# Performance Of Grid-Connected Inverter Fed From PV Array

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March 26, 2020

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***Abstract* -This paper proposes a power flow control strategy based on theory of symmetrical components for implementing bi-directional power flow between the utility grid and local PV array. The system includes a three phase bidirectional inverter with a battery bank at the input interfaced through a boost converter with solar arrays. The battery bank operates in discharge mode when power is fed to the grid and charges from the grid during low demand period. For grid synchronization, principle of phase locked loop (PLL) is implemented in dq synchronous rotating frame (SRF) and PI controller has been used in the feedback loop for the necessary control. The PLL block is implemented using the concept of instantaneous symmetrical component theory. The active and reactive power flow in the grid is controlled by changing the value of reference dc voltage at the input side of inverter. The system has been simulated in PSIM software for a 1kVA inverter. This simple scheme of bi-directional power flow is useful for connecting remote areas with abundant solar energy to the local grid.**

***Keywords* – Bidirectional, Grid-connected, PLL, PV-array, Utility grid.**

## I. INTRODUCTION

The present scenario of insufficient storage of energy resources and day by day increasing power demand of society along with the warning of global warming has motivated practicing engineers to carry on research activities on efficient integration of renewable energy resources with the existing grid [1-2]. This has promoted use of renewable sources of energy like solar, wind, tidal, geothermal etc. along with the conventional energy sources. Among these the abundance availability of solar energy has made it possible to harvest it and utilize it properly. But, output of solar cells depends on solar radiation- a factor which is beyond the scope of control. This makes output of PV cells unpredictable. However, different strategies have been proposed [3-4] to overcome this drawback and to ensure maximum power extraction from sun rays during day time. Solar energy stations can either be standalone generating unit or can be grid connected generating unit depending on the availability of a grid nearby.

The components of a grid connected PV system include solar panels, inverters, power conditioning unit and grid connection equipments. When installed on rooftop of a building, a portion of the energy demand of the building can be fulfilled by electricity generated from PV panel and the rest from utility grid. Also, excess power generated from the roof-top PV panel can be traded with the utility grid. Thus, electricity flows back and forth to and from the main grid according to the weather conditions and electric demand at a time [5]. Thus, the key component in a grid tied solar energy system is the bidirectional converters. Two bidirectional converters are essential-one is dc/dc boost converter for charging the battery bank either from solar panel or from utility grid through the other bidirectional converter, which is basically an inverter. Hence, grid synchronization of the bidirectional inverter is very important for satisfactory performance of a grid tied PV system. Several control strategies [6-8] are present in the literature to describe grid synchronization techniques. Another important issue in grid connected solar systems is control of the bidirectional inverter [9-18] to decide direction of power flow between the utility grid and solar panel depending on load demand and generated capacity of the PV panel. However, for grid connected PV stations other than the control of bidirectional inverters, another important issue is the unpredictable solar output that produces serious impact on performance of the grid [6].

In this paper control of direction of power in a three phase bidirectional inverter has been proposed for a grid tied PV station based on theory of symmetrical components. In section-2, architecture of the system has been presented. In section-3, theory of grid synchronization based on instantaneous value of symmetrical components has been described. Section-4 prescribes control of direction of power flow between grid and the PV system through the intermediate link of bidirectional inverter and bi-directional dc/dc converter. In section-5 PSIM model of the system and simulation results have been presented.

## II. SYSTEM DESCRIPTION

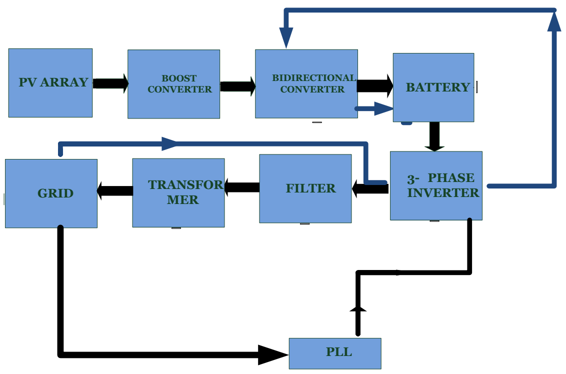


Fig.1: Schematic of the grid tied PV based bi-directional inverter (black lines show power flow from PV array to grid and black lines reverse power flow

