A Grid Synchronization Method Based on Adaptive Notch Filter for SPV System with Modified MPPT

Priyanka Chaudhary, M. Rizwan

***Abstract*—**This paper presents a grid synchronization technique based on adaptive notch filter for SPV (Solar Photovoltaic) system along with MPPT (Maximum Power Point Tracking) techniques. An efficient grid synchronization technique offers proficient detection of various components of grid signal like phase and frequency. It also acts as a barrier for harmonics and other disturbances in grid signal. A reference phase signal synchronized with the grid voltage is provided by the grid synchronization technique to standardize the system with grid codes and power quality standards. Hence, grid synchronization unit plays important role for grid connected SPV systems. As the output of the PV array is fluctuating in nature with the meteorological parameters like irradiance, temperature, wind etc. In order to maintain a constant DC voltage at VSC (Voltage Source Converter) input, MPPT control is required to track the maximum power point from PV array. In this work, a variable step size P & O (Perturb and Observe) MPPT technique with DC/DC boost converter has been used at first stage of the system. This algorithm divides the dP_{pv}/dV_{pv} curve of PV panel into three separate zones i.e. zone 0, zone 1 and zone 2. A fine value of tracking step size is used in zone 0 while zone 1 and zone 2 requires a large value of step size in order to obtain a high tracking speed. Further, adaptive notch filter based control technique is proposed for VSC in PV generation system. Adaptive notch filter (ANF) approach is used to synchronize the interfaced PV system with grid to maintain the amplitude, phase and frequency parameters as well as power quality improvement. This technique offers the compensation of harmonics current and reactive power with both linear and nonlinear loads. To maintain constant DC link voltage a PI controller is also implemented and presented in this paper. The complete system has been designed, developed and simulated using SimPower System and Simulink toolbox of MATLAB. The performance analysis of three phase grid connected solar photovoltaic system has been carried out on the basis of various parameters like PV output power, PV voltage, PV current, DC link voltage, PCC (Point of Common Coupling) voltage, grid voltage, grid current, voltage source converter current, power supplied by the voltage source converter etc. The results obtained from the proposed system are found satisfactory.

***Keywords*—**Solar photovoltaic systems, MPPT, voltage source converter, grid synchronization technique.

I. INTRODUCTION

THE rapid depletion of fossil fuels and continuous increase in the level of greenhouse gas emissions are becoming the major challenge and main driving forces to utilize various renewable energy sources including solar, wind, biomass etc. Among renewable energy sources, solar energy constitutes a suitable choice for a variety of application mainly due to the possibility of direct conversion of solar energy into electrical energy using PV systems [1]. The downward tendency in the price of the photovoltaic modules, together with their increasing efficiency, put solid-state inverters under the spot lights as enabling technology for integrating PV systems into grid. DC-AC converter stage should inject sinusoidal current in the grid i.e. current in phase with the grid voltage. A grid synchronization technique is used to serve this purpose and maintain generation during grid faults fast and accurate detection of positive sequence component of grid voltage. An efficient grid synchronization technique detects various constituents of grid signal like phase and frequency as well as provides security to the grid from various unwanted signals like harmonics and other disturbances. Another important aspect of SPV generation system is to provide a constant DC link voltage as input to VSC. As PV array output is varying in nature because of various meteorological parameters such as irradiance, temperature, wind etc. In order to get its output near to a constant value of DC voltage at VSC input, MPPT control is required for tracking of the maximum power point of PV array [3]-[7]. MPPT controls form the heart of the complete PV power generation system. In this work a three phase grid connected SPV generation system is modeled with a variable step size P&O maximum power point tracking control algorithm with DC-DC boost converter at very first stage of the system. Large numbers of control techniques are reported in the literature for VSC like Synchronous Reference Frame theory (SRFT), Instantaneous Reactive Power Theory (IRPT), PI controller based algorithms, Adaline based algorithm etc. In the present work adaptive notch filter based control technique is proposed for VSC in PV generation system. The proposed control technique of VSC provides better compensation of harmonics and reactive power with both linear and nonlinear loads. A constant DC link voltage is maintained by using a PI controller. Modeling and simulation of complete system has been done using SimPower System and Simulink toolbox of MATLAB. The block diagram of the system under study is presented in Fig. 1. This paper is organized as follows: system description with detailed modeling of components is presented in first section. Next Section presents control techniques including MPPT algorithm and ANF based control technique for VSC. Simulation results are discussed under the heading results and discussions. A conclusion followed by references is presented in last section.

