

# FUZZY CONTROLLED DEVELOPMENT AND COMPARISON OF AN IMPROVED INCREMENTAL CONDUCTANCE ALGORITHM FOR MPPT

<sup>1</sup> N JYOTHSNA <sup>2</sup> K.DILLIBABU

<sup>1</sup>M.Tech, Vemu Institute of Technology, Chittoor, AndhraPradesh

<sup>2</sup>Associate Professor, Vemu Institute of Technology, Chittoor, AndhraPradesh

**Abstract:**This paper proposes an adaptive and optimal control methodology for a solar photovoltaic (PV) system. The control strategy ensures that the solar PV panel is always perpendicular to sunlight and always operated at its maximum power point (MPP) for continuously harvesting maximum power. The proposed control methodology is the control combination between the solar tracker (ST) and MPP tracker (MPPT) that can significantly improve the generated electricity from solar PV systems. Regarding the Solar Tracker ST system, the paper presents two drive approaches including open- and closed-loop drives. Further, the paper also proposes an improved incremental conductance (InC) algorithm for improving the speed of the MPP tracking of a solar PV panel under various atmospheric conditions as well as assuring that the operating point always moves towards the MPP using this proposed algorithm using Fuzzy Logic Controller. The simulation results obtained validate the efficacy of the proposal under various atmospheric conditions.

**Index Terms:**Photo-Voltaic (PV), Solar Tracker (ST), Maximum Power Point Tracker (MPPT), Incremental Conductance (InC), Constant Voltage (CV), Fuzzy Logic Controller (FLC)

## I.INTRODUCTION

Energy is entirely essential for our life and demand has drastically increased worldwide in recent years. The research efforts in moving towards renewable energy can solve these problems. Compared to fossil fuel energy sources, renewable energy sources have the following major advantages: they are sustainable and unconventional, never going to run out, free and moreover non-polluting. Renewable energy is the energy generated from renewable natural energy resources such as solar irradiation, wind, tides, waves, etc.

Amongst them, solar energy is becoming very popular in a variety of applications relating to heat, light and electricity. It is particularly attractive because of its abundance, renewability, cleanliness and its eco-friendly nature. One of the important technologies of solar energy is photovoltaic (PV) technology which converts irradiation directly to electricity by the Photo Voltaic -PV effect. However, it can be realized that the solar PV panels have a few disadvantages such as low conversion efficiency (9% to 17%) and other effects of various atmospheric conditions [1]. In order to overcome these issues, the materials used in solar panel manufacturing as well as collection approaches need to be enhanced. Obviously, it is particularly difficult to make effective improvements in the materials used in the solar PV panels.

Therefore, increasing of the irradiation intensity received from the sun is a realizable solution for improving the performance of the solar PV panels. One of the major approaches for maximizing power extraction in solar PV systems is a sun tracking ST system. The sun tracking systems were introduced in [2]-[3] using a micro-processor, and in [4] using a programmable logic controller respectively. Usually, there is a unique point on the V-I or V-P curve which is called the Maximum Power Point (MPP). This means that the solar PV panel will operate with a maximum efficiency and generate a maximum output power. The MPP is not known on the V-I or V-P curve, and it can be realized by search algorithms such as the Perturbation and Observation (P&O) algorithms [7]-[12], the Incremental Conductance (InC) algorithm [13]-[14], the Constant Voltage (CV) algorithm [15]-[16], the Artificial Neural Network (ANN) algorithm [17]-[18], the Fuzzy Logic (FL) algorithm [19]-[20], and the Particle Swarm Optimization (PSO) algorithm [21]-[24].

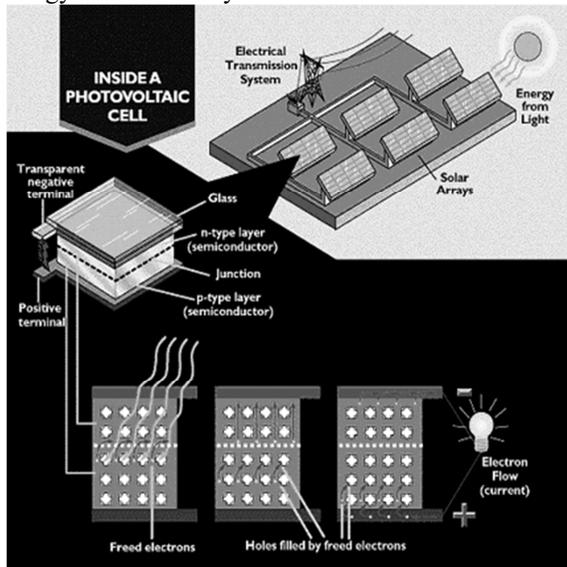
These existing algorithms have several pros and cons concerned with simplicity, convergence speed, hardware and capital. This paper proposes an improved InC algorithm for tracking a MPP on the V-I characteristic of the solar PV panel. Based on the ST and MPPT, the solar PV panel is always guaranteed to operate in an optimal situation for all conditions.

