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Z – Source Inverter Using Renewable Energy System

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Abstract: ***This paper presents a high performance, low cost inverter for Photo voltaic systems based on Z-source concept. Traditional Voltage-source inverter and Current Source Inverter has improved to the new Z-Source Inverter. This impedance source inverter can provide a single stage power conversion concept where as the traditional inverter requires two stage power conversion. They can control the inverter output power, track the PV panel's maximum power point, and manage the battery power, simultaneously. Simulations results are carried out with the help of Matlab/simulink software. Experimental results are presented for validation of the theoretical analysis and controller design.***

Keyword: z-source, matlab, simulink, renewable energy

1. Introduction

Z-source inverter is a low-cost, efficient, and reliable inverter for traction drives of solar cell. To reduce the cost and to increase the system reliability, Z-source as a single-stage transformer-less inverter topology is proposed. By utilizing the unique *LC* network, a shoot-through zero state can be added to replace the traditional zero state of the inverter and to achieve the output voltage boost function. There exist two traditional converters: voltage-source and current-source converters.

1.1 Voltage Source Inverter

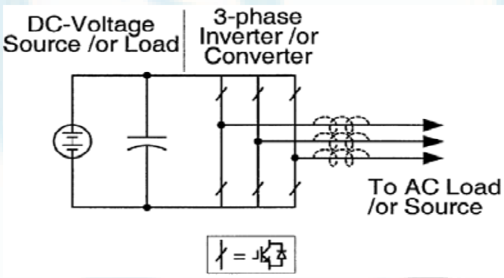


Figure 1: Voltage Source Inverter

Fig. 1 shows the traditional three-phase voltage-source converter structure. A dc voltage source supported by a relatively large capacitor feeds the main converter circuit, a three-phase bridge [1]. The dc voltage source can be a battery, fuel-cell stack, diode rectifier, and/or capacitor. Six switches are used in the main circuit; each is traditionally composed of a power transistor and an anti-parallel (or freewheeling) diode to provide bidirectional current flow and unidirectional voltage blocking capability [2].

The V-source converter is widely used. It, however, has the following conceptual and theoretical barriers and limitations.

- The ac output voltage is limited below and cannot exceed the dc-rail voltage or the dc-rail voltage has to be greater than the ac input voltage.
- External equipment is needed to boost up the voltage
- An output *LC* filter is needed for providing a sinusoidal voltage compared with the current-source inverter, which causes additional power loss and control complexity.
- The shoot-through problem by electromagnetic interference (EMI) noise's misgating-on is a major killer to the converter's reliability.

1.2 Current Source Inverter

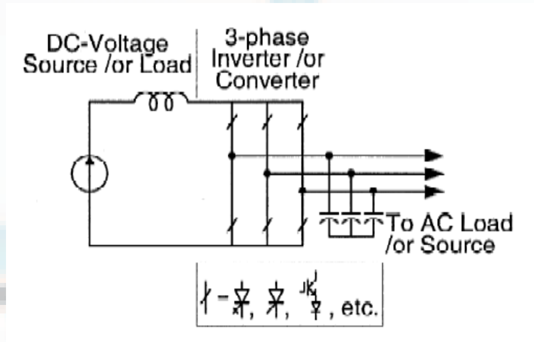


Figure 2: Current Source Inverter

The traditional three-phase current-source converter structure is shown in Fig. 2. A dc current source feeds the main converter circuit, a three-phase bridge. The dc current source can be a relatively large dc inductor fed by a voltage source such as a battery, fuel-cell stack, diode rectifier, or thyristor converter [1].

Six switches are used in the main circuit; each is traditionally composed of a semiconductor switching device with reverse block capability such as a gate-turn-off thyristor (GTO) and SCR or a power transistor with a series diode to provide unidirectional current flow and bidirectional voltage blocking. However, the I-source converter has the following conceptual and theoretical barriers and limitations.

