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# Photovoltaic-Based Z-Source Inverter for Grid Integration

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***Abstract*— This paper proposes an Impedance-Source Inverter (ZSI) for a three-phase photovoltaic (PV) system connected to the grid. Unlike conventional Voltage Source Inverters (VSI), the ZSI incorporates a shoot-through mode that enables buck–boost operation directly, eliminating the need for an additional DC–DC stage. This mode is achieved using a modified Pulse Width Modulation (PWM) technique, allowing flexible control of the output voltage while improving system reliability. The Z-source network, composed of inductors and capacitors, facilitates single-stage power conversion, simplifying the system and enhancing efficiency. The paper details the design considerations for these passive components to ensure optimal performance and stable operation. To verify the design, the ZSI-based PV system was modeled and simulated in MATLAB/Simulink. The results confirm effective voltage regulation, reliable buck–boost capability, and efficient power transfer to the grid, highlighting the suitability of the proposed configuration for renewable energy applications.**

***Keywords*— DC-DC, photovoltaic; Z-source Inverter; Shoot-through Boost Control component; Pulse Width Modulation.**

## I. INTRODUCTION (HEADING 1)

The requirement of Electrical Energy is never ending and it is increasing vastly day by day as Number of Consumer-domestic and Industrial are increasing. As Fossil Fuel Resources are limited it makes us to divert towards another type of resources for Generation of Electrical Energy. The Renewable energy sources like Solar Photo-Voltaic (PV), Wind and fuel Cells are environmentally clean and Pollution free in Nature. The Output voltage achieved from Natural Resources like Solar and Wind provide wide variation in Voltage. To acquire fixed and desirable level of output voltage as per application it is necessary to pass this voltage through power conditioning stages like DC-DC Boost Chopper converter or step-up transformer. Due to this involvement of power conditioning stage cost and complexity rises.

The ZSI is a rising configuration in family of Power electronics converters with fascinating ability to buck or boost characteristic in single stage conversion. Due to this, the ZSI receives more attention recently for various application [1], By providing some modification in modulation technique the reduction in leakage current for transformer-less Z-Source PV inverter can be achieved in [2], By implementing CWMN cell in impedance Source inverter, improvement in the Boost Factor is achieved. This enhances the Boost Capacity of ZSI at higher level [2], Magnetically coupled impedance Source network provides higher switching voltage spikes as leakage inductance is present there. These voltage spikes are affecting converter performance. By using Negative Embedded Differential mode gamma ZSI, Voltage spikes reduction and higher voltage gains can be achieved [3]. A hybrid switched inductor impedance source inverter operates in two modes: a) Continuous Current Mode and b) Discontinuous current mode. A Hybrid Switched Inductor ZSI is capable to provide higher gains in both modes of operation [4].

The Z-Source Inverter (ZSI) was firstly introduced in the year 2003[6], Many more research work have been done in ST control method. There are four modes ST control method. The Simple boost control method proposed in [7], Maximum Boost control [8], Maximum constant Boost Control [9] and Modified Space Vector Modulation [10]. The pulses required for the operation of ZSI are achieved by including shoot thorough state in conventional PWM technique. This novel switching pulse technique is implemented in ZSI for inverting DC input voltage to desired step-up AC output voltage [11]. By regulating shoot through mode duty cycle, the control on output voltage from PV Panel can be obtained. ZSI implements a unique LC circuit configuration which boosts up DC input voltage level. [12] The PV panel connected with ZSI provides Single stage system structure as there is absence of DC to DC boost conversion stage. The ease in control of ZSI provides Voltage Level Boost up and Inverting operation in single stage. The combination of PV and ZSI can gives wide range of operation and the output voltage from it can be satisfactorily synchronized with the grid. [13]

The Inverters are classified in to four categories- a) Based on Cascade connection of Power conditioning stages b) Based on the mode of Power separation (decoupling) between the PV panel and Grid c) Based on the use of Transformer or not d) Based on Power Staged for Grid interconnection. In olden days, Large area solar PV modules are connected to the Centralized Inverter System. This system has many drawbacks. So, to overcome these drawbacks multi-string inverter scheme is implemented [14].

