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A Z-Source based Inverter System and its Implementation within Photovoltaic System

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Abstract: This paper elaborates a novel Z-source based inverter structure for a grid-connected photovoltaic generation. The study presents details of the operating principle, control strategy and voltage gain received out of the circuit. Shortcomings of the existing system and the advantages offered by the novel system are described.
Keywords: Photovoltaic (PV), power conditioning, MPPT, Z-source inverter.

I. INTRODUCTION

Because of the adverse effects observed on environment by the generating stations, more efforts are now being put into uncontaminated distributed power like geothermal, wind power, fuel cells, and photovoltaic (PV) that directly harnesses the energy available in nature to produce electrical energy. PV module uses the energy through the sun to generate electricity. The worldwide grid-connected PV system grows at a rate of 25% every year.

The major cost of photovoltaic generation is the installation cost, which is mainly consists of the costs of solar modules and the interface converter system, also called the power conditioning system (PCS). With the evolving solar cell technology, the cost of solar modules has dropped intensely. A recent worldwide survey claims that in the past three years, the retail price of solar modules has fallen by 16.95%. However, on the other hand the cost for the PCSs almost remained the same. Furthermore, while compared with converters used in drive systems, the cost for the converters used in PV systems are still approximately 50% higher. Therefore, the cost of the PCSs has become a very imperative issue of grid connected PV systems [1]. This paper suggests use of a Z-source inverter based PCS, which connects the PV arrays to the residential electrical systems. Implementing the Z-source inverter, the number of switching elements and the total volume of the system can be reduced. Hence, the total price of the PCS is decreased.

II. GENERAL CONCEPT OF PCS USED FOR RESIDENTIAL PV APPLICATIONS

In order to supply energy from PV arrays to the utility grids, PCS converter systems need to serve the following three requirements:

A. To tranform the dc voltage into ac voltage;
B. To step up the voltage, if the PV array voltage is less than the grid voltage;
C. To insure extraction of maximum power out of the PV module. Fig. 1 displays the two most commonly used converter structures

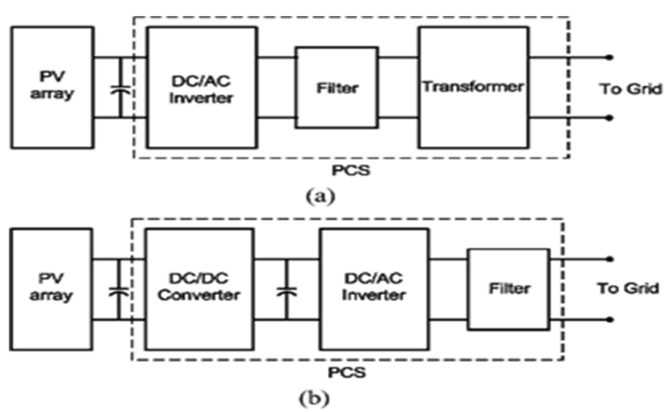

Fig -1: Conventional PV systems: (a) dc/ac with step up transformer and (b) dc/ac with dc–dc boost.

Fig. 1 shows the two most generally used converter structures in practical applications. In the system shown in Fig. 1(a), a transformer operating at line frequency is employed to boost the voltage provided by the dc–ac inverter. Typically, a line frequency transformer is accompanying large size, loud acoustic noise, and high cost. In addition, the inverter requires to be oversized to deal with the widespread PV array voltage change. The KVA rating of the inverter is greatly affected by the variation in PV voltage even if it is small. So with the purpose of eliminating the transformer and to lessen the required KVA rating of the inverter, in most of the applications, a high frequency dc-dc converter is used to step up the voltage to a constant value as shown in Fig. 1(b). Unfortunately, the switch used in the dc–dc converter adversely impacts the cost and efficiency of the system [2], [3]. Another choice is to use a single step inverter to perform dc–ac conversion directly as shown in Fig. 2. For the split-phase system used in United States' residential power supply, two 120-V ac outputs with common ground and phase difference of 180 are needed. For this purpose, there are two circuit options for the dc–ac inverters in the PCS are available: four-switch inverter and six-switch inverter. The circuit configurations of these two choices are shown in Fig. 2. For the four-switch inverter as shown in Fig. 2(a), the neutral point is tapped at the center of the two dc capacitors, whereas in six-switch inverter shown in Fig. 2(b), the neutral point is connected to the third phase leg.

