

**PERFORMANCE ANALYSIS OF MAXIMUM POWER POINT TRACKING  
(MPPT)ALGORITHM FOR A SINGLE-PHASE FIVE-LEVEL PWM INVERTER  
CONNECTED PV SYSTEM****Amit Kumar Sharma\* , Ravinder Singh Chauhan, Gaurav Rajoria**Department of Electrical Engineering, Govt. Women Engineering College Ajmer, India  
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**ABSTRACT**

This paper attempts an in-depth analysis of maximum power point tracking (MPPT) algorithm for a single-phase five-level PWM inverter connected PV system. The MPPT technique considered in proposed work is Perturb & Observe (P & O). The simulation carried out for PV array cascaded with boost converter. In this paper, five level inverter designs was discussed in detail, relevant waveforms are presented and analysis. From this analysis, it can be conducted that five level inverter offer low THD, lower switching frequency and high efficiency, but in past work three level inverter output waveform provides an High switching frequency. In future, we use renewable energy source instead of ac source.

**KEYWORDS:** MPPT, Five-level, PWM inverter, PV System, Converter

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**INTRODUCTION**

Photovoltaic power generation is the world's fastest growing high-tech in the 20th century. The increasing of the world energy demand, due to the modern industrial society and population growth, is motivating many investments in alternative energy solutions, in order to improve energy efficiency and power quality issues. The use of photovoltaic energy is considered to be a primary resource, because there are several countries located in tropical and temperate regions, where the direct solar density may reach up to 1000W/m. At present, photovoltaic (PV) generation is assuming increased importance as a renewable energy sources application because of distinctive advantages such as simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts. The cell conversion ranges vary from 12% of efficiency up to a maximum of 29% for very expensive units. In spite of those facts, there has been a trend in price decreasing for modern power electronics systems and photovoltaic cells, indicating good promises for new installations.

However, the disadvantage is that photovoltaic generation is intermittent, depending upon weather conditions. Thus, MPPT makes the PV system providing its maximum power and that energy storage element is necessary to help get stable and reliable power from PV system for both loads and utility grid, and thus improve both steady and dynamic behaviors of the whole generation system.

In the proposed work, one MPPT algorithms viz. Perturb and Observe (PO) analyzed and implemented for PV array. Thereafter, PV array connected to a boost converter to optimize the PV output and DC/AC inverter (five-level multi-level) to convert the DC output voltage of the solar modules into the AC system. The results of MPPT algorithm responses compared for grid connected PV array. In addition, performance analysis of PV array with MPP tracking done in terms of voltage response, current response and power response using the input parameters, temperature and solar radiation obtained from reference data sheet. The proposed model, the entire components and control systems simulated under MATLAB/Simulink.

### MPPT TECHNIQUES

Tracking of the maximum power point of a photovoltaic array is usually an essential part of PV systems. In general, PV generation systems have two major problems; the conversion efficiency of electric power generation is low (in general less than 17%, especially under low irradiation conditions), and the amount of electric power generated by solar arrays changes continuously with weather conditions. Moreover, the solar cell (current – voltage) characteristic is nonlinear and varies with irradiation and temperature. There is a unique point on the I-V or PV curve of the solar array called MPP, at which the entire PV system (array, converter, etc.) operates with maximum efficiency and produces its maximum output power. The location of the MPP is not known, but can be located, either through calculation models, or by search algorithms. Therefore, MPPT techniques needed to maintain the PV array operating point at its MPP. The two most popular techniques for extracting power for PV system discussed in the next sub-topic.

#### Perturb and Observe

Perturb and Observe (PO) method, also known as perturbation method, is the most commonly used MPPT algorithm in commercial PV products. This is essentially a “trial and error” method. The PV controller increases the reference for the inverter output power by a small amount, and then detects the actual output power. If the output power is indeed increased, it will increase again until the output power starts to decrease, at which the controller decreases the reference to avoid collapse of the PV output due to the non-linear PV characteristic.

Although the PO algorithm is easy to implement, it has a number of problems, including PV system cannot always operate at the maximum power point due to the error process, and thus solar energy from the PV arrays not fully utilized. PV system may always operate in an oscillating mode even with a steady condition, leading to fluctuating inverter output.

