Energy Storage using Flexible stand-alone Photovoltaic PV System on multi loop PI Controller

D. Munnirunisa[1], G. Siva Sankar Reddy[2]

[1]Associate Professor Dept. of EEE, Svr Engineering College Nandyal.

Email id: - munnirunisa@rediffmail.com

[2]PG-ScholarDept. of EEE, Svr Engineering College Nandyal.

Email Id: - sivareddy0242@gmail.com

Abstract

A standalone photovoltaic (PV) system with energy storage requires a complex control architecture to take into account the various operating modes. This paper presents a flexible architecture of a PV power conditioning system with energy storage is executed. It consists of boost converter, a single-phase inverter, and bidirectional DC/DC converter connected to the PV side of the boost converter. The boost converter regulates the dc-link bus-voltage. The bidirectional DC/DC converter used for battery charge/discharge control and PV maximum power point tracking. The multi loop PI controller used to control the operation of DC to DC converter. In this system there is no change in controller configuration when the storage disconnects.

Keywords: Energy storage, flexible stand-alone, photovoltaic (PV), PV system, multi loop PI controller.

1. Introduction

NOWADAYS, solar energy is considered to be one of the most effective resources, attracting much attention due to its ubiquity and sustain ability. Stand-alone photovoltaic system (SPVS) is one of the popular applications in photovoltaic (PV) generation and has highly practical values in off-grid areas. Such areas are categorized as micro grid, including remote areas, desert and border-outpost moveable military equipment, street light systems, etc.. However, the power generation is significantly influenced by the light intensity and the temperature. In addition, PV cells cannot store the energy inside; thus, an energy storage device is normally required to balance the energy of the PV systems. In such types of distributed-sourced micro grid systems, the multiple connection issues of the SPVS to grid have been considered previously and some solutions using droop control methods have been provided. In the design procedure of the individual SPVS

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 01
January 2017

architecture, one of the major concerns is the need of a high output dc-voltage bus (400 Vdc) inside the individual SPVS to supply the following inverter from the low voltage power sources. Since a commercialized battery bank voltage is relatively low, such as 12, 24, or 48 V, a power conditioning unit (PCU) is required to interface the battery to dc-link bus with high step-up ratios. This issue has led to many multiple stage PCU topologies. A conventional topology used widely for an SPVS, including an energy storage device connected with the dc link through a bidirectional dc–dc power converter was proposed [see Fig. 1 (a)]. This power converter acts as a step-up converter when the stored energy flows from the battery bank to the dc-link bus (discharging mode) and as a step-down converter when the energy flows from the dc link to the battery bank (charging mode). The controller regulates the dc-link voltage and another dc–dc converter associated with PV source performs an maximum power point tracking (MPPT) operation for the PV source. As aforementioned, because the dc-link bus voltage is usually very high (for most applications), the bidirectional dc–dc converter needs to have a high step-up gain along with a high efficiency. It is difficult to achieve the high efficiency and the high gain simultaneously in conventional bidirectional dc–dc converters due to the losses in semiconductor devices, leakage inductance. Another traditional stand-alone PV system architecture is that whereby the energy storage device (battery) is placed between the first dc/dc and the dc link, or the battery is interfaced with the dc link by the second dc/dc converter [see Fig. 1 (b)] . In case without the second dc/dc converter, the first dc/dc converter performs MPPT while the dc/ac inverter regulates the ac output voltage. Despite the advantages of this configuration (such as reducing the number of power converters), it also has some disadvantages such as a highvoltage battery, which leads to stacking up of the multiple battery modules. Furthermore, the battery current is uncontrollable; thus, when the load changes abruptly, it often damages the battery due to the large transient current. Also, there can be a small cycle of charging and discharging in the battery from the consistent power flow during the operation, which causes a serious reduction of battery lifetime. In order to overcome these drawbacks, the secondary dc/dc converter is normally added to this configuration. However, the battery is still involved in energy conversion, affected by load disturbance directly, which could seriously affect the battery life-time and utilization. Recently proposed topology of an SPVS is classified as a three-port converter as shown in

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 01
January 2017

Fig. 1(c). The main advantages of this topology are the low voltage stress across the active switches, the low input current ripple, etc.