## II. PROPOSED AND CLASSICAL INVERTERS AND THEIR INTEGRATION

### A. Traditional Inverter

Conventionally, two configurations of Inverters are used:

a) Voltage Source Inverter (VSI)

b) Current Source Inverter (CSI)

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In Voltage Source Converter (VSI), an input DC supply is in the shunt of a Capacitor shown in Fig (1). When dc to ac conversion is achieved through VSI, it operates as a Buck (Step-down) mode that is output AC Voltage is lower than given DC Voltage input. Thus, DC to DC Boost Chopper Circuitry is used in this system to Boost up the voltage level at the needed range.
In the case of VSI, the upper electronic switch and lower electronic switch of one leg of any phase are not to be conducted at a one-time simultaneously. Otherwise, there is an occurrence of shoot through phenomena which damage devices. So, in between these upper electronic switches and lower electronic switches of the leg of inverter for all phases, a delay in switching time must be introduced. This delay in switching time results in a waveform distortion.

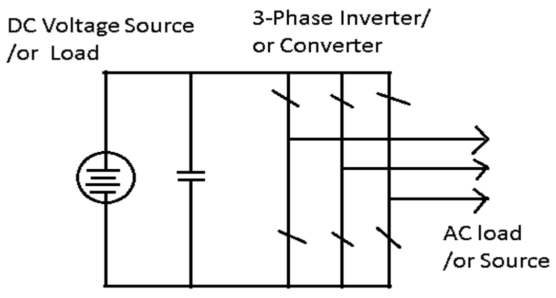


Fig (1) Voltage Source Network

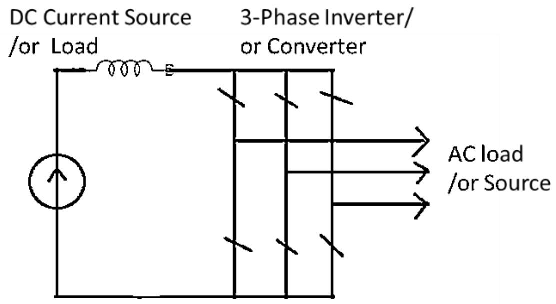


Fig (2) Current Source Network

In a Current-Source Inverter (CSI), the DC power supply is connected in series with an inductor, as shown in Fig. (2). In CSI operation, when the AC output voltage exceeds the input DC supply voltage, the inverter functions in boost mode. To obtain the desired voltage level, a DC–DC buck chopper circuit is employed.
In CSI, both the upper and lower switching devices of a leg can be turned on simultaneously and kept conducting for the required duration. If this is not maintained, the input inductor may become open-circuited, potentially damaging the device. To prevent this, an overlap period in switching is introduced between the devices in the same phase leg. However, this overlap leads to waveform distortion. Common disadvantages of Voltage-Source and Current-Source Inverters:
They cannot operate as both buck and boost converters at the same time. Hence, the output voltage is limited to being either higher or lower than the input voltage.
The main circuits of a Voltage-Source Converter (VSC) and a Current-Source Converter (CSC) are not interchangeable; the VSC topology cannot be directly used for CSC operation.

Thus, conventional inverters can perform either buck or boost operation, but not both simultaneously.

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## B. Z-Source Inverter

To overcome conventional inverters above disadvantages, Impedance Sourced Network is connected between the source of power at the input side and the Conventional Inverter Circuitry. This impedance (Z) network involves two numbers inductors and two numbers capacitors which are joined like X cross shape and it is implementing for power transformation of dc-dc conversion, dc-ac conversion, ac-dc, and ac-ac conversion as shown in fig. (3)

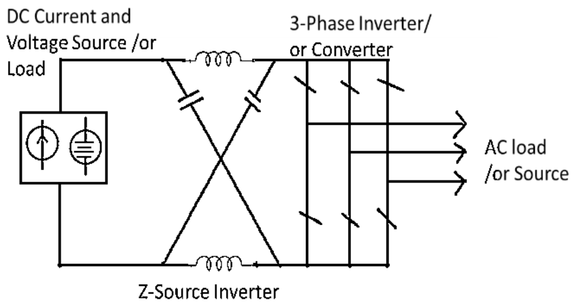


Fig (3) Impedance Source Network

The DC Supply can be achieved from Batteries, Fuel-cell Bank, Rectifier, Thyristorized converter, and a capacitor. In the main power circuitry, the six conducting switches are power transistors in combination of Freewheeling diode in anti-parallel combination to give current flow in bi-direction and blockage of unidirectional voltage.
Impedance Source Network uses state of shoot through inclusion with the active state and non-shoot through state for operation. By doing some modifications in the conventional PWM technique, the Shoot through the state is introduced in a system. In shoot-through mode, the simultaneous shorting of one of the phase leg of inverters occurs. By the use of this shoot through mode, Buck or Boost operation of input DC Voltage can be achieved.
The feature of ZSI is it provides a buck and boost operation in the inverter system so that a wide range of voltage can be obtained.

