A Study On Novel MPPT Method Using Averaging of Voltage Ripple

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Abstract - Of two photovoltaic systems such as stand-alone type and utility interactive one, the utility interactive systems are so valuable for power peak-cut particularly in summer season. For the maximum power point tracking(MPPT) by which the generating energy can be maximized, many control methods have been reported up to now. To overcome the disadvantages of the conventional ones, a new MPPT algorithm is proposed which can improve both tracking ability and generating efficiency of photovoltaic system without chopper.

1. Introduction

The photovoltaic systems with solar cell array provide electrical energy to the utility/consumers, which are becoming one of the promising energy substitutes.
Photovoltaic systems are classified into two types as utility interactive and stand-alone photovoltaic system.
Among these systems, utility interactive photovoltaic system doesn't require battery for energy storage, but dc chopper must be used to control exact MPPT for obtaining the maximized output. Typical MPPT methods for photovoltaic system with dc chopper, are considered as constant voltage-control, the method of nonlinear function-calculation, Perturbation & Observation method (below P&O method), and Incremental Conductance method (below IncCond method). Among these methods, the basic idea of both P&O and IncCond methods, which have widely used, depends on the slope of P-V curve of solar array. In many papers, it has been proven experimentally that IncCond method is more enhanced method than P&O method .

When dc chopper is used for MPPT, the circuit and control could be complicated as well as system efficiency would be reduced. If the chopper could be eliminated, these defects could be solved.
So, in this paper a new maximum power point tracking (MPPT) method is proposed for photovoltaic system without chopper. From this proposed MPPT algorithm, the system cost could be reduced. In addition the possibility of tracking failure is tried to maintain even in case of rapidly changing atmospheric conditions.
It is verified that the proposed algorithm is superior to conventional. Moreover it is shown that the system efficiency could be enhanced without the tracking failure.

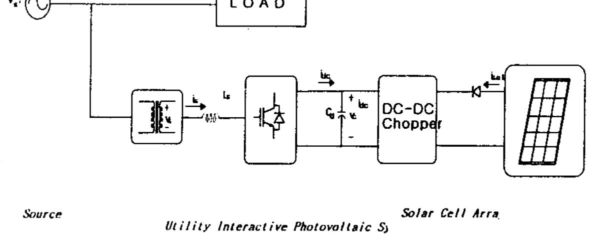
2. Utility interactive photovoltaic system

2.1 System configuration

Fig.1 shows the line interactive photo-voltaic system which is composed of isolation transformer, PWM converter, and solar array. Also dc chopper may be used depending on the system types. A transformer is used to isolate with load & utility. The goal of dc chopper used in Fig. 1(a) is to achieve MPPT and to improve power factor at AC side.
The topology shown in Fig.1(b) has the merit of simplicity. But, this topology has the limitation of solar cell output by lack of dc chopper. Without dc chopper, a PWM converter has to be designed for the function of dc chopper. But it is very difficult to track maximum power point with conventional algorithms in chopperless photovoltaic system.

2.2 Output characteristics of solar cell

The electric power generated by a solar array fluctuates depending on the variation of solar radiation and temperature, as shown in Fig2,3. It could be known that the variance of solar radiation influences the radiation current.
Also, the radiation current increases before cell voltage arrives at maximum power point. The solar array is nonlinear device and can be regarded as current source.



(a) with chopper

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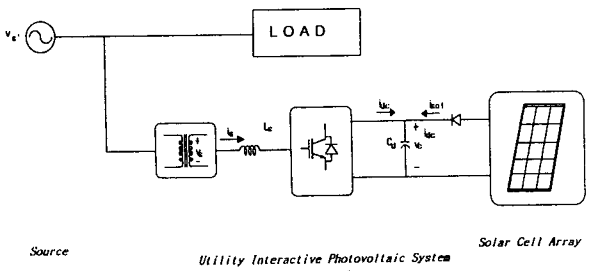


(b)without chopper

Fig. 1 Utility interactive photovoltaic system.

When the internal shunt resistance is neglected, the I-V characteristics of solar array is given by the following equation :

$$I_o = I_g - I_{sat}\left\{\exp\left[\frac{q}{AKT}(V_0 + I_0 R_s)\right] - 1\right\} \quad (1)$$

Here,

I_0 : the output current of the solar array

V_o : the output voltage of the solar array

I_g : the generated current under a given insolation

I_{sat} : the reverse saturation current

q :the charge of an electron

K : the Boltzmann's constant

A : the ideality factor for a p-n junction

T : the temperature(K)

Rs : the intrinsic series resistance of the solar array.