**II. SOLAR CELL**

**A. Structure of a solar cell:**

Solar cells as the name implies, these are designed to convert available light into Electrical energy which doesn't involve any chemical reactions or moving parts. The development of the solar cell starts from the work of the French physicist Antoine-César Becquerel in 1839. Becquerel discovered the photovoltaic effect while experimenting with a solid electrode in an electrolyte solution. He observed that voltage develops when light falls upon the electrode.

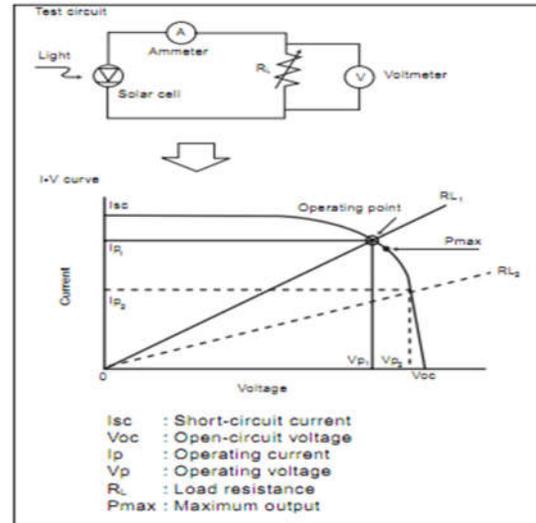
After 50 years, Charles Fritts constructed the first true solar cells using junctions formed by coating the semiconductor selenium with an ultrathin, nearly transparent layer of gold. Fritts's devices were very inefficient, transforming less than 1% of the absorbed light into electrical energy. Modern solar cells are based on semiconductor physics principles. They are basically just P-N junction photodiodes with a very large light-sensitive area. The photovoltaic effect, which causes the cell to convert light directly into electrical energy, occurs in the three energy-conversion layers.



**Fig.1. Solar power system showing parts of a Photovoltaic cell**

**B. Output characteristics of solar cells:**

The output characteristics of solar cells are expressed in the form of I - V curve. An I - V curve test circuit and typical I - V curve produced by the circuit are shown below. The I-V curve is produced by varying  $R_L$  (load resistance) from zero to infinity and measuring the current and voltage along it. The point at which the I-V curve and resistance ( $R_L$ ) intersects is the Operating Point of the solar cell. The current and voltage at this point are  $I_p$  and  $V_p$ , respectively.



**Fig 2. Output characteristics of Solar Cell**

The largest operating point in the square area is the maximum output of the solar cell.

**III. MAXIMUM POWER POINT TRACKING**

**A. Introduction**

Maximum power point tracking is a technique used widely with wind turbines and photovoltaic (PV) solar systems to maximize power extraction under all conditions. Although solar power is mainly covered, the principle applies generally to sources with variable power: for example, optical power transmission and thermo-photo-voltaic.

PV solar systems exist in many different forms with regard to their relationship to inverter systems, external grids, battery banks, or other electrical loads.[3] Regardless of the ultimate destination of the solar power, the central problem addressed by MPPT is that the efficiency of power transfer from the solar cell depends on both the amount of sunlight falling on the solar panels and the electrical characteristics of the load. As the amount of sunlight varies, the load characteristic that gives the highest power transfer efficiency also changes, so that the efficiency of the system is optimized when the load characteristic changes to keep the power transfer at highest efficiency.

**B. Analysis of MPPT**

This load characteristic is called the maximum power point and MPPT is the process of finding this point. Electrical circuits can be designed to control arbitrary loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other devices or systems, and MPPT solves the problem of choosing the best load to be presented to the cells in order to get the most usable output power. Solar cells have a complex relationship between temperature and total resistance that produces a non-linear output efficiency.

Solar inverters convert the DC power to AC power and incorporate MPPT: such inverters sample the output power (I-V curve) from the solar modules and apply the proper resistance (load) so as to obtain maximum power. The power at the MPP ( $P_{mpp}$ ) is the product of the MPP voltage ( $V_{mpp}$ ) and MPP current ( $I_{mpp}$ ). i.e. ( $P_{mpp} = V_{mpp} * I_{mpp}$ ).

