Design of Novel MPPT Technique For A Photovoltaic System Under Partial Shading Conditions

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Abstract- *Photovoltaic (PV) system is used to produce electricity from solar cells. The characteristics exhibited by PV array are normally non-linear. The characteristics changed by changing the level of irradiance. They become complicated when PV arrays are under partial shading conditions, because multiple peaks of maximum power points are formed. Conventional Perturb and Observe (P&O) technique give good results for the tracking of maximum power points (MPP) for non-linear characteristics but it fails to track under partial shading conditions. So we introduced a new MPPT technique to extract maximum power point under partial shading conditions. But this algorithm did not give good results for rapidly varying conditions, to track the MPP under rapidly varying environmental conditions rapid global scanning algorithm is proposed, but it increases the low power points under tracking and also it cannot track the MPP under all modules are shading condition. So that by introducing fuzzy logic controller in the proposed algorithm it reduces low power points and to track the MPP all modules under shading conditions and also comparative analysis of results are submitted.*

Keywords- perturb and observe; PV array; MPP; PV curve periodic scanning; rapid global scanning algorithm; fuzzy logic controller; partial shading condition.

I. INTRODUCTION

Electricity is most essential need for human being at present. This electrical energy generated from various resources, but energy generated from clean, efficient and environmental friendly systems is important. Among all renewable energy sources solar energy is most useful energy resource because they provide opportunity to generate electricity while green house emissions are reduced. The main part of photovoltaic system is solar cell. Solar cells are arranged in the form of panel. Panels are generally combination of series cells in order to obtain high output voltages. Panels with high output currents are achieved by increasing the surface area of the cells or by connecting cells in parallel. A PV array may be either a panel or a set of panels connected in series or parallel to form large PV systems. Solar cell is an electrical device which converts light energy into electricity through photovoltaic effect. A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light [1], [2]. Photovoltaic cells are made of several types of semiconductors by using different manufacturing processes. The mono crystalline and polycrystalline silicon cells are present at commercial scale.

Silicon PV cells are composed of a thin layer of Si film Connected to electric terminals. One of the sides of the Si layer is doped to form the p–n junction.

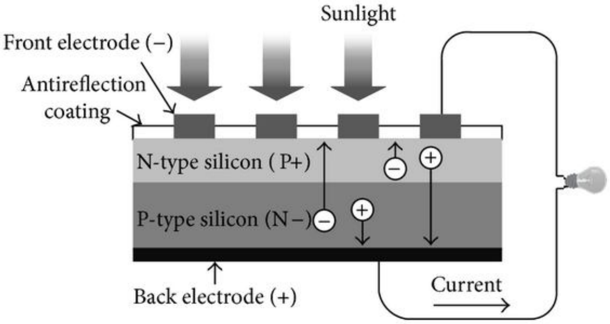

Fig.1 basic structure of PV cell

A thin metallic film is placed at sun facing of the surface of the semiconductor. Fig. 1 shows the basic structure of a PV cell. The incident light on the cell generates charge carriers that produce an electric current if the cell is short circuited [2]. Charges are generated when the energy of the incident photon is sufficient to discharge the covalent electrons of the semiconductor. The PV cell working process depends on the semiconductor material and on the wavelength of the incident light. Basically, in the PV cell working process may be described as the absorption of solar radiation, the generation and transport of free carriers at the p–n junction, and the collection of these electric charges at the terminals of the PV device [3], [4]. The rate of generation of electric carriers depends on the flux of incident light and the capacity of absorption of the semiconductor. The absorption capacity depends mainly on the semiconductor energy gap, on the reflectance of the cell surface (that depends on the shape and treatment of the surface), on the intrinsic concentration of carriers of the semiconductor, on the electronic mobility, on the recombination rate, on the temperature, and on several other factors. Solar cells have complicated relationship between solar irradiation, temperature, and total resistance so that they exhibit non-linear output characteristics.