- An additional dc–dc buck (or boost) converter is needed. The additional power conversion stage increases system cost and lowers efficiency.
- At least one of the upper devices and one of the lower devices have to be gated on and maintained on at any time. Otherwise, an open circuit of the dc inductor would occur and destroy the devices.
- The cost of CSI is high and Start-up difficult

1.3 Z - Source Inverter

The Z-source inverter is attractive for three main reasons.
1. The traditional PWM inverter has only one control freedom, used to control the output AC voltage. However the Z-source inverter has two independent control freedoms; shoot through duty cycle and modulation index.
2. The Z-source inverter provides the same features of a DC-DC boosted inverter.(single stage less complex & more effective)
3. The z-source inverter has the benefit of enhanced reliability

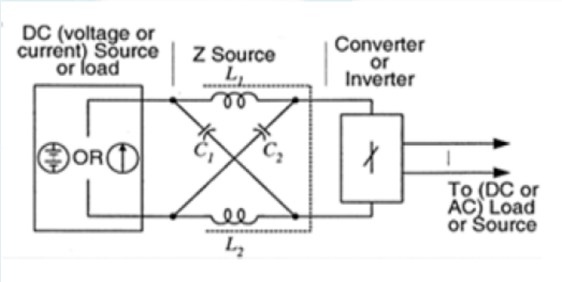


Figure 3: Z - Source Inverter

Fig. 3 shows the general Z – source inverter. The network employs aunique impedance circuit to couple the converter main circuit to that of the power source in order to obtain the unique features that cannot be achievedusing conventional VSI or CSI. The Z-source inverter (ZSI) has been report edsuitable for residential PV system because of the capability of voltage boost and inversion in a single stage [2].

The Z-source inverter has overcame the problem associated with the conventional voltage source inverter for implementing DC-AC, AC-DC, AC-AC and DC-DC power conversion. It employs a unique impedance network (circuit) to couple the converter main circuit to the power source, thus providing unique features that cannot be obtainable in conventional voltage source inverter. The Z-source inverter reduces harmonics, electromagnetic interference noise and low common made noise. The Z-source inverter can be used to feed the adjustable induction motor drive system and it has better performance and results as compared to the conventional VSI. This new approach has been implemented to solar cell system for boosting and inverting the DC voltage into AC voltage. The Z-source inverter is also implementable to grid connected PV system, which is transformer less and has low cost.

Unique Features of Z-Source Inverter:
- Provides the buck-boost function by one stage conversion;
- Is immune to EMI noise and mis-gating
- Solves the problems of the traditional converters;
- Has low or no in-rush current compared with the V-converter; and has low common-mode noise.

2. Operation Modes

2.1 Mode I

In this mode, the inverter bridge is operating in one of the six traditional active vectors; the equivalent circuit is as shown in figure 4.

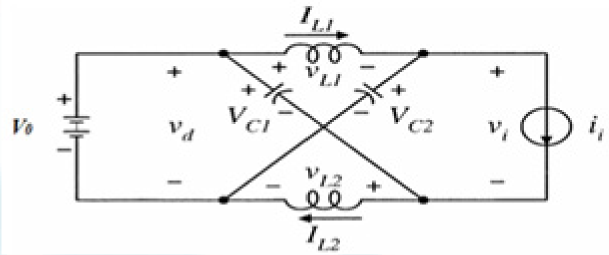


Figure 4: Equivalent Circuit of the ZSI in one of the Six Active States

The inverter bridge acts as a current source viewed from the DC link. Both the inductors have an identical current value because of the circuit symmetry. This unique feature widens the line current conducting intervals, thus reducing armonic current.

2.2 Mode II:

The equivalent circuit of the bridge in this mode is as shown in the fig. 5

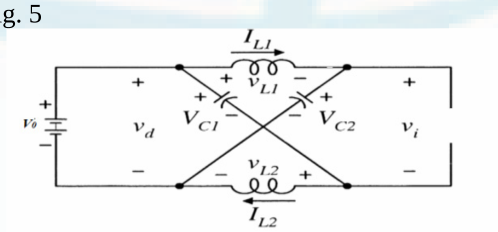


Figure 5: Equivalent Circuit of the ZSI in one of the Two Traditional Zero States.

The inverter bridge is operating in one of the two traditional zero vectors and shorting through either the upper or lower three device, thus acting as an open circuit viewed from the Z-source circuit. Again, under this mode, the inductor carry current, which contributes to the line current's harmonic reduction as shown in below fig 6.

