Analysis and simulation of maximum power point tracker of photovoltaic system using fuzzy logic controller.

A. Borni, R. Chenni & L. Zarour
Laboratoire d'électrotechnique, Faculty of sciences engineering
University Mentouri of Constantine. Algeria
rachid.chenni@gmx.fr, Borni.abdelhalim@yahoo.fr

Abstract.

This paper aims at deriving the maximum power output from the Photovoltaic (PV) panel by using a
Maximum Power Point Tracking (MPPT). A fuzzy controller is designed to control the DC-DC Converter that much between the photovoltaic generator and the load through it's variable duty cycle and PWM technique. An appropriate incremental conductance method is used to achieve the Maximum Power Point at different operating conditions of temperature and irradiance. This simulating manner of such system has allowed us to develop a computer model with Simulink / Matlab software making possible to analyze the performance of the whole system under varying conditions with load fluctuation.

Key words*:* Solar energy, photovoltaic arrays modelling, optimization, fuzzy logic, MPPT.

1- INTRODUCTION.

Photovoltaic (PV) generation systems have two big problems that the efficiency of electric power generation is very low, especially under low irradiation states and the amount of the electric power generated by solar arrays is always changing with weather conditions, i.e., the intensity of the solar radiation (irradiation). A maximum power point tracking (MPPT) method which has quick response characteristics and is able to make good use of the electric power generated in any weather is needed to solve the former problem. Many MPPT control methods have been proposed that search for the maximum operating conditions from the output power and voltage characteristics of solar arrays using differential techniques like perturb and observe [5], incremental conductance [6], parasitic capacitance [7], constant voltage [8], neural network [9] and fuzzy logic controller (FLC) [9, 10]. These strategies have some disadvantages such as high cost, difficulty, complexity and instability.

The Proposed MPPT system is studied through simulation model where the optimization control is doing by adjusting the duty ratio of MOSFET DC-DC buck converter, then a comparison between P & O and fuzzy logic method is presented to show the more effective method .problem that the smaller change of duty ratio is, the closer maximum power point, however there will be an increase in the time required by the system to reach equilibrium.

2- ELECTRICAL MODEL OF A PHOTOVOLTAIC CELL.

Solar cells are basically p-n junctions. In the dark, their *I-V* characteristic is similar to that of a diode. Most of the models used in the literature include an ideal diode, related to the junction behavior, and a series resistance, taking into account the ohmic losses. We obtain then the equivalent circuit shown in figure 1. [1].

The equation describing the *I-V* cell characteristics is given by:

$$I = I_L - I_0\,[\exp\left(\frac{q\left(V + R_S.I\right)}{\gamma.K.T_c}\right) - 1] \qquad \textbf{(1)}$$

Where: I_L, I_0, I, V, are the photocurrent, saturation current, Operating current and voltage, Rs and γ are series resistance and diode quality which depend on the incident solar irradiation and the cell's temperature respectively .At a given temperature, the chosen cell model (or four parameters model) studied in this paper has four parameters to define :I_L, I_0, γ and R_S.

If we have V_{oc} the open-circuit voltage, V_p and I_p the voltage and the current at the maximum power point, and I_{sc} the short-circuit current, the equation (1) becomes at the reference conditions of irradiation and temperature as follows:

$$\begin{cases} I_{L,ref} - I_{0,ref}[\exp\left(\frac{q.V_{oc,ref}}{\gamma.K.T_{c,ref}}\right) - 1] = 0 \\ I_{mp,ref} = I_{L,ref} - I_{0,ref}[\exp\left(\frac{q\left(V_{mp,ref} + R_s.I_{mp,ref}\right)}{\gamma.K.T_{c,ref}}\right) - 1] \\ I_{sc,ref} = I_{L,ref} - I_{0,ref}[\exp\frac{q.R_s.I_{sc,ref}}{\gamma.K.T_{c,ref}} - 1] \end{cases} \qquad \textbf{(2)}$$

As we have only three known points on the characteristic, the fourth point can be got from the maximum point Power point ($P = V.I$).