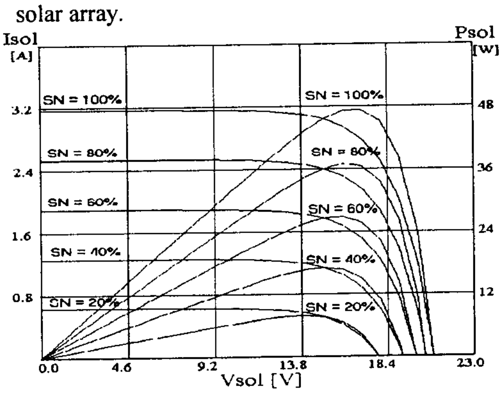


Fig. 2 Output characteristics of photovoltaic cell according to the intensity of radiation. (SN: standard radiation energy)

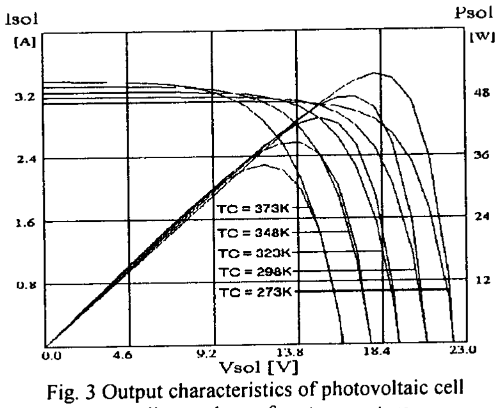


Fig. 3 Output characteristics of photovoltaic cell according to the surface temperature.

3. MPPT algorithm

The purpose of the MPPT is to move the array operating voltage close to the maximum power point under changing atmospheric conditions. Like Fig.4 many methods for tracking maximum power point have been proposed up to now. Generally two algorithms are mainly used to achieve the MPPT. One is perturbation and observation (P&O) method and the other is incremental conductance (IncCond) method.

The flow chart to implement these algorithms is shown Fig. 5.

3.1 Conventional algorithms

1. Perturbation and observation method

In this method, the peak power point is tracked by periodic increase / decrease of the array voltage. If a given perturbation leads to an increase in array power, the subsequent perturbation is made in the same direction. However this method doesn't consider the case that perturbation voltage is zero.

2. Incremental conductance method

The array voltage can be adjusted to the maximum power point voltage by measuring the incremental and instantaneous array conductance (dI/dV and I/V, respectively). Although the incremental conductance method offers good performance under rapidly changing atmospheric conditions, the drawback is a large amount of power loss.

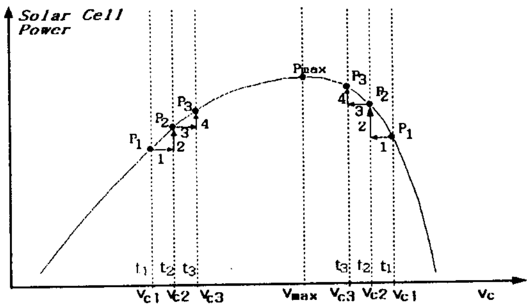
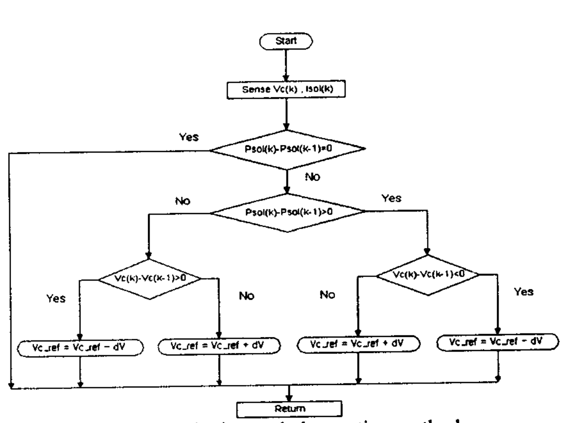
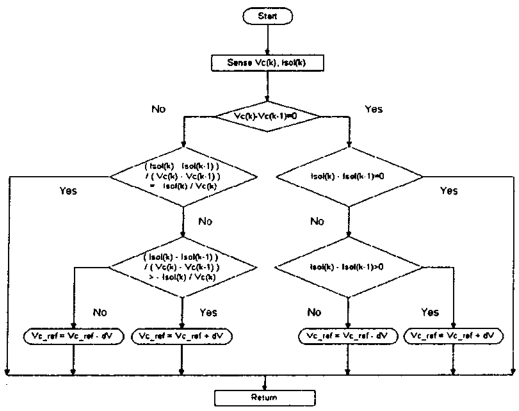


Fig. 4 MPPT operation.



