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Design and Implementation of PV Z source Inverter topology

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Abstract: Photovoltaic energy is one of the ruling area due to it's easy availability and pollution free nature. At the same time the voltage from the PV is needed to be stepped up for different load requirements. There are various pulse width modulation techniques for the control of impedance Source inverter(ZSI).Here we have considered Carrier based various PWM techniques for PV-ZSI Converter. The proposed converter consists of cascade connection of PV Modules and Conventional-ZSI which provides higher boosting factor and smaller size than that of existing VSI .The performance of inverters depend on the type of modulation technique used to switch them. This work depicts a detailed analytical approach in MATLAB/Simulink platform as well hardware consists of sine triangle PWM method for proposed new topology PV-ZSI. It has been observed output voltage of proposed inverter is more in comparison to conventional VSI. As the proposed inverter is lesser in size and output voltage is greater so it is more efficient than conventional VSI. There is no requirement of Boost converter .

Keywords : Photovoltaic(PV) system, Impedance source inverter(ZSI),Pulse width modulation(PWM) techniques..

I. INTRODUCTION

Day by day, the energy demand increases. Significantly, due to advancement in different fields in this world and limitations of fossil fuels, the researchers has focused on searching for alternate energy sources to meet the world's energy demand. As for that solar energy, wind energy and nuclear energy came into picture. Due to the environmental constraints like global warming, the renewable energy or clean energy source like solar energy and wind energy become popular. As we know renewable energy sources has been a vital source for electricity production. So day by day mankind are depending upon renewable energy sources for the generation of electricity.

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Government gives funding for the installation of solar panels on the rooftops for the domestic use Generally PV systems are divided into 2 parts, they are Standalone Photovoltaic or off grid systems and Grid PV systems. Generally Off grid or standalone systems are used for small generation purpose or in other words it is used for domestic appliances like solar cooker, solar lamps etc. Whereas Grid connected PV systems are used for greater generation purpose or in other words, power generated from grid connected PV systems are supplied or transmitted to several consumers and the consumers have to pay for the consumption of the electricity. In these two cases power converters are required for carrying out electrical conversion. In 2003, Z-Source Inverter came in the field of Power Electronics and Drives by Prof. Fang Zehng Peng [1]. The uniqueness of the Z-Source Inverter is that, it can buck or boost the input voltage as per requirement with very simple Z-network [2]. The researchers have modified the Z-network to get better boosting factor and lesser size during the last decade. On the other hand, the researchers have introduced different modulation strategies for inverters [7]. These modulation techniques are implemented with inverters to generate desired gate pulses. The PWM control techniques are also implemented with ZSI to obtain better results [10] [14]. The PWM methods can be either carrier based or space vector based methods. Further both types PWM techniques can be divided into classical as well as advanced PWM techniques [13].

ZSI having a typical boosting technique provides wide platform for researches. For improving gain factor, efficiency decrement of ripples and boosting factor, ZSI provides a perfect solutions. There are various technical challenges that are faced by the converter. The new designed method gives a better result and size is reduced than that of traditional VSI. The suggested system has cascade connection of PV Modules and Conventional ZSI.

II. PHOTOVOLTAIC STRUCTURE

A photovoltaic system consists of several modules connected in series parallel combination where as a solar module is made of 36 number of crystalline silicon solar cells. The non-linear relationship of the IV graph states that current decreases with increase in voltage. But at knee point the power remains maximum corresponding to maximum voltage and maximum current. There are several designs of solar cell like single diode cell, two diode cell etc. In the PV cell diode is connected in parallel with the current source in reverse direction.

In practical solar cell the circuit consists of resistances in shunt and series connection hence the output current depends on the shunt branch elements. The photo current depends on solar irradiance and temperature. The operating temperature affects diode reverse saturation current[14].

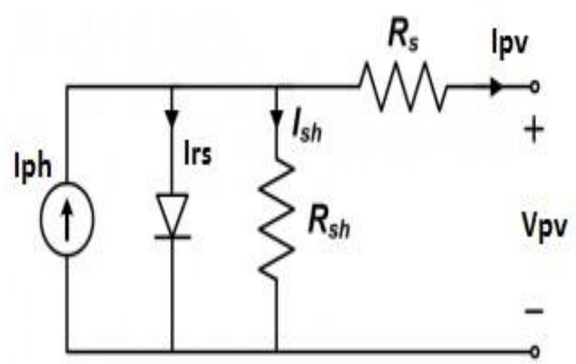

Fig 1: Basic arrangement of PV system

Figure 1 shows one diode model of PV system having resistances connected in series and parallel. The output current of the PV array can be found out by using the below given equations as follows:

$$Ipv = Iph - Is\left[\exp\left(\frac{q \times Vpv + Ipv \times Rs}{Ns \times A \times K \times Top}\right) - 1\right] \quad (1)$$

