Simulation and Performance Analysis of a Novel Seven-Level Inverter with DC-DC Converter for Photovoltaic System

Dr.R.Seyezhai, P.Vaishnavi

***Abstract*— This paper deals with simulation of PV based single-phase seven level inverter employing maximum power point tracking algorithm. Incremental conductance (INC)is employed in this work because it has high tracking accuracy at steady state and good adaptability to the rapidly changing atmosphere. A novel dual carrier PWM is employed for the proposed inverter. A detailed study of PV based seven level inverter is carried out in MATLAB/SIMULINK and the performance parameters such as crest factor, peak to average ratio, weighted THD, harmonic spread factor and Distortion factor of the proposed inverter are computed and the results are verified.**

***Index Terms*— Maximum Power Point Tracking, Incremental Conductance, Photovoltaic systems, Pulse Width Modulation.**

I. INTRODUCTION

The extensive use of fossil fuels has been resulted in the global problem of green house emissions. Moreover, as the supplies of fossil fuels are depleted in the future, they will become increasing expensively. Thus, solar energy is becoming more important since it produces less pollution and cost of fossil fuel energy is rising, while the cost of solar energy is decreasing [1]. The MPPT is necessary for any solar systems need to extract maximum power from PV module. It forces PV module to operate at close to maximum power operation point to draw maximum available power. Compared with other methods Incremental conductance has a good tracking performance in case of environmental changing. This paper focuses on a seven level cascaded H-bridge inverter with fewer number of dc sources which overcomes the disadvantages of the conventional MLI. The proposed inverter has reduced dc sources and power electronic switches it reduces the switching losses of the inverter. Moreover, this paper proposes a new hybrid modulation technique employing dual carrier signal in order to obtain a reduced THD.

II. MODELING OF PV

A.Equivalent circuit:

A PV module consist of a number of solar cells connected in series and parallel to obtain the desired voltage and current levels. The model of PV cell consist of an ideal current source in parallel with an ideal diode. The current source I_{ph} represents the cell photo current. R_{sh} and R_s are the intrinsic shunt and series resistance of the cell respectively. The value of R_{sh} is very large compared with the R_s. This model is known as single diode model of a PV cell[2].

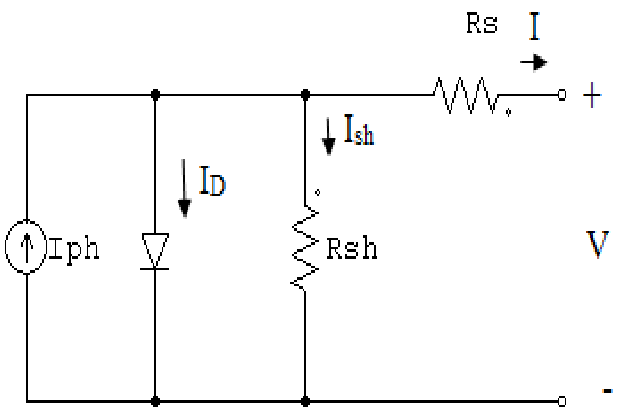

Fig.1.PV equivalent circuit

The output current from the PV cell is calculated by applying KCL

$$I = I_{ph} - I_D \tag{1}$$

I is the output current, I_{ph} is photon current, I_D is diode current. The ideal diode equation is

$$I_D = I_S \left(\frac{qV_d}{KT} - 1\right) \tag{2}$$

I_s is saturation current, q is electron charge, k is Boltzman constant, T is the actual temperature. substitute Equation(2) in (1)we get Equation (3). The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as

$$I_{ph} = \left[I_{scr} + K_i(T - 298) \times \frac{\lambda}{1000}\right] \tag{3}$$

I_{sc} is the cell's short-circuit current, K_i is the cell's short-circuit current temperature coefficient, T is the solar cell's actual temperature, and λ is the solar insolation. The reverse saturation current is

$$I_{rs} = \frac{I_{scr}}{\left[e\left(\frac{qV_{oc}}{N_s KAT}\right) - 1\right]} \tag{4}$$

where I_{scr} the reverse saturation current, V_{oc} is the open circuit voltage, N_s is the number of cells connected in series, A is the ideality factor. The module saturation current I_s varies with the cell temperature, which is described by

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$$I_s = I_{rs}[\frac{T}{T_r}]^3 e^{\left[\frac{qE_{go}}{Bk(\frac{1}{T_r}-\frac{1}{T})}\right]} \quad (5)$$

where I_s is the saturation current, E_g is the band-gap energy of the semiconductor used in the cell, T_r is the reference temperature. The current output of the PV module is

$$I_{pv} = N_p \times I_{ph} - N_p \times I_s[e^{\left\{\frac{q(V_{pv}+I_{pv}R_s)}{N_s AKT}\right\}}-1] \quad (6)$$

Using the above equations simulink modeling is done.

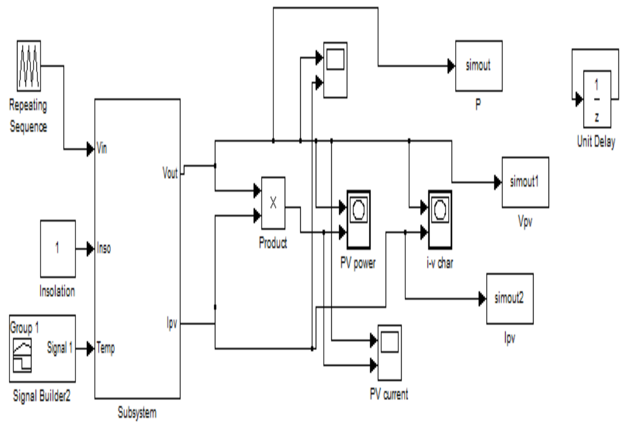

Fig. 2.Simulink model of PV

Table 1.Electrical Characteristics data of 100W PV Module

Rated power	**100W**
Voltage at Maximum power (V_{mp})	17.53 V
Current at Maximum power (I_{mp})	5.43A
Open circuit voltage (V_{OC})	21.16V
Short circuit current (I_{scr})	5.87 A
Total number of cells in series (N_S)	36
Total number of cells in parallel (N_P)	1

I-V and P-V characteristics under varying irradiation with constant temperature are obtained as shown in Figs 3&4. I-V and P-V characteristics under varying temperature with constant irradiation are obtained as shown in Figs 5 & 6.

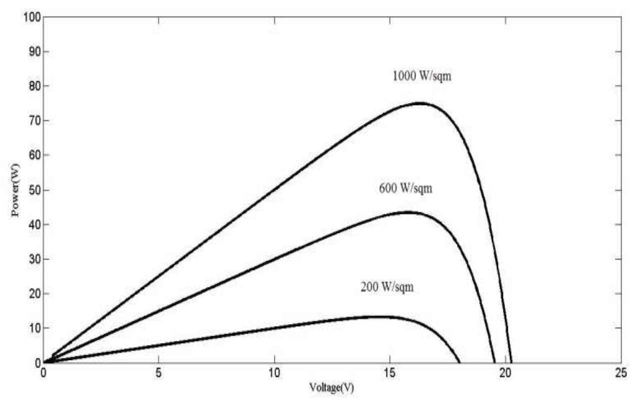

Fig. 3. PV characteristics with varying irradiation

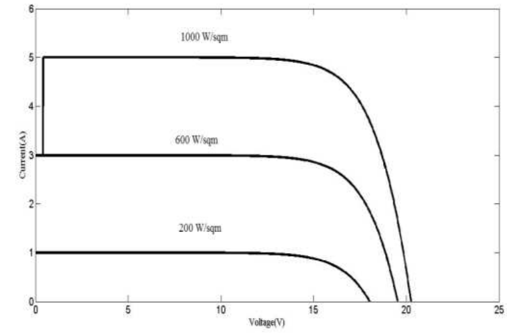

Fig. 4.VI characteristics with varying irradiation

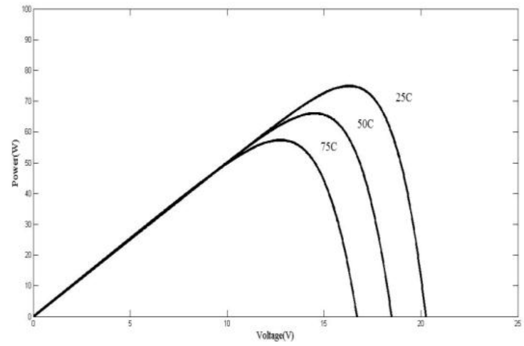

Fig. 5. PV characteristics with varying temperature

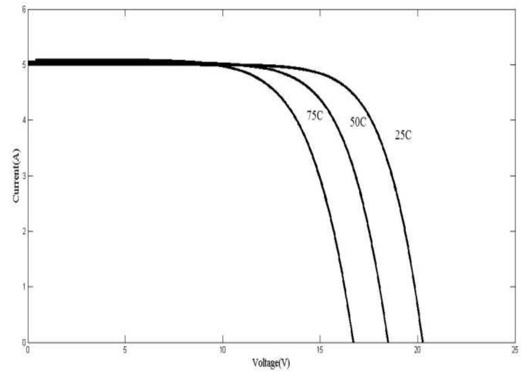

Fig. 6. VI characteristics with varying temperature

III. MAXIMUM POWER POINT TRACKING

The overall block diagram of PV based inverter and MPPT is shown in Fig. 7. A typical solar panel converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel[3].

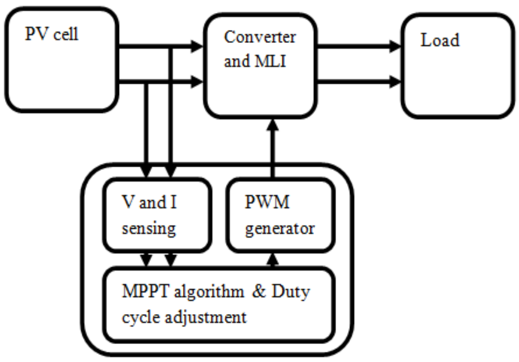

Fig. 7.Overall block diagram of PV based MLI with MPPT

Usually, the INC MPPT algorithm as shown in Fig. 8, uses a fixed iteration step size, which is calculated by the accuracy and tracking speed requirement. It produces a more oscillations. To solve these problems, a modified INC MPPT with variable step size is proposed in this paper. The duty cycle is automatically tuned according to the inherent PV cell characteristics. If the operating point is far from MPP, it increases the duty cycle which enables a fast tracking ability. If the operating point is near to the MPP, it decrease the duty cycle so that the oscillations are well reduced, it improves the efficiency. Incremental conductance method uses voltage and current sensors to sense the output voltage and current of the PV cell. At MPP the slope of the PV curve is equal to zero[4].

$$\frac{dI}{dV} = -\frac{I}{V} \quad \left(\frac{dP}{dV} = 0\right) \tag{7}$$

when equation(9) is satisfied the maximum power point is reached.

$$\frac{dI}{dV} > -\frac{I}{V} \quad \left(\frac{dP}{dV} > 0\right) \tag{8}$$

$$\frac{dI}{dV} < -\frac{I}{V} \quad \left(\frac{dP}{dV} < 0\right) \tag{9}$$

Equations (8 & 9) are used to direction in which a perturbation must occur to move the operating point toward the maximum power point and the perturbation is repeated until maximum power point is reached.

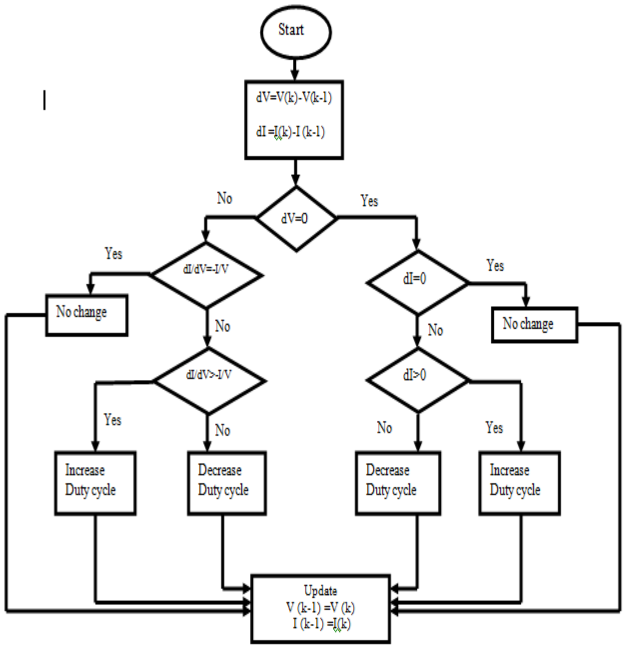

Fig. 8. Flow chart for Incremental Conductance Algorithm

The output of the MPPT is taken as V_m and it is converted into sinusoidal reference waveform by using this equation,V_m sinωt and the triangular signal is compared with sinusoidal reference signal and pulses are generated and it is given to the MLI and the simulink model is shown in Fig. 9.

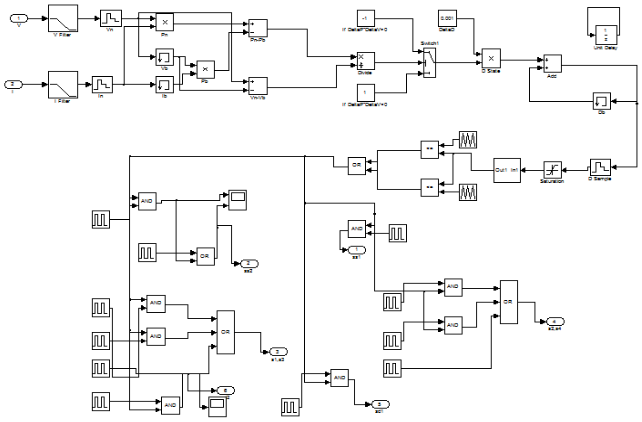

Fig. 9. Simulink model of MPPT

IV. PROPOSED SEVEN LEVEL INVERTER

Fig. 10 shows a seven level inverter together with dc-dc power converter. The proposed system consist of new seven level inverter and DC/DC power converter. The DC/DC power converter consists of DC/DC boost converter and current fed forward converter. DC/DC power converter is used to convert the dc voltage into two independent voltage sources. The new seven-level inverter is composed of capacitor selection circuit and full bridge converter. The capacitor selection circuit and full bridge converter converts two independent three level dc voltage and the full bridge converter converts the three-level dc voltage into seven level ac voltage [5].

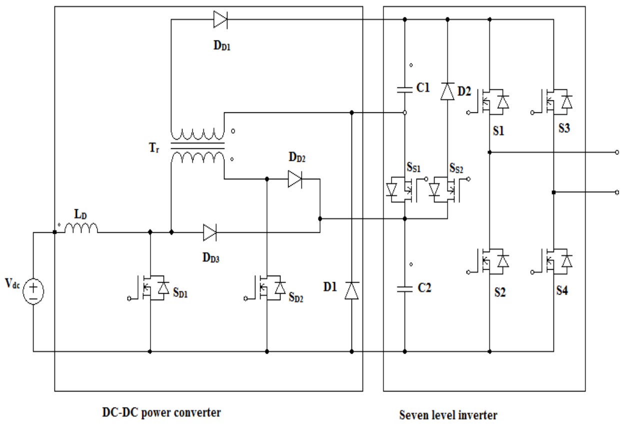

Fig. 10 . Seven level inverter together with DC-DC power converter

DC-DC power converter is composed of boost converter and current fed forward converter with turns-ratio of 2:1.Fig 2 shows the operation of DC-DC power converter. When switch S_{D1} is turned ON, boost converter charges the capacitor C_2 of the new seven level inverter. When switch S_{D1} is turned OFF and S_{D2} is turned ON , the current fed forward converter charges the C_1 of the new seven level inverter.

The voltage across the C_2 is

$$V_{c2} = \frac{1}{1-D} V_s \tag{10}$$

The voltage across the C_1 is

$$V_{c1} = \frac{1}{2(1-D)} V_s \tag{11}$$

All switches are operated in fundamental frequency. The circuit operation is explained as follows. The circuit operation of seven level inverter classified as 8 modes. Positive and negative half cycles have four modes each.

Mode 1: In this mode, switches S_1 and S_4 conducts, switches S_{S1} and S_{S2} are turned off. The capacitor C_1 discharges through the diode D_1 so the output voltage of the inverter is $V_{dc}/3$.

Mode 2: In this mode, switches S_{S2}, S_1 and S_4 conducts, switch S_{S1} is turned off. The capacitor C_2 discharges through the diode D_2 so the output voltage of the inverter is $2V_{dc}/3$.

Mode 3: In this mode, switches S_{S1}, S_{S2}, S_1 and S_4 conducts, both the capacitors C_1 and C_2 discharges through the diode D_1 and D_2 so the output voltage of the inverter is V_{dc}.

Mode 4: In this mode, switches S_2 and S_4 conducts, other switches are turned off. So the output voltage of the inverter is zero.

Mode 5: In this mode, switches S_2 and S_3 conducts, switches S_{S1} and S_{S2} are turned off. The capacitor C_1 discharges through the diode D_1, so the output voltage of the inverter is $-V_{dc}/3$.

Mode 6: In this mode, switches S_{S2}, S_2 and S_3 conducts, switch S_{S1} is turned off. The capacitor C_2 discharges through the diode D_2 so the output voltage of the inverter is $-2V_{dc}/3$.

Mode 7: In this mode, switches S_{S1}, S_{S2}, S_2 and S_3 conducts, both the capacitors C_1 and C_2 discharges through the diode D_1 and D_2 so the output voltage of the inverter is $-V_{dc}$.

Mode 8: In this mode, switches S_2 and S_4 conducts, other switches are turned off. So the output voltage of the inverter is zero[5].

V. PWM TECHNIQUE

In MLI, seven-level output voltage is obtained by different combination of conduction state of six switches. The gating pulse for these switches are given by using hybrid modulation which is the combination of fundamental frequency modulation (FPWM) and sinusoidal PWM. In the sinusoidal PWM, Dual Carrier Modulation of MLI is employed.The output is obtained with reduction in switching loss from FPWM and good harmonic reduction from SPWM.

A) Dual Carrier Modulation for MLI

The triangular signal is compared with sinusoidal reference signal and pulses are generated whenever the amplitude of the reference signal is higher than the carrier signal. Switches S_{D1},S_{D2} will be switched at fundamental frequency and switches S_{S1},S_{S2},S_1,S_2, S_3,S_4 are switched at high carrier frequency. The amplitude and frequency modulation ratio is defined as,Amplitude modulation (m_a) ratio is expressed as,

$$m_a=\frac{\text{Amplitude of Vref}}{\text{Amplitude of Vcarrier}} \tag{12}$$

Frequency modulation ratio (m_f) can be expressed as,

$$m_f=\frac{f_s}{f_1} \tag{13}$$

where, f_s is PWM frequency and f_1 is fundamental frequency. m_f should be an odd integer, otherwise DC component may exist and even harmonics will be present at the output voltage Fig. 11 shows the carrier and reference waveform for dual carrier modulation technique.

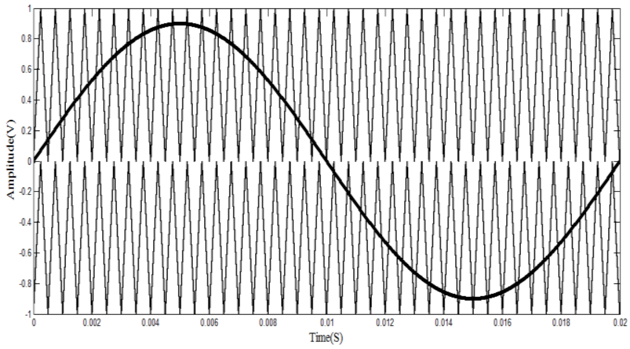

Fig. 11.Dual carrier modulation of MLI

VI. SIMULATION RESULTS

Simulation was performed in MATLAB SIMULINK to verify that the proposed inverter topology for PV system which is shown in Fig. 12 and the simulation parameters are shown in Table 2.

Table 2.Simulation parameters

Parameters	Specification
DC-DC Power Converter	
Input voltage(V_{dc})	20 V
Inductor(L)	1mH
f	50Hz
Seven Level Inverter	
Capacitor C_1,C_2	500mF
Resistor r_1,r_2	0.01Ω
Load(R)	50Ω

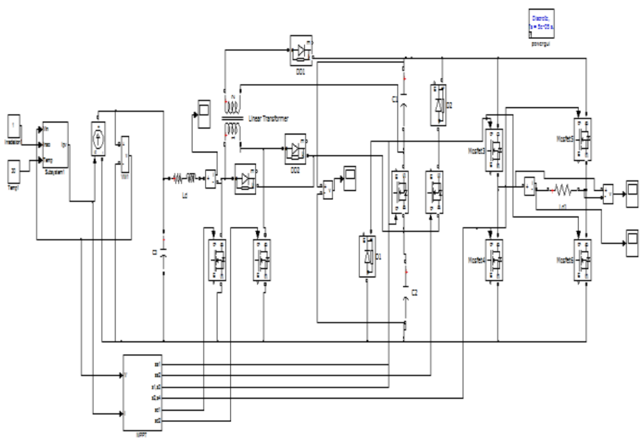

Fig. 12. Simulink model for PV based MLI with MPPT

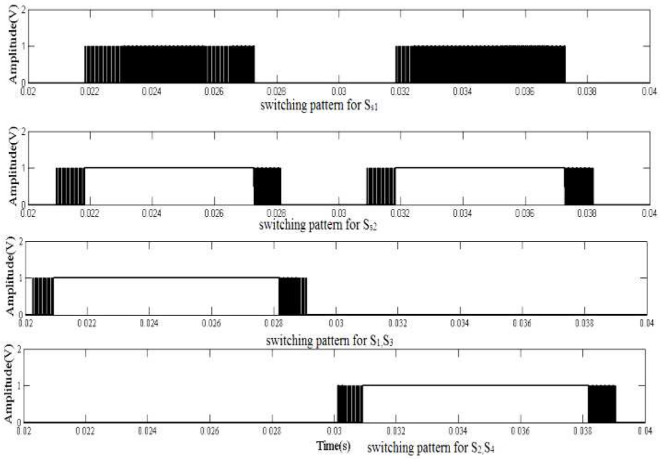

Fig. 13. Switching pattern for seven level inverter

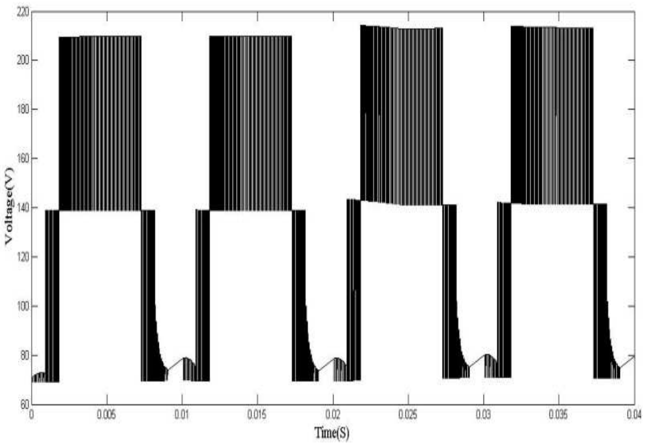

Fig. 14.Output voltage of capacitor selection circuit

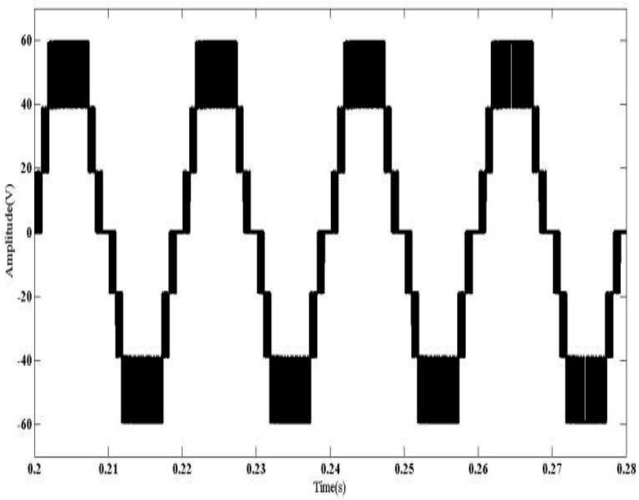

Fig. 15.Output voltage waveform for PV based MLI with MPPT

Fig. 13 shows PWM switching pattern for single phase seven level inverter. Fig. 14 shows the output voltage waveform of capacitor selection circuit. Fig. 15 shows output waveform of the proposed single phase PV based seven-level inverter with MPPT. The FFT spectrum of the load voltage is found using the FFT analysis tool is shown in Fig..

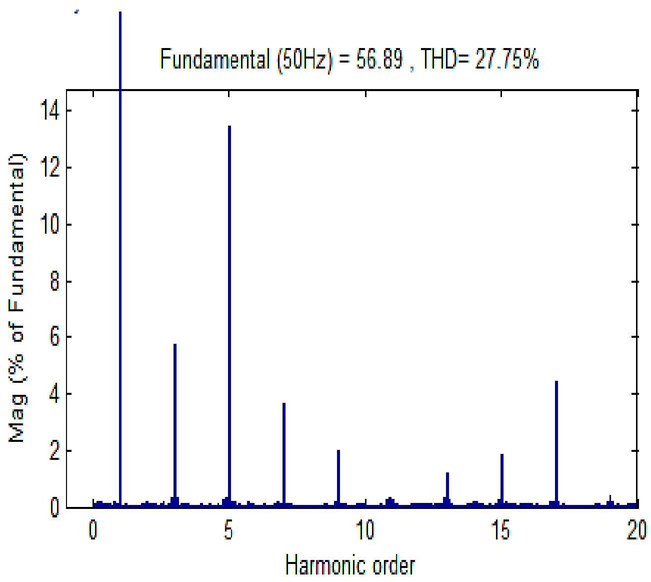

Fig. 16.FFT analysis of load voltage of seven level inverter

VII. CALCULATION OF PERFORMANCE PARAMETER

A.Crest Factor:-

Crest factor is a measure of a waveform, such as alternating current or sound, showing the ratio of peak values to the average value. In other words, crest factor indicates how extreme the peaks are in a waveform.

$$C.F = \frac{V_{peak}}{V_{rms}} \tag{14}$$

B.PAPR:-

The peak-to-average power ratio (PAPR) is a related measure that is defined as the peak amplitude squared (giving the peak power) divided by the RMS value squared (giving the averagepower).

$$PAPR = \frac{{V_{peak}}^2}{{V_{rms}}^2} \tag{15}$$

C.Distortion factor:-

The distortion factor is the result from a mathematical equation. The equation is resembles the geometrical means. It is a measure for the intensity of the nonlinear distortions.

$$D.F = \frac{1}{V_1}\left[\sum_{n=2,3,....}^{\infty}\left(\frac{V_n}{n^2}\right)^2\right]^{1/2} \tag{16}$$

V_1 – Fundamental voltage
V_{on} – total Harmonics voltage

D.WTHD:-

The weighted total harmonic distortion (WTHD) is a commonly used expression to assess the quality of pulse width modulated (PWM) inverter waveforms. The WTHD weights the voltage harmonics inversely with its frequency. While this is adequate for some inductor type loads, the commonly employed induction motor load has important effects resulting from eddy currents in the rotor bars not incorporated in the WTHD.

$$WTHD = \frac{\sqrt{\sum_{n=2}^{\infty}\left(\frac{V_n}{n}\right)^2}}{V_1} \tag{17}$$

E.Harmonic Spread Factor:-

Harmonic Spread Factor is one of the deciding factors to indicate noise generation in the motor. The harmonic spread factor can be calculated for evaluating the quality of voltage spectra of inverters.

$$HSF = \sqrt{\frac{1}{N}\sum_{j=2}^{N}\left(H_j - H_0\right)^2} \tag{18}$$

H_j = V alue of jth harmonic
H_0 = Average value of all N Harmonics

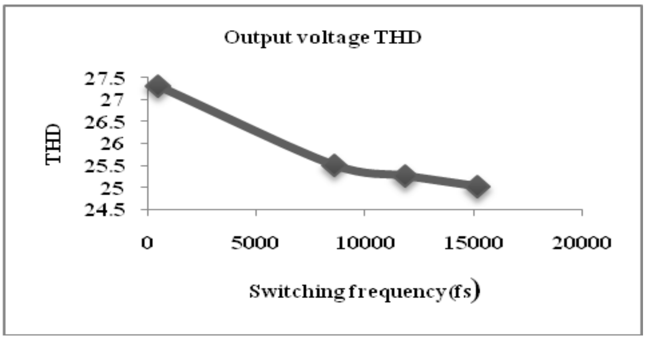

Fig. 17.Switching Frequency Vs THD for PV based Dual carrier PWM

The THD values for the seven level inverter with PV based Dual carrier PWM was around 27.75% for $m_a = 0.8$.

Table 3.PARAMETER VALUES

Parameters	Calculated Values
Crest factor	1.414
PAPR	1.999
Distortion factor	0.8796%
Weighted THD	3.4%
Harmonic spread factor	2.3806

The THD value of PV based MPPT for single- phase seven level inverter is calculated theoretically as well as by simulation and the results are verified.

Table 4. THD VALUES

Methods	THD (%)
Theoretical value	17.2%
Simulation	16.61%

VIII. CONCLUSION

This paper has presented a single- phase seven level inverter for PV application. A dual carrier modulation technique has been proposed for the multilevel inverter. The circuit topology, modulation strategy and the operating principle of the proposed inverter has been analyzed.The inverter has been simulated using PV as a source. Using incremental conductance algorithm, maximum power point has been tracked. The performance parameters are computed. From the FFT analysis, it is observed that THD is less for the proposed dual carrier PWM technique and therefore, multilevel inverter is a suitable topology for photovoltaic applications.

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