In the proposed system PV arrays are connected to dc bus through boost converter. As an energy storage system, a battery is connected to the dc bus through bi-directional dc/dc converter. The dc bus voltage is maintained stable by boost converter and the bidirectional dc/dc converter. The dc bus is coupled with utility grid through bi-directional inverter, transformer and filter.

## III. GRID SYNCHRONIZATION

In a grid tied PV based inverter, the act of grid synchronization is important to ensure automatic adjustment of phase angle of inverter generated voltage with that of grid voltage. In particular, this is achieved by a phase locked loop, which consists of a voltage controlled oscillator, phase detector and loop filter. Moreover, grid synchronization also helps in control of higher harmonics, active and reactive power control, voltage regulation and grid monitoring. In this paper, grid synchronization has been achieved by transforming three phase variables to synchronously rotating reference frame. Although theory of symmetrical component can be applied in steady state only, but its use in time domain was first presented by Lyon. According to Lyon's theory instantaneous values of positive sequence component, negative sequence component and zero sequence component can be described by 1.1.

$$v_a = v_a^0 + v_a^+ + v_a^+ \qquad (1.1)$$

Neglecting the zero-sequence component for simplification, positive and negative components can be evaluated as in (1.2).

$$v_{abc} = v_{abc}^+ + v_{abc}^- \qquad (1.2)$$

$$= V^+ \begin{bmatrix} \cos(\omega t) \\ \cos\left(\omega t - \frac{2\pi}{3}\right) \\ \cos\left(\omega t - \frac{4\pi}{3}\right) \end{bmatrix} + V^- \begin{bmatrix} \cos(-\omega t) \\ \cos\left(-\omega t - \frac{2\pi}{3}\right) \\ \cos\left(-\omega t - \frac{4\pi}{3}\right) \end{bmatrix}$$

In (1.2), $V^+, V^-$ represent amplitude of positive and negative sequence component. According to Lyon's theory instantaneous values of positive and negative component of three phase voltage $v_{abc}$ can be described as in (1.3).

$$v_{abc}^+ = \begin{bmatrix} v_a^+ \\ v_b^+ \\ v_c^+ \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & \alpha & \alpha^2 \\ \alpha^2 & 1 & \alpha \\ \alpha & \alpha & 1 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad (1.3)$$

$$v_{abc}^- = \begin{bmatrix} v_a^- \\ v_b^- \\ v_c^- \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & \alpha^2 & \alpha \\ \alpha & 1 & \alpha^2 \\ \alpha & \alpha & 1 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad (1.4)$$

Here, $\alpha$ takes the value of $\left(-\frac{1}{2} + j\frac{\sqrt{3}}{2}\right)$. Lyon's transformation in $dq$ synchronous reference frame takes the form as described in (1.5).

$$v_{dq} = v_{dq}^+ + v_{dq}^- \qquad (1.5)$$

In (1.5) $v_{dq}^+$ takes the form as described in (1.6).

$$v_{dq}^+ = v_d^+ + jv_q^+ \qquad (1.6)$$

Assuming dq reference frame rotating synchronously with the positive voltage component $v_{dq}$ can be represented as shown in (1.7).

$$v_{dq} = V^+ \begin{bmatrix} 1 \\ 0 \end{bmatrix} + V^- \begin{bmatrix} \cos(-2\omega t) \\ \sin(-2\omega t) \end{bmatrix} \qquad (1.7)$$

Thus, synchronous reference frame phase locked loop (SRF-PLL) is based on Park's transformation of three phase grid voltage to synchronous rotating dq frame. Aim of SRF-PLL is to align d-axis of the reference frame with grid voltage vector. This is achieved by making q-component of the grid voltage vector to zero with the use of PI controller as shown in Fig.1.2.

