Predictive control of three-phase inverter

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A new method for current control based on a predictive strategy is presented. This uses a discrete-time model of the load to predict the future value of the current for each of the possible voltage vectors generated by the inverter. The vector which minimises the current error at the next sampling time is selected. Experimental results that confirm the feasibility of the method are given.

Introduction: Current control in three-phase inverters has been extensively studied in the last decade. Nonlinear methods, such as hysteresis control, and linear methods, such as proportional-integral (PI) controllers with subharmonic voltage modulation (PWM) are well established in the literature [1, 2].

In this Letter we present a conceptually new approach to the nonlinear current control in three-phase inverters. A model of the inverter and load is used to predict the behaviour of the current for each different voltage vector generated by the inverter. The vector that minimises a quality function is selected.

Predictive control is a topic of control theory that has found some application in power converters [2]. There are applications of predictive control in drives [3], active filters [4] and power factor correction [5]. All these works consider a linear model and use modulation techniques for the generation of the voltage. In [6] it is demonstrated that the use of nonlinear predictive control in a matrix converter avoids the use of complex modulation strategies. This present work uses predictive current control avoiding the application of any modulation method in the inverter.

Control method: Fig. 1 shows a model of the system and the possible voltage vectors generated by the inverter. This method uses a discrete-time model of the system to predict the future value of load current $\mathbf{i}(k+1)$ for each possible voltage vector $\mathbf{v}(k)$, for a sampling time T_s

$$\mathbf{i}(k+1) = \left(1 - \frac{RT_s}{L}\right)\mathbf{i}(k) + \frac{T_s}{L}\mathbf{v}(k) - \frac{T_s}{L}\mathbf{e}(k) \tag{1}$$

where R is the load resistance and L is the load inductance, $\mathbf{v}$ is the voltage generated by the inverter and $\mathbf{e}$ is the load EMF. The load EMF can be estimated as

$$\hat{\mathbf{e}}(k) = \mathbf{v}(k) + \left(\frac{L}{T_s} - R\right)\mathbf{i}(k) - \frac{L}{T_s}\mathbf{i}^*(k+1) \tag{2}$$

where $\mathbf{i}^*(k+1)$ is the future reference current calculated via a second-order extrapolation given by

$$\mathbf{i}^*(k+1) = 3\mathbf{i}^*(k) - 3\mathbf{i}^*(k-1) + \mathbf{i}^*(k-2) \tag{3}$$

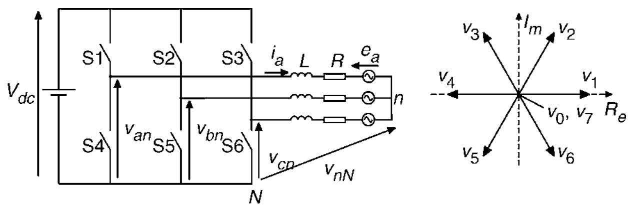

Fig. 1 *Inverter model and possible voltage vectors*

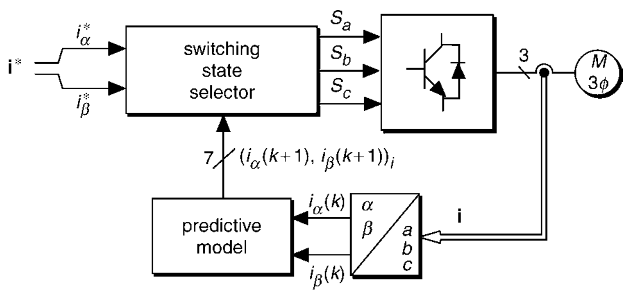

Fig. 2 *Predictive current control*

Predictive current control: Fig. 2 shows a block diagram of the predictive control. Actual values of load current are measured and used with the predictive model to generate seven predictions of future current, one for each voltage vector. These predictions are evaluated with a quality function g and the vector that minimises this function is applied during the next sampling interval.