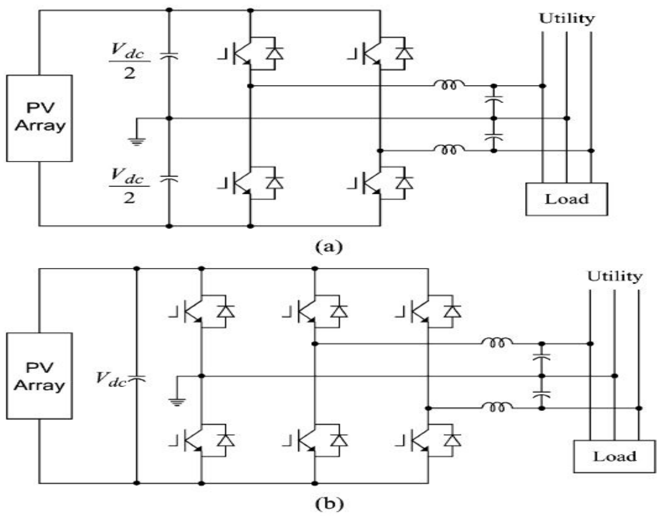

Fig -2: Direct PV inverter systems for 120 V split phase residential power supply. (a) Four switch inverter. (b) Six switch inverter.

The two phase legs in the four-switch inverter are controlled through synchronized pulse width modulation (SPWM). Two sinusoidal control references with a 180 phase difference and the same amplitude are employed to compare with a triangular carrier. In case of a six switch inverter two of the phase legs, "b" and "c," have the exact same SPWM control as that of the four-switch inverter. The third phase leg, "a," is usually controlled to draw a square waveform having 50% duty ratio at the carrier frequency to function as the neutral phase and to achieve the maximum utilization of the dc bus voltage simultaneously. The switching frequency of the third leg can differ from the other two phase legs. By appropriately coordinating the control of the neutral phase leg and the other two phase legs, the correspondent switching frequency can be doubled, thus the output filter can be augmented. It is generally supposed that the six-switch inverter performs better than the four-switch inverter for the split-phase application [4].

III. NOVEL Z-SOURCE BASED INVERTER SYSTEM

For the PCS proposed hereby, a Z-source inverter [5] is used to perform inversion and boost action with single stage operation. The proposed system is shown in Fig. 3. Unlike the conventional voltage source or current source inverters, the Z-source inverter uses a unique impedance network with split inductor L_1, L_2 and capacitor C_1, C_2 connected in X shape. Using the impedance network, the Z-source inverter can use the shoot through states to accomplish the boost action and turns the system more reliable [5], [6]. Both the inductors and capacitors used in the Z-source are energy storage devices, so their value can be optimally calculated to ensure smaller size and lower cost. When compared with the systems shown in Fig. 1, it can be noticed that the proposed system neither includes a no bulky transformer nor a dc–dc converter to perform the boost action. Therefore, the size and cost for the PCS are reduced. As the need of the dead time has been eliminated, the accuracy of control and improved THD value can also be achieved. Moreover, the split-phase Z-source inverter naturally includes all the features of the split-phase six-switch inverter. Thus, the 120-V ac output filter can be optimized.

