COMPARISON OF MAXIMUM POWER POINT TRACKING ALGORITHMS FOR PHOTOVOLTAIC SYSTEM

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ABSTRACT

Photovoltaic systems normally use a maximum power point tracking (MPPT) technique to continuously deliver the highest possible power to the load when variations in the isolation and temperature occur, Photovoltaic (PV) generation is becoming increasingly important as a renewable source since it offers many advantages such as incurring no fuel costs, not being polluting, requiring little maintenance, and emitting no noise, among others. PV modules still have relatively low conversion efficiency; therefore, controlling maximum power point tracking (MPPT) for the solar array is essential in a PV system. The Maximum Power Point Tracking (MPPT) is a technique used in power electronic circuits to extract maximum energy from the Photovoltaic (PV) Systems. In the recent days, PV power generation has gained more importance due its numerous advantages such as fuel free, requires very little maintenance and environmental benefits. To improve the energy efficiency, it is important to operate PV system always at its maximum power point. Many maximum power point Tracking (MPPT) techniques are available and proposed various methods for obtaining maximum power point. But, among the available techniques sufficient comparative study particularly with variable environmental conditions is not done. This paper is an attempt to study and evaluate two main types of MPPT techniques namely, Open-circuit voltage and Short-circuit current. The detailed comparison of each technique is reported. The SIMULINK simulation results of Open-circuit voltage and Short-circuit current methods with changing radiation and temperature are presented.

KEYWORDS: *Photovoltaic system, modelling of PV arrays, Open-circuit voltage algorithm Short circuit current algorithm, Boost converter and Simulation Results*

I. INTRODUCTION

Renewable sources of energy acquire growing importance due to its enormous consumption and exhaustion of fossil fuel. Also, solar energy is the most readily available source of energy and it is free. Moreover, solar energy is the best among all the renewable energy sources since, it is non-polluting. Energy supplied by the sun in one hour is equal to the amount of energy required by the human in one year. Photo voltaic arrays are used in many applications such as water pumping, street lighting in rural town, battery charging and grid connected PV system

The maximum power point tracker is used with PV modules to extract maximum energy from the Sun [1]. Typical characteristics of the PV module shown in Fig.1 clearly indicate that the operating point of the module (intersection point of load line and IV characteristic) is not same as the maximum power point of the module. To remove this mismatch power electronic converter is accompanied with the PV system as shown in Fig.1 The electrical characteristics of PV module depend on the intensity of solar radiation and operating temperature. Increased radiation with reduced temperature results in higher module output. The aim of the tracker is to derive maximum power always against the variations in sunlight, atmosphere, local surface reflectivity, and temperature. or to operate the module at MPP, a dc-to-dc power electronic converter is accompanied with the PV system. The electrical characteristic of PV module depends on the intensity of solar radiation and operating temperature. Increased radiation with reduced temperature results in higher module output.

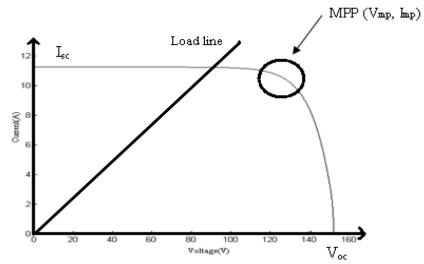

Figure 1: PV Module Characteristics

Since a PV array is an expensive system to build, and the cost of electricity from the PV array systems is more expensive compared to the price of electricity from the utility grid, the user of such an expensive system naturally wants to use all of the available output power. A near sinusoidal current as well as voltage with minimum harmonic distortion under all operating conditions [2], [3].
Therefore, PV array systems should be designed to operate at their maximum output power levels for any temperature and solar irradiation level at all the time. The performance of a PV array system depends on the operating conditions as well as the solar cell and array design quality. Multilevel converters are particularly interesting for high power applications. The main tasks of the system control are maximize the energy transferred from the PV arrays to the grid and to generate a near sinusoidal current as well as voltage with minimum harmonic distortion under all operating conditions.
The paper is organized in the following way. Section II presents the entire system configuration Section III discuss about the Mathematical modeling of PV array, Maximum Power Point Tracking Methods, analyzing the boost converter, about the concept of multilevel inverter with Five- level H-bridge cascade multilevel inverter. In section IV Simulation results for the multilevel inverter system under considerations are discussed. Finally, conclusions are made in Section V.

II. SYSTEM CONFIGURATION

The system configuration for the topic is as shown figure 2. 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. [1], [2].

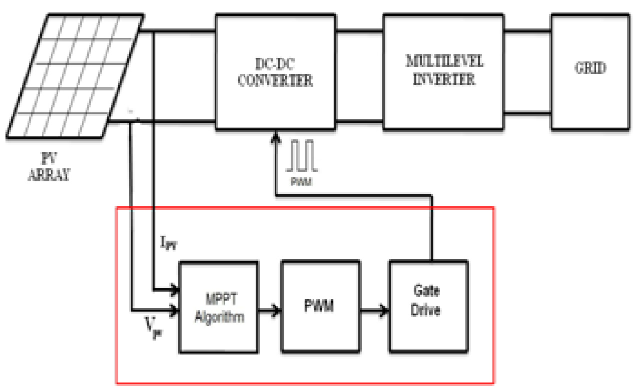

Fig. 2. System Configuration of PV System

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.

III. PROPOSED MPPT ALGORITHM FOR PHOTOVOLTAIC SYSTEM

3.1. Mathematical Modeling of PV Array

The PV receives energy from sun and converts the sun light into DC power. The simplified equivalent circuit model is as shown in figure.3.

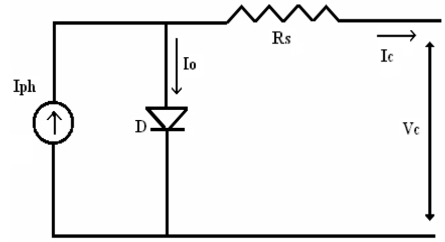

Figure.3. Simplified – equivalent Circuit of Photovoltaic Cell

The PV cell output voltage is a function of mathematical equation of the photocurrent that mainly determined by load current depending on the solar irradiation level during the operation. The equation (1) is,

$$V_{cx} = \frac{AKT_c}{q} \ln\left[\frac{I_{ph} + I_0 - I_c}{I_0}\right] - R_s I_c \quad (1)$$

Where the symbols are defined as follows:

q: electron charge (1.602 × 10-19 C).
k: Boltzmann constant (1.38 × 10-23 J/^{0}K).
I_c: cell output current, A.
I_{ph}: photocurrent, function of irradiation level and junction temperature (5 A).
I_o: reverse saturation current of diode (0.0002 A).
R_s: series resistance of cell (0.001 Ω).
T_c: reference cell operating temperature (25 °C).
V_c: cell output voltage, V.

