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Comparison of Advanced MPPT Technique for Photovoltaic System

Hina N.Kadeval[1], Dr.V.K.Patel[2]

Ph. D Scholar, College of Renewable Energy &Environmental Engineering, Sardarkrushinagar[1]

Associate Professor, U.V.Patel College of Engineering & Technology, Ganpat University[2]

Abstract: Temperature and sun radiation varies nonlinearly. Photovoltaic generation varies with reference to radiation and temperature. To gain maximum energy is very essential. MPPT are used to harvest maximum energy throughout the whole day. Various advanced technique of like Fuzzy Logic, Particle swarm optimization, I & C, P & O are compared in terms of power output, response time, and increase in efficiency, steady state oscillation at constant irradiance and variable irradiance. This MPPT technique are simulated and compared. PSO gives good result compared to P &O and I &C method especially in partial shading condition.

Keywords: MPPT; I & C; P & O; PSO; Partial shading

I. INTRODUCTION

Non-Renewable sources are now depleting day by day so utilization of renewable sources are very essential. To achieve maximum solar energy in photovoltaic, Various MPPT technique are used nowadays. Each method have different convergence speed, cost, and complexity, sensors, adaptability & tracking ability. So it is difficult to define particular method for specific application.

Paper is composed of different section: section 1 explain introduction section 2 explain solar cell modelling and its characteristic Section 3 introduces MPPT and its need. In section 4 different technique and its model. In section 5 summary and conclusion in which detailed comparison of the various techniques are presented in tabular form. In section 6 references are presented

II. SOLAR CELL MODELLING AND ITS CHARACTERISTIC

2.1 Cell modelling

Sunlight based cell electrical model can be spoken to utilizing diode, opposition (arrangement and shunt)[4,6] as delineated in Fig. 1

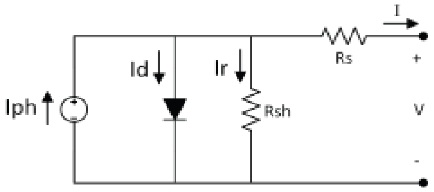

Fig. 1: solar cell model

Load current can be described as,

$$I = I_{ph} - I_d - I_r \quad (1)$$

Due to photovoltaic effect current generated is $I_{ph,}$diode current Id and current in shunt resistance is Ir. photovoltaic current is dependent on solar irradiance and T.

$$I_{ph} = [I_{ph,stc} + K_i(T - T_{stc})]\frac{G}{G_{stc}} \quad (2)$$

photovoltaic current produced at standard test condition is Iph,stc temperature coefficient is Ki, at 25∘C temperature is Tstc,at 1000$W/m2$ radiation is Gstc. Id is dependent on k,q,a1,n as per

$$I_D = I_0\left\{exp\left(\frac{q\ X(V+IXR_s)}{n_s XkXTXa_1}\right) - 1\right\} \quad (3)$$

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Saturation current dependent on Ki,Iscstc,Vocstc and Kv.

$$I_0 = I_{s,stc} + k_i(T - T_{stc})exp\left[\frac{q\left(V_{oc,stc}+kv(T-T_{stc})\right)}{n_s x K x T}\right] \quad (4)$$

Two imperative parameter are have to ascertain which matches computed greatest power point to the exploratory most extreme power point ($Vmp \times Imp$).

2.2 Output characteristic of PV array

PV cell have low power and voltage rating so for practical application cells are always connected in series or parallel to get required voltage and power. The output characteristic of PV array under uniform solar irradiation [2] can be expressed by the following equation:

$$I^M = N_p I_{ph}^C - N_p I_s^c\left\{exp\left(\frac{\frac{V^M}{N_s}+\frac{I^M R_s}{N_p}}{V_t}\right)-1\right\} - \frac{\left(\frac{N_p V^M}{N_s}+IR_s\right)}{R_{sh}} \quad (5)$$

$$V_t = \frac{nKT}{q} \quad (6)$$

The subscript M show PV modules, the subscript C demonstrate PV cell Np show parallel cell and Ns show arrangement/series cell. Array of solar cell have same characteristic as solar cell.

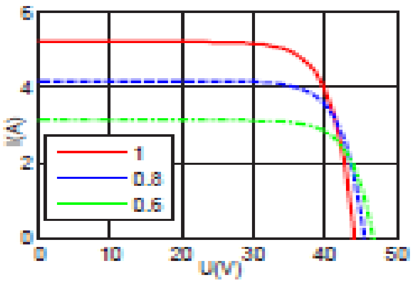
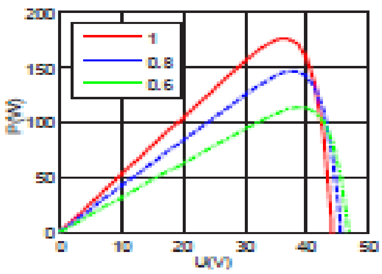


Fig.2 IV-characteristic of PV array



PV-characteristic of PV array

III. MPPT AND ITS NEED

3.1 MPPT

MPPT figuring are imperative in PV applications in light of the way that the MPP of a daylight based module shifts with the enlightenment and temperature The best power following framework makes use of an estimation and an electronic equipment. The instrument relies upon the govern of impedance coordinating among load and PV module, which is vital for most prominent power transfer[23]. By changing the duty cycle of converter impedance of solar module and load can be match. (d) the switch. Fig.3 exhibits a clear DC to DC converter used for MPPT. Automated controller that drives the converter errand with MPPT limit. The power from the sunlight based module is registered by evaluating the voltage and current. This power is contribution to controller which alters the obligation cycle of the switch, realizing the adjustment of the reflected load impedance as indicated by the power yield of PV module.

