Energy Conversion and Management 79 (2014) 449–455

Contents lists available at ScienceDirect

Energy Conversion and Management

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

A novel single-phase phase space-based voltage mode controller for distributed static compensator to improve voltage profile of distribution systems

Abdollah Shokri [a], Hussain Shareef [a], Azah Mohamed [a], Masoud Farhoodnea [a,*], Hadi Zayandehroodi [b]

[a] Department of Electrical, Electronic and Systems Engineering, UniversitiKebangsaan Malaysia (UKM), Malaysia
[b] Department of Engineering, Kerman Branch, Islamic Azad University, Kerman, Iran

ARTICLE INFO

Article history:
Received 3 September 2013
Accepted 14 November 2013
Available online 19 January 2014

Keywords:
Voltage fluctuation
Voltage control
Phase space
D-STATCOM controller
Power quality

ABSTRACT

Distribution static synchronous compensator (D-STATCOM) has been developed and attained a great interest to compensate the power quality disturbances of distribution systems. In this paper, a novel single-phase control scheme for D-STATCOM is proposed to improve voltage profile at the Point of Common Coupling (PCC). The proposed voltage mode (VM) controller is based on the phase space algorithm, which is able to rapidly detect and mitigate any voltage deviations from reference voltage including voltage sags and voltage swells. To investigate the efficiency and accuracy of the proposed compensator, a system is modeled using Matlab/Simulink. The simulation results approve the capability of the proposed VM controller to provide a regulated and disturbance-free voltage for the connected loads at the PCC.

1. Introduction

The power electronic based compensators (also known as custom power devices (CPDs)) are broadly used in today's power distribution systems to provide various compensating functions against power quality disturbances, such as voltage sag/swell, harmonic distortion and power interruption, at whole or specific parts of the distribution systems [1]. The most important advantages of a CPDs are the faster and better dynamic characteristics compare to that of the conventional methods. Among the well-known CPDs, D-STATCOM, which is an Insulated Gate Bipolar Transistors (IGBT) based compensator, is wildly applied to rapidly control the voltage magnitude and phase angle at the PCC using a pulse with modulation (PWM) power converter technology. Nevertheless, the functionality of the D-STATCOM strongly depends on the performance of control unit [2].

There are two traditional voltage mode (VM) control methodology to detect and compensate voltage disturbances using a D-STATCOM namely the root mean square (RMS) and standard decoupled d–q vector control schemes [3]. In the first controller the rms value of the PCC voltage is compared with the reference value (usually 1 p.u) and the obtained error determines the magnitude of the missing voltage that should be compensated using the D-STATCOM. While in the second control scheme the PCC voltage is decomposed into direct-quadratic voltage components. Then the obtained decomposed values are fixed by multiplying the ac instantaneous voltage values with a predefined matrix to calculate the missing voltage. To improve the missing voltage estimation, a phase-locked loop (PLL) can be used to lock the grid voltage and predict the voltage magnitude and phase, and then the result is compared with the reference voltage [4,5]. In some approaches, the peak voltage value is used to estimate the absolute peak voltage amount of the missing voltage. In such methods, the gradient of the PCC voltage for each sampling time is computed, and the peak voltage is determined as the voltage instant when the gradient is zero [6]. Artificial neural network (ANN) based-controllers are also applied to estimate the reference signal using the least mean square (LMS) algorithm [7,8]. Nonetheless, the ANN-based methods need a massive training data which make these controller unsuitable for detecting some PQ disturbances such as voltage sags. Generally, most of these methods are unable to detect short-duration voltage disturbances especially in an appropriate time frame. To cope with this problem, the Goertzel controller based D-STATCOM was proposed to rapidly detect and compensate voltage sags. This method is based on the digital Fourier transform (DFT), but uses half number of real multiplications compared to DFT calculation [9]. This method is not sensitive to noise or harmonics, but the detection speed still needs improvement.

Apart from voltage sag mitigation, different controller can also be applied on D-STATCOM to carry out different power quality compensation such as harmonic distortion mitigation. A modified

* Corresponding author. Tel.: +60 111 2800403.
E-mail address: frahoodnea_masoud@yahoo.com (M. Farhoodnea).

0196-8904/$ - see front matter © 2014 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.enconman.2013.11.024

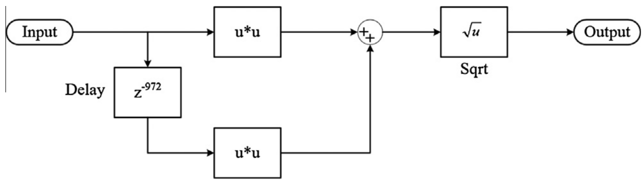

Fig. 1. Phase space block.

