A Review of Hybrid Converter Topologies

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Abstract: There is a growing interest in solar energy systems with storage battery assistance. There is a corresponding growing interest in hybrid converters. This paper provides a comprehensive review of hybrid converter topologies. The concept of a hybrid inverter is introduced and then classified into isolated and non-isolated structures based on using a galvanic transformer. The classification and description of each type are presented based on the features and applications. Furthermore, the most popular commercial solutions are investigated in terms of their simplicity, flexibility, efficiency, and battery technology. The summarizing features are presented through tables, and future trends for researchers to follow to develop efficient hybrid converters are discussed. This review paper is intended as a convenient reference for hybrid converter users.

Keywords: dc-dc/ac converter; hybrid converter; buck-boost converter; derived converter

1. Introduction

Electrical energy consumption over the whole world is rapidly growing. There is a consistent increase in the demands on power capacity and the efficient production, distribution, and utilization of energy. The general power generation capacity must be increased to meet dynamic load variations [1]. A decrease in the accessibility of conventional energy resources has prompted power engineers and researchers around the globe to look for better and more productive means of the utilization of renewable energy sources (RES).

Power electronic converters play a crucial role in the usage of RES [2]. Power electronic converters are increasingly used in various applications including electric cars, ships, and photovoltaic (PV) panels. An independent power system can be formed by combining renewable energy with local loads. This approach is widely incorporated into modern power systems [3,4]. In this system, dc and ac loads are provided by different types of energy sources using efficient power electronic converters.

Figure 1a shows a simple example of a solar energy system in which a single dc source supplies an ac grid or load. Figure 1b shows the same system with battery assistance. Hybrid converters as multi-output converters are used to provide simultaneous dc and ac outputs for systems, delivering better power density and improved reliability [5,6]. Researchers have been focused on improving the performance of hybrid converters through topological innovations and control methods [7–9].

As a result of the limited amount of power that can be injected into the grid by renewable energy produced by local households, the feed-in energy costs of solar systems are decreasing and are expected to be zero in the current decade [10]. With this in mind, the use of battery storage systems along with renewable energy sources has great importance.

Some review papers have been published in the literature [11–14]. However, this paper focuses on the existing solutions on the market in terms of structure (simplicity), rating powers, and insulation, as well as high efficiency. The main goal of this paper is to propose a general classification of hybrid converters, as well as a brief overview of their state in the marketplace. In this regard, Section 2 presents the ancillary services of converters. Section 3 describes the various functions of the Hybrid converter. The existing solutions for hybrid
converters are analyzed in Section 4. A research overview of isolated and non-isolated hybrid converters is presented in Sections 5 and 6 respectively. Finally, the conclusion is presented in Section 7.

![Schematic diagram of a solar energy system: without (a) and with (b) battery storage assistance.](image)

**Figure 1.** Schematic diagram of a solar energy system: without (a) and with (b) battery storage assistance.

### 2. Ancillary Services of Converters

The Federal Energy Regulatory Commission (FERC) defines ancillary services as “those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system”. They are needed for grid reliability [15]. FERC identified six ancillary services including reactive power and voltage control, loss compensation, scheduling and dispatch, load following, system protection, and energy imbalance [16]. Among these services, the power electronics converters seem to be best suited for providing reactive power and voltage control. Voltage regulation has traditionally been done on transmission lines because distribution networks are passive networks. The diffusion of RES directly connected to the distribution networks gave rise to the problem of voltage regulation on these networks. Voltage regulation can be achieved by compensating the reactive power required by the users and aims primarily to maintain voltages within certain ranges, but it is also concerned with minimizing temporal variations in voltage and harmonic distortion. The voltage that is traditionally controlled is that acting on the ratio-changing devices (e.g., transformer taps and voltage regulators), reactive-power-control devices (e.g., capacitors, static-var compensators, and occasionally synchronous condensers), and harmonic-control devices (active power filters). The system operator must monitor and control these voltages and compensate for the reactive power of the grid. Sometimes the network management may find it more economical to purchase reactive power from a customer than to directly compensate the customer for the same reactive power. In this case, some customers can provide this ancillary service to the network [17,18].

