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Active Power Sharing and Reactive Power Compensation in a Grid-tied Photovoltaic System

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Abstract

In the present scenario of energy crisis, researches on non-conventional energy sources have grown appreciably. The electrical energy derived from the PV panel is considered as the most useful natural resources. This paper deals with the operation and control of a grid interfaced PV system. Inverter control is achieved by using adaptive hysteresis current control scheme. The proposed inverter control technique interfaces renewable energy source and the AC bus of micro grid. It provides the possibility of injecting power from the renewable sources and favours reactive power compensation. The resulting controller is simulated in MATLAB/SIMULINK and results are analyzed.

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Keywords: Active Power Injection, DC-DC Boost Converter, Hysteresis Controller, Photovoltaic System, MPPT Algorithm, SRF.

1. Introduction

Renewable energy resources play a vital role in generating power in the current era. Besides reducing the emission of greenhouse gases, the flexibility to the energy resource is provided by reducing the dependence on fossil fuels. Among renewable resources, the photovoltaic (PV) generator is more popular due to its clean and environment friendly. Grid integration of PV power generation system has the advantage of most effective utilization of generated power. However, the technical requirements from both the PV system and the utility power grid side system need to be satisfied to ensure the safety of the PV installer and the reliability of the utility grid [1].

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In the current scenario of energy crisis studies are being conducted on feasibility of using grid interfaced inverters fed from photovoltaic arrays, fuel cells etc [2]. Output current at the inverter determines the quality of photovoltaic power. This necessitates the use of efficient current control scheme for grid connected inverters [3].

The concept of using active power filters for reactive power compensation was proposed a while ago. Since then, the theories and applications of active power filters have got a great attention. Among the common current control techniques used for active power filtering, hysteresis current control method is more popular due to its quick current controllability and easier implementation. However, the current control with a fixed hysteresis band has the drawback of varying switching frequency within the band because peak to peak current ripple is to be controlled at all points of the fundamental frequency. To overcome this problem, adaptive hysteresis current control scheme can be used [4].

This work proposes effective utilization of photovoltaic system for injecting real power and compensating reactive power compensation. Three phase grid connected voltage source inverter interfaces PV system with the grid. Inverter control is achieved by adaptive hysteresis current controller. Reference current extraction has been done with synchronous reference frame method. Section 2 gives a description about the system configuration under study. Section 3 describes the control strategies. Section 4 discusses the Simulation and experimental results. Section 5 concludes the work with future scope.

2. System Configuration

Voltage source inverter based three phase grid connected inverter with adaptive hysteresis current control circuit is employed in this work. It acts as a shunt active power filter and is in parallel with the loads at the Point of Common Coupling (PCC). System configuration is shown in Figure 1. A nonlinear load is connected to three phase grid source and PV system is connected in parallel to it. Synchronous reference frame method (SRF) is used for extracting the reference current and the reference current is compared with the filter current in the hysteresis loop and corresponding pulses are given for inverter switching. Current waveform for cancelling out the harmonics is attained with Voltage Source Inverter (VSI) and interfacing inductor. Inductor provides smoothing and isolation for high frequency components. Desired current waveform is obtained by controlling the switching of Insulated Gate Bipolar Transistor (IGBT) switches in the inverter.

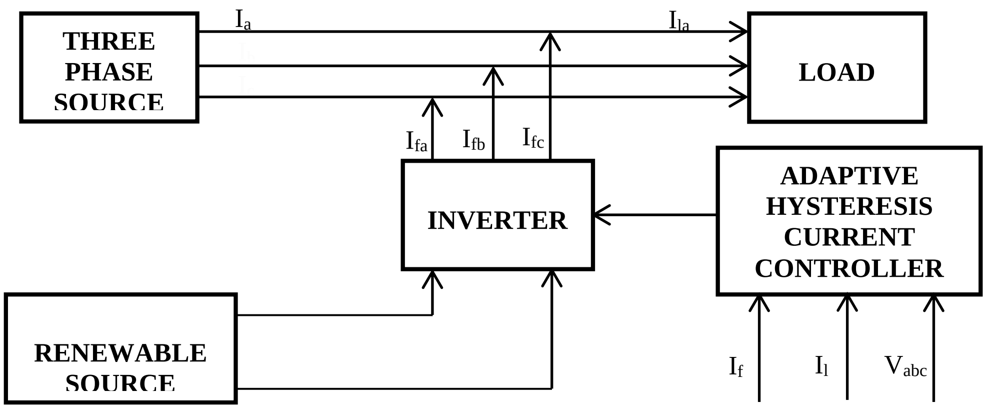

Fig.1. System Configuration: Block Diagram

PV system is equipped with MPPT control, DC-DC converter and a bidirectional inverter. Referring to the Fig. 2, PV module can be modeled by using Kirchhoff's law of current and voltage [3].

$$I_{dc} = I_g - I_D - (V_D / Rp) \quad (1)$$

$$V_{dc} = V_D - R_s I_{dc} \quad (2)$$

where I_g is the current generated from insolation, R_p is the internal parallel resistance, R_s is the internal series resistance and I_D and V_D are the current and voltage of the diode respectively. From the diode characteristic, I_D can be calculated by

$$I_D = I_o(e^{\frac{V_D}{V_T}} - 1) \quad (3)$$

where I_0 is the reverse saturation current of the diode, and V_T is the thermal voltage of the diode.