Where Iph is the light generated photo current and is given by the equation as

$$Iph = [Iscref + Ki(Top - Tn)] \quad (2)$$

From equation 1 Is is the current through the shunt branch which is represented by the below equation

$$I_S = I_{rs}\left({}^{T_{op}}/_{T_n}\right)^3 \times \exp\left[\frac{q \times E_g}{A \times K}\left(\frac{1}{T_n} - \frac{1}{T_{op}}\right)\right] \quad (3)$$

From equation no 3 Irs refers to Reverse Diode current.

$$I_{rs} = \left[\frac{I_{SCref}}{\exp\left(q \times V_{OC}/_{Ns \times A \times K \times T_n}\right) - 1}\right] \quad (4)$$

Where Ipv- PV output current in ampere, q- charge of electron, 1.602×10^{-19},Rs-Shunt resistance in ohm,Ns-No of cells in series, A-Diode Ideality constant, 1.5,Ki-Temperature coefficient, 0.0017, K-current temperature constant, 1.3805×10^{-23}, Top-Operating temperature, Tn- Nominal temperature, k-Constant, 1.6,Eg-Band gap of silicon, 1.1volt Iscref-Reference short circuit current. The photovoltaic System is modelled in Matlab/Simulink by using these above 4 equations[15,16].

III. PV ZSI CONVERTER

The proposed Inverter overcomes the barriers associated with the traditional VSI and CSI. The boosting in the C-ZSI occurs only because of the X-shaped unique impedance system. This is a two port network and is nothing but the combinations of the split L and C in such a manner that it gives a shape of X. The ZSI unit has inductors named as L1 & L2 and capacitors as C1 & C2. These inductors are either of split type or normal types. The ZSI unit is placed in between the input source and traditional CSI or VSI to supply the boosted input voltage to the Inverter. So the boosted output results. The output voltage equation of inverter is as follows

$$v^{\wedge}_{out} = BM\frac{V_0}{2} \quad (5)$$

Where: $v^{\wedge}_{out}$:Boosted output voltage of inverter.

B : incremental factor

M: Modulation Index

Vo: voltage fed to the inverter

Replacing BM by G(inverter Gain), so the equation (5) modified to

$$v^{\wedge}_{out} = \frac{V_0}{2}G \quad (6)$$

G : inverter gain,

$$G = MB \quad (7)$$

$$v^{\wedge}_{out} = M\frac{V_0}{2} \quad (8)$$

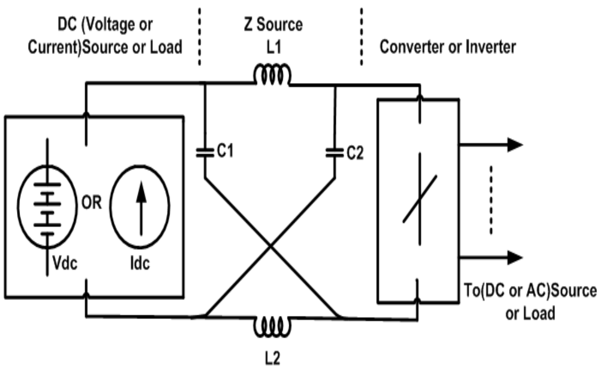

Fig 2: Basic topology for ZSI

The control schemes of impedance source inverters are of three types **[5]** for the implementation of PWM techniques and injection of shoot-through .These are classified as

a)simple boost control

b)constant boost control

c)maximum boost control

In the first case, a potion from the zero state is changed to shoot-through state for increase in the voltage. In the second case complete zero state is changed to shoot through state.

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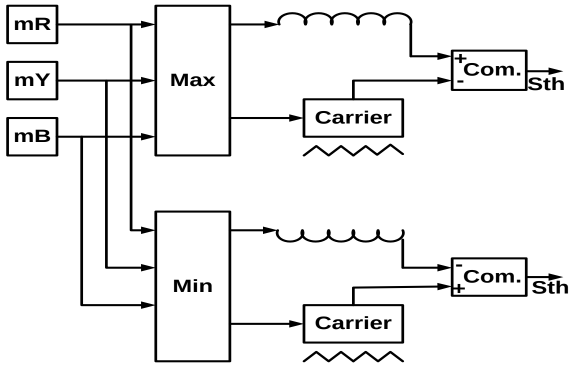

Fig.3: Maximum Boost control of ZSI

Figure 3 shows the circuit diagram for the third method.Here the operations are carried out using the third method which gives more boosted voltage than the other two methods. The highest increase in the input voltage supplied to the inverter is obtained which is given in the figure-3.