When the electrical energy conversion is made with photovoltaic (PV) arrays, an intermediate converter is needed for the connection to the grid. This converter can be either single-stage or dual-stage [19]: the first stage is a dc-dc converter, whereas the second is an inverter synchronized with the utility grid. The dc-dc converter boosts the voltage of the PV arrays up to values suitable for the PWM modulation of the inverter. Maximum Power Point Tracking control (MPPT) is usually implemented on the boost converter to extract the maximum power available from the solar source. Finally, the inverter supplies the power generated by the PV array with the desired power factor to the grid.
When PV systems are used to perform ancillary services to improve grid power quality, they pose several control challenges. For example, in harmonic compensation, it is important to detect the current or voltage harmonic information.

Reference [20] proposed a method based on conservative power theory to detect the harmonic current of the load. In [21], the Point of Common Coupling (PCC) voltage information for harmonic compensation is used through a voltage control loop. In addition, reactive power compensation methods are discussed in [22].

3. Functionalities of Hybrid Converters

An intelligent hybrid converter is a trending type of converter for solar applications using renewable energy for home consumption, especially for solar photovoltaic installations. Some see this as a new technology, however, in some parts of the world such products have been around since the 1990s. In solar systems, power generation fluctuates and may not be synchronized with a load’s electricity consumption since solar panels generate electricity only during the day. To fill the gap between what is produced and what is consumed during the evening when solar electricity is not produced, it is necessary to store energy for later use and to manage energy storage as well as consumption with a hybrid converter.

Hybrid converters enable the selection and orientation of renewable energy, grid energy, and energy storage based on consumption. Unlike conventional converters, which systematically store energy in batteries, hybrid converters only store energy when it is needed. This system also allows a choice between whether electricity from photovoltaic panels should be stored or consumed through an internal intelligent apparatus control unit. Hybrid converters can operate in different modes: on-grid, off-grid, hybrid (both on-grid and off-grid at the same time), and backup (in case of a black-out) as described in the following subsections.

3.1. On-Grid General Mode (Hybrid)

As illustrated in Figure 2a,b respectively, if PV has sufficient power to inject the required power of the load, the surplus power of PV is used to charge the battery and feed into the grid. Conversely, when PV has insufficient power, batteries and the grid have the responsibility to supply the load.

![Figure 2. On-grid general mode: PV power is sufficient (a), PV power is insufficient (b).](image)

3.2. On-Grid with Battery Backup Mode

PV and the grid both supply the load and charge the batteries (Figure 3a). When the grid is working smoothly, the battery’s State of Charge (SOC) is always in full state as depicted in Figure 3b. Batteries discharge only when a grid faults occur (Figure 3c).
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Figure 3. On-grid with battery backup mode: PV power is sufficient (a), PV power is insufficient (b), when a grid fault occurs (c).

3.3. Off-Grid Mode

PV and battery constitute an off-grid system. If PV can supply the required power of the load, the priority is to supply the required power to the load. Any surplus power is used to charge the battery, as shown in Figure 4a. When PV has insufficient power, the battery is used to supply power to the load (Figure 4b).

Figure 4. Off-grid mode: PV power is sufficient (a), PV power is insufficient (b).
4. Analysis of Hybrid Inverters Available on the Market

The purpose of this section is to provide a comparative analysis of hybrid solar inverters on the market. Several of the most popular commercial hybrid inverters have been chosen for comparison [23]. The selected power range is from 3 kW to 5 kW, which is the typical PV power range for residential applications. All characteristics of the commercial hybrid inverters have been obtained from open sources and are shown in Table 1 [24–35]. These inverters illustrate a variety of solutions that are available on the market currently. The most popular manufacturers were selected for analysis. Most of the inverters are single-phase with an average maximum efficiency of about 97%.

Table 1. Table of commercial hybrid inverters.