The solar radiation is combination of photons of different energies. Photons with energies lower than the energy gap of the PV cell are useless and generate no voltage or electric current. Photons with energy greater to the energy gap of PV cell generate electricity, but only the energy corresponding to the energy level gap is used as the energy is dissipated as heat in the BODY of the PV cell. Semiconductors with lower energy level gaps may take advantage or a larger radiation spectrum, but the generated voltages are lower. Si is not the only, and probably not the best, semiconductor material for PV cells, but it is the only one whose fabrication process is economically feasible in large scale. Other materials can achieve better conversion efficiency, but at higher and commercially unfeasible costs.

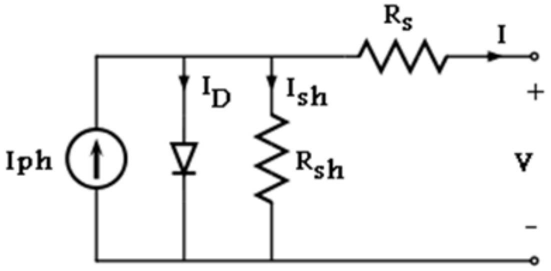

Fig.2 Equivalent circuit of the ideal PV cell

Fig. 2 shows the equivalent circuit of the ideal PV cell. The basic equation of the semiconductors that mathematically describes the I–V characteristic of the ideal PV cell is

$$I = I_{pv} - I_0 \left[exp\left[\frac{V + IR_s}{aV_T} \right] - 1 \right] - \left[\frac{V + IR_s}{R_P} \right] \quad \textbf{(1)}$$

Where I_{pv} is the photo current of the diode, I_0 is the diode's reverse saturation current, a is the ideality factor, V_t is the thermal voltage, R_s is the series resistance, R_p is the shunt resistance, q is the electron charge ($1.6021746*10^{-19}$ C), k is the Boltzmann constant ($1.3806*10^{-23}$ J/K).

Maximum power point (mppt) tracking techniques are used to maximize the output power of the photovoltaic systems. There are many conventional MPPT techniques are used for the photovoltaic systems, but these techniques do not give better results for the problem of partial shading conditions. These conditions are formed because of curved installation of photovoltaic systems, shadow of buildings, trees, clouds etc,. to reduce this so we introduce a new MPPT technique gives better results compared to conventional MPPT techniques, this new technique involves basic perturb and observe loop and find maximum power point and run the loop for specified intervals of time to reduce the loss in the PV system. This technique is called as “pv curve periodic scanning”, But for rapidly varying environmental conditions we introduced another technique with little modification of “pv curve periodic scanning” that is called “rapid global scanning algorithm”. In this technique we divide the solar cells into groups and applied the technique individually. But with this rapid global scanning algorithm there are some low power points still exists, and with neither pv curve periodic scanning nor rapid global scanning algorithm because of continuous tracking of partial shading there is more power loss exists. So to reduce this more power loss and increase the speed of tracking we replace this conventional controller with fuzzy logic controller. With this new method we reduce low power points and increase the power of the each panel. The rest of the paper organized as fallows. Section-II describes the certain observations on power-voltage (P-V) characteristics, and current-voltage (I-V) characteristics of solar cell under partial shading conditions. Section-III describes the proposed algorithm to track the MPPT and section-IV describes the control strategies of the system. Section-V describes the results and discussions of the proposed system. Section-VI describes the main conclusions of the system.

II. PARTIAL SHADING CONDITIONS

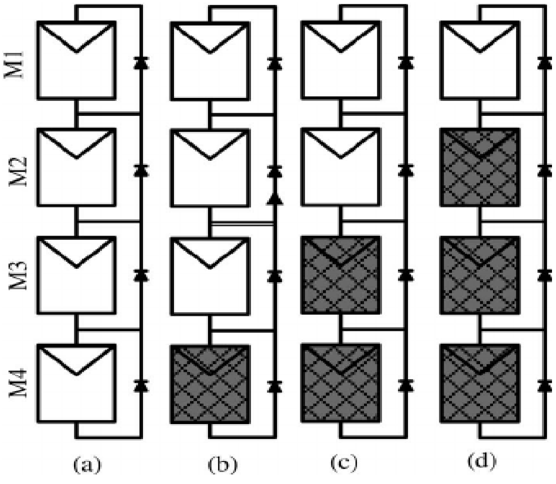

Fig.3 PV array under different partial shading conditions. (a) Simple PV array with insolation of *1000W/m²* on the un shaded modules.(b) One shaded module with *400W/m²*. (c) Two shaded modules with *400 W/m²*. (d) Three shaded modules with *400W/m²*.