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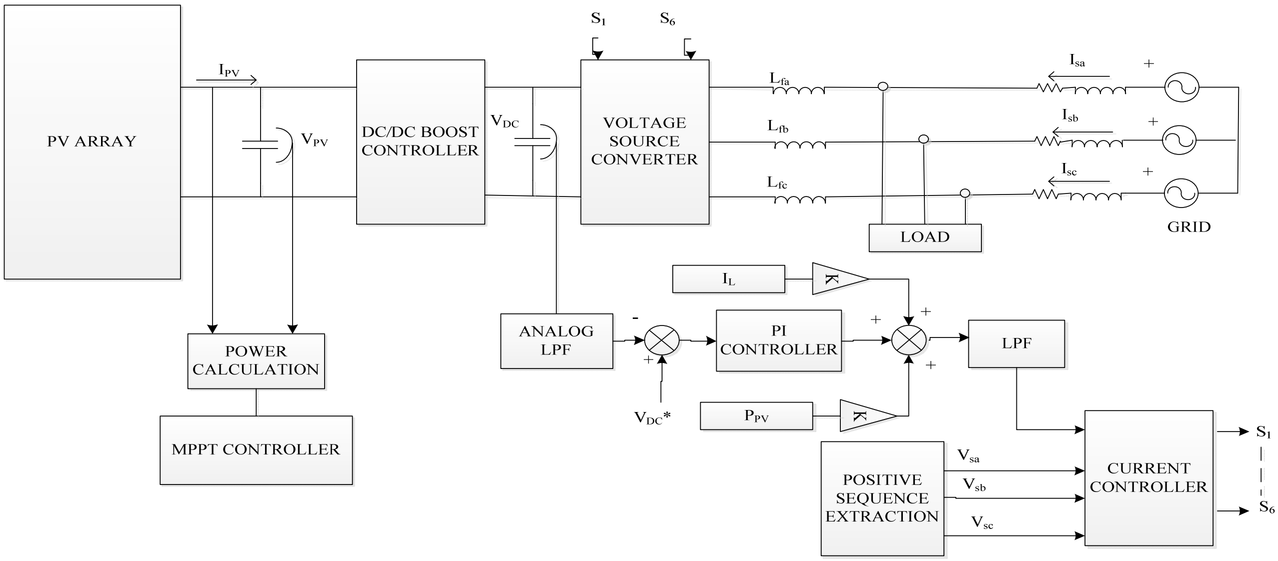

Fig. 1 Block Diagram of System under Study

II. System Configuration

Fig. 1 shows the block diagram of proposed solar photovoltaic (SPV) generating system integrated with the grid. The given system consists of Solar PV array, maximum power point tracking (MPPT) controller with dc-dc boost converter, voltage source converter (VSC), linear and nonlinear consumer loads and grid. The dc-dc boost converter enhanced the voltage level of photovoltaic system before feeding power to the inverter. In this presented system a PI controller is implemented to maintain the dc link voltage 700 V between VSC and SPV system. A filter consisting capacitors and inductors is connected between VSC and utility grid in order to damp out the ripples in the output of VSC. A control scheme using adaptive notch filter is employed for VSC control for compensation of reactive power required by load, power factor improvement and harmonic elimination. The proposed control algorithm is applied to evacuate full amount of power from SPV system. The present section describes the modeling of various components.

A. PV Array Modeling

The power generated by solar cell is not enough for various applications. To obtain the higher power, solar cells are interconnected and hermetically sealed to constitute a photovoltaic module. Further, series – parallel combination of PV modules constitute a PV array. The solar photovoltaic array (SPVA) is designed for the 25 kwatts [1], [2]. SPV array module can be designed to any desired rating by choosing the appropriate number of series and parallel modules (cells).