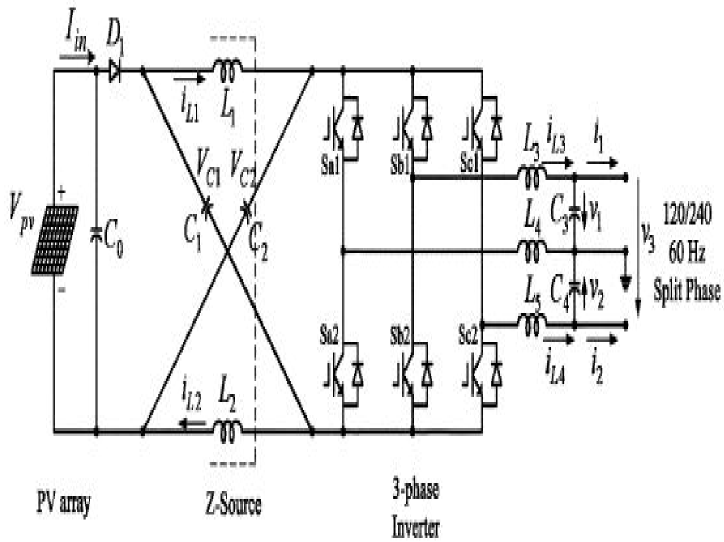

Fig -3: The novel Z-Source based inverter system

When a comparison between the proposed converter and the direct inverter systems in Fig. 2 is performed, it can be observed that the Z-source inverter has a lower KVA requirement. For the inverter system in Fig. 2 with a PV voltage change of 1:2 range, the PV dc voltage is required to at a level of 340–680 V minimum to generate ±120 V split-phase power supply. Because of this, 1200-V IGBTs are required in the system. For a 10-kW PV system, a 20-kW inverter is required to match the voltage change. Using the proposed system shown in Fig. 3, the PV voltage can be derived to be 225–450 V, which can be inverted to ±120 V split-phase power with the help of the Z-source inverter employing 600 V IGBTs. Besides this, the required KVA rating of the Z-source inverter remains to be the same as 10 kW for a 10 kW PV system. Thus, the use of the Z-source inverter provides minimized volume and cost as well as the number of active switching devices. As the system has a single stage operation, the efficiency of the system can be significantly improved. As a summary, the proposed system:

A. employs only one stage to perform inversion, boost, and maximum power tracking;
B. has the minimum number of switching devices;
C. does not require to have any dead time;
D. can include shoot through state in the inverter operation
E. includes all the benefits of the six switch inverter system.

IV. CONTROL AND OPERATION PRINCIPLE

When the triangular waveform is greater than the maximum value or lower than the minimum value of the three reference waveforms, all upper three switches or all bottom three switches are respectively turned on. These are known as the zero states as the output voltage of the inverter is zero during these times. For the Z–source inverter, the basic idea of control is to transform zero states into shoot through states and keep the active switching states unchanged, thus we can maintain the sinusoidal output and at the same time achieve voltage step up using the shoot through of the dc link [5], [6].

Fig. 4 shows the control method used to perform boost action with the split-phase Z-source inverter. Phase legs “b” and “c” are controlled by SPWM to fabricate ac output, and the shoot-through command, and is used to boost voltage as per the need of the system. The control of these two phase legs is familiar to the basic boost control proposed in [5] and [6]. Two straight lines are used to control the shoot through duty ratio. When the carrier is greater than the upper straight line, phase leg “b” goes to shoot through state, while phase leg “c” goes to shoot through state when the lower straight line is greater than the carrier. Phase “a” of the inverter is switching at 50% duty cycle without shoot through. The switching frequency of phase “a” is the frequency of the carrier signal. Through this, each phase leg shoots through only once during one carrier cycle and hence, the corresponding switching frequency can be doubled for the output filter.