A. MAXIMUM BOOST CONTROL METHOD

This method transforms zero state to higher state without changing the sin active form. The minimum and maximum point the sinusoidal wave is compared to get the triangular carrier [10]-[13]. At high minimum and low maximum we get triangular as the mode of operation is PWM. The control technique of the third method is shown in fig 3 [4]. Mean value of duty cycle in the span $\pi/2, \pi/6$ can be expressed as

$$B = \frac{1}{1-2T_0} = \frac{1}{1-2D_0} \qquad (9)$$

gain in voltage (G) of inverter:

$$G = BM = \frac{\pi M}{3\sqrt{3}M - \pi} \qquad (10)$$

Stress voltage across the inverter

$$V_{inv} = BV_0 = \frac{\pi}{3\sqrt{3}M - \pi} V_0 \qquad (11)$$

IV. PWM TECHNIQUES

Like other inverters, ZSI also uses PWM techniques for its switching pulse generation. The PWM methods are of two types: Carrier based and Space Vector based. There are different features for various PWM techniques [14,15,16].

A.Carrier based PWM techniques

The modulating signal in this concept is a sine wave and it is always having less frequency than the carrier signal. The sine wave can be added with different sine waves and similar waves to generate modified sine waves, which in results gives concepts for other different Carrier based PWM methods. In all cases, carrier wave remains same. In this work five different types of carrier based PWM methods are summarized such as Sine Triangle PWM, Third Harmonic Injected PWM, Triplen Harmonic Injected & Bus Clamping 30^0 & 60^0 PWM techniques. The Bus Clamping concept is an advanced concept. The details of all these proposed techniques are discussed below.

B.Sine Triangle PWM:

In this method, sine wave is considered as modulating signal and compared with the triangular signal to produce pulse. This technique is the basic and the traditional technique of PWM techniques [15]. For three phase circuit, the modulating signal is generated by common mode addition to the sinusoidal signal. Figure 4 shows the basic of the sine triangle technique.

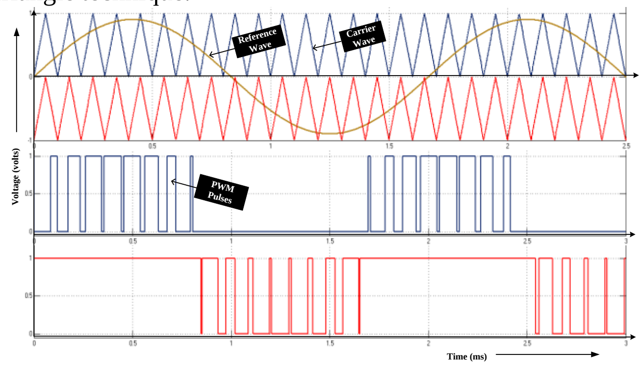

Fig.4: Sine-Triangle PWM

C.Third Harmonic Injected PWM (THI PWM):

In this method, injection of one sinusoidal signal with other is carried out and the result is matched with the triangular signal which produces pulse.

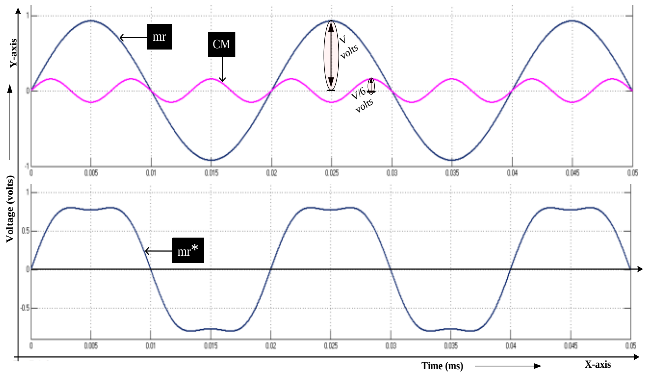

Fig.5: Third Harmonic Injected PWM

D.Triplen Injected PWM:

In this case, the sinusoidal modulating signal is injected with repeating signal having different magnitude and time period and compared with triangular wave to generate pulse.