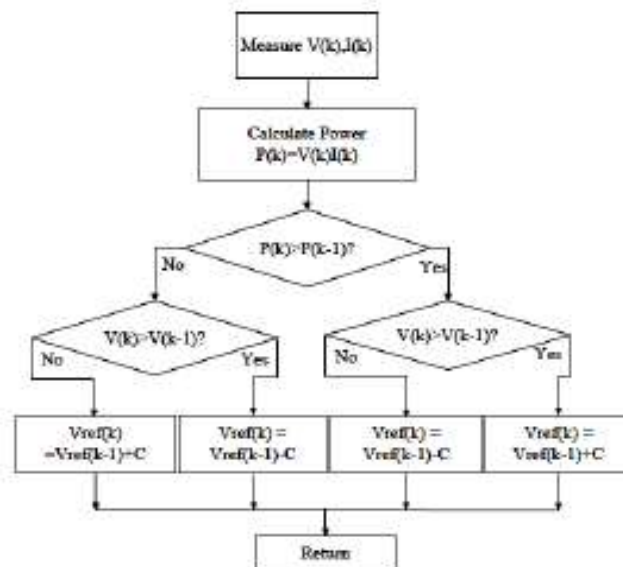


Figure 1. Perturb & Observe Flowchart

### SINGLE PHASE FIVE LEVEL PWM INVERTER

A single-phase five-level PWM inverter whose output voltage has five values: zero, half and full supply dc voltage levels (positive and negative, respectively), so called a five level single phase PWM inverter. Single-phase inverters adopt the full-bridge type using approximation sinusoidal modulation technique as the power circuits. The output voltage of them has three values: zero, positive and negative supply dc voltage levels. Therefore, the harmonic components of their output voltage are determined by the carrier frequency and switching functions. Moreover, the harmonic reduction of them is limited to a certain degree

Figure below shows a configuration of the proposed single-phase five level PWM inverter. One switching element and four diodes added in the conventional full-bridge inverter are connected to the center-tap of dc power supply. Proper switching control of the auxiliary switch can generate half level of dc supply voltage. The proposed single-phase five-level PWM inverter various steps of operation.

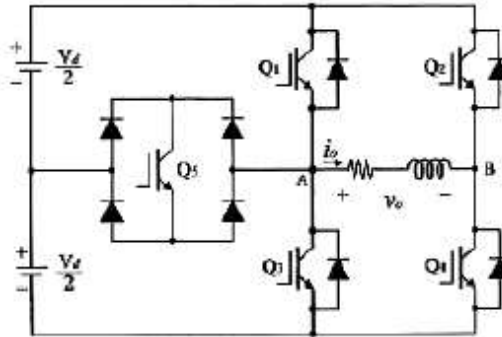


Figure 2. Configuration of the proposed Single-phase Five Level PWM Inverter

**Output Voltage According to the switch On-Off condition**

**Table 1. Output Voltage According to the Switch On-Off condition**

On Switches	Node A Voltage	Node B Voltage	Output Voltage (V <sub>AB</sub> - V <sub>o</sub> )
Q <sub>1</sub> , Q <sub>4</sub>	V <sub>d</sub>	0	+V <sub>d</sub>
Q <sub>5</sub> , Q <sub>4</sub>	V <sub>d/2</sub>	0	+V <sub>d/2</sub>
(Q <sub>3</sub> , Q <sub>4</sub> ) OR (Q <sub>1</sub> , Q <sub>2</sub> )	0(V <sub>d</sub> )	0(V <sub>d</sub> )	0
Q <sub>2</sub> , Q <sub>5</sub>	0	V <sub>d/2</sub>	-V <sub>d/2</sub>
Q <sub>2</sub> , Q <sub>3</sub>	0	V <sub>d</sub>	-V <sub>d</sub>

In this state V<sub>o</sub> = -V<sub>d</sub>

i<sub>o</sub> = Negative (-)

Figure Operational states according to the switch on off conditions and the direction of load current. (a) State 1: V<sub>o</sub> = V<sub>d</sub>, i<sub>o</sub> = (+). (b) State 2: V<sub>o</sub> = -V<sub>d</sub>, i<sub>o</sub> = (-). (c) State 3: V<sub>o</sub> = -V<sub>d/2</sub>, i<sub>o</sub> = (+). (d) State 4: V<sub>o</sub> = -V<sub>d/2</sub>, i<sub>o</sub> = (-). (e) State 5: V<sub>o</sub> = 0, i<sub>o</sub> = (+). (f) State 6: V<sub>o</sub> = 0, i<sub>o</sub> = (-). (g) State 7: V<sub>o</sub> = -V<sub>d/2</sub>, i<sub>o</sub> = (+). (h) State 8: V<sub>o</sub> = -V<sub>d/2</sub>, i<sub>o</sub> = (-). (i) State 9: V<sub>o</sub> = -V<sub>d</sub>, i<sub>o</sub> = (+). (j) State 10: V<sub>o</sub> = -V<sub>d</sub>, i<sub>o</sub> = (-). Operational states of the conventional inverter are shown in Fig.4.2 (a), (b), (e), (f), (i), and (j) in sequence, and additional states in the proposed inverter synthesizing half level of dc bus voltage are shown in Fig.2 (c), (d), (g), and (h). The additional switch Q<sub>5</sub> must be properly switched considering the direction of load current. Basic principle of the proposed switching strategy is to generate gate signals by comparing the reference signal with the two carrier waves having same frequency and in phase, but different offset voltages. Largely, there are two switching methods according to the output voltage levels. If the required output voltage for a certain load can be produced using only the half of dc bus voltage, only the lower carrier wave is compared with the reference signal the lower dc bus voltage is used to generate the output voltage. Namely, the modulation index is equal or less than 0.5, the behavior of proposed inverter is similar to the conventional full-bridge three-level PWM inverter, and the distribution of harmonic components in output voltage is similar to that of the conventional inverter having the values of two times the modulation index. The mentioned above is the first operational mode. On the other hand, if the required output voltage is increased beyond the modulation index 0.5, it comes into the second mode using the upper bank of capacitor. In this case, the switching

function produced by upper carrier wave is prior to that of the lower. According to the amplitude of the voltage reference, the operational interval of each mode varies within a certain period. The modes are separated as

$$\text{Mode A: } 0 < \omega t \leq \theta_1, \quad \theta_2 < \omega t < \pi$$

$$\text{Mode B: } \theta_1 < \omega t \leq \theta_2$$

$$\text{Mode C: } \pi < \omega t \leq \theta_3, \quad \theta_4 < \omega t < 2\pi$$

$$\text{Mode D: } \theta_3 < \omega t \leq \theta_4 \quad (1)$$

The Phase angle depends on the modulation index  $M_a$ . The modulation index of the proposed five-level PWM inverter is defined as [5]

$$M_a = \frac{A_M}{2A_c} \quad (2)$$

$$\text{Modulation index} = \frac{\text{Peak value of reference signal}}{\text{Peak value of carrier signal}}$$

Where  $A_M$  is the peak value of voltage reference  $V_{ref}$ , and  $A_c$  is peak-to-peak value of carrier. When the modulation index is less than 0.5, the phase angle displacement is equal to

$$\theta_1 = \theta_2 = \frac{\pi}{2},$$

$$\theta_3 = \theta_4 = \frac{3\pi}{2} \quad (3)$$

On the other hand, when the modulation index is greater than 0.5, the phase angle displacement is determined by

$$\theta_1 = \sin^{-1}\left(\frac{A_c}{A_M}\right)$$

$$\theta_2 = \pi - \theta_1$$

$$\theta_3 = \pi + \theta_1$$

$$\theta_4 = 2\pi - \theta_1 \quad (4)$$

The control signals are generated by the signals  $C_A$  and  $C_B$  come from the comparators, which compare the respective carrier signals with the voltage reference, the gate signals  $Q_1$ –  $Q_5$  are produced by the phase angle displacement. The switching functions of proposed inverter are then given by the use of logical AND, OR, NOT gates.

$$Q_1 = \overline{C_A} * P_2 + \overline{C_B} * P_4 + \overline{C_B} * P_6$$

$$Q_2 = P_4 + P_5 + P_6$$

$$Q_3 = \overline{C_B} * P_2 + \overline{C_B} * P_3 + \overline{C_A} * P_5$$

$$Q_4 = P_1 + P_2 + P_3$$

$$Q_5 = C_B * P_1 + C_A * C_B * P_2 + C_B * P_3 + C_B * P_4 + C_B * C_A * P_5 + C_B * P_6 \quad (5)$$

The harmonic components of output voltages in the proposed and the conventional inverter will be presented in the following. From the two carrier waves and output voltage, the analysis of harmonic components in the proposed

inverter can be performed. The output voltage produced by comparisons of the reference signal and two carrier waves can be expressed as

$$V_o(\theta) = A_0 + \sum_{n=1}^{\infty} (A_n \cos n\theta + B_n \sin n\theta) \quad (6)$$

If there are P pulses per a quarter periods, and it is an odd number, the coefficients  $B_n$  and  $A_0$  would be a zero where an even number is. Therefore, the equation (6) can be rewritten as

$$V_o(\theta) = \sum_{n=1,3,\dots}^{\infty} A_n \cos n\theta \quad (7)$$

$$A_n = -\frac{2V_{dc}}{n\pi} \sum_{m=0}^P \sum_{i=1}^4 [(-1)^{\text{int}(i/2)} \sin(n\alpha_{m+i})] \quad (8)$$

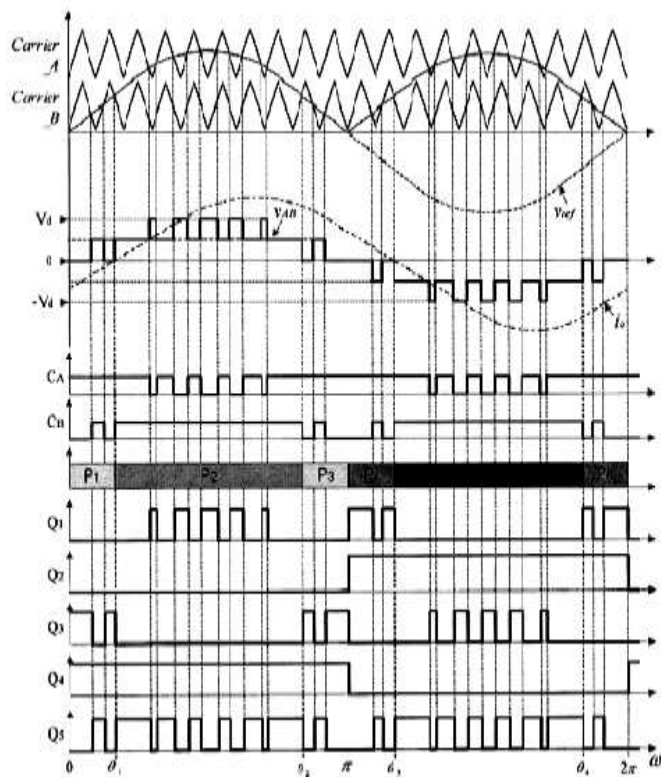
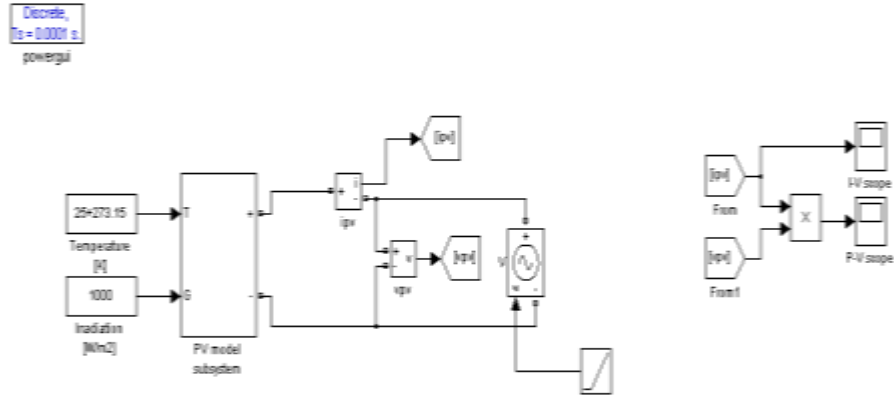


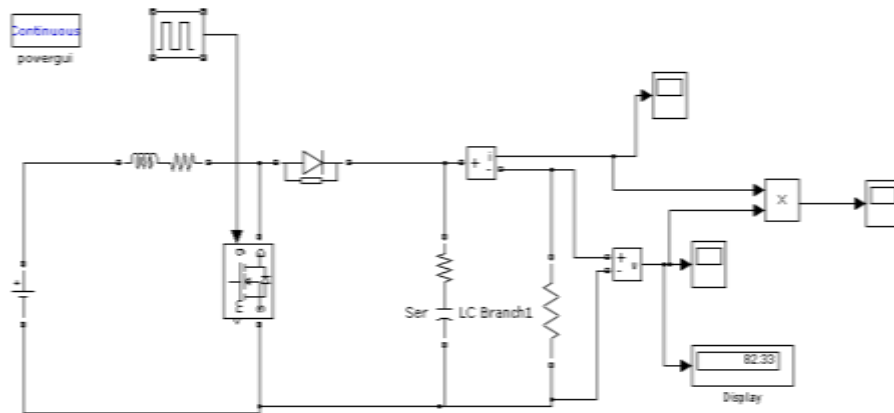
Figure 3. Switching patterns of the Proposed Single-Phase Five-Level PWM Inverter

**MODELING AND SIMULATION RESULTS**  
**PV Array Circuitry**



*Figure 4. Final PV Array Circuitry*

Fig. 4 depicts the circuitry model of PV array with considering shunt resistance and series resistance. Input to the temperature and insolation provided. In addition, provision of adding no. of cell and module provided.



*Figure 5. Simulink Model of Boost Converter*

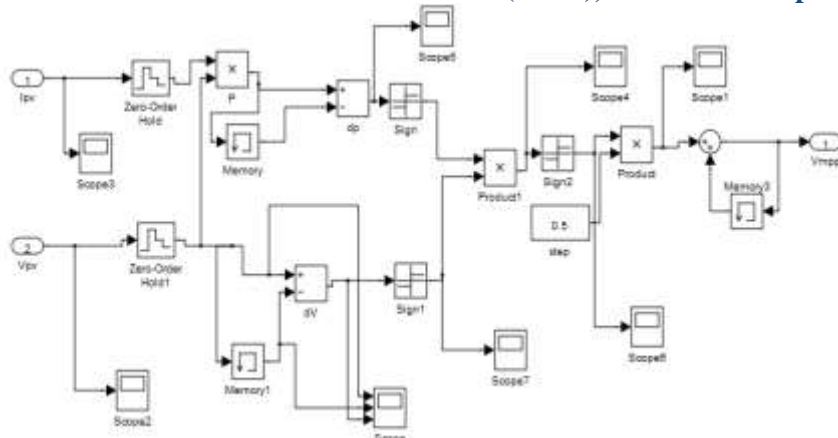


Figure 6. Simulink Model of Perturb & Observe

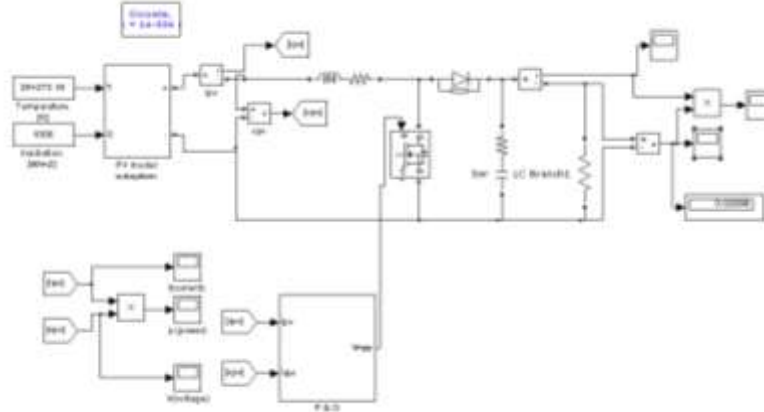


Figure 7. Simulink Model of PV Array with Boost Converter & PO Algorithm

**Simulation Results**

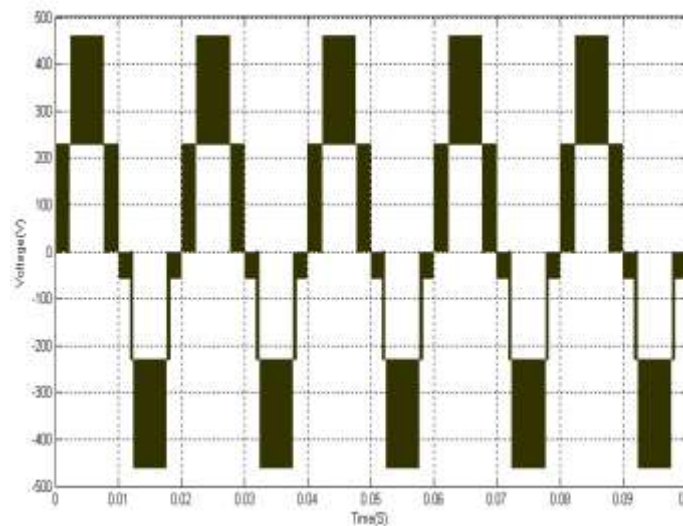


Figure 8. Inverter output voltage with Boost Converter, PO Algorithm

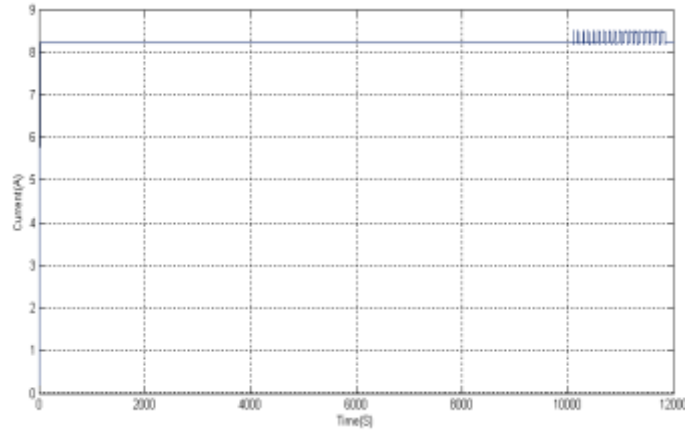


Figure 9. PV Current response with Boost Converter, PO algorithm & Single-phase reduced Switch Count Five Level inverter

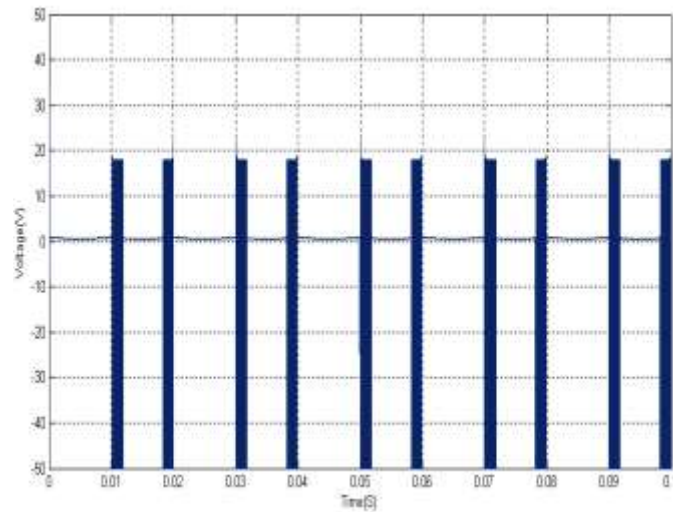


Figure 10. PV Voltage response with Boost Converter, PO algorithm & Single-phase reduced Switch Count Five Level inverter

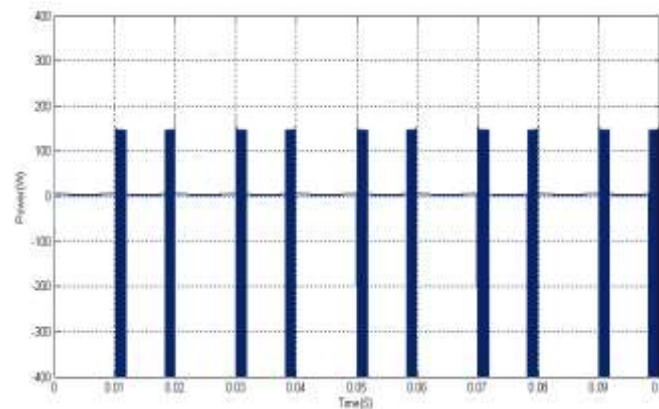


Figure 11. PV Power response with Boost Converter, PO algorithm & Single-phase reduced Switch Count Five Level inverter

## CONCLUSION

In the proposed paper, five-level with reduced switch count inverter is discussed in detail, relevant waveforms are presented and analyzed. Therefore two capacitors with equal capacitance rating are used. In Single-phase reduced






switch count five-level PWM Inverter utilizes two carrier signal and one reference signal to generate switching signal. By controlling the modulation index, the desired number of levels of the inverter's output can be achieved. From this analysis, it can be concluded that five-level with reduced switch count PWM inverter offer's low THD, lower switching frequency and higher efficiency.

## REFERENCES

- [1] Yuncong J., Qahouq Jaber A. A., and Orabi M., "Matlab / Pspice Hybrid Simulation of Solar PV Cell / Module", *Proc. of IEEE international Conference on Power Electronic Conference and Exposition (APEC)*, USA, pp. 1244-1250, 2011.
- [2] Ramazan B., Illami C., Orhan K., and Celal C. "Matlab / GUI Based Simulation for Photovoltaic System", *Proc. of IEEE International Conference on Power Engineering, Energy and Electrical Drives, Torremolinos (Malaga)*, Spain, May 2011.
- [3] Bhuvaneshwari G., Annamalai R., "Development of a Solar Cell Model in MATLAB for PV Based Generation System", *Indian Conference (INDICON)*, Hyderabad, pp. 1-5, 2011.
- [4] Jenifer A., Newlin Nishia R., Rohini G., and Jamuna V., "Development of MATLAB Simulink Model for Photovoltaic Array", *Proc. of IEEE International Conference on Computing, Electronics and Electrical Technologies*, Kumara Coil, Tamil Nadu, pp. 436-442, 2012.
- [5] Karthik P., Sesham H., and Hrisheeksha P. N., "Simulation & Performance Analysis of Renewable based Standalone System for Smart Mini Grid Applications", *Proc. of IEEE International Conference on Advances in Engineering, Science and Management*, Nagapattinam, Tamil Nadu, pp. 600-605, March 2012.
- [6] Eidelloth S., Haase F. and Brendel R., "Simulation tool for Equivalent Circuit Modeling of Photovoltaic Devices", *IEEE Journal of Photovoltaic's*, Vol.- 2, no.- 4, pp. 572-579, October 2012.
- [7] Michel E. R, Gonalez S., "Development of MATLAB / Simulink Model of a Single – Phase Grid Connected Photovoltaic System", *IEEE Transaction on Energy Conversion*, Vol.- 24, pp. 1-8, March 2009.
- [8] Namin M. H., Afsharnia S., "Grid Connected PV with MPPT Techniques Implemented in Real Case Study of Variable Radiation", *Pro. of IEEE International Conference on Control and Modeling for Power Electronic*, Zurich, Switzerland, 2009.
- [9] Youjie M., Deshu C., Xuesong Z., and Runrui G., "MPPT Control of Photovoltaic System based on Hybrid Modeling and its Simulation", *Proc. of International Conference on Sustainable Power Generation and Supply*, Nanjing, China, pp. 1-5, 2011.
- [10] Youjie M., Deshu C., Xuesong Z., and Runrui G., "Hybrid Modeling & Simulation for the Boost in PV System", *Proc. of IEEE 2nd International Conference on Information and Computing*, Manchester, England, pp. 85 – 87, May 2009.

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