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Z-Source Inverter for Maximum Power Tracking in Solar Photovoltaic System

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This paper discusses the various inverter topologies used in solar photovoltaic system for electrical energy. This paper gives comparison between the conventional type of inverters i.e. voltage source inverter (VSI) and current source inverter (CSI) .New z-source inverter topology is proposed which will overcome the drawbacks in VSI and CSI. Pulse width modulated (PWM) signals are generated for the power semiconductor switches of the z-source inverter for controlling the power to the grid. The characteristics of this inverter are used to obtain maximum power tracking control and delivering to the grid.

Key words: *Inverter, photovoltaic (PV) system, z-source network, pulse width modulation (PWM).*

1.0 INTRODUCTION

With the fast depletion and increase in prices of the non-renewable energy sources required for power generation, more research is being carried out in the power generation using renewable energy sources (hydro, solar, wind, bio-mass etc,.). Solar energy is one of the most freely available renewable sources for energy. Extracting maximum power from solar and feeding the grid with high quality electricity are the two main objectives for solar photovoltaic grid connected system. To realize these objectives power conditioning unit (PCU) or power electronic circuits are required to power conditioning (DC/DC or DC/AC). A proposed block diagram is as shown in Figure 1. PCU in solar PV system is an inverter which converts DC signal to AC signal and also achieve the required voltage level. [1], [2] helps in realizing the importance of inverter in solar PV system.

There are various topologies [11], [13] for this conversion: VSI, CSI, variable dc link, z-source inverter. VSI and CSI are the most commonly used topologies. The output voltage can be controlled with the help of various control techniques [9] for power electronic switches. Pulse width modulation (PWM) techniques are the most commonly used to control the output voltage of inverters. The sinusoidal inverter output voltage will contain harmonics which can be reduced by using proper control schemes.

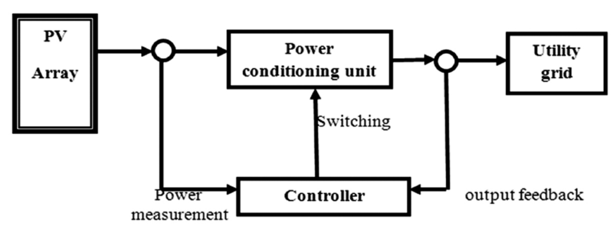

FIG. 1 BLOCK DIAGRAM OF PCU WITH CONTROLLER

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This paper presents the comparison between VSI and CSI and introduction to z-source inverter.

2.0 VOLTAGE SOURCE INVERTER

When DC input voltage to the inverter is remains constant, then it is called voltage source inverter (VSI) or voltage fed inverter (VFI). Figure 2 shows a full bridge single phase VSI.

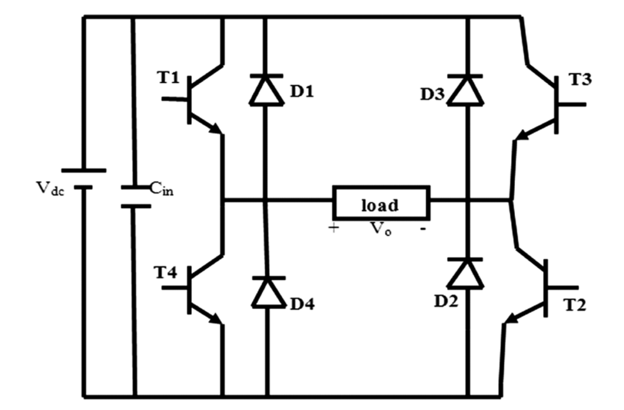

FIG. 2 FULL BRIDGE SINGLE PHASE VSI

The single phase VSI consists of four power transistors and four anti parallel diode (or freewheeling) to provide bi-directional current flow and unidirectional voltage blocking capability. The developed ac output voltage will be less (buck conversion) than its input dc voltage level. Inverter output voltage needs to be varied as per the load requirement, so that whenever the DC inverter input changes, its output can also change. These variations need to be compensated to control the output voltage. Some of the PWM techniques used for inverter output voltage and depending upon the inverter application, suitable PWM technique is to be used. The PWM control techniques can be implemented digitally. [3], [12].