The quality function g is expressed in orthogonal co-ordinates in the following form

$$g = |i_\alpha^* - i_\alpha^p| + |i_\beta^* - i_\beta^p| \tag{4}$$

where i_α^p and i_β^p are the real and imaginary part of the predicted load current $\mathbf{i}(k+1)$, i_α^* and i_β^* are the real and imaginary part of future reference current determined by (3).

Results: Simulation results are shown in Fig. 3 for PWM and predictive current control. At instant $t = 0.015$ s the amplitude of the reference current i_α^* is reduced from 13 to 5.2 A. The amplitude of current i_β^* has not been changed to assess the decoupling on the current control. Note that for the proposed method, no interaction between i_α and i_β is observable, and that a better dynamic response than PWM control is achieved.

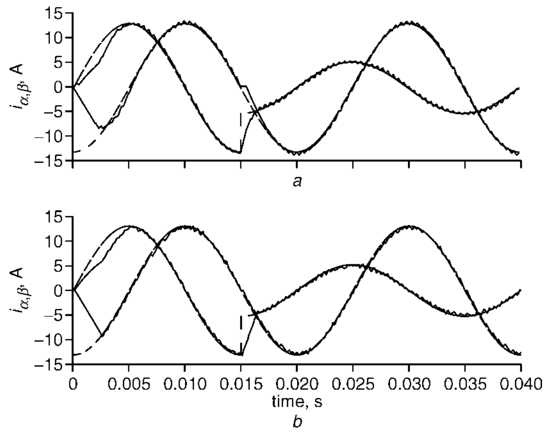

Fig. 3 *Simulation results: step change in* i_α^*

a PWM
b Predictive

Experimental results: The control algorithm was implemented on a DSPT MX320F2812 by Texas Instruments for a sampling time $T_s =$ 100 µs and tested with an RL load ($R = 20\ \Omega$, $L = 30$ mH) and a DC link voltage of $V_{dc} = 220$ V.

Dynamic response of the system is shown in Fig. 4 for a step change in the amplitude of i_α^* (from 5 to 2.5 A at time $t = 0$), reference is followed with fast dynamic without affecting i_β. This confirms simulation results.

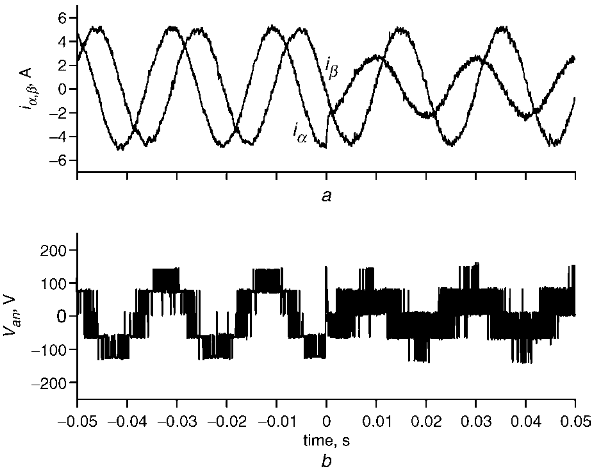

Fig. 4 *Experimental result for step on* i_α^*

a Load currents
b Load voltage

Fig. 4*b* shows the load voltage for the predictive current control. It is observed that the waveform of load voltage v_{an} is very similar to a voltage generated with classical modulation techniques. With this control strategy no modulator needs to be implemented and the control signals for the switches are generated directly by the predictive controller. For the implemented sampling frequency of 10 KHz ($T_s = 100\ \mu s$) the load voltage spectrum concentrates near 2 KHz.

Conclusions: The predictive current control presented in this Letter does not require any current controller or modulator. It presents a very effective control of the load currents. In addition, this control strategy compares well with established control methods such as subharmonic modulation (PWM). The dynamic response of this method is better than the classical PWM solution. These results show that predictive control is a very powerful tool with a conceptually different approach that opens new possibilities in the control of power converters.

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