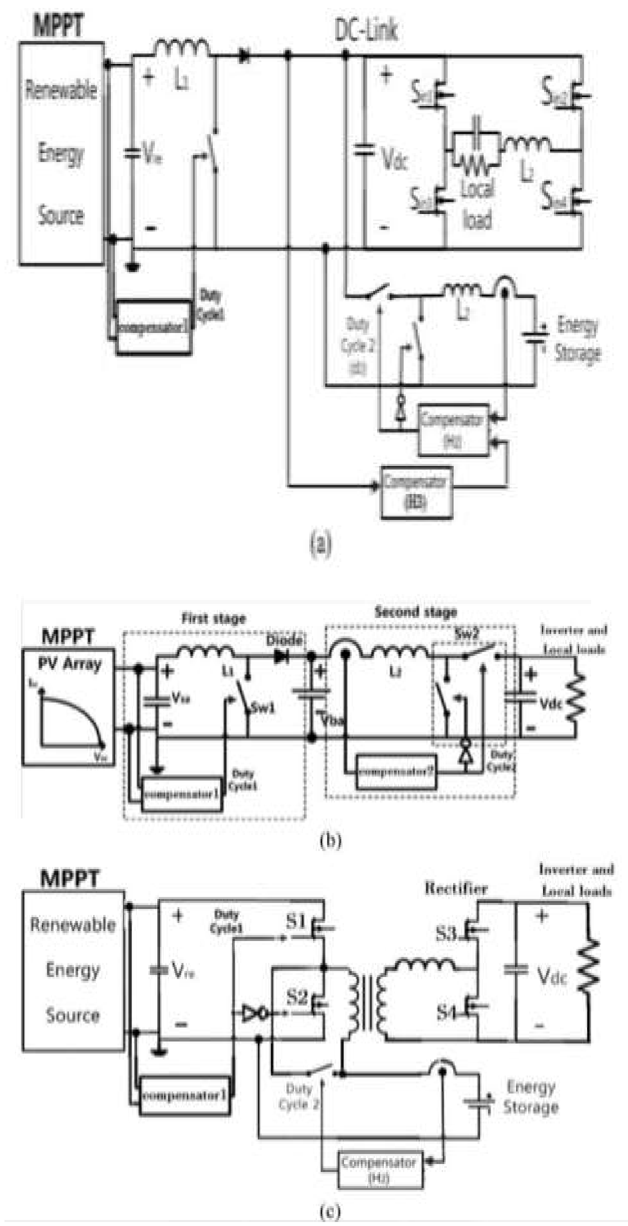
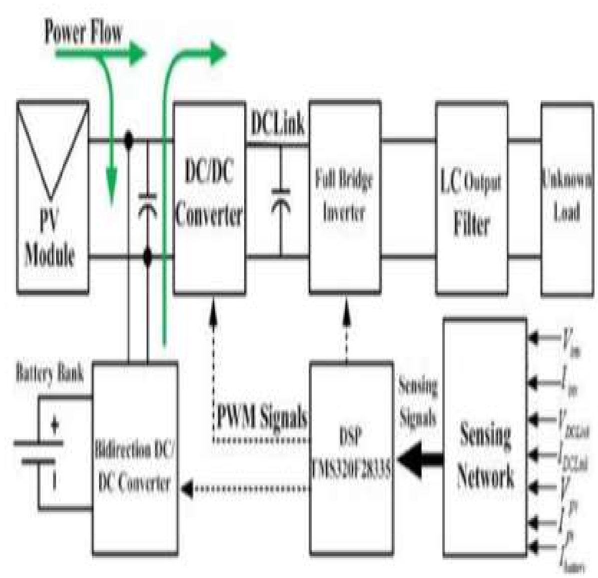


Fig. 1. Convectional circuits of the SPVS proposed in previous literature.

(a) Stand-alone PV power generation an energy storage device connected with dc link.

(b) Stand-alone PV power generation an energy storage device connected between first and second converters.

(c) Stand-alone PV power generation used three port converters. However, the architecture and the control method are quite complex and the control architecture is difficult to instantaneously adapt for multiple mode variation. In addition, a multiport ac link, as an alternative configuration for SPVS, is a configuration that utilizes many high-frequency switches, which leads to low efficiency of the overall system. Main advantages of this topology are the low voltage stress across the active switches, the low input current ripple, etc. However, the architecture and the control method are also quite complex and the control architecture is difficult to instantaneously adapt for multiple mode operation, as well.