The maximum power is obtained when $\left(\frac{dP}{dV} = \frac{d}{dV}(V.I) = 0\right)$

Applying the reference conditions allow us to get:

$$\frac{I_{mp,ref}}{V_{mp,ref}} - I_{0,ref}\left(\frac{\frac{\left(1 - R_S \cdot I_{mp,ref} / V_{mp,ref}\right)}{\gamma.K.T_{c,ref}}}{\gamma.K.T_{c,ref}}\right). \exp\left(q.\left(V_{mp,ref} + R_s.I_{mp,ref}\right)/\gamma.K.T_{c,ref}\right) = 0 \quad \textbf{(3)}$$

1. THERMAL BEHAVIOR

The junction temperature is explicitly presented in the equation (1). However, the main effect of the temperature is on I_0. The following expression for the I_0 dependence temperature is an extension of expressions frequently encountered in the literature: [14]

$$I_0 = I_{0,ref}\left(\frac{T_c}{T_{c,ref}}\right)^{3/\gamma'} .\exp\left(\frac{q}{\gamma.K}\left(\frac{E_{g\,ref}}{T_{c,ref}} - \frac{E_g}{Tc}\right)\right) \quad \textbf{(4)}$$

Where E_g is the band gap energy of the semiconductor material.

Equation (4) is an extension for two raisons. First of all, most of the authors assume that γ' and γ are identical. However, as mentioned above, more sophisticated models use several exponential terms of the form (1), (4). In some of that terms, one has effectively $\gamma = \gamma'$, but it is not the case for all the term.

$E_{g\ ref} = E_g$ and simplify the last expression in brackets in (4). This is equivalent to assume E_g independent of the temperature. In fact, E_g is a function of the temperature. In the case of the crystalline silicon, an analytic approximation of E_g as a function of the temperature can be found [14]. This approximation has been used in the present study.

If we adopt the expression (4), we can deduce by derivation

$$\left.\frac{\partial I_0}{\partial T_c}\right|_{ref} = I_{0,ref}\left(\frac{3}{\gamma.T_{c,ref}}\right) - I_{0,ref}\left(\frac{q}{\gamma.K.T_{c,ref}}\right)\left.\frac{\partial E_g}{\partial T_c}\right|_{ref} \quad \textbf{(5)}$$

The thermal variation of the *I-V* characteristic of the cell depends of three parameters which have not yet been determined, namely γ', $\partial I_L / \partial T_c$ and $\partial R_S / \partial T_c$. In this paper, we want to determine the thermal behavior using only the two nominal value $\partial V_{oc} / \partial T_c |_{ref}$ and $\partial I_{sc} / \partial T_c |_{ref}$. It is thus possible to determine only two parameters. For that raison, we have fixed arbitrarily the value of $\partial R_S / \partial T_c$ (fixed to zero in the numerical example). The two other parameters can then be determined as described below. The derivative of (1) gives

$$\frac{\partial I}{\partial T_c} = \frac{\partial I_L}{\partial T_c} - \frac{\partial I_0}{\partial T_c}.[\exp\left(\frac{q\left(V + R_s.I_{sc}\right)}{\gamma.K.T_c}\right) - 1] + I_0\left(\frac{q}{\gamma.K.T_c}\right)\left(\frac{\partial V}{\partial T_c} + \frac{\partial R_s}{\partial T_c} I_{sc} + R_s\frac{\partial I_{sc}}{\partial T_c} - \frac{V + R_s.I_{sc}}{T_c}\right).\exp\left(\frac{q\left(V + R_S.I_{sc}\right)}{\gamma.K.T_c}\right) \quad \textbf{(6)}$$

At the short-circuit point, (4) gives

$$\left.\frac{\partial I_{sc}}{\partial T_c}\right|_{ref} = \left.\frac{\partial I_L}{\partial T_c}\right|_{ref} - \left.\frac{\partial I_0}{\partial T_c}\right|_{ref} [\exp\left(\frac{q R_{s,ref} I_{sc,ref}}{\gamma.K.T_{c,ref}}\right) - 1]$$

$$+ I_{0,ref}\left(\frac{q}{\gamma.K.T_{c,ref}}\right)\left(\left.\frac{\partial R_s}{\partial T_c}\right|_{ref} I_{sc,ref} + R_{s,ref}\left.\frac{\partial I_{sc}}{\partial T_c}\right|_{ref}\right).\exp\left(\frac{q R_{s,ref} I_{sc,ref}}{\gamma K T_{c,ref}}\right) \quad \textbf{(7)}$$

