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Review on Photovoltaic Battery Powered DC Bus System for Common Portable Electronic Devices

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Abstract — Non-Conventional energy sources such as Photovoltaic (PV) along with battery based energy storage requires power conditioning to be connect to electrical grid. This is done through dc-dc converter or dc-ac inverter stages. When the load is dc there is no need of dc-ac conversion, the aim of this project is to present hybrid PV-Battery powered dc bus system that will eliminate dc-ac conversion stage. A hybrid boost-flyback converter is used.

Keywords- DC Bus, Dc-Dc Converter, Hybrid Boost-Fly Back Converter, Photovoltaic (PV) Power System

I. INTRODUCTION

The increase in the use of modern electronic equipment's and appliances has changed nature of load on electrical grid as they require dc power. As the electrical grid is ac, an ac-dc conversion stage is needed to supply power to these devices. The power available from renewable energy sources is tapped by ac grid by dc-conversion. The research work shown in paper on how to improve inversion efficiency by using different converter topologies and control strategies [1]-[7]. When a renewable energy source like solar power is present and it is fluctuating dc in nature, we can reduce the dc-ac inversion and ac-dc conversion if the output is dc. By connecting a simple dc-dc converter with maximum power point tracking (MPPT) technique in between the solar panel and the load, it would save the extra conversion losses. The problem with solar energy is its intermittent nature therefore some kind of storage typically a battery is used to maintain the voltage regulation. The cascade connection of battery charger and converter is used to provide dc (or ac) voltage for load. The PV-battery dc-dc converter for proposed dc bus system has to achieve charging of battery, MPPT function, and provide tight output regulation i.e. high voltage gain and simple circuitry is required. In [13] the battery charger and the inverter are combined into circuitry for PV-battery powered lightning system but in that input was processed twice. To achieve high step up voltage a coupled inductor used in [14] but resonance produced between leakage inductance and output rectifier. To reduce leakage inductance a dc-dc converter proposed in [16] which uses forward transformer coupling. But this converter deal with single power source only and we have to consider both an energy source and an energy storage unit. The objectives of this paper are to: 1) propose a new dc/dc converter configuration powered by a combination of a PV source and a battery while fulfilling the dc bus system requirements; and 2) propose a new high step-up ratio dc/dc converter for the dc bus system with lower voltage stress. In traditional power systems, large power generation plants located at adequate geographical places produce most of the power, which is then transferred toward large consumption centers over long distance transmission lines. The system control centers monitor and control the system continuously to ensure the quality of the power, namely the frequency and the voltage. However, the power system is changing, a large number of dispersed generation (DG) units, including both renewable and non-renewable sources such as wind turbines, wave generators, photovoltaic (PV) generators, small hydro, fuel cells and gas/steam powered combined heat and power (CHP) stations, are being developed [17]-[19]. A wide spread use of renewable energy sources in distribution networks and a high penetration level will be seen in the near future. E.g., Denmark has a high penetration (20%) of wind energy in major areas of the country and today 14% of the whole electrical energy consumption is covered by wind energy. The main advantages of using renewable sources are the elimination of harmful emissions and the inexhaustible resources of the primary energy.

II. LITERATURE REVIEW

The day to day increase in the use of modern electronic equipment's and appliances has changed the load profile seen by the ac electrical grid as they require dc power. Therefore a switching ac adaptor for every device is provided. To tap renewable energy sources for the ac grid the conventional way is by dc–ac conversion. There has been a great deal of research work reported in the technical literature on how to improve the inversion efficiency by utilizing different converter topologies and control strategies [1]–[7].

If a dc–dc converter with maximum power point tracking (MPPT) capability is inserted in between the renewable energy source and the load would save the extra conversion losses associated with the unnecessary conversion stages. For example, a dc–dc buck–boost powering an array of LEDs from the photovoltaic (PV) panels is introduced in [8].

The major concerns with the solar energy are its intermittent nature and therefore it needs some kind of alternate storage which is typically provided by battery to maintain the output voltage regulation. A common practice is to adopt a cascaded connection of a battery charger and a converter (or inverter) to provide dc (or ac) voltage for the load. A multiple-port or multiple-input configuration becomes more popular because this allows the intake of multiple energy sources [9]–[13] such as a Photovoltaic panel, wind turbine, fuel cell, and battery at the same time, and favors the hybrid power system development.