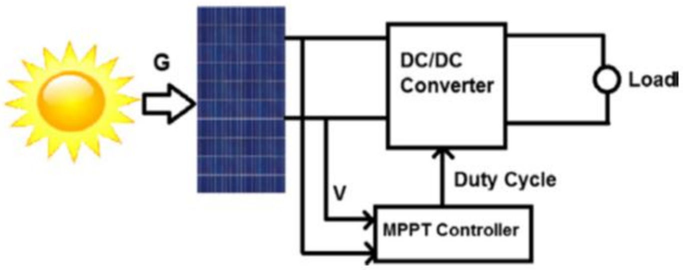


Fig.3 MPPT controller block schematic

and impedance of load (R_L) reflected at the input side (R_i) of a buck type DC to DC converter can be given as

$$V_o = V_i \times d \quad (7)$$

$$R_i = \frac{R_L}{d^2} \quad (8)$$

Where d is the obligation cycle. By altering the obligation cycle, can be changed which ought to be same as the impedance of sun based PV module in a given working condition for most extreme power exchange.

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IV. MPPT TECHNIQUE AND ITS SIMULATION MODEL

4.1 Perturb & Observe(P & O)

The perturb and observe or hill-climbing MPPT algorithm is based on the fact that, on the voltage-power characteristics, variation of the power against voltage dP/dV > 0 on left of the MPP, while on the right, dP/dV < 0 as shown in Fig.4.1 If the operating voltage of the PV array is perturbed in a given direction and dP/dV > 0, the perturbation moves the array's operating point toward the MPP. The P&O algorithm is continued to perturb the PV array voltage in the same direction. If dP/dV < 0, then the change in operating point moves the PV array operating point away from the MPP, and the P&O algorithm reverses the direction of the perturbation.

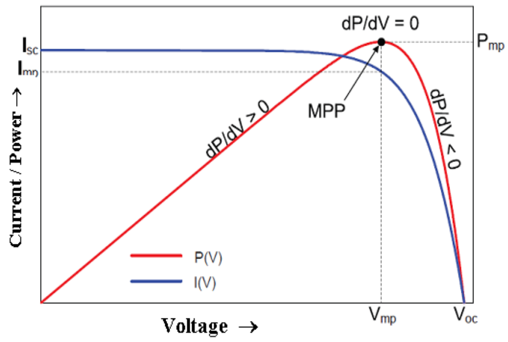

Fig.4.1 PV module P Vs V Curve for dp/dv variation

The flow chart of P&O algorithm is as shown in Fig.4.2 The main advantage of the P&O method is that it is easy to implement, it has low computational complexity and it is applicable for most of the PV systems. It does not require any information about the PV array except the measured voltage. Because of this, the P&O is one of the most-often used MPPT method nowadays. The two main problems of the P&O are the oscillations around the MPP in steady state conditions, and poor tracking (possibly in the wrong direction, away from MPP) under rapidly-changing irradiations[4]. In order to evaluate the performance of P&O algorithm, a commercially available PV module(Kyocera solar module KC200GT) with a peak output power of 200.143W_p watts, short circuit current (I_{sc}) of 8.21A and open circuit Voltage (V_{oc}) of 32.9 V under standard test conditions of irradiance (G = 1000 W/m^2) and nominal operating cell temperature (NOCT) of 25°C was simulated using MATLAB. As well as same module is simulated under ramp up-down input variation for irradiance and constant temperature(25°C) under MATLAB Simulink environment. Irradiance and temperature variation is shown in below Fig.4.3(a)&(b)

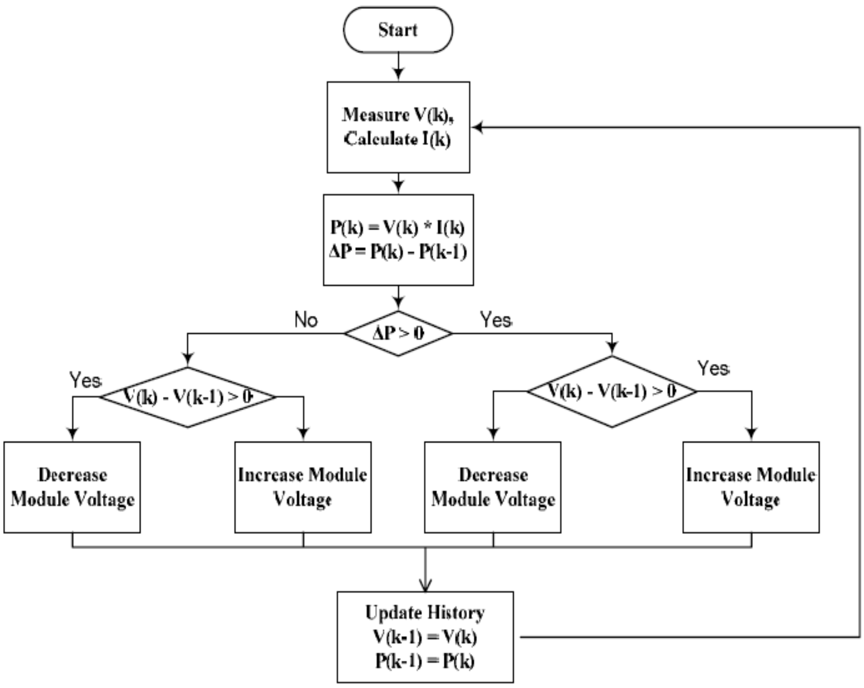

Fig.4.2 P & O algorithm flow chart

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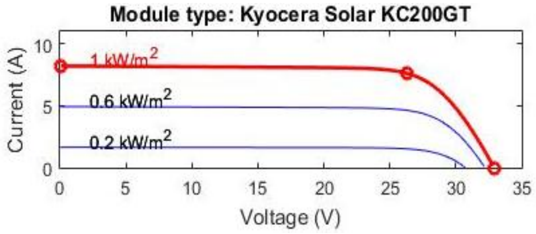


Fig.4.3(a)

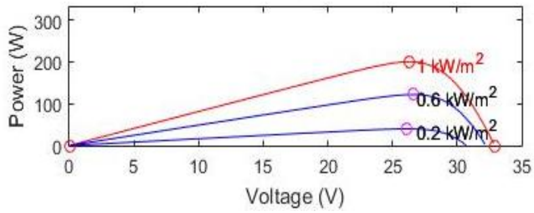


Fig.4.3(b)

