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Direct Power Control of Three-Phase Voltage Source Converters using Feedback Linearization Technique

Nirawit Muangruk[a,*], Suksun Nungam[b]

Department of Electrical and Computer Engineering, Faculty of Engineering King Mongkut's University of Technology North Bangkok, 1518 Pracharat 1 Road, Wongsawang, Bangsue, Bangkok 10800, Thailand

Abstract

This paper describes the direct power control (DPC) of a three-phase voltage source converter (VSC) using feedback linearization technique. This technique transforms nonlinear model of the VSC into a linear one so that the controller design is easy and independent of the operating point. The problem is formulated in the DPC framework. The DPC with space-vector modulation (DPC-SVM) is adopted because of its constant switching frequency operation. The control scheme is implemented on a STM32F4DISCOVERY board. The validity of the scheme has been verified through experiment which shows that the proposed control strategy provides the VSC operation with wide operating range and fast transient responses.

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Keywords: Direct power control, Feedback linearization, Three-phase converter ;

1. Introduction

A three-phase voltage source converter (VSC) offers many advantages, namely bidirectional power flow, low harmonic distortion of line current and regulation of input power factor to unity. These advantages are made possible by means of control strategies. Direct power control (DPC) for the VSC has attracted the attention of many researchers. In the original DPC strategy [1], the conventional current control loops and PWM modulator are replaced by a lookup table control scheme to obtain fast transient responses. However, this scheme causes problem

* Corresponding author. Tel.: +66 86 234-5656.
E-mail address: tummaster@hotmail.com

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of variable switching frequency. In [2], the DPC with space-vector modulation (DPC-SVM) is proposed, providing the VSC with a constant switching frequency operation without sacrificing the original DPC performance. Since the dynamic model of the VSC is nonlinear, controllers are conventionally designed using the linearized model of the VSC around an operating point. This presents the problem that the controller design is dependent on the operating point. On the other hand, the feedback linearization technique [3] transforms the nonlinear system into a linear decoupled one. This technique is applied for VSC in [4-5], resulting in fast transient responses and operation on whole operating range. However, due to the complexity of the control algorithm, it is difficult to implement in practice. Further improvement has been proposed in [6], where the energy stored in the output capacitor, instead of DC bus voltage, is chosen as a state variable. Applying feedback linearization to this state variable gives rise to a much simpler control algorithm. This paper proposes to use the power of the output capacitor as a state variable of the system, and to apply feedback linearization technique in the framework of the DPC. Problem formulation is described and the experimental results are illustrated. The proposed control strategy provides the VSC with fast transient responses and the control performances do not depend on the operating point.

2. Mathematical model of the VSC and feedback linearization technique

The power circuit of the VSC under investigation is shown in Fig. 1, where R_L is a resistive load. The dynamic model of the VSC in the rotating *d-q* frame can be expressed by Eq. 1 where R, L are resistance and inductance of the line reactor; C is the capacitance of the DC bus capacitor; ω is the angular frequency of the line voltage; i_d, i_q, e_d, e_q are currents and supply voltages in the *d-q* axis.

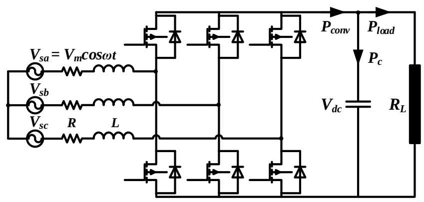

Fig. 1. Power circuit of the VSC

$$\begin{bmatrix} \dot{i}_d \\ \dot{i}_q \\ \dot{P}_c \end{bmatrix} = \begin{bmatrix} -\frac{R}{L}\cdot i_d + \omega\cdot i_q \\ -\omega\cdot i_d - \frac{R}{L}\cdot i_q \\ \frac{3}{2}\cdot V_m\cdot\left(-\frac{R}{L}\cdot i_d + \omega\cdot i_q\right) - \frac{2}{R_L\cdot C}\cdot P_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{L} \\ \frac{3\cdot V_m}{2\cdot L} & 0 \end{bmatrix}\cdot\begin{bmatrix} e_d - v_d \\ e_q - v_q \end{bmatrix} \tag{1}$$

v_d, v_q are the control input voltages; P_c is the power in the capacitor. Note that the power in the DC bus capacitor, P_c is chosen as a state variable. By defining, $P_c = (3/2)\cdot\left(e_d\cdot i_d + e_q\cdot i_q\right) - \left(V_{dc}^2 / R_L\right)$, $P_{conv} = (3/2)\cdot\left(e_d\cdot i_d + e_q\cdot i_q\right)$ and $P_{Load} = V_{dc}^2 / R_L$, and using the power balance principle in Fig. 1, we obtain $P_c = P_{conv} - P_{Load}$. Feedback linearization technique assumes the plant to be described in the following form;

$$\dot{x} = f(x) + g(x)\cdot u \tag{2}$$

$$y = h(x) \tag{3}$$

where x, u and y are state vectors, control inputs and outputs respectively. We propose to regulate V_{dc} at a reference value by directly controlling, P_c; it is named as direct power control. The power factor at the AC-side is controlled by i_q. Therefore, P_c and i_q are chosen as the dummy outputs in Eq. 3. Hence, from Eq. 1, Eq. 2 and Eq. 3 we have,

$$\begin{bmatrix} f_1(\mathrm{x}) \\ f_2(\mathrm{x}) \\ f_3(\mathrm{x}) \end{bmatrix} = \begin{bmatrix} -\frac{R}{L}\cdot i_d + \omega\cdot i_q \\ -\omega\cdot i_d - \frac{R}{L}\cdot i_q \\ \frac{3}{2}\cdot V_m\cdot\left(-\frac{R}{L}\cdot i_d + \omega\cdot i_q\right) - \frac{2}{R_L\cdot C}\cdot P_c \end{bmatrix} \tag{4}$$

$$g(\mathrm{x}) = \begin{bmatrix} g1 & 0 \\ 0 & g2 \\ g3 & 0 \end{bmatrix} = \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{L} \\ \frac{3\cdot V_m}{2\cdot L} & 0 \end{bmatrix} \tag{5}$$

$$u = \begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{bmatrix} e_d - v_d \\ e_q - v_q \end{bmatrix} \tag{6}$$

$$h(\mathrm{x}) = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} P_c \\ i_q \end{bmatrix} \tag{7}$$

Where $\begin{bmatrix} x_1 & x_2 & x_3 \end{bmatrix}^T = \begin{bmatrix} i_d & i_q & P_c \end{bmatrix}^T$ and $e_d = V_m$, $e_q = 0$.