International Journal of Research
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p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 01
January 2017

Fig. 2 Block diagram of the SPVS.

2. Related Work

2.1 Proposed Pv-Storage System Architecture:

The proposed SPVS is shown in Fig. 2 and consists of a PV panel, batteries, two converters, and a single-phase dc/ac inverter. The boost converter (BC) is used to maintain the dc link voltage, while the charging or discharging mode of the bidirectional dc/dc converter is applied to track the MPPT of the PV array when the available PV power is insufficient to meet the load. Therefore, the two dc/dc converters in the system need to be coordinated by an upper level controller. This configuration provides a flexible smooth operation for the system, since the role of the main PV power stream and that of the storage subsystem are clearly separated from each other. The system could work with and without battery both, without any major mode change in the local controllers, which is preferable from industrial point of view.

The proposed system architecture makes the switch between the different modes of operation smooth and simple without the need for supervisory controller. Furthermore, this arrangement provides more flexibility in choosing the battery‘s nominal voltage with a reasonable step-up ratio. It also stores the excess PV energy in the battery to balance the system and supplies the instantaneous peak power demand. One of the main concerns in the previous architecture is the battery voltage, which needs stacking up of multiple packs to enhance the voltage range. Actually, the stacking up requires a balancing circuit, a so-called charge balancer, which makes the system structure more complicated, resulting in an undesirable configuration in terms of the size and cost competitiveness. Also, some safety issues are observed, whereby the high-voltage dc lines can cause fatal damage to the human body since the battery is alive even during the main power system turn-off. Therefore, the proposed scheme is more desirable for the PV-storage combination system. In the previous section, it has already been seen that the battery voltage in the conventional schemes should be greater than 100 V because of a fundamental characteristic that the bidirectional converter (BDC) should discharge the battery energy to 400 V dc link.

TABLE I
SUMMARY OF OPERATION MODES

Modes	Power Condition	Battery Condition	PV Condition
I	$P_{MPP} < P_{load}$	discharging	MPPT
II	$P_{MPP} < P_{load}$	Fully discharged	Non-MPPT
III	$P_{MPP} > P_{load}$	Charging	MPPT
IV	$P_{MPP} > P_{load}$	Fully charged	Non-MPPT
V	$P_{MPP} = 0, P_{bat} = P_{load}$	Discharging	Non-MPPPT

International Journal of Research
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p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 01
January 2017

Five flexible operation modes are possible for the proposed scheme. These modes depend on the power producing and energy-storing conditions, as follows.

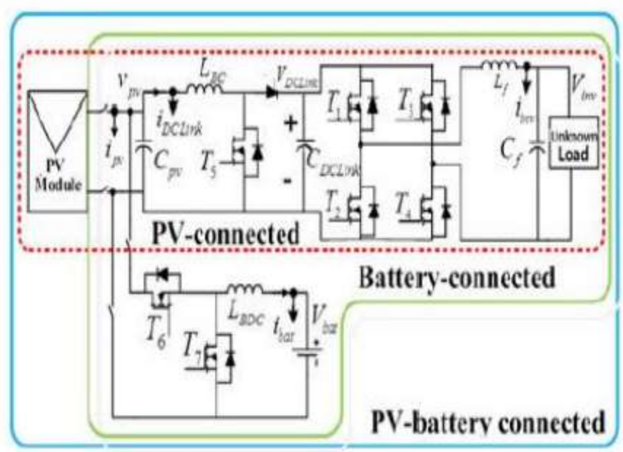
Mode I—PV-storage connected (PMPP <Pload): The PV is not enough to meet load demand, so the battery bank is discharged to meet the load demand. The BDC discharges the stored energy to the input of PV PCS, and the BC enhances PV voltage up to the 400 V dc link.

Mode II—PV-connected (PMPP <Pload): If the battery becomes fully discharged, or when the battery bank is removed, the system enters the non-MPPT mode or under voltage lockout and shuts down.