Both k and T_C should have the same temperature unit, either Kelvin or Celsius. A method to include these effects in the PV array modeling is given in [4]. These effects are represented in the model by the temperature coefficients C_{TV} and C_{TI} for cell output voltage and cell photocurrent, respectively, as in equation (2) and (3),

$$C_{TV} = 1 + \beta_T (T_a - T_x) \quad (2)$$

$$C_{T1} = 1 + \frac{\gamma_t}{sc}(T_x - T_a) \quad (3)$$

Where, β_T=0.004 and γ_T=0.06 for the cell used and T_a=20°C is the ambient temperature during the cell testing. If the solar irradiation level increases from S_{X1} to S_{X2}, the cell operating temperature and the photocurrent will also increase from T_{X1} to T_{X2} and from I_{Ph1} to Iph2, respectively. C_{SV} and C_{SI}, which are the correction factors for changes in cell output voltage V_C and photocurrent I_{ph} respectively in equation (4) and (5),

$$C_{SV} = 1 + \beta_T \alpha_S (S_x - S_C) \quad (4)$$

$$C_{ST} = 1 + \frac{1}{S_c}(S_X - S_C) \quad (5)$$

where S_C is the benchmark reference solar irradiation level during the cell testing to obtain the modified cell model. The temperature change, ΔT_C occurs due to the change in the solar irradiation level and is obtained using in equation (6),

$$\Delta_{TC} = 1 + \alpha_S (S_X - S_C) \quad (6)$$

The constant α_S represents the slope of the change in the cell operating temperature due to a change in the solar irradiation level [1] and is equal to 0.2 for the solar cells used. Using correction factors C_{TV}, C_{TI}, C_{SV} and C_{SI}, the new values of the cell output voltage V_{CX} and photocurrent I_{PHX} are obtained for the new temperature T_X and solar irradiation S_X as follows in equation (7) and (8),

$$V_{CX} = C_{TV} C_{SV} V_C \quad (7)$$

$$I_{ph} = C_{T1} C_{SI} I_{ph} \quad (8)$$

V_C and I_{PH} are the benchmark reference cell output voltage and reference cell photocurrent, respectively. The resulting I-V and P V curves for various temperature and solar irradiation levels were discussed and shown in [3, 4, and 5]; therefore they are not going to be given here again. The output power from PV is the result from multiplying PV terminal voltage and PV output current are obtained from equation (9) and (10). The power output from PV modules is shown in (2).

$$P_c = V_c\left(I_{ph} - I_a * \exp(\frac{q}{AKT}V_c - 1)\right) \quad (9)$$

$$I_c = I_{ph} - I_0 * \exp\left(\frac{q}{AKT}V_c - 1\right) \quad (10)$$

3.2 MPPT Methods

The tracking algorithm works based on the fact that the derivative of the output power P with respect to the panel voltage V is equal to zero at the maximum power point as in Fig.4.The derivative is greater than zero to the left of the peak point and is less than zero to the right.

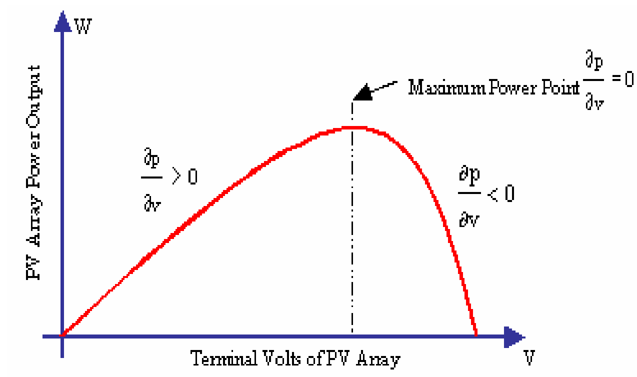

Figure 3: P-V Characteristics of a module

$$\partial P/\partial V = 0 \text{ for } V = Vmp \quad (11)$$

$$\partial P/\partial V > 0 \text{ for } V < Vmp \quad (12)$$

$$\partial P/\partial V < 0 \text{ for } V > Vmp \quad (13)$$

Various MPPT algorithms are available in order to improve the performance of PV system by effectively tracking the MPP. However, most widely used MPPT algorithms are considered here, they are

a) Open Circuit Voltage
b) Short Circuit Current

A. Open-Circuit Voltage

The open circuit Voltage algorithm is the simplest MPPT control method. This technique is also known as constant voltage method. V_{OC} is the open circuit voltage of the PV panel. V_{OC} depends on the property of the solar cells. A commonly used V_{MPP}/V_{oc} value is 76% This relationship can be described by equation (14),

$$V_{MPP} = k_1 * V_{oc} \quad (14)$$

Here the factor k1 is always less than unity. It looks very simple but determining best value of k is very difficult and k1 varies from 0.71 to 0.8. The common value used is 0.76; hence this algorithm is also called as 76% algorithm. The operating point of the PV array is kept near the MPP by regulating the array voltage and matching it to a fixed reference voltage Vref. The Vref value is set equal to the VMPP of the characteristic PV module or to another calculated best open circuit voltage this method assumes that individual insulation and temperature variations on the array are insignificant, and that the constant reference voltage is an adequate approximation of the true MPP.