3.0 CURRENT SOURCE INVERTER (CSI)

Inverter in which input current remains constant is called as current source inverter (CSI) or current fed inverter (CFI). CSI requires a large inductance to generate constant current source. The main circuit as shown in Figure 3 consists of four power semiconductor switches with a series diode to provide unidirectional current flow and bidirectional voltage blocking.

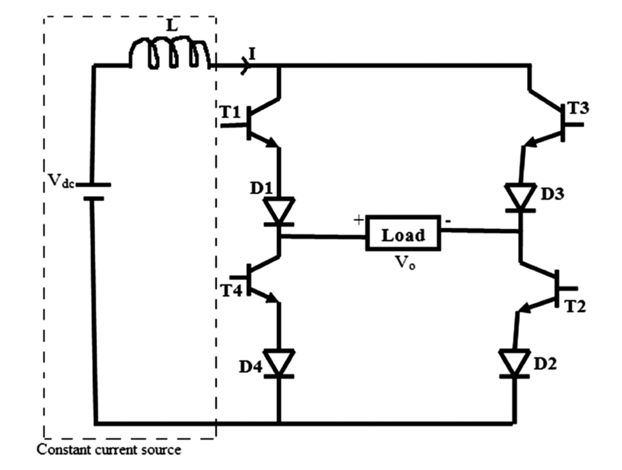

FIG. 3 SINGLE PHASE CURRENT SOURCE INVERTER

The developed ac output voltage will always be greater (or boost converter) than its input dc voltage that feeds the dc inductor.

Limitations of VSI and CSI:

There are some common limitations observed in VSI and CSI as listed below:

- Both the inverters can perform either buck or boost function and not buck-boost. That is, their output voltage range is limited to either greater than or less than input voltage.
- Reliability will be compromised due to EMI noise.
- The main circuits cannot be interchanged. That is, VSI cannot be used as CSI and vice-versa.

4.0 Z-SOURCE INVERTER

A traditional inverter (VSI or CSI) if connected directly to PV module would require a higher maximum power point MPP voltage because of a module manufacturing tolerance. Such high MPP voltages are not feasible. Thus an additional dc-dc boost converter (BC) would be required so as to work with lower MPP voltages as shown in Figure 4.

ZSI can buck or boost output AC voltage which is not possible with traditional VSI and CSIs.

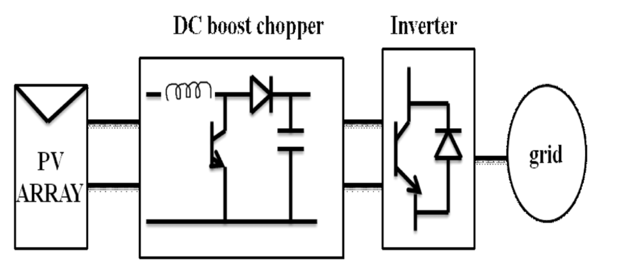

FIG. 4 CONVENTIONAL GRID CONNECTED PV SYSTEM WITH DC BOOST CHOPPER

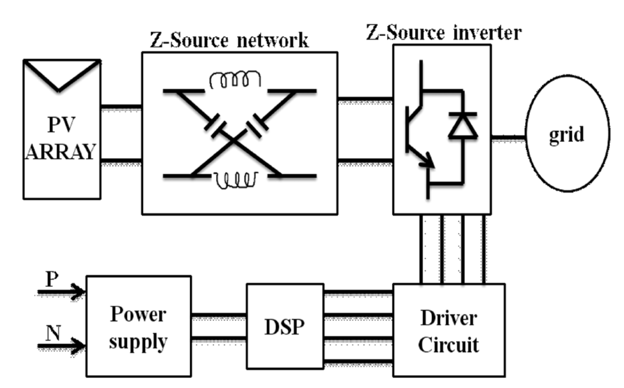

FIG. 5 PROPOSED Z-SOURCE INVERTER IN GRID CONNECTED PV SYSTEM

Traditional VSI and CSI technology has advanced to the new Z-source inverter (ZSI) with a built-in impedance network. In Figure 5, it can be seen that there is no need for DC boost converter if ZSI is used without any change in the objective of PV system.