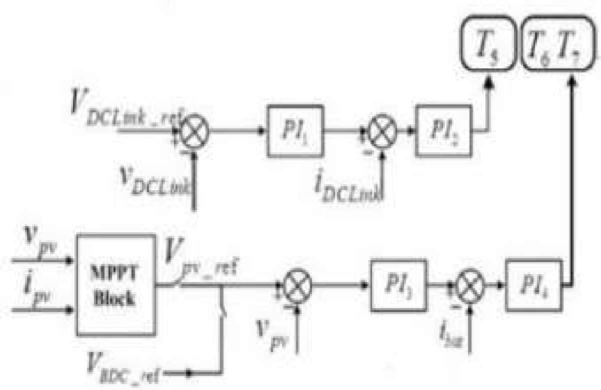
Mode III—PV-storage connected (PMPP >Pload): The harvested power exceeds the load and the battery is charged with the excess power, until the battery is fully charged. Electric power can flow from the PV source to the load as well as charge the battery.

Mode IV—PV-connected (PMPP >Pload): If the battery is fully charged, the battery bank should be disconnected from the PV power conditioning system. The MPPT must be disabled (non-MPPT), and the PV voltage reference is set at constant to hold the CPV voltage, providing the load-power tracking.

Mode V—Battery-connected (nighttime): When PV sources do not produce sufficient power for the load, for example, at night or on a cloudy day, the PV modules are disconnected from the power conditioning system. Ploadis provided only by the battery through cascading the BC, BDC, and full-bridge inverter. Such a cascaded operation makes it possible to step up the voltage from 24 Vdc, given by the battery bank, up to 400 Vdc to feed the dc/ac inverter and the load.



(a)



(b)

International Journal of Research
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p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 01
January 2017

Fig. 3. Circuit diagram of the overall system configuration of the SPVS.
(a) Power stage.
(b) Control strategy.

In this paper, a multi loop proportional-integral (PI) controller is presented. The multi loop PI is used to control the operation of the dc/dc converters due to its robustness and good performance with any type of unknown arbitrary load. This system has a number of advantages. First, the flexibility for various types of operating modes, with and without energy storage, is strongly guaranteed without the control configuration change. Second, the system can be applied even with a single 24 V commercial battery without any extra connection.

3. Implementation

3.1 Bidirectional Dc-Dc Converter:

Energy storages in general uses bidirectional DC-DC converter for charging and discharging applications may be either in half-bridge or full-bridge arrangement of semi-conductor switching devices. The buck type of converter has energy storage on the high voltage side, whereas boost type of converter has energy storage on the low voltage side.

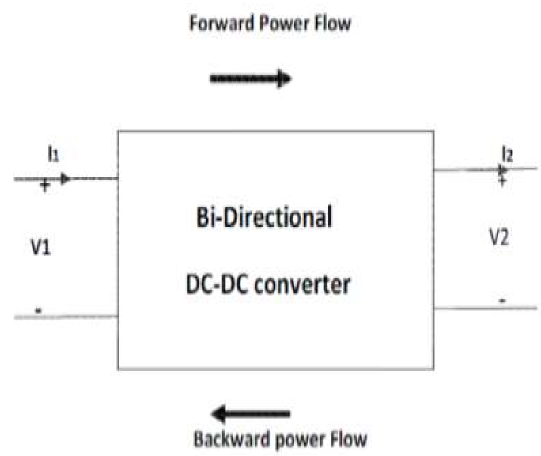

Fig.4. General Block diagram f bidirectional DC-DC converter.

The concept of power flow in both direction for bidirectional dc-dc converter is operation of switching devices realize current flow in each way. Bidirectional dc-dc converters are developed from two unidirectional semiconductor switching devices such as; MOSFET, Transistors and IGBT power switches constructed with parallel diodes. These parallel diodes serve double sided power flow. Even though there are many topologies of bidirectional dc-dc converter; basically they are divided into two types such as an isolated bidirectional DC-DC converters and non - isolated bidirectional DC-DC converters based on the isolation material between input and load.

3.2 Boost Converter:

A Boost converter is a switch mode DC to DC converter in which the output voltage is greater than the input voltage. It is also called as step up converter. The name step up converter comes from the fact that analogous to step up transformer the input voltage is stepped up to a level greater than the input voltage. By law of conservation of energy the input power has to be equal to output power (assuming no losses in the circuit).

