Electrical Power and Energy Systems 54 (2014) 376–386

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Investigating the performance of photovoltaic based DSTATCOM using $I\cos\Phi$ algorithm

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ARTICLE INFO

Article history:
Received 2 June 2012
Received in revised form 18 July 2013
Accepted 23 July 2013

Keywords:
Distribution Static Compensator
Photovoltaic array
Boost converter
Voltage source converter
$I\cos\Phi$ controlling algorithm
Fuzzy logic controller

ABSTRACT

In this paper, a three-phase three-wire Distribution Static Compensator (DSTATCOM) which is fed by Photovoltaic (PV) array or battery operated DC–DC boost converter is proposed for power quality improvement in the distribution system. The DSTATCOM consists of a three-leg Voltage Source Converter (VSC) with a DC-link capacitor. The PV array or battery operated boost converter is used to maintain the desired voltage across the DC bus capacitor to provide continuous compensation. The proposed DSTATCOM provides continuous source harmonic reduction, reactive power compensation and load compensation throughout the day. The $I\cos\Phi$ controlling algorithm is proposed for three-phase three-wire DSTATCOM. The performance of the Fuzzy Logic Controller (FLC) is compared with the conventional Proportional Integral (PI) controller at AC voltage controller in $I\cos\Phi$ algorithm. The fuzzy controller further reduces the source current Total Harmonic Distortion (THD) when compared with the conventional PI controller. The main advantage of this proposed system is to provide continuous compensation for the whole day. The switching of VSC will occur by comparing the reference source current with the sensed source current using hysteresis based Pulse Width Modulation (PWM) current controller. The performance of the DSTATCOM is validated using MATLAB software with its simulink and Power System Blockset (PSB) toolboxes.

1. Introduction

Extensive application of power electronic devices and other distorting loads inject harmonics and reactive current into the distribution system which is harmful to electronic equipments that require high power quality [1–3]. To provide clean power to the consumers many researchers have focused on renewable energy source based power quality improvement in the distribution system [4–7]. Power quality has caused a great concern to electric utilities with the growing use of sensitive and susceptive electronic and computing equipments such as personal computers, computer-aided design workstations, fax machines, uninterruptible power supplies, printers and other nonlinear loads such as fluorescent lighting, adjustable speed drives, heating and lighting control. Power quality is often considered as a combination of voltage and current quality. In most of the cases, it is considered that the network operator is responsible for voltage quality at the point of connection while the customer's load often influences the current quality at the point of connection. Increase in the number of nonlinear power electronic equipment and presence of sensitive electronic equipment in the distribution side, results in the flow of harmonic current in the line. This harmonic current leads to the additional losses in the distribution equipments, interference with the communication systems and maloperation of the control equipment. The group of controllers used in the distribution system for the benefits of customers is known as Custom Power Devices (CPDs). These devices have the ability to provide remedial measures and cost effective solution to the power quality problems [8,9]. Among these, DSTATCOM is one of the most effective devices [10,11].

The DSTATCOM is one of the shunt connected custom power device which injects current through the interface inductor at the Point of Common Coupling (PCC). Hence, source current harmonic reduction, reactive power compensation and load current compensation can be achieved. The different topologies of DSTATCOM are reported in the literature such as a 4-leg VSC, three single phase VSC and 3-leg VSC with split capacitor [12,13]. The proposed DSTATCOM consists of three-leg VSC with a DC-link capacitor. The operation of VSC is supported by a DC-link capacitor with proper DC voltage across it. Hence, in this paper Photovoltaic (PV) module or battery interfaced boost con-

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http://dx.doi.org/10.1016/j.ijepes.2013.07.027

Nomenclature

I_{ph}	light generated current or photocurrent
I_{sat}	saturation current of the diode (10^{-4} A)
Q	electron charge (1.6×10^{-19} Coulombs)
A	ideal factor (1.23)
K	Boltzmann's constant (1.38×10^{-23} J/K)
T	cell working temperature (25 °C)
R_s	series resistance (0.001 Ω)
R_{sh}	shunt resistance (200 Ω)
I	cell output current
V	cell output voltage
V_{out}	boost converter output voltage
V_{in}	input voltage
D	duty cycle
V_L	voltage across the inductor
I	output current
X_L	leakage reactance
F	switching frequency
$I_{L(abc)n}$	amplitude of nth harmonic current in a, b and c phases
$\Phi_{(abc)n}$	phase angle of nth harmonic current in a, b and c phases
$I_{L(abc)}$	load current in a, b, and c phases
i_{smd}	output of the DC bus voltage PI controller
$V_{dcr(n)}$	reference DC bus voltage
$V_{dc(n)}$	sensed DC-link voltage
K_{pd} and K_{id}	proportional and integral constants of the DC bus voltage
$V_{dce(n)}$ and $V_{dce(n-1)}$	voltage errors in nth and $(n-1)$th instant
i_{smq}	output of the FLC employed at AC voltage controller
$V_{tr(n)}$	reference AC terminal voltage
$V_{t(n)}$	three-phase AC terminal voltage