(a) Perturbation and observation method



(b) Incremental conductance method
Fig. 5 Control flow chart.

3.2 Tracking failures

Both P&O and IncCond method is based upon the assumption that solar radiation is constant. As the solar radiation varies at each time it is difficult to track maximum power point exactly. The tracking failure is described in Fig.6.

Suppose that a controller has longer MPPT period than the period of solar radiation and thus reference voltage changes a bit. Then tracking possibility is determined by solar cell power with respect to dc link voltage.

When a point A moves to a point B in left side of Fig.6, it is natural that a controller considers the decrease of dc link voltage as the increase of the solar cell output. But it means the failure of MPPT and the reference voltage of dc link moves to the opposite direction of maximum power point.

In other case a tracking failure can be investigated like Fig. 7. It results from the voltage ripple of dc link. Although dc link voltage(Vc) for MPPT is selected, voltage ripple in dc capacitor prevents solar cell from operating in maximum power point.

Namely when Vc-Vr is sensed due to voltage ripple, the reference voltage of dc link moves to the opposite direction of maximum power point too. Particularly this appearance is serious in case photovoltaic system without dc chopper.

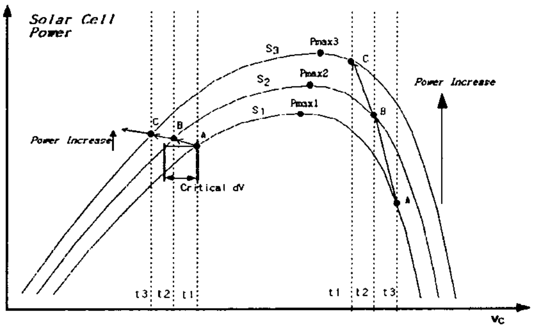


Fig. 6 Tracking failure (I).
(due to the variation of solar radiation)

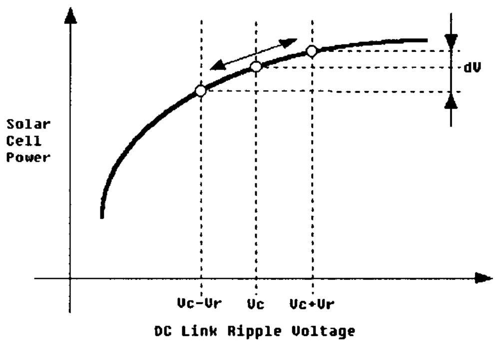


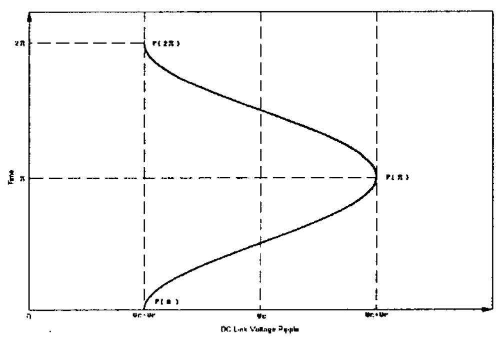
Fig. 7 Tracking failure (II)
(due to dc link ripple voltage)

4. Proposed MPPT algorithm

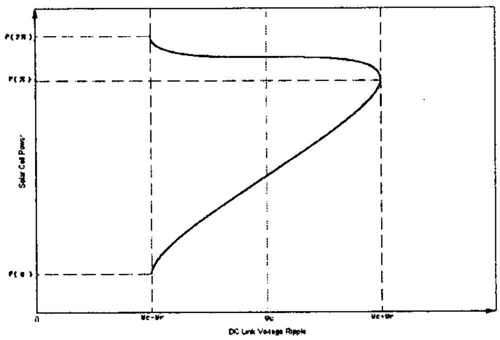
The object of proposed MPPT is to prevent the tracking failure due to the variation of solar radiation and dc link ripple voltage. A new MPPT algorithm uses the ripple voltage of dc link, which uses the moving average method. By computing the slope of P-V curve during a MPPT period, the averaging slope of P-V curve can be obtained.