The Photovoltaic-battery dc–dc converter for the proposed dc bus system has to achieve charging of the battery, Maximum power point tracking function, and provide tight output regulation, i.e., a dc–dc converter with high voltage gain and simple circuitry is required. An attempt was made in [14] to combine the battery charger and the inverter into a circuit for PV-battery-powered lighting system, but it was still a two stage design (i.e., input power has been processed twice). A coupled inductor was 6 employed in [15] to achieve high step-up voltage, but resonance was produced between the leakage inductance and the output rectifier.

An attempt was made in [16] to eliminate the ringing issue but there is a potential of voltage imbalance between the series output capacitors. A high efficiency dc–dc converter was proposed in [17], which uses a forward transformer coupling to reduce the leakage inductance. This converter further developed into a bidirectional converter [18]. However, these converters deal with a single power source only, and this projects aim is to consider both an energy source and an energy storage unit.

There are many commercial controller ICs and circuits for ac adaptor available in the market [16]–[17]. Due to low parts count, inherent isolation, and large conversion ratio by the transformer, flyback converter topology is a popular choice for most ac adaptors design. Regardless of the topology selection, it is observed that all these technical documents show a typical circuit [17]. In these circuits, there is always a bridge rectifier followed by a large capacitor to provide a dc voltage for the converter to operate on.

The modelling of the photovoltaic model by programming with the help of equations and evaluating different Maximum power point tracking converter topologies [18]. For tracking the maximum power point different techniques are employed. The modelling of Maximum power point tracking controller algorithm and comparison between two Maximum power point tracking techniques [19].

Boost converter steps up the input voltage magnitude to a required output voltage magnitude without the use of a transformer. The main components of a boost converter are an inductor, a diode and a high frequency switch. These in a co-ordinate manner supply power to the load at a voltage greater than the input voltage magnitude [13].

Fly-back converter is the most commonly used Switch Mode Power Supply (SMPS) circuit for low output power applications where the output voltage needs to be isolated from the input main supply. The output power of fly-back type Switch Mode Power Supply circuits may vary from few watts to less than 100 watts [16].

III. PROPOSED WORK

3.1 Proposed PV-Battery-Powered DC Bus System

The schematic of the proposed dc bus system is shown in Fig. 1. With the PV-battery-powered dc bus, the ac adaptors can share this bus to power the various devices. In general, the requirements of implementing the proposed dc bus system involving PV panels, batteries, and dc–dc converters are listed as follows:

1) Regulation of the dc bus voltage;
2) MPPT for the PV panels.
3) Capability of the battery to support the dc bus voltage when the solar source is not present.

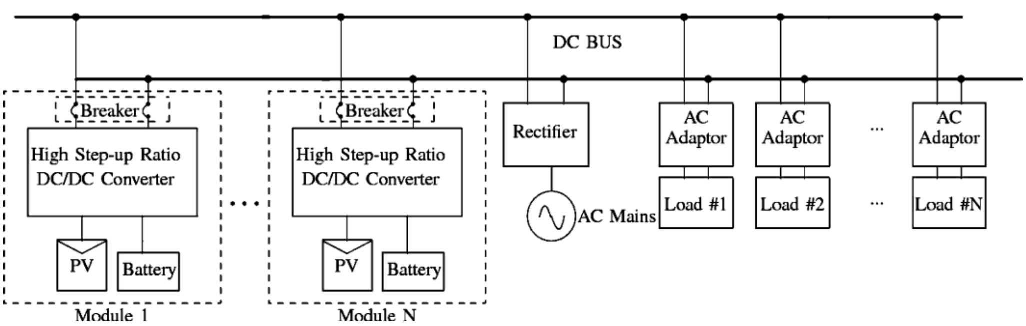

Fig. 1. Proposed PV-battery-powered dc bus system.