<table>
<thead>
<tr>
<th>№</th>
<th>Device</th>
<th>Nominal AC Power, W</th>
<th>Max. Efficiency, %</th>
<th>Number of Phases</th>
<th>Battery Type</th>
<th>Battery Voltage Range, V</th>
<th>Max. Battery Power, W</th>
<th>Battery Communication</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Huawei SUN2000-5KTL-L1 [27]</td>
<td>5000</td>
<td>97.8</td>
<td>1</td>
<td>Li-ion</td>
<td>350–450</td>
<td>5000</td>
<td>RS485</td>
<td>Battery is connected to dc-link</td>
</tr>
<tr>
<td>2</td>
<td>Fronius SYMO Hybrid 5.0-3-S [26]</td>
<td>5000</td>
<td>96</td>
<td>3</td>
<td>LiFePO₄</td>
<td>240–345</td>
<td>4800</td>
<td>RS485</td>
<td>Different battery packs can be used (BATTERY 9.0 is shown)</td>
</tr>
<tr>
<td>3</td>
<td>Sungrow SH5K-30 [28]</td>
<td>5000</td>
<td>97.1</td>
<td>1</td>
<td>Li-ion</td>
<td>32–70</td>
<td>4500</td>
<td>CAN/RS485</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Redback SH5000 [31]</td>
<td>5000</td>
<td>97</td>
<td>1</td>
<td>Li-ion</td>
<td>42–60</td>
<td>4600</td>
<td>CAN</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>ABB REACT2-UNO-50-TL [30]</td>
<td>5000</td>
<td>96.6</td>
<td>1</td>
<td>Li-ion</td>
<td>170–575</td>
<td>5000</td>
<td>RS485</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Solis RHI-1PSK-HVES-5G [32]</td>
<td>5000</td>
<td>97.5</td>
<td>1</td>
<td>Li-ion</td>
<td>120–500</td>
<td>7000</td>
<td>CAN/RS485</td>
<td>Continuous maximum battery power is 6 kW</td>
</tr>
<tr>
<td>7</td>
<td>Imeon 3.6 [33]</td>
<td>3000</td>
<td>94.5</td>
<td>1</td>
<td>Li-ion</td>
<td>42–62</td>
<td>3840</td>
<td>RS485</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>SolaX X3 Hybrid 5.0 T [34]</td>
<td>5000</td>
<td>97</td>
<td>3</td>
<td>Li-ion</td>
<td>200–500</td>
<td>5000</td>
<td>CAN/RS485</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Sunny Boy Storage 5.0 [35]</td>
<td>5000</td>
<td>97.5</td>
<td>1</td>
<td>Li-ion</td>
<td>100–550</td>
<td>5000</td>
<td>CAN/RS485</td>
<td></td>
</tr>
</tbody>
</table>

As Table 1 shows, there are two types of inverters. The first type is those with a low battery voltage range such as the Sungrow SH5K-30, Redback SH5000, and Imeon 3.6. A low voltage range (42–58.8 V) leads to high charging/discharging currents. In the case of the Redback SH5000 inverter, these are 85 A/100 A, respectively. The second type is inverter is those with a high battery voltage. For example, the Solis RHI-1PSK-HVES-5G. The battery voltage of the latter varies from 120 V to 500 V. However, the charging and discharging current in this system is only 20 A. Compatible batteries for inverters are mostly Li-ion. However, according to its datasheet, the 3-phase Fronius SYMO Hybrid uses the LiFePO₄-type battery technology, which guarantees a long service life, short charging times, and high depth of discharge. Furthermore, the storage capacity of the Fronius Solar Battery can be adapted to meet individual customer needs. All the selected inverters use the same standard communications—an RS485 connection or a CAN Bus.

The possible structure of the hybrid inverters is illustrated in Figure 5. They consist of solar terminals, a grid-connected Voltage Source Inverter (VSI), a buck-boost cell, which realizes the Maximum Power Point Tracking (MPPT) function, and a common dc-link. In addition, most commercially available inverters have terminals for backup operation.

In the case of string solar hybrid inverters, the battery can be connected directly to the dc-link, or with an additional interface converter, which is integrated into the Energy Storage Systems (ESS), as shown in Figure 5a,b, respectively.

An example of an inverter with a structure without an additional interface converter is the Huawei SUN2000-5KTL-L1. It is evident that simplicity and low cost are the main advantages, while limited battery types and voltage are the main drawbacks. An example
of an inverter with an external ESS with an additional interface converter, as in Figure 5a, is the Fronius SYMO Hybrid 5.0-3-S. In this case, the company provides the ESS system as an additional feature, while the inverter has dc-link terminals for connection. Other hybrid solar inverters, such as the Sungrow SH5K-30, have an isolated integrated battery interface converter. This corresponds to the structure illustrated in Figure 5b. A high step-up of the battery voltage can be realized through this topology. In addition, Figure 5c shows the internal structure of a hybrid inverter where the internal interface battery converter can be connected to the solar panel terminals.

