International Journal of Emerging Engineering Research and Technology
Volume 5, Issue 7, 2017, PP 17-29
ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)

Effect of MPPT Techniques on the THD Value of Five-Level Cascaded H-Bridge Converter for Photovoltaic Application

Bal Mukund Sharma[1], Dr Kuldeep Sahay[2]

[1]*Department of Electrical Engineering, Dr. A.P.J. Abdul Kalam Technical University, India*

[2]*Department of Electrical Engineering, Institute of Engineering and Technology, UP, India*

***Corresponding Author:** Bal Mukund Sharma, Department of Electrical Engineering, Dr. A.P.J. Abdul Kalam Technical University, India*

Received Date: 08-11-2017 ***Accepted Date: 13-11-2017*** ***Published Date: 16-11-2017***

ABSTRACT

This paper presents the performance comparison of a Five-level cascaded H-bridge converter photovoltaic inverter topology with a novel Sinusoidal Pulse Width Modulated(SPWM) control scheme employing perturb and observe Maximum Power Point Tracking (MPPT) algorithm and incremental conductance MPPT algorithm. The new SPWM is implemented with two reference signals that were identical to each other with an offset that was equivalent to the amplitude of the triangular carrier signal were used to generate PWM signals for the inverter switches. The performance comparison of proposed system is verified through simulation model. The total harmonic distortion (THD) of inverter is reduced from 39% to 28% and operates at better power factor under rapidly changing atmospheric condition with incremental conductance MPPT algorithm compared to perturb and observe MPPT method. In photovoltaic (PV) power systems where a set of series-connected PV arrays (PVAs) is connected to a conventional Five-level inverter, the occurrence of partial shades and/or the mismatching of PVAs leads to a reduction of the power generated from its potential maximum. To overcome these problems, the connection of the PVAs to a Five-level cascaded H-bridge converter is considered in this paper. A control and pulse width-modulation scheme is proposed, capable of independently controlling the operating voltage of each PVA. Compared to a conventional Five-level inverter system, the proposed system configuration allows one to extract maximum power, to reduce the devices voltage rating (with the subsequent benefits in device-performance characteristics), to reduce the output-voltage distortion, and to increase the system efficiency.

Keywords: *Five-level cascade H-bridge Multilevel inverters, photovoltaic (PV) power systems, power conversion, pulse-width modulation technique.*

INTRODUCTION

The advent of high power electronic modules has encouraged the use of more dc transmission and made the prospects of interfacing dc power sources such as photovoltaic and fuel cells. The shortage of fossil fuels and environmental problems caused by conventional energy sources increased the demand for renewable energy significantly over the years.

The solar and wind energy have become very popular and demanding compared with other types of renewable energy sources because of the advancement in power electronics techniques. Multilevel inverter structures have been developed to overcome shortcomings in solid-state switching device ratings so that they can be applied to high-voltage electrical systems. The general function of multilevel inverter is to synthesize a desired ac voltage from several levels of dc voltages. For this reason multilevel inverters are ideal for connecting either in series or in parallel to the ac grid with renewable energy sources like photovoltaic or with energy storage devices such as capacitors and batteries. Additional applications of multilevel inverters include adjustable speed drives, static var compensation.

Photovoltaic (PV) sources are used today in many applications as they have the advantages of being maintenance and pollution free. PV inverter is used to convert dc power obtained from PV modules into ac power to be fed into the grid. Improving the output waveform of the inverter reduces its respective harmonic content and, hence, the size of the filter used and the level of Electromagnetic Interference (EMI) generated by switching operation of the inverter[1]. This paper proposes a single-phase multi string five-level inverter topology with perturb and observe Maximum Power Point Tracking (MPPT) algorithm and incremental conductance MPPT algorithm.

The circuit consists of strings of PV arrays connected to their own dc–dc boost converter. An auxiliary circuit comprising four diodes and a switch is configured together with a conventional full-bridge inverter to form this topology. A novel PWM control scheme is introduced to generate switching signals for the switches and to produce five output-voltage levels: zero, $+1/2V_{dc}$, V_{dc}, $-1/2V_{dc}$, and $-V_{dc}$ (assuming that V_{dc} is the supply voltage).

This inverter topology uses two reference signals instead of one to generate PWM signals for the switches. Both reference signals V_{ref1} and V_{ref2} are identical to each other, except for an offset value that is equivalent to the amplitude of carrier signal $V_{carrier}$. The comparison studies of proposed inverter configuration with perturb and observe MPPT and incremental conductance MPPT algorithm is verified through MATLAB simulation model.

SYSTEM CONFIGURATION

The system configuration for the topic is as shown figure 1. Here the PV array is a combination of series and parallel solar cells. This array develops the power from the solar energy directly and it will be changes by depending up on the temperature and solar irradiances[2].

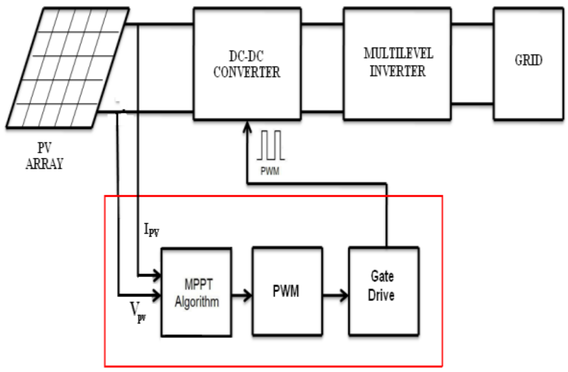

Figure1. *System configuration of pv system.*

So we are controlling this to maintain maximum power at output side we are boosting the voltage by controlling the current of array with the use of PI controller. By depending upon the boost converter output voltage this AC voltage may be changes and finally it connects to the utility grid that is nothing but of a load for various applications. Here we are using Five-level H-Bridge Cascade multilevel inverter to obtain AC output voltage from the DC boost output voltage.

PROPOSED MPPT ALGORITHM FOR PHOTOVOLTAIC SYSTEM

Modeling of Solar PV Module

In electrical terminology Modeling of Photovoltaic cell means representing with its equivalent circuit. PV cell can be represented in three equivalent circuits.

A solar cell can be operated at any point along its characteristic current-voltage cure, as shown in figure 2. Two important points on this curve are the open circuit voltage (V_{oc}) and short-circuit current (Isc). The open-circuit voltage is the maximum voltage at zero current, where as the short-circuit current is the maximum current at zero voltage [3].

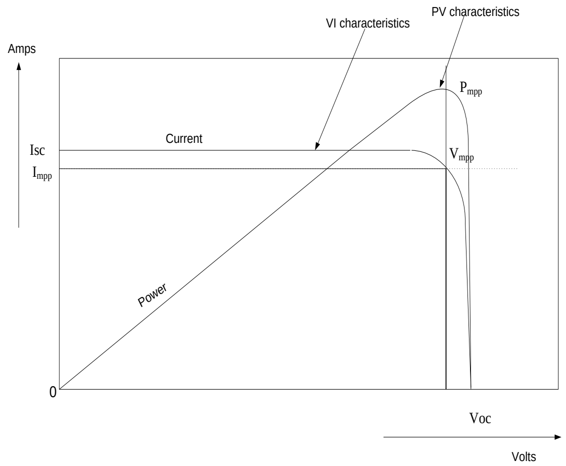

Figure2. *Photovoltaic characteristics.*

A plot of power (P) against voltage (V) for this device shows that there is a unique point on the I-V curve at which the solar cell will generate maximum power. This is known as the maximum power point (V_{mpp}, I_{mpp}).