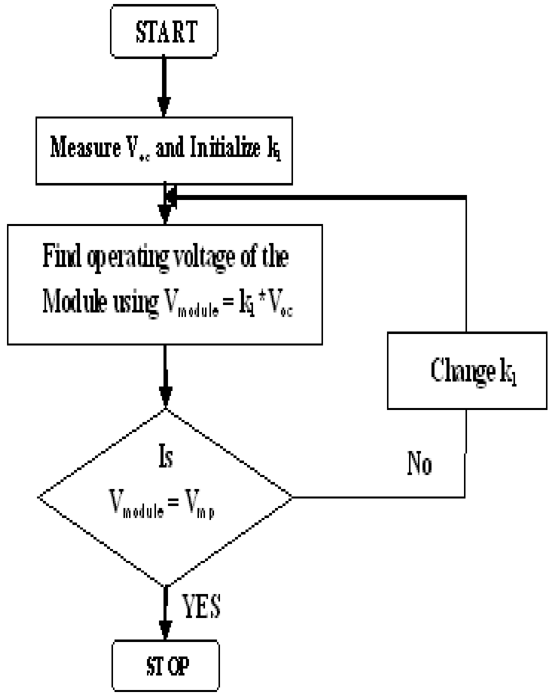

Figure.4. Flow Chart of Open Circuit Voltage.

The open circuit voltage method does not require any input. It is important to observe that when the PV panel is in low insulation conditions, the open circuit Voltage technique is more effective. Detailed flowchart of the open circuit voltage algorithm is depicted in Figure.4.

B. Short -Circuit Current

The Short Circuit Current algorithm is the simplest MPPT control method. This technique is also known as constant current method. I_{SC} is the Short circuit current of the PV panel. I_{SC} depends on the property of the solar cells as shown in figure.3..This relationship can be described by equation (15),

$$I_{MPP} = k_2 * I_{SC} \qquad (15)$$

Here the factor k_2 is always <1. It looks very simple but determining best value of k_2 is very difficult and k_2 varies from between 0.78 and 0.92.

When the PV array output current is approximately 90% of the short circuit current, solar module operates at its MPP. In other words, the common value of k_2 is 0.9. Measuring I_{SC} during operation is problematic. An additional switch usually has to be added to the power converter. A boost converter is used, where the switch in the converter itself can be used to short the PV array. Power output is not only reduced when finding I_{SC} but also because the MPP is never perfectly matched. A way of compensating k_2 is proposed such that the MPP is better tracked while atmospheric conditions change. To guarantee proper MPPT in the presence of multiple local maxima periodically sweeps the PV array voltage from short-circuit to update k_2. Detailed flowchart of the short circuit current algorithm is depicted in Figure.5.

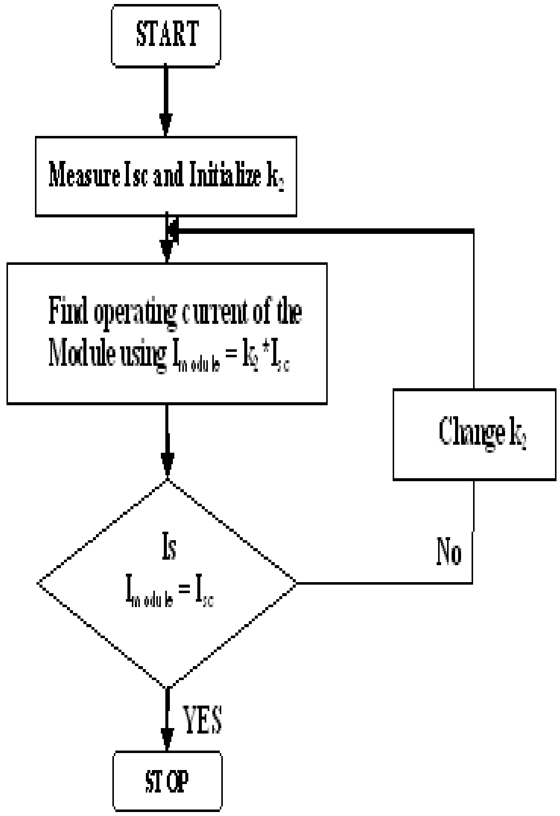

Figure.5. Flow Chart of Short Circuit Current MPPT

3.3 MPPT Methodology

When compared with the system without control algorithms PV system output approximately 20 to 65%. By using Control algorithms the dc-to-dc converter and performs all control functions required for MPP Tracking process. The MPP of a module varies with radiation and temperature. The variation of MPP position under changing conditions demands optimized algorithm, which in turn control the dc to- dc converter operation to increase the PV efficiency. Table.1 shows the detailed comparisons of the above two methods. Each MPPT algorithm has its own merits and barriers in view of changing environmental conditions. The Open circuit voltage and short circuit current methods are simple and easy for implementation. However, it is very tedious to find the optimal value of k factor for the changing temperature and irradiance. The open circuit voltage algorithm suffers from low efficiency 92%, as it is very tedious to identify the exact MPP. Also, this method fails to find MPP when partially shaded PV module or damaged cells are present. The short circuit current algorithm has the higher efficiency 96%.The advantage of this method is, response is quick as ISC is linearly proportional to the Imp respectively. Hence, this method also gives faster response for changing conditions. When rapidly changing site conditions are present and the efficiency depends on how the method is optimised at design stage. The implementation cost of this method is relatively lower. The Open circuit voltage method is easy to implement as few parameters are to be measured and gives moderate efficiencies about 92%.

Table 1: Comparison of MPPT methods

Specification	***Open Open Circuit Voltage***	***Short Circuit Current***
Efficiency	Low About 90%	High About 94%
Complexity	Very simple but Very difficult to Get optimal k1	Very simple but Very difficult to Get optimal k2
Realization	Easy to implement With Analog hardware	Easy to implement as few measured parameters
Cost	Relatively Lower	Relatively Lower
Reliability	Not accurate and may not operate exactly at MPP (below to it)	Accurate and operate exactly at MPP
Rapidly changing Atmospheric conditions.	Slower response as Vmp is proportional to the VOC but may not locate Correct MPP	Faster response as Imp is Proportional to the I_{SC} and locate correct MPP
k factor	0.73 < k1 < 0.8 k1 ≈ 0.76 Varies with Temp and Irradiance	0.85 < k2 < 0.9 k2 ≈ 0.9Varies with Temp and Irradiance

The implementation cost of Open circuit voltage method is relatively lower. The problems with this method are it gives arbitrary performance with oscillations around MPP particularly with rapidly changing conditions and provides slow response. Sometimes, this method is not reliable as it is difficult to judge whether the algorithm has located the MPP or not. The Short circuit method offers high efficiencies about 96%. It has several advantages such as more accurate, highly efficient and operates at maximum power point. This method operates very soundly with rapidly changing atmospheric conditions as it automatically adjusts the module's operating voltage to track exact MPP with almost no oscillations.

