Electrical Power and Energy Systems 56 (2014) 325–331

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Sliding mode direct power control strategy of a power quality based on a sliding mode observer

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ARTICLE INFO

Article history:
Received 3 May 2013
Received in revised form 5 October 2013
Accepted 22 October 2013

Keywords:
Harmonics
Three phase APF
PWM rectifier
DPC
Sliding mode observer SMO
Mode sliding (SM)

ABSTRACT

The first problem in our third millennium is energy. For this raison, we try to find a new solution to develop different ways of distribution and energy use. This article presents the design of a sliding mode controller using sliding mode observation technique which aims to simplify the control procedure. According to the justified tendency of reduction of the number of the sensors. The sliding mode observer has been presented as a robust estimation method. We propose a new multi-function converter as an efficient solution to improve the power quality. For improving the quality of the energy transfer from the power supply to the load, and reducing the harmful effects of the harmonics generated by nonlinear load. The good dynamic and static performance under the proposed control strategy is verified by simulation and experiment.

1. Introduction

The three-phase boost-type PWM rectifier is used increasingly in a wide diversity of applications in recent years owing to its superior performance compared to conventional diode or thyristor bridge rectifiers [6]. It can provide constant dc bus voltage, low harmonic distortion of the utility currents, bidirectional power flow, and controllable power factor [14].

The sliding mode control (SMC) is one of the popular strategies to deal with uncertain control systems [10]. The main feature of SMC is the robustness against parameter variations and external disturbances. Various applications of SMC have been conducted, such as robotic manipulators, aircrafts, DC motors, chaotic systems [11].

The main idea of DPC is similar to the well known direct torque control (DTC) for induction motors. Instead of torque and stator flux the instantaneous active and reactive powers are controlled [2]. AC voltage sensors can be avoided in this technique which improves the reliability, cost effective and increases the speed of response.

This paper presents a new control method entitled sliding mode direct power control (SMDPC) strategy based on a virtual flux observer and switching table to control PWM rectifier with the function of an active filter.

2. Control of PWM rectifier with active filtering function

Nowadays, harmonic pollution in electrical power systems due to nonlinear loads such as AC-to-DC power converters has become a serious problem [4].

To eliminate or reduce harmonics in the power systems, a number of methods have been developed and put into practice. Active power filters and PWM rectifiers are two typical examples of these methods. The active power filter and PWM rectifier have basically the same circuit configuration and can operate based on the same control principle [8].

2.1. Sliding-mode current observer for virtual grid flux

The aim of virtual flux (VF) approach is to improve the Voltage Oriented Control (VOC) [2,9]. The Sliding-Mode Direct Power Control technique with the pseudo-sliding mode DC-link voltage controller presented in Fig. 1 has been examined in the simulation and experimental research. For the PWM rectifier the inductor voltages v_L and the converter input voltages u_f balance the grid voltages v_s according to the matrix equation:

$$v_s = v_L + v_f. \tag{1}$$

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http://dx.doi.org/10.1016/j.ijepes.2013.10.032

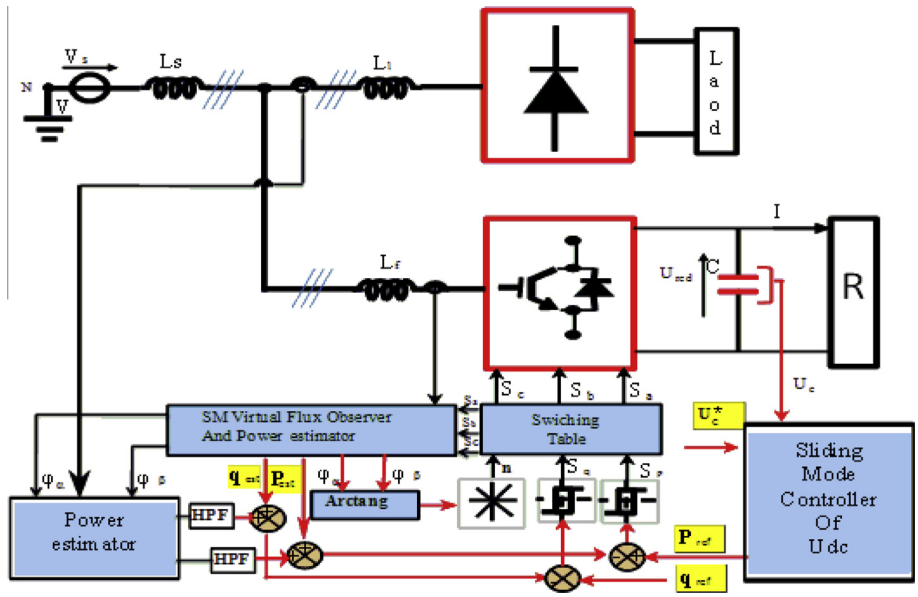

Fig. 1. Control of PWM rectifier with active filtering function based on sliding-mode observers.