It should be noted that the dc bus could also be powered from a rectified ac mains voltage (Fig. 1). The rectified voltage with low-frequency ripple would not affect the dc bus system because the switching ac adaptors can provide tight output regulation for the loads for ac and dc inputs. The proposed dc bus system could be scaled up for higher Power

applications by increasing the number of PV panels, the Size of the battery, and the power ratings of the components of each converter. Fig. 1 shows a possible modular approach. Each module contains a PV panel (or a string of PV panels or paralleled PV panels), a battery bank, the proposed dc/dc converter, and a dc circuit breaker. This modular approach has several advantages. First, it enhances system reliability over the centralized approach as when one module fails, it can be isolated from the dc bus. Second, each module has its own control of MPPT to maximize the utilization of the PV power.
In this paper, a novel integrated high-voltage gain step-up dc–dc converter, combining a buck–boost converter and a new Hybrid boost–flyback converter, capable of achieving battery charging, MPPT function, and tight output regulation, is proposed. The proposed solution overcomes all the previously mentioned problems with capacitor voltage imbalance, single sourced converters, and ringing/resonance due to leakage inductances. In summary, the new hybrid boost–flyback converter combines the advantages of boost and flyback converters and has the following features: 1) higher step-up ratio than that of the boost converter or flyback converter; 2) lower voltage stress on the power switch.

3.2 Photovoltaic Module

Solar cells consist of a p-n junction fabricated in a thin wafer or layer of semiconductor. In the dark, the I-V output characteristic of a solar cell has an exponential characteristic similar to that of a diode. When exposed to light, photons with energy greater than the band gap energy of the semiconductor are absorbed and create an electron-hole pair. These carriers are swept apart under the influence of the internal electric fields of the p-n junction and create a current proportional to the incident radiation. When the cell is short circuited, this current flows in the external circuit; when open circuited, this current is shunted internally by the intrinsic p-n junction diode. The characteristics of this diode therefore set the open circuit voltage characteristics of the cell.

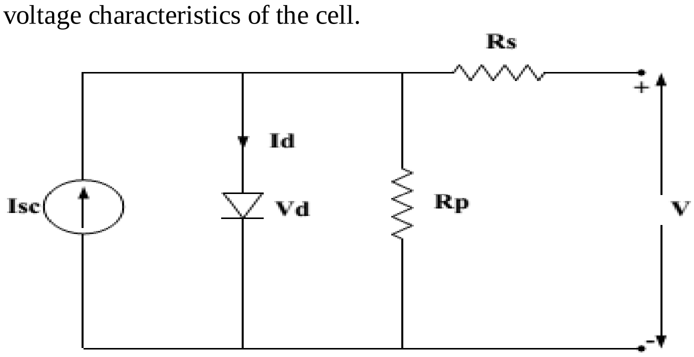

Fig. 2. Equivalent circuit of solar cell.

Thus the simplest equivalent circuit of a solar cell is a current source in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell. The diode determines the I-V characteristics of the cell. The circuit diagram for the solar cell is shown in figure 2. The equations which describe the I-V characteristics of the cell areas,

$$I = I_L - I_0\left(e^{\frac{q(V+IRs)}{nkT}} - 1\right) \quad (1)$$

$$I_L = I_L(T_1)(1 + K_0(T - T_1)) \quad (2)$$

$$I_L(T_1) = G * I_{SC}(T_{1,nom}) / G_{(nom)} \quad (3)$$

$$K_0 = (I_{SC(T2)} - I_{SC(T1)}) / (T_2 - T_1) \quad (4)$$

$$I_0 = I_0(T_1) * \left(T/_{T_1}\right)^{\frac{3}{n}} * e^{\frac{-qVg}{nk} * \left(\frac{1}{T} - \frac{1}{T_1}\right)} \quad (5)$$

$$I_{o(T1)} = I_{SC(T1)} /(e^{\frac{qV_{oc(T1)}}{nkT_1}} - 1) \quad (6)$$

$$R_s = -\frac{dV}{dI_{Voc}} - 1 / X_v \quad (7)$$

$$X_v = I_{o(T1)} * \frac{q}{nkT_1} * e^{qV_{oc(T1)}/nkT_1} \quad (8)$$

All of the constants in the above equations can be determined by examining the manufacturer's ratings of the PV array, and then the published or measured I-V curves of the array. As a typical example, the Solarex MSX60 60W array will be used to illustrate and verify the model. The parameters used are shown in table I.