## C. Operation of ZSI

There are three states of operation of ZSI:
1) Active state: ZSI having Six active states similar to the traditional inverter in which dc voltage is applied to the circuit and ac voltage appearing across the load.
2) Zero state: ZSI consisting Two number of zero states in which load is short by upper or lower three switches respectively.

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3) Shoot-through zero state: ZSI having only one shoot-through state in which there are seven possibilities of shorted load terminal using pair of the upper switch and lower switch turning on of the same phase leg. These shoot-through zero state unique features of Buck-Boost. Therefore, it is called a shoot-through state.

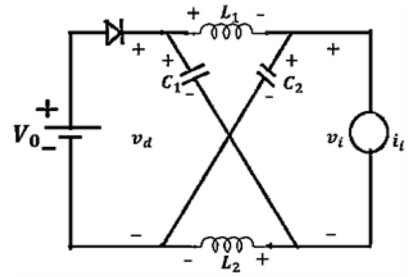


Fig (4) Active State of ZSI

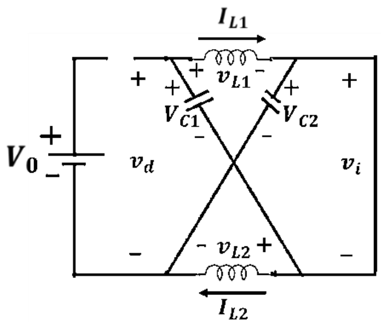


Fig (5) Zero State of ZSI

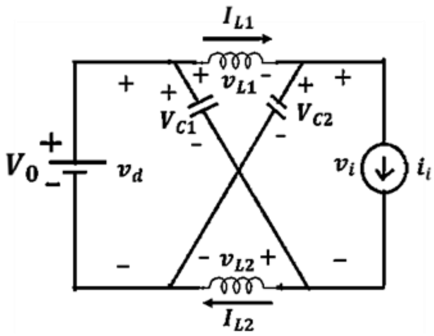


Fig (6) Shoot-through State of ZSI

D. Analysis Of Circuit

Consider two inductors L1 and L2 of equal inductance ratings and capacitors C1 and C2 of equal capacitance ratings. Thus, the impedance-sourced network appears to be symmetrical. So, from the equivalent circuit and according to symmetry, we have

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

During the shoot through zero state, from equivalent circuit,

$$V_L = V_C \quad V_d = 2V_C \quad V_i = 0 \qquad (2)$$

Now, Suppose that bridge inverter system is in one of the nonshoot- through state out of the eight nonshoot- through states. From equivalent circuit shown in Fig (f),

$$V_L = V_o - V_C \quad V_d = V_o \quad V_i = V_C - V_L = 2V_C - V_o \qquad (3)$$

Where, $V_o$ is noted as a dc voltage of source

Total time $T = T_o + T_1$

In steady-state condition, the mean value of voltage appearing across the inductors is to be zero, from (2) and (3), thus,

$$V_L = \frac{T_0 . V_C + T_1 .(V_0 - V_C)}{T} = 0 \qquad (4)$$

Or

$$\frac{V_C}{V_0} = \frac{T_1}{T_1 - T_0} \qquad (5)$$

Also, the mean value of voltage appearing across dc-link and the bridge of inverter is given out by expression:

$$V_i = \frac{T_0 . 0 + T_1 .(2V_C - V_0)}{T} = \frac{T_1}{T_1 - T_0} V_0 = V_C \qquad (6)$$

So, by implementing equation (6) in equation (3), and can be rewritten as

$$V_i = V_C - V_L = 2V_C - V_o = \frac{T}{T_1 - T_0} V_0 = B.V_0 \qquad (7)$$

Where,

$$B = \frac{T}{T_1 - T_0} = \frac{1}{1 - 2\frac{T_0}{T}} \geq 1 \qquad (8)$$

B is noted as a boosting factor which can be obtained from switching of shoot through zero state. On another side, maximum phase voltage from the inverter at output side can be provided as,

$$v_{ac} = M . \frac{V_0}{2} \qquad (9)$$

Where, M is noted as a modulation index. From equation (7), and equation (9) it can be written as,

$$v_{ac} = M . B . \frac{V_0}{2} \qquad (10)$$

In Conventional PWM Voltage-Source Inverter (VSI), there is one common expression

$$v_{ac} = M . \frac{V_0}{2}$$

From Equation (10) it is get that the voltage at output side can be raised up (Boost) or stepped down (Buck) with selecting a proper buck–boost factor $B_B$ ,

$$B_B = M . B = (0 \sim \infty) \qquad (11)$$

Voltage appearing across the z-source network capacitor from equations (1), (5) and (8), can be obtained by an expression,

$$V_{C1} = V_{C2} = V_C = \frac{1 - \frac{T_0}{T}}{1 - 2\frac{T_0}{T}} V_0 \qquad (12)$$

