

## Z - Source Multi Level Inverter Based PV Generation System

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### Abstract

In this paper a novel technique of Z-Source multilevel Inverter based PV Generation system is implemented and simulated using MATLAB-Simulink simulation software. The Photovoltaic cells are healthier option for converting solar energy into electricity. Due to high capital cost and low efficiency PV cells have not yet been a fully smart choice for electricity users. To enhance the performance of the system, Z-Source multi level inverter can be used in place of conventional Voltage Source Inverter (VSI) in Solar Power Generation System. The PV cell model is developed using circuit mathematical equations. The Z-Source multilevel inverter is modeled to realize boosted DC to AC conversion (inversion) with low THD. Outcome shows that the energy conversion efficiency of ZSMLI is a lot improved as compared to conventional voltage Source Inverter (VSI). By doing FFT analysis we can know the total THD.

**Key words:** PV Panel; Z-MLI; MPPT; PWM Inverter.

### I. INTRODUCTION

The Solar Energy Source has attracted the attention for electrical power generation because the generated power is environment friendly, noiseless, has longer life with little maintenance, highly mobile and portable because of light weight. Advancement is going on in solar power generation technologies day by day. A simple way to increase the output voltage of Solar Energy sources is to connect a number of Solar Panel in series and use a conventional voltage source inverter. However, this series configuration has some drawback, such as low reliability and low efficiency. For analyzing the performance of the Solar Power Generation System a simulation model has been developed using basic circuit equations of photovoltaic (PV) cells including the effects of solar irradiation and temperature changes. This model was tested using a directly coupled DC load as well as AC load using IGBT based inverter [3]. For the better accuracy at low irradiation level, a two diode model to represent a PV cell has been proposed. This topology needs additional iteration method for the calculation of series and parallel resistance [4]. A simple PV array modeling has also been presented with parallel resistance [5].

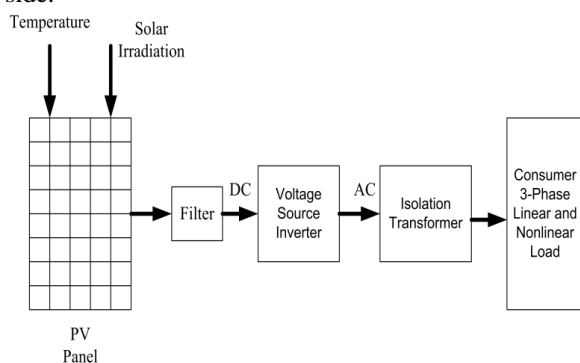
Most of the investigations in the literature for solar energy system have adopted the topologies and control algorithm for DC-AC Inverter to improve the conversion efficiency. A step-up transformer can be utilized at line frequency to boost the voltage after the inverter. However, this solution has several disadvantages, such as huge size, loud acoustic noise,

and relatively high cost [6]. The three-phase multi-level inverters can also be employed to interface the output of several Solar Energy sources to the load [7]. Although the multi-level inverters are effective for this application, the added complexity of the circuit, the additional components, reduce both the overall efficiency and reliability of the system, and may raise the on the whole price of interface. Another option is the z-source inverter that can be applied for solar energy systems. The z-source inverter has the capability of boosting and inverting the dc voltage in a single-stage, with less no of switches in comparison with multi-level inverters and the two-stage topologies. The Z-source inverters and ultra capacitors based fuel cell system has been developed [8-10]. The harmonic study of Z-source inverter proves that it works more efficiently and has better performance as compared to traditional voltage and current source inverter [11]. The transient Modeling and Analysis of advanced Pulse-Width Modulated Z-Source Inverter has been presented. For improving the performance and efficiency of the Photovoltaic system the Z-source inverter can also be employed [12-14].

In this paper a simulation model of photovoltaic system feeding AC load is modeled using simulink toolbox. For DC to AC energy conversion the Z-Source inverter is used, which also acts as a boost inverter. The system is analyzed for linear resistive/R-L and nonlinear rectifier load. A comparison study of solar power generation using conventional PWM inverter and Z-Source inverter has also been performed.

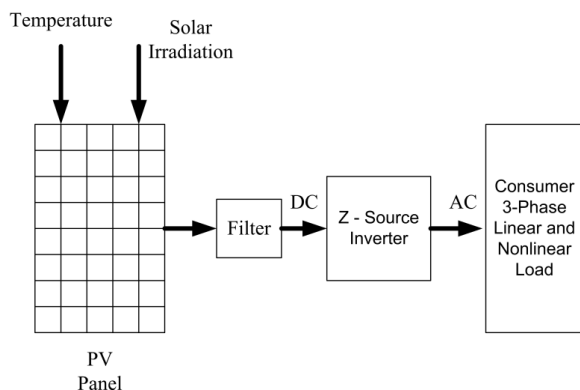
## II. SYSTEM CONFIGURATION

Fig. 1a shows the block diagram of conventional Solar Power Generation System using the PWM voltage source inverter. The PV Panel or Array is defined as the group of PV cells electrically connected in series or parallel to generate the required voltage and current. Voltage or current generated by PV Panel is DC quantity. A Filter is connected to reduce the ripples caused by the temperature and irradiation variations. This filter is also capable of maintaining stable voltage at the load side.