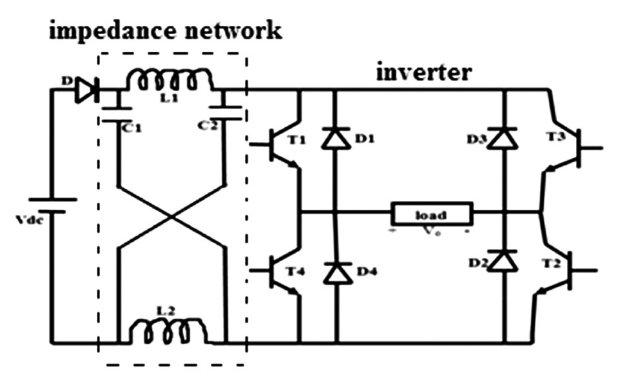

FIG. 6 Z-SOURCE INVERTER

Single phase single stage ZSI is as shown in Figure 6 [4]. ZSI can be controlled by PWM technique. The construction and operation of the converter is explained in the next sections [5-9].

A Z- source inverter based drives can:

- Produce any desired output a voltage, even greater than the line voltage, regardless of the input voltage, thus reducing motor ratings.
- Provide ride-through during voltage sags without any additional circuits.
- Improve power factor reduces harmonic current and common-mode voltage.

4.1 Construction

ZSI has impedance network on its dc side, connecting source to inverter. The unique impedance network consists of passive components (inductors and capacitors) which gives a single-stage conversion. The impedance network forms a second order filter which handles undesirable voltage sags of the dc voltage source. It reduces the inrush current and harmonics in the current because of two inductors in z-source network.

The presence of two inductors and capacitors in z-source network, allows both the switches in the same phase leg in ON state, simultaneously, called as "shoot through state". This state gives boosting capability to the inverter without damaging the switching devices. During shoot through state, energy is transferred from capacitor to inductor and hence ZSI gains the voltage boosting capability [10]. A diode (D) is required to prevent the discharge of charged capacitor through the source.

4.2 Operation

Z-source inverter has 5 possible switching states: active states (two), zero states (two) and shoot through states (three). The switching states of the z-source inverter are as shown in Table 1. The ZSI operation in shoot through and non-shoot through states is shown in Figures 7 and 8 respectively. In active states one switch in each arm (upper switch in 1st leg and lower switch in 2nd leg or vice versa) will conduct thus a finite output voltage will appear across load. In zero state the switches in upper arm or switches in lower arm will conduct. There will be zero voltage across the load.

TABLE 1

SWITCHING MODES IN Z-SOURCE INVERTER

Switching states	**T_1**	**T_2**	**T_3**	**T_4**	**Output voltage**
Active states	1	1	0	0	Finite voltage
	0	0	1	1	
Zero states	1	0	1	0	zero
	0	1	0	1	
Shoot through state	1	T_2	T_3	1	Zero
	T_1	1	1	T_4	
	1	1	1	1	

In shoot-through state the load terminals are shorted through both the upper and lower switches of any one leg or both the legs. The switching states and their combinations introduce a new PWM method for the Z-source inverter.