B. DC/DC Boost Converter

Output of PV array is highly affected by the meteorological parameters like irradiance, temperature and keeps on changing. A control technique named as MPPT (maximum power point tracking) is required to continuously track the maximum power point of PV array. A power converter is required to implement the MPPT control and to step up the voltage level at a value so that the DC link voltage can be maintained at a constant value. The value of inductor and capacitor is designed and calculated according to desired output levels. The equivalent circuit of DC-DC boost converter is presented in Fig. 2.

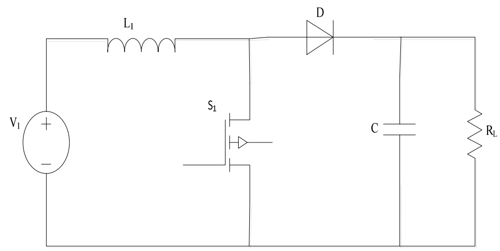

Fig. 2 Equivalent circuit of DC/DC boost converter

The values of different components of DC-DC boost converter can be obtained as:

Input Inductance (L_1),

$$L_1 = \frac{V_{PV}\,\mathrm{D}}{2\Delta i_1 f_{sw}}$$

DC link Capacitors (C)

$$C = \frac{I_{in}\mathrm{D}}{\Delta v f_{sw}}$$

Duty Cycle (D)

$$\mathrm{D} = 1 - \frac{V_{PV}}{V_{DC}}$$

C. Voltage Source Converter

The three phase voltage source converter consists of a six switching devices is used to convert DC voltage into AC voltage. The VSC consists of capacitors to filter the DC link voltage [8], [9]. In the VSC, IGBT semiconductor switches are used and designed for 415 V, 25 kW at 0.8 p.f. lagging load.

III. Control Techniques

A. Maximum Power Point Tracking

There are number of MPPT techniques available in the literature to track the maximum power point. These techniques includes perturb and observe, incremental conductance, constant voltage, open circuit voltage, short circuit current, extremum seeking control and hybrid etc. Some techniques based on artificial neural networks, fuzzy logic, genetic algorithms are also available in the literature.

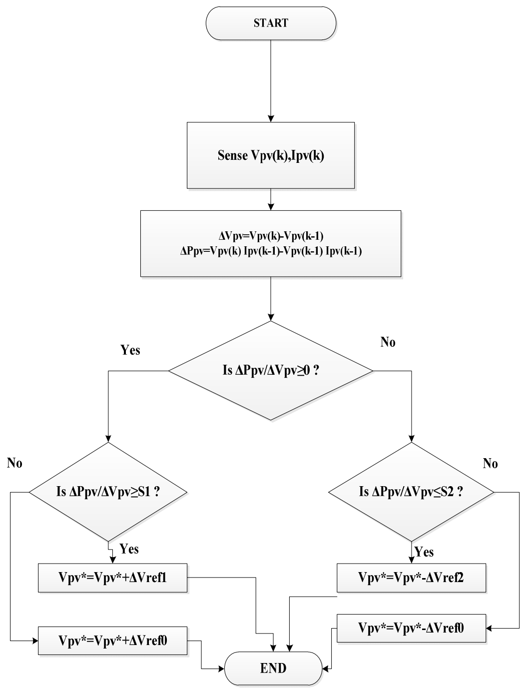

Fig. 3 Flowchart of P&O algorithm

Variable step size Perturb and Observe method for tracking the maximum power point of solar PV array is implemented in this work. After the application of perturbation the output power is compared with the previous perturbation cycle power output. If the power increases then the increment in voltage or current remains continuous in same direction. If power decreases then the variation in voltage or current in reverse direction. This algorithm divides the dP_{pv}/dV_{pv} curve of PV panel into three separate zones i.e. zone 0, zone 1 and zone 2. A fine value of tracking step size is used in zone 0 while zone 1 and zone 2 require a large value of step size in order to obtain a high tracking speed. Operation of algorithm can be explained further by using flowchart given in Fig. 3. Δv_{ref0}, Δv_{ref1} and Δv_{ref2} represent different step sizes in zone 0, zone 1 and zone 2 respectively, k denotes the iteration count. Δv_{ref0}, Δv_{ref1} and Δv_{ref2} is taken as 0.1 V, 0.3 V and 0.3 V respectively.

