Abstract—This paper focuses on the control of power flow management system for photovoltaic (PV) applications with a high efficiency bi-directional converter. The proposed PV system involves a power source (PV array), a power sink (load), and power sources/sink (battery), and hence, a power flow management system is required to balance the power flow among these sources. One such system is developed for selecting the operating modes of the battery by sensing the dc link voltage. The bidirectional converter includes fewer switches, has less conduction and switching losses. The viability of the scheme has been ascertained by performing experimental studies on a laboratory prototype.

Keywords—Bidirectional converter; photovoltaic; power flow management system; DC link voltage

I. INTRODUCTION

PV-based systems are being increasingly employed in developing countries, the demand for power is growing Indeveloping countries, the demand for power is growing with the ever-increasing demand for low-cost energy and growing concern about environmental issues[1]. Photovoltaic systems can be broadly classified into standalone system and grid-connected system [2], [3]. The standalone system is widely used in remote places where access to electricity is not available. The standalone configuration can provide a well-regulated load voltage, but the reliability of power supply cannot be guaranteed [3]. To improve the reliability of the stand-alone system, storage batteries are widely used [4]. Due to the improvement in the power electronics technology the integration of a PV system to the grid is rapidly increasing [5], [6]. Various topologies and control strategies [1]–[4], [7]–[28] for grid-connected inverters have been reported in the literature. In grid-connected PV systems (GCPVs) [13]–[24], the generated PV power is fed to the grid, or it supplies the linear and nonlinear loads connected at the ac side. A fair amount of literature [3], [4], [25]–[29] has dealt with the operation of hybrid systems. In some hybrid systems [4], [23] battery is used to compensate the mismatch between the generation and demand.

Indeveloping countries, the demand for power is growing beyond the planner’s estimation, and the power grid is weak, and scheduled power outages throughout the year are common. In addition, there are also unscheduled short-term outages which are random and frequent. As a result, a grid-connected PV system with a battery backup has many advantages such as peak shaving to generate power during peak load hours, and therefore, the grid-side inverter should operate in grid-tied mode and off-grid mode to supply uninterrupted power to the critical loads during power outages [9]. In some applications [15], [26], [29], a battery was connected directly in parallel with the dc bus. The size of the battery can be reduced when a battery charger/discharger circuit is inserted between the dc bus and the battery [25], [30]. Utilizing the battery charger/discharger circuit for regulating dc link voltage decouples the dc link control from the ac current control and achieves faster regulation of dc link voltage.

The proposed PV system consists of three power sources (PV array, Grid and battery), two power sinks (battery and load), and a bi-directional converter to balance the power flow among these. This paper illustrates an effective power flow management scheme for providing uninterrupted power supply to the loads with less number of power devices. Therefore conduction as well as switching losses are reduced. Incremental Conductance based MPPT algorithm is used to track the maximum power of the PV array.

II. SYSTEM DESCRIPTION

In the proposed system of power flow management for PV systems as shown in Fig. 1, the instantaneous power relationship is given by,

\[ p_{bo}(t) = p_{b}(t) + p_{dc}(t) + p_{inv}(t) \]  

where \( p_{bo} \) is the output power of the boost converter, \( p_b \) is the power delivered by the charger/discharger circuit, \( p_{dc} \) is the power to the dc link capacitor and \( p_{inv} \) is the power extracted by the inverter. The instantaneous ac power can be written as

\[ p_{ac} = \frac{V_m \sin(\omega t) I_m \sin(\omega t)}{2} = \frac{V_m I_m}{2} \cos 2\omega t \]

where \( V_m \) is the amplitude of the phase voltage and \( I_m \) is the amplitude of grid current. The ac power includes a dc term and a second-order ripple in the dc voltage.

The average power on the dc side can be written as

\[ P_{dc} = V_{dc} I_{dc} \]  

where \( V_{dc} \) is the average dc voltage and \( I_{dc} \) is the average dc current.

The power flow management system connects the battery charger/discharger circuit to the dc side, and the bi-directional converter controls the power flow among the sources.