3.4 Boost Converter

The boost converter which has boosting the voltage to maintain the maximum output voltage constant for all the conditions of temperature and solar irradiance variations. A simple boost converter is as shown in figure.6.

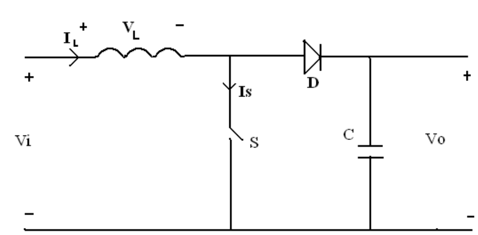

Figure.6. Boost Topology

For steady state operation, the average voltage across the inductor over a full period is zero as given in equation (16), (17) and (18).

$$V_{in}*t_{on} – (V_o-V_{in})\ t_{off} = 0 \quad (16)$$

Therefore,

$$V_{in}*D*T = (V_o-V_{in})(1-D)T \quad (17)$$

and

$$\frac{V_o}{V_{in}} = \frac{1}{1 - D} \quad (18)$$

By designing this circuit we can also investigate performance of converters which have input from solar energy. A boost regulator can step up the voltage without a transformer. Due to a single switch, it has a high efficiency.

3.5 Multilevel Inverter topology

The DC-AC converters have experienced great evaluation in the last decade due to their wide use in uninterruptible power supplies and industrial applications. Figure.6 shows the voltage source inverters produce an output voltage or a current with levels either 0 or ± $V_{dc.}$ They are known two-level inverter. To obtain a quality output voltage (230.2V rms) or a current (4.2 Amps rms) waveform with a minimum amount of ripple content.

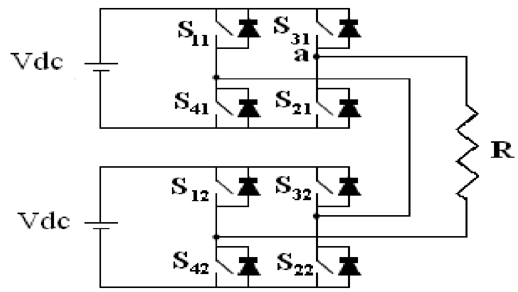

Figure.7. Five-level H-Bridge Cascade Multilevel inverter circuit

IV. SIMULATION RESULTS

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. Photovoltaic array V-I and P-V characteristics are obtained by considering the varying temperature and the varying irradiance conditions shown in Fig. 8, 9, 10 and 11.