B. ANF Based Grid Synchronization Technique for Voltage Source Converter

Adaptive notch filter (ANF) approach is used to synchronize the interfaced PV system with grid to maintain the amplitude, phase and frequency parameters in power quality improvement [10]-[12]. The signal is in the periodic form and is defined as:

$$u(t) = \sum_{i=1}^{n} A_i \sin \varphi_i where \varphi_i = \omega_i + \varphi_i \tag{6}$$

$$\ddot{x} + \theta^2 x = 2\zeta\theta e(t) \tag{7}$$

$$e(t) = u(t) - \dot{x} \tag{8}$$

$$\dot{\theta} = -\gamma\theta x e(t) \tag{9}$$

where, $u(t)$is the input signal, θrepresents the estimated frequency and ζ and γ are real and positive parameters, that determines the performance of ANF in terms of proper synchronization in phase and frequency for the injection of fundamental signal to the grid.

For extracting the fundamental component

$$u(t) = A_1 \sin(\omega_1 t + \delta) \tag{10}$$

Dynamics of the signal in (2) has a periodic function in state equation in the form of

$$v(t) = \begin{pmatrix} x \\ \dot{x} \\ \theta \end{pmatrix} = \begin{pmatrix} -\frac{A_1}{\omega_1}\cos(\omega_1 + \delta) \\ A_1 \sin(\omega_1 + \delta) \\ \omega_1 \end{pmatrix} \tag{11}$$

The third entry of $v(t)$is the estimated frequency and it is identical to its correct valueω_1. The basic block diagram for ANF based controller is presented in Fig. 4.

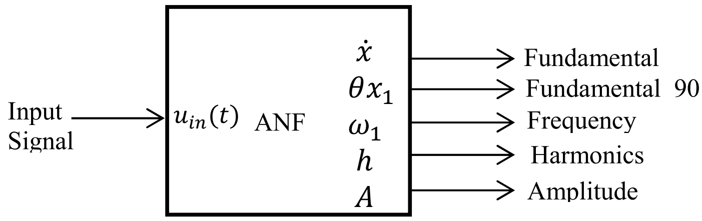

Fig. 4 ANF based controller for grid connected PV system

IV. Results and Discussions

Performance analysis of three phase grid connected solar photovoltaic system has been carried out on the basis of various parameters. These parameters includes PV output power, PV voltage, PV current, DC link voltage, PCC voltage, grid voltage, grid current, voltage source converter current, power supplied by the voltage source converter etc. The performance of the proposed system with linear and non-linear load is carried out in this paper.

A. Performance of System with Linear Load

A linear load of 50 kW with lagging PF is used for simulation studies. The maximum power output of designed SPV array is 20 kW. MPPT control is applied to the system to feed maximum power to the load. Reference value of the DC link voltage is kept 700 V. A PI controller tunes the DC link voltage at its reference value. It can be clearly observed from the waveform that the initially the complete load current is feeding by the source only. But after the switching of inverter the load, current is shared in between grid and SPV system. The performance of the proposed system is presented in Figs. 5 and 6 for linear load. Change in irradiance of PV array is applied to check the accuracy and efficiency of the proposed MPPT algorithm. At 0.1s irradiance is raised to 1200 W/m2 and again at 0.2 it is reduced to 800 W/m2. Up to 0.35s a part of active power of the load is feeding by the solar PV array.

Complete reactive power compensation is provided by the inverter, that means source is not supplying reactive power to the load. The voltages at PCC and grid currents are in phase thus achieving the unity power factor operation of the proposed system. The solar irradiance is reduced to zero at 0.35s as a result of it, the PV current becomes zero. For this mode of operation, the required compensation is provided by the voltage source converter. With the help of simulated results, it can be observed that the system performance is satisfactory under linear load conditions.

