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REVIEW AND COMPARISON OF SINGLE-STAGE INVERTERS FOR A PHOTOVOLTAIC (PV) SYSTEM

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ABSTRACT:
Through the use of a photovoltaic (PV) array, solar energy is converted into direct current (DC). Depending on the application, this accessible DC voltage is transformed into AC for use in homes or businesses. In some topologies, a boost or buck-boost converter is used to step up the extracted DC voltage to a higher level of DC, and an inverter is then used to convert the higher DC voltage to AC. However, due to the higher volume of components used, this technique is rather expensive. The Single-Stage Inverter is a productive substitute for this two-stage strategy (SSI). The Single-Stage Boost Inverter, or SSI, performs DC boosting and DC to AC inversion using just one circuit.SSBI gives us the advantage of reduced and robust circuitry along with reliability and efficiency. This paper presents a review of the various (however not all) SSI topologies in PV systems.

Keywords: PV, SSI, MPPT, INVERTERS, DC-DC converters

1. INTRODUCTION

Conventional (nonrenewable) energy sources are being harnessed at a very quick rate due to the spike in electrical energy demand around the world [1], and quite soon humanity would run out of these resources. The usage of conventional energy sources also contributes to environmental damage. The human race has, however, been able to utilise non-conventional (renewable) energy sources like wind, solar, geothermal, and hydro thanks to technological breakthroughs. The non-conventional energy sources have a number of advantages over the traditional energy sources, including the fact that they are abundant in nature and simple to obtain. The fact that these alternative energy sources produce less pollution and have no harmful byproducts is by far their biggest advantage over traditional fossil fuels. When comparing the many renewable energy sources, it is discovered that solar energy is the greatest choice. With the aid of a PV array, solar energy is first transformed into DC, which can then be used to power a DC load like a street light or a water pump for irrigation, or it can be used to power an independent load like a home appliance or business. PV inverters can be divided into two groups: multi-stage inverters and single-stage inverters, depending on how many stages of power processing they include. A multi stage inverter uses more than one power processing stage [3] and can raise the DC output from a PV array and/or galvanic isolation at one or more stages, with the final stage converting the enhanced DC into high-quality AC. A low level DC voltage can be converted into a commercial-grade AC output using the SSI circuit (see Fig. 1).The first section of this paper discuss about the introduction. Section two will explain the evolution of the architecture of grid connected PV inverters. As a boost converter is required to raise the voltage levels the third section will descibe about DC-DC converters. In next section for some of the recent SSI topologies will be reviewed. The three most fundamental MPPT techniques (hill climbing, perturb & observe and incremental conductance) will be discussed in section five. The last section of this paper is a conclusion mentioned in section six.

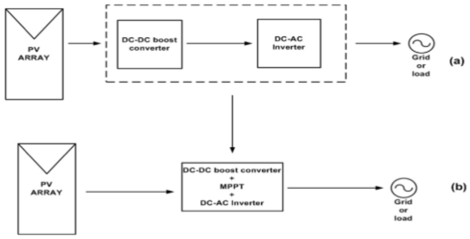

Fig. 1. PV based inverter

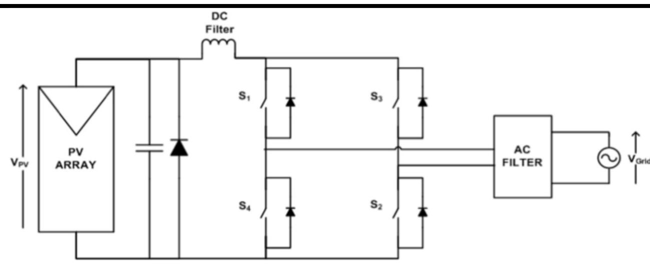

Fig 2 Line commutated PV inverters

2. Evolution of grid connected PV inverters and various standards

The central inverter, string inverter, multi-string inverter, and module inverter are the traditional topologies for converting solar energy into AC and integrating it into the grid. Either a single phase or three phase AC output is possible.

2.1. Central inverters

The motor drives industry used inverter topologies in the early central inverters. The line-commutation approach (Fig. 2) was utilised by the first grid-connected PV inverters to commutate thyristors [18]. Thyristors have been superseded by more sophisticated semiconductor switches, like MOSFETs or IGBTs, as technology has progressed. The switches are turned off by self-commutation in modern central inverters (Figs. 5 and 6) [18,19]. With the aid of string diodes, these strings can be joined in parallel to raise the entire PV array's current rating. Central inverters are made up of PV arrays coupled in series for a greater DC voltage [20]. These inverters have a power rating of several kilowatts [18, 21].

2.2. String inverters

String inverters can be considered as a derivative of the central inverters, as only one string of PV module provides input to the inverter. The DC output of the PV string is quite high which avoids the need of voltage amplification. However if less number of PV modules are to be used then the options of using a DC-DC boost converter or a line frequency transformer for voltage amplification do exist.