![Figure 5](image_url)

**Figure 5.** Typical structures of hybrid solar inverters. The battery connected directly to the dc-link (a), The battery integrated into the Energy Storage Systems and connected to dc-link (ESS) (b), the integrated battery interface connected to the dc low voltage (c), the integrated battery interface connected to the ac voltage (d).

There are several examples of hybrid microconverters. The concept of hybrid microconverters is the same as that of hybrid converters. The difference consists of the power and voltage levels. Usually, microconverters are intended for connecting to a single solar panel in a range from 10 V to 60 V and a low-voltage battery. Due to the significant voltage difference between the input side and the grid, a step-up transformer is utilized [36]. This concept is illustrated in Figure 5d. Despite being an interesting idea, which seems to be suitable for residential use, some difficulties are reported in [37,38]. The main constraints are related to the battery overheating in the case of tied coupling with a solar panel.

The structure of the hybrid inverter can be much more complex. There are many studies dedicated to alternative solutions. The next part of this work is devoted to the detailed analysis of possible solutions.

### 5. Overview of the Non-Isolated Multi-Port Converters

As was mentioned above, hybrid inverters can be realized with and without an isolation stage. This chapter is devoted to an overview of different structures of the non-isolated Multi-Port Converters (MPC) reported in the research literature that are considered suitable candidates for hybrid inverters [39–47].
5.1. Battery Connected to the DC Bus

A simple example of the battery connected directly to the dc-link is shown in [48]. This system consists of a PV array, a dc-dc converter, and a single-phase battery energy storage system that is formed by a bidirectional converter, and connects in parallel with the batteries, the load, and the grid. The power of the PV is controlled by a dc-dc converter to track the MPPT point. The generated power is stored in a battery connected to the dc-link, as illustrated in Figure 6.

5.2. DC Bus Multi-Port Converter

In the more general case, an electrolytic capacitor is used as a dc-link, while the multiple dc sources are connected through non-isolated power electronics interfaces. An ac inverter links the dc sources and the ac grid. In [49], a commonly used topology of dc bus MPCs is discussed, as shown in Figure 7. The PV array is connected to the dc bus via a boost converter, the battery is connected to the dc bus through a bi-directional boost dc-dc converter, and the dc bus is integrated into the ac utility grid by a three-phase VSI.

5.3. Diode-Clamped Multi-Port Converter

Based on a three-level diode-clamped converter, a topology is presented in [51] using a battery and a supercapacitor instead of the standard two dc-link capacitors, as shown in Figure 9. A new space vector modulation method is used for diode-clamped three-level converters with variable dc-link voltages. The authors tested the system experimentally.
5.3. Diode-Clamped Multi-Port Converter

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5.4. Z-Source Based Multi-Port Converters (ZS-MPC)

The Z-Source Converter (ZSC) is a single-stage buck-boost converter with two independent control freedoms, a modulation index that controls the output of the ZSC, and a shoot-through to boost the dc-link voltage [52,53]. The quasi-Z-Source Converter (qZSC) is created from the Z-source converter and, as well as all the benefits of the ZSC for application in a RES system, it has continuous input current. Many different solutions were proposed based on a Z-source network [54,55].

Similarly, several solutions based on ZSC were proposed with battery integration [56–58]. To create a ZS-MPC, one of the capacitors is replaced by a battery. This solution is studied in [56] and is shown in Figure 10. In the study, the SOC of the battery is simulated and experimentally tested.

A single switch quasi-Z-Source MPC with a PV power generation system and battery connected to the upper capacitor of the qZSC, as shown in Figure 11, is analyzed and simulated in [57,58].
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Despite several solutions based on qZS networks being reported as pre-industrialization prototypes [59,60] that show acceptable efficiency, it is reported that qZS-based solutions may have a problem with power and volume density compared to comparable designs [61–63]. Moreover, the solution reported in [57] is not feasible for hybrid inverter applications because the battery is not usable during the night when power from solar panels is not available [64].