The bucking factor or boosting factor is to find out from the modulation index. By controlling the duty cycle provided for shoot-through zero states, the Boost factor in equation (8) can be controlled. Main Point here is that the PWM controlling of an inverter cannot be affected by Shoot- through zero state, due to there is an equal production of zero voltage across load side terminal. Limitation on the shoot-through switching time span is provided from the time period for zero states which can find out from modulating index value.

E. Shoot-Through Control Method

For regulating the operation of Z-source Inverter, controlling methods of Shoot through state are used which include four different types of Shoot-through control methods.

1. Simple-Boost Control (SBC)
2. Maximum-Boost Control (MBC)
3. Maximum Constant Boost Control (MCBC)
4. Modified Space vector modulation Boost Control

The Amplitude Modulation ratio (Modulation Index M) is main control factor and it is the ratio of maximum peak value of Reference wave signal to maximum peak value of carrier wave signal.

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$$M = \frac{V_{ref}}{V_{car}}$$

The control on output result voltage is achieving by using the Modulation Index (M <1).

Here, Simpler Boost Control method is used for boosting operation in which Two straight line shows the Shoot-though Duty Ratio Do. The first line is equal as the maximum peak of the Reference Sinusoidal voltage signal and another is the negative peak of the Reference Sinusoidal voltage signal. When the amplitude of the triangular wave is more than first-line and lesser than the second line, then the shoot-through state is implemented in the Circuit.

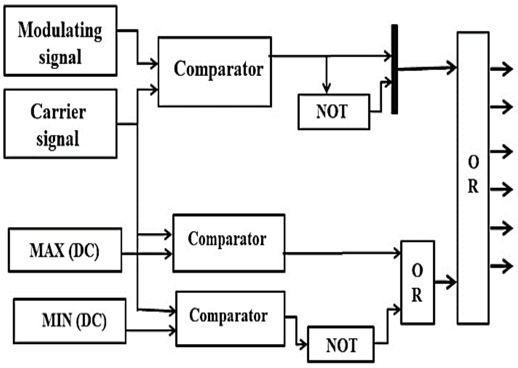


Fig (7) Block Diagram of Simple-Boost Control (SBC)

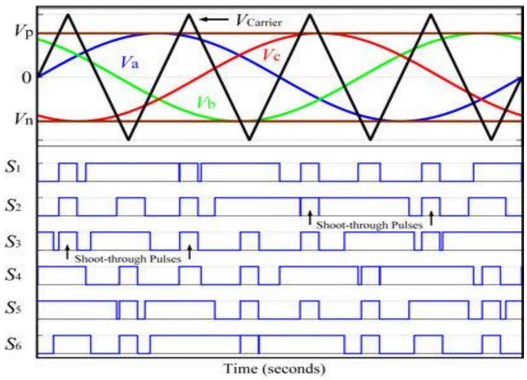


Fig (8) Simple-Boost Control (SBC) Pulses

## III. RESULTS AND DISCUSSIONS

For validation of results PV System and Z-source converter are modeled in MATLAB/Simulink. PV module gives output voltage Vdc ≈ 180V. The parameters used for this model are as follows: L1=10mH, L2=10mH, C1=100µF, C2=100µF. The moto to be achieved behind this system is generation of 3ph, 415V, 50Hz Voltage from PV System by using Boost factor Control in Impedance Source Inverter (ZSI). The resultant voltage appearing across capacitor of Z-source network is as shown in fig (l). This Voltage level is boosted up to 750V. The Modulation Index used for Boost control is 0.8 and switching frequency is 10 kHz. From the inverter system, 415V RMS ac voltage is get between two phases.