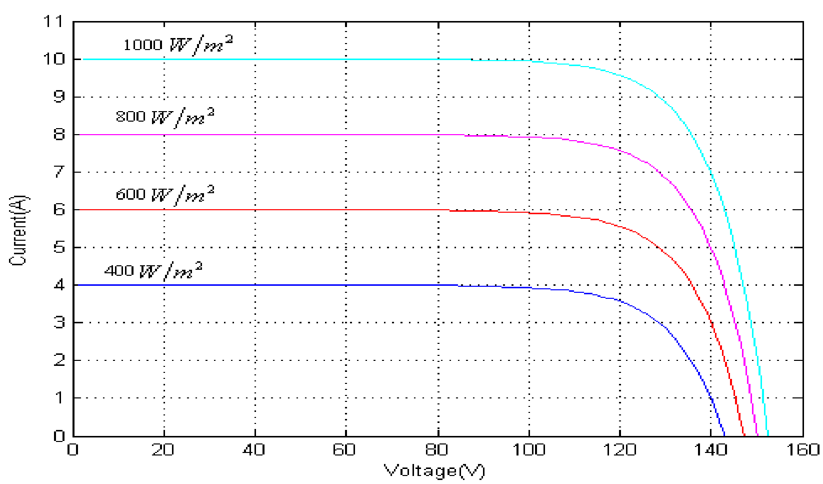

Fig.8. Variations of V-I Characteristics of PV system with varying irradiance

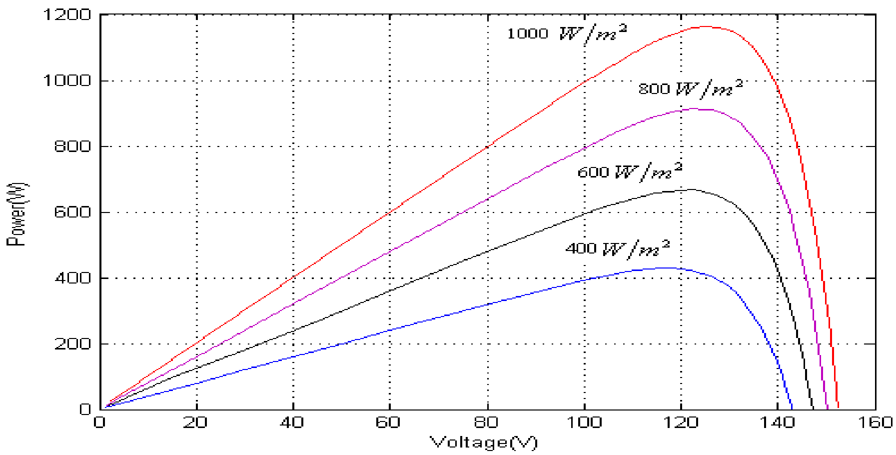

Fig.9 Variations of .P-V Characteristics of PV system with varying irradiance

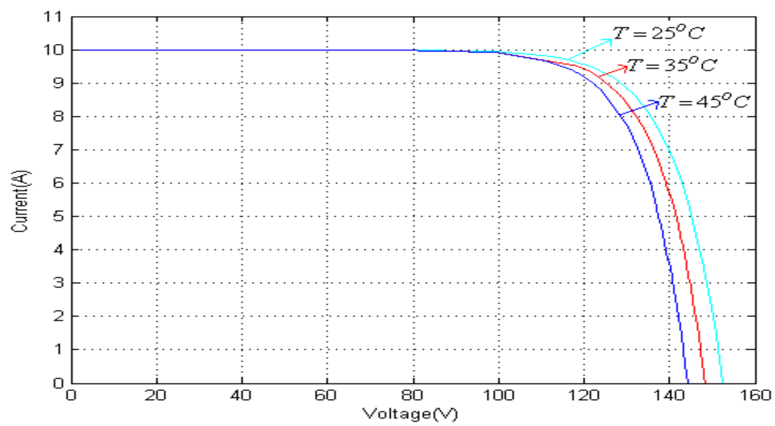

Fig.10.V-I Characteristics of PV system with three different varying temperature

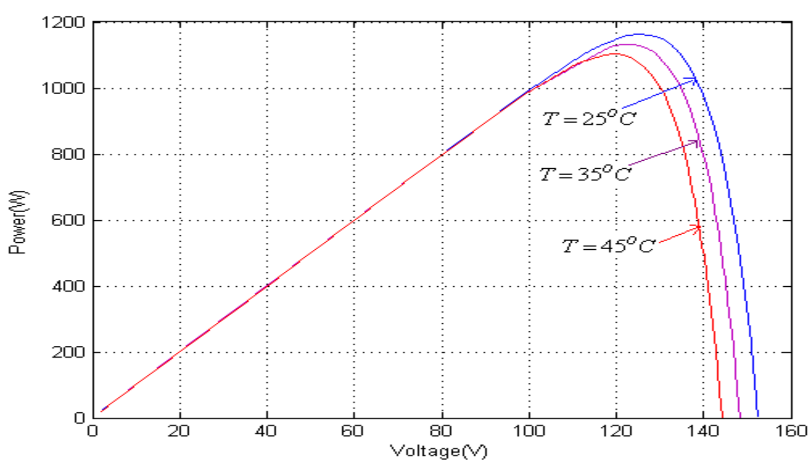

Fig.11. P-V Characteristics of PV system with varying temperature

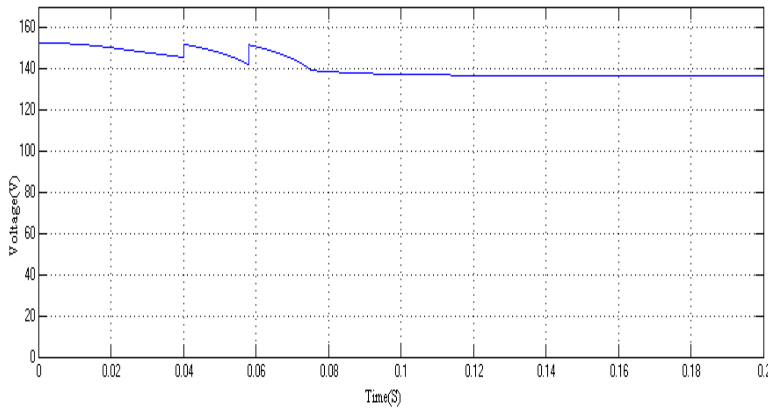

Fig.12. Voltage curve of PV system with Open circuit voltage control

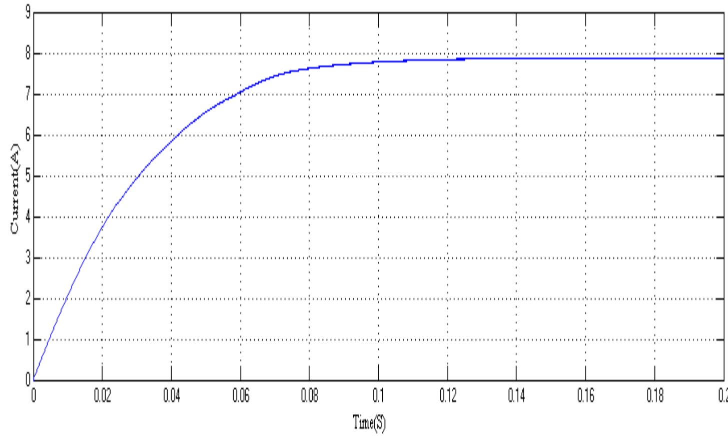

Fig.13. Current curve of PV system with Open circuit voltage MPPT control

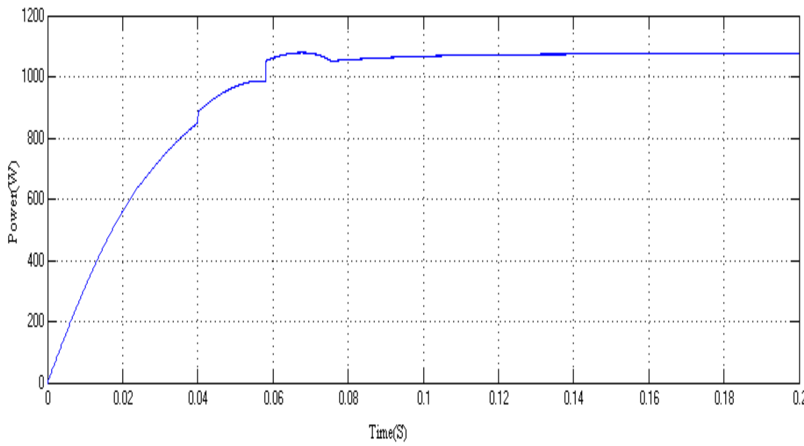

Fig.14. Power curve of PV system with Open circuit voltage MPPT control

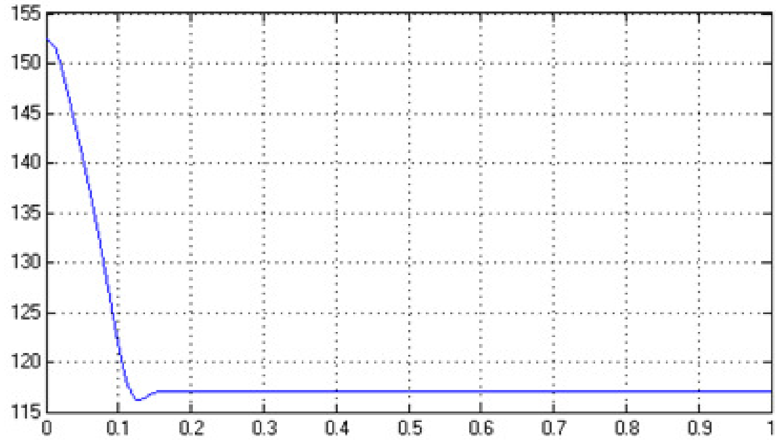

Fig.15. Voltage curve of PV system with Short circuit current MPPT control

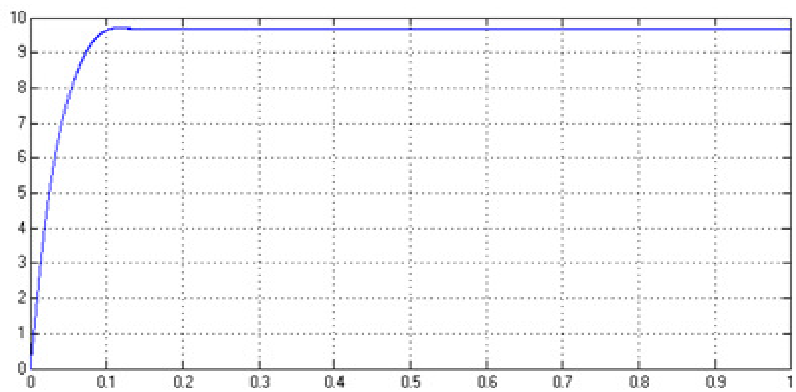

Fig.16. Current curve of PV system with Short circuit current MPPT control

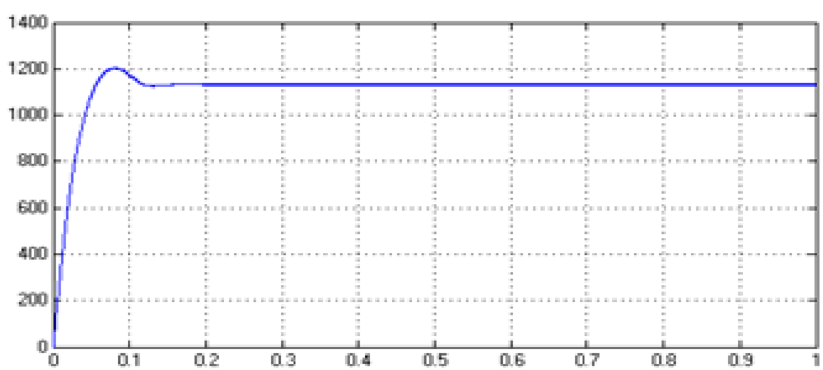

Fig.17. power curve of PV system with Short circuit current MPPT control

The Efficiency of maximum power point tracker is defined as

$$\eta_{MPPT} = \frac{\int_0^1 P_{actual}(t)}{\int_0^1 P_{\max}(t)} \quad (19)$$

Fig.12, 13 and Fig.14 shows the simulation results of Voltage, Current and Power of the Open circuit voltage method with radiation as 1000w/m^2 and with temperature as 25^{0}C. Where as Fig.15,16 and Fig.17 shows the simulation results Voltage, Current and Power of the Short circuit current method. The results clearly indicate that, the Short circuit current method is comparatively good in terms of tracking the peak power point (at that particular situation) At STC conditions (1000 w/m2, 25^{0}C), the efficiency of Open circuit voltage method is calculated using Eqn.(15) as 91.95% and for Short circuit current method as 96%. These values are relatively high and obviously validate the algorithm of the two methods. The maximum power is 1kW for the solar irradiation and temperature levels. Fig. 18, 19, 20 and 21 shows the gate pulses of the boost converter from Short Circuit Current MPPT algorithm, current, output voltage and power response of the boost converter. Fig.22 and 23are shows the output voltage and voltage with harmonic spectrum (THD = 11.59%) from five level H-bridge multilevel-inverter.