On an other hand, at the open circuit point, (4) gives

$$\left.\frac{\partial I_L}{\partial T_c}\right|_{ref} - \left.\frac{\partial I_0}{\partial T_c}\right|_{ref} . [\exp\left(\frac{q.V_{oc,ref}}{\gamma K T_{c,ref}}\right) - 1] +$$

$$I_{0ref}\left(\frac{q}{\gamma.KT_{cref}}\right)\left(\frac{\partial V_{oc}}{\partial T_c}\bigg|_{ref}-\frac{V_{oc,ref}}{T_{cref}}\right)\exp\left(\frac{qV_{oc,ref}}{\gamma.KT_{cref}}\right)=0 \quad \textbf{(8)}$$

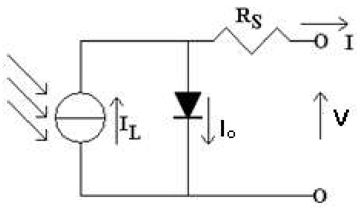

Fig .1. Equivalent circuit of PV cell

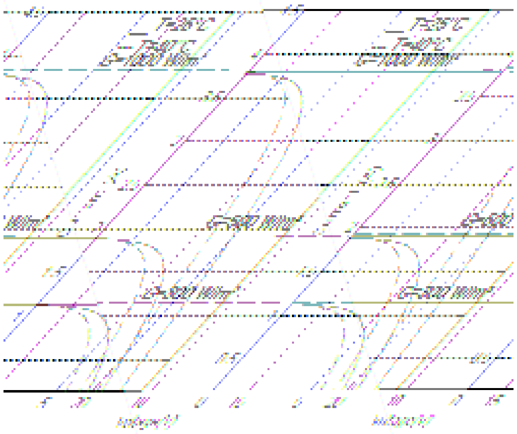

Fig.2. PV characteristics T2=25°C, T3=40°C.

3- STEP-UP CONVERTER FOR MPPT.

In order to minimize the long-term system loses, it is required that the converter input current has very small ripple and conversion efficiency and very high even at part load. Therefore is the installation of converter DC-DC.

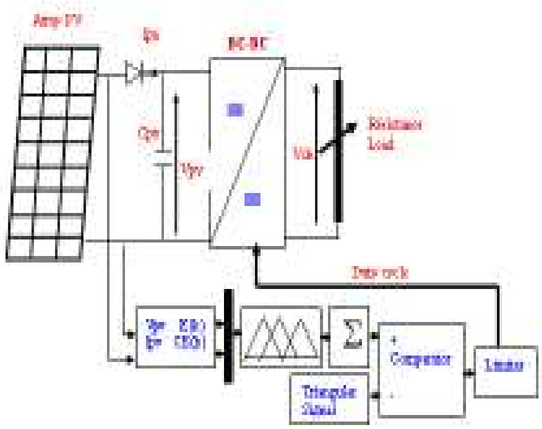

Fig. 3. Control global system PV aliment load resistance

4- FUZZIFICATION.

The actual voltage and current of PV arrays can be measured continuously on A/D converter. We have focused on single input, single output plant in which control is determined on the basis of satisfaction of two criteria relating to the two input variables error (E) and change error (CE). The variable E and (CE) as expressed as follows:

$$E(K) = \frac{P_{pv}(k+1) - P_{pv}(k)}{i_{pv}(k+1) - i_{pv}(k)} \quad \textbf{(9)}$$

$$CE(K) = E(k+1) - E(k) \quad \textbf{(10)}$$

Where $P_{pv}(k), i_{pv}(k)$ are the power and current of the PV array respectively, there for $E(k)$ is zeros at the maximum power point of PV array.