Because a silicon solar cells typically produce only about 0.5V. A number of cells are connected in series in a PV module. A panel is a collection of modules physically and electrically grouped together on a support structure. An array is a collection of panels.

Model I

In model I the PV cell is represented with a current source in parallel with a diode. The current source generated the photo current I_{ph}, which is directly proportional to the solar irradiance E. The p-n transition area of the solar cell is equivalent to a big diode which is also integrated in the picture [4].

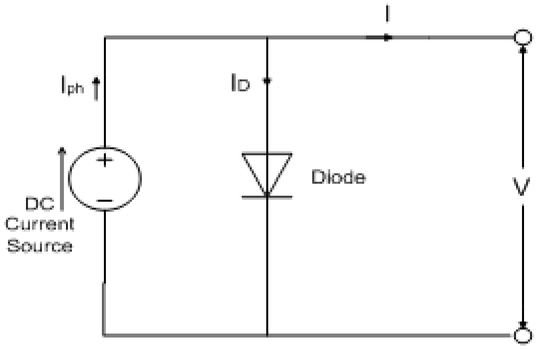

Figure3. *PV ideal model.*

The V-I equation of the simplified equivalent circuit could be derived from Kirchhoff's current law.

$$I = I_{ph} - I_D = I_{ph} - I_S \times \left(\exp\left(\frac{V}{m.v_T}\right) - 1\right)$$
(1)

With

I_{ph} = Photo current

I_D = Diode current

I_S = diode reverse saturation current

m = Diode "ideality factor" m=1…..5

v_T = Thermal Voltage v_T= (k.T/e)

k = constant of Boltzmann k= 1.380658*10^{-23} Jk^{-1}

T = absolute temperature, [T] =K (Kelvin)

E = charge of an electron e=1.6021733*10^{-19}

Model II

As mention above, the simplified equivalent circuit doesn't give an optimal representation of the electrical process at the solar cell. At real solar cells a voltage loss on the way to the external contacts could be observed. This voltage loss could be expressed by a series resistor, R_s. Furthermore leakage currents could be observed, which could be described by a parallel resistor, R_p

Derived from Kirchhoff's first law the equation for the extended I-V curve is achieved.

$$0 = I_{ph} - I_D - I_P - I$$

With $I_p = \frac{V_D}{R_P} = \frac{V + I \cdot R_s}{R_P}$ follows

$$0 = I_{ph} - I_s \cdot \left(\exp\left(\frac{V + I \cdot R_s}{m \cdot V_T}\right) - 1\right) - \left(\frac{V + I.R_s}{R_p}\right) - I$$

$$\Rightarrow I = I_{ph} - I_s \cdot \left(\exp\left(\frac{V + I \cdot R_s}{m \cdot V_T}\right) - 1\right) - \left(\frac{V + I.R_s}{R_p}\right) \quad (2)$$

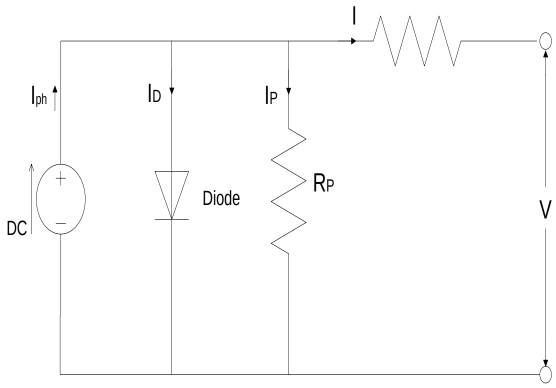

Figure4. *PV real model.*

MPPT Algorithm Implementation

Tracking the maximum power point of a photovoltaic array is usually an essential part of a PV system. The problem considered by MPPT techniques is to automatically find the voltage VMPP or current IMPP at which a PV array should operate to obtain the maximum power output PMPP under a given temperature and irradiance.

Here we implement Perturb and observe (P&O) MPPT method and Incremental conductance MPPT method. In Perturb and observe (P&O) method the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases[5]. It is referred to as a *hill climbing* method, because it depends on the rise of the curve of power against voltage below the maximum power point, and the fall above that point. In the incremental conductance method, the controller measures incremental changes in array current and voltage to predict the effect of a voltage change.

This method requires more computation in the controller, but can track changing conditions more rapidly than the perturb and observe method (P&O) [5]. The fig.5 and fig.6 explain the operation of Perturb and observe method and incremental conductance method with a flow chart.