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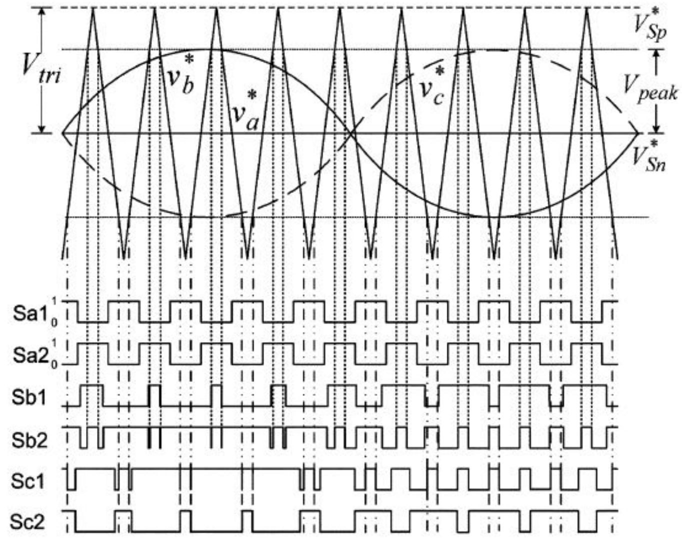

Fig -4: Control method to perform boost action

As described in [5] and [6], the inductors L_1 and L_2 , which can be wounded around the same core, have the same inductance, and the capacitors C_1 and C_2 have the same capacitance, the relationship between the output ac voltage and input dc voltage is expressed as

$$\widehat{v_0} = MB.V_{pv}/2 \qquad (1)$$

where v_0 is the output voltage, V_{pv} is the output voltage of PV module, M is the modulation index, which is derived as

$$M = V_{peak}/V_{tri} \qquad (2)$$

and B is the boost factor, which is calculated as

$$B = \frac{1}{1-2\,.\,T_0/T} \qquad (3)$$

where T_0 is the total shoot-through period per carrier cycle, and T is carrier cycle. In the basic control method [5], [6], the amplitude of the two straight lines is the peak of modulation waveform, therefore the correlation of modulation index, M and the shoot through ratio, T_0/T can be expressed as

$$T_0/T = 1 - M \qquad (4)$$

Substitting (4) into (3), the boost factor turns out to be

$$B = \frac{1}{2M-1} \qquad (5)$$

From (1) and (5), the peak amplitude of the output can be derived as

$$\widehat{v_0} = \frac{M}{2(2M-1)}V_{pv} \qquad (6)$$

While the capacitor voltage is given by

$$V_{C1} = V_{C2} = \frac{1-T_0/T}{1-2T_0/T}V_{pv} = \frac{B+1}{2}V_{pv} \qquad (7)$$

There is no need of having the shoot through state if the PV output voltage value is sufficiently high to produce the required ac voltage, i.e., T= 0 and B= 1. Under this condition, the relationship between the inverter peak output voltage and the PV output voltage can be calculated as

$$\widehat{v_0} = M\,V_{pv}/2 \qquad (8)$$

It should also be noted that the shoot-through states can be formed by shorting both legs “b” and “c,” or all the three legs instantaneously during any given shoot through state in accordance with the two straight lines. For all these shoot-through conditions, the boost effect and output voltage waveforms remain unchanged. In the proposed control strategy, only one phase leg is used to create shoot through at any time, thus the switching frequency is minimized. However, at the same time, the current stress on each switch during shoot through is doubled when compared with shooting through two phase legs simultaneously at any time. A trade off in the control must be made, one can

A. either reduce the switching frequency by shorting one or two phase legs
B. or reduce the current stress on each device through shorting all phase legs during shoot-through periods
C. in order to make a decision in practical applications, the switching and conduction losses at different conditions are required to be calculated and investigated for variety of cases.

V. CONCLUSION

This paper presented a new PV power conditioning system based on Z-source inverter. The proposed system offers the boost and inversion action with maximum power tracking employing only one power stage, thus reducing the number of switching devices. All the benefits of the Z-sources inverter and the six-switch split-phase inverter are included and united together to derive a highly reliable PCS system with reduced volume and cost. With the cutting-edge features, the proposed system confirms it's suitability for the power conditioning applications in PV.