Charging may begin at a voltage considerably below the PV panel maximum power point voltage, and an MPPT can solve this mismatch. When the batteries in an off-grid system are fully charged and PV production exceeds local loads, an MPPT can no longer operate the panel at its maximum power point as this excess power has no load to absorb it.

The MPPT must then shift the PV panel operating point away from the peak power point until production exactly equals demand. An alternative approach commonly used in spacecraft is to divert surplus PV power into a resistive load, allowing the panel to operate continuously at its peak power point. In a grid connected photovoltaic system, all delivered power from solar modules will be diverted to the grid. Therefore, the MPPT in a grid connected PV system will always try to operate the PV modules at its maximum power point.

#### IV. SOLAR TRACKER

A solar tracker is a device that orients the payload toward the Sun. Payloads are usually solar panels, parabolic troughs, Fresnel reflectors, mirrors or lenses. For flat-panel photovoltaic systems, trackers are used to decrease the angle of incidence between the incoming sunlight and a photovoltaic panel. The effective collection area of a flat-panel solar collector varies with the cosine of the misalignment of panel with the Sun. Sunlight has two components, the "direct beam" that carries about 90% of the solar energy.



Fig.3.8-megawatt PV plant using horizontal single axis tracker

For example, trackers that have accuracies of  $\pm 5^\circ$  can deliver more than 99.6% of the energy delivered by the direct beam plus 100% of the diffuse light. As a result, high accuracy tracking is not typically used in non-concentrating PV applications. The Sun travels through 360 degrees east to west each day, but from the perspective of any fixed

location the visible portion is 180 degrees during an average 1/2 day period (more in spring and summer and less in fall and winter). Local horizon effects decreases this somewhat, making the effective motion about 150 degrees. A solar panel in a fixed orientation between the dawn and sunset extremes will see a motion of 75 degrees to either side, and thus, as per the table above, will lose 75% of the energy in the morning and evening. Rotating the panels to the east and west can help recapture those incurred losses.

#### V.FUZZY LOGIC CONTROLLER

##### 1. Architecture of Fuzzy Logic Control

The following diagram shows the architecture of Fuzzy Logic Control (FLC).

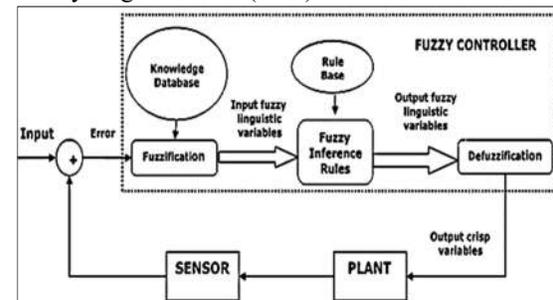


Fig.4. Architecture of Fuzzy Logic Control (FLC)

##### 2. Major Components of FLC

- **Fuzzifier** – Fuzzifier converts the crisp input values into fuzzy values.
- **Fuzzy Knowledge Base** – this stores the knowledge about all the input-output fuzzy relationships. It also has the membership function which defines the input variables to the fuzzy rule base and the output variables to the plant under control strategy.
- **Fuzzy Rule Base** – It stores the knowledge about the operation of the process
- **Inference Engine** – It acts as a kernel of any FLC. Basically it simulates human decisions by performing approximate reasoning evaluations.
- **Defuzzifier** – The defuzzifier converts the fuzzy values into crisp values getting from fuzzy inference engine.

#### V. SOLAR PHOTOVOLTAIC PANEL

A solar PV panel is used to generate electricity. An equivalent circuit model for a solar PV cell consists of a real diode in parallel with an ideal current source [25]. It is realized that the solar PV panels are sensitive to shading. Hence, a more accurate equivalent circuit for the solar PV cell is presented to consider the impact of shading as well as account for losses due to the cell's internal series resistance, contacts and interconnections between cells and modules [25]. Then, the V-I characteristic of the solar PV cell is given by:

$$I = I_{sc} - I_0 \left( e^{\frac{q(V+IR_s)}{kT}} - 1 \right) - \left( \frac{V + IR_s}{R_p} \right)$$

Where  $R_s$  and  $R_p$ : the resistances used to show the impact of shading and losses.

Though, the manufacturers try to minimize the effect of both resistances to improve their products, the ideal scenario is not at all possible. The maximum power is generated by the solar PV cell at a point of the V-I characteristic where the product ( $V \times I$ ) is obtained maximum. This point is known as the MPP and it is unique. It is also obvious that two important factors which have to be taken into account in the electricity generation of a solar PV panel are the irradiation and temperature. These factors highly affect the characteristics of solar PV panels. Thus, the solar PV panel needs to be perpendicular to sunlight to maximize the irradiation obtained. Moreover, as a result, the MPP varies during the day and the solar PV panel is essential to track the MPP in all conditions to ensure that the maximum power is obtained. This problem is given to the maximum power point tracking (MPPT) algorithms through searching and determining MPPs in various conditions.