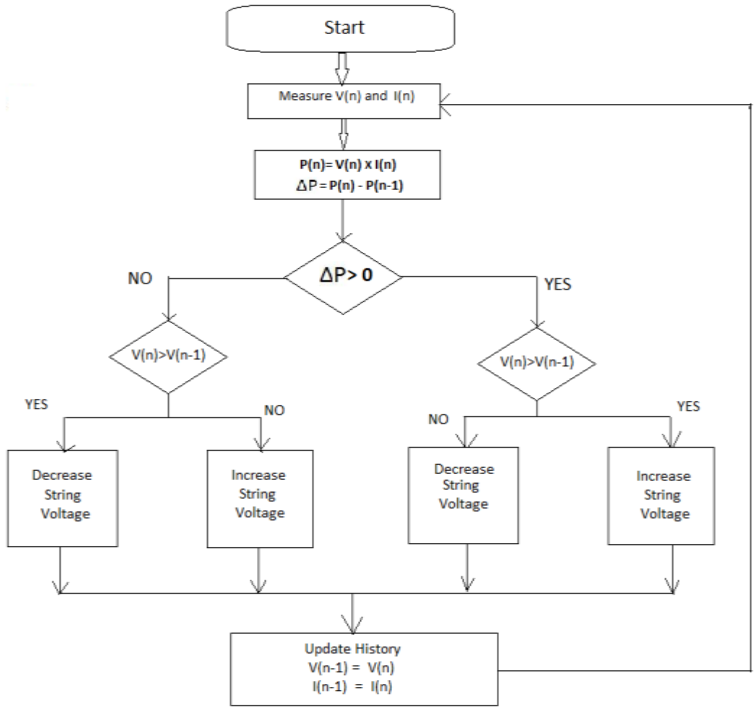

Figure5. *Perturb and observe method.*

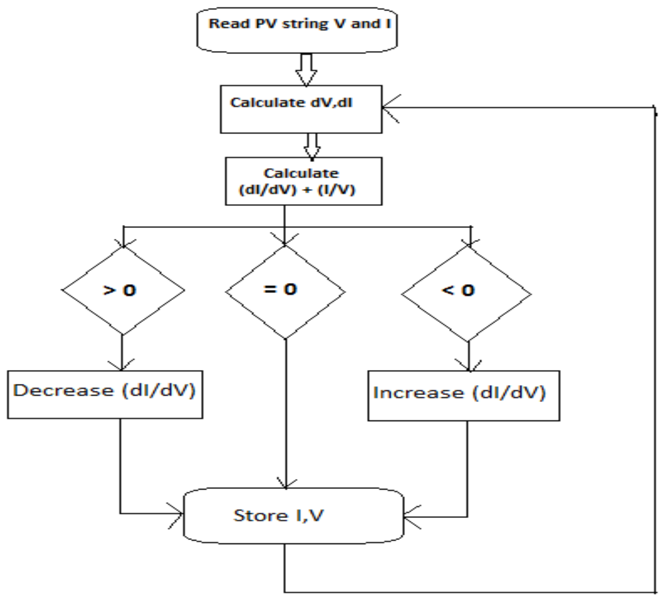

Figure6. *Incremental conductance method.*

Boost Converter

The boost converter or the step up converter has the output voltage greater than the input the voltage transformation ratio is.

$$\frac{V_o}{V_i} = \frac{1}{(1-D)} \quad (3)$$

For steady state operation, the average voltage across the inductor over a full period is zero as given in equation (4), (5) and (6).

$$V_{in} \times t_{on} - (V_o - V_{in})\, t_{off} = 0 \quad (4)$$

Therefore,

$$V_{in} \times D \times T = (V_o - V_{in})(1-D)T \quad (5)$$

and

$$\frac{V_o}{V_i} = \frac{1}{(1-D)} \quad (6)$$

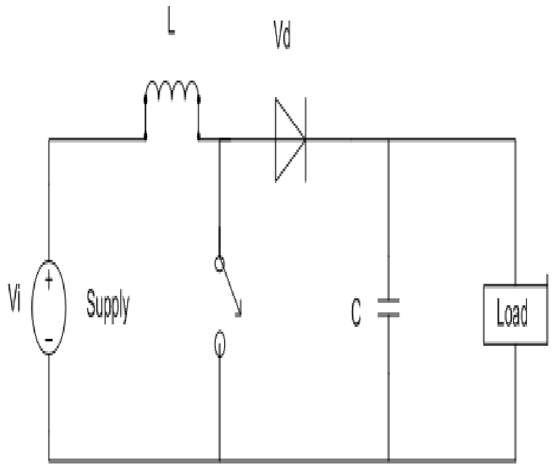

Figure7. *Boost converter circuit.*

By varying D the output voltage can be changed and it is always more than Vi. The advantage of this converter is that the input and output current both are continuous. Where, as in the step down converter the input current is discontinuous [6]. The boost converter can be implemented in the MPPT system where the output voltage of the system is required to be higher than the input voltage. Generally in grid-connected systems where the MPPT system is part a boost converter is utilized which maintains a high voltage even if the array voltage falls [7].

Proposed Cascaded H-Bridge Inverter Topology

A single-phase structure of an *m*-level cascaded inverter is illustrated in Figure below. Each separate dc voltage source (SDVS) is connected to a single-phase full-bridge, or H-bridge inverter [8, 9].

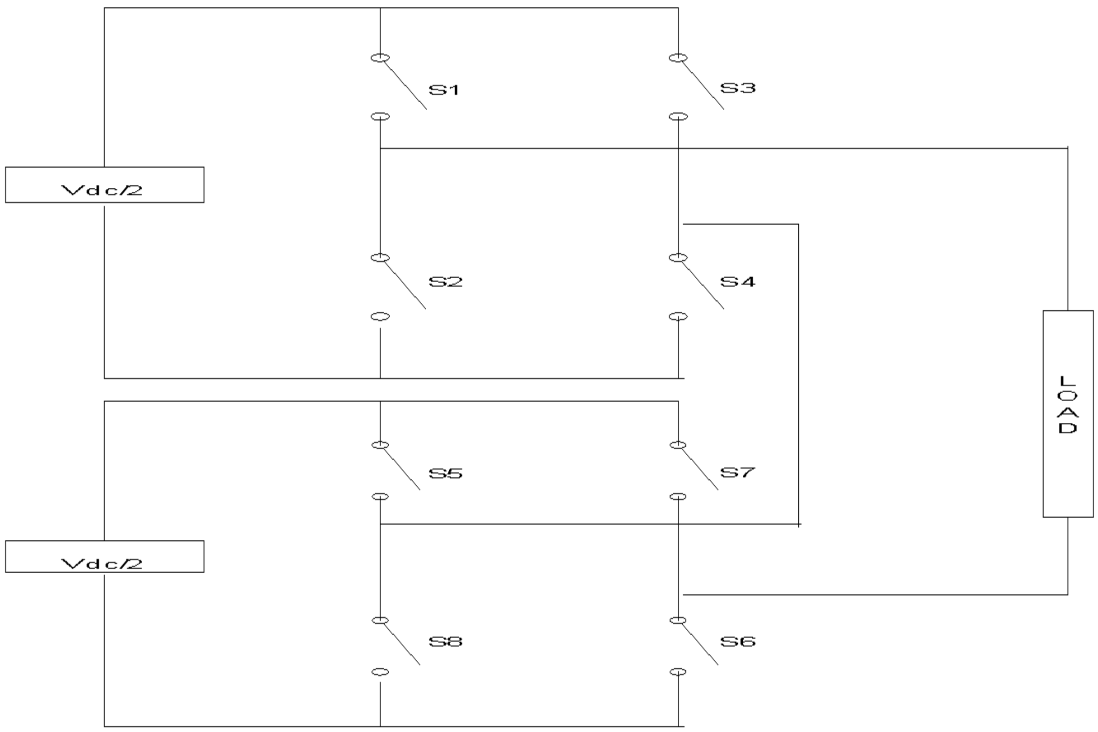

Figure8. *Five-level cascaded multilevel inverter*

Working Principle of Proposed Inverter

Each inverter level can generate three different voltage outputs, $+V_{dc}$, *0* and $-V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches, S1, S2, S3, S4, S5, S6, S7 and S8. The single phase cascaded five level inverter topology has been proposed in Fig.8.The circuit consists of eight main switches in two series connected H-bridge configuration S1~S4, and S5~S8.

The number of dc sources are two so the output voltage of the cascaded multilevel inverter is Vo = V_1+V_2 [10]. The output waveforms of multilevel inverters are in a stepped waveform therefore they have reduced harmonics compared to a square wave inverter.

Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge inverter. Each inverter level can generate three different voltage outputs, +Vdc, 0, and –Vdc by connecting the dc source to the ac output by different combinations of the four switches, S1, S2, S3, and S4. To obtain +Vdc, switches S1 and S2 are turned on, whereas –Vdc can be obtained by turning on switches S3 and S4. By turning on S1 and S2 or S3 and S4, the output voltage is 0.Similarly S5 and S6 for +Vdc, switches S7 and S8 are turned on for Vdc.