The proposed PV system involves a power source (PV array), a power sink (load), and power sources/sink (battery), and hence, a power flow management system is required to balance the power flow among these sources. One such system is developed for selecting the operating modes of the battery by sensing the dc link voltage. The bidirectional converter includes fewer switches, has less conduction and switching losses. The viability of the scheme has been ascertained by performing experimental studies on a laboratory prototype.

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where \( I_{\text{inv}} \) is the average current on the dc side of the inverter. Equating the average power on the dc side to the dc term on the ac side.

\[
\frac{V_m I_m}{2} = \eta V_{dc} I_{\text{inv}} \tag{5}
\]

where \( \eta \) is the efficiency of the inverter. If \( V_{dc} \) and \( V_{dc}^{\text{(ref)}} \) are the actual and reference values of dc link voltage, respectively, the change in energy \( \Delta E_{dc} \) stored in the dc link capacitor \( C_{dc} \) can be written as

\[
\Delta E_{dc} = \frac{C_{dc}}{2} (V_{dc}^{2} - V_{dc}^{2}) \tag{6}
\]

The average current at the dc link can be written as

\[
I_{bo} = I_{\text{inv}} + I_b + I_{dc} \tag{7}
\]

where \( I_{bo} \) is the output current of the boost converter, and \( I_{\text{inv}} \) is the current on the input side of the inverter.

If \( V_{PV} \) and \( I_{PV} \) are the PV voltage and current respectively, for the boost converter operating at a duty cycle \( D \), the following equations can be written:

\[
(1 - D)I_{PV} = I_{\text{inv}} + I_b + I_{dc} \tag{8}
\]

\[
V_{dc} = \frac{V_{PV}}{(1 - D)(1 + \frac{R_L}{R}(1 - D))} \tag{9}
\]

where \( R_L \) is the parasitic resistance of the inductor and \( R \) is the equivalent resistance of the load.

The control structure of the system is shown in Fig. 1 where \( V_{dc} \) is regulated by the charger/discharger circuit. The converter control to output transfer function \( G_{dc}[32] \) is expressed as (10), shown at the bottom of the next page, where \( r \) is the resistance of the battery, \( C_1 \) and \( C_2 \) are the input and output capacitances, respectively, \( L \) is the leakage inductance of the transformer, \( f_{sw} \) is the switching frequency, and \( d \) is the phase shift between the two bridges. The source to input transfer function [32] is given by (11), shown at the bottom of the page. The transfer function of the load is represented by \( G_L \).

\[
G_{dc}(s) = \frac{V_{dc}(s)}{I_{L}(s)} = -\frac{1}{C_{dc}(s + 1/R_{dc})} \tag{10}
\]

Where \( R \) is the equivalent resistance of the load, and the relation between PV current and the dc link voltage is expressed as

\[
G_{pv}(s) = \frac{V_{dc}(s)}{I_{PV}(s)} = R(1 - D) \tag{13}
\]

\( G_{inv} \) denotes the transfer function of the grid-connected inverter

\[
G_{inv}(s) = \frac{k}{(1 + s\tau)} = V_{dc}(s) \tag{14}
\]

Where \( k \) is the amplitude gain and \( \tau \) is the sampling delay.

III. RESULTS AND DISCUSSION

To evaluate the performance of the proposed system, experimental tests are carried out on a prototype unit built in the laboratory and their results are discussed. The system consists of a PV array, a boost converter, a single-phase full bridge bi-directional converter and a charger/discharger circuit for the battery.
Inference: Neither charging nor discharging of battery takes place.

Inference: Excess power from the PV array is utilized for charging the battery.

Inference: Battery discharges to support the load with insufficient power from PV array.

Inference: Power from AC mains supports the load also charges the battery. It is similar to UPS system.

IV. CONCLUSION
A versatile control strategy for power flow management in a PV system feeding a residential load with bi-directional converter has been presented. The importance of the scheme has been brought out by performing experimental studies on a laboratory prototype. The proposed configuration has been proved to be attractive from the perspective of providing uninterruptible power to the load.

REFERENCES