Table I: Specifications of Solarex MSX Panel**.**

At Temperature	T	25°C.
Open ckt. Voltage	V_{oc}	21.0V
Short ckt. current	I_{sc}	3.7A
Voltage, max	V_m	17.1V
Current, max	I_m	3.5A
Maximum power	P_m	59.9W

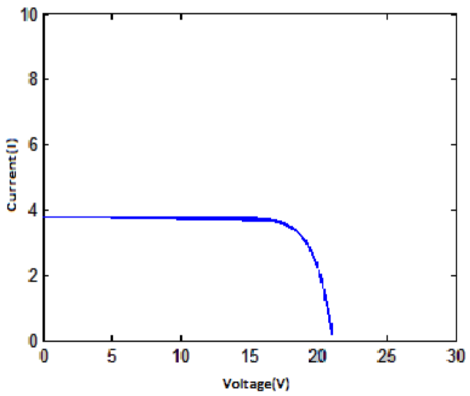

Fig. 3. I-V characteristics of the solar panel.

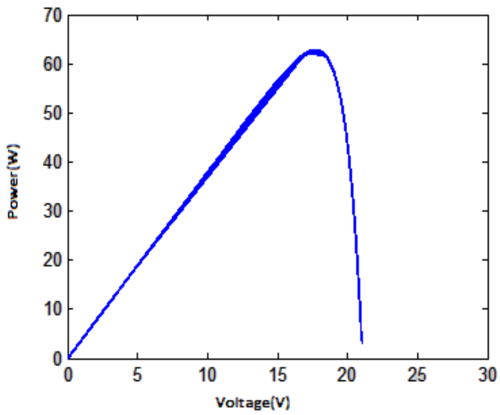

Fig. 4. P-V characteristics of the solar panel.

3.4 P & O MPPT Technique

The Perturb and Observe (P&O) algorithm operates perturb the PV voltage periodically by varying the duty cycle, and observe the PV power to increase or decrease PV voltage in the next cycle.

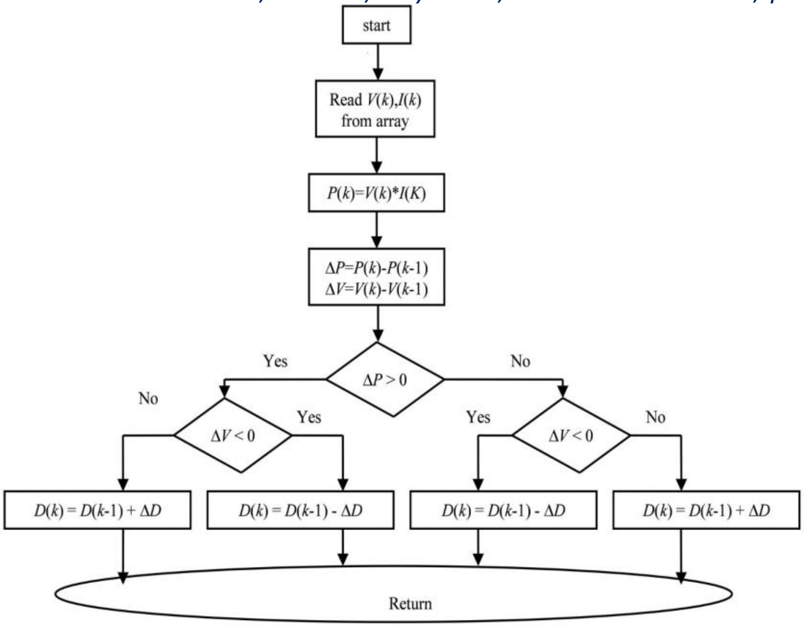

Fig. 5. Flow chart of P & O algorithm.

If the perturbation voltage produces an increase of the power, then the direction or slope of perturbation voltage (duty cycle) is the same as the previous cycle. On the contrary, if the perturbation voltage produces a decrease of the power, then the direction or slope of perturbation voltage (duty cycle) is the opposite from the previous cycle. The advantage of P&O algorithm is simple and easy to be implemented, especially using the low cost microcontroller system. However, the main drawback of the algorithm is that it oscillates around the maximum power point, due to the perturbing process to find the maximum power point.