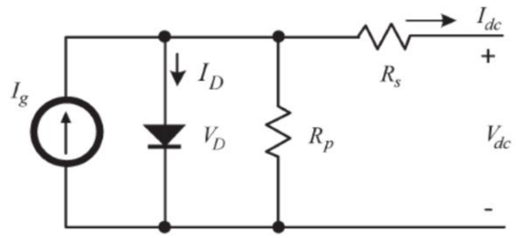

Fig 2. Equivalent circuit of a PV cell

The PV panel voltage is boosted to 650 V using a DC-DC converter. P & O MPPT algorithm [5] is employed for extracting maximum power from PV panel.

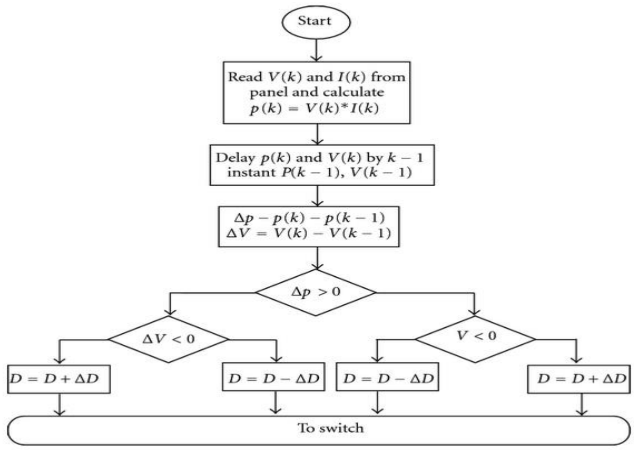

Fig 3. P & O MPPT Algorithm.

3. Control Strategies

The time domain based Synchronous Reference Frame (SRF) theory [8] is employed to extract the reference current from the distorted load current. The SRF control strategy operates in steady-state as well as in dynamic-state perfectly to control the active power line conditioner in real-time application. The important characteristic of SRF theory is the simplicity of calculations, as it involves only algebraic equations. The basic structure of SRF method consists of PLL circuit for vector orientation and PI-controller as voltage regulator for DC-link capacitor. Fig.4 shows the block diagram of the conventional SRF method.

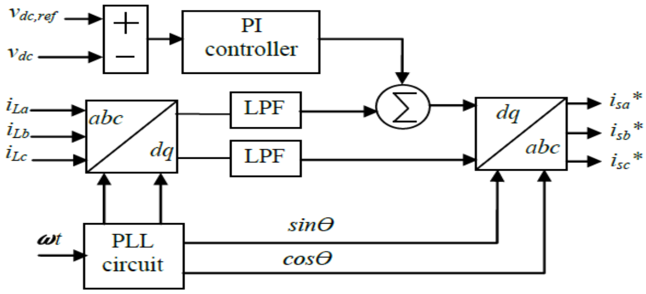

Fig **4** Block diagram of conventional SRF method

The reference frame transformation works with the conversion of current components in the three-phase stationery system (a-b-c) to the two phase direct axis (d) – quadratic axis (q) rotating coordinate system components. In this algorithm, the three-phase load currents in a-b-c system are converted to currents in d-q frame using the equations (4) and (5):

$$i_d = \frac{2}{3}\left[i_{La} \sin \omega t + i_{Lb} \sin\left(\omega t - \frac{2\pi}{3} \right) + i_{Lc} \sin\left(\omega t + \frac{2\pi}{3} \right) \right] \quad (4)$$

$$i_d = \frac{2}{3}\left[i_{La} \cos \omega t + i_{Lb} \cos\left(\omega t - \frac{2\pi}{3} \right) + i_{Lc} \cos\left(\omega t + \frac{2\pi}{3} \right) \right] \quad (5)$$

The d-q transformed output signals depend on the load currents and the performance of the phase locked loop. The PLL circuit provides sinθ and cosθ for synchronization. The i_d and i_q currents are passed through low pass filter (LPF) for filtering the higher order harmonics and thereby allowing only the fundamental components at its output. For harmonic current compensation and reactive power compensation, low pass filtered d axis component (i_d*) and the q axis component (i_q*) respectively is taken as reference. Using inverse park transformation d-q-0 axis is converted back to a-b-c system. Zero sequence currents are neglected for balanced three phase system. Proportional Integral (PI) controller regulates DC link capacitor voltage. Then the reference current signals in d-q rotating frame are converted back into a-b-c stationery frame by using the equations (6)-(8).

