Electrical Power and Energy Systems 46 (2013) 392–399

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

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

An investigation on combined operation of active power filter with photovoltaic arrays

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ARTICLE INFO

Article history:
Received 16 September 2010
Received in revised form 16 June 2012
Accepted 20 October 2012
Available online 30 November 2012

Keywords:
Power electronic interface
Photovoltaic
Modeling
Control system
Active Power Filter (APF)

ABSTRACT

In this paper, the combined operation of the active power filter with the photovoltaic generation system has been studied. The proposed system consists of a PV power plant, a DC–DC boost converter, and an active power filter. A novel control strategy for the DC–DC converter has been developed in order to extract the maximum amount of power from PV arrays. Also, a novel control strategy, which is based on generalized instantaneous reactive power theory, has been proposed for the active power filter. The simulation results, based on PSCAD/EMTDC, show that the proposed system can provide the power factor correction, load balancing, harmonic elimination, reactive power compensation and simultaneously inject the maximum power available from the PV array into the grid.

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1. Introduction

Solar energy has great potential to supply energy with minimum impact on the environment, since solar energy is clean, pollution-free and inexhaustible. With the decrease in the price of photovoltaic (PV) modules and the increase in the price of conventional petrochemical fuels, the application of the PV generation system becomes more practical, feasible and realizable [1,2]. PV cells are normally connected together to make up modules, which can be combined into PV arrays as required. Therefore, power electronic converters are an enabling technology that is necessary to convert PV array DC power into usable AC power for grid support or supplying special loads [1–5].

Grid-connected PV generation is one of the major development trends of solar energy applications. Moreover, PV grid-connected generation operates during the day and has to stop at night. This affects the stabilization of power system and the utilization of equipment. Therefore, in order to increase the utilization, the PV system can be designed to also provide the function of power quality managements [6]. Also, grid-connected PV system can be used to reduce the peak demand that the utility must satisfy. In this application, the PV system does not require a battery bank, but the power stage remains idle during the night [7]. One drawback of solar energy sources is the need for battery bank for the system to be utilized for a significant percentage of the day. Avoiding adding a battery bank to a PV generation system results in a design, which needs the combine operation with Active Power Filter (APF) to also provide the power factor correction, load balancing, harmonic elimination, reactive power compensation and simultaneously inject the maximum power available from the PV array into the grid. When the solar irradiation is unavailable, then the active power filter can still be utilized to improve the power quality. When the solar irradiation is available, the proposed system can supply the load and simultaneously solve growing problems of harmonics, unbalanced loads and reactive consumption in distribution system.

The PV array is interfaced with the utility network via DC–DC boost converters and a three-phase Pulse-Width Modulation (PWM) DC–AC converter, The DC voltage generated by a PV array varies widely and is low in magnitude. Therefore, a DC–DC boost converter is necessary to generate a regulated higher DC voltage for desired converter input voltage. Generally, the grid connected PV systems extract maximum power from the PV arrays. The Maximum Power Point Tracking (MPPT) technique is usually associated with a DC–DC converter.

The shunt APF, which has a DC–AC Voltage Source Converter (VSC) can provide the harmonic elimination, load balancing and power factor correction. Moreover, VSC is employed to interface PV array with utility grid under both on-grid and off-grid operation modes [1,3]. The DC–AC converter injects sinusoidal current into the grid, and can control the power factor [1–5]. Therefore, DC–AC converter in grid-connected PV system can have the function of shunt APF.

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0142-0615/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2012.10.033

This paper proposes the combined operation of shunt APF and PV grid-connected generation system. The suggested system has been used as shunt APF, when solar irradiation is not available. Also, it can generate the power by PV array and works as APF, when solar irradiation is available. The control strategy of the APF should be able to deliver a preset amount of active and reactive power to the grid or to provide the power factor correction, load balancing, harmonic elimination or reactive power compensation.

In this paper, a novel control strategy of the DC–DC converter has been developed, in order to extract the maximum amount of power from the PV array. Also, a new control strategy based on generalized instantaneous reactive power theory has been presented for the active power filter. The generalized instantaneous reactive power theory gives a generalized definition of instantaneous reactive power, which is very easy to calculate and decompose all components, such as fundamental active/reactive power and current, harmonic current and load unbalancy [8,9]. The advantage of the proposed system over the system presented in [7] is the capability of the proposed system to compensate the unbalanced load current, the harmonics and reactive power.

The effectiveness of the proposed system has been verified by simulations. The simulation results show that the novel control scheme can adjust the DC energy, compensate the power factor of the utility grid and improve the dynamic behavior of the grid-connected PV system.