2.3. Multi string inverters

As they combine the increased power output benefit of a string inverter with the affordable price of a central inverter, multi string inverters [19,20,26,28] can be thought of as a hybrid of string and central inverters. A number of DC-DC converters are each connected to a number of PV strings [23,24]. Individual MPPTs are used by each PV string to extract the maximum amount of power possible. A common DC bus serves as the input to a common inverter, and it is coupled to the output of each DC-DC converter. The grid is then supplied with the AC output of this common inverter. Multistring inverters are adaptable because a PV string and a DC-DC converter can be added to the system already in place to improve the power rating.

2.4. Global PV inverter standards

The solar sector has shown consistent growth of 20–25% annually over the past few years, which has increased interest in grid-connected PV inverters [29]. Since these inverters can be connected to the grid, they must adhere to a set of rules established by the electricity providers in order to operate reliably, safely, and with high-quality power.There are several standards available in the market, like the International Electrotechnical Commission (IEC), Institute of Electrical and Electronics Engineers (IEEE), and National Electrical Code (NEC), which deal with the interfacing of PV inverters with the grid. Some of the widely used standards are IEC 61727 [30], IEEE 1547 [31], EN 6100-3-2 [32], IEEE 929-2000 [33]. Some of the standards specified by MNRE (India) [34] are IEC 62116, UL 1741, IEEE 1547. These standards apart from addressing grounding issues; specify the limits for voltage fluctuations in inverters, frequency variation range, operating power factor, current harmonics fed to the grid, DC current fed to the grid.

3. DC-DC converters

The input voltage can be amplified by conventional boost and buck boost converters, however those traditional converters have substantial switching losses and poor efficiency, making the necessity for high gain boost converters clear. Only a few of the most recent high gain boost converters and their gain summaries are introduced in this section. There is a thorough analysis of DC-DC converters in [35,36]. A step up converter with two different types of gains for two different configurations employing four switches has been presented by Hwu and Yau (37).

4. Single stage boost inverters (SSBI)

The benefits of SSIs have already been covered in the introduction. These SSIs can have a PV array as their input, and they can have a grid or an independent load—like street lights or irrigation water pumps—as their output. Thus, these SSIs might function in one of two modes, namely stand-alone mode or grid-connected mode, depending on the type of load they are linked to.

4.1. Boost type SSI

An SSI based on a bidirectional boost converter has been proposed by Caceres and Barbi. (Fig.3). Two bi-directional boost converters are connected differentially across the load in the circuit. It has proven possible to produce an AC output of 127 Vrms at a frequency of 60 Hz using sliding mode control. The circuit is among the oldest SSIs to have been created, and numerous researchers have used it as prior art. Switching losses and serious EMI issues result from the high frequency ON/OFF switching of all semiconductor components.

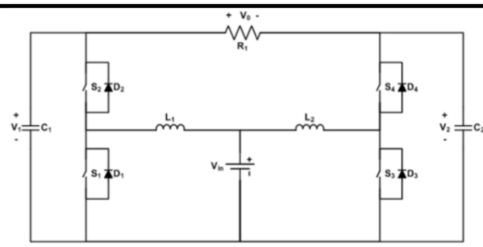

Fig 3 A differential boost converter

4.2. Flyback based SSI

Kasa and Iida [43] developed a circuit (Fig. 4) based on the flyback converter concept. The proposed topology consists of three switches along with two diodes and a transformer with a tapping at the middle of secondary winding. To prevent any electrical accident the transformer provides isolation between the PV array and grid. The power output of this circuit is 300W with an efficiency of about 89% while working in DCM. P&O MPPT without any current sensor has been used in this circuit to extract maximum power from the PV module.

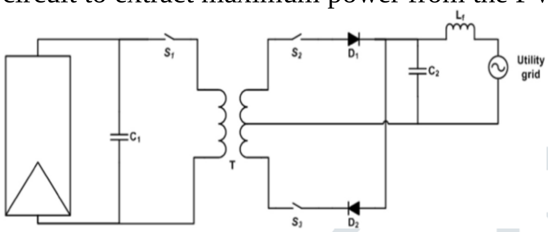

Fig 4 flyback converter based SSI

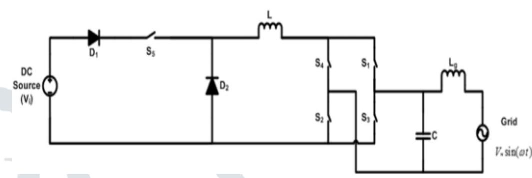

Fig 5 Universal SSI

4.4. Universal SSI

Prasad et al[44]. have proposed a universal SSI that can conduct all three types of operations—buck, boost, and buckboost—under various switching patterns, making it appropriate for supplying the electric grid mode. The suggested idea operates in DCM mode to allow the circuit to switch between modes of operation (to change from any one of the three modes to either of the remaining to modes e.g. from boost mode to buck mode etc.). Every positive or negative cycle of grid voltage has three stages for each configuration: inductor charging, inductor discharge, and zero current periods.