In shoot through mode as in Figure 8., a diode placed at the input side is reverse biased and the capacitors charge the inductors and voltage across the inductor is:

$$V_{L1}=V_{C1};\ V_{L2}=V_{C2} \qquad ....(1)$$

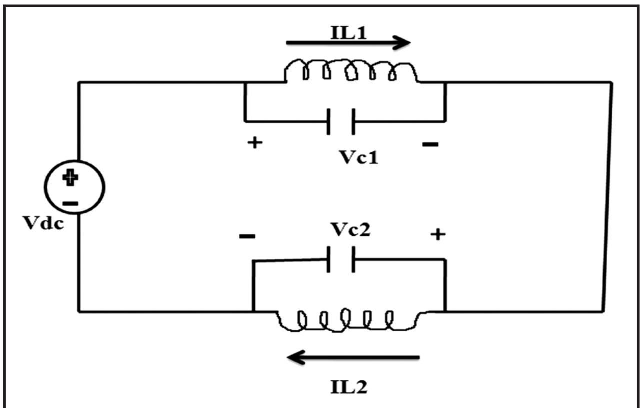

FIG. 7 SHOOT THROUGH MODE

It is assumed that the impedance network is a symmetric network (C_1=C_2=C and L_1=L_2=L), it can be observed that $V_{L1}=V_{L2}=V_L$ and $I_{L1}=I_{L2}=I_L$ and the DC link voltage across the inverter bridge during shoot through interval is

$$V_i=0 \qquad ....(2)$$

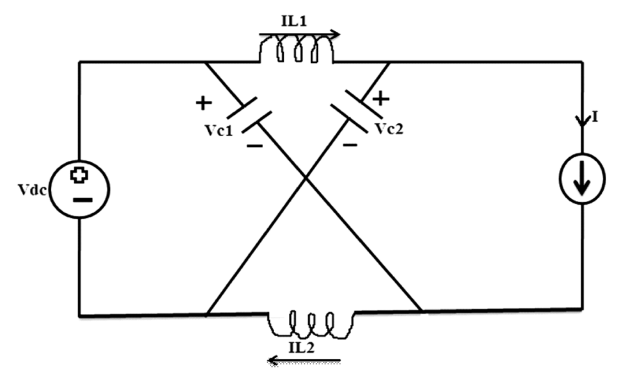

FIG. 8 NON-SHOOT THROUGH STATE

The inductor voltages in two modes:

Shoot through mode: $V_L=V_C$ ....(3)

Non-shoot through mode: $V_L=V_{dc}-V_C$ ....(4)

The average inductor voltage over one switching period is zero.

$$V_L=\frac{T_0 * V_c + T_1 * (V_{dc}-V_c)}{T}=0 \qquad ....(5)$$

$$\frac{V_c}{V_{dc}}=\frac{T_1}{T_1-T_0} \qquad ....(6)$$

V_L-inductor voltage

V_C- capacitor voltage

V_{dc}-input dc voltage

T_1- non-shoot through period

T_0- shoot through period

T- total switching period= T_0+T_1

Capacitor voltage of z-source network is given as

$$V_c=\frac{T-T_1}{T-T_1-T_0}V_{dc} \qquad ....(7)$$

$$V_c=\frac{1-\frac{T_0}{T}}{1-2\frac{T_0}{T}}V_{dc} \qquad ....(8)$$

$$V_c=\frac{1-D}{1-2D}V_{dc} \qquad ....(9)$$

D-duty cycle= T_0/T

Peak dc link voltage V_i appearing across inverter input is

$$V_i = V_C - V_L = V_C - V_{dc} + V_C = 2V_C - V_{dc} \quad ....(10)$$

$$= 2\left(\frac{T1}{T1 - T_0}\right)V_{dc} - V_{dc} \quad ....(11)$$

$$= \frac{T}{T_1 - T_0}V_{dc} \quad ....(12)$$

$$V_i = B\,V_{dc} \quad ....(13)$$

B- Boost factor of inverter, where

$$B = \frac{T}{T_1 - T_0} = \frac{1}{\frac{T_1 - T_0}{T}} = \frac{1}{\frac{T - T_1 - T_0}{T}} = \frac{1}{1 - \frac{2T_0}{T}} \quad ....(14)$$

5.0 COMPARISON BETWEEN CSI VSI AND ZSI

TABLE 2

REQUIRED PASSIVE COMPONENTS

Inverter	No. of inductors	No. of capacitors
dc/dc boosted PWM	1	2
CSI PWM inverter	1	0
z-source inverter	2	2