verter is connected to the DC bus capacitor of VSC which is used to maintain the desired voltage across the DC bus for providing continuous source current harmonic reduction, reactive power compensation and load compensation throughout the day.

In order to control the DSTATCOM and to generate the reference currents, there are number of controllers reported in the literature survey such as instantaneous reactive power theory [14–16], Synchronous Reference Frame (SRF) theory [17], Synchronous Detection (SD) theorem [18], neural network controller [19] and power balance theory [20]. Among these, synchronous detection theorem [18] and synchronous reference frame theory [17] are the most widely used reference current generation techniques for three phase system. A thorough study reveals that the methods discussed above require fine tuning to make the circuit implementation as simple and rugged as possible. Specifically, the SRF theory is easy to implement because the controller deals mainly with the DC quantities. In Ref. [7], the SRF theory is employed to generate the reference source current for the operation of PV based DSTATCOM. From the obtained result, the source current THD for SRF theory employed DSTATCOM is not less than IEEE 519-1992 permissible limit of 5%. A simple and effective current compensation algorithm has been proposed to compensate for harmonics [21]. This algorithm is effective in case of nonlinear load which does not require reactive power compensation. Hence, an $I \cos \Phi$ controlling algorithm has been proposed for reduction in current harmonics (<5%) and to supply reactive power to the load [22]. After tracking the reference currents with the help of this controlling algorithm and by comparing it with sensed source currents, the switching of VSC will occur and hence cancel out the disturbances caused by the nonlinear load.

In this paper, PV or battery fed boost converter operated DSTATCOM is mainly employed to provide continuous compensation against the source current harmonics for the whole day. When continuous compensation is required, the PV array is directly connected to the boost converter in the day time and during the night time battery acts as a DC source for the boost converter. In $I \cos \Phi$ controlling algorithm, FLC has been proposed at AC voltage controller in order to investigate the performance of the controller in reducing the source current harmonics. This paper does not discuss the maximum power point algorithm and the boost converter presented in this paper utilizes the PWM technique. The proposed system is simulated under Matlab/Simulink software package. The organization of the rest of this paper is as follows: Section 2 describes the proposed system configuration with different operating modes. Section 3 depicts the modeling of PV module via Matlab/Simulink and design of boost converter. The proposed FLC employed at AC voltage controller in $I \cos \Phi$ algorithm to generate the reference source current is depicted in Section 4. The simulation results of the proposed algorithm are reported in Section 5. Finally, the conclusion and the findings from the investigation are presented in Section 6.

2. System configuration with different operating modes

Fig. 1 shows the circuit diagram of the three-phase three-wire system which is used to feed the nonlinear load continuously. The utilized nonlinear load is a three-phase uncontrolled bridge rectifier supplying an R-type load. The nature of the nonlinear load is to cause distortion in source current. In order to eliminate the source current distortion, the control of DSTATCOM is achieved by using $I \cos \Phi$ algorithm. The load currents, source voltages and the DC bus voltage are given as an input to the $I \cos \Phi$ controlling algorithm. The controlling algorithm is used to generate the reference source currents. Then the hysteresis based PWM current controller compares the reference and sensed source currents to generate the firing pulse to the DSTATCOM. The DSTATCOM consist of six Insulated Gate Bipolar Transistor (IGBT) based three-leg VSC which is used as a Voltage Source Inverter (VSI) with a DC-link capacitor. The PV module or battery fed boost converter is connected to the DC-link capacitor, which is used to provide a desired voltage across the capacitor for continuous compensation. According to the gate pulse given, the switching of VSI will occur which injects a currents at the PCC through the interface inductor L_r. The inductance allows the output of the VSI to look like a current source to the distribution system.

The operation of the proposed DSTATCOM has been divided into four different operating modes. The modes are (i) Day time excess power mode, (ii) Day time mode, (iii) Night time mode and (iv) Idle mode. Table 1 shows the switching states of four different operating modes.