The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs [11, 12, 13, 14]. The number of output phase voltage levels '*m*' in a cascaded inverter is defined by $m=2n+1$, where n is the number of separate dc sources [15].

The following are switching patterns for two cascaded H-bridges

Table1. *Switching Logic for a 5-Level Cascaded Multilevel Inverter*

S8	S7	S6	S5	s4	s3	s2	s1	Output voltage
1	0	0	1	1	0	0	1	V_{dc}
1	0	1	0	0	1	0	1	$V_{dc}/2$
0	0	0	0	1	1	1	1	0
0	1	0	1	1	0	1	0	$-V_{dc}/2$
0	1	1	0	0	1	1	0	$-V_{dc}$

Simulation of Boost Converter with Maximum Power Point Tracking

The converter circuit topology is designed to be compatible with a given load to achieve maximum power transfer from the solar arrays. The boost converter output which is giving to input to five-level H-bridge multilevel inverter. We observed that the designed Five-level H-Bridge cascade multilevel inverter successfully followed the variations of solar irradiation and temperatures. Here the power is maintaining maximum value and similarly the boost converter boosting the voltage under the control of the MPPT. By this, PV array, boost converter output voltages are converted to AC voltages which are supplied to the grid by using Five-level H-Bridge cascade multilevel inverter and its characteristics also mentioned here.