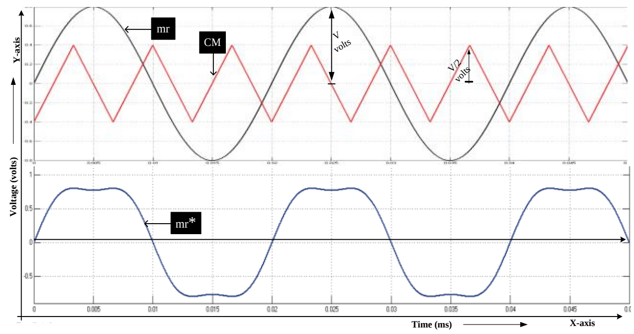

Fig.6: Triplen Injected PWM

V. RESULT ANAYSIS

Considering M-=1,VC= 1% of Vcripple ,We get
$L_1 = L_2 = 3.61*10^{-3}$ **H**, $C_1 = C_2 = 470*10^{-6}$ **F**

The input voltage of PV system = 60V, Duty cycle=0.173, Supply frequency f=50 Hz, Switching frequency f=1 KHz, Load Resistance=100 ohm, Load Inductance= 25 mH

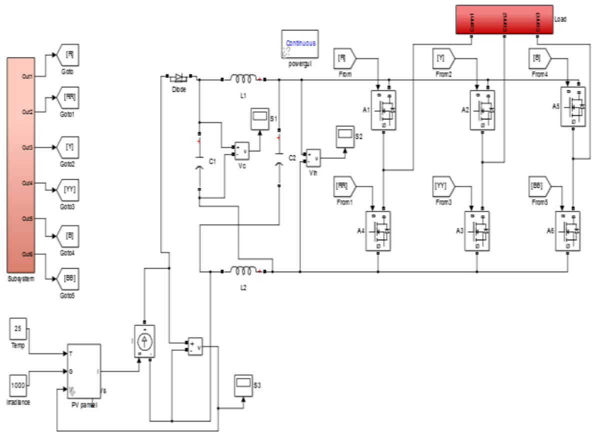

Fig 7 Simulink diagram of PV-ZSI topology

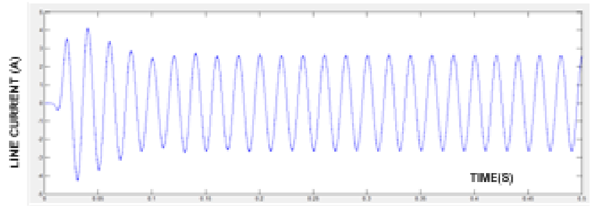

Fig 8: Line Current of PV-ZSI with STPWM

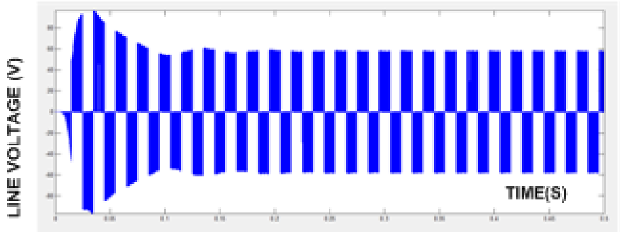

Fig 9: Line Voltage of PV-ZSI with STPWM

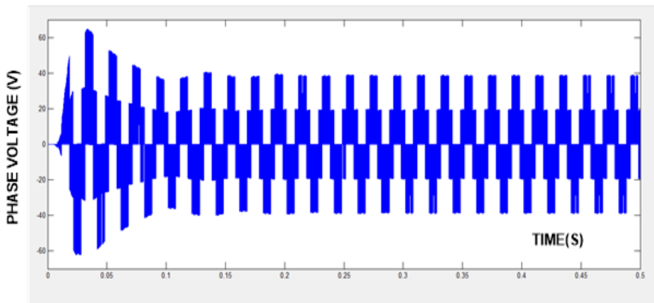

Fig 10.: Phase Voltage of PV-ZSI with STPWM

TABLE 1: PV Array integrated Carrier based simulation results of Conventional ZSI and PVZSI

M=1	Input Voltage(V)	$V_{Phase}(V)$	$V_{Line}(V)$	$I_{Line}(A)$
1. VSI	60	38.51	60.38	1.15
2. PV-ZSI	60	44.28	65.22	2.85

From the result analysis, it is clear that PV-ZSI gives more boosting than that of traditional VSI.