## IV. POWER FLOW CONTROL

The power control strategy for the control of grid converter in both rectifier and inverter mode based on the synchronous reference frame (d-q). The dq control structure is normally associated with proportional–integral (PI) controllers since they have a satisfactory behavior when regulating dc variables.

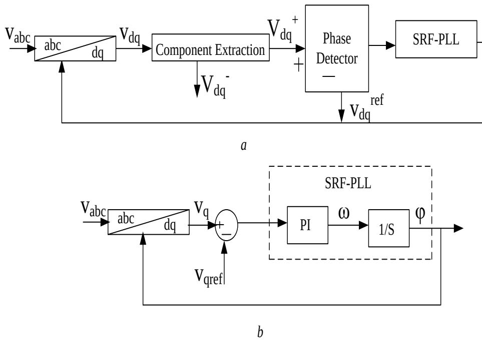


Fig.2: Block diagram showing technique of grid synchronization by using SRF-PLL.

In grid tied mode main converter is the bidirectional one allowing exchange power between ac and dc buses. This converter has the task to provide both stable dc bus voltage and required reactive power Operation of this main converter is decided by the reference active and reactive power will decide reference current in dq frame $I_d^*, I_q^*$ as shown in (1.8). It is controlled to supply high quality ac bus voltage. Choice for operating mode of the bidirectional ac/dc converter (rectifier or inverter) is also decided by $I_d^*, I_q^*$ .When battery voltage becomes less than that required by dc loads, bidirectional inverter acts as a rectifier with $I_q^* = 0$ . However, when generation by PV array is in excess to make voltage of dc bus constant, bidirectional inverter acts as an inverter and thereby connecting the PV array to utility grid through transformer and filter.

$$I_d = \left(\frac{2}{3}\right) * \frac{PV_d + QV_q}{V_d^{\,2} + V_q^2}$$

$$I_q = \left(\frac{2}{3}\right) * \frac{PV_q + QV_d}{V_d^2 + V_q^2}$$

## V. SIMULATION RESULTS

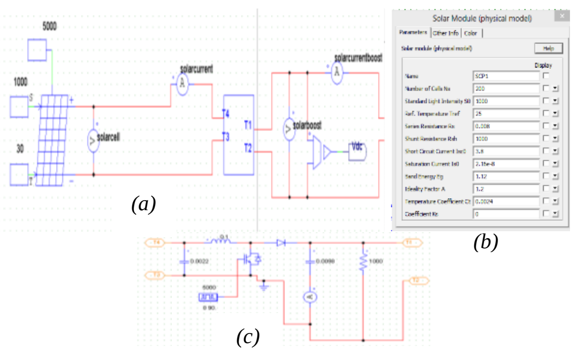


Fig.3: PSIM model of solar module and boost converter; *(a)*: Schematic of solar panel, *(b)*: parameters of solar panel, *(c)*: schematic of boost converter

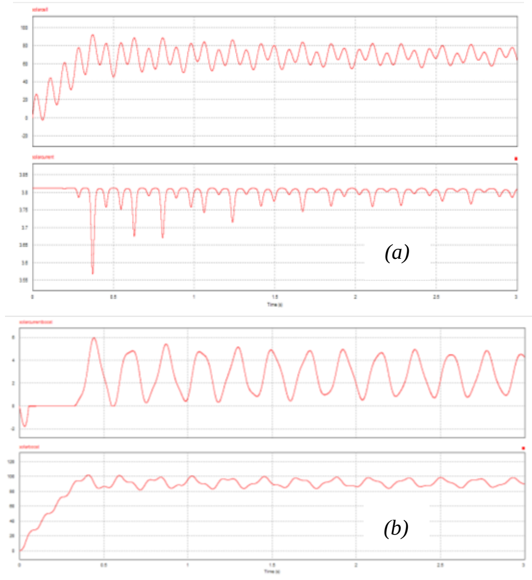


Fig.4: Simulation results of solar panel and boost converter; *(a)*: voltage and current o/p of solar panel, *(b)*: voltage and current o/p of boost converter