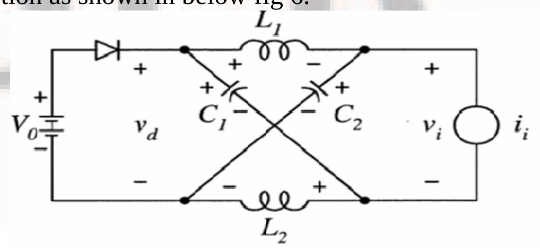


Figure 6: Equivalent Circuit of the ZSI in the Non Shoot-Through States.

2.3 Mode III

The inverter bridge is operating in one of the seven shoot-through states. The equivalent circuit of the inverter bridge in this mode is as shown in the below figure 7. In this mode, separating the dc link from the ac line.

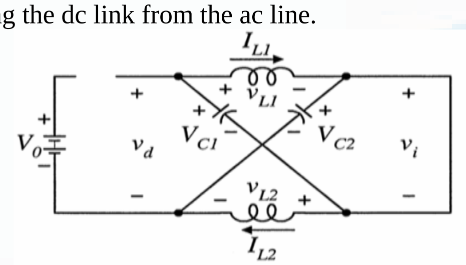


Figure 7: Equivalent Circuit of the ZSI in the Shoot-Through State.

This shoot-through mode to be used in every switching cycle during the traditional zero vector period generated by the PWM control. Depending on how much a voltage boost is needed, the shoot-through interval (T0) or its duty cycle (T0/T) is determined. It can be seen that the shoot-through interval is only a fraction of the switching cycle [2].

2.4 Advantages of Z-source Inverter

The following are the advantages of Z-source inverter when compared to the two traditional inverters i.e. voltage source inverter and current source inverter.

- Secures the function of increasing and decreasing of the voltage in the one step energy processing. (lower costs and decreasing losses)
- Improve resistant to failure switching and EMI distortions.
- Relatively simple start-up (lowered current and voltage surges).
- Provide ride-through during voltage sags without any additional circuits. Improve power factor reduce harmonic current and common-mode voltage.
- Provides a low-cost, reliable and highly efficient single stage for uck and boost conversions.
- Has low or no in-rush current compared to VSI.

2.5 Solar Photovoltaic Cell

With no pollutant emission, Photovoltaic cells convert sunlight directly to electricity. They are basically made up of a PN junction. Figure 1 shows the photocurrent generation principle of PV cells. In fact, when sunlight hits the cell, the photons are absorbed by the semiconductor atoms, freeing electrons from the negative layer. This free electron finds its path through an external circuit toward the positive layer resulting in an electric current from the positive layer to the negative one.

Typically, a PV cell generates a voltage around 0.5 to 0.8 volts depending on the semiconductor and the built-up technology. This voltage is low enough as it cannot be of use. Therefore, to get benefit from this technology, tens of PV cells (involving 36 to 72 cells) are connected in series to form a PV module. These modules can be interconnected in series and/or parallel to form a PV panel. In case these modules are connected in series, their voltages are added with the same current. Nevertheless, when they are connected in parallel, their currents are added while the voltage is the same.

3. PV Cell Model

The equivalent circuit of a PV cell is shown in Fig. 8. It includes a current source, a diode, a series resistance and a shunt resistance.

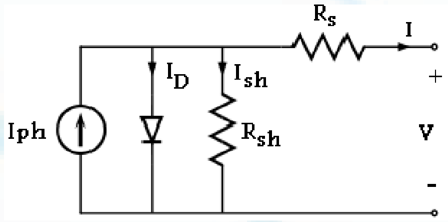


Figure 8: PV cell equivalent circuit

In view of that, the current to the load can be given as:

$$I = I_{ph} - I_s\left(\exp\frac{q(V + R_s I)}{NKT} - 1\right) - \frac{(V + R_s I)}{R_{sh}}$$

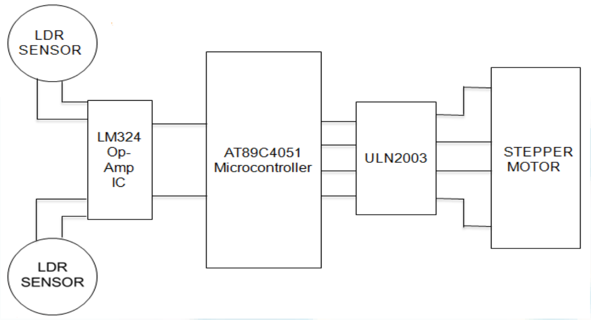
In this equation, *Iph* is the photocurrent, *Is* is the reverse saturation current of the diode, *q* is the electron charge, *V* is the voltage across the diode, *K* is the Boltzmann's constant, *T* is the junction temperature, *N* is the ideality factor of the diode, and *Rs* and *Rsh* are the series and shunt resistors of the cell, respectively.