$$i_{sa}{}^{*} = i_d \sin wt + i_q coswt \quad (6)$$

$$i_{sb}{}^{*} = i_d \sin\left(wt - \frac{2\pi}{3}\right) + i_q cos\left(wt - \frac{2\pi}{3}\right) \quad (7)$$

$$i_{sc}{}^{*} = i_d \sin\left(wt + \frac{2\pi}{3}\right) + i_q cos\left(wt + \frac{2\pi}{3}\right) \quad (8)$$

The inverter performance is determined by the control scheme employed for generating the gate pulses. Current controllers control the dynamic response of the system. The current controller forces the load current to follow a reference one through the switching action of the inverter, keeping the current within the hysteresis band. Among the commonly used current control methods, hysteresis control is the most used one for voltage source inverter. After sensing the load currents, it is compared with respective reference currents by hysteresis comparators having a hysteresis band “HB”. The inverter power switches is activated by the output signal of the comparator. The switching function is illustrated in Fig. 5

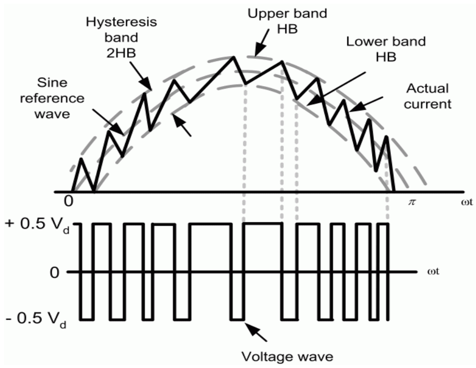

Fig 5 Hysteresis Currrent control waveform

The fixed band hysteresis control technique [10] is simple, has faster response, robust performance with high stability, inherent ability to control peak current and easier to implement. Also the technique does not seek any information on system parameters. But, this method has the disadvantage of variable switching frequency, harmonic content around switching side band and heavy interference [7]. These drawbacks result in high current ripples and acoustic noise. To overcome these drawbacks, this paper proposes an adaptive hysteresis current control [3][9]. Adaptive hysteresis controller adjusts the band width, in accordance with the load current. The concept of adaptive hysteresis controller is shown in Fig.6 where the switching frequency is determined by the reference current and derivative of the load current.

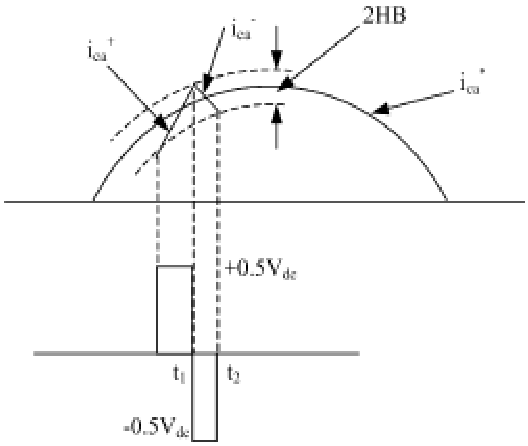

Fig. 6 Current and voltage waveform with adaptive hysteresis band current control

The hysteresis controller that depends on the system parameters can be represented by equation (9).

$$HB = \frac{V_{dc}}{4 f_s L_f}\left[1 - \frac{{L_f}^2}{{V_{dc}}^2}\left(\frac{V_{grid}}{L_f} + m\right)^2\right] \tag{9}$$

Hysteresis band is obtained by substituting the switching frequency. Adaptive hysteresis controller operates at nearly constant frequency.

4. Simulation and Experimental Results

Table 1 gives parameter of PV system modeled in MATLAB.

Table 1 Parameter details of PV panel

Parameter	Set value
Rated output power	220 W
Short circuit current	10 A
Open circuit voltage	22.2 V
Current at maximum power	9.9 A
Voltage at maximum power	17.2 V

A load of 8000 W was connected to the system. The active and reactive power at the three phase source side, PV generation system and at the load side is analyzed. 20 PV panels were connected in series so that the power output is 4400 W. The Fig.7 shows the active power and reactive power provided by the three phase source (grid). Fig.8 shows the active power and reactive power supplied by the PV generation system. Fig.9 shows active power and reactive power at the load side.