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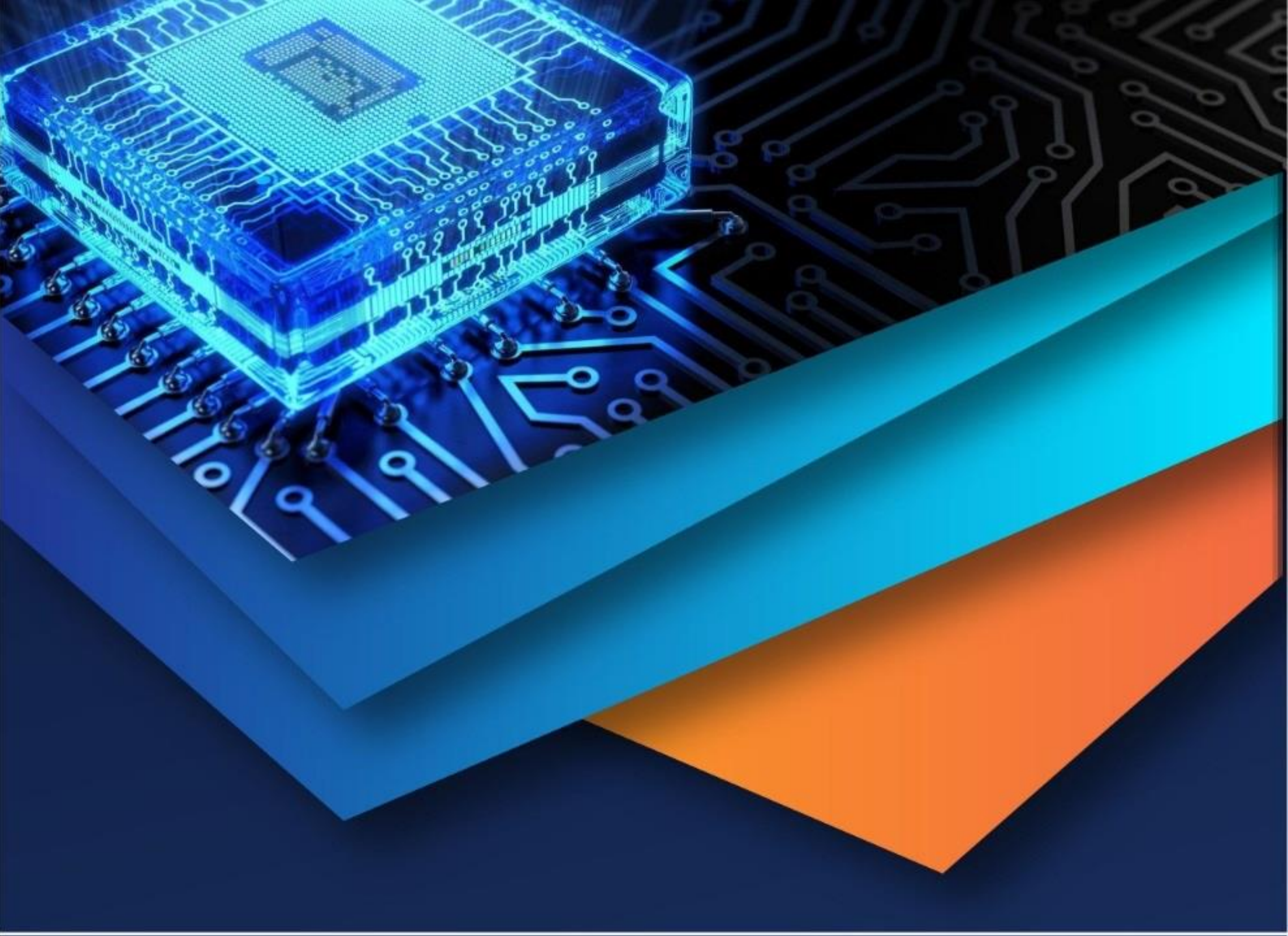

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