

Improved DC utilization using advanced modulation techniques with Z source Inverter

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Abstract

Generally, an inverter is required to convert DC power generated by PV cell into AC power. A multilevel inverter (MLI) can synthesizes a staircase waveform. In this paper, a comparative study is made on performance of 5-level Z Source H Bridge inverter by considering advanced pulse width Modulation (PWM) strategies. PWM strategies of proposed ZSI's is quite similar to the traditional carried-based PWM control method, the only difference is that to turn null states into shoot through states and keep the active switching states unchanged, so that the reliability of the inverter is greatly improved because miss-gating can no longer destroy the circuit.

Keywords: Z source Inverter; PWM Schemes; Shoot Through; Photo voltaic

I. Introduction

Photovoltaic cells are static energy conversion devices, which converts the solar energy directly into DC electrical energy. Conventional Voltage Source Inverters and Current Source Inverters are used for AC machine drives applications. The AC drive system requires to operate the machine over a wide speed range. It is much preferable that the power converter should be capable of doing both buck-boost operations. The conventional inverter will suffers from following problems

- Limited output voltage
- Either Buck or Boost operation only
- Shoot-through or open circuit problem-reliability
- Not inter changeable main circuit
- Vulnerable to EMI noise
- Difficult to use IGBT module and IPM for I-source
- Start-up difficulty

All these drawbacks can be overcome by using ZSI [1], [2]

II. Z-SOURCE INVERTER

Fig. 1 presents the of basic Z source inverter (ZSI). In attribute from VSI and CSI inverters, on DC side of ZSI a diode D and impedance network in "X" shape is placed, composed of two capacitors C_1 and C_2 and two inductive chokes L_1 and L_2. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source & load. The diode D prevents prohibited reversed current flow. For this reason application of ZSI is possible only where there is no necessity of regeneration, further it is even prohibited in case of fuel cell or photo-voltaic cell. The ZSI provides unique features i.e., buck & boost, that cannot be observed in the traditional Voltage and current source converters where a capacitor and inductor are used, respectively.

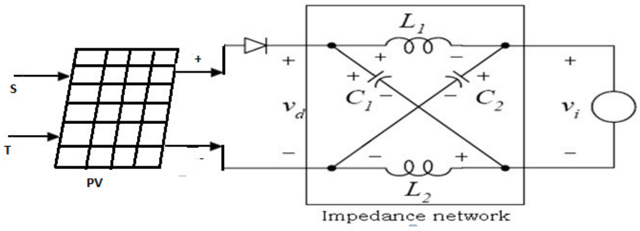

Fig.1: General Structure of ZSI with PV cell

The firing control of the Z-source inverter includes the shoot through states.
Features of Z-source inverter:

- Able to produce any desired output AC voltage, even greater than the line voltage regardless of the input voltage.
- Shoot through is allowable
- Able to provide ride-through during voltage sags without any additional energy storage elements.
- Immunity to EMI noise greatly increases reliability.
- Improve power factor and reduces harmonic current and common-mode voltage.

The ZSI will operate in three states: active state, zero-state and shoot-through state. In active mode (six states) and zero-state (null state) mode, the ZSI operates as traditional inverter. In the shoot-through mode, all the switches in one or two or three legs are turned on & the shoot-through state is forbidden in the traditional inverter. In shoot through mode the dc capacitor voltage can be boosted to the desired value. Assume the inductors (L1&L2) and capacitors (C1 & C2) have the same inductance and capacitance values. [2], [3], [4]
The equivalent circuit of ZSI's operating in null, active & shoot through state shown in Fig. 2, Fig. 3 & Fig. 4 respectively.

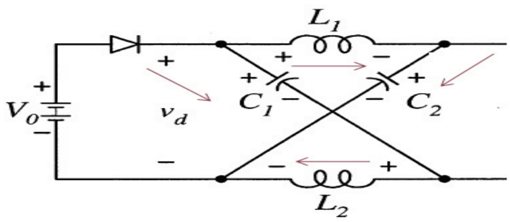

Fig.2: ZSI Equivalent circuit in null sates

The inverter is in one of the 2 traditional zero states shown in Fig.2 and the inductor current decreases to zero, thus a new operation mode appears. In this Mode, the diode stops conducting and the inverter is an open circuit i.e., Ii=0. The inductor current becomes zero and maintains zero until the next switching action. Therefore in this mode, the Z-source circuit is isolated from both the dc source and the load.