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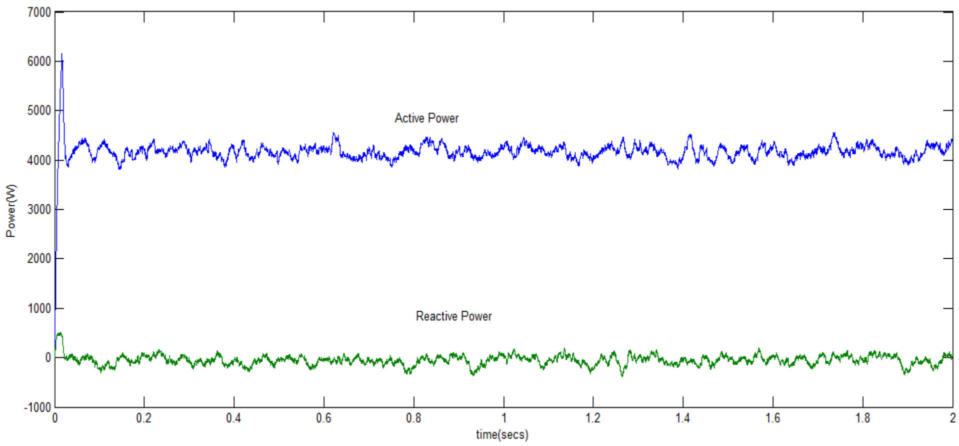

Fig 6 Reactive power and Active power provided by three phase source

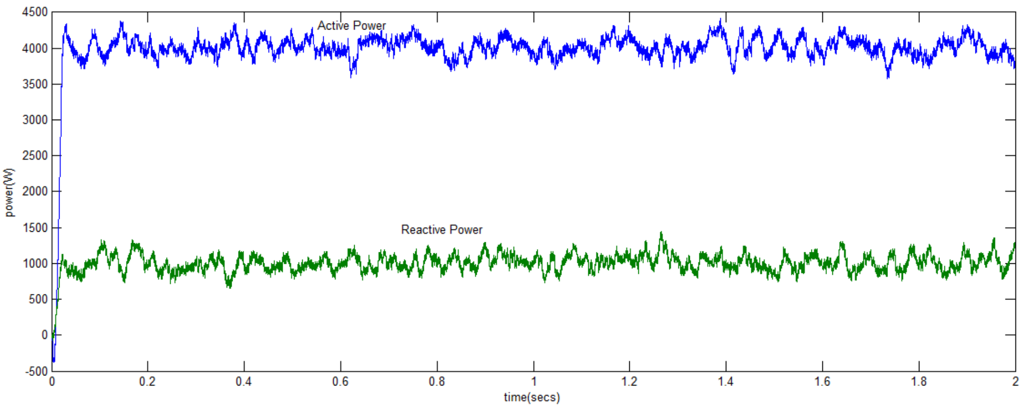

Fig 7 Reactive power and active power supplied by PV generation system

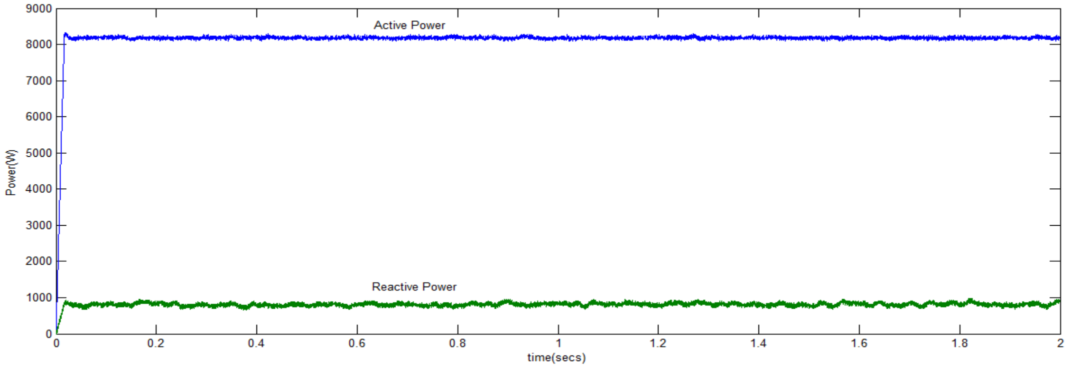

Fig 8. Reactive power and active power at load side

From the waveforms of active power and reactive power, it is observed that the load is shared between the grid and the PV system. The load is equally shared by the PV generation system and the grid i.e., 4000 W is provided by the PV system (its rated capacity) and the grid supports the remaining 4000 W. Reactive power drawn by the load is provided by the PV system only i.e., reactive power at the grid side is zero, improving the power quality.

5. Conclusions

Grid connected PV system is implemented with adaptive hysteresis current controller for inverter control. Real power sharing, reactive power compensation are analyzed and found that the given controller is effective in meeting the desired requirements.

Initially there is an overshoot in the power shared by the three phase system till 0.1 sec of time. This may be improved by using either IRPT algorithm or modified SRF algorithm for the reference current extraction. Also the adaptive hysteresis current controller scheme can be applied for eliminating the harmonics due to nonlinear load.

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