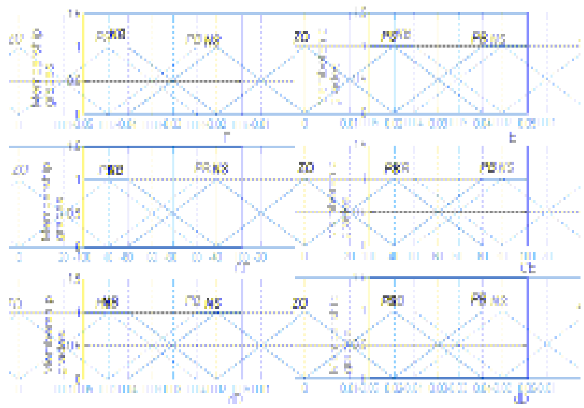

Fig. 4. Memberships function for E, CE, and dD.

Shows the rule table of fuzzy controller, where all the entries of the matrix are fuzzy sets of error, change error and duty cycle dD of the chopper. The control rule must be designed in order that input variable E has to always be zeros.

E	CE	NB	NS	ZE	PS	PB
NB		ZE	ZE	PB	PB	PB
NS		ZE	ZE	PB	PB	PB
ZE		PS	ZE	ZE	ZE	NS
PS		NS	NS	NS	ZE	ZE
PB		NB	NB	NB	ZE	ZE

Fig. 5. Table rule.

5- DEFUZZIFICATION.

The final combined fuzzy set is defined by the union of all rule output fuzzy set using the maximum aggregation method .for a sampled data representation, the center of gravity dD_o is computed point wise by.

$$dD_o = \frac{\sum_{j=1}^{n} \mu(D_j) - D_j}{\sum_{j=1}^{n} \mu(D_j)} \qquad \textbf{(11)}$$

Recently fuzzy logic controllers have been introduced in the tracking of the MPPT in PV systems [11-12]. They have the advantage to be robust and relatively simple to design as they do not require the knowledge of the exact model. They do require in the other hand the complete knowledge of the operation of the PV system by the designer.

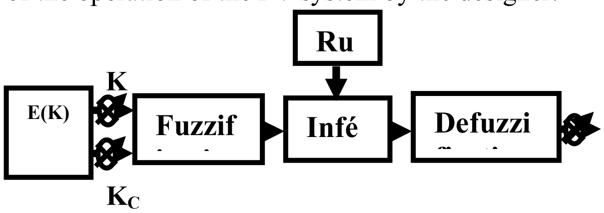

Fig.6. Memberships function for E, CE, and dD_o.

6- SIMULATION RESULTS AND DISCUSSION.

In this section the simulation results of the optimization of a photovoltaic are presented. All the parameters of the photovoltaic system components are depicted in the Appendix A.

If we applied during 0.3 sec each one three levels of irradiation and two temperature *G*=300W/m², *G*=500W/m² and the third level corresponding to *G*=1000W/m² and the temperature *T*=25°C and *T*=40°C.

For application of the two optimisation method (MPPT) incremental conductance and fuzzy logic, the third stage of radiation corresponding to *G*=1000W/m² at the optimization have no effect on the various studied quantities. Fig (7), Fig (8)

The different components corresponding to once and the second stage of radiation are low; the optimization has a remarkable effect on the various studied quantities. (Table.1)

Simulation results are carried out to verify control of dynamic performance, One notes that the fuzzy logic technique is more performing that incremental conductance technique or response time by incremental conductance is bigger by method (FL) contribution, see Fig (7) and Fig (8), so the abrupt irradiation change has *T*=5°C, the results that gotten by remained always fuzzy logic better that once method, years here or the temperature changes has *T*=45°C, the mistake by the method of (incremental conductance) goes increases but by (FL) remains better.