**Fig- 1a:** Conventional Solar Power Generation System

The Z-Source Inverter based Solar Power Generation System consists of PV panel, filter, Z-Source Inverter (ZSI), DC-DC boost converter. Fig. 1b shows the block diagram of the system Solar Power Generation System using the ZSI.



**Fig- 1b:** Proposed Z-Source based MLI Solar Power Generation System

For feeding the 3-phase load, ZSI is employed to convert the DC voltage into pure sinusoidal AC voltage waveform. The ZSI is a latest topology for the successful electrical power conversion that can buck or boost the input voltage/current with unique single circuit, which is not possible in conventional PWM voltage/current source inverter. An additional isolation transformer is connected between the VSI and load. This transformer has higher cost and

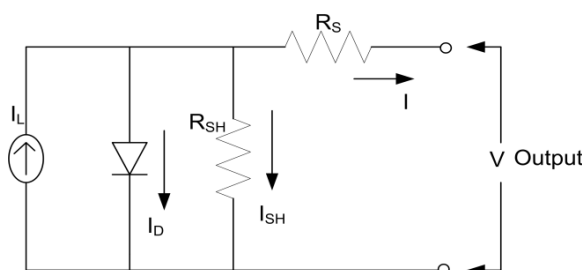
weight. In the developed system, ZSI is implemented for DC-AC conversion and acts as a boost inverter for obtaining the desired voltage level and there is no need of transformer. The pure sinusoidal AC output voltage of the ZSI is fed to the consumer load.

## III. MATHEMATICAL MODELING

The Solar Power Generation System using the Z-Source inverter can be mathematically modeled as:

### 3.1. PV Panel Modeling

The PV cells are usually represented by a simplified equivalent circuit model as shown in the fig. 2.



**Fig. 2.** Equivalent Circuit of PV Cell

The PV cell output voltage, which is function of photocurrent depending on the temperature and solar irradiation level, is explained as below:

$$V = \frac{AkT}{e} \ln\left(\frac{I_{ph} + I_0 - I}{I_0}\right) - R_s I \quad (1)$$

If the temperature and solar irradiation levels change, the V & I yields the PV array will follow this change. The effect of variable ambient temperature  $T_a$  is represented by the temperature coefficients  $C_{TV}$  and  $C_{TI}$  for the cell output voltage and cell photocurrent respectively as:

$$C_{TV} = 1 + \beta_T (T_a - T_x) \quad (2)$$

$$C_{TI} = 1 + \frac{\alpha_T}{S_C} (T_x - T_a) \quad (3)$$

Where,  $\beta_T = 0.004$  and  $\alpha_T = 0.06$  for the cell used. The ambient temperature ( $T_a$ ) throughout the cell testing is approximates to 200 Centigrade. The change in the temperature is represented by  $T_x$ . This will be responsible for the change in the voltage generated by the PV Panel.

A change in solar irradiation level causes a change in the cell photocurrent and operating temperature, which affects the cell output voltage. The change in the operating temperature and in the photocurrent due to variation in the solar irradiation level can be expressed by the correction factors i.e.

CRV and CRI for changes in cell output voltage V and PV currents are as;

$$C_{RV} = 1 + \beta_T \alpha_s (S_x - S_R) \quad (5)$$

$$C_{RI} = 1 + \frac{1}{S_C} (S_x - S_R) \quad (6)$$

Where,  $S_C$  is the reference solar irradiation level during the cell testing.  $S_x$  is the new level of solar irradiation. The new values of the cell output voltage  $V_{Cx}$  and photocurrent  $I_{Phx}$  for the new temperature  $T_x$  and solar irradiation  $S_x$  can be given as:

$$V_{Cx} = C_{TV} C_{RV} V_C \quad (7)$$

$$I_{Phx} = C_{TI} C_{RI} I_{Ph} \quad (8)$$

### 3.2. Z-Source Inverter Modeling

The equivalent circuit arrangement of Z-Source Inverter Bridge is shown in the fig. 3. Assuming that  $L_1 = L_2$  and  $C_1 = C_2$  for the symmetrical Z-source network. Hence, the voltages across capacitors and inductors are as follows [8]:

$$V_{C1} = V_{C2} = V_C \text{ and } V_{L1} = V_{L2} = V_L \quad (9)$$

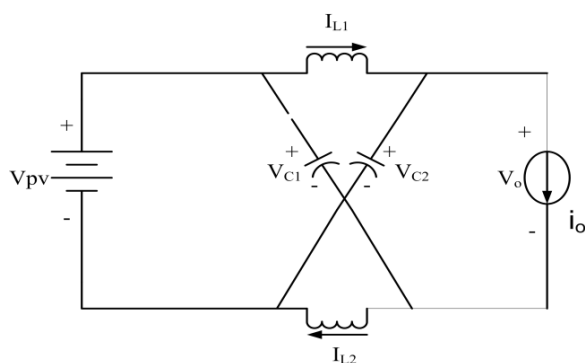


Fig- 3: Z-source Inverter Bridge

During the shoot - through zero state for an interval ( $T_0$ ) during a switching cycle ( $T_z$ ),

$$V_L = V_C, V_d = 2V_C, V_0 = 0 \quad (10)$$

Now consider that the inverter bridge is in one of the eight non-shoot-through states for an interval of  $T_1$ , during the switching cycle,  $T_z$

$$V_L = V_0 - V_C,$$

$$V_0 = V_C - V_L = 2V_C - V_{pv} \quad (11)$$

Where  $V_{pv}$  is the output DC voltage of PV panel and  $T_z = T_0 + T_1$ .

The average voltage of the inductors over one switching period  $T$  should be zero in steady state. From Eq.10 and Eq.11 voltage across inductor and capacitor are obtained as:

$$V_L = [T_0 V_C + T_1 (V_{pv} - V_C)] / T_z = 0 \quad (12)$$

$$V_C / V_{pv} = T_1 / (T_1 - T_0) \quad (13)$$

Similarly, the average DC-link voltage across the inverter bridge can be found as follows:

$$V_0 = [T_0 * 0 + T_1 (2V_C - V_{pv})] / T_z$$

$$= [T_1 / (T_1 - T_0)] V_{pv} \quad (14)$$

The peak DC-link voltage across the inverter bridge is expressed in eqn.11 can be rewritten as:

$$V_0 = V_C - V_L$$

$$= 2V_C - V_{pv} = [T_z / (T_1 - T_0)]$$

$$= B * V_{pv} \quad (15)$$

$$\text{Where, } B = T_z / (T_1 - T_0) = 1 / (1 - 2T_0 / T_z) \geq 1 \quad (16)$$

The DC-link voltage is the boost factor resulting from the shoot-through zero state. The peak DC-link voltage  $V_0$  is the equivalent DC-link voltage of the inverter. On the other side, the output voltage from the inverter can be presented as:

$$V_{ac} = M V_0 / 2 \quad (17)$$

Where,  $M$  is the modulation Index. Using Eq. 15 and Eq. (17) can be further expressed as:

$$V_{ac} = M * B * V_{pv} / 2 \quad (18)$$

Eqn. 17 shows that the output voltage can be stepped up and down by choosing an appropriate buck-boost factor  $BB$ ,  $BBF = M * B = (0 \sim \infty)$  (19) from eqn. 9, eqn. 13 and eqn. 16, the capacitor voltage can express as:

$$V_{C1} = V_{C2} = V_C = [1 - (T_0 / T_z)] / [1 - (2T_0 / T_z)] V_{pv} \quad (20)$$

The buck-boost factor  $BBF$  is determined by the modulation index  $M$  and boost factor  $B$ .

## IV. MPPT TECHNIQUE

A typical solar panel converts only 30% to 40% of the incident solar irradiation into electrical energy. Hence, the efficiency of the PV Panel is about 15-20%. The only alternative to improve the efficiency of PV panel is Maximum power point tracking technique. Using these MPPT techniques, the PV array is controlled to generate the maximum power at any particular environment condition.

There are different techniques used to track the maximum power point. Few of the most popular techniques are:

1. Perturb and observe (hill climbing method)
2. Incremental Conductance method
3. Fractional short circuit current

4. Fractional open circuit voltage
5. Neural networks
6. Fuzzy logic

In the proposed system Incremental Conductance method is chosen for our consideration. In this method, the system measures incremental variations in array V & I to find the effect of a change in voltage. This method requires more calculations in the regulator, but can get altering circumstances more fastly than the perturb and observe method (P&O). Like the P&O algorithm, it can produce oscillations in power. This method consumes the incremental conductance ( $dI/dV$ ) of the photovoltaic array to calculate the sign of the change in power with respect to voltage ( $dP/dV$ ).