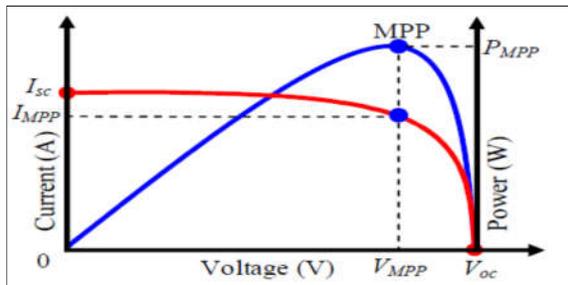


Fig.5. Important points in the V-I and V-P characteristics of a solar PV panel  
**VI.CONTROL STRATEGIES**

**A.Sun tracking control:**

The sun rises in the east and moves across the sky to the west every day. In order to increase solar yield and electricity production from solar PV panels, the idea is to be able to tilt the solar PV panels in the direction which the sun moves throughout the year as well as under changing weather conditions. It can be realized that the more the solar PV panels can face directly towards the sun, the more power can be obtained. This idea is called a solar tracker (ST) which orients the solar PV panels towards the sun so that they harness high sunlight. In the open-loop tracking control, the tracker does not actively find the sun's position but instead determines the position of the sun for a particular site.

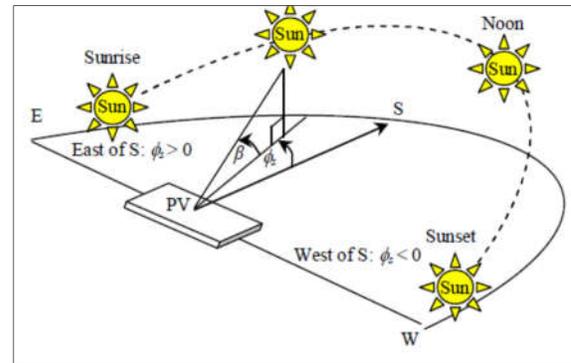


Fig.6. Description of the sun's position

The tracker receives the current time, day, month and year and then calculates the position of the sun without feedback. The tracker uses a stepper motor to track the sun's position. It can be realized that no sensor is used in this open loop control strategy. The sun's position can be described in terms of its altitude angle,  $\beta$  and its azimuth angle,  $\theta$  at any time of day which depend on the latitude, the day number and the time of day [25]. The altitude angle,  $\beta$  is given by:

$$\sin \beta = \cos L \cos \delta \cos H + \sin L \sin \delta$$

The solar declination angle,  $\delta$  is the angle between the plane of the equator and line drawn from the center of the sun to the center of the earth.

The azimuth angle is given as:

$$\sin \phi_s = \frac{\cos \delta \sin H}{\cos \beta}$$

Moreover, it depends on the hour angle,  $H$ , the azimuth angle, can be estimated as follows:

$$\cos H \geq \frac{\tan \delta}{\tan L}, \text{ then } |\phi_s| \leq 90^\circ; \text{ otherwise } |\phi_s| > 90^\circ$$

The declination angle,  $\theta$  is given by:

$$\delta = 23.45 \sin \left| \frac{360}{365} (n - 81) \right|$$

Where,  $L$ : the latitude of the site (degrees);

$\delta$ : the declination angle (degrees);

$n$ : the number of days from January 1;

$H$ : the hour angle (degrees).

The hour angle,  $H$ , shows the time of day according to the solar noon. It is angle between the planes of the meridian-containing observer and meridian that touches the earth-sun line. It is zero at solar noon and increases by 15 degrees every hour since the earth rotates 360 degrees in 24 hour. Then, the hour angle is described as follows:

$$H = 15^\circ (t_s - 12)$$

Where,  $t_s$ : the solar time in hours.

It is a 24-hour clock with 12:00 as the exact time when the sun is at the highest point in the sky.

The open-loop ST must turn the solar PV panel to the east at sunrise time and stop its motion at the sunset time.