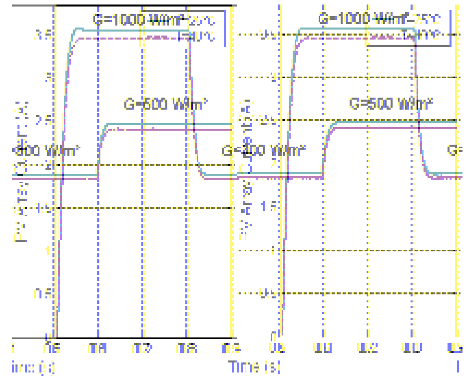

Fig 7. a PV array current fuzzy logic

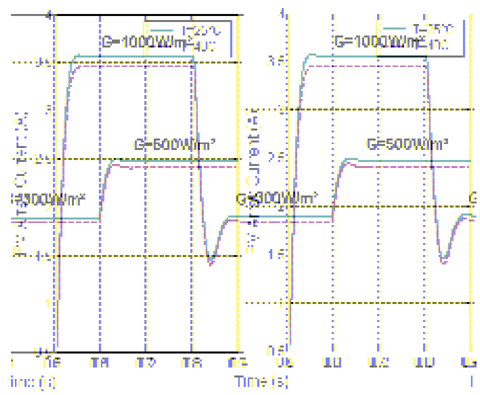

Fig 8.a- PV array current INC

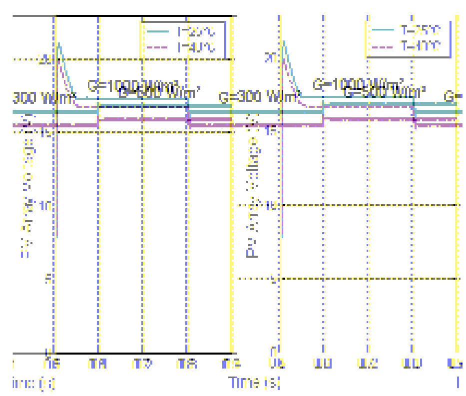

Fig 7. b. PV array voltage fuzzy

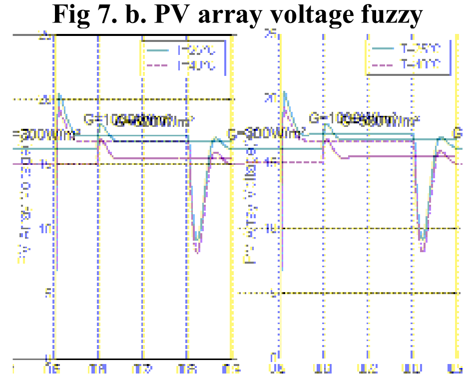

Fig 8.b. PV array voltage INC

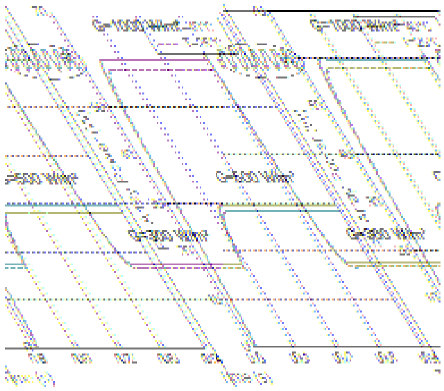

Fig 7. c. PV array power fuzzy

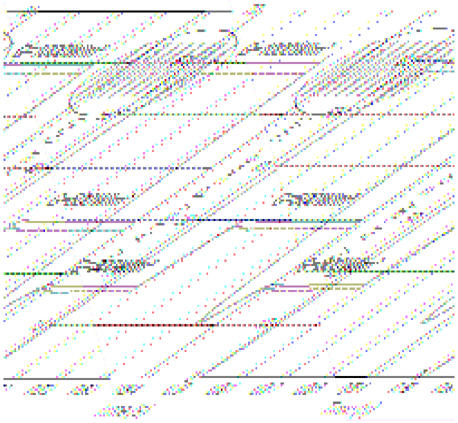

Fig 8.c. PV array power.INC

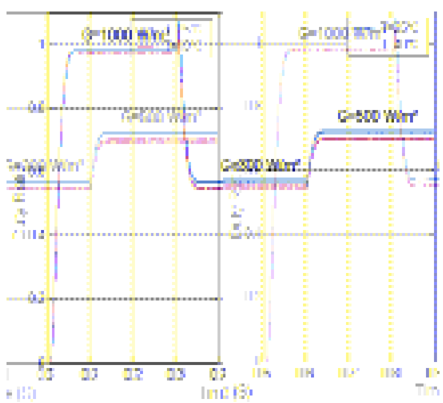

Fig 7. d. Duty ratio.fuzzy

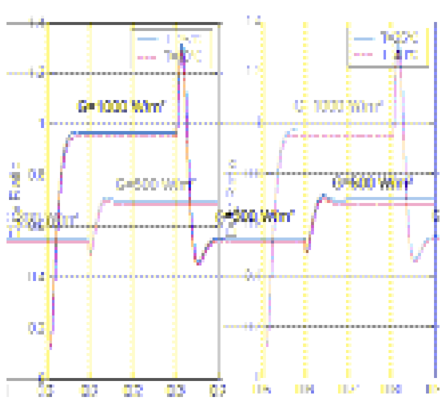

Fig 8.d. Duty ratio.INC

7- CONCLUSION

We showed the principal characteristics of a photovoltaic system allowing the resistance load with solar energy. A photovoltaic generator outputting on an electronic power inverter detecting the working optimal point, is presented. The electric model of the system is simulated using the software MATLAB 6p5 for various solar irradiation and temperatures.

This paper has presented the Fuzzy Logic and incremental conductance method for controlling MPPT of a load Photovoltaic system. The simulation resultants show that this system is able to adapt the fuzzy parameters for fast response, good transient performance, insensitive to variations in external disturbances. In addition, the resultants of simulation have shown that MPPT controllers by using Fuzzy Logic provided more power than conventional.

8- APPENDIX and PV Array Characteristics

ZO (zero), **PB** (Positive big), **PB** (Positive small), **NS** (negative small), **NB** (negative big)

PV generator, AM=1.5. K =$1.08.10^{23}$J/K, P_{max}=60W, $V_{oc,ref}$=21.5V, Isc =3.4A, I_{mpref} =3.5A, V_{mpref} =17.1V.

G_{ref} =1000 W/m², T_{ref}=298°K, μIsc =3.10^{-3} A/°C, μ_{Voc} =-82. 10^{-5} V/°C.

9- REFERENCES