The incremental conductance method computes the maximum power point by comparison of the incremental conductance ( $\Delta I/\Delta V$ ) with the array conductance ( $I/V$ ). When the incremental conductance is nilling, the output of the voltage is the MPP voltage. The system controller maintains this voltage until the irradiation changes and the process is repeated.

### V. MULTILEVEL INVERTER

The modified single phase five-level inverter circuit diagram is shown in Fig 4. This is a five level fly back capacitor multi level invereter. By using this type of multi level inverter we can reduce the THD of the system, boost operation also can be done by Z source network before the Multi level inverter.

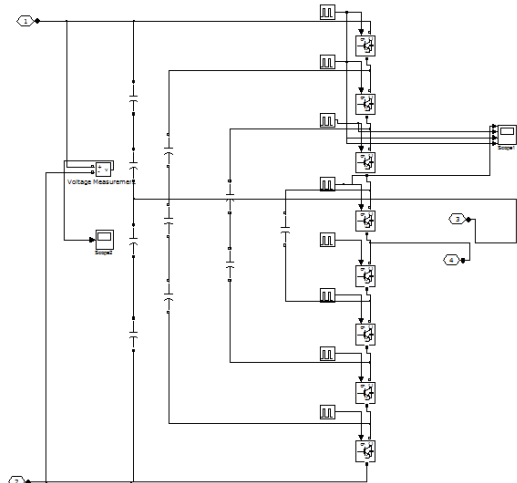


Fig- 4: Single phase five level flying capacitor MLI

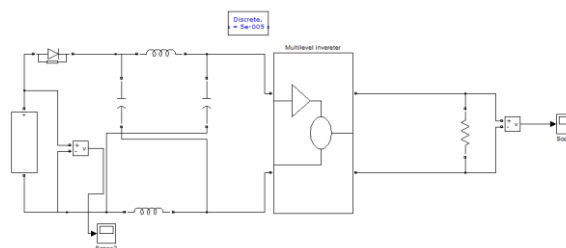


Fig-5: Simulink diagram for PV based z source multi level inverter

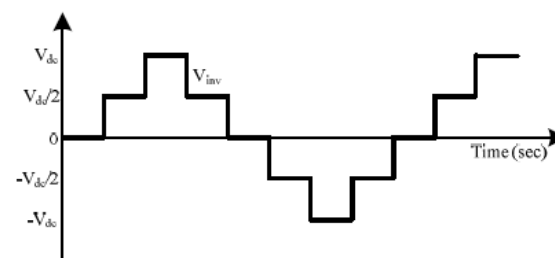


Fig- 6: Ideal five level output voltage waveform

### VI. SIMULATION RESULTS

The below figure will gives you the Simulation results of a Z- source MLI output with five levels & low Total harmonic distortion value. THD can be calculated by using FFT analysis in MATLAB.

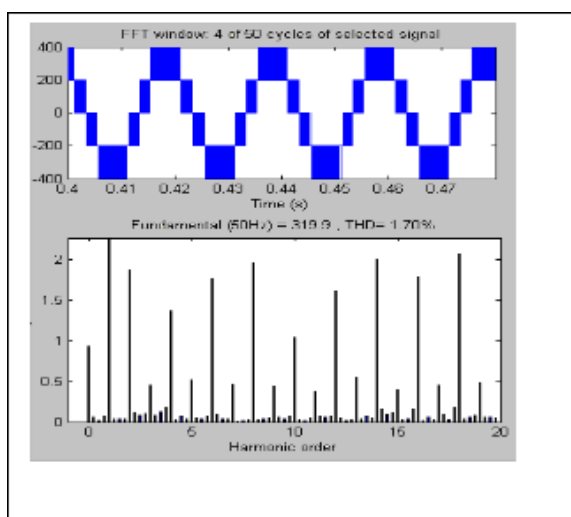


Fig-7: Five level output voltage with THD

### VII. CONCLUSION

This paper proposes a simulation model for Z- source multi level inverter based solar power generation system. The Z-source multi level inverter is used in place of conventional voltage source inverter. The Z-source multi level inverter provides exceptional features that cannot be seen in the conventional DC-AC inverter. The conventional voltage source inverter needs a step up or step down

transformer to meet the supply requirements. The Z-source inverters do not require the additional transformer because it can act as either buck or boost inverter as per the requirement. Hence it can produce any desired output AC voltage. After the analysis of simulation results it is concluded that system is able to supply the linear and nonlinear resistive/R-L load efficiently. The proposed system is having low cost, small size, reduced weight, more efficient and reliable as compared to conventional topology for energy conversion. After the analysis it is concluded that the ZSI has the better performance as compared to conventional VSI because it can produce any desired output ac voltage, even greater than line voltage, reduces harmonic currents.

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## BIOGRAPHIES



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