TABLE 3

COMPARISON BETWEEN VSI, CSI AND Z-SOURCE INVERTER

CSI	VSI	ZSI
Inductor is used in dc link, therefore, the source impedance is high.	Capacitor is used in dc link, it acts as low impedance voltage source	Capacitors and inductors are used in the dc link, it acts as a constant high impedance voltage source.
Momentary short circuit on load and misfiring of switches are acceptable	Momentary Short circuit is also very dangerous.	ZSI misfiring of switches sometimes are also acceptable.
Power loss is high	Power loss is high	Power loss will be low
Efficiency low due to losses	Efficiency is low due to losses	Higher efficiency can be expected
The main circuits can be interchanged	The main circuit cannot be interchangeable here also	The main circuits are inter changeable
This is used only in buck or boost operation of inverter	Used in buck or boost operation	Can be used for buck or boost or both buck-boost operation of inverter.

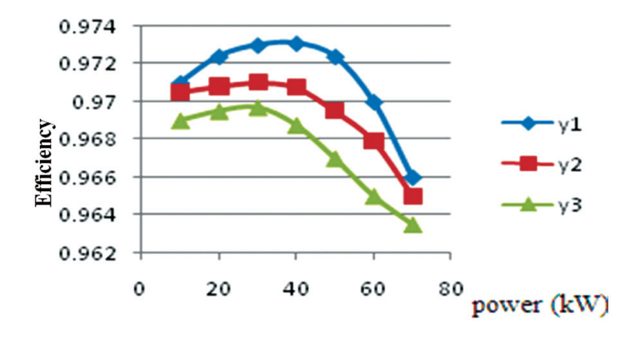

FIG. 9 EFFICIENCY V/S POWER COMPARISON OF INVERTERS

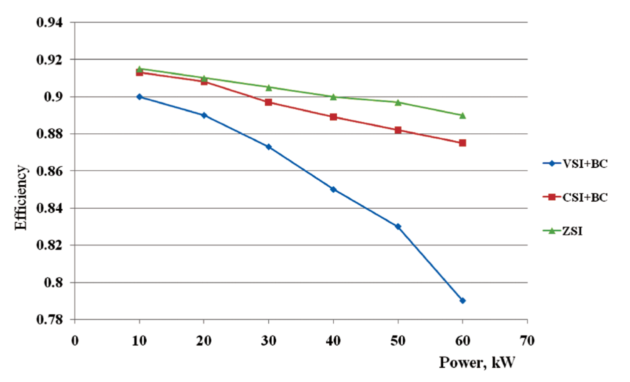

FIG.10 EFFICIENCY V/S POWER COMPARISON OF INVERTERS FOR HEAVY LOAD CONDITION

Table 2 gives the component comparison of three types of inverters. Table 3 gives the functional and characteristic comparison of VSI, CSI and z-source inverters. In Figure 9 the efficiency comparison is shown where y_1, y_2 and y_3 are efficiency curves of z-source inverter, current source inverter and voltage source inverter respectively. From the graph, it is seen that due to the reduced power loss in z-source inverter, its efficiency is higher in comparison with CSI and VSI. The calculated efficiency curves at heavy loads conditions using different inverter topologies are as shown in Figure 10. From the curve it can be seen that at higher power rating the z-source inverter efficiency is consistent and the efficiency of VSI+BC falls considerably.

6.0 CONCLUSION

A comprehensive comparison of the three inverter systems has been performed. The comparison results show that the Z-source inverter can increase inverter conversion efficiency by 1% over the two existing inverter topologies. The Z-source inverter topology can minimize stresses and size of the PV system and increase output power greatly. Along with these promising results, the Z-source offers a simplified single stage power conversion topology and higher reliability because the shoot through can no longer destroy the inverter. The existing two inverter systems suffer the shoot through reliability problem. In summary, the Z source inverter is very promising for solar photovoltaic systems.

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