

A Novel Grid Connected Photovoltaic System

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Abstract

In this paper, a novel grid connected photovoltaic system is proposed which can function as an Active Power Filter (APF) with Maximum Power Point Tracking (MPPT). Filter reference current is derived using Fourier Transform. Considering 33% reduction in inverter switches, cost of the grid-connected photovoltaic power plant can be reduced considerably. Using this approach, it is also possible to compensate for reactive and harmonic components of the local loads; moreover it can inject generated active power into grid at maximum power point of the photovoltaic cells. According to this, during daytime, the proposed system injects active power to the grid and at the same time compensates for the reactive power of the load. When there is no sunlight, the inverter only compensates local loads. Considering cost reduction, such capabilities may result in more application of the grid connected photovoltaic systems. Main novelty of the proposed system is simultaneous APF and MPPT functioning using single DC/AC converter. In fact, extra DC-DC converter is not required in the proposed system for MPPT. In order to verify the performance of the proposed method, some simulation is done using MATLAB/Simulink software. Also, some experimental results are presented for practical verification of the proposed grid connected inverter.

Keywords: reactive and harmonic compensation, active power filter, Fourier Transform, grid connected photovoltaic, B_4 inverter, cost reduction, MPPT and DC-DC converter elimination

1. Introduction

Power electronics converters application in industrial and commercial utilizations have been resulted in the problem of drawing non-sinusoidal current the grid [1]. These power electronic devices, together with the application of non-linear controllers, inject harmonics to the power system and presence of these harmonics may result in increased loss. Different equipment can be used to eliminate harmonics in power networks e.g. active and passive filters, shunt, series and hybrid compensators. Shunt Active Power Filter (SAPF) is used more widely considering better performance and its reliability [2]. In SAPFs, principal of operation is based on appropriate harmonic current injection at the point of common coupling. Hence, load required harmonic currents is supplied from SAPF instead of the grid. Therefore, grid current will be purely sinusoidal. In SAPFs, Load compensation depends on three important factors: accurate measurement of the load current and voltage, calculation of the reference current and finally appropriate switching strategy [3]-[4]. Reference current may be calculated in three different domains. First approach is time-domain method. For example in [5], a d-q transformation is proposed for reference currents calculations in SAPF which is based on the instantaneous reactive power theory. The compensation currents are extracted using p-q transformation. However, application of these transformations may cause complexity in implementation of shunt active power filters. In 1996 Peng et al [6] have presented a general theory of the instantaneous reactive power in abc coordinates. Although this method doesn't require consecutively transformation, but still extra calculations should be done for generation of the instantaneous reactive power vector. In fact, time-domain calculations are based on some measurements and transformations of the three phase quantities [7]. The second method is frequency-domain techniques such as: fast Fourier transform [8], discrete Fourier transform [9] and recursive discrete Fourier transform [10]. It should be noted that, main advantage of the time-domain methods, compared with the frequency-domain methods is its fast response. On the other side, frequency-domain methods provide accurate individual and multiple detection of the load harmonic current [11]. The third approach is based on time-frequency domain. Wavelet Transform (WT) is a powerful signal processing tool for computing time-frequency

representation of power signals [12]. In [13], in order to obtain the reference current for SAPF based on fundamental positive sequence, discrete wavelet transform is used.

Among different switching methods, current controllers are more popular in grid connected photovoltaic systems due to: a) Since utility is a fixed voltage source, in order to control power flow between photovoltaic systems and the utility, it is only enough to control the current flow [14], b) If the voltage control method is used, small phase error in the output voltage of the inverter may cause very large power error [15].

Various current control techniques are proposed for grid connected inverters such as Hysteresis Current Control (HCC) [16]-[17], Adaptive-Fuzzy Hysteresis Current Control [18], Delta Modulation Control [19]-[20] and Carrier-Based PWM Control [21]-[22]. The performance index for comparison of different methods is THD value of the source currents after compensation.

The requirements for generation of the clean energy resulted in application of the renewable energy resources such as wind and solar systems. It should be noted that, invention of the low-cost thin film panels, may increase application of photovoltaic power plants in the future [23]. There are some advantages in motivation toward grid-connected photovoltaic system:

- 1) Cost reduction
- 2) Reactive and harmonic compensation of the load.
- 3) Elimination of the backup battery