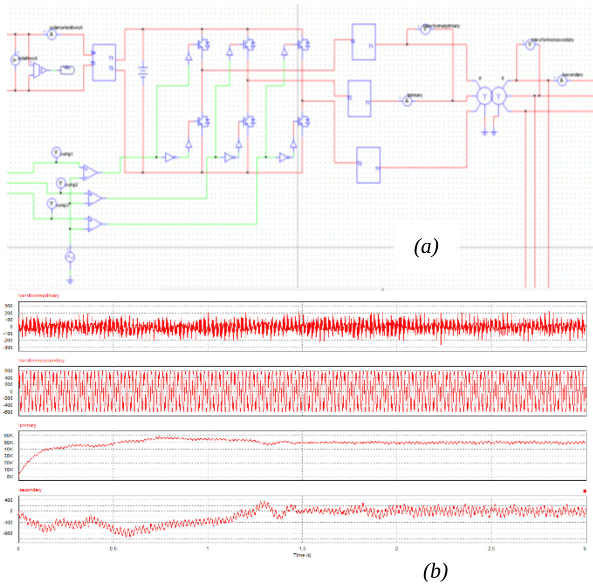


Fig.5: *(a)*: Bi-directional Inverter, *(b)*: Simulation Result Of Y-Y Transformer

- **CONNECTION:**

*(a)*: PARAMETERS:

Sawtooth: Peak-To- Peak:2V, Frequency: 5 kHz, Duty Cycle= 0.5

DC BATTERY: 100 V

*(b)*: Primary Voltage: 200V; Primary Current: 50kASecondary Voltage: 600V; Secondary Current: 400A

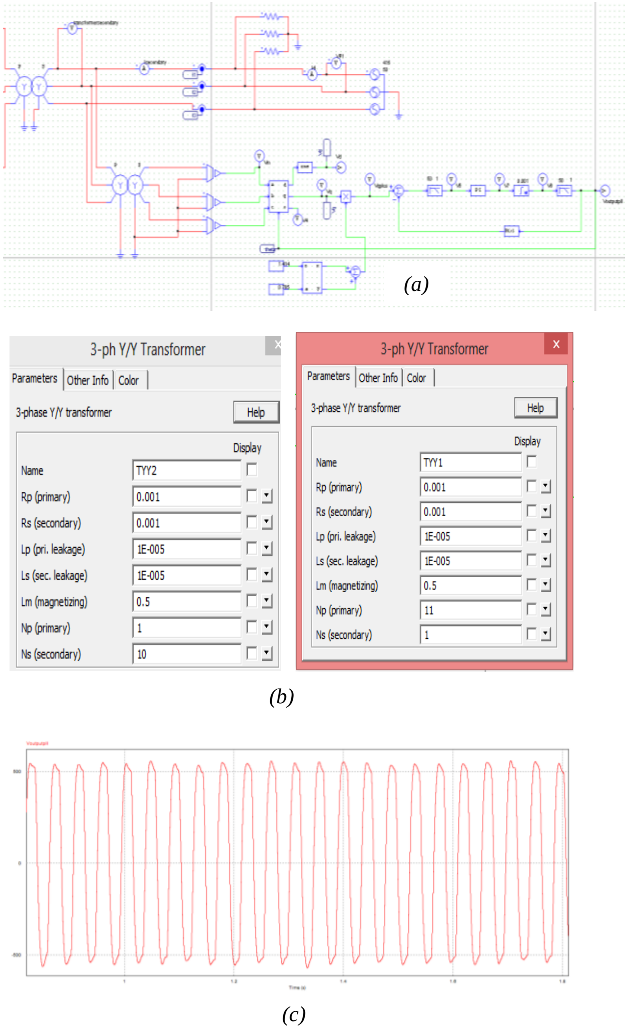


Fig.6: Phase Locked Loop; *(a)*: PSIM model of PLL block, *(b)*: Transformer Parameters, *(c)*: Simulation Result of PLL