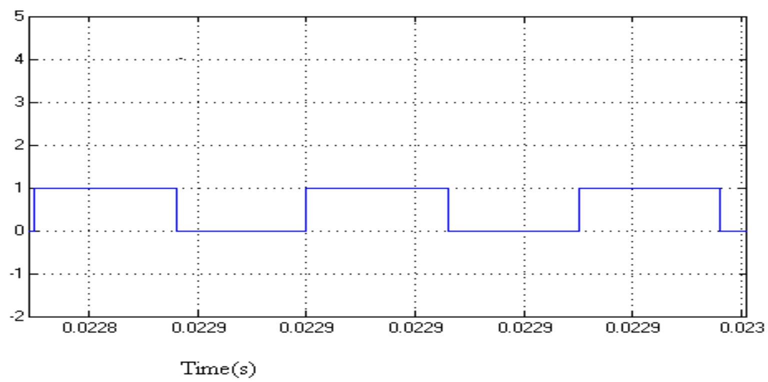

Fig. 18. Gate pulse response

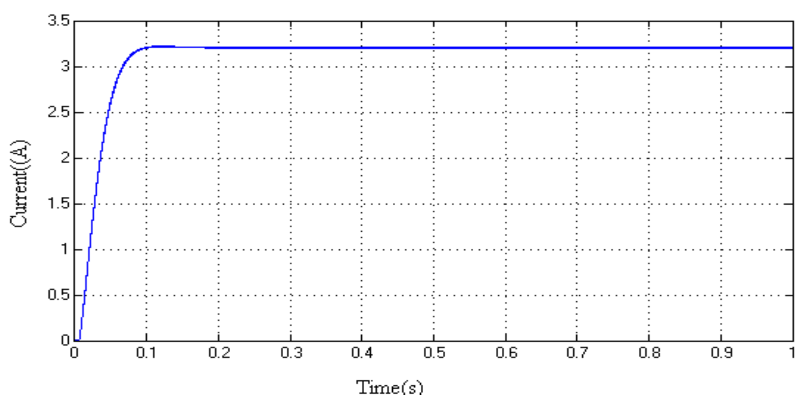

Fig. 19. Current response of boost converter

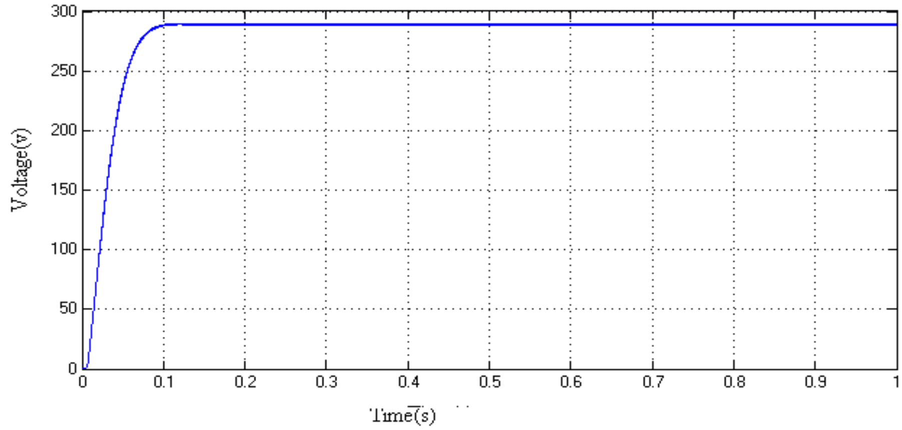

Fig. 20. Voltage response of boost converter

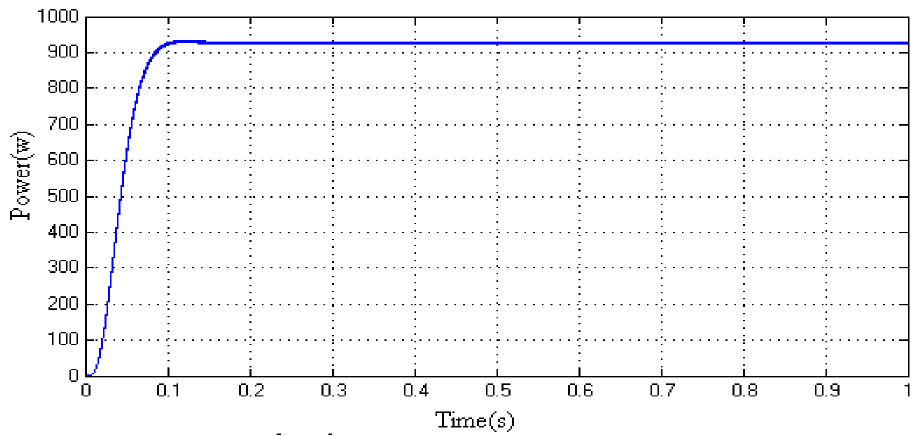

Fig. 21. Power response of boost converter

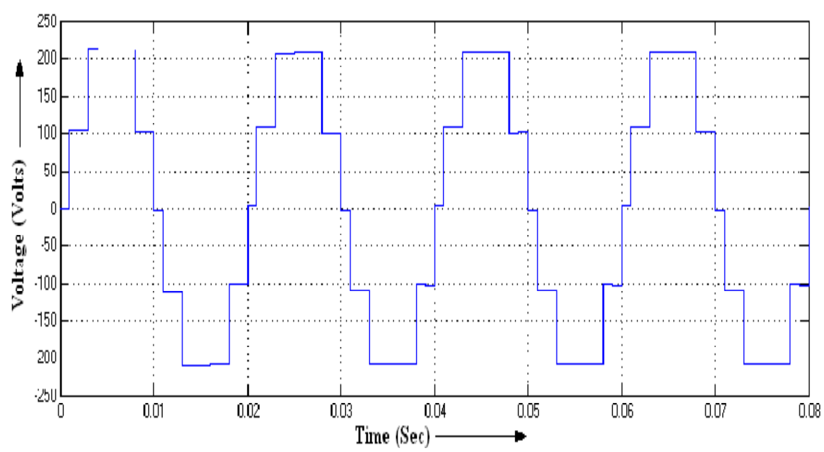

Fig. 22. Five-level output voltage of inverter.

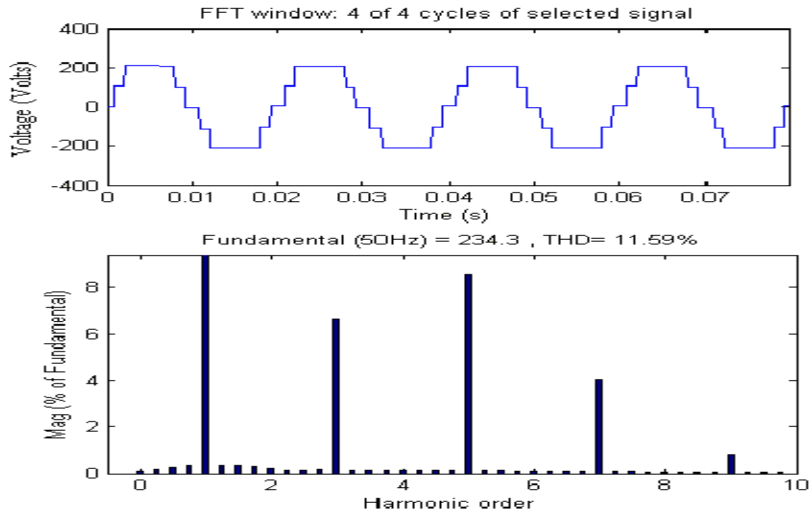

Figure.23. Output Voltage with Harmonic Spectrum (THD = 11.59%)

Table 2 Comparison Evaluation of MPPT Methods

MPPT methods	Open circuit voltage method	Short circuit current method
Voltage	136.4	117
Current	7.88	9.76
Power	1075	1132
Efficiency	90.4%	93.4%

Table 3 Comparison Evaluation of various parameters of Photovoltaic systems with MPPT methods

Irradiance W/m^2	Open circuit voltage(V)	Short Circuit current (A)	Maximum Voltage(V)	Maximum current(A)	Maximum Power(W)
1000	152.4	10	125	9.352	1169
800	150.1	8	122.7	7.436	912.39
600	147.2	6	122.5	5.445	667.01
400	143	4	116.4	3.694	429.98

V. CONCLUSIONS

The derivative of the output power P with respect to the panel voltage V is equal to zero at the maximum power point ($\partial P/\partial V = 0$). Employing Control algorithms improves flexibility and fast response. Methodology of two major open circuit voltage and short circuit current are discussed. The open circuit voltage easy to implement and offers relatively moderate efficiencies but results in unpredictable performance against rapidly changing conditions. The short circuit current method is complex and expensive when compared to open circuit voltage. However, the short circuit current method gives very high efficiencies about 96% 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 short circuit current 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 multilevel inverter topology suitable for photovoltaic applications have been presented in this paper. The cost savings is further enhanced with the proposed cascade multilevel inverters 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. Solar cells in PV array works only in part of volt-ampere characteristic near working point where maximum voltage and maximum current can be obtained. Photovoltaic system works most of time with maximum efficiency with minimum ripple and harmonics. But by using the P and O and Incremental Conductance Algorithms are easy to implement and offers relatively high efficiencies against rapidly changing conditions than above algorithms. Employing microcontroller, DSP processors improves flexibility and fast response.