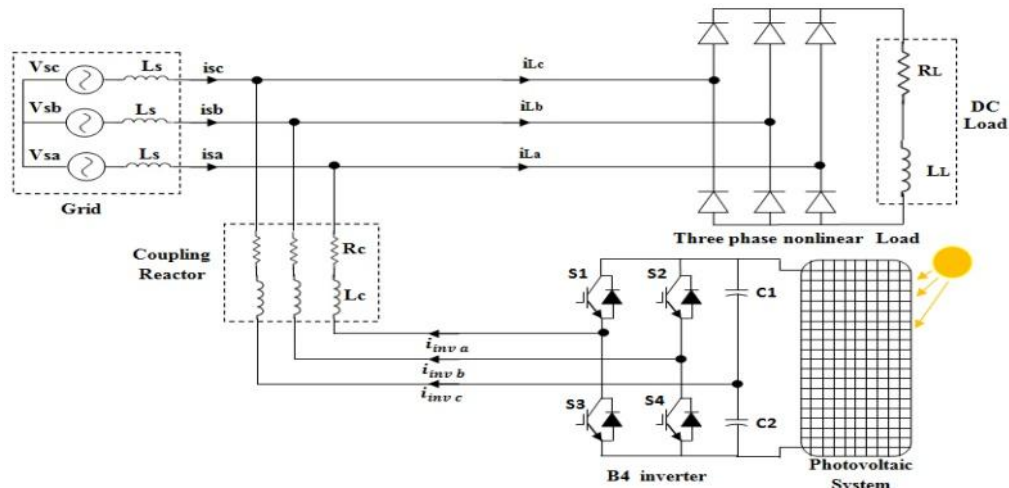


Figure 1. Proposed grid connected PV system using B4 inverter

In order to improve performance of the grid connected PV system, it is possible to compensate local loads using photovoltaic power plants [24]. A controller that combines the photovoltaic grid-connected generation and power quality managements is proposed in [25]. Also in [26], an efficient method for power factor correction of the local loads with grid connected photovoltaic systems has been introduced. In [27], a simple control approach has been proposed for PV system which is capable of local load compensation. A model reference based adaptive controller for SAPFs is present in [28] to cancel the harmonic/reactive components in the line current. Also in [29], another method for combination of the SAPF with photovoltaic system is proposed. In this case, grid connected inverter can inject active power into grid and compensates load. In [14], instead of the traditional three-phase inverters, a novel inverter is used which can reduce total cost of the system considerably.

Primary version of this research is published by author of this paper in [30]. In this paper, some modifications are considered for improvement of the system capability. Main objectives of this paper which are different from previously published papers can be summarized as:

- 1- MPPT capability is added to the control system. In fact, in the proposed system extra DC-DC converter is not required and APF and MPPT functions are accomplished using a single DC/AC converter.
- 2- For practical investigation of the presented system, some experimental results are presented.

In this paper, a novel method for calculation of the reference current in low-cost grid connected PV system with active power filtering capability is proposed. In the following, at first SAPFs are reviewed in Section II. Then in the Section III, reference current calculation by Fourier series expansion is developed. Finally, the accuracy of proposed control strategy has been verified using the MATLAB / Simulink software.

2. Low Cost Grid Connected PV System

The main idea of this paper is control of the proposed system for simultaneous APF and MPPT functions. In APF, the reference current is calculated to eliminate harmonic and reactive components in point of common coupling. Also the system injects active power of the photovoltaic panels into grid at maximum power point of the photovoltaic cells. The structure of low-cost grid connected photovoltaic system is illustrated in Figure 1. It is implemented using a B4 three-phase DC to AC inverter which is connected to the DC-link capacitors and photovoltaic cells in the input port of the inverter. In order to analyze performance of the proposed system as a harmonic filter, a three phase uncontrolled rectifier is connected to the inverter as a nonlinear local load at the point of common coupling.

