Electrical Power and Energy Systems 78 (2016) 916–925

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Improved tracking of shunt active power filter by sliding mode control

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ARTICLE INFO

Article history:
Received 7 December 2014
Received in revised form 19 September 2015
Accepted 10 November 2015
Available online 29 January 2016

Keywords:
Shunt Active power filter
CC-VSI
Non linear load
Sliding mode control
Feedback linearization
Variable structure system

ABSTRACT

An improved tracking technique of the reference current waveform in a shunt type active power filter is proposed in this paper using sliding mode control and feedback linearization. Feedback linearization approach helps to reduce the complexity of the controller. Excellent tracking is achieved in both for steady state and dynamic performance. A three-phase four-wire system is considered. The proposed algorithm is simulated first in MATLAB/SIMULINK. An experimental prototype using a dspace1104 based controller is also produced in the laboratory. Results from simulation match well with the corresponding results from experimental prototype confirming the usefulness of the proposed technique.

Introduction

In recent times most of the ac electrical power systems include several kinds of non-linear load. Non linear load involves harmonics that contaminate the sinusoidal supply voltage and current.

Harmonics not only increase the losses in the system but also produce unwanted disturbance to the communication network, more voltage and/or current stress, etc. The uses of passive filters are not desirable as they are bulky and de-rate itself with age.

Moreover this passive element may cause resonance with source impedance. This has motivated the introduction of the Active Power Filter (APF) for improving power quality. Shunt APF is used to eliminate the current harmonics, whereas, the series compensation does the same job for the voltage harmonics. Fig. 1 shows the system where a Voltage Source Inverter (VSI) operating as an APF and connected in parallel with the load [1]. Discusses the prospects of research in power quality improvement [2]. Provides extensive discussions on the robust performance of HPFC using digital simulation. While three phase reactive power compensation has been discussed in [3]. Singh et al. [4] have developed a fuzzy rule based generalized unified power flow controller. Sasaki [5] worked on systematic nonlinear control approach to a power factor corrector design. The basic principle of operation is to inject a correct nature of current to compensate for the load harmonics. This requires detection of harmonic component of the load current following which the reference-current needs to be produced. Different methods of reference generation have been proposed. These include different variants of p–q theory [12,19,21,22], synchronous reference frame [20], FFT, RDFT, wavelet based techniques and more recently ANN, GA and soft computing based approaches [27–33]. Reference [6] provides a survey of such methods. Once the reference is generated, the VSI needs to track the reference current. Many controller strategies are employed to explore better performance of tracking. Most popular techniques are PI controller, standard hysteresis controller, one cycle control, sliding mode control, etc. Adaptive control and negative feedback based repetitive control are also employed to improve the dynamic performance and stability of the overall system [17,18]. Sliding mode controller is more immune to parameter uncertainties. This feature encourages the researcher to apply sliding mode controller (SMC) to mitigate tracking error in APF [6,9,13–17,23]. Singh et al. [8,9] applied sliding mode on a three phase four wire system. The SMC is used to control the dc bus voltage. Furga et al. [10,11] reported an improved dynamic performance of the APF by applying SMC and a passive LC filter with and without active source. Feedback linearization based control is also applied to shunt APF to reduce the computation burden [24–26]. Matas et al. [7] reported feed back linearization by Tellegen's theorem [34–36] of single phase APF and then SMC is applied to simply the overall design. This paper has applied SMC to a three phase four wire system to study tracking and also to take up unbalance in the three phase load. Contrary to the available approach [11], this paper utilizes two

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http://dx.doi.org/10.1016/j.ijepes.2015.11.015
0142-0615/

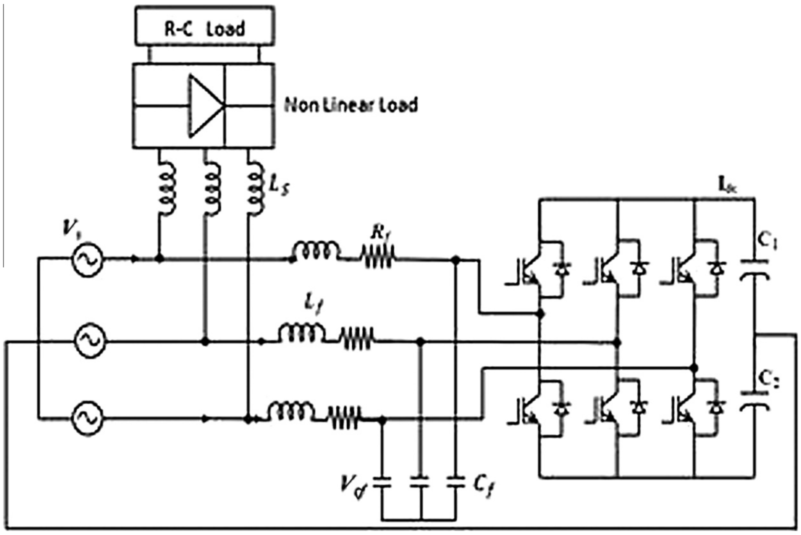

Fig. 1. Active power filter to compensate for a non-linear load.

sliding mode controllers, one for dc bus regulation and another for tracking the current reference.