Input power (P_{in}) = output power (P_{out})

Since $V_{in}<V_{out}$ t in a boost converter, it follows then that the output current is less than the input current. Therefore in boost converter.

$V_{in}<V_{out}$ And $I_{in}>I_{out}$

The main working principle of boost converter is that the inductor in the input circuit resists sudden variations in input current. When switch is OFF the inductor stores energy in the form of magnetic energy and discharges it when switch is closed. The capacitor in the output circuit is assumed large enough that the time constant of RC circuit in the output stage is high. The large time constant compared to switching period ensures a constant output voltage **$V_o(t)$ = V_o(constant)**.

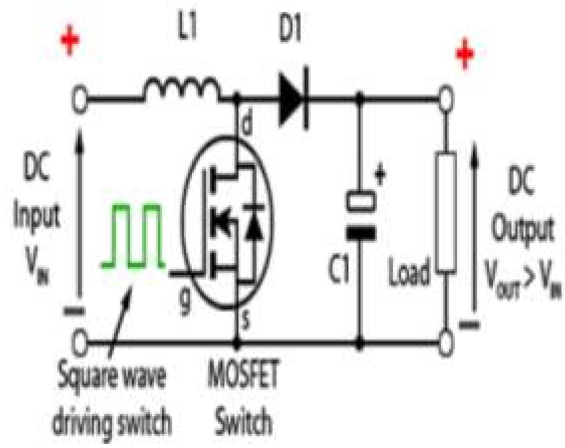

Fig.5.Circuit diagram of boost converter.

The boost converter can be operated in two modes: Continuous conduction mode in which the current through inductor never goes to zero i.e. inductor partially discharges before the start of the switching cycle. Discontinuous conduction mode in which the current through inductor goes to zero i.e. inductor is completely discharged at the end of switching cycle.

3.4 Single Phase Inverter:

In this four switches (in 2 legs) are used to generate the ac waveform at the output. Any semiconductor switch like IGBT, MOSFET or BJT can be used. Four switches are sufficient for resistive load because load current Io is in phase with output voltage vo. However this is not true in case of RL load where the Io is not in phase with vo and diodes connected in anti-parallel with switch will allow the conduction of the current when the main switch is turned off.

p-ISSN: 2348-6848
e-ISSN: 2348-795X
Volume 04 Issue 01
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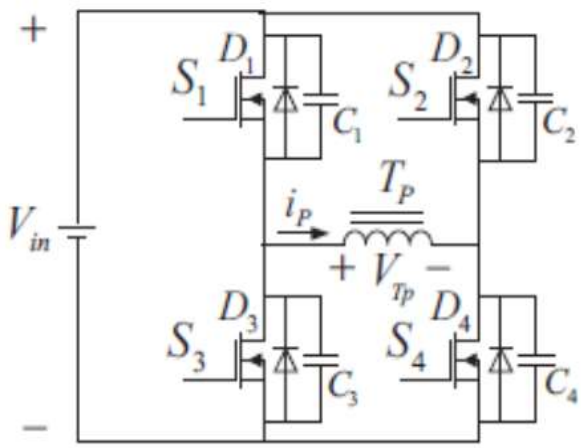
These diodes are called as feedback diodes since the energy is fed back to the dc source.



In full bridge inverter, when T1, T2 conduct the output voltage is Vs and when T3, T4 conducts the output voltage is -Vs. The switches T1, T2 conducts for period of 0period of T/2<t≤T where ‗T' is the time period of the gate pulses to the devices. The frequency of output ac voltage can be varied by varying the T of the gate signal.

The root mean square (rms) value of output ac voltage:

$$V_0 = \left(\frac{1}{T}\int_0^T V_s^2\,dt\right)^{1/2} = V_s$$

TABLE II
CIRCUIT PARAMETERS

Parameter	Value
V_{PV} (max)	100 V
I_{PV} (max)	4 A
R_{eq}	25 Ω
V_{bat}	24 V
L_{BDC}	1.8 mH
C_{PV}	2200 μF
L_{BC}	1.8 mH
C_{dc_link}	1300 μF
f_{sw}	20 kHz