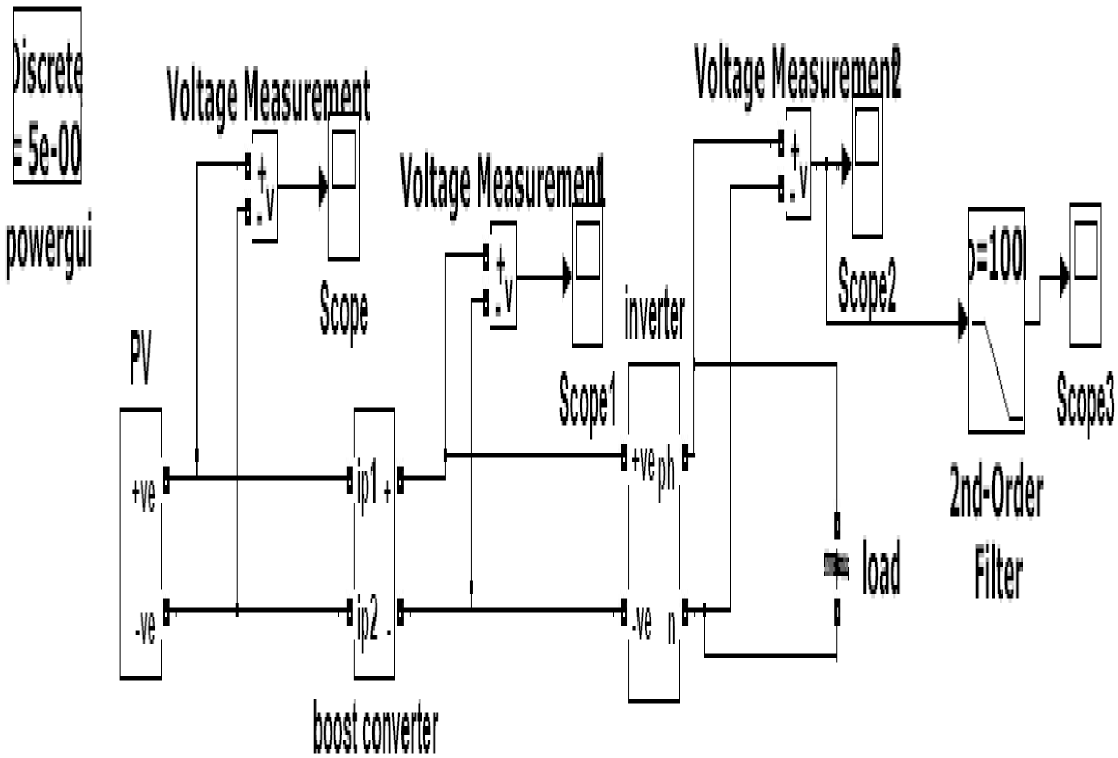

Figure9. *Simulation of five-level cascaded H-bridge Converter with MPPT.*

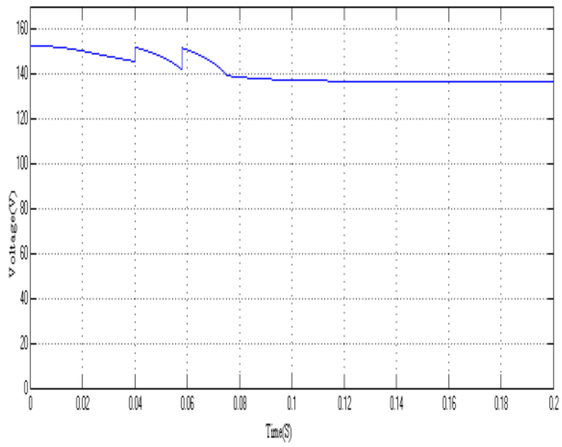

Figure10. *Voltage curve of PV system with Perturb & observe voltage control.*

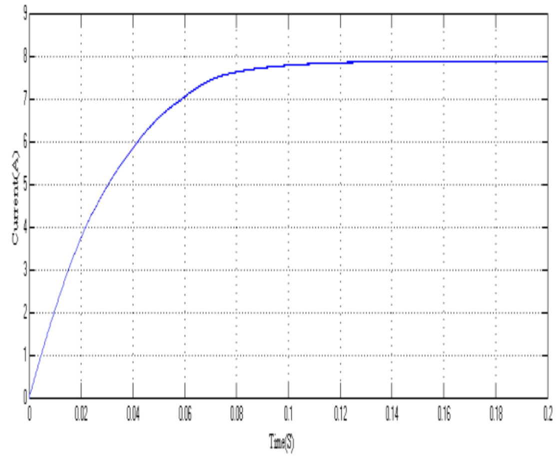

Figure11. *Current curve of PV system with Perturb & observe MPPT control.*

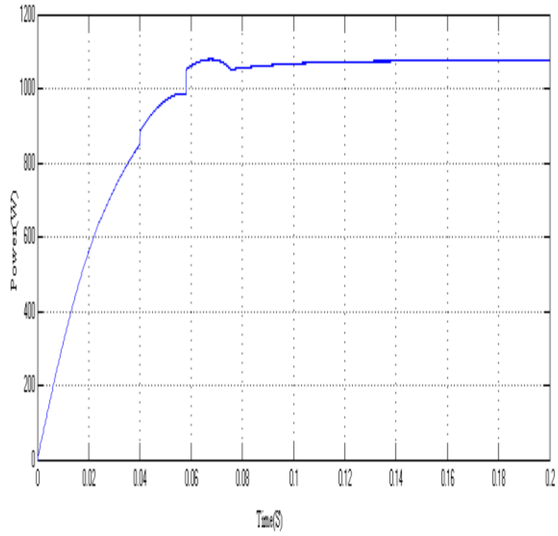

Figure12. *Power curve of PV system with Perturb & observe MPPT control.*

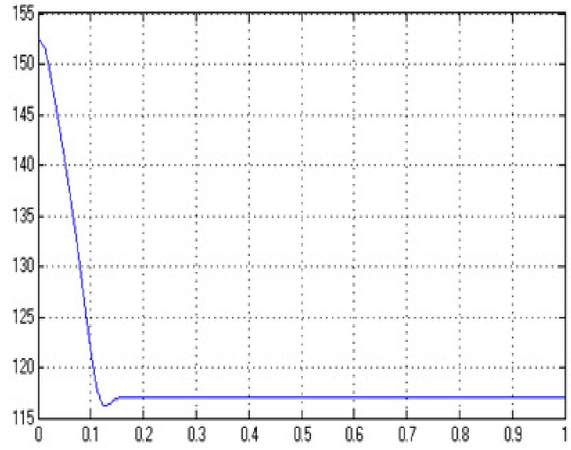

Figure13. *Voltage curve of PV system with Incremental conductance MPPT control*

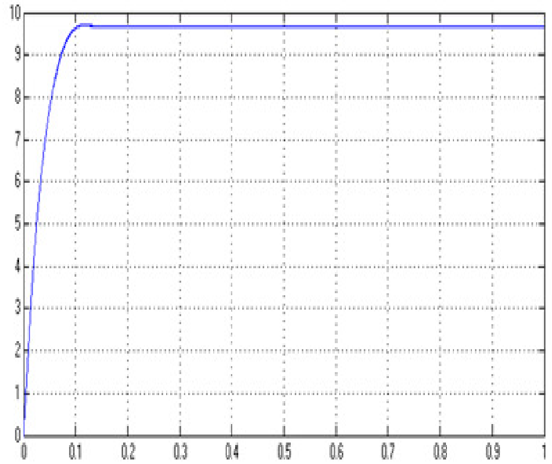

Figure14. *Current curve of PV system with Incremental conductance MPPT control.*

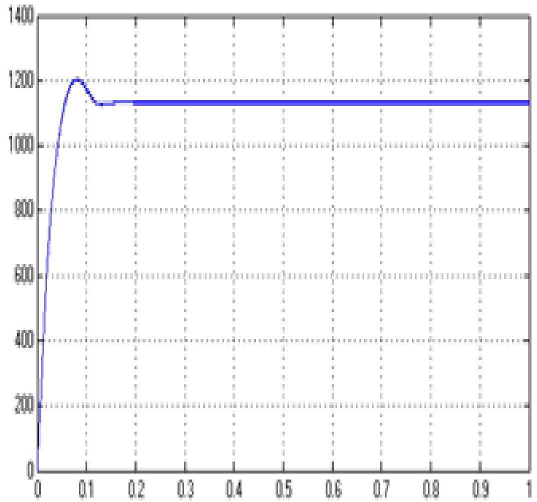

Figure15. *Power curve of PV system with Incremental conductance MPPT control.*

Table2. *Comparison Evaluation of MPPT Methods*

MPPT Methods	Perturb & observe method	Incremental conductance method
Voltage	136.4	117
Current	7.88	9.76
Power	1075	1132
Efficiency	90.4%	93.4%

SIMULATION RESULTS OF FIVE LEVEL INVERTER WITH MPPT TECHNIQUES AT DIFFERENT MODULATION INDEX

The simulation result of the five level cascaded H-bridge Inverter at the different modulation Index is shown below. The simulink model of five-level is the shown in the figure 16.

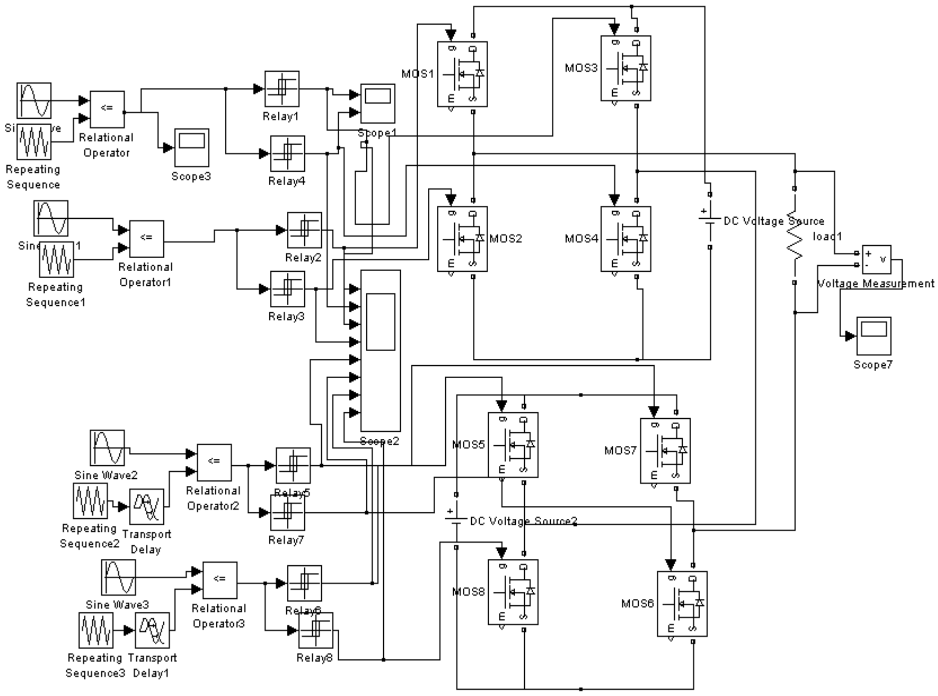

Figure16. *Cascaded H-bridge five level Inverter*

Output voltage and control pulses at different Modulation index with Perturb & observe Algorithm and Incremental conductance algorithm is given below:

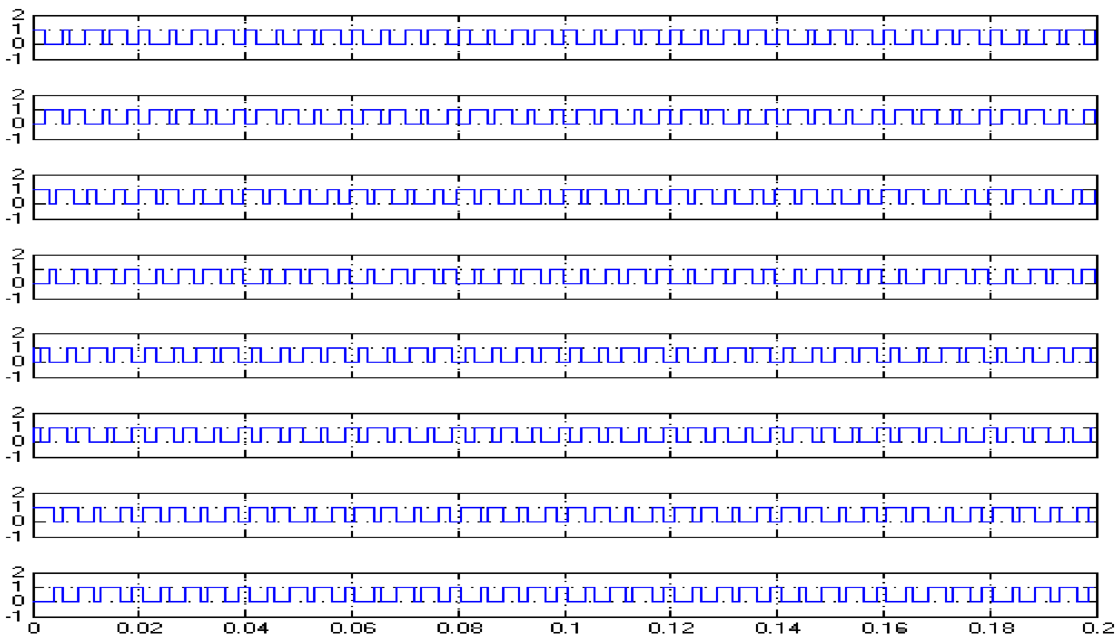

Figure17. *Control pulse for two H-bridge connected in series*

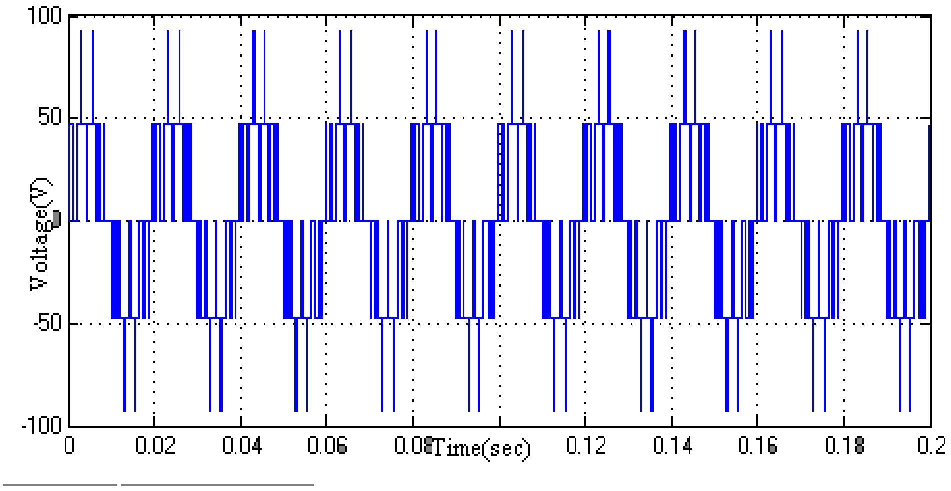

Figure18. *Five-level output voltage of two H-bridge is connected in series* MI=0.5

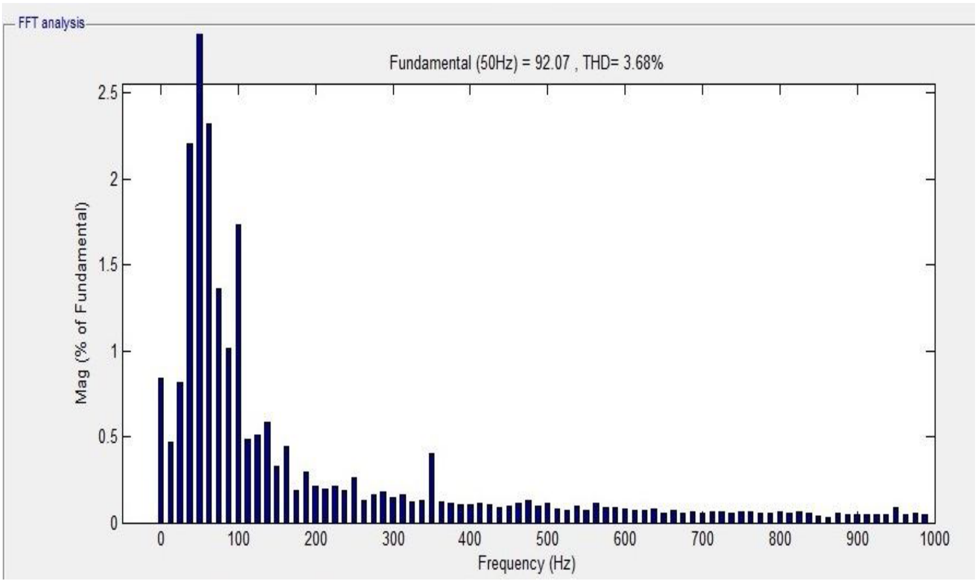

Figure19. *FFT analysis for 0.5 modulation index with perturb & observe algorithm*

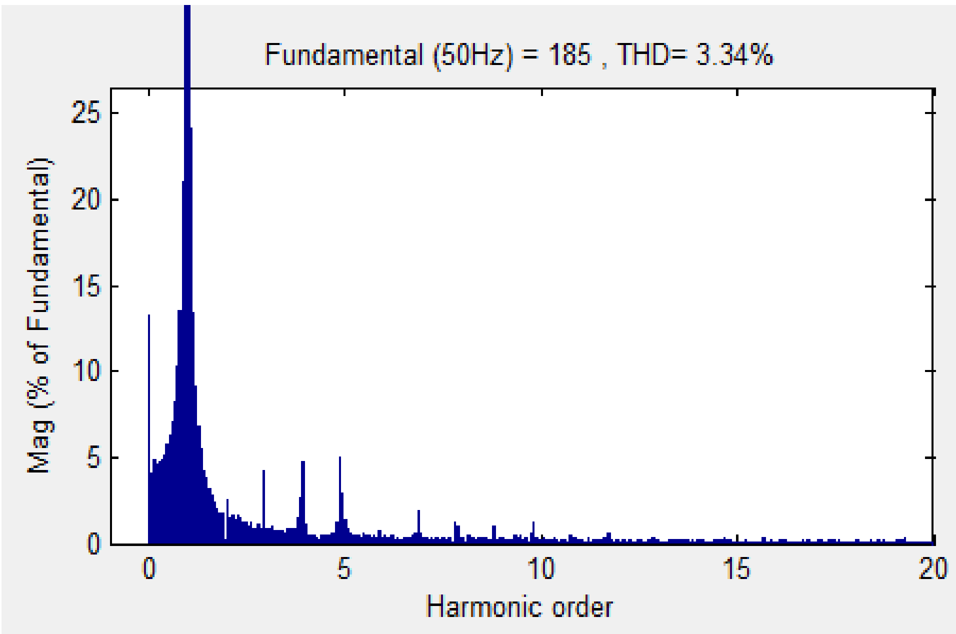

Figure20. *FFT analysis for 0.5 modulation index with incremental conductance algorithm* MI=0.7