As a result, the complete physical behavior of the PV cell is in relation with *Iph, Is, Rs* and *Rsh* from one hand and with two environmental parameters as the temperature and the solar radiation from the other hand

3.1 Solar Tracking System

Solar system is considered to be as a renewable energy solution for most of energy crises and environmental pollutions. In order to increase the solar system efficiency, it is required to maximize the output power by keeping the solar panels aligned with sun. Consequently, a tracking of the sun position with high degree of accuracy is required [6]. The main purpose of a solar tracking system is to track the movement of the sun during the aunshine in order to orientate the solar panel to the maximum radiation in all time. Large numbers of tracking systems have been developed and introduced previously in the literature. More details can be found in the high level overview of the sun tracking systems. Extracting usable electricity from the sun was made possible by the discovery of the photoelectric mechanism and subsequent development of the solar cell – a semi conductive material that converts visible light into a direct current [6]. The process of sensing and following the position of the sun is known as Solar Tracking. It was resolved that real-time tracking would be necessary to follow the sun effectively, so that no external data would be required in operation [7].

3.2 Block diagram of Solar Tracking System



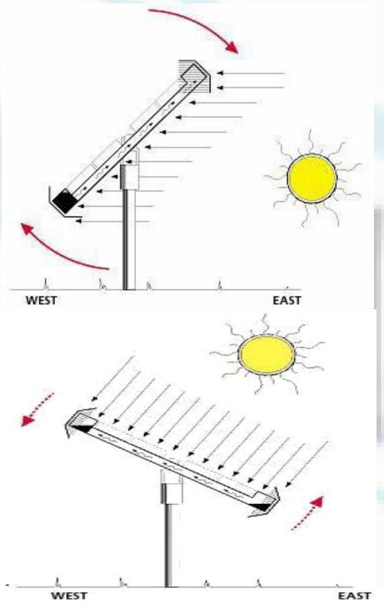
3.3Solar Trackers

Solar Tracker is a Device which follows the movement of the sun as it rotates from the east to the west every day. The main function of all tracking systems is to provide one or two degrees of freedom in movement. Trackers are used to keep solar collectors/solar panels oriented directly towards the sun as it moves through the sky every day. Using solar trackers increases the amount of solar energy which is received by the solar energy collector and improves the energy output of the heat/electricity which is generated. Solar trackers can increase the output of solar panels by 20-30% which improves the economics of the solar panel project [6].

3.4 Types of Solar Trackers

3.4.1 Passive Tracking Systems

The passive tracking system realizes the movement of the system by utilizing a low boiling point liquid. This liquid is vaporized by the added heat of the sun and the center of mass is shifted leading to that the system finds the new equilibrium position[12].The two basic types of active solar tracker are single-axis and double-axis.



3.4.2 Single axis trackers

The single axis tracking systems realizes the movement of either elevation or azimuth for a solar power system. Which one of these movements is desired, depends on the technology used on the tracker as well as the space that it is mounted on. For example the parabolic through systems utilize the azimuthally tracking whereas the many rooftop PV-systems utilize elevation tracking because of the lack of space. A single-axis tracker can only pivot in one plane – either horizontally or vertically [12].

This makes it less complicated and generally cheaper than a two-axis tracker, but also less effective at harvesting the total solar energy available at a site. Trackers use motors and gear trains to direct the tracker as commanded by a controller responding to the solar direction. Since the motors consume energy, one wants to use them only as necessary [12].

Single axis trackers have one degree of freedom that acts as an axis of rotation. There are several common implementations of single axis trackers. These include horizontal single axis trackers (HSAT) and vertical single axis trackers (VSAT). A horizontal-axis tracker consists of a long horizontal tube to which solar modules are attached. The tube is aligned in a north-south direction, is supported on bearings mounted o n pylons or frames, and rotates slowly on its axis to follow the sun's motion across the sky.