5.5. Hybrid Transformerless PV Converter

The hybrid transformerless PV converter is discussed in [65]. This system has one ac and two dc outputs. In this case, the inductor of the conventional boost converter is split into two symmetrical ones placed at the positive and negative dc rails, as shown in Figure 12. In addition, the switch of the conventional boost converter is replaced with a transformerless VSI.
6. Overview of the Isolated Multi-Port Converters

In this section, isolated converter topologies are discussed. Isolated multiport converters involving galvanic isolation between different ports have been introduced in several papers [66–71]. The use of a high-frequency transformer ensures isolation. Most of the topologies have been derived from conventional full-bridge or half-bridge dc-dc converters.

6.1. Symmetric Boost Integrated Phase Shift Converter

The topology of a three-port partially isolated converter is shown in Figure 13 and discussed in [72]. Ports 1 and 2 are inherently bidirectional. This means that each port can source or sink average power depending on the state of the converter and connected devices. Port 0 is unidirectional due to the use of diode rectifiers. The main power source is connected to port 0, and the battery is connected to port 2. Switch Q2 is driven complimentary to Q1 and switch Q4 is driven complimentary to Q3 with a short dead time in between. The power delivered to the load is controlled by controlling the phase shift between the gating signals of switches Q1 and Q3, and by controlling the duty ratio of the switches Q1 and Q3, which are required to be the same.

6.2. PV-Partially Isolated Three-Port Converter

A three-port partially isolated converter is shown in Figure 14 and discussed in [73]. The PV array is connected to port 1, the battery is connected to port 2, and port 0 is the load port. This converter has three operational modes: single input, dual output mode (PV to dc bus and battery), dual input, single output mode (PV and battery to dc bus), and single input, single output mode (battery to dc bus).
6.1. Symmetric Boost Integrated Phase Shift Converter

The topology of a three-port partially isolated converter is shown in Figure 13 and discussed in [72]. The module has three ports, one fuel cell port, one energy storage port, and one load port, and all of these ports are bidirectional. The fuel cell port should be protected from reverse current, and diode D1 is used in this case for that purpose. Inductor L1 is used to mitigate current ripples. The phase shift between the active bridge interfacing port 1 and the active bridge interfacing port 0 is maintained at 90°. In the paper, this converter is modeled as a square wave voltage source and the transformer is modeled with its equivalent T model.

6.2. PV-Partially Isolated Three-Port Converter

A three-port partially isolated converter is shown in Figure 14 and discussed in [73]. Each module has three ports, one fuel cell port, one energy storage port, and one load port, and all of these ports are bidirectional. The fuel cell port should be protected from reverse current, and diode D1 is used in this case for that purpose. Inductor L1 is used to mitigate current ripples. The phase shift between the two input ports is used to control the output voltage.

6.3. Fully Isolated Three-Port Converter

A three-port fully isolated converter is shown in Figure 15 and discussed in [73]. These modular systems have multiple modules. Each module has three ports, one fuel cell port, one energy storage port, and one load port, and all of these ports are bidirectional. The fuel cell port should be protected from reverse current, and diode D1 is used in this case for that purpose. Inductor L1 is used to mitigate current ripples. The phase shift between the active bridge interfacing port 1 and the active bridge interfacing port 0 is used to control the power flow.

6.4. Multiport CLL-Resonant Converter

A three-port fully isolated converter is shown in Figure 16 and discussed in [75]. Port 1 is the main input port, port 2 is an auxiliary input port, and port 0 is the load port. The phase shift between the two input ports is used to control the output voltage.

The phase shift between the two input ports is maintained at 90°. In the paper, this converter is modeled as a square wave voltage source and the transformer is modeled with its equivalent T model.