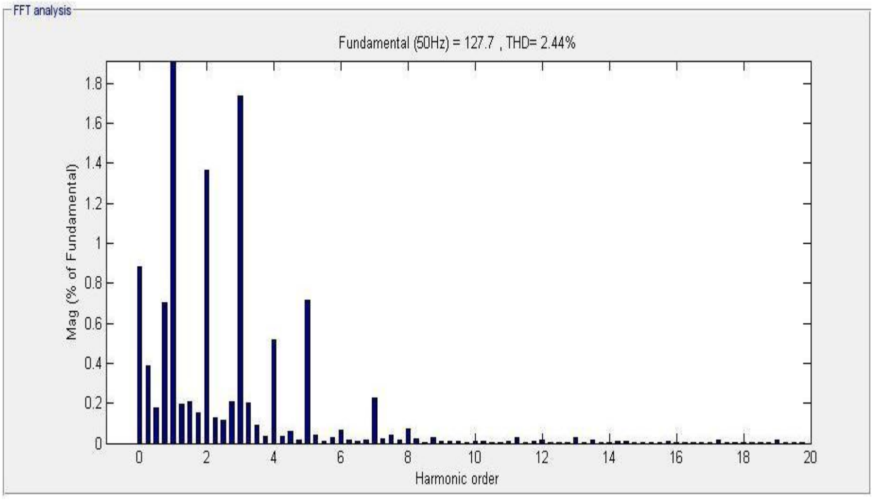

Figure21. *FFT analysis for 0.7 modulation index with perturb & observe algorithm*

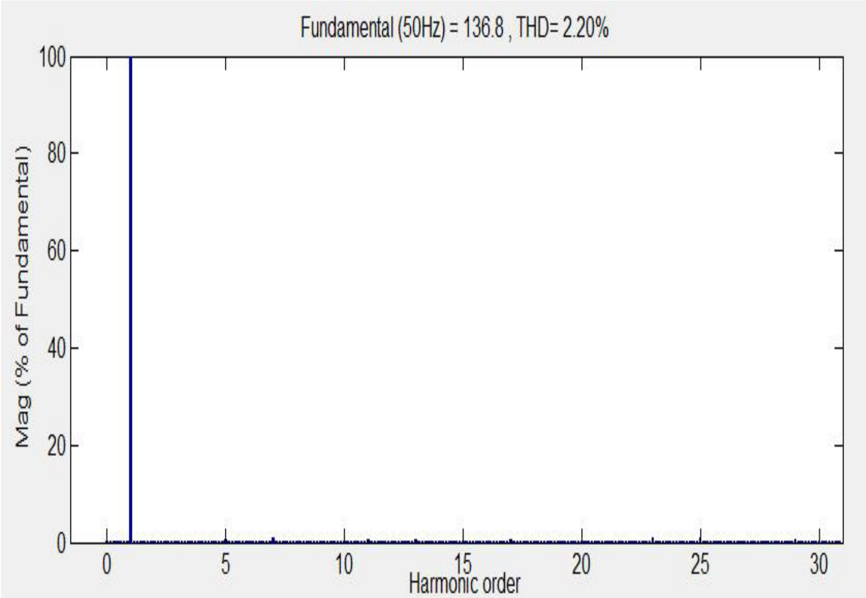

Figure22. *FFT analysis for 0.7 modulation index with incremental conductance algorithm* MI=0.9

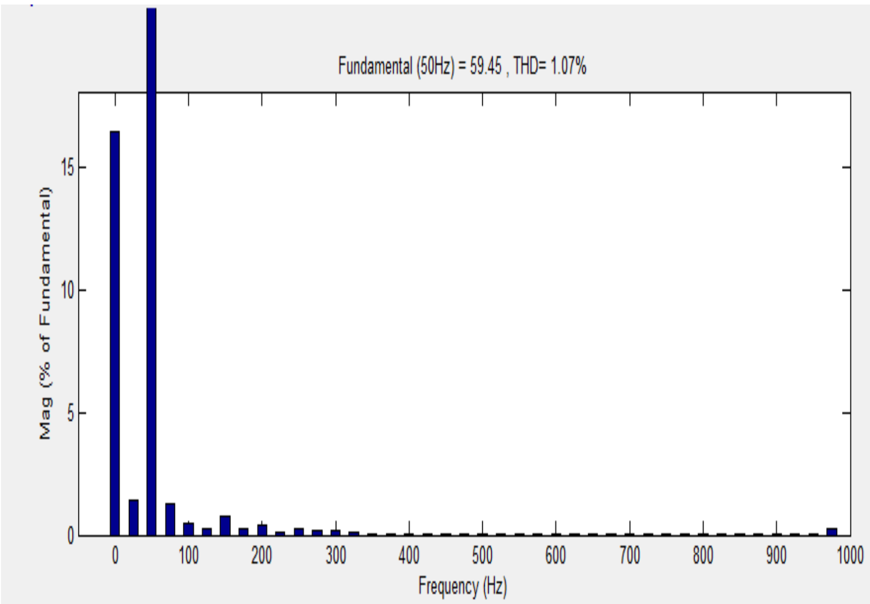

Figure23. *FFT analysis for 0.9 modulation index with perturb & observe algorithm*

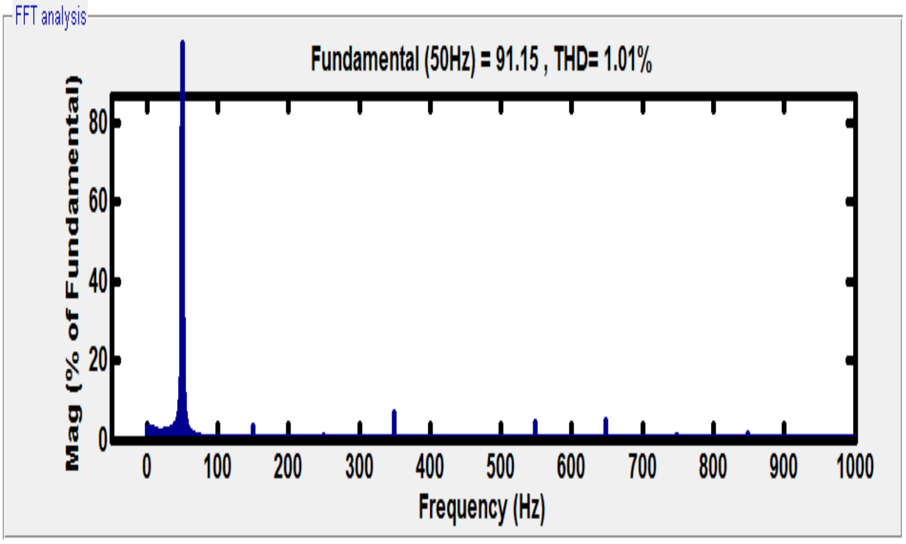

Figure24. *FFT analysis for 0.9 modulation index with incremental conductance algorithm.*

Table3. *Comparison of THD Values for Different Modulation Index*

Algorithm	Modulation Index (m)	THD %
Perturb & observe Algorithm	0.5	3.68
Incremental conductance	0.5	3.34
Perturb & observe Algorithm	0.7	2.44
Incremental conductance	0.7	2.20
Perturb & observe Algorithm	0.9	1.07
Incremental conductance	0.9	1.01

CONCLUSIONS

Methodology of two major perturb & observe maximum power point tracking algorithm and incremental conductance maximum power point tracking algorithm are discussed. The incremental conductance easy to implement and offers relatively moderate efficiencies but results in unpredictable performance against rapidly changing conditions. Furthermore, the simulation results indicates that the THD of three-level inverter is reduced from 3.68% to 1.01% by replacing perturb & observe MPPT with incremental conductance MPPT with different modulation index, also the power factor and the shape of waveform is improved by implementing incremental conductance MPPT algorithm.