The $(\alpha{-}\beta)$ components of the converter voltage vector u_{conv} can be estimated out of the dependence involving the DC-link voltage and the PWM pattern:

$$\begin{cases} v_{f\alpha} = \sqrt{\frac{2}{3}}\cdot U_c\left(S_a - \frac{1}{2}(S_b + S_c)\right) \\ v_{f\beta} = \sqrt{\frac{2}{3}}\cdot U_c(S_b - S_c) \end{cases}. \tag{2}$$

The sliding mode observer uses the system model with model with the sign feedback function. The continuous time version of the SMO is described by

$$\frac{d}{dt}\begin{bmatrix} i_{f\alpha} \\ i_{f\beta} \end{bmatrix} = \frac{1}{L_f}\lambda\cdot sign\left(\begin{bmatrix} i_{f\alpha} - \hat{i}_{f\alpha} \\ i_{f\beta} - \hat{i}_{f\beta} \end{bmatrix}\right) - R_f\begin{bmatrix} i_{f\alpha} \\ i_{f\beta} \end{bmatrix} - \begin{bmatrix} v_{f\alpha} \\ v_{f\beta} \end{bmatrix}. \tag{3}$$

The estimated values of the grid voltage are obtained from the law-pass filter:

$$\begin{bmatrix} \hat{\varphi}_{s\alpha SMO} \\ \hat{\varphi}_{s\beta SMO} \end{bmatrix} = LPF\lambda\cdot sign\left(\begin{bmatrix} i_{f\alpha} - \hat{i}_{f\alpha} \\ i_{f\beta} - \hat{i}_{f\beta} \end{bmatrix}\right). \tag{4}$$

The effective approach to the problem of the line voltage disturbances is based on the introduction of the virtual grid flux vector [13]. The virtual flux vector described by (5) is far less sensitive to the line disturbances and maintains near sinusoidal shape even in case of the low-harmonic pollution in the supply voltage:

$$\begin{bmatrix} \hat{\varphi}_{\alpha} \\ \hat{\varphi}_{\beta} \end{bmatrix} = \int\begin{bmatrix} \hat{v}_{s\alpha SMO} \\ \hat{v}_{s\beta SMO} \end{bmatrix}dt + \begin{bmatrix} \hat{\varphi}_{\alpha 0} \\ \hat{\varphi}_{\beta 0} \end{bmatrix}. \tag{5}$$

While the $(\alpha{-}\beta)$ components of the virtual grid flux are calculated as follows:

$$\begin{bmatrix} \hat{\varphi}_{\alpha} \\ \hat{\varphi}_{\beta} \end{bmatrix} = \lambda\cdot\int sign\left(\begin{bmatrix} i_{f\alpha} - \hat{i}_{f\alpha} \\ i_{f\beta} - \hat{i}_{f\beta} \end{bmatrix}dt\right) + \begin{bmatrix} \hat{\varphi}_{\alpha 0} \\ \hat{\varphi}_{\beta 0} \end{bmatrix}. \tag{6}$$

$\varphi_{\alpha\beta 0}$ Vector of initial values of virtual grid flux assumed during operation of grid voltage integration.

Hence the structure of the virtual grid flux sliding-mode observer presented in Fig. 2.

The instantaneous active and reactive powers are estimated in the block (power observer) by measurement of line current and the estimation of the virtual flux components $\varphi_{f\alpha}$, $\varphi_{f\beta}$ [13].

$$\begin{cases} \hat{P}_C = \omega(\hat{\varphi}_{\alpha}\cdot i_{f\beta} - \hat{\varphi}_{\beta}\cdot i_{f\alpha}) \\ \hat{q}_C = \omega(\hat{\varphi}_{\alpha}\cdot i_{f\alpha} + \hat{\varphi}_{\beta}\cdot i_{f\beta}) \end{cases}. \tag{7}$$

The command reactive power q_{ref} and (delivered form the outer sliding mode DC-link voltage controller) active power P_{ref} values are compared with the estimated q and p values, in reactive and active powers hysteresis controllers, respectively.

$$\begin{aligned} &\text{If } (\text{qref} - q > H_q),\ d_q = 1;\ \text{Else},\ d_q = 0; \\ &\text{If } (\text{pref} - p > H_p),\ d_p = 1;\ \text{Else},\ d_p = 0; \end{aligned} \tag{8}$$

H_p and H_q are the hysteresis band. Table 1 shows the switching table for VF-DPC control with: V_0 (000), V_7 (111), V_1 (100), V_2 (110), V_3 (010), V_4 (011), V_5 (001), V_6 (101).

Fig. 3 shows the 12 voltage sectors plane for switching table.

2.2. Stability analysis

The sliding surface representing the error between the measured and references currents are given by this relation:

$$s_{\alpha\beta} = \begin{bmatrix} s_{\alpha} \\ s_{\beta} \end{bmatrix} = \begin{bmatrix} i_{f\alpha} - \hat{i}_{f\alpha} \\ i_{f\beta} - \hat{i}_{f\beta} \end{bmatrix}. \tag{9}$$

The Lyapunov function is chosen as:

$$V = \frac{1}{2}s_{\alpha\beta}^2. \tag{10}$$

The derivative of (10) is given by:

$$\dot{V} = \dot{s}_{\alpha\beta}s_{\alpha\beta}.$$

Subtracting the Eq. (3) from the respective phase current equation of the model of the PWM rectifier yields:

$$\frac{d}{dt}\begin{bmatrix} \bar{i}_{f\alpha} \\ \bar{i}_{f\beta} \end{bmatrix} = \frac{1}{L_f}\left(\begin{bmatrix} v_{f\alpha eq} \\ v_{f\beta eq} \end{bmatrix} - \lambda.sign\left(\begin{bmatrix} \bar{i}_{f\alpha} \\ \bar{i}_{f\beta} \end{bmatrix}\right) - R_f\begin{bmatrix} \bar{i}_{f\alpha} \\ \bar{i}_{f\beta} \end{bmatrix}\right) \tag{11}$$

where

$$\begin{bmatrix} \bar{i}_{f\alpha} \\ \bar{i}_{f\beta} \end{bmatrix} = \begin{bmatrix} i_{f\alpha} - \hat{i}_{f\alpha} \\ i_{f\beta} - \hat{i}_{f\beta} \end{bmatrix} = \begin{bmatrix} s_{\alpha} \\ s_{\beta} \end{bmatrix}. \tag{12}$$