3.5 Proposed DC–DC Topology

The proposed dc–dc topology is shown in Fig. 6 and is formed by combining a buck–boost converter with a hybrid boost–flyback converter. The converter is simulated using MATLAB/SIMULINK software and its high step up outputs are shown. The buck–boost converter formed by $L1$, $S1$, and $D1$ works both as a battery charger for V_{batt} and a circuit for MPPT. The hybrid boost–flyback converter formed by a coupled inductor ($L2$ and $L3$), $S2$, $D3$, and $C1$ is used to regulate the bus voltage Bus. VPV and V_{batt} are connected in series and serve as the input of the hybrid boost–flyback converter.

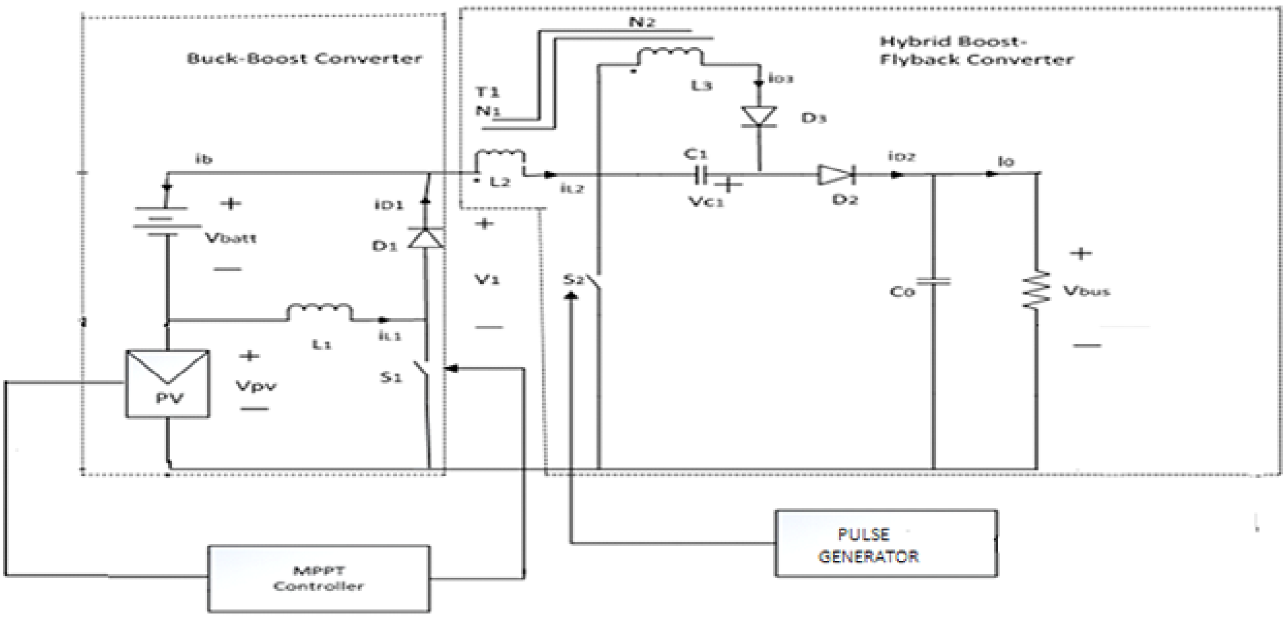

Fig. 6. Proposed PV-Battery step-up dc-dc converter for dc bus system

Table II: Details of Components used in MATLAB MODEL for Simulation

Components	**Details**
Inductor	L_1=100μH.
Capacitors	C_1=68μF, C_0=47μF.
Resistor	R = 300Ω
Linear transformer	N_1/N_2 = 1:4
Battery	12V/2.3 AH lead-acid battery

IV. SIMULATION RESULTS

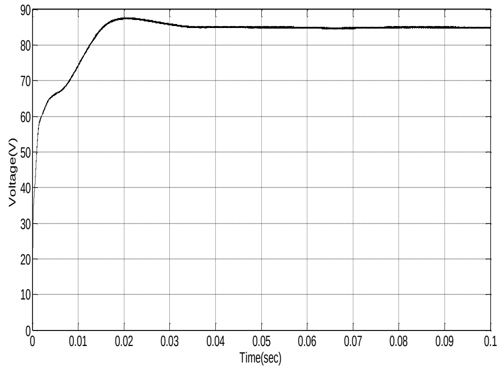

Fig. 7. Output Voltage of proposed dc-dc converter

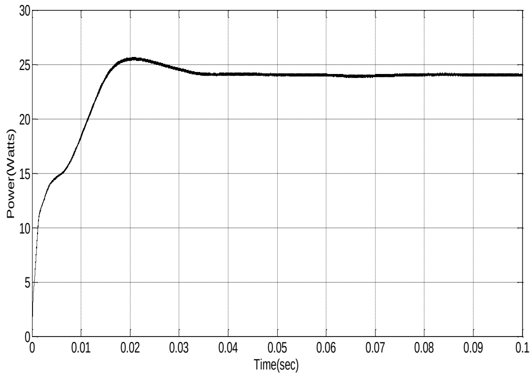

Fig. 8. Output Power of proposed dc-dc converter.