4.5. ZSI SSI

The traditional voltage source inverters (VSI) and current source inverters have some drawbacks (CSI). In reality, the traditional VSI is a buck or step down inverter. Power inverters, which switch from direct current to alternating current, include Z-source inverters. Due to its distinctive circuit design, it performs as a buck-boost inverter without using a DC-DC Converter Bridge.

4.7. qZSI SSI

Ge et al. [45] have presented a three port qZS single stage three phase inverter. The circuit's power flow has been managed using the equation shown below: Pin = 0 Pout + Pb (4) Pout is the power provided by the inverter, Pb is the power from the batteries, and Pin is the input power from the PV. The battery discharges if Pin is less than Pout, Pb is larger than zero, and il2 is greater than iL1. The battery charges if Pin is higher than Pout, Pb is negative, and iL2 is lower than iL1. There is no energy exchange in the battery if Pin equals Pout, Pb is equal to zero, and iL1 and iL2 are equal.

4.8. MCSI SSI

A multilevel current source inverter (MCSI) which uses only a single stage to extract the maximum power from input and invert the DC input to AC has been proposed by Cossutta et al. [46] This configuration works in grid connected mode taking the input from a fuelcell and uses P&O algorithm to track the maximum power..

4.9. Zeta SSI

A zeta converter based SSI ,which works in continuous conduction mode (CCM). CCM leads to a circuit with higher efficiency, lower levels of current stress and lower rating of components. This idea based on zeta converter contains a high frequency centre tapped transformer to isolate input from output along with five switches, one inductor and three capacitors. The circuit however suffers from the issues such as EMI and high levels of voltage stress on the load side switches.

5. MPPT

The basic principle of several MPPT approaches relies on the observation of variation in currents and voltages which occur because of pulsations in instantaneous power. Processing these changes lets anyone to find out the power gradient and lets that person decide if the PV system is working in vicinity of the maximum power point coordinates. The maximum power supplied by a PV array is: $P\text{max} = Vmpp*Impp$ (7)

Where Vmpp and Impp correspond to the points of optimum performance. i.e, maximum power.

5.1. Hill climbing method

One of the earliest methods created to track maximum power from PV is hill climbing (HC). This strategy is commonly utilised since it is straightforward and simple to apply [48–50]. In order to put this algorithm into practise, sensors are used to measure the voltage and current in the PV system. By multiplying the measured voltage by the measured current, the instantaneous output power is calculated, and as a result, the duty cycle for a converter is adjusted to track the maximum power.

5.2. Perturb and observe method

Despite being a simple algorithm to utilize, perturb and observe (P&O) is not employed in high power applications. Voltage and current are measured by sensors, which leads to the calculation of the PV output and the introduction of voltage disturbances into the circuit to establish the tracking direction.

5.3. Incremental conductance method

At MPP, the slope of the PV array power-voltage curve is zero. In order to track MPP, the incremental conductance algorithm makes use of this fact. The slope turns positive as the operating point moves away from the MPP's left side, and turns negative as it moves toward the MPP's right side.

6. Conclusion

In this paper, an attempt was made to review SSI. The first step covered the benefits of solar energy, and the introduction itself included some information on SSI. The second chapter discussed the development of grid-connected inverters and various international quality requirements. The final portion took a cursory look at current developments in step up converters. The fourth segment covered some of the SSI that is now in existence in great detail. The choice of topology to use is up to the researcher because each idea has pros and cons, and compromises must be made with other factors in order to reach one goal. Certain observations have been made based on the review of SSIs conducted thus far, and the authors would like to include them in this section. The two options are to develop a high gain DC-DC converter that makes use of MPPT and integrate it with an unfolding circuit, or to use a straight SSI with a high gain. High gains are also provided by the ZSI and qZSI principles, however regulating the circuit can be quite difficult if the inductors, capacitors, and switching frequency are chosen incorrectly. The benefits and drawbacks of the various approaches applied to the topologies outlined in Section 4 are compiled in Table 1.

Table 1:Advantages and disadvantages of the various techniques mentioned in Section 4.

Technique	**Advantage(s)**	**Disadvantage(s)**
High switching frequency	Size reduction of passive parts like inductors and capacitors	EMI concerns
DCM operation	DCM operation leads to a high power factor operation	Low efficiency due to the inductor's high current stresses, which necessitate higher rated components
CCM operation	Higher efficiency as compared to DCM mode	Can result in core saturation of magnetic components
DC link capacitor	Filters out power pulsation	Lifetime of electrolytic during high-temperature operations
Transformer	Provides a physical separation between input and output	Circuit weight increases, efficiency reduces due to core losses
Coupled inductors/ tapped inductors/switched inductor	High gain	Component rating goes up, cost increases
ZSI and qZSI	High gain	An unstable circuit results from improper inductor and capacitor choices or switching frequency.

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