It is realized that altitude angle,  $\beta$  is equal to zero at the sunrise and sunset moments which is described as follows [25]:

$$\sin \beta = \cos L \cos \delta \cos H + \sin L \sin \delta = 0$$

$$\cos H = -\frac{\sin L \sin \delta}{\cos L \cos \delta} = -\tan L \tan \delta$$

$$H = -\cos^{-1}(\tan L \tan \delta)$$

The hour angle,  $H$ , is the inverse cosine function which has both positive and negative values. The positive values represents sunrise whereas the negative values represents sunset. In order to determine the sun's position, two similar light sensors are mounted. They are located at the east and west, or south and north, to sense the light source. There is an opaque object between two sensors which is to isolate the light from other directions to obtain a wide-angle search and to determine the sun's position. The sensors used are Light Dependent Resistors (LDR). The closed-loop ST receives the signals which are the resistance values of two LDRs, RA and RB respectively. Then, it makes a comparison between RA and RB as follows.

- \* If RA=RB, then the solar PV panel will be kept its position.
- \* If RA≠RB and RA<RB, then the solar PV panel will be rotated towards A.
- \* If RA≠RB and RA>RB, then the solar PV panel will be rotated towards B.

The sample time is  $\Delta t$  for the comparison and determination of the rotated direction. It is obvious that the solar tracking systems are best choice for the solar PV systems. The differences between the open- and closed-loop STs are shown in Table I below. It is easily realized that the open loop ST is simpler, less expensive, as well as in need of less maintenance than the closed-loop ST.

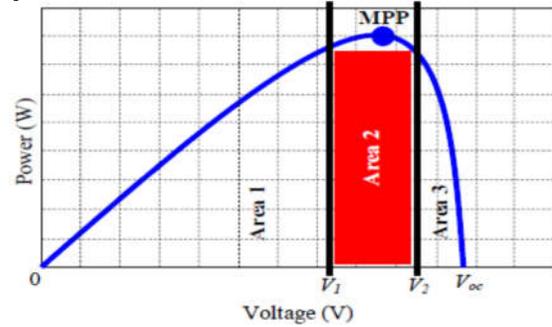
Its performance can be sometimes lower than that of the closed-loop ST, because the open-loop ST does not observe the output of the processes.

**TABLE I: Comparison between the Open- And Closed-Loop STs**

Item	Open-loop	Closed-loop
Structure	Simple	Complicated
Extra-hardware	No required	LDRs
Cost	Cheap	Expensive
Feedback signal	No required	Required
Control	Simple	Complicated

No feedback signal is required. While the closed-loop ST can produce a better tracking efficiency, its feedback signals tracking the sun's position will be

lost when the LDRs are shaded or the sun is blocked by clouds which is unreliable.



**Fig.8. Area partition of the P-V characteristic**

**B.MPP Tracking Control:**

**1)InC Algorithm:**

The principle of the InC algorithm is that the derivative of the power with respect to the voltage or current becomes zero at the MPP, the power increases with the voltage in the left side of the MPP and the power decreases with the voltage in the right side of the MPP [26]-[27]. This description can be rewritten in the following simple equations:

$$\frac{dp}{dv} = 0 \text{ at the MPP}$$

$$\frac{dp}{dv} > 0 \text{ to the left of the MPP}$$

$$\frac{dp}{dv} < 0 \text{ to the right of the MPP}$$

where

$$\frac{dp}{dv} = \frac{d(iv)}{dv} = I + V \frac{di}{dv}$$

$$\frac{1}{V} \frac{dp}{dv} = \frac{I}{V} + \frac{di}{dv}$$

Therefore, the voltage of the PV panels can be adjusted based to the MPP voltage by measuring the incremental conductance,  $di/dv$  and the instantaneous conductance,  $I/V$ . It can be observed that the InC algorithm overcomes the oscillation around the MPP when it is reached. When  $di/dv = -I/V$  is satisfied, this means that the MPP is reached and the operating point is remains constant. Additionally, the search space is larger in InC algorithm. This directly affects the search performance capability of the algorithm.

**2) Improved InC Algorithm**

An improved InC algorithm is proposed in order to cope up the disadvantages of the InC algorithm. The CV algorithm applies the operating voltage at the MPP which is linearly proportional to the open circuit voltage of PV panels with changing atmospheric conditions. Initially, the computation for the differential of the operating point,  $dp/dv$  is simplified by the following approximation:

$$\frac{dp}{dv} = \frac{P(k) - P(k-1)}{V(k) - V(k-1)}$$

Later, the InC algorithm is combined with the Constant Voltage (CV) algorithm [28]-[29] for the estimation of the MPP voltage which can limit the search space for the InC algorithm. The ratio of VMPP/Voc is commonly used around 76% [14].

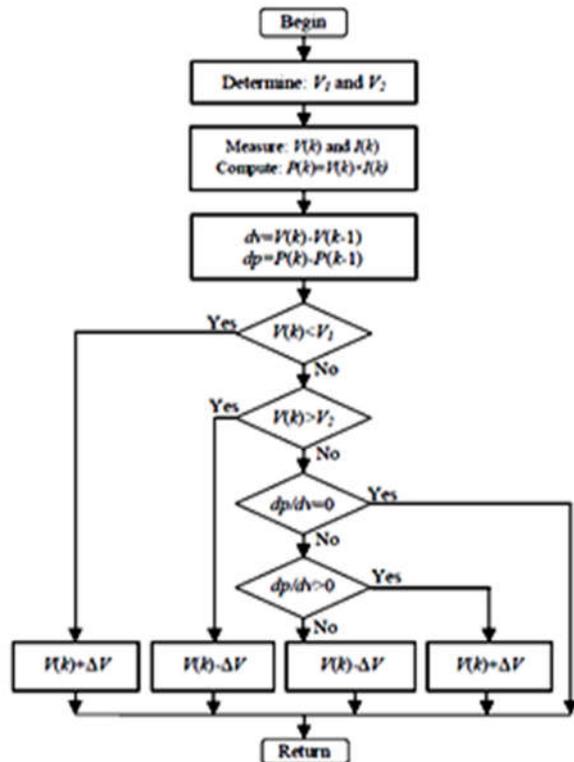


Fig.8. Flow chart of the improved InC algorithm

So, the improved InC algorithm is implemented to divide the P-V characteristic into three areas i.e. area 1, area 2 and area 3, where area 1 is from 0 to 70%Voc, area 2 is from 70%Voc to 80%Voc and area 3 is from 80%Voc to Voc. Area 2 is the area including the MPP. It can be realized that the improved InC algorithm only needs to search the MPP within area 2, from 70%Voc to 80%Voc.

$$V_{ref} = (70\% - 80\%)V_{oc} = (V_1 - V_2)$$

In the improved InC algorithm, the MPPT system momentarily configures the PV panels current to zero allowing measurement of the panels' open circuit voltage. The operation of the improved InC algorithm is depicted in the flow chart. At last, the ST and MPPT are combined to control the solar PV panel so that the obtained electricity is maximized under all atmospheric conditions

**VII. SIMULATION RESULTS**

Simulations are performed using MATLAB/SIMULINK software for tracking MPPs of the solar PV array with 7 panels, RS-P618-22

connected in series whose specifications and parameters are in Table II. The solar PV panel provides a maximum output power at a MPP with VMPP and IMPP. The MPP is defined at the standard test condition (STC) of the irradiation, 1 kW/m2 and module temperature, 25 0C but this condition does not exist most of the time. The following simulations are implemented to confirm the effectiveness of the improved InC algorithm which is compared with those of the InC and P&O algorithms.

Case 1: It is assumed that the module temperature is constant, T=250C. Fig.9 describes the variation of the solar irradiation where 0s≤t<1s: G=0.25 kW/m2; 1s≤t<2s: G=0.5kW/m2; 2s≤t<3s: G=0.75kW/m2; 3s≤t<4s: G=1kW/m2 and 4s≤t≤5s: G=0.25kW/m2. Then, the obtained output powers are shown below using the P&O, InC and improved InC algorithms, respectively under the various solar irradianations.

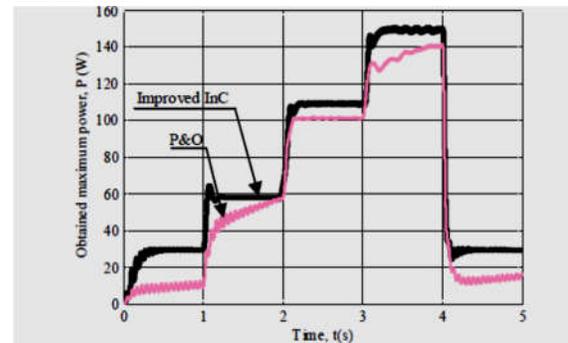


Fig.9. Obtained maximum output power with the P&O and improved InC algorithms under the variation of the solar irradiation