B. Performance of System with Non-Linear Load

A nonlinear load of 50 kW is used for simulation studies to analyze the performance of the three phase grid connected PV system. The maximum power output of designed SPV array is 20 kW. Figs. 7 and 8 show the various parameters of proposed system under non-linear load condition. It can be observed that the grid currents are in phase with PCC voltages achieving unity power factor operation of grid. The grid currents are balanced and sinusoidal irrespective of the nonlinear load due to the compensation provided by the VSC. At 0.5s, the solar intensity becomes zero and now the compensation of the loads is provided by the VSC. Again in this case also change in irradiance has been applied to the PV array. From the output waveforms it can be clearly seen that the system performs well for non-linear loads also with the proposed control algorithm.

V. CONCLUSION

A three phase grid connected PV system has been designed and simulated with adaptive filter based grid synchronization technique. The capability of the designed control algorithm in extracting the positive sequence component has been tested and found better as compared to the other conventional techniques. In the proposed work, the performance of grid connected PV system in terms of PV output power, PV voltage, PV current, DC link voltage, PCC voltage, grid voltage, grid current, voltage source converter current, power supplied by the voltage source converter is found satisfactory and presented in Figs. 5-8 for linear and non-linear loads. In addition the THD of the source current is also found as 3.75% which is in the desired limit.

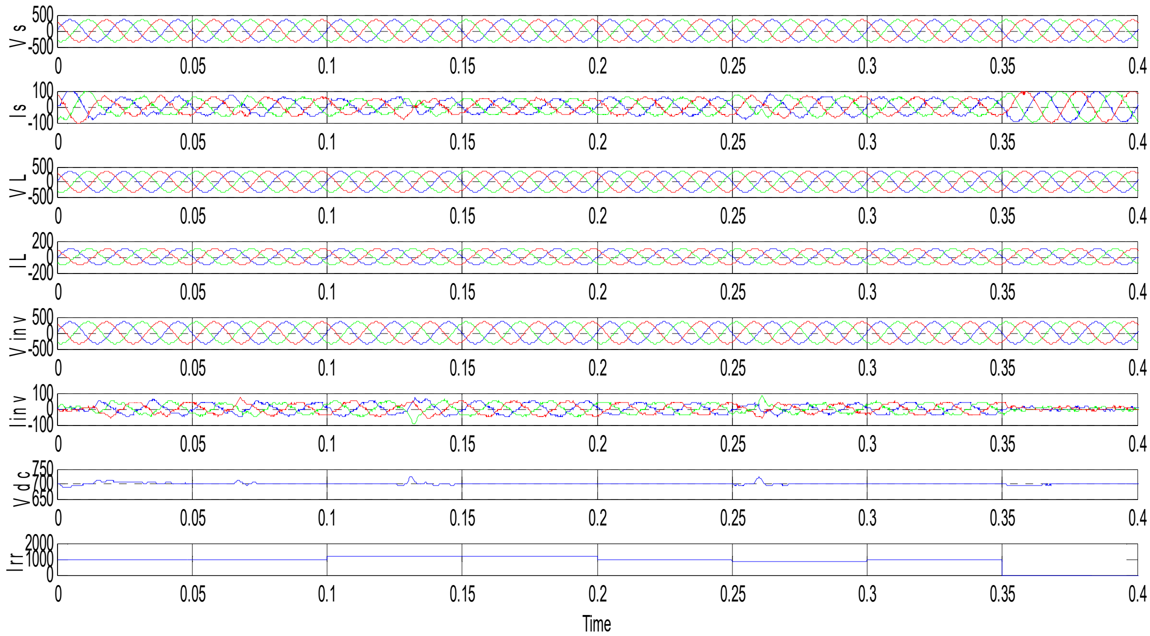

Fig. 5 Source side voltage V_s (V), Source side current I_s (A), Load voltage V_L (V), Load current I_L(A), Inverter side voltage V_{inv}(V), Inverter side current I_{inv} (A), DC link voltage V_{dc} (V), Change in Solar Irradiance I_{rr}