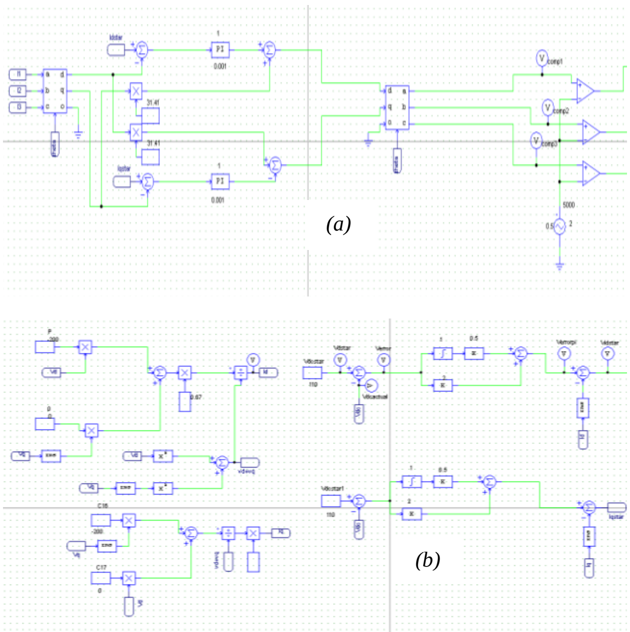


Fig. 7: *(a)*: Power Control Circuit-1, *(b)*: Power Control Circit-2

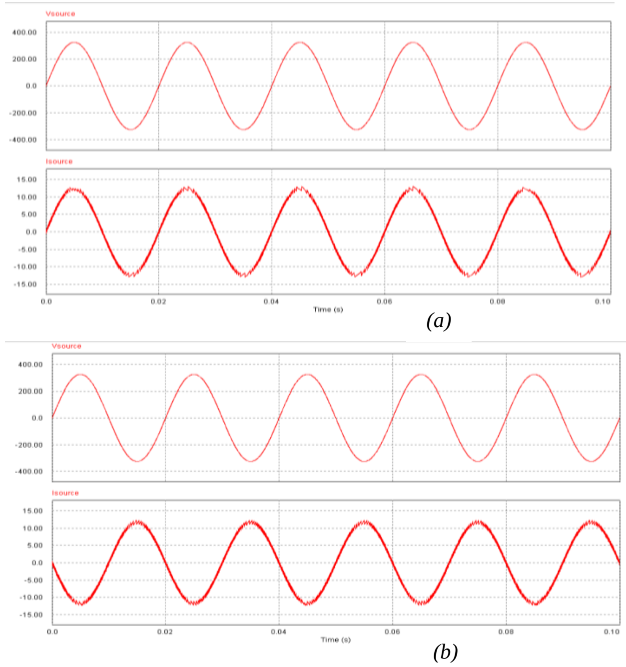


Fig.8: Simulation Result; *(a)*: Rectifier Mode, *(b)*: Inverter Mode

## VI. CONCLUSION

The paper has discussed a scheme for bi-directional power flow between the grid and a local PV array. The performance of bi-directional inverter fed from PV array was studied, using PSIM software. In order to inject a quality AC current into the grid, a bi-directional DC-AC/AC-DC converter was controlled in stationary reference frame. Simulation and experimental results show that the control technique offers an excellent steady state response and low current harmonic distortion and the current injected into the grid is in phase with the grid voltage. The biggest problem for proper grid-connected converter operation is appearance of oscillations at double grid frequency, which cause stabilization problems in the system. To solve the problem, the instantaneous symmetrical component theory was employed. Furthermore, for power flow control, the instantaneous power theory was used. Hence, the contribution of the paper is sort of indication of future solution useful for connecting remote areas with abundant solar energy to the local grid.

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