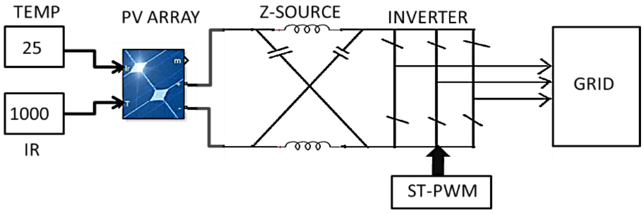


Fig (9) Model of PV Connected ZSI

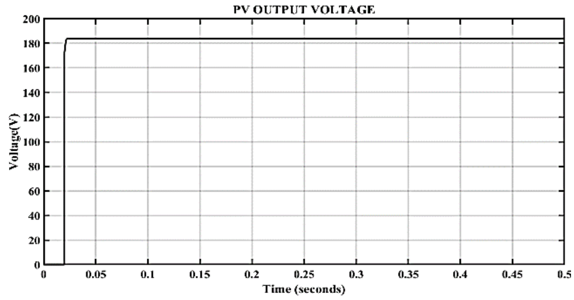


Fig (10) Output Voltage of PV Module

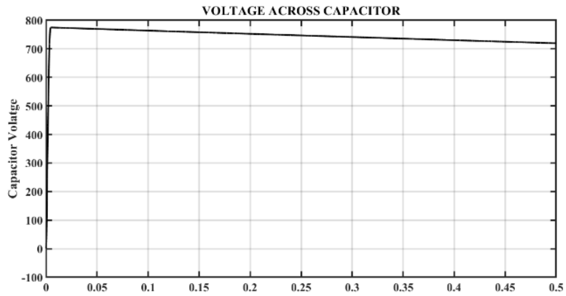


Fig (11) Voltage across Capacitor

The three combinations of line voltage waveforms are as shown below:

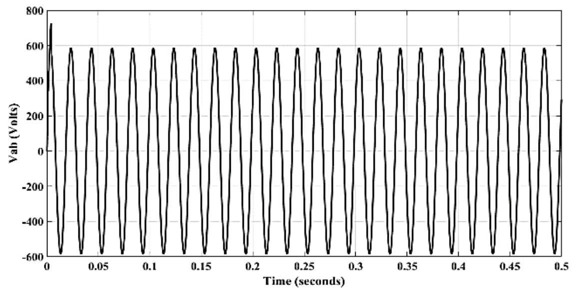


Fig (12) Line Voltage $V_{ab}$

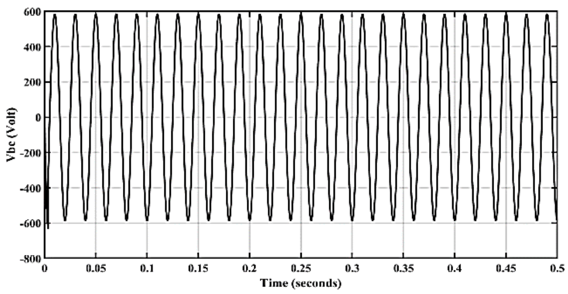


Fig (13) Line Voltage $V_{bc}$

The output voltage got form the Inverter system is further provided to a step-up transformer of 415V/11kV rating. This stepped-up voltage is injected in to a 11kV grid. The Grid Voltage waveform is as follows:

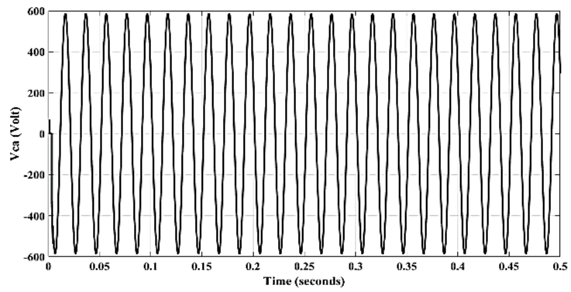


Fig (14) Line Voltage $V_{ca}$

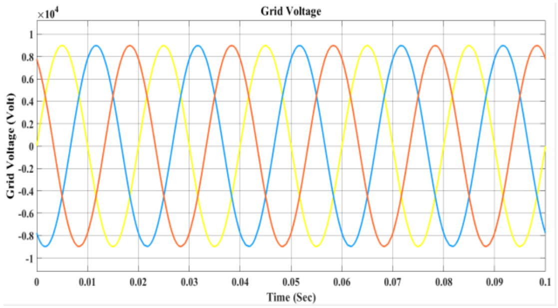


Fig (15) Grid Voltage

## IV. CONCLUSION

This paper presents a grid-connected Z-source inverter powered by a photovoltaic (PV) module. The performance of the proposed system is verified through MATLAB simulations. The system offers the following advantages:

i) A simple structure and an easy-to-implement control scheme enable inherent boost capability.
ii) Since the inverter itself provides the boost function, a separate DC–DC chopper is unnecessary, reducing the power conversion to a single-stage configuration.
iii) The boost operation supports a wide voltage range, while the output current remains sinusoidal, making the system highly suitable for grid integration.

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