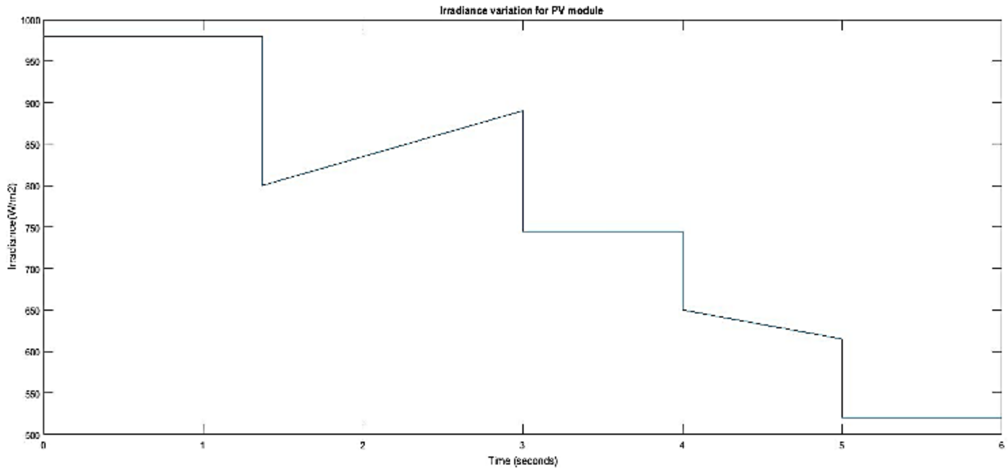


Fig.4.4 (a) Irradiance variation

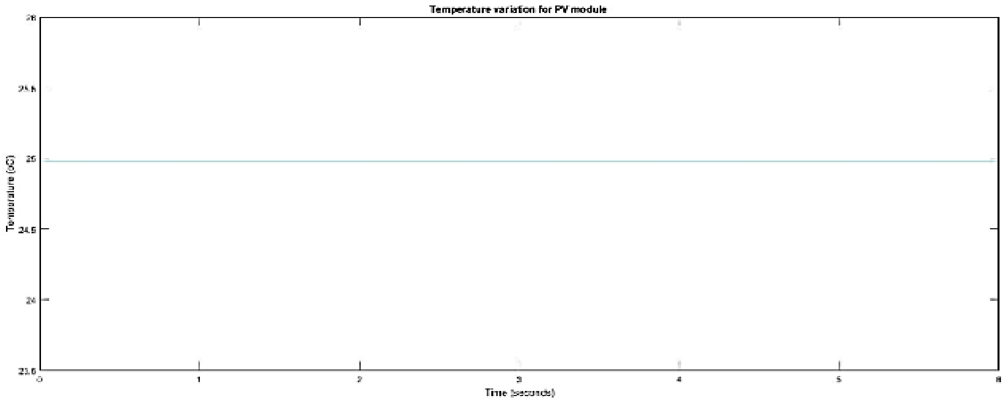


Fig.4.4(b) Temperature variation

4.1.1 P & O Simulation model & results:

The simulation have been done for various value of irradiance and temperature(constant) as ramp input shown in graph & Simulink block. The implementation of MATLAB programme for P&O algorithm is stated below:

Input for GUI interface

- Vpv & Ipv
- Load Irradiance and temperature from signal builder block

Constants for initialization

- Enable input, Dinit, Dmax, Dmin, delta D

Method: (Refer flow chart of P&O)

- Insert old value as Vold=0, Pold=0, Dold=Dinit
- Calculate P= V*I, dV= V – Vold, dP= P – Pold
- D = Dold – deltaD increase voltage
- D = Dold +deltaD decrease voltage

Output Files:

- Create plot of irradiance, temperature, voltage, power and duty cycle from scope in Simulink

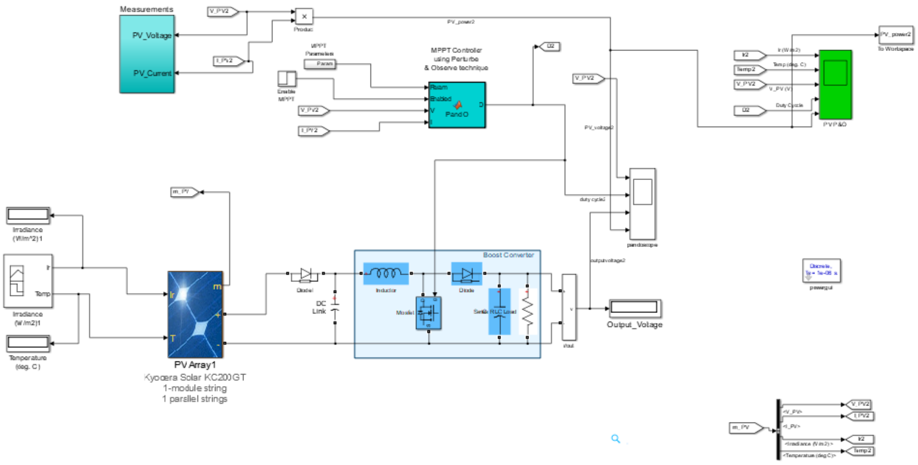
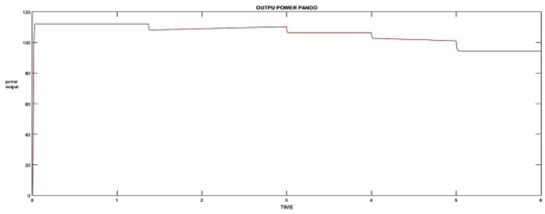
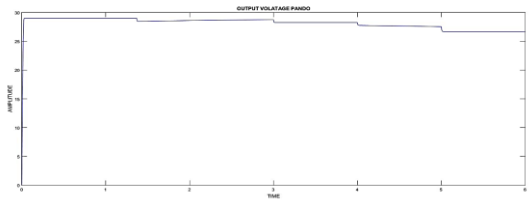
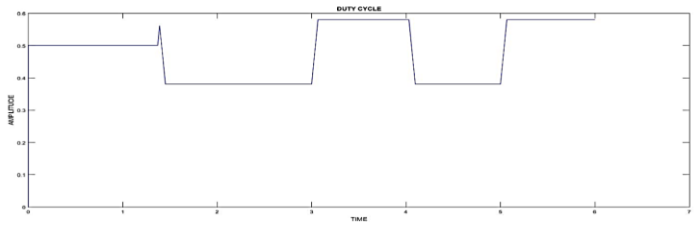


Fig.4.5 P & O simulation model

P & O Simulation results:







4.2 Incremental Conductance (I & C): The Incremental Conductance (INC) algorithm is similar to P & O algorithm. It uses instantaneous ratio of current & voltage (I/V) and incremental conductance [5-7] dI/dV for obtaining the MPP. The mathematical relations can be written as:

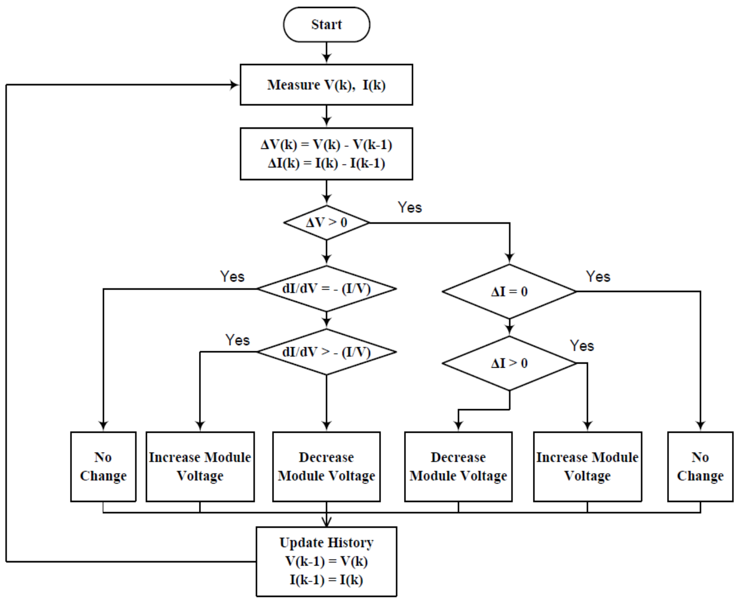


Fig. 4.6 I & C Flow chart

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$$\frac{dP}{dV} = \frac{d(VI)}{dV} = V\frac{dI}{dV} + I$$

$$\frac{dP}{dV} = 0\ at\ I = Imp, V = Vmp$$

$$\frac{dI}{dV}\ at\ I = I_{mp}, V = V_{mp} = -\frac{I_{mp}}{V_{mp}}$$

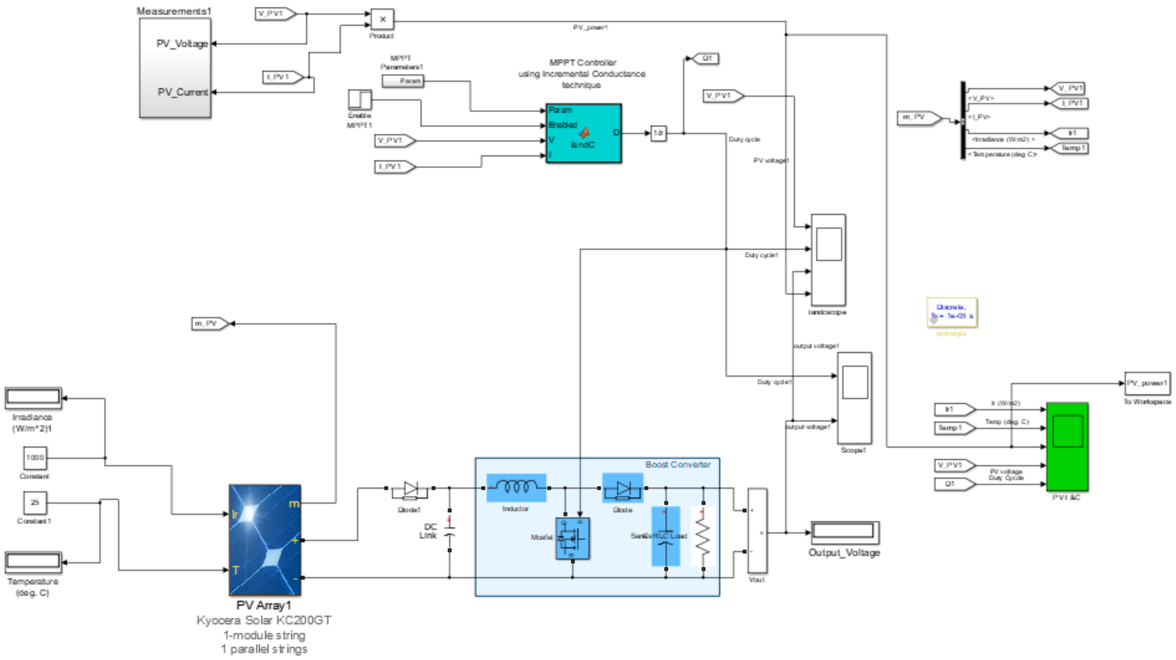
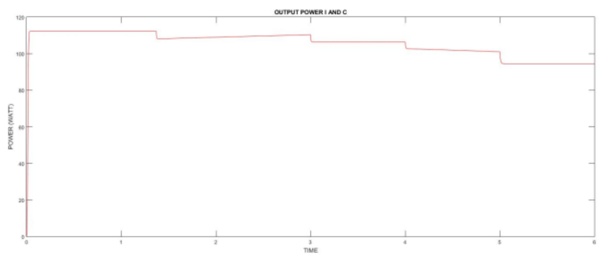
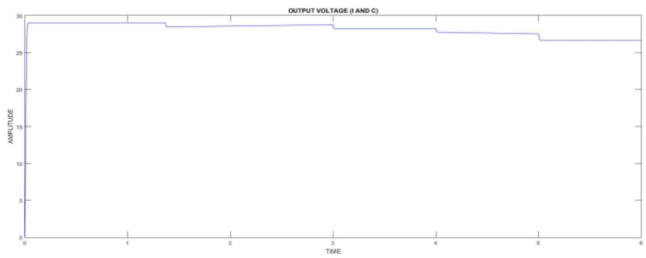
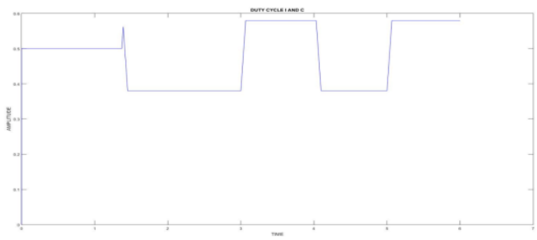


Fig 4.7 I & C Simulation Model & results







4.3 Fuzzy Logic Control Algorithm:

A fuzzy logic controller basically includes three blocks. They are Fuzzification, Inference and Defuzzification. The fuzzy logic controller requires that each input/output variable which define the control surface be expressed in fuzzy set notations using linguistic levels. The process of converting input/output variable to linguistic levels is termed as Fuzzification. The behaviour of the control surface which relates the input and output variables of the system are governed by a set of rules. A typical rule would be–"If x is A THEN y is B" [11]. When all the rules are fired, the resulting control surface is expressed as a fuzzy set to represent the constraints output. This process is termed as inference. Defuzzification is the process of conversion of fuzzy quantity into crisp quantity. There are several methods available for defuzzification. The most commonly used is centroid method. Fuzzy Logic based controllers overcome the disadvantages of conventional methods in tracking maximum power point. Fuzzy Logic based controller is simple to implement gives better convergence speed and improves the tracking performance with minimum oscillations.

Fuzzy logic is implemented to obtain the MPP operating voltage point faster and also it can minimize the voltage fluctuation afterMPP has been recognized. The proposed fuzzy logic based MPPT controller has two inputs and one output. The error E(k) and change in error CE(k) are the input variables to Fuzzy Logic Controller.

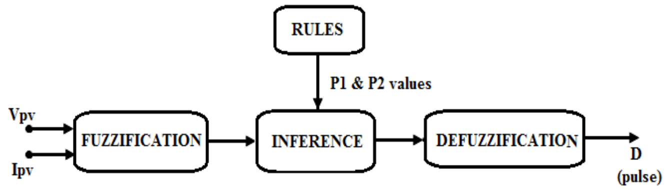


Fig 4.8 Fuzzy logic control

$$E(k) = \frac{dP}{dV} = \frac{(PPV(k) - PPV(k-1))}{(VPV(k) - VPV(k-1))} \quad CE(k) = E(k) - E(k-1)$$

Where Ppv(k) denotes the power of photovoltaic panel. The input variable E (k) represents the error which is defined as the change in power with respect to the change in voltage. Another input variable CE (k) expresses the change in error. The output of the Fuzzy Logic Controller is duty cycle (D) which should be given to the boost converter.Fuzzy Logic Controller in which E (k) and CE (k) are the input variables and D as the output variable.

Variables which can control the dynamic performance can be used as input and output. The input and output variables are converted into linguistic variables. In this case, five fuzzy subsets, NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small) and PB (Positive Big) have been chosen.

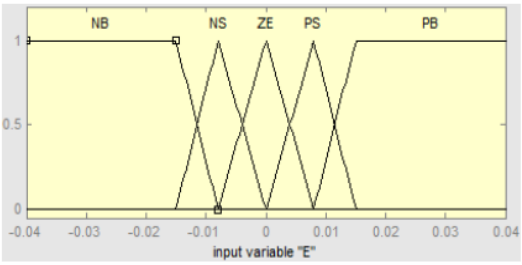


Fig.4.9Membership function for E(k)

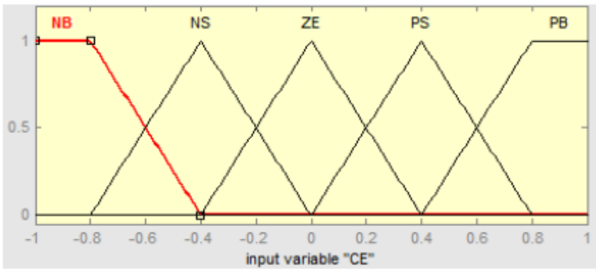


Fig.4.10 Membership function for CE(k)

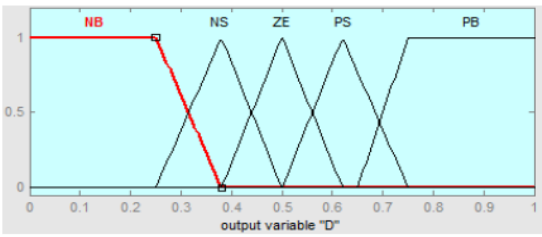


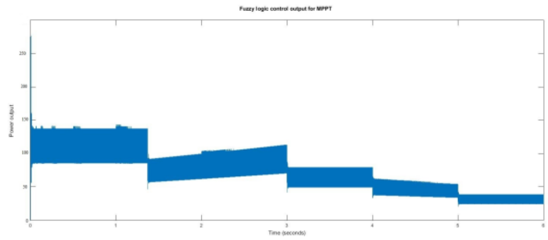
Fig.4.11Membership function for D

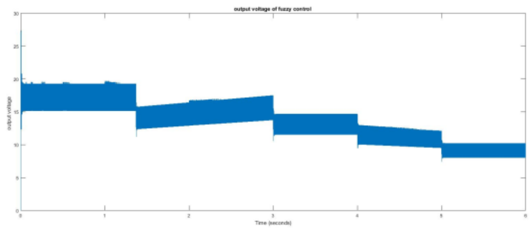
Membership functions used for the input variables and output variables are shown in Fig.4.9, Fig.4.10 andFig.4.11 respectively. A fuzzy rule base is formulated for the present application and is given in table 1. The fuzzy inference of the FLC is based on the Mamdani's method which is associated with the max-min composition. The defuzzification technique is based on the centroid method which is used to compute the crisp output.

Table 1.Fuzzy rule table

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

4.12 Fuzzy Logic algorithm simulation:





4.4 Particle Swarm Optimization algorithm:

PSO is Simple in structure, fewer parameters are required, faster convergence and no steady state oscillations at the MPP. Performance of PV modules will be degraded by passing clouds, high neighbouring buildings, trees and towers, etc[16-20]. Due to this some portion of the solar cell will not receive the sunlight. This situation is called as a partial shading condition. Under this situation several local MPPs will appear in the characteristic curve. So Under partial shading conditions, it is possible to have multiple local maxima in a photovoltaic (PV) system, but overall there is still only one true maximum power point (MPP) in the system[22]. To track the true MPP, a strategy called variable size of particle swarm optimization (PSO) is need to develop. The strategy increases the movement step of particles at the initial iteration, and decreases it gradually with iteration. The simulation results showed that the strategy can track the global MPP fast and accurately in PV systems.

Particle swarm optimization is a stochastic and population based EA(Evolutionary algorithms) search method. It was developed by Russel C.Eberheart and James Kennedy in the year 1995 and modified by Eberheart, Simpson and Dobbins .It is based on the search method for food by birds and fishes. It is a global optimization algorithm with swarm intelligence. Swarm refers to a huge group of co-operative agents. These are otherwise called particles, working together to achieve a target.

The basic equations to find the velocity and position of the particles are given by:

$$v_i^{(t+1)} = v_i^{(t)} + c_1 r_1^{\left(\left(p_{best,i} - x_i^{(t)} + c_2 r_2\left(g_{best} - x_i^{t}\right)\right)\right)} \quad (8)$$

$x_i^{(t+1)} = x_i^{(t)} + v_i^{(t+1)}$First component is velocity component and second and third component are change in velocity.

New position of particle are given by :

$$x_i^{(t+1)} = x_i^{(t)} + v_i^{(t+1)} \quad (9)$$

$$x_i^{(t)} \mathit{are\ particle\ position}$$

C1, C2 - are simply the acceleration constants or cognitive and social constants respectively. r1, r2 are random variables uniformly distributed with in [0, 1]

$p_{best,i}$ is the best position of particle i

$g_{best,i}$ is the best position of particle i ranges from 1 to N and t indicates the number of iterations.It is further improved by the insertion of a constant, called inertia weight 'w', with velocity to improve the performance.It can be a positive,positive linear or non- linear constant, with the function of time.A better value of w decides the global and local search convergences[19]. w<0.8 is the best for local search, w>1.2 provides the best global search, and 0.9<w<1.2 is optimum for both. Features of the algorithm are robust, faster and capable of solving nonlinear, non differentiable and multimodal problems. In this algorithm, the particles are assigned random positions. Then, these are accelerated to move toward the targeted position. The position of the particle is compared with that of its neighbours. The particle closer to the target position is called the personal or individual best pbest . Determination of the target's closer location by the group is called the global best gbest.

$$v_i^{(t+1)} = w v_i^{(t)} + c_1 r_1^{\left(\left(p_{best,i} - x_i^{(t)} + c_2 r_2\left(g_{best} - x_i^{t}\right)\right)\right)} \quad (10)$$

where$w$ are inertia weight and all other are same.

(11)

$$P_{besti} = x_{ik} i = 1,2, \dots \dots N \quad (12)$$

$$d_i^{k} = \lfloor d_1 d_2 d_{3\,\dots\dots} d_N \rfloor$$

$$d_i^{new} = \left\lfloor d_2 - d_{x,} d_{2\,,\dots\dots} d_2 + d_{x,} \right\rfloor$$

Another form of velocity equation with Constriction factor 'K' is necessary to converge the PSO. It is given by

$$v_i^{(t+1)} = K * \left(w v_i^{(t)} + c_1 r_1^{\left(\left(p_{best,i} - x_i^{(t)} + c_2 r_2\left(g_{best} - x_i^{t}\right)\right)\right)} \right) \quad (13)$$

K-Constriction factor given by :

$K = \frac{2}{\left[2 - \varphi - \sqrt{\varphi^2 - 4\varphi}\right]}$where$\varphi = c1 + c2\,, \varphi > 4$

This is special case of inertia weight.

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Basic PSO steps:
Step 1: Initialization of the particle position and velocityrandomly.
Step 2: Objective function evaluation.
Step 3: *pbest*and *gbest*evaluation.
Step 4: Updating of the velocity and position.
Step 5: Repetition of steps 2–4 until the criteria met.

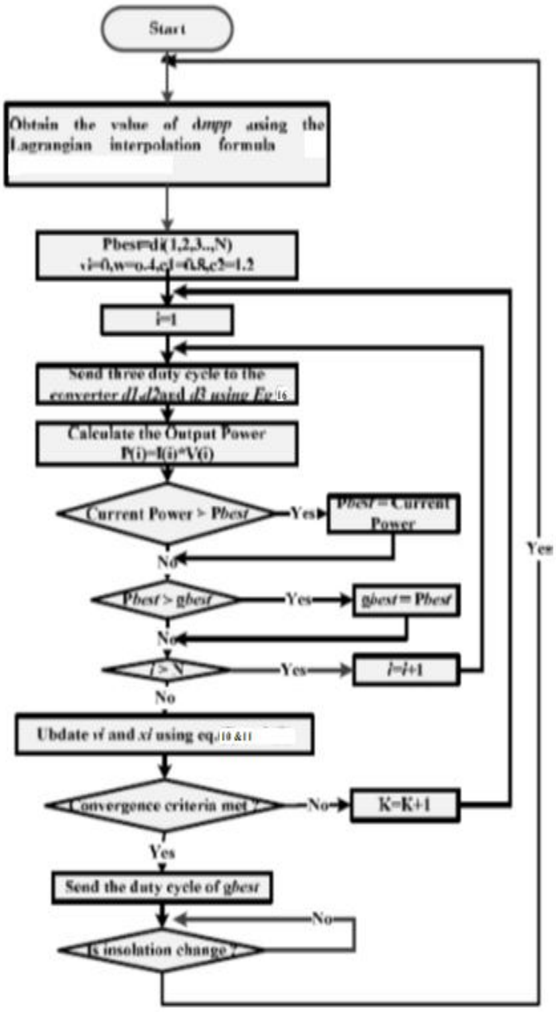
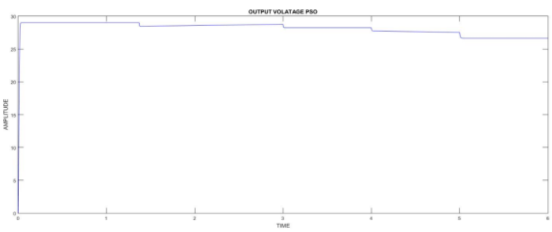
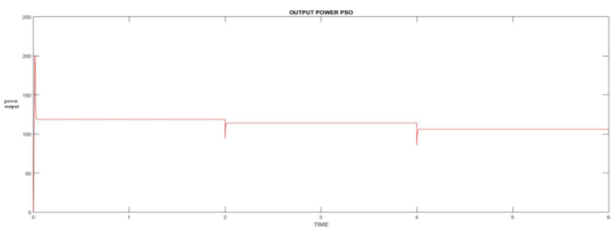
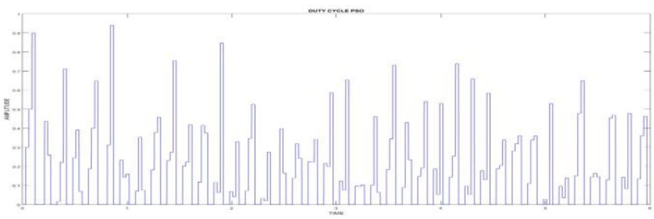


Fig.4.12 PSO algorithm

4.4.1 Simulation results of PSO algorithm:



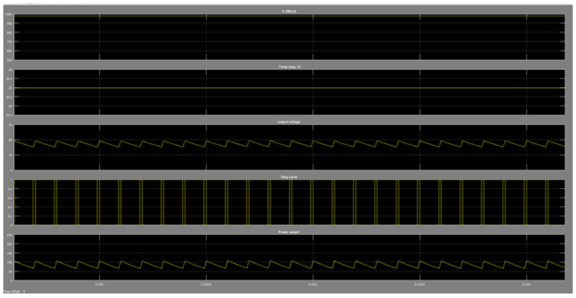




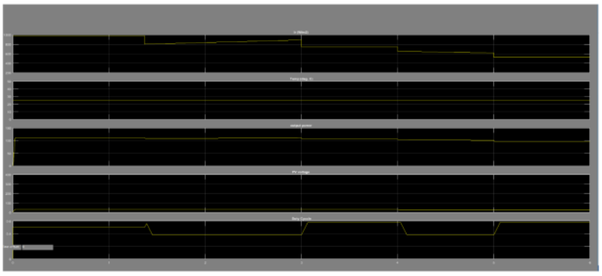
V. RESULTS AND ANALYSIS OF ALGORITHM

Different algorithm are simulated in MATLAB environment with same input of irradiance and temperature as shown in Fig.4.2(a) and Fig.4.2(b). All the algorithm like P&O,I&C,Fuzzy and PSO gives good results which are compared as below:

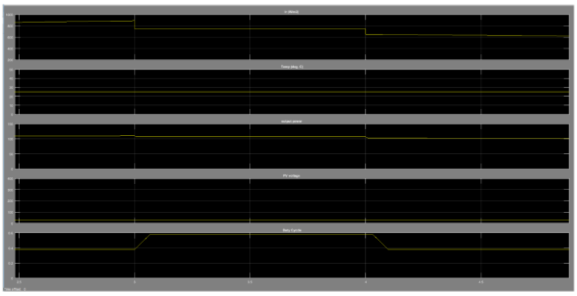
Simulation scope results: Fuzzy logic control result is good in terms of response time, speed of conversion and tracking ability. As shown from enlarge view of fuzzy scope output power is nearly constant with respect to irradiance variation. Steady state response is very good as in zooming result variation of output is small during period of very small span from 0s to 0.05s which is very negligible and then after steady state response is achieved but variation of duty cycle is very large according to fixed rule based fuzzification so it need to be optimized with the help of swarm optimization. Time response is also good compared to other algorithm as it achieves peak power within very small span of time say 0.0025s.Mainly fuzzy logic can work better in low irradiance condition than other algorithm.



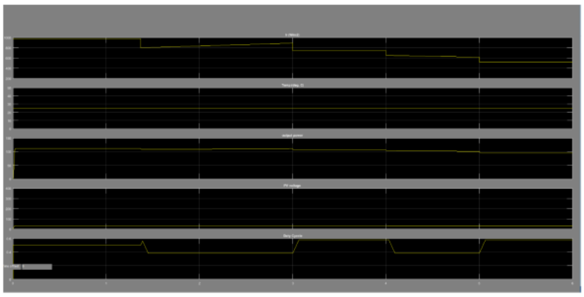
Enlarge view of fuzzy starting response of power output from 0s to 0.5s



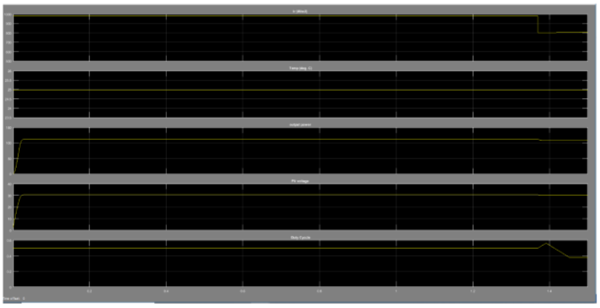
I & C scope response with duty, power and voltage



I & C scope under enlarge view from 0s to 2.95s



Perturb & Observe scope results with output power, voltage and duty cycle



Initial response enlarge view of perturb & observe scope output from 0s to 1.4s

In perturb & observe method tracking response is achieved within 0.02s as shown from plot results and steady state is achieved afterwords while that response time is achieved in fuzzy control is 0.0025s which is fast in tracking compared to P & O.

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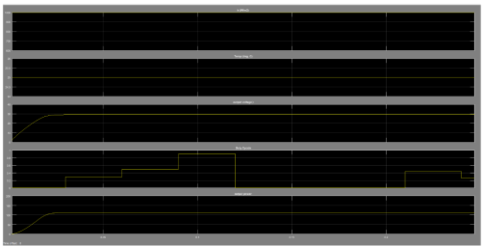
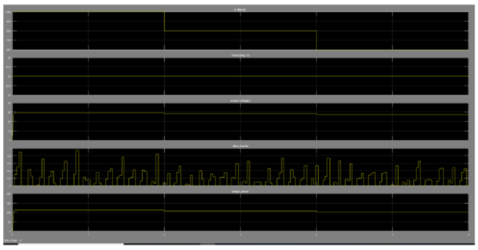
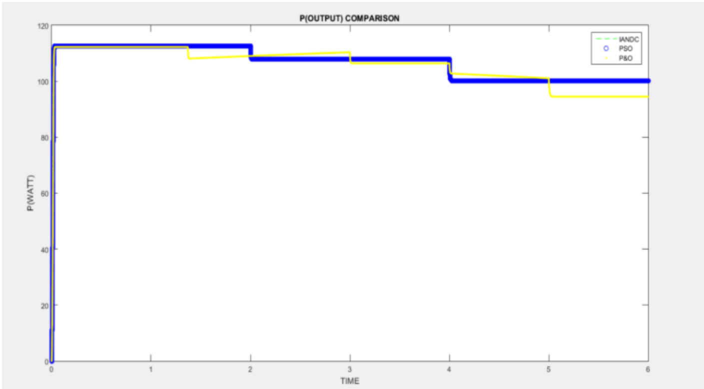


PSO scope result with output voltage, duty and output power



PSO scope enlarge with result shows 0s to 0.2s for initial response

PSO response is enlarge from time period 0s to 0.2s ,which shows tracking response time is 0.005s.As in low irradiation condition PSO will perform good as compared to other algorithm, where irrespective of variation in irradiance power output is constant.



Power comparison for different technique

VI. SUMMARY AND CONCLUSION

Simulation of P&O, I&C, Particle Swarm Optimization and Fuzzy algorithm is verified and power output is compared. The changes in irradiance is also verified with all algorithm. Incremental conductance algorithm shows the result from 0s to 2.95s with constant output without any variation. PSO response is enlarge from time period 0s to 0.2s ,which shows tracking time response is short say 0.005s.With variation in duty cycle w.r.t variation in irradiance condition ,output voltage and power remains constant in particle swarm optimization algorithm which is shown in results. In perturb & observe method tracking response is achieved within 0.02s as shown from plot results and steady state is achieved after words while that response time is achieved in fuzzy control is 0.0005s which is fast in tracking compared to P & O algorithm.fuzzy output power is nearly constant with respect to irradiance variation. Steady state response is very good as in zooming result. Variation of output is small during period of very small span from 0s to 0.05s which is very negligible and then after steady state response is achieved but variation of duty cycle is very large according to fixed rule based fuzzification so it need to be optimized with the help of swarm optimization. Response time is also good compared to other algorithm as it achieves peak power within very small span of time say 0.005s.Mainly fuzzy logic can work better in low irradiance condition than other algorithm. Speed of conversion is also fast as compared to other algorithm. Summary of analysed algorithm:

Table 3: Comparative power for different technique for different solar radiation

Sr. No	**Solar radiation W/m^2**	**P&O (W)**	**I &C (W)**	**PSO (W)**	**Fuzzy logic control (W)**	**Theoretical value of PV (W)**
1	**1000 W/m^2**	**110**	**110**	**185**	**150**	**198**
2	**900 W/m^2**	**105**	**105**	**125**	**110**	**180**
3	**800 W/m^2**	**103**	**103**	**120**	**90**	**160**
4	**750 W/m^2**	**100**	**100**	**110**	**80**	**150**
5	**650 W/m^2**	**90**	**90**	**105**	**75**	**130**
6	**600 W/m^2**	**80**	**88**	**102**	**70**	**120**
7	**480 W/m^2**	**78**	**80**	**98**	**60**	**100**

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Table 4: Comparison for uniform radiation and partial shading condition

Sr. No	Irradiance W/m^2	Maximum power from PV curve P_{MPP}(W)	MPPT technique	Power (W)	Tracking Time(s)	Steady state oscillation	Efficiency
1	Uniform at STC 1000W/m^2	200.143	P&O	110	0.02s	insignificant	54.96%
2		200.143	I&C	110	0s	insignificant	54.96%
3		200.143	PSO	195	0.005s	less	92.43%
4		200.143	FLC	150	0.0025s	medium	74.94%
5	Partial shading 480 w/m^2	100	P&O	78	0.02s	insignificant	78%
6		100	I&C	80	0s	insignificant	80%
7		100	PSO	90	0.005s	less	90%
		100	FLC	60	0.0025s	medium	60%

Table 5: Comparative parameter for different technology

Sr. No	Parameter of Evaluation	P&O Method	I &C Method	PSO Method	Fuzzy logic control
1	Average power (maximum=200.143W)	110W	115W	125W	135W
2	Increase in average output power compared to P & O (%)	N.A	2.49%	5.005%	7.50%
3	Response Time at start (in ms)	0.02s	0s	0.005s	0.0025s
4	Increase in Efficiency compared to P&O	N.A	2.5%	5.00%	7.5%

6.1 Future Work

The MPPT controller was first implemented using conventionalP&O algorithm and I & C algorithm. Later was implemented using particle swarm optimization & fuzzy logic control as described. Simulation results of power output, output voltage and duty cycle are compared. PV power which is controlled by the proposed fuzzy logic controller is more stable than the conventional MPPT techniques. The power curve obtained with FLC is smoother when compared to P&O algorithm. PSO MPPT algorithms are capable of tracking maximum power rapidly under varying atmospheric conditions (low irradiance) with due changes in duty cycle and maintain constant output power compared to other conventional algorithm. P & O algorithm shows an oscillatory behaviour but fuzzy logic controller provides a smooth operation. The future work for the hybrid algorithm will be proposed for optimization of fuzzy with PSO for (low irradiance condition)environmental varying condition specially for partial shading condition. Suitable method and its optimization will be decided based on future review.

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