To describe a new MPPT, it is assumed that the variation of solar radiation and cell temperature are constant, the shape of dc voltage ripple is sinusoidal and the slope of P-V curve is constant. Voltage ripple section is defined from Vc+Vr to Vc-Vr and then P-V curve is approximated as a linear equation (P=aV+b). Accordingly, (2) is deduced from Fig. 4-1, and is defined for a period of dc ripple voltage. Also, to consider the variation of solar radiation in PV coordinates, (3) is deduced, and is plotted in Fig.9. Through a differential expression, the slope of P-V curve for dc ripple voltage can be obtained as (4) and also be plotted as Fig. 10.

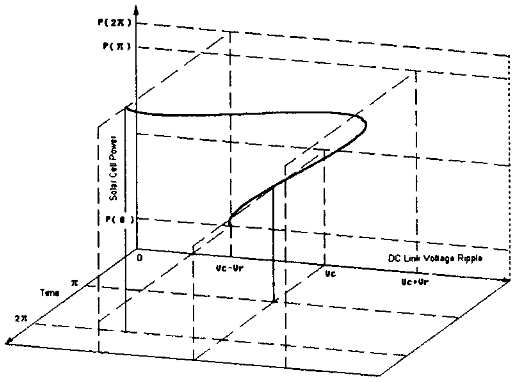
Through the equations mentioned above, PV slope can be deduced as (7). As the right term of (7) has symmetric condition, the averaging value of P-V slope is **k** during a ripple period. In result, the sign of **k** determines the direction for maximum power point. The symmetric term in (7) is shown in Fig.9 . By the integration of the term during ripple period, the slope of PV curve has a constant value (**k**).



(a) dc link ripple voltage



(b) dc link ripple voltage at changing radiation



(c) dc link ripple voltage at changing radiation and time
Fig. 8 dc link ripple voltage

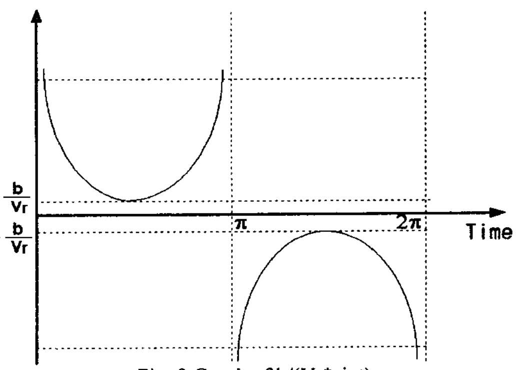


Fig. 9 Graph of b/(Vr*sint)

$$V(t) = -V_r \cos t + V_C \quad (2)$$

$$P(V,t) = kV(t) + bt \quad (3)$$

$$\frac{dP(V,t)}{dt} = k\frac{dV(t)}{dt} + b \quad (4)$$

$$\frac{dV(t)}{dt} = V_r \sin t \quad (5)$$

$$\therefore \frac{dP(t)}{dt} = kV_r \sin t + b \quad (6)$$

$$\therefore \frac{dP(t)}{dV(t)} = k + \frac{b}{V_r \sin t} \quad (7)$$

The flow chart of a new MPPT is made to implement a new MPPT method in Fig.10. The function in process is the calculation of PV slope(ℵ), average value of the PV slope(Ʒ) and the redefinition of reference voltage.