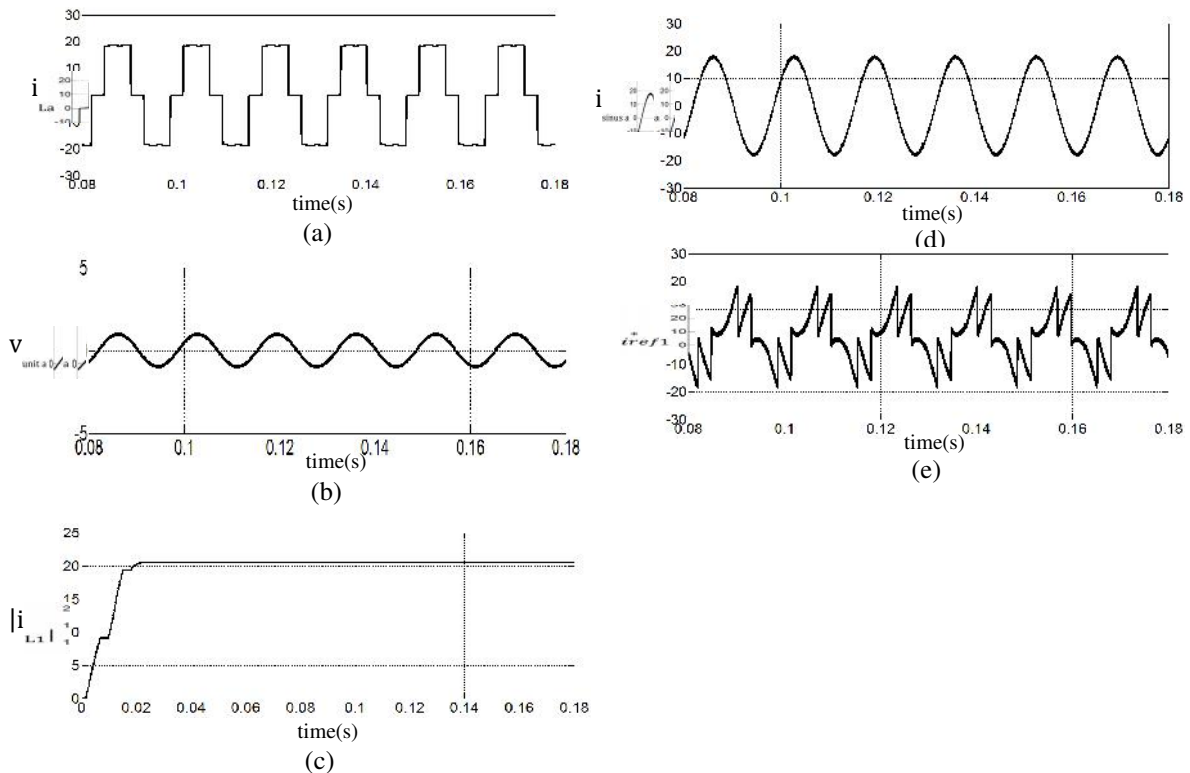


Figure 2. Calculation of the reference current: (a) Load current (b) Amplitude of the load current (c) Unit sinusoidal voltage in phase with the grid voltage (d) Desired current of the source (e) reference current (i_{ref1}^*)

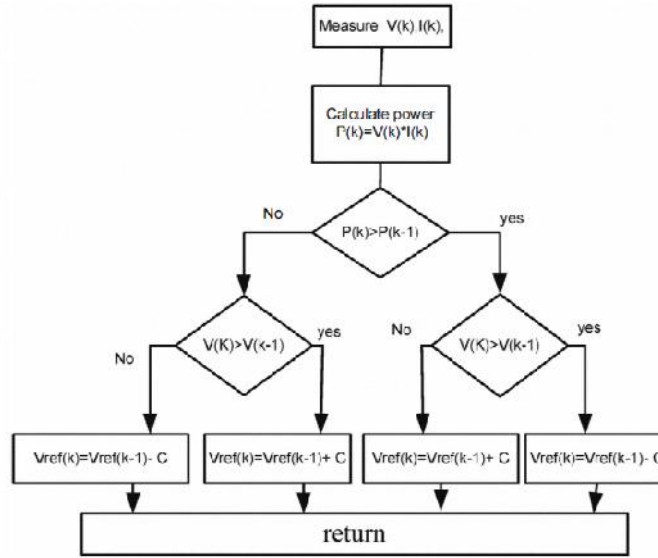


Figure 3. PI control loop for regulation of the capacitors voltage

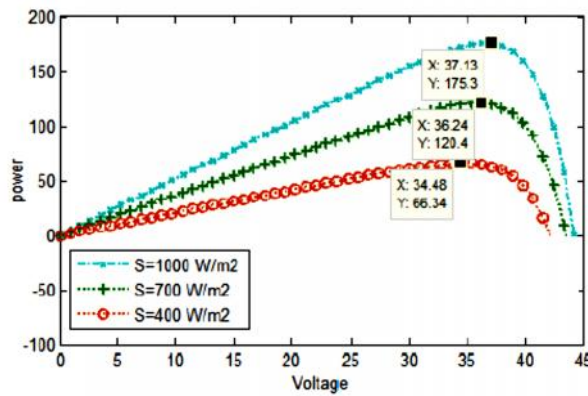


Figure 4. Output power of the PV panel in different conditions

3. Calculation of the Reference Current [30]

Reference compensation current is determined mainly using the information about both the fundamental and the harmonic contents of the measured load current. This method is based on time-domain analysis. In this paper, Fourier series expansion method is used to extract magnitude of the fundamental component of the load current. In this approach, on-line samples of the load current and voltage is used in the Fourier series expansion. Load current can be written as follows:

$$i_L(t) = i_{sin}(t) + i_h(t) \tag{1}$$

where i_{sin} , i_h are ideal current of the source and harmonic components respectively. Fundamental component magnitude of the load current is:

$$|i_{L1}(t)| = \sqrt{a_1 + b_1} \tag{2}$$

where: