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Improved Voltage Vector Sequences on Model Predictive Control for a Grid Connected Three Phase Voltage Source Inverter

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Abstract

In this paper, improved voltage vector sequences on model predictive control is proposed for a grid connected three-phase voltage source inverter. Two adjacent voltage vectors and zero voltage vectors are utilized in one switching period. Optimal duty cycles for all sectors are calculated. Voltage vector pair with minimum value of the cost function is selected and applied in the next switching period. Voltage vector sequences are arranged similar to the swing patterns generated by the space vector PWM. Thus, minimum number of switching transition and even loss distribution can be achieved. Computer simulation is carried out to validate viability of the proposed method. The simulation results confirm that the proposed MPC has superior performance compared to the convention MPC.

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1. Introduction

In the past decade, inverters have played an important role in modern industries. They have become indispensable for a myriad of applications, for instance adjustable speed drives, grid connected inverters and uninterruptible power supply. A great number of control techniques have been presented for controlling the inverter currents.[1-4] For example, hysteresis control is a nonlinear control method that turns switches on/off to regulate the inverter currents

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that reside in hysteresis bands. Linear PI controllers with modulators regulate the inverter currents equal to the reference values by generating the control commands for modulators to produce appropriate output voltages applied to loads. In sliding mode control, suitable sliding surfaces are selected to force the inverter currents to follow a desired trajectory [2]. Deadbeat control is a class of predictive control [3]. It uses known models to calculate output voltages that make zero errors in one sampling period.

Model predictive control MPC extends the concept of deadbeat control [4]. It provides more flexible criteria that are expressed as cost functions to be minimized. In particular for a finite set MPC with predictive horizon $N = 1$, it is simple, intuitive, and suitable for application of three-phase inverters. However, the conventional MPC may suffer from computational burdens and require high switching frequency.

This paper presents improved voltage vector sequences on model predictive control for three-phase voltage source inverter. Two adjacent voltage vectors and zero voltage vector are utilized in one switching period. The cost functions in terms of the current errors in $\alpha\beta$ frame are formulated. Analytical solutions of optimal duty cycles for all sectors are derived. The proposed voltage vector sequences minimize the number of switching transitions. The proposed method is validated by computer simulation and its performance is compared to the conventional MPC.

2. Conventional MPC

A three-phase voltage source inverter circuit is shown in Fig. 1. Each leg of a three-phase inverter consists of two IGBT switches which are connected in series. The upper and lower switches of the same leg cannot be turned on at the same time. Thus, a three-phase inverter can generate 6 active vectors and 2 zero vectors in the vector space as shown in Fig. 2. All possible voltage vectors can be expressed in the vector space definition by eq (1) as given in Table 1. Likewise, the load currents can be transformed into $\alpha\beta$ frame by eq (2)

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

The load currents dynamic for each phase in $\alpha\beta$ frame are expressed as,

$$V_\alpha = L \frac{di_\alpha}{dt} + Ri_\alpha + E_\alpha \quad V_\beta = L \frac{di_\beta}{dt} + Ri_\beta + E_\beta \quad (2)$$

where L is the filter inductance, R is the filter resistance, $v_{\alpha\beta}$ and $e_{\alpha\beta}$ are the inverter voltage and the grid voltage in $\alpha\beta$ frame respectively. Using the forward Euler approximation, the future load currents in the $\alpha\beta$ frame can be derived in the discrete-time domain as,

$$i_{\alpha(k+1)}^p = i_{\alpha(k)} + \frac{T}{L}(v_{\alpha(k)} - Ri_{\alpha(k)} - e_{\alpha(k)}) \quad i_{\beta(k+1)}^p = i_{\beta(k)} + \frac{T}{L}(v_{\beta(k)} - Ri_{\beta(k)} - e_{\beta(k)}) \quad (3)$$

In the conventional MPC method, the future current behaviors generated by the corresponding seven voltage vectors can be predicted by the load current dynamics (3). Then, the cost functions are determined in terms of the quadratic error which is defined in eq (4).

$$g = (i_{\alpha(k+1)}^* - i_{\alpha(k+1)}^p)^2 + (i_{\beta(k+1)}^* - i_{\beta(k+1)}^p)^2 \quad (4)$$

A voltage vector which yields minimum value of the cost function is selected and it will be applied in the next sampling period.

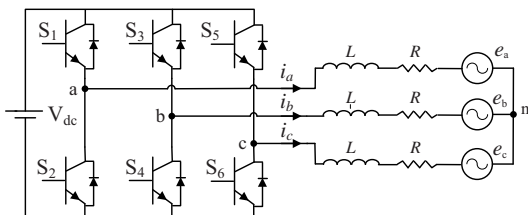


Fig. 1 Three-phase VSI configuration

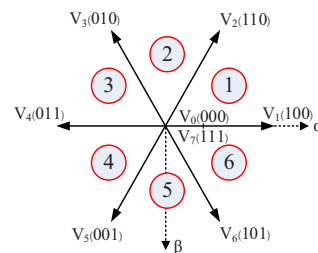


Fig. 2 Eight voltage vectors generated by VSI

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