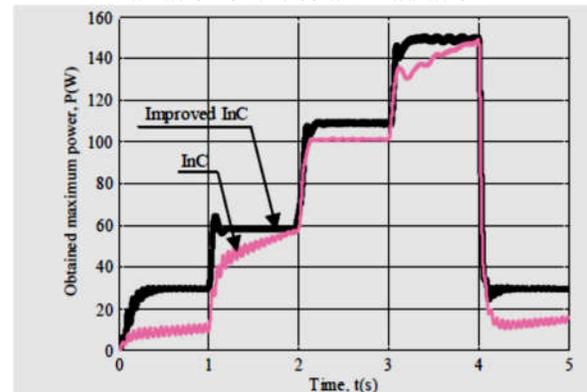
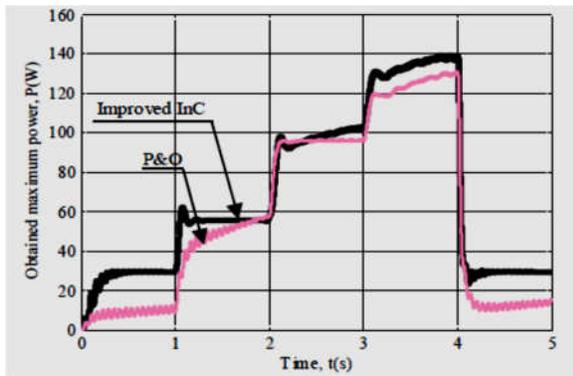
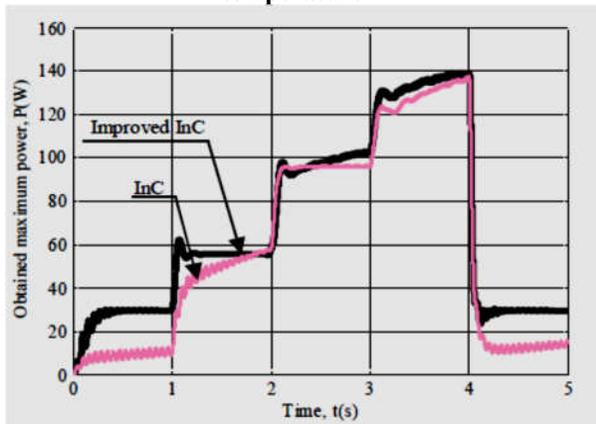


Fig.10. Obtained maximum output power with the InC and improved InC algorithms under the variation of the solar irradiation



**Fig. 11. Obtained maximum output power with the P&O and improved InC algorithms under both the variations of the solar irradiation and temperature**



**Fig.12. Obtained maximum output power with the InC and improved InC algorithms under both the variations of the solar irradiation and temperature**

Case 2: It is assumed that both the module temperature and solar irradiation are changed, where the module temperature variation is as follows:  $0s \leq t < 1s$ :  $T=250C$ ;  $1s \leq t < 2s$ :  $T=300C$ ;  $2s \leq t < 3s$ :  $T=350C$ ;  $3s \leq t < 4s$ :  $T=400C$ ;  $4s \leq t \leq 5s$ :  $T=250C$  and the solar irradiation variation is as in case 1. Then, the obtained output powers are shown using the P&O, InC and improved InC algorithms under the variation of both the temperature and solar irradiation

### VIII. CONCLUSION AND FUTURE SCOPE

It is obvious that the adaptive and optimal control strategy plays an important role in the development of solar PV systems. This strategy is based on the combination between the ST and MPPT in order to ensure that the solar PV panel is capable of harnessing the maximum solar energy following the sun's trajectory from dawn until dusk and is always operated at the MPPs with the improved InC algorithm. The proposed InC algorithm improves the conventional InC algorithm with an approximation which reduces the computational burden as well as the application of the CV algorithm to limit the search space and increase the convergence speed of

the InC algorithm. This improvement overcomes the existing drawbacks of the InC algorithm. The simulation and experimental results confirm the validity of the proposed adaptive and optimal control strategy in the solar PV panel through the comparisons with other strategies.