Solar irradiance is the measure of solar power and it is defined as the sun delivers energy to the earth by means if electromagnetic radiation. The radiation density decreases with square of the distance. These solar arrays catch the irradiance convert it into electricity. As the solar irradiance keeps on changing throughout the day, the I-V, and P-V characteristics also changes. With the changing irradiance the open circuit and short circuit currents also changes and hence the maximum power point also changes. Under normal days all solar cells gets equal amount of power. Temperature is another major factor in determining the solar cell efficiency. It acts like a negative factor affecting the solar cell performance. Under partial shading condition, if there one cell in solar array is less illuminated, the shaded array will dissipate less amount of power by the rest of the array. It means the current available in series connected array is limited by the current of the shaded cell. This can be avoided by using bypass diodes placed parallel with the solar array as shown in fig. 3[1]. The method of using bypass diodes allows the array current to flow in correct direction even if one of the arrays is completely shadowed. But because of these bypass diodes P-V curve posses multiple maxima occurs under this partial shading condition. There are two observed peaks in P-V curve, because of the natural behavior of bypass diodes and pv array connection inside the module.. For example if we consider the fig 3(a) [1], every PV module in that have same voltage, current and output power at any time. In this every module works as source. In the example 3(c) [1] shows that, the modules in the series exposed to two different irradiance conditions, So that the voltage of the module is completely different compared to modules under un shaded condition. The P-V curve of that case divided into two parts. In the first part the photo current of the module is grater then the maximum reference current of the diode. It means the condition of shading will be produced at the module, so the current flow into the bypass diodes of M_3 and M_4 modules. At this time only M_1 and M_2 produces power to the total module. The remaining diodes bypassed through the bypass diodes. The voltages M_3,M_4 are may be negative. The second part of the P-V curve shows that all PV modules are supplying power, but the shaded and unshaded modules receive different amounts of irradiance levels. The voltage of the unshaded modules has greater voltage than the shaded modules. From the above analysis we observed that I-V and P-V curves characterized by multiple steps and peaks as shown in fig4,5. The no of peaks are equal to no of different irradiance levels in the P-V curve any of the peak may be GMPP. The voltages of the PV modules depends upon the irradiance that received by the solar array. The voltage of the shaded PV module is equal to the negative of the diode forward voltage. Under these conditions traditional algorithm can track only two MPPT's, and they cannot distinguish between GMPP and LMPP. If the operating point obtained by the PV array algorithm is LMPP, the output power is significantly lower. So That a complex algorithm is required to calculate the GMPP of the curves. This method is able to obtain the GMPP, and it can determine whether the PV cell is operating under shading conditions, but it scans blindly and constantly for the MPP, wasting the output energy. For these reasons, a new improved MPPT method for the PV system under the partial shading condition is discussed in further sections.

b. more levels of insolation:

From the above discussion we only see the PV array under two levels of insolation. But in some extreme situations also occur as shown in fig 5. At that time the four PV modules are under four different irradiance conditions, so that the characteristics of PV array are under four different steps and four different peaks. The proposed algorithm no longer works out at these type of situations. So, a new algorithm will proposed for these extreme situations as shown in fig 6