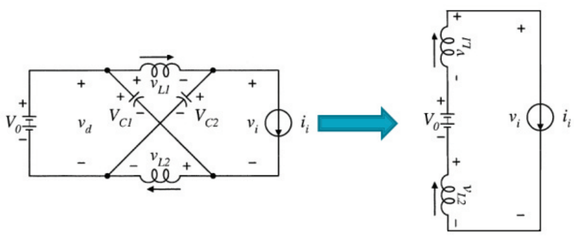

Fig.3: Approximate Equivalent circuit in active states

In active state the inverter will operate as normal inverter but input voltage to the inverter is boosted shown in Fig.3.

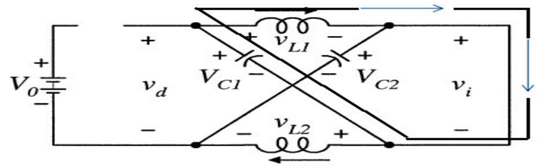

Fig.4: Equivalent circuit in shoot through state

The circuit is in a shoot-through zero state, the sum of the two capacitors voltage is greater than the dc source voltage ($V_{C1}+V_{C2} > V_0$), the diode is reverse biased, and the capacitors charge the inductors. The voltages across the inductors are: $V_{L1} = V_{C1}$ & $V_{L2} = V_{C2}$.
The inductor current increases linearly assuming the capacitor voltage is constant during this period. Because of the symmetry ($L_1=L_2=L$ and $C_1=C_2=C$) of the circuit, one has $V_{L1} = V_{L2} = V_L$, $I_{L1} = I_{L2} = I_L$, & $V_{C1} = V_{C2} = V_C$

III. Operating Principle & Control

When the dc voltage is high enough to generate the desired ac voltage, the traditional PWM can be used. While the dc voltage is not sufficient to directly generate a desired output voltage, a modified PWM controller is used so as to meet the requirement. A uniqueness of PWM control in ZSI is the ability of the shoot-through state to boost to a desired output voltage (greater than available dc-link voltage) and to buck the voltage under single stage process. PWM pulses can be generated by

1) Simple Boost PWM
2) Maximum Boost PWM
3) Maximum Constant PWM.

In this work the Simple boost control method is used to generate the shoot through states, Simple boost control utilizes two straight lines as shown in Fig. 5. Illustrate about the single phase configuration of H-Bridge inverter & simulated for three phase configuration. When the triangular carrier waveform is greater than the upper constant value or lower than the bottom constant value, the circuit turns into shoot-through state [6], [7], [8], [10] Otherwise it operates just as traditional carrier-based PWM. Fig. 5 shows the pulse generation for one phase switch. This method is very straightforward. In order to produce an output voltage that requires a high voltage gain, a small modulation index (*ma)* has to be used.