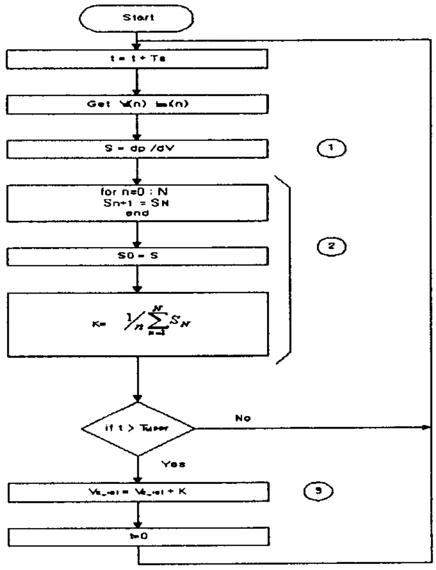


Fig. 10 Flow chart of a new MPPT

5. Results

5.1 Simulation

To evaluate a new MPPT algorithm, digital simulation is accomplished and that the sampling frequency is set to 10[kHz]. Constant step P&O method, variable step P&O method and constant step IncCond method are compared with a new MPPT respectively. To evaluate the accuracy of MPPT, we can compare the quantitative results by calculating the variance as shown in Fig. 12. The simulation conditions are shown in Table 1 and the surface temperature of solar cell is 298K(25℃) assuming its variation is small.

Table 1. System Parameter

Source voltage(primary)	**220[V]**
Source voltage(secondary)	**140[V]**
Dc capacitor	**7050[uF]**
Input reactor	**2[mH]**
Equivalent resistance of input	**0.6[Ω]**
Voltage controller (P gain)	**1**
Voltage controller (I gain)	**20**
Constant voltage step	**3[V]**

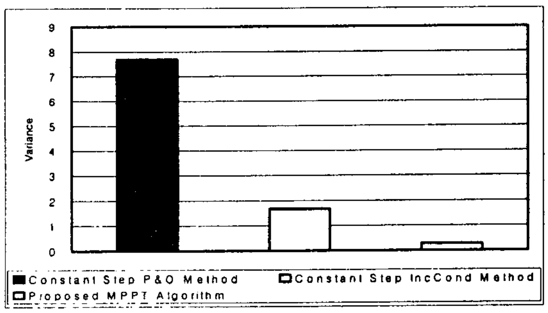
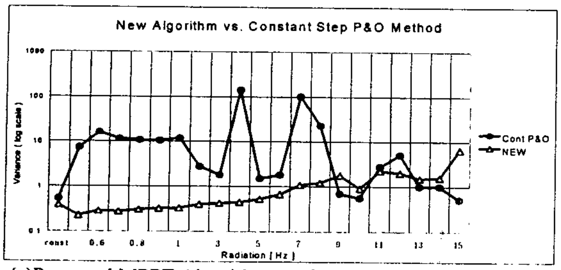
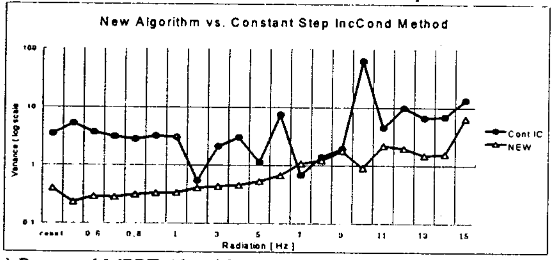


Fig. 11 Comparison of variance .



(a)Proposed MPPT Algorithm vs. Constant Step P&O Method



(b) Proposed MPPT Algorithm vs. Constant Step IncCond Method
Fig. 12 Standard deviation with respect to radiation frequency

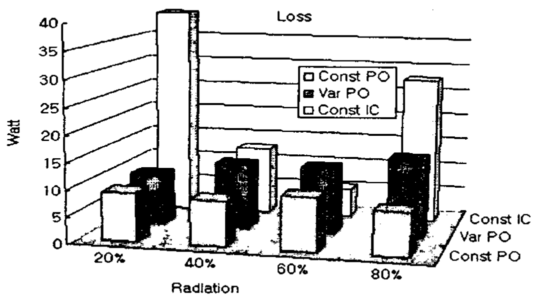
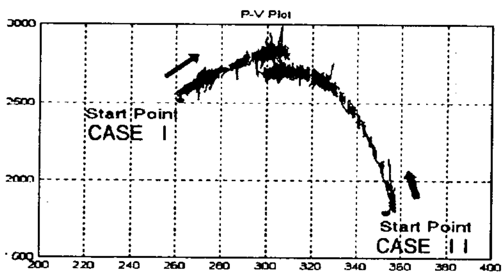


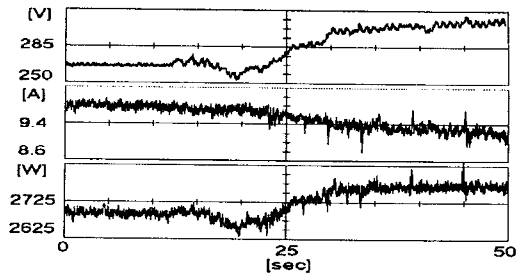
Fig. 13 Loss of radiation in conventional algorithm, compared with proposed algorithm.