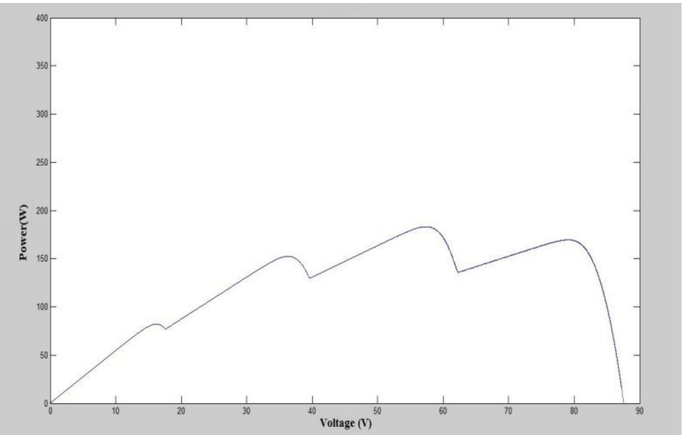

Fig.4 characteristics of PV array under extreme partial shading conditions

III. MPPT CONTROL METHODS

There are different MPPT techniques are used to increase the efficiency of solar panels. They are Perturb and Observe (P&O) technique, Incremental Conductance (INC) technique, Neural networks (NN), and Fuzzy logic (FL) technique are used. In this paper we discuss mainly about Perturb and Observe (P&O) technique. P&O is basic and simple technique to track the maximum power point in the P-V curve of modules. This technique operates on the basis of periodical checking of the array terminal voltage or current and comparing the array output voltage with that previous voltage. This technique determines that small change in PV voltage and power of the module. If the small change in PV module voltage and the corresponding variations in power of the PV module is ΔP are positive, which describes a change is occurred towards the MPP and continuously variations occurred in the same track until MPP is reached. If the changes are negative it describes that changes are far away from the MPP, so that tracking direction must be changed. The algorithm of P&O technique is shown in fig.5

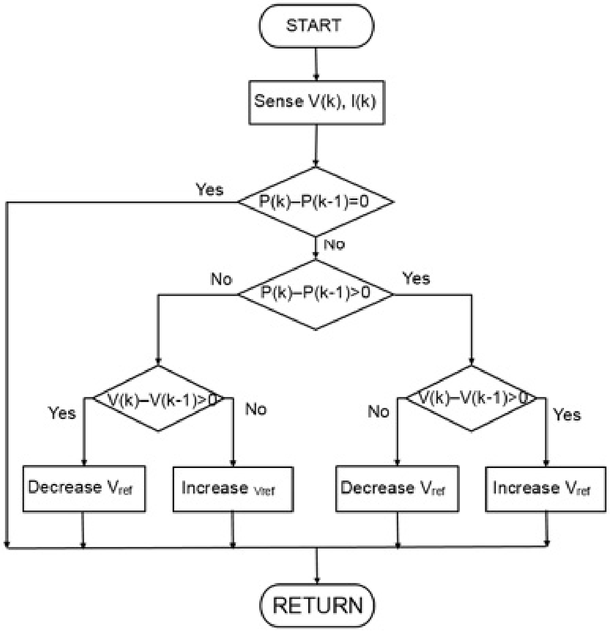

Fig.5 Algorithm of P&O technique

The system oscillates around MPP, which causes power loss the oscillation can be minimized by decreasing the size of the duty cycle of the system. The drawback of the P&O algorithm is it fails during rapidly changing climatic conditions.

a. Improvement of MPPT controller:

To reduce the blind scans and wasting of energy in the conventional MPPT techniques a new technique is introduced, this new techniques improve tracking speed and also checking for the partial shading conditions. It also check for the global and local maxima under partial shading conditions The flow chart of improved MPPT algorithm as shown in fig 6. The algorithm execution always starts with 85% of the reference voltage. It calculates the no of PV modules. Generally under uniform irradiation conditions there is only one peak in the P-V curve. Under these conditions conventional MPPT techniques can perform well. So that until the partial shading conditions occur conventional P&O algorithm continuously implementing. The maximum power point is tracked then it stores the information of power and voltage. A timer interrupt program is used to for regular checking of partial shading conditions. When one PV module voltage is greater than another one $(V_i > V_j)$, at that point partial shading condition has occurred. The difference between V_i and V_j are greater than the predetermined value in the “main program” calls the “GMPP track subroutine”. This “GMPP track subroutine” finds the true GMPP and passes the control to the main program” which maintains the operation at this new GMPP.