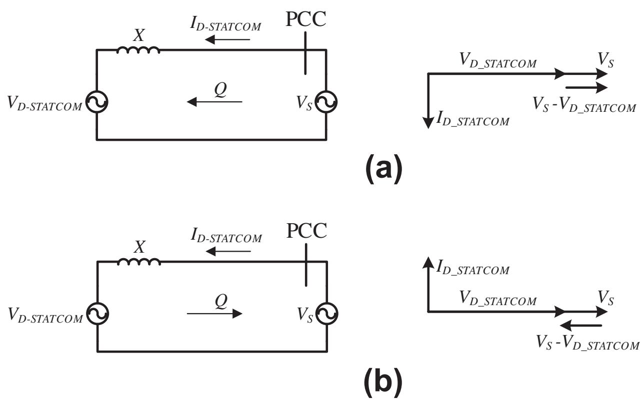

Fig. 2. D-STATCOM operation for voltage profile improvement, (a) inductive operation for over-voltages and swells and (b) capacitive operation for under-voltages and sags.

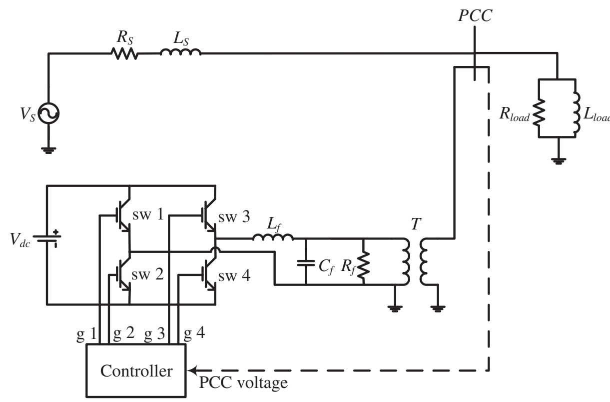

Fig. 4. Single phase diagram of the test system and the D-STATCOM compensator.

Table 1
Test system data.

Components	Value
V_{dc}	400 V
R_f	10 Ω
C_f	10 μF
L_f	20 mH
T	1:1 (N:n), 250 kW
V_s	280 V_{pik}
R_S	0.4 Ω
L_S	100 mH
R_{load}	50 Ω
L_{load}	15 mH

synchronous detection algorithm was proposed based on equal current approach for extraction of reference supply currents and current harmonic mitigation in three-phase systems [10]. An improved instantaneous active and reactive current component theory [11], and an adaptive notch filters [12] – based controller were separately proposed in order to compensation of network's reactive power, balancing of source currents, current and voltage harmonic contents.

This paper presents a novel voltage mode D-STATCOM controller to rapidly detect and mitigate voltage disturbances including voltage sags, swells and unregulated voltage. The VM control scheme is based on the phase space approach with is very fast and accurate in detection of voltage disturbances. To examine the performance of the proposed compensator, a system is modeled using Matlab/Simulink and several types of voltage disturbances are created. The results approve the ability of the proposed controller to provide a regulated and disturbance-free voltage at the PCC.

2. Control methodology

2.1. Phase space approach

Phase space approach (also known as embedding) can be used as a tool to reconstruct a time series signal in a higher-dimensional space to observe the signal features more clearly [13]. Hence, any d-dimensional system can be represented by d first-order differential equations, and the state solution of these equations can be shown as $s \in R^d$, where R denotes the Euclidean space. The measured function, $x = h(s)$, transforms a collection of s state to a scalar time series with the delay-coordinate, τ, which is a positive number. Function $F_\tau(s_i) = s_{i+\tau}$ is defined to evaluate the s state at time i and the delay-coordinate. The embedding Φ: $R^d \to R^{dE}$ is determined as:

$$\begin{aligned}\phi(h,F,\tau)(s_i) &= \{h(s_i), h(s_{i+\tau}), \ldots, h(s_{i+(d_E-1)\tau})\} \\ &= \{x_i, x_{i+\tau}, \ldots, x_{i+(d_E-1)\tau}\} = x_i \end{aligned} \quad (1)$$

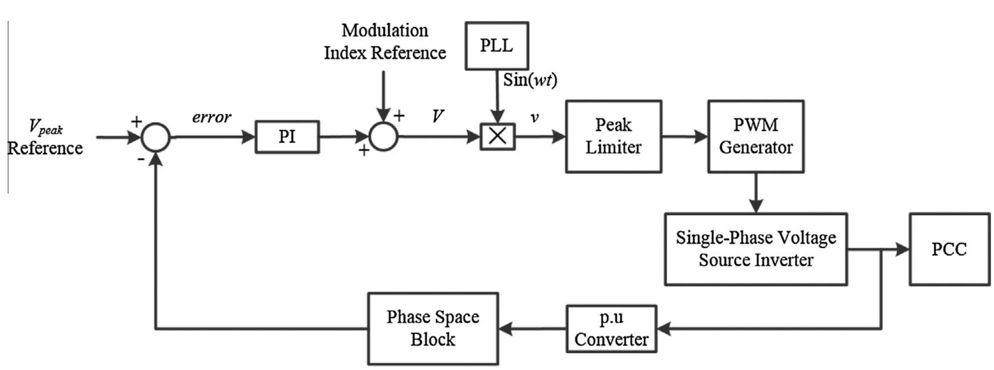

Fig. 3. Proposed control block diagram.