The perturb & observe method is complex and expensive when compared to incremental conductance. However, the incremental conductance method gives very high efficiencies about 93.4% and performs well with changing radiation and temperature. It can be concluded that, if economical aspect is not a constraint and rapidly changing site conditions are obligatory, the incremental conductance method is the best choice among the two methods discussed. A comprehensive evaluation of these two methods with the simulation results is also stated. The principles of operation of five-level H-Bridge cascade converter topology suitable for photovoltaic applications have been presented in this paper. The cost savings is further enhanced with the proposed cascade converter because of the requires the least number of component to achieved the same number of voltage level. These configurations may also be applied in distributed power generation involving photovoltaic cells.

REFERENCES

[1] Juan David Bastidas-Rodriguez, Edinson Franco, Giovanni Petrone, Carlos Andrés Ramos-Paja and Giovanni Spagnuolo, Maximum power point tracking architectures for photovoltaic systems in mismatching conditions:a review, *IET Power Electron.*, Vol. 7, Iss. 6, pp. 1396–1413,(2014).

[2] Ram JP, Babu TS, Rajasekar N., A comprehensive review on solar PV maximum power point tracking techniques. *Renewable and Sustainable Energy Reviews*, Vol.67, pp. 826-47,(2017).

[3] Shongwe, Samkeliso, and Moin Hanif, Comparative analysis of different single-diode PV modeling methods. *IEEE Journal of Photovoltaics,*Vol.5, no.3,pp.938-946, (2015).

[4] Rajasekar N, KK Neeraja and R Venugopalan, Bacterial foraging algorithm based solar PV parameter estimation. *Solar Energy.,* Vol. 97,pp.255–265, (2013).

[5] Ahmed Koran, Thomas LaBella, and Jih-Sheng Lai, High Efficiency Photovoltaic Source Simulator with Fast Response Time for Solar Power Conditioning Systems Evaluation, *IEEE Transactions On Power Electronics.,* Vol. 29, no. 3, pp.1285-1296, (2014).

[6] Mohammed A. Elgendy, Bashar Zahawi and David J. Atkinson, Assessment of Perturb and Observe MPPT Algorithm Implementation Techniques for PV Pumping Applications, *IEEE transactions on sustainable energy.,* Vol.3, no.1, pp.21-33 ,(2011).

[7] Ahmed K. Abdelsalam; Ahmed M. Massoud; Shehab Ahmed; Prasad N. Enjeti, High-Performance Adaptive Perturb and Observe MPPT Technique for Photovoltaic-Based Microgrids, *IEEE transactions on power electronics.,* Vol.26, no.4, pp 1010–1021, (2011).

[8] Mohammed A. Elgendy, Bashar Zahawi and David J. Atkinson, Operating Characteristics of the P&O Algorithm at High Perturbation Frequencies for Standalone PV Systems, *IEEE transactions on energy conversion;* Vol.30, no.1,pp.189-198, (2015).

[9] Azadeh Safari and Saad Mekhilef, Simulation and Hardware Implementation of Incremental Conductance MPPT With Direct Control Method Using Cuk Converter, *IEEE transactions on industrial electronics.,;* Vol 58, no.4,pp.1154-1161, (2011).

[10] Guan-Chyun Hsieh, Hung-I Hsieh, Cheng-Yuan Tsai, and Chi-Hao Wang, Photovoltaic Power-Increment-Aided Incremental-Conductance MPPT With Two-Phased Tracking, *IEEE transactions on power electronics.,* Vol.28, no.6, pp.2895-2911, (2012).

[11] Hadeed Ahmed Sher, Ali Faisal Murtaza, Abdullah Noman, Khaled E. Addoweesh, Kamal Al-Haddad and Marcello Chiaberge, A New Sensorless Hybrid MPPT Algorithm Based on Fractional Short-Circuit Current Measurement and P&O MPPT, *IEEE transactions on sustainable energy.,* Vol.6,no.4.;pp.1426-1434, (2015).

[12] Bal Mukund Sharma and Kuldeep Sahay, A Comprehensive Survey of Maximum Power Tracker Techniques for Photovoltaic System, *I-Manager's Journalon Electrical Engineering,* , 8(1), 39-55,(2014).

[13] Bal Mukund Sharma and Kuldeep Sahay, Implementation of Perturb and Observe (P& O) Method to Track the Maximum Power Point Using Buck Converter, *I-Manager's Journal on Electrical Engineering,* , 9 (4), 37-46, (2016).

[14] Bal Mukund Sharma and Kuldeep Sahay, Effect of Perturb & Observe Algorithm and Incremental Conductance Algorithm on the Performance of Cuk Converters for Photovoltaic Application, *European Journal of Advances in Engineering and Technology,* 4 (7), 516-523, (*2017*).

[15] Bal Mukund Sharma and Kuldeep Sahay, "New Trends in Solar Energy Modeling and Developing a Relation for Performance of Solar Radiation", *European Journal of Advances in Engineering and Technology, 2017,* 4(9), 649-656.

AUTHORS' BIOGRAPHY

Bal Mukund Sharma, is Research Scholar in the Department of Electrical Engineering, UPTU, Lucknow. He received his B.Tech degree in Electrical Engineering from Radha Govind Engineering College, Meerut, India, in 2007, the M.Tech degree in Power Electronics & Drives from Madan Mohan Malaviya Engineering College,(presently Madan Mohan Malaviya University of Technology) Gorakhpur, India, in 2010. He has publshed 2 international Journal papers and 3 papers presented in the conferences. He has total 06 years of teaching experience in ITM Maharajganj, MMM Engg. college Gorakhpur, presently in ITM GIDA Gorakhpur as Assistant Professor. His research area of interest in Maximum Power Tracker Techniques for Photovoltaic System.

Kuldeep Sahay, Ph.D. is associated with Institute of Engineering & Technology, Lucknow since 1996, where, he is presently Professor in the Department of Electrical Engineering, An Autonomous Constituent Institute of Uttar Pradesh Technical University, Lucknow. He has authored numbers of research paper in National and International Journal having good citation and published a book. His research interests are in the area of Mathematical Modeling of Energy Storage System, Integration of Renewable

Energy System with Grid. Prof. Sahay for his overall contribution in research and academics has been awarded "Shikha Rattan Puraskar" and "Rashtriya Gaurav Award" by India International Friendship Society, New Delhi in 2011.E-mail:-ksahay.iitd@gmail.com.

Citation: *S. Bal Mukund and S. Kuldeep, "Effect of MPPT Techniques on the THD Value of Five-Level Cascaded H-Bridge Converter for Photovoltaic Application", International Journal of Emerging Engineering Research and Technology, vol. 5, no. 7, pp. 17-29, 2017.*