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REFERENCES

[1] J Surya Kumari, Ch Sai Babu et.al, "An Enhancement of Static Performance of Multilevel Inverter for Single Phase Grid Connected Photovoltaic modules", International journal of Recent Trends in Engineering, Academy Publishers, Finland, Vol. 3, No. 3, May 2010, pp.20-24.

[2] J Surya Kumari, Ch Sai Babu et.al, " Design and Investigation of Short Circuit Current Based Maximum Power Point Tracking for Photovoltaic System" International Journal of Research and Reviews in Electrical and Computer Engineering (IJRRECE) Vol. 1, No. 2, June 2011 ISSN: 2046-5149.

[3] J Surya Kumari, Ch Sai Babu et.al, Mathematical Model of Photovoltaic System with Maximum Power Point Tracking (MPPT) International Conference on Advances in Engineering and Technology, (ICAET-2011), May 27-28, 2011.

[4] Balakrishna S, Thansoe, Nabil A, Rajamohan G, Kenneth A.S., Ling C. J.', "The Study And Evaluation Of Maximum Power Point Tracking Systems", Proceedings Of International Conference On Energy And Environment 2006 (ICEE 2006), Organized by University Tenaga Nasional, Bangi, Selangor, Malaysia; 28-30 August 2006, pp.17-22.

[5] Jawad Ahmad, "A Fractional Open Circuit Voltage Based Maximum Power Point Tracker for Photovoltaic Arrays", Proceedings of 2nd IEEE International Conference on Software Technology and Engineering, ICSTE 2010, pp. 287-250.

[6] R. Faranda, S. Leva, V. Maugeri, "MPPT techniques for PV systems: energetic and cost comparison." Proceedings of IEEE Power and Energy Society General Meeting- Conversion and Delivery of Electrical Energy in the 21st Century, 2008, pp-1-6.

[7] I.H. Altas; A.M. Sharaf, "A Photovoltaic Array Simulation Model for Matlab-Simulink GUI Environment". Proceedings of IEEE, IEEE 2007.

[8] Abu Tariq, M.S. Jamil, "Development of analog maximum power point tracker for photovoltaic panel." Proceedings of IEEE International Conference on Power Electronic Drive Systems, 2005, PEDS 2005, pp-251-255.

[9] M.A.S. Masoum, H. Dehbonei, "Theoretical and experimental analysis of photovoltaic systems with voltage and current based maximum power point trackers", IEEE Transactions on Energy Conversion, vol. 17, No. 4, pp 514-522, Dec 2002.

[10] J.H.R. Enslin, M.S. Wolf, D.B. Snyman and W. Swiegers, "Integrated photovoltaic maximum power point tracking converter", IEEE Transactions on Industrial Electronics, Vol. 44, pp-769-773, December 1997.

[11] D.Y. Lee, H.J. Noh, D.S. Hyun and I. Choy, "An improved MPPT converter using current compensation methods for small scaled pv applications." Proceedings of APEC, 2003, pp-540545.

[12] A.K. Mukerjee, Nivedita Dasgupta, "DC power supply used as photovoltaic simulator for testing MPPT algorithms.", Renewable Energy, vol. 32, no. 4, pp-587-592, 2007.

[13] Katshuhiko ogata, "MODERN CONTROL ENGINEERING" - Printice Hall of India Private Limited.

[14] Chihching Hua and ChihmingShen "Study of Maximum Power Tracking Techniques and control of DC/DC Converters for Photovoltaic Power Systems" IEEE 1998
[15] Gui-Jia Su "Multilevel DC-Link Inverter" IEEE Transactions on Energy Conversion, vol. 41, No. 3, IEEE-2005
[16] Martina Calais Vassilios G "A Transformer less Five Level Cascaded Inverter Based Single – Phase Photovoltaic Systems" IEEE-2000.
[17] D.P. Hohm, D.P, M.E. Ropp, "Comparative Study of Maximum Power Point Tracking Algorithms, Journal of Progress in Photovoltaic: Research and Applications, Wiley Interscience, vol. 11, no. 1, pp. 47-62, 2003.
[18] D.P Hohm, M.E. Ropp, Comparative Study of Maximum Power Point Tracking Algorithm Using an Experimental, Programmable, Maximum Power Point Tracking Test Bed. [Online], Available: IEEE Explore Database [12th July 2006]
[19] V. Salas, E. Olias, A. Barrado, and A. Lazaro, "review of maximum Power Point Tracking Algorithms for Standalone Photovoltaic systems." Solar Matter, Solar Cells, vol. 90, no. 11, pp. 1555-1578, July 2006.
[20] Mohammad A.S. Masoum, Hooman Dehbonei and Ewald F.Fuchs "Theoretical and Experimental Analysis of Photovoltaic System With Voltage –and Current-Based Maximum – Power- Point –Tracking IEEE Transactions on Energy conversion.Vol.17, No.4, December. 2002.
[21] Yang Chen, Jack brouwer, "A New Maximum –Power- Point –Tracking Controller for Photovoltaic Power Generation" IEEE 2003.
[22] Yeong –Chau Kuo, Tsorng-Juu Liang, Jiann-Fuh Chen "Novel Maximum –Power- Point –Tracking Controller for Photovoltaic Energy Conversion System" IEEE Transactions on Industrial Electronics.Vol.48, No.3, June 2001.
[23] K.H.Hussein, IMuta, T.Hoshino, M.Osakada, "Maximum Photovoltaic Power : an algorithm for rapidly changing atmospheric conditions" IEEE Transactions on Industrial Electronics.Vol.142, No.1, January 1995.
[24] T.J.Liang J.F.Chen, T.C.Mi, Y.C.Kuo and C.A Cheng "Study and Implemention of DSP- based Photovoltaic Energy Conversion System"2001 IEEE.
[25] Chihchiang Hua, Jongrong lin and Chihming Shen "Implemention of a DSP-Controlled Photovoltaic System with Peak Power Tracking" IEEE Transactions on Industrial Electronics.Vol.45, No.1, February

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