A dspace1104 based controller is produced to implement the control-algorithm and generate the switching pattern to the power circuit. Fig. 1 shows the active power topology used for experimental and simulation purpose. The system may be modeled as a set of the current sources that injects reactive and harmonic current to the source. The paper is organized in six sections. Section 'Modeling of shunt active power filter for sliding mode control' deals with theoretical aspects of feedback linearization, sliding mode control and modeling of shunt active power filter with the same is presented. Simulation result is presented in Section 'Simulation results'. Experimental verification of proposed scheme is presented in Section 'Experimental results'. Section 'Conclusions' concludes the work.

Modeling of shunt active power filter for sliding mode control

Tracking of current reference

From Fig. 1 the following equation may be written for shunt active power filter. It is also assumed that source inductance is small and thus the drop across the source inductance may be neglected. The voltage at the point of common coupling is same as that of the source voltage.

$$L_f\frac{dic}{dt} = [v_s]_{abc} - [v_{cf}] + R_f i_c \tag{1}$$

$$C_f\frac{d[V_{cf}]_{abc}}{dt} = [u]_{abc} i_{dc} - [i_c]_{abc} \tag{2}$$

u_a, u_b and u_c are the switching function for the leg a, b and c for the voltage source inverter. Following way switching function is defined:

$u = 1$: If upper switch is on and lower switch is closed.

$u = 0$: If upper switch is off and lower switch is on.

Applying KCL we may establish the relation between source current, load current and compensating current as:

$$[i_s]_{abc} = [i_L]_{abc} + [i_c]_{abc}$$

$$[i_s]_{abc} = [i_L]_{abc} + [i_c]_{abc} \tag{3}$$

From (A13) (in Appendix) tracking error may be defined as follows:

$$[\varepsilon]_{abc} = [i_c^*]_{abc} + [i_c]_{abc} \tag{4}$$

Detail derivation is available in Appendix.

The reference is generated by capacitor based predictive algorithm and then followed by THD minimization technique [18]. For tracking the quantities in *abc* frame is transformed in $\alpha\beta$ frame.

Thus (4) may be expressed in the following way in $\alpha\beta$ frame:

$$[\varepsilon]_{\alpha\beta} = [i_c^*]_{\alpha\beta} + [i_c]_{\alpha\beta} \tag{5}$$

From (1)–(4) the state space representation of the APF may be expressed

$$[\ddot{\varepsilon}]_{\alpha\beta} = -\frac{1}{T_r^2}[\varepsilon]_{\alpha\beta} - \frac{T_{rd}}{T_r^2}[\varepsilon]_{\alpha\beta} + [f]_{\alpha\beta} - \frac{1}{T_r^2}[u_{\alpha\beta}]i_{dc}. \tag{6}$$

Where $T_r = 2\pi/\sqrt{L_f C_f}$ and $T_{rd} = 2\pi/\sqrt{R_f C_f}$ (7)

The tracking function $[f]_{\alpha\beta}$ may be expressed as follows:

$$[f]_{\alpha\beta} = \left([\ddot{i}_c^*]_{\alpha\beta} - [\ddot{i}_c]_{\alpha\beta}\right) + \frac{T_{rd}}{T_r^2}\left([\dot{i}_c^*]_{\alpha\beta} - [\dot{i}_c]_{\alpha\beta}\right) + \frac{1}{T_r^2}\left([i_c^*]_{\alpha\beta} - [i_c]_{\alpha\beta}\right). \tag{8}$$

The resonance frequency (ω_r) of the L-C filter is much higher than supply frequency, i.e $\omega_r \gg \omega_s$. Where

$$\omega_r = \frac{1}{\sqrt{L_F C_F}} \tag{9}$$

Eq. (9) may be further simplified considering the fact that the resistance present in the shunt path is very low. Thus modified expression of $[f]_{\alpha\beta}$ is:

$$[f]_{\alpha\beta} \approx \left([\ddot{i}_c^*]_{\alpha\beta} - [\ddot{i}_c]_{\alpha\beta}\right) + \frac{1}{T_r^2}\left([i_c^*]_{\alpha\beta} - [i_c]_{\alpha\beta}\right) \tag{10}$$

The use of sliding mode control and design of sliding surface has been discussed in detail in [19,21].

For active damping of L-C filter and reduction in tracking error, following relation is established between the sliding surface "s" and nonlinear control command "u".

$$[u^i]_{\alpha\beta} = sign([s]_{\alpha\beta}) \tag{11}$$