This kind of tracker is most effective at equatorial latitudes where the sun is more or less overhead at noon. In general, it is effective wherever the solar path is high in the sky for substantial parts of the year, but for this very reason, does not perform well at higher latitudes. For higher latitude, a vertical-axis tracker is better suited. This works well wherever t he sun is typically lower in the sky and, at least in the summer months, the days are long [12].

3.4.3 Dual Axis Trackers

Dual axis trackers as shown in the figure have two degrees of freedom that act as axes of rotation. Double-axis solar trackers, as the same suggest, can rotate simultaneously in horizontal and vertical directions, and s o are able to point exactly at the sun at all times in any location.

3.4.4 Boost Converter

A DC – DC converter is commonly used to convert from one DC voltage level (often unregulated) to another regulated DC voltage level. Depending on the converters configuration, the resulting output voltage can be a step – up or step – down function of the input voltage, and can appear as a positive or negative voltage to the load.

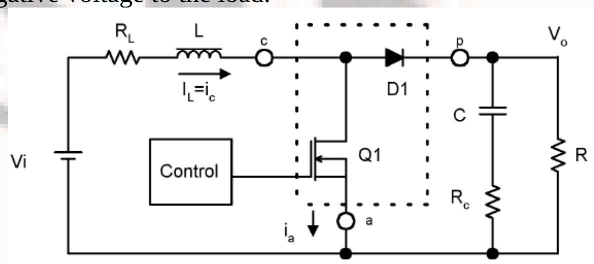


Figure 9: Boost converter

Figure 9 shows a simplified schematic of the boost power stage. Inductor L and capacitor C make up the effective output filter. The capacitor equivalent series resistance (ESR), RC, and the inductor dc resistance, RL, are included in the analysis. Resistor R represents the load seen by the power supply output [12].

A power stage can operate in continuous or discontinuous inductor current mode. In continuous inductor current mode, current flows continuously in the inductor during the entire switching cycle in steady-state operation. In discontinuous inductor current mode, inductor current is zero for a portion of the switching cycle. It starts at zero, reaches peak value, and return to zero during each switching cycle. It is desirable for a power stage to stay in only one mode over its expected operating conditions because the power stage frequency response changes significantly between the two modes of operation [11].

4. Simulation Results

4.1 Photovoltaic System

The PV array module is implemented using a generalized photovoltaic model using MATLAB Simulink software package. The effect of solar irradiation cell temperature, output current and power characteristics of PV module are simulated, analyzed and optimized.

A simple mathematical relation is used to model the non-linear characteristics of solar cell. The solar irradiation level is controlled by varying the short circuit current in the characteristic equation. From the characteristics the maximum power point is calculated. The simulation of solar cell is performed using the MATLAB software and I-V and P-V Characteristics are obtained.

4.2 PV Cell Model

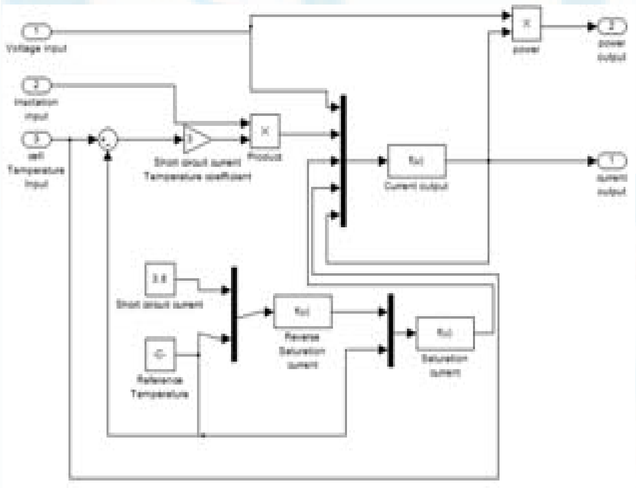
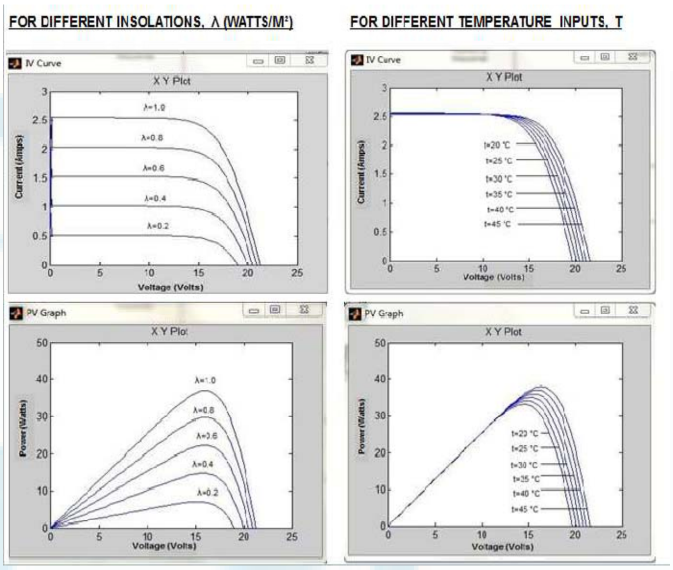