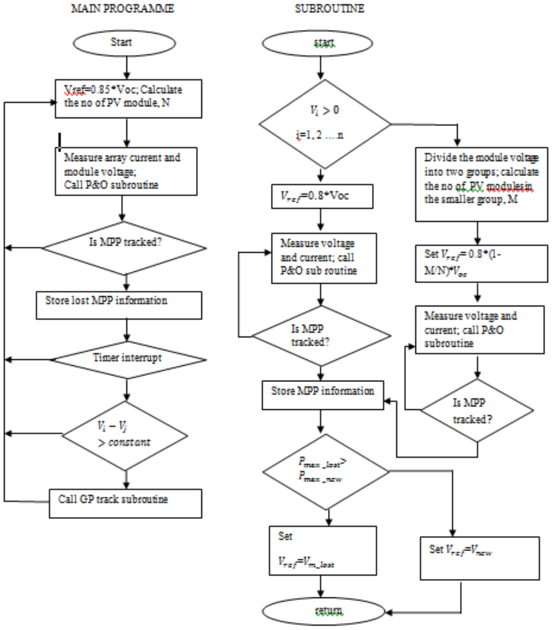

Fig.6 PV curve periodic scanning flow chart

The “GMPP track subroutine” determines the new MPP on the P-V curve, whenever the voltage of any PV module is less than zero (V_i <0) it shows that the new MPP left the peak of P-V curve, and reference voltage of the right peak set about 80% of the open circuit voltage and conventional perturb and observe MPPT technique track this peak. Then if any PV module greater than zero, the new MPP is the right peak on the P-V curve. After that the algorithm divides the voltages into two groups and calculates the no of modules in a group with smaller voltages that is M. These M modules will be under shading conditions so that these modules cannot produce any power. So that the reference voltage of the left peak is set in the value of $80\%(1-M/N) *V_{oc}$ and then same MPP technique is applied for tracking. After that by comparing the powers this left peak and previous one the new GMPPT produced. After that reference voltage is set to new GMPP and control passes to the “main program”, this maintains the operation of GMPP until the timer interrupt occur again.

In general situations the PV array is irradiated at two levels of insolation, but under extremely varying environmental conditions fig.7 shows the characteristics of PV array, in this four PV modules are connected in series and irradiated at four levels of insolation. The above algorithm cannot handle this situation, but the observations are considered. Therefore by applying small modifications in the GMPPT subroutine the above algorithm can give good observations for extremely varying situations. To track MPP for that extremely varying situations the new GMPPT track subroutine is introduced. The new algorithm is shown in fig.8.

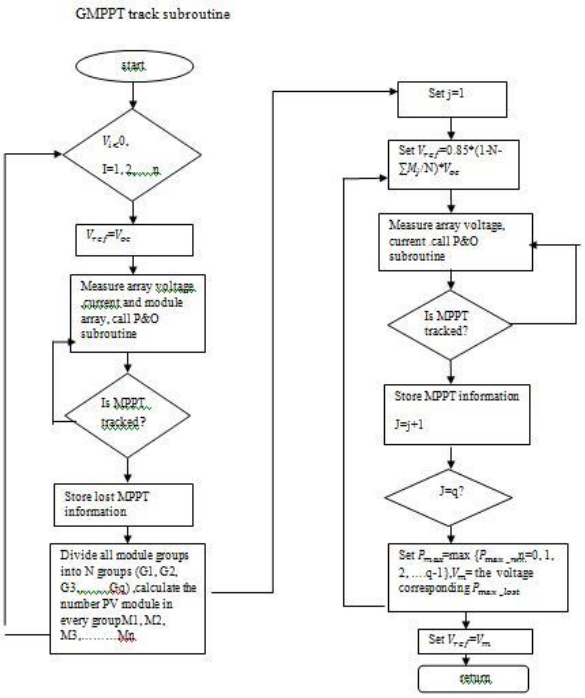

Fig.7 Flow chart of new GMPPT track subroutine

The above algorithm starts with from the right peak of the P-V curves. If any of the PV module voltage that is right most peak value is stored, otherwise it tracked the right most peak value and the information of the MPP is stored. All the PV modules divided into *q* groups with respect to voltages and arrangements.