[1] J.Appelbaum and J. Bany, "Performance Characteristics of a Permanent Magnet DC Motor Powered by Solar Cells" *Sol. Energy*22, 439 (1979).

[2] Townsend, Timothy U. "A Method for Estimating the Long-Term Performance of Direct-Coupled photovoltaic Systems". M. S. Thesis. Solar Energy Laboratory, University of Wisconsin,Madison 1989.

[3] J. Eckstein, J. Helmut. "Detailed Modeling of Photovoltaic Components". M. S. Thesis Solar Energy Laboratory, University of Wisconsin, Madison: 1990.

[4] Fry, Bryan "Simulation of grid-tied building integrated Photovoltaic systems" M. S. Thesis SolarEnergy, Laboratory, University of Wisconsin, Madison: 1998.

[**5**] H ohm DP, Ropp ME." Comparative study of maximum power point tracking algorithm using an experimental, programmable, maximum power point tracking test bed". Proc 28th IEEE photovoltaic Specialist Conf 2000; 28:1699–702.

[6] Swiegers W, Enslin J. An integrated maximum power point tracker for photovoltaic panels. Proc IEEE Int Symp Ind Electron 1998;1:40–4.

[7] Hiyama T, Kitabayashi K. Neural network based estimation of maximum power generation from PVmodule using environment information. IEEE Trans Energy Conver 1997; 12(3):241–7.
[8]HiyamaT, KouzumaS, ImakuboT, Ortmeyer, TH.Evaluation of neural network based real time maximum power tracking controller for PV system. IEEE Trans Energy Conversion 1995;10 (3):543–8.
[9] Won CY, Kim DH, A new maximum power point tracker of photovoltaic arrays using fuzzy controller. Proc Annu IEEE Power Electron Specialists Conf 1994; 396–403.
[10] SenjyuT, Uezato K." Maximum power point tracker using fuzzy control for photovoltaic arrays "Proc IEEE Int Conf Ind Technol 1994; 143–7.
[11] BP Solar datasheets, http://www.windsun.com/PV_Stuff/Solar_Panel_PDF.htm
[12] Basic source code used in this paper http://www.lei.ucl.ac.be/~matagne/SOLAIRE/PARCELL1.BAS