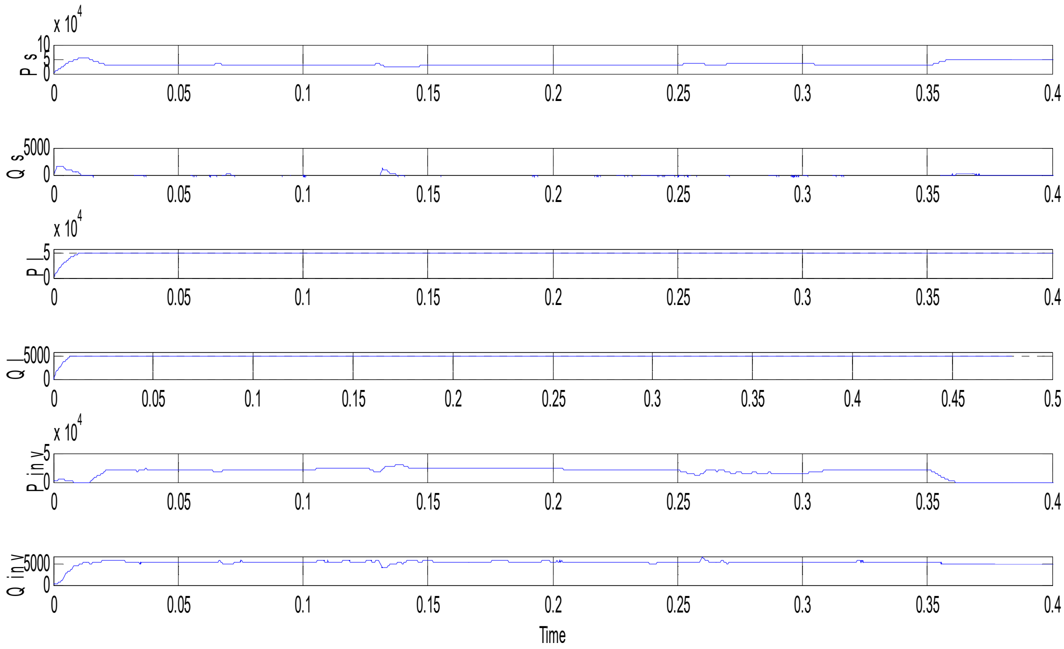

Fig. 6 Active power delivered by source P_S (kW), Reactive power delivered by source Q_S (kVAR), Active power required by load P_l (kW), Reactive power required by source Q_l (kVAR), Active power delivered by PV system P_{inv} (kW), Reactive power delivered by VSC Q_{inv} (kVAR)