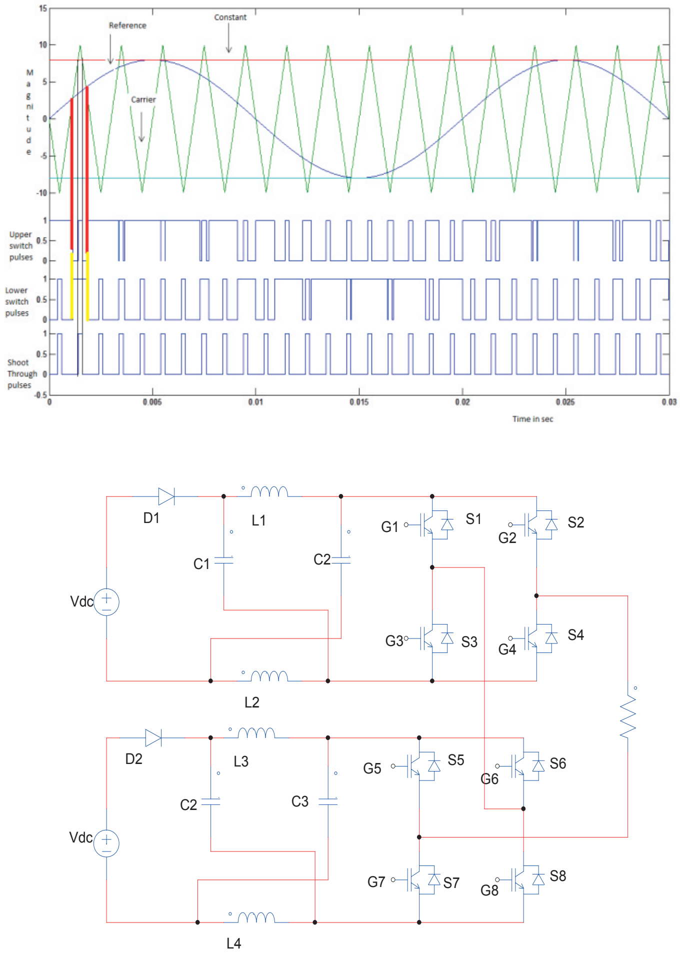

Fig.5: a. Pulses generation for ZSI b. ZSI H-Bridge Inverter

Shoot-through zero states are evenly allocated into each phase. That is, the active states are unchanged. However, the equivalent dc-link voltage to the inverter is boosted because of the shoot-through states.

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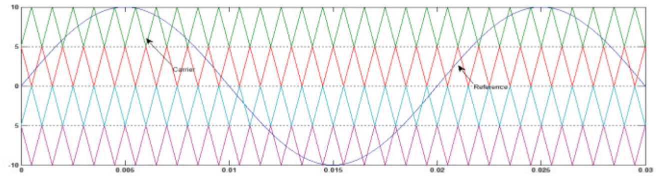

Fig.6: Pulse generation using alternate phase disposition

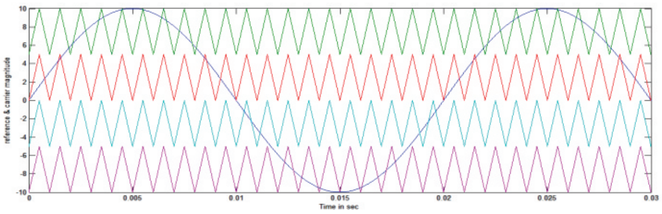

Fig.7: Pulse generation using phase disposition

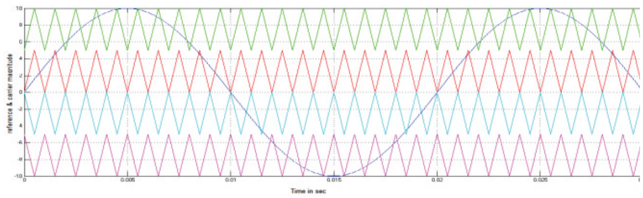

Fig.8: Pulse generation using phase opposition disposition

Fig. 6 to 8 shows the carrier & reference waveform for generating PWM pulses.

- ✓ Alternate phase disposition (APOD): Carrier waveform is in out of phase with its neighbor carrier by 180° shown in Fig.6.
- ✓ Phase disposition (PD) - All carrier waveforms are in phase shown in Fig.7.
- ✓ Phase opposition disposition (POD): All carrier waveforms above zero reference are in phase and are out of phase with those below zero reference by 180° shown in Fig.8.
- ✓ Fig. 9 shows the pulse generation for ZSI

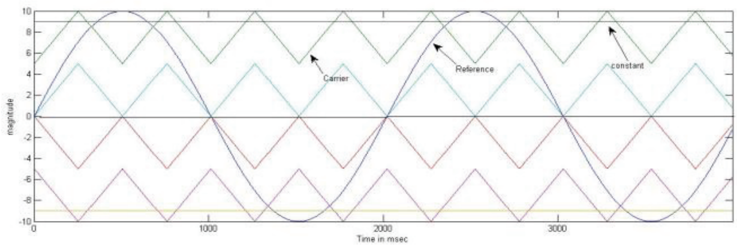

Fig.9: Pulse generation for ZSI by Phase opposing disposition

IV. MODELLING OF PV MODULE

The most commonly used model for PV-cell is one – diode equivalent circuit as shown in Fig.10. The shunt resistance R_{sh} is large, it is neglected. This simplified circuit is used in this paper for modelling of a PV-cell.

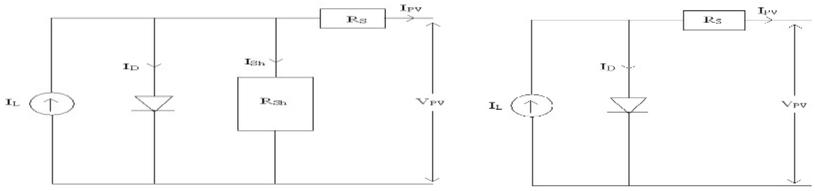

Fig10: One-diode equivalent circuit model for a PV cell. (a) Five parameters model; (b) Simplified four parameters model.

The non-linear of V_{pv}-I_{pv} and P-V curves are shown in Fig.11.