A summary of the hybrid solutions discussed above is presented in Table 2. The table illustrates the number of components, power rating, and insulation, as well as electrical features. L and C represent the number of inductors and capacitors, respectively.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Features</th>
<th>Ratings</th>
<th>Isolation</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional solution, low cost</td>
<td>Limited range of photovoltaic voltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV-Partially Isolated Three-Port Converter</td>
<td>Conventional solution, low cost.</td>
<td>Limited range of battery voltage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isolated Three-Port Bi-Directional DC-DC Converter</td>
<td>Conventional solution, low cost.</td>
<td>Limited range of battery voltage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isolated Three-Port CLL-Resonant Converter</td>
<td>Conventional solution, low cost.</td>
<td>Limited range of battery voltage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symmetric Boost Integrated Phase Shift Converter</td>
<td>Conventional solution, low cost.</td>
<td>Limited range of battery voltage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fully Isolated Three-Port Converter</td>
<td>Conventional solution, low cost.</td>
<td>Limited range of battery voltage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiport CLL-Resonant Converter</td>
<td>Conventional solution, low cost.</td>
<td>Limited range of battery voltage</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 15. Isolated Three-Port Bi-Directional DC-DC Converter [74].

6.4. Multiport CLL-Resonant Converter

A three-port fully isolated converter is shown in Figure 16 and discussed in [75]. Port 1 is the main input port, port 2 is an auxiliary input port, and port 0 is the load port. The phase shift between the two input ports is used to control the output voltage.

Figure 16. Isolated Three-Port CLL-Resonant Converter [75].

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<table>
<thead>
<tr>
<th>References</th>
<th>Number of Components</th>
<th>Power Ratings</th>
<th>Isolation</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref [48]</td>
<td>6 2 3 600 W No</td>
<td>Conventional solution, low cost.</td>
<td>Limited range of battery voltage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ref [50]</td>
<td>7 2 1 5 kW No</td>
<td>Conventional solution, low cost.</td>
<td>Limited range of photovoltaic voltage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ref [51]</td>
<td>19 3 1 10 kW No</td>
<td>Possible improved power density</td>
<td>The inverter complexity, losses, limited range of photovoltaic voltage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ref [57]</td>
<td>7 5 2 10 kW NO</td>
<td>Greater reliability</td>
<td>Complexity of the control and limited range of battery voltage, cannot work without photovoltaic input</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ref [65]</td>
<td>7 4 1 4.5 kW No</td>
<td>Low leakage current, High efficiency</td>
<td>Limited range of battery and photovoltaic voltage, range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ref [72]</td>
<td>8 3 3 5 kW Yes</td>
<td>High-efficiency, isolated solution</td>
<td>Voltage Limitation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ref [74]</td>
<td>13 1 2 1 kW Yes</td>
<td>Isolated solution</td>
<td>Voltage Limitation, not high efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ref [75]</td>
<td>8 2 3 1 kW Yes</td>
<td>Isolated solution, Simplicity, high efficiency</td>
<td>Voltage Limitation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Despite the many benefits provided by hybrid converters, there are some technical challenges that still need to be resolved to accelerate their practical feasibility. Future trends that should be followed by researchers in order to develop efficient hybrid converters are as follows:

- Derived hybrid converters can be further improved to reduce the number and size of electrical components such as semiconductors, passive elements, etc. This will result in a reduction in the cost of manufacturing converters as well as their size.
- Derived hybrid converters can be improved to reduce power conversion stages, which will reduce the total loss of the system.
• Improved controllers can be designed in order to reduce switching complexity.
• The power quality factors create a major problem when integrating the renewable energy system with the grid. Therefore, hybrid converters should be developed to take care of these power quality issues.
• In order to enhance the performance of the power electronics converters, various improved switches should be developed, such as GaN-based switches. Therefore, while designing new hybrid converters, improved semiconductor devices must be employed to augment the performance of the system.

7. Conclusions
This paper presents a review of hybrid converter topologies. It is intended as a convenient reference for engineers. The main goal of this work was to analyze possible internal power electronics configurations that can be utilized inside commercial solutions.

The paper presents a review of significant commercially available single-phase and three-phase hybrid solar inverters. The review shows that the maximum input voltage range differs between different manufacturers and starts from 480 V and goes up to 1000 V. The MPPT voltage range also varies depending on the manufacturer. At the same time, the battery input voltage range is significantly smaller as is battery power.

The review also shows that most solutions are built based on a configuration consisting of a boost converter and VSI, while a bidirectional dc-dc converter provides power exchange between the battery and a common dc-link. Furthermore, solutions can be divided into isolated (have an isolated battery and/or load) and non-isolated. In addition, many different and more complex solutions have been proposed that are doubtful for practical utilization.

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