4. Experimental Work

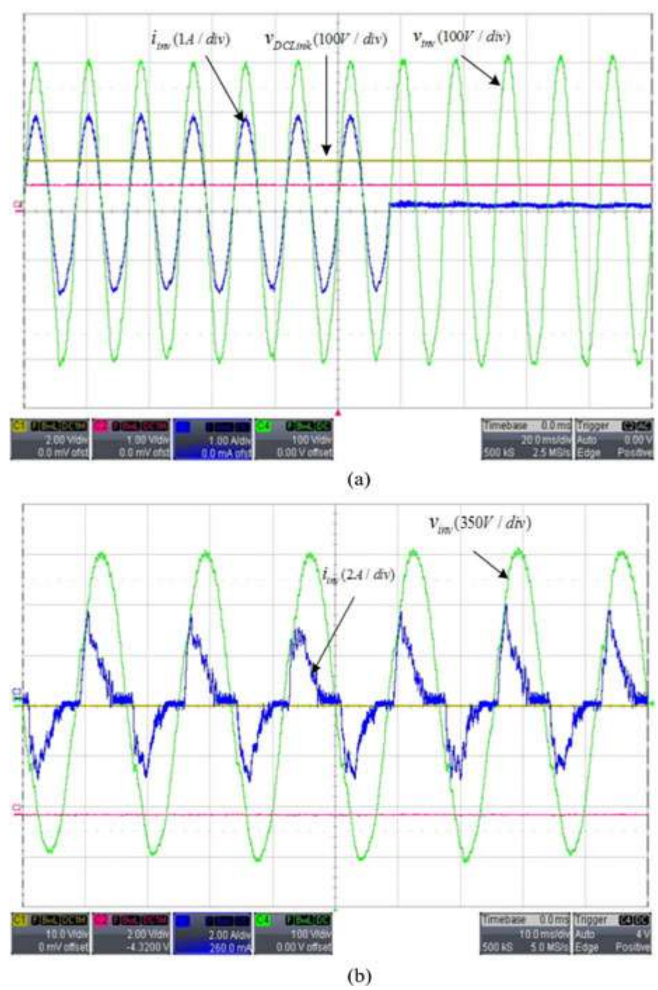


Fig. 6. Output waveforms of voltage and current for (a) step change with resistive load between

full load and no-load; (b) worst case: SPVS feeds a nonlinear load (a 2 kW dc supply-Sorensen).

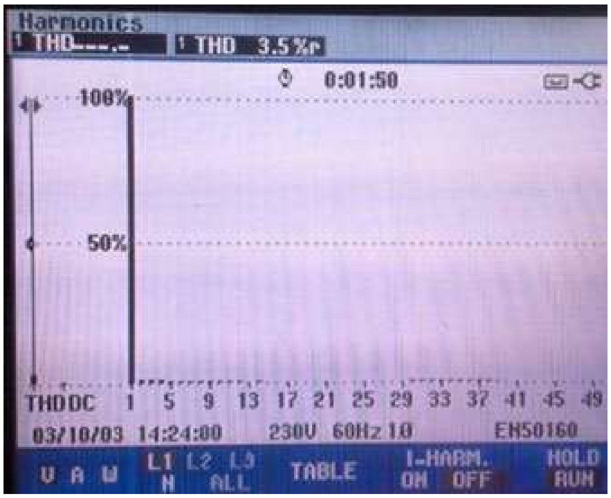


Fig. 7. FFT plot and the THD value of the output voltage shown in Fig. 6 (nonlinear load), obtained using FLUKE 434 Power Quality Analyzer.

5. Conclusion

In this project present, dynamic-response analysis and the controller-design procedure of the flexible SPVS. Both dc/dc converters are successfully controlled in a variable operation condition, and the control strategy achieves fast and accurate control of the inverter output voltage, even with nonlinear loads and step load changes. From the proposed control architecture of the PV-storage system, multiple operating modes such as PV-only, storage only, and PV-storage coupled are allowed without any instantaneous control configuration changes. The experimental tests are verified by utilizing a 36-V battery bank; actually, the SPVS can also operate well when associated with a 24 V commercial single battery. The proposed topology, along with its control strategy, is very practical because of the flexibility of the configuration and the controlling strategy of the bidirectional dc/dc converter and dc/ac inverter is simple and strong. As a result, it is compatible with a conventional PV or battery systems without any control configuration modification. This topology is highly promising for a commercial product of PV conversion systems.

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