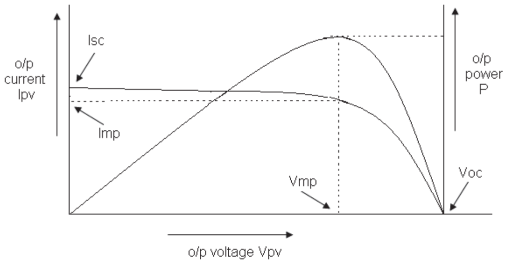

Fig11. V_{pv}-I_{pv} & P-V_{pv} characteristics of a PV cell

From Fig 10.b the relation between the output V_{pv} and the output current I_{pv} can be expressed as:

$$I_{PV} = I_L - I_D$$

$$I_{PV} = I_L - I_O\left(\exp\left(\frac{V_{PV} + I_{PV}R_S}{\propto}\right) - 1\right) \qquad (1)$$

Where I_L= Light current; I_o= Saturation current; R_s= Series Resistance; α = Thermal voltage timing completion factor.

The above four parameters are need to determined the I-V characteristics of PV-module. Thus, this model can be termed as Four-parameter model. The equations for determining the four parameters are given below:

4.1. *Light Current (I_L)*

$$I_L = \frac{G}{G_{ref}}\left(I_{Lref} + \mu_{Isc}(T_C - T_{Cref})\right) \qquad (2)$$

Where G=irradiance (W/m^2); G_{ref}= reference irradiance (200 W/m^2 is used in this study); I_{Lref}= light current at the reference condition (200 W/m^2 and 25 ˚C); Tc = PV cell temperature (˚C); T_{cref} = reference temperature (25 ˚C is used in this study); μ_{Isc} = temperature coefficient of the short-circuit current (A/˚C).

From the above equation for light current it can be observed that I_L is a function of both temperature and irradiance. Both I_{Lref} and μ_{Isc} can be obtained from manufacturer data sheet.

4.2. *Saturation Current (I_O)*

$$I_O = I_{Oref}\left(\frac{T_C + 273}{T_{Cref} + 273}\right)^3 \exp\left(\frac{e_{gap}q}{N_S \propto_{ref}}\left(1 - \frac{T_{Cref} + 273}{T_C + 273}\right)\right) \quad (3)$$

Where I_{oref}= saturation current at the reference condition (A); e_{gap} = band gap of the material 1.17 eV; N_S = number of cells in series of a PV module; q = charge of an electron (1.60217733×10^{-19} C); α_{ref} = the value of α at reference condition.

I_{oref} can be calculated as:

$$I_{Oref} = I_{Lref}\exp\left(-\frac{V_{OCref}}{\propto_{ref}}\right) \qquad (4)$$

Where V_{ocref} = the open circuit voltage of the PV module at reference condition (V).

4.3. *Calculation of α*

$$\propto = \frac{T_C + 273}{T_{Cref} + 273} \propto_{ref} \quad (5)$$

The value of α_{ref} can be calculated as:

$$\propto_{ref} = \frac{2V_{mpref} - V_{ocref}}{\frac{I_{scref}}{I_{scref} - I_{mpref}} + ln\left(1 - \frac{I_{mpref}}{I_{scref}}\right)} \quad (6)$$

Where V_{mpref} = maximum power point voltage at the reference condition (V);
I_{mpref} = maximum power point current at the reference condition (A);
I_{scref} = short circuit current at the reference condition (A).

4.4. *Series Resistance(R_S)*

Some manufacturers provide the value of R_S. If not provided, the following equation can be used to estimate its value:

$$R_S = \frac{\propto_{ref} ln\left(1 - \frac{I_{mpref}}{I_{scref}}\right) + V_{ocref} - V_{mpref}}{I_{mpref}} \quad (7)$$

R_S is taken as a constant in the model of this study.

4.5. *Thermal Model of PV*

From equations (1) to (7), it can be renowned that the temperature is acting an important role in the PV performance. Therefore, it is necessary to have a thermal model for a PV cell/module. In this study, a lumped thermal model is developed for the PV module. The temperature of the PV module varies with surrounding temperature, irradiance, and its output current and voltage, and can be written as:

$$C_{pv}\frac{dT_C}{dt} = K_{inpv}G - \frac{V_{pv}I_{pv}}{A} - K_{loss}(T_C - T_a) \quad (8)$$

C_{PV} = the overall heat capacity per unit area of the PV cell /module[J/(˚C-m^2)]; K_{inpv}= Transmittance-absorption product of PV cells; K_{loss} = overall heat loss coefficient[W/(˚C-m^2)];T_a=ambient temperature (˚C); A = effective area of the PV cell/module (m^2).

V. Simulation Results

The Z source network values for L & C is 1mh & 1600 µF respectively. The inputs to PV cell: temperature 25 °C, constant irradiance of 200 W/m^2 & produces a constant voltage of 79.12V. Input voltage to each H-Bridge inverter is output of PV i.e., 79.12V & switching frequency is 5 kHz. The complete system is simulated & results are presented.

The model I_{pv}-V_{pv} characteristic curves under different irradiances are shown in Fig.10 at 25 °C. It is noted, that the higher is the irradiance the larger are the short-circuit current (I_{sc}) and the open-circuit voltage (V_{oc}). Obviously, the larger will be the maximum power (P), shown in Fig.11.

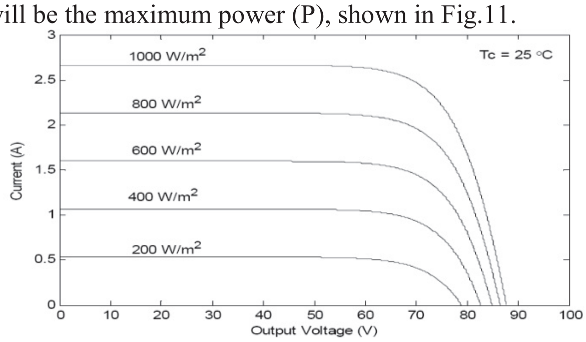

Fig.10: I_{PV}-V_{PV} characteristic curves of the PV model under different irradiances

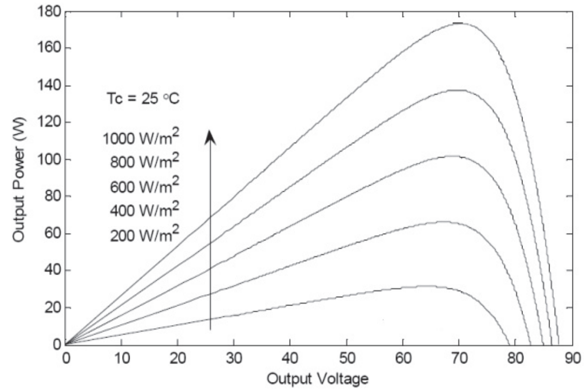

Fig. 11: P-V_{pv} characteristic curves of the PV model under different irradiances

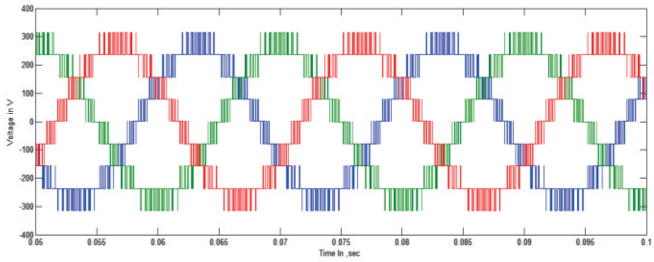

Fig.12. Output Line to Line voltage of Conventional H-Bridge Inverter

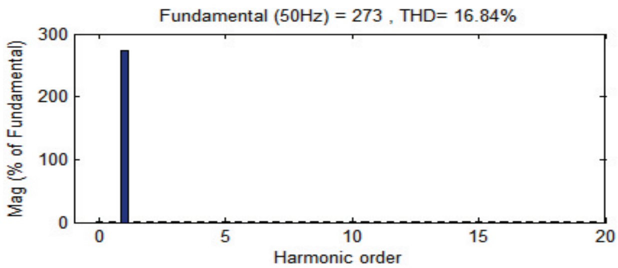

Fig.13: Spectrum analysis of line to line voltage of Conventional H-Bridge Inverter

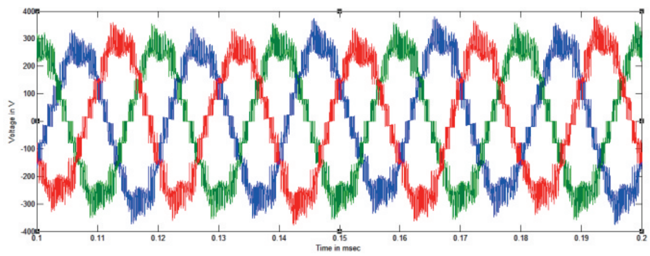

Fig.14: Line to Line voltage of ZSI H-Bridge with PD

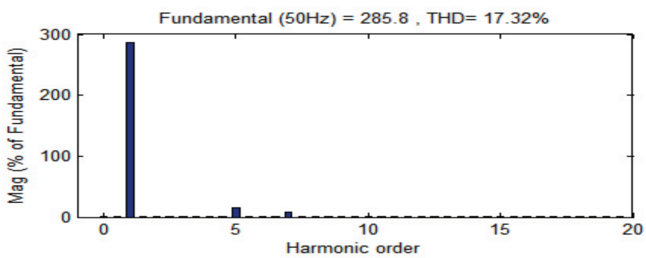

Fig.15: Spectrum analysis of line to line voltage of ZSI H-Bridge Inverter with PD

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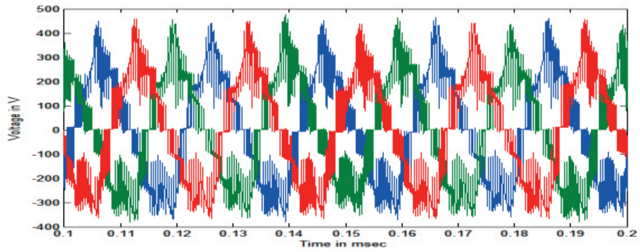

Fig.16: Line to Line voltage of ZSI H-Bridge with APOD

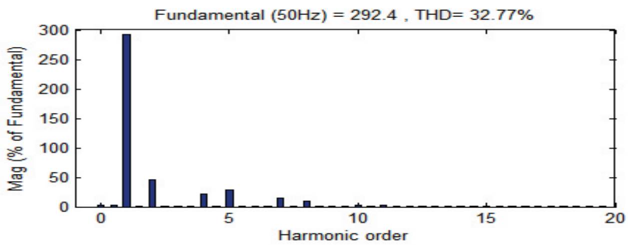

Fig.17: Spectrum analysis of line to line voltage of ZSI H-Bridge Inverter with APOD

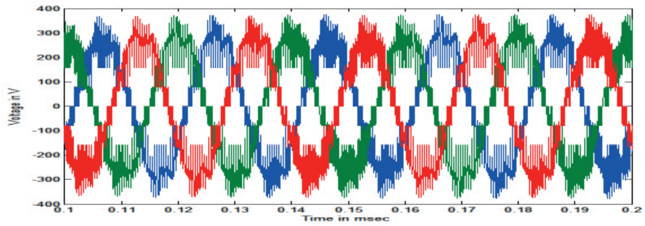

Fig.18: Line to Line voltage of ZSI H-Bridge with POD

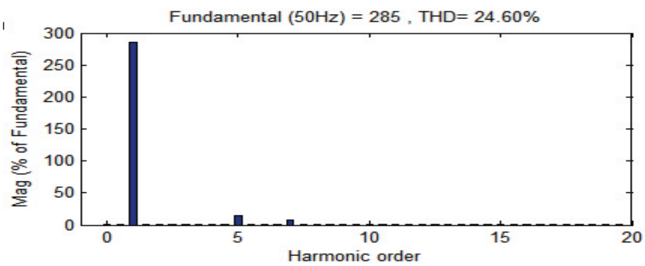

Fig.19: Spectrum analysis of line to line voltage of ZSI H-Bridge Inverter with POD

Table 1 shows the comparison results of the ZSI system by considering the Line to Line voltage. With constant PV output voltage of 79.12V with Boost factor (K) of 0.9. if K =1 ZSI operates as a normal inverter.

Table 1: Comparison of Output voltage (RMS) of the ZSI & Conventional Inverter with three PWM Technique

	PWM Technique	Fundamental Voltage	RMS output voltage	THD(%)
ZSI	PD	285.2	209	17.32
	POD	285	208.6	24.60
	APOD	292.4	215.8	32.77
Conventional	PD	273	195	16.84
	POD	273	197	21.48
	APOD	258.3	195	29.93

VI. Conclusion

From the results tabulated, the work carried out in this paper has the following conclusions

- ✓ In view of conventional & ZSI outputs, it is concluded that ZSI has good fundamental voltages at output.
- ✓ ZSI has good DC utilization using advanced modulation technique such as PD, POD & APOD
- ✓ APOD based ZSI has better DC utilization among other modulating techniques
- ✓ The better design values of Z-source i.e., L & C values will help to improve the system performance.

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