmatrix} \frac{1}{\alpha} \\ 0 \end{bmatrix},\ x(t) := \begin{bmatrix} i_{dqs}(t) \\ \lambda_{dqr}(t) \end{bmatrix},\ u(t) := \begin{bmatrix} v_{dq}(t) \\ 0 \end{bmatrix}$$

$$\alpha := L_s - \frac{L_m^2}{L_r}, \beta := \frac{L_m}{L_r},$$

where ω_r is rotor speed of the induction motor. Following the rectangular rule of numerical integration, (11) can be discretized as follows with sampling period h:

$$x[k+1] = Ax[k] + Bu[k] \tag{12}$$

$$A = I_{4\times4} + A_c h,\ B = B_c h,$$

$$x[k] = \begin{bmatrix} i_{dqs}[k] \\ \lambda_{dqr}[k] \end{bmatrix}, u[k] = \begin{bmatrix} v_{dq}[k] \\ 0 \end{bmatrix}.$$

The output torque of an induction motor is given in terms of stator current and rotor flux as:

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}(\lambda_{dr} i_{qs} - \lambda_{qr} i_{ds}), \tag{13}$$

where P is the number poles of the induction motor.

2.2 NPC type Three-level Inverter

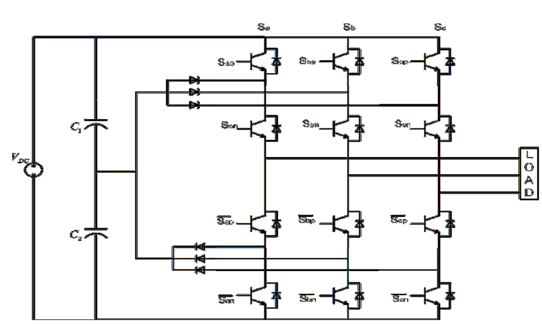

Fig. 1. NPC type Three-level Inverter Circuit

Figure 1 shows a neutral point clamped(NPC) 3-level inverter, where the neutral point of the dc-link is connected