VI. HARDWARE IMPLEMENTATION OF PV-ZSI

The above method has been experimentally verified by using the various components shown in Fig 11.The components are PV Modules,Gate Drive circuit, Microcontrollers ,ZSI network(X-Shaped capacitor and inductor),VSI network, R Load, CRO.

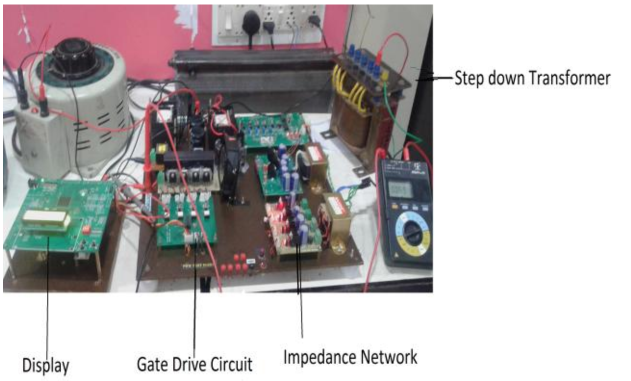

Fig 11. Hardware implementation of proposed system

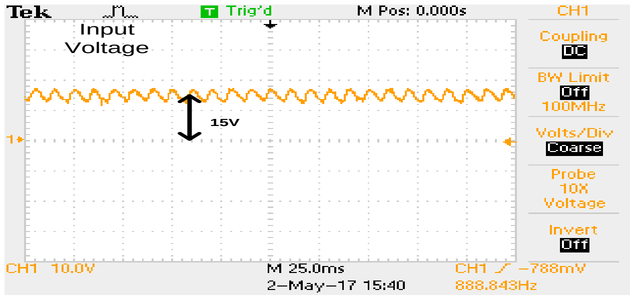

Fig 12. Input Voltage for PV-ZSI Topology

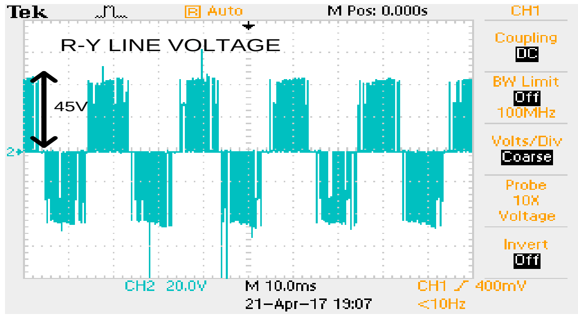

Fig 13. Line Voltage in R-Y Phase of PV-ZSI for R-Load

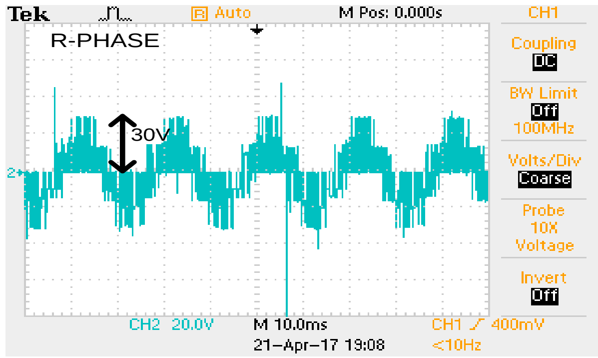

Fig 14. Phase Voltage in R-Phase of PV-ZSI for R-Load

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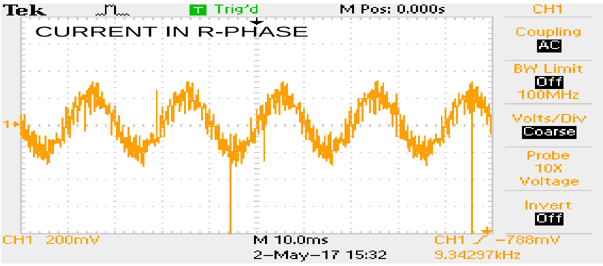

Fig 15.Load Current in R-Phase

VII. CONCLUSION

In this research work, the details of C-ZSI and PV-ZSI are discussed. Different types of PWM techniques and their implementation with ZSI are also studied. A comparative study of three Different types of PWM techniques(ST,THI,Triplen) are discussed. The details of proposed new topology of ZSI, which is PV-ZSI is also studied. The advantages of the new topology over VSI is discussed. Simulation studies of new topology with Sine triangle PWM techniques are done. The study for theoretical values of PV-ZSI is also done. The validation of theoretical study is validated with the hardware implementation.

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