### REFERENCES

- [1] R. Faranda and S. Leva, "Energy comparison of MPPT techniques for PV systems," *Trans. Power Syst.*, vol. 3, no. 6, pp. 446-455, 2008.
- [2] X. Jun-Ming, J. Ling-Yun, Z. Hai-Ming and Z. Rui, "Design of track control system in PV," .
- [3] Z. Bao-Jian, G. Guo-Hong and Z. Yan-Li, "Designment of automatic tracking system of solar energy system," 2nd Int. Conf. Industrial Mechatronics.
- [4] W. Luo, "A solar panels automatic tracking system based on OMRON PLC," *Proc. 7th Asian Control Conf.*, pp. 1611-1614, 2009.
- [5] W. Chun-Sheng, W. Yi-Bo, L. Si-Yang, P. Yan-Chang and X. Hong- Hua, "Study on automatic sun-tracking technology in PV generation," *Third Int. Conf. Electric Utility Deregulation and Restructuring and Power Technologies, DRPT2008*, pp. 2586-2591, 2008.
- [6] C. Alexandru and C. Pozna, "Different tracking strategies for optimizing the energetic efficiency of a photovoltaic system," *Int. Conf. Automation, Quality and Testing, Robotics*, pp. 434-439, 2008.
- [7] R. Sridhar, S. Jeevanathan, N. T. Selvan and P. V. SujithChowdary, "Performance improvement of a photovoltaic array using MPPT P&O technique," *Int. Conf. Control and Comput. Technol.*, pp. 191-195, 2010.
- [8] N. M. Razali and N. A. Rahim, "DSP-based maximum peak power tracker using P&O algorithm," *IEEE First Conf. Clean Energy and Technol.*, pp. 34-39, 2011.
- [9] L. Chun-Xia, L. Li-qun, "An improved perturbation and observation MPPT method of photovoltaic generate system," *4th IEEE Conf. Ind. Electron. and Appl.*, ICIEA2009, pp. 2966-2970, 2009
- [10] Y. Jung, J. So, G. Yu and J. Choi, "Improved perturbation and observation method (IP&O) of MPPT control for photovoltaic power systems," *31st IEEE Photov. Specialists Conf.*, pp. 1788-1791, 2005.
- [11] X. Liu, L. A. C. Lopes, "An improved perturbation and observation maximum power point tracking algorithm for PV arrays," *IEEE 35th Annual Power Electron. Specialists Conf.*, pp. 2005-2010, 2004.
- [12] D. C. Huynh, T. A. T. Nguyen, M. W. Dunnigan and M. A. Mueller, "Maximum power point tracking of solar photovoltaic panels using advanced perturbation and observation algorithm," *IEEE Conf.*

Industrial Electronics and Applications 2013, pp. 864-869, 2013.

[13] B. Liu, S. Duan, F. Liu and P. Xu, "Analysis and improvement of maximum power point tracking algorithm based on incremental conductance method for photovoltaic array," 7th Int. Conf. Power Electron. and Drive Syst., PEDS2007, pp. 637-641, 2007.

[14] W. Ping, D. Hui, D. Changyu and Q. Shengbiao, "An improved MPPT algorithm based on traditional incremental conductance method," 4th Int. Conf. Power Electron. Syst. and Appl, PESA2011, pp. 1-4, 2011.

[15] Y. Zhihao and W. Xiaobo, "Compensation loop design of a photovoltaic system based on constant voltage MPPT," Asia-Pacific Power and Energy Eng. Conf., APPEEC2009, pp. 1-4, 2009.

[16] K. A. Aganah and A. W. Leedy, "A constant voltage maximum power point tracking method for solar powered systems," IEEE 43rd Southeastern Sym. Syst. Theory, SSST2011, pp. 125-130, 2011.

[17] P. Q. Dzung, L. D. Khoa, H. H. Lee, L. M. Phuong and N. T. D. Vu, "The new MPPT algorithm using ANN based PV," Int. Forum on Strategic Technology, IFOST2010, pp. 402-407, 2010.

[18] R. Ramaprabha, V. Gothandaraman, K. Kanimozhi, R. Divya and B. L. Mathur, "Maximum power point tracking using GA-optimized artificial neural network for solar PV system," 1st Int. Conf. Electr. Energy Syst., ICEES2011, pp. 264-268, 2011.

[19] S. J. Kang, J. S. Ko, J. S. Choi, M. G. Jang, J. H. Mun, J. G. Lee and D. H. Chung, "A novel MPPT control of photovoltaic system using FLC algorithm," 11th Int. Conf. Contr., Autom. and Syst., pp. 434-439, 2011.

[20] V. Padmanabhan, V. Beena and M. Jayaraju, "Fuzzy logic based maximum power point tracker for a photovoltaic system," Int. Conf. Power, Signals, Contr. and Comput., EPSCICON2012, pp. 1-6, 2012.

[21] Md. A. Azam, S. A. A. Nahid, M. M. Alam and B. A. Plabon, "Microcontroller based high precision PSO algorithm for maximum solar power tracking," Conf. Electron. and Vision, pp. 292-297, 2012.

[22] K. Ishaque, Z. Salam, M. Amjad and S. Mekhilef, "An improved particle swarm optimization (PSO)-based MPPT for PV with reduced steady-state oscillation," IEEE Trans. Power Electron., pp. 3627-3638, 2012.

[23] M. Veerachary, T. Senjyu, and K. Uezato, Feed-forward maximum power point tracking of PV systems using fuzzy controller, IEEE Trans. Aerosp. Electron. Syst., vol. 38, no. 3, pp. 969-981, Jul. 2002.

[24] Lee C.C, Fuzzy logic in control systems: Fuzzy Logic Controller- Part II, IEEE Transactions on Systems, Man and Cybernetics, Volume: 20, NO.2, March/April 1990, pages 418-435