Figure 9.1: PV Cell Model

4.3 Pv Model Characteristics



4.4 Z – Source Inverter with Boost Converter

Figure 9.3 shows the simulation model of Z – Source Inverter using Solar Tracking System. A diode is connected in series to prevent the circuit from reverse current flow. This model consists of Z-source network i.e. combination of two equal values inductor (L1 = L2 = 160µH) and capacitor (C1 = C2 = 1000 µF). Solar cell powered Z-source inverter is modeled and simulated using MATLAB/SIMULINK package.

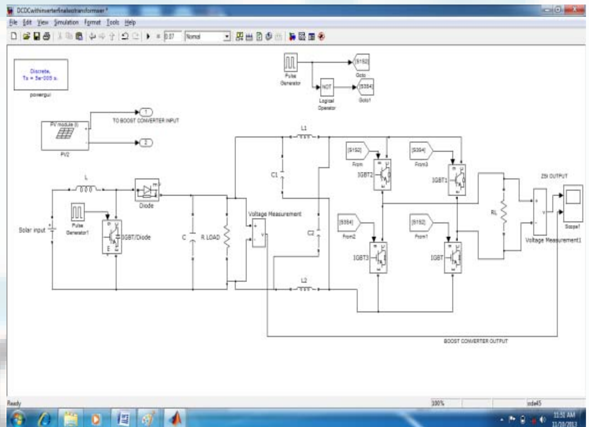
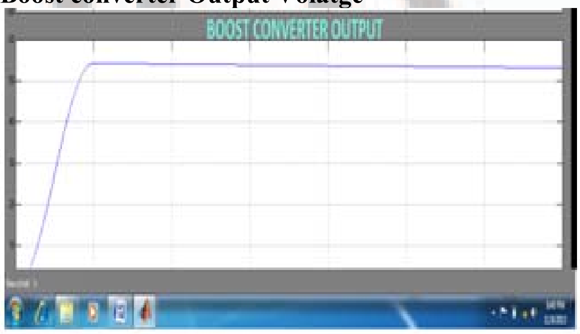


Figure 9.3: z- source inverter model

4.5 Boost converter Output Volatge



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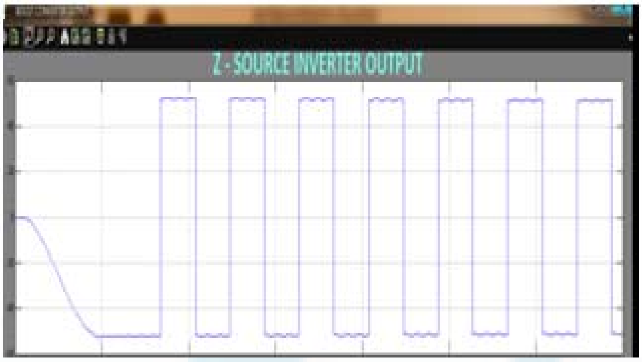
4.6 Z Source Inverter Output Voltage



5. Hardware Kit

The following Fig.10 shows the Demo hardware implementation of the proposed improved Z- Source inverter by using solar tracking system.

6. Conclusion

In this paper solar cell powered Z-source source inverter system is modeled and simulated. The three phase Z-source inverter has both voltage buck boost capabilities due to its unique impedance network within it. Z-source network does not need a dead time leads to improved performance. It also has a wide range of input voltage that results in low power losses. The results of digital simulation are presented. It also confirms that the THD of Z-source inverter system is very less than its counterpart and it is very much promising power conversion concept for photo voltaic system in order to increase the overall system efficiency, thereby reducing system complexity and cost.

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