Irradiation G (W/m²)			**G=300 W/m²**	**Error (%)**	**G=500 W/m²**	**Error (%)**	**G=1000 W/m²**	**Error (%)**
MPPT (P&O)	T=278K°	Ipv (A)	1	1.00	1.755	2.15	3.49	0.28
		Ppv W)	16.55	0.18	27.36	5.21	60.9	0.01
	T=318K°	Ipv (A)	0.96	5.88	1.685	0.89	3.3	4.890.
		Ppv(W)	15.9	4.67	28.84	5.37	57.81	1.85
Fuzzy MPPT	T=278K°	Ipv (A)	1.09	9.00	1.8	4.77	3.54	1.72
		Ppv (W)	15.85	6.03	27.5	4.71	60.71	0.31
	T=318K°	**Ipv (A)**	**1.065**	**4.41**	**1.83**	**9.58**	**3.46**	**0.28**
		Ppv (W)	**15.45**	**0.706**	**27.1**	**0.98**	**58.5**	**0.67**

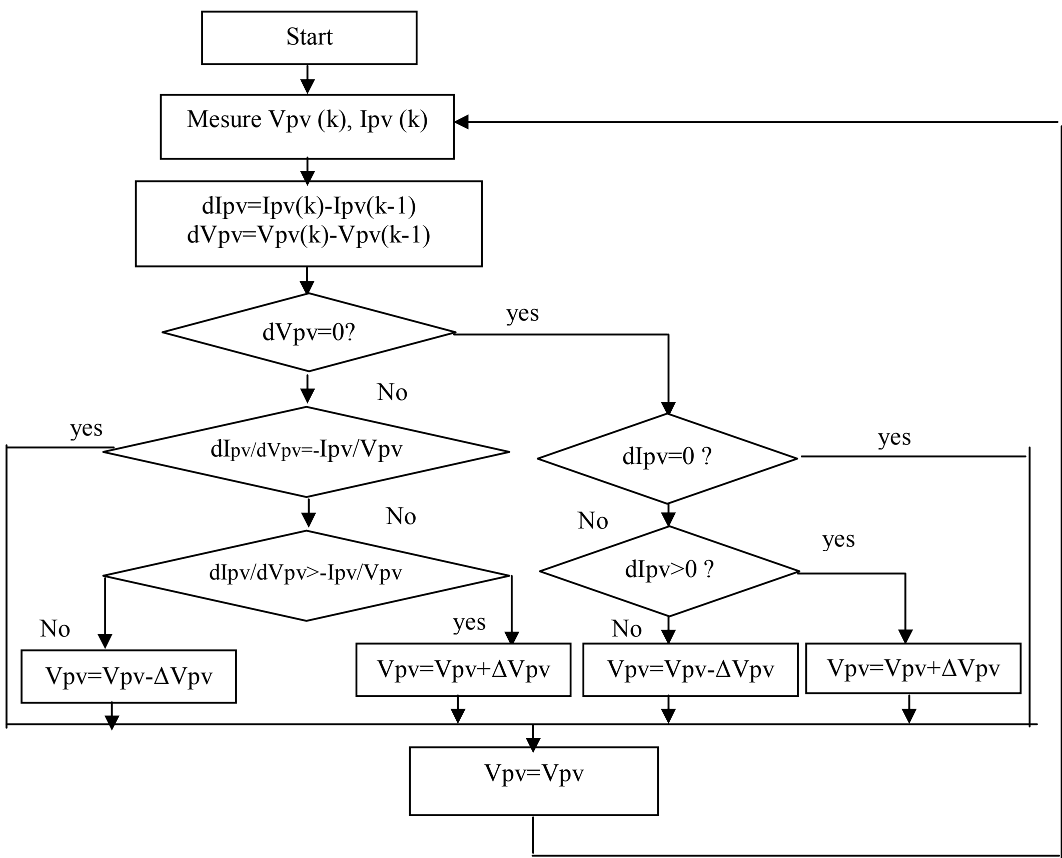

Fig.10 Algorithm of incremental conductance