2. Proposed system

The proposed configuration of APF and grid-connected PV generation system is shown in Fig. 1. A verified model of a 200 W PV module has been used for the PV power plant [10]. The PV power plant consists of five PV arrays connected in parallel. The DC–DC boost converters drain the energy from PV arrays and feed the DC bus capacitor based on MPPT control method. In this paper, the DC bus voltage (DC–DC converter output) is V_{dc} = 750 V. The DC bus is connected to a bi-directional six-switch current controlled VSC, with neutral clamped DC capacitors. Through this converter, the energy, generated by the PV arrays is transferred to the three phase utility grid (400 V/50 Hz) or the AC loads. An LC filter has been used at the output of VSC to filter the switching frequency harmonics. In this paper, the filter inductor is equal to 1.3 mH and the filter capacitor is equal to 0.1 μF. The AC loads are nonlinear and unbalanced.

A novel control strategy for the DC–DC converter has been developed in order to extract the maximum amount of power from the PV array. Also, a novel control strategy, which is based on generalized instantaneous reactive power theory, has been proposed for the active power filter. The proposed control scheme for the active power filter is designed to keep this DC bus voltage within a specified limit (i.e., ±5%). Also, this converter controller adjusts the active and reactive power delivered to the utility grid. However, the proposed system, based on novel current controller, can provide the power factor correction, load balancing, harmonic elimination, reactive power compensation and simultaneously inject the maximum power available from the PV array into the grid. Super-capacitors are connected to the DC bus to provide energy storage capability under different operation modes.

3. Power management of proposed system

Power management strategy of AC–DC converter provides suitable power transfer and regulation between AC source and active power filter. Fig. 2 shows the ideal active and reactive power flow of PV power plant. The reference active power of a PV unit is specified by its power management system which should consider various technical and economical constraints and environmental conditions. The operation of the proposed system can be divided into daytime and nighttime operation modes. As shown in Fig. 2, the AC loads are absorbing the active power (p_{Ls}) and reactive power (q_{Ls}). In the daytime mode, if the APF starts to inject active power (p_f), clearly the active power supplied by the AC source, p_s will decrease. When the PV power is larger than the load demand throughout the system, the excessive power of PV will be injected to the AC source. If the available power is insufficient for loads, the AC source will supply the loads. In the nighttime mode, p_f is equal to zero and the AC source will supply AC loads. However, we have:

$$p_{Ls} = p_f + p_s \quad \text{and} \quad p_f = p_{dc} = p_{pvs} \tag{1}$$

In both modes, the reactive power of AC loads must be compensated by APF. If q_f is equal to q_{Ls}, then the source power factor can be kept equal to unity under different load conditions. However, we have:

$$q_{Ls} = q_f \quad \text{and} \quad q_s = 0 \tag{2}$$

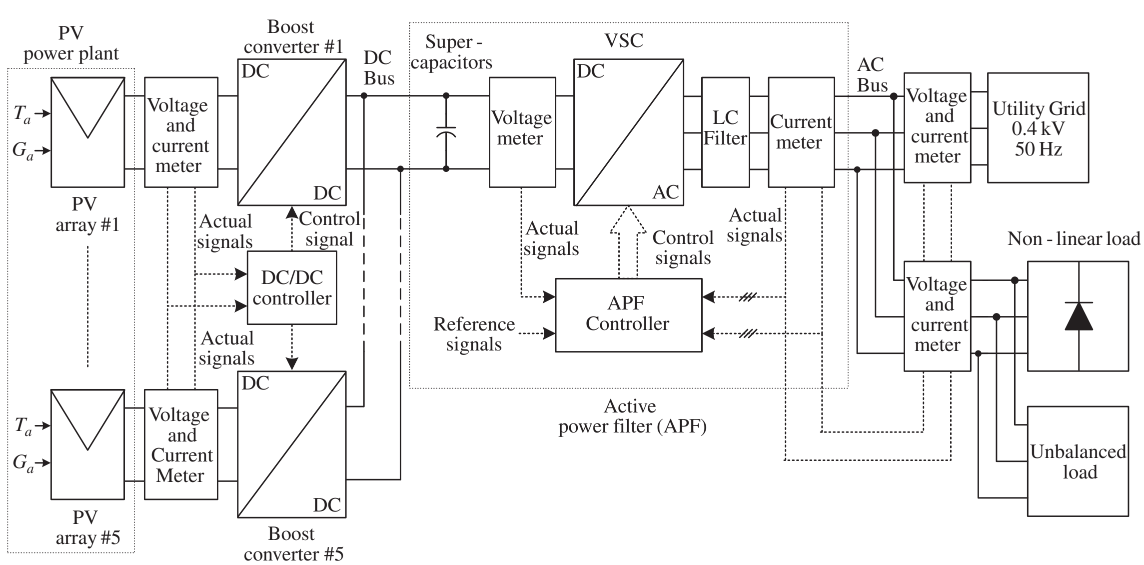

Fig. 1. Proposed system, which based on APF and grid-connected PV.

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