5.2 Experiment

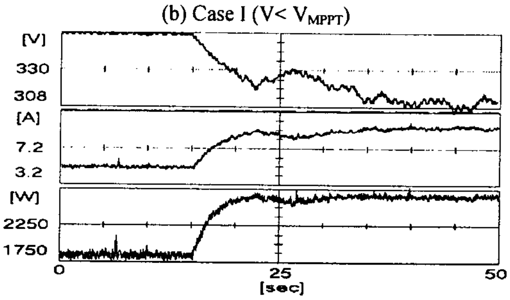
The experimental results of MPPT are shown in Fig. 14. We can confirm the exact operation for MPPT in the higher and the lower voltage than that of the maximum power from Fig.14. Fig.14(b) shows the tracking of maximum power in the left side of maximum power point. Fig.14(c) shows the tracking of maximum power in the right side of maximum power point. The accuracy of MPPT can be verified by executing simulation because it is difficult to know the experimental results quantitatively. From Input voltage & current waveform of photovoltaic system, it is noted that power flows from solar-cell to utility or load and that power factor is being improved.as shown in Fig.15.



(a) MPPT operation



(b) Case I (V< V_{MPPT})



(c) Case II(V>V_{MPPT})
Fig. 14 Trace of MPPT

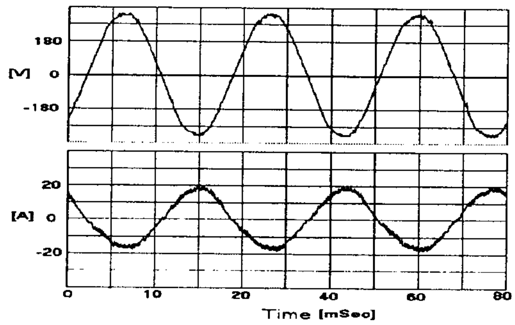


Fig. 15 Input voltage & current waveform

6. Conclusion

The utility interactive photovoltaic system without chopper is quantitatively investigated using a new MPPT algorithm. The results obtained can be summarized as follows.

1)Utility interactive photovoltaic system without dc chopper was constructed for high system efficiency

2)Tracking performance was improved under atmospheric changes.

3)Through variance, tracking performance was verified.

4)Stable operation was confirmed through the simulation and experiment for photovoltaic generation

The results obtained in this paper provide efficient method for utility interactive photovoltaic system.
This system is superior to conventional one. Also the output power of solar array increases in condition of the same weather.

Acknowledgement

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Reference

[1] J. S. Gho, et al., "Design of Anti-islanding Algorithm for Utility Interactive Photovoltaic System", KIEE95, pp 440-442, 1995.
[2] Y. J. Joe, et al., "Source Side Power Factor Correction for Utility Interactive Photovoltaic System", PEAC1997, pp386-392, 1997.
[3] S. Y. Lee, et al., "Analysis and Design of Utility Interactive Photovoltaic System with Source Side VAR Compensation", PEAC1999, pp1328-1331, 1997.
[4] H. Dong, H. Sugimoto, "A New Utility Interactive Photovoltaic Power Conditioning System And Its Maximum Power Tracking Control", IPEMC97, PP 238-243, 1997.
[5] C. Hua, C. Shen, "Control of DC Converter for Solar Energy System with Maximum Power Tracking", Proceedings of the 23rd International Conference on Industrial Electronics, Control, and Instrumentation Vol. 2, 1997.
[6] C. Hua, C. Shen, J. Lin, "Implementation of a DSP-Controlled Photovoltaic System with Peak Power Tracking", IEEE Trans. on Industrial Electronics, Vol. 45, No 1, PP 99-107, 1998.
[7] K.H. Hussein, I. Muta, T. Hoshino, M. Osakada, "Maximum Photovoltaic Power Tracking: An Algorithm for Rapidly Changing Atmospheric Conditions", IEE Proceedings Generation Transmission & Distribution, Vol. 142, No 1, 1995.
[8] U. Herrmann, H. G. Langer, "Low Cost DC to AC Converter for Photovoltaic Power Conversion in Residential Applications", PESC 93, PP 588-594, 1993.