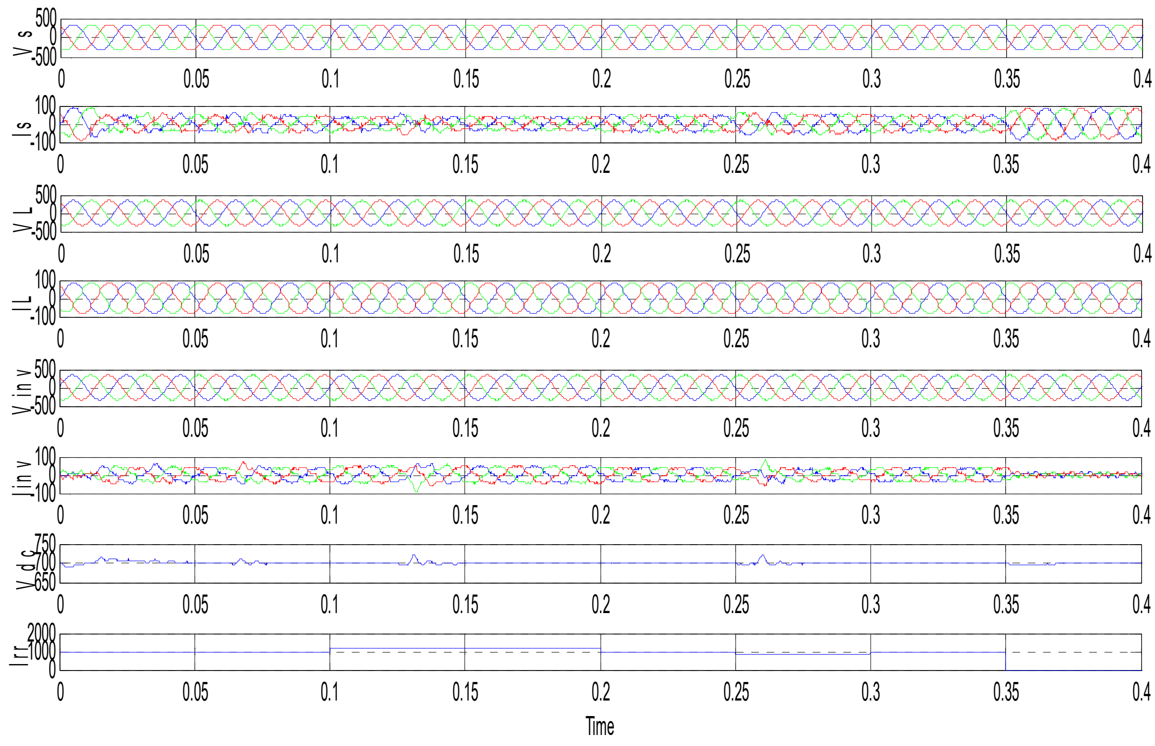

Fig. 7 Source side voltage V_s (V), Source side current I_s (A), Load voltage V_L (V), Load current I_L(A), Inverter side voltage V_{inv}(V), Inverter side current I_{inv} (A), DC link voltage V_{dc} (V), Change in Solar Irradiance I_{rr}

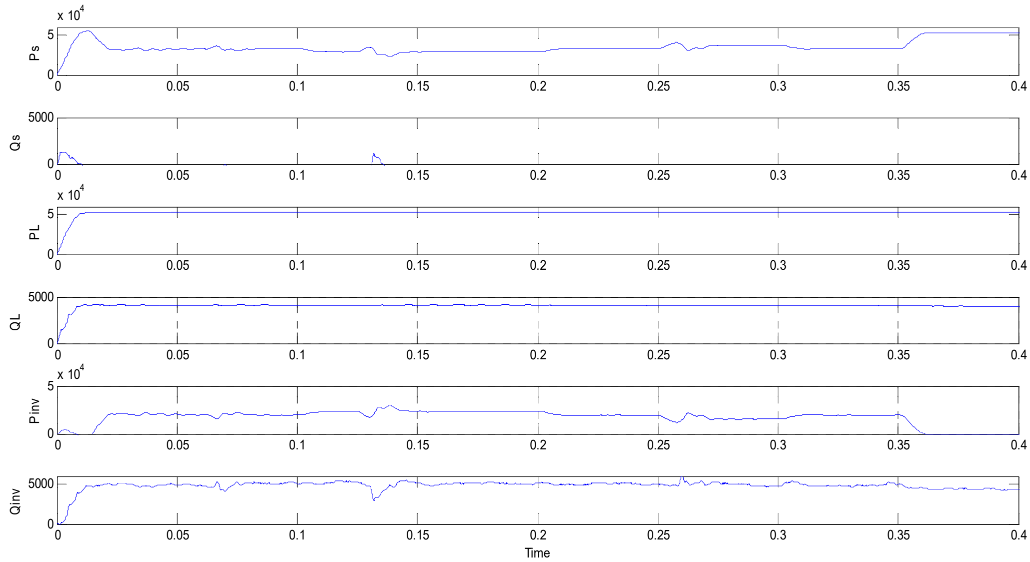

Fig. 8 Active power delivered by source P_S (kW), Reactive power delivered by source Q_S (kVAR), Active power required by load P_l (kW), Reactive power required by source Q_l (kVAR), Active power delivered by PV system P_{inv} (kW), Reactive power delivered by VSC Q_{inv} (kVAR)

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