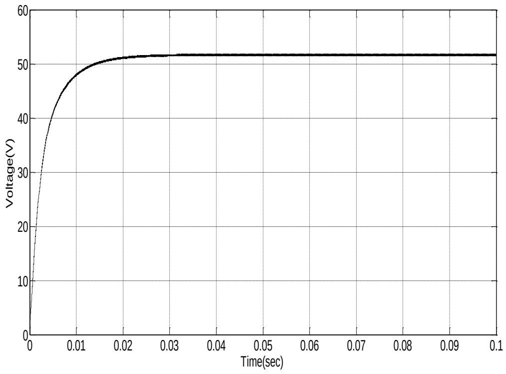

Fig. 9. Output Voltage of Boost converter.

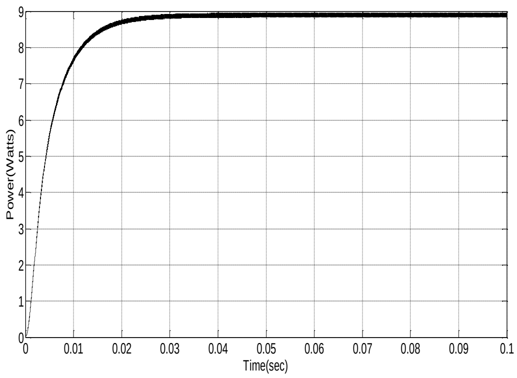

Fig. 10. Output Power of Boost Converter.

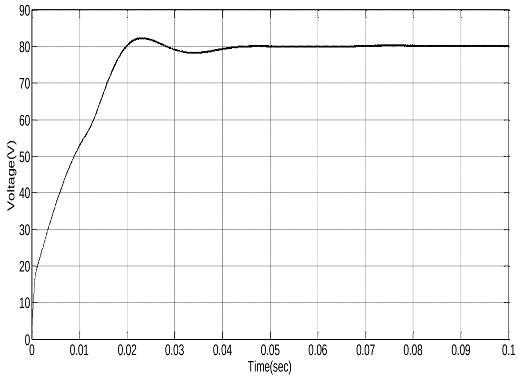

Fig. 11. Output Voltage of Hybrid Boost-flyback Converter.

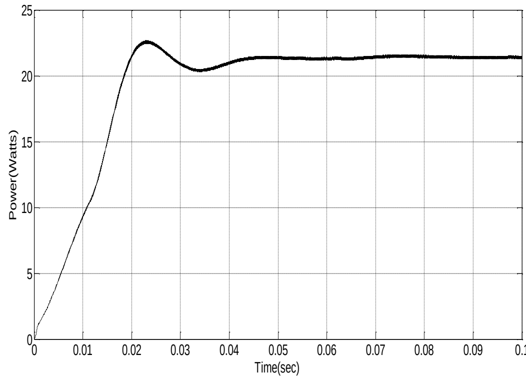

Fig. 12. Output Power of Hybrid Boost-flyback Converter.

V. CONCLUSION & FUTURE SCOPE

This paper has suggested a Photovoltaic battery powered dc bus for the common portable electronic devices. The proposed system has been implemented using MATLAB/SIMULINK software. A high step up hybrid dc-dc converter is proposed which have high step up ratio than conventional boost and flyback converter. The proposed converter boosts the output voltage from the PV array of 20 V to about 86V.

The hybrid high step up dc/dc converter can used to step up the voltage for the dc bus with higher efficiency and lower losses. The dc bus system can be very efficient to supply the common portable electronic devices which require dc power. The dc/dc converter also has battery attached in series with PV so when irradiance is not available, the battery can supply to the load. This makes the converter more reliable.

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