In those groups the lowest voltages consisting cells are named as G_1, while in that largest voltage groups are called as G_q. next the subroutine calculates no of modules in every group. Generally, *q* is the number of different insolation levels irradiated on PV array. There are *q-1* MPP information that need to be found, and the tracking to be carried out from right peak to left peak. When PV array is operating at a rightmost peak on the P-V curves,M_1 modules are found that the lowest levels are irradiation, and these modules under shading conditions and bypassed by the bypass diodes. They will not produce any output power, so the reference voltage of the peak is 85% of $(1-(N-M_1)/N)*V_{oc}$. The previous method is used to find all other MPP's. After that by comparing the powers of all peaks, the true MPP is obtained. Finally the reference voltage of true GMPPT is stored and the control is passed to the main program. It continuous and maintains with the new GMPP when the timer interrupt occurs again.

IV. CONTROL STRATEGY

In the proposed system, PV systems are used as primary power sources to produce power. But the power generated and integrating them highly depends on whether condition. In order to give continuous supply with primary generation, there must be a controller that controls the variations that depends on weather.

a. *Conventional controllers*

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P Controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of the response. The drawback of PI controller is it does not predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller.

b. *PID controllers*

In the process industry, majority of the control loops are based on proportional-integral-derivative (PID) controllers because of their simplicity, reliability, robustness and successful practical application. Design methods leading to an optimal and effective operation of the PID controllers are economically vital for process industry. Various tuning methods have been proposed for gaining better and more acceptable control system response based on our desirable control objective such as percent of overshoot, settling time.
Thus transfer function of the most basic form of PID Controller is

$$C(s) = K_P + \frac{K_I}{s} + K_D s \qquad (2)$$

Where K_P is proportional gain, K_I is integral gain, and K_D is derivative gain [15]. PID controller has all necessary dynamics; fast reaction on change of the controller input (D mode), increase in control signal to lead error towards zero (I mode) and suitable action inside control area error to eliminate oscillations (P mode).

c. *Fuzzy Logic Controller*

Fuzzy logic Controller having capability that handling the problem with imperfect knowledge and it acts as effective alternative. A fuzzy logic controller has been introduced in the tracking of maximum power point in PV systems. It gives several advantages like fast tracking and better performance and simple design. This technique generally does not need the information of complete model, but it pre requisite the model. The fuzzy logic controller has two inputs and one output as shown in fig.8. The two FLC variable inputs are error *E*, and change in error *CE* and these two variables sampled *K* times

$$E(k)=P(k)-P(k-1)/V(k)-V(k-1) \quad (3)$$
$$E(k)=E(k)-E(k-1) \quad (4)$$

Where P(K) is the instant power generated in photovoltaic, the input E(k) shows if the load operating point at the instant k is located at right or left of the MPP on P-V characteristics. The CE(k) determines the moving direction of load operating point. The fuzzy logic sets divides the input variable (error E) into five fuzzy sets NL (negative low),NM(negative medium), P (zero), PB (positive big), PM(positive medium), the second input variables also divided into the above mentioned 5 types. The fuzzy inference is carried out by using mamdani's method. The output is calculated by using diffuzifier block. The centroide method is used for this diffuzifier block to determine the output of this Fuzzy Logic Controller. The output is the duty cycle which uses the base rule of table1.

Table 1. Rule Base of Fuzzy Logic Controller.

C/CE	***NL***	***NM***	***P***	***PB***	***PM***
NL	*PB*	*PB*	*P*	*NL*	*NM*
NM	*PB*	*PB*	*PM*	*NM*	*P*
P	*NM*	*NM*	*NM*	*NM*	*NM*
PB	*NL*	*NL*	*P*	*PM*	*NL*
PM	*NM*	*P*	*NM*	*NL*	*NM*

For example, assume that M rules in the fuzzy system, where the $_{i}^{th}$ rule has the fallowing form:

R^i: if E is the F_e^i and CE is F^i_{ce} then dD is U^i
With i=1,2…….M

Where F_E^i and F_{CE}^i are antecedent linguistic triangular terms modeled by the interval of triangular fuzzy sets, dD is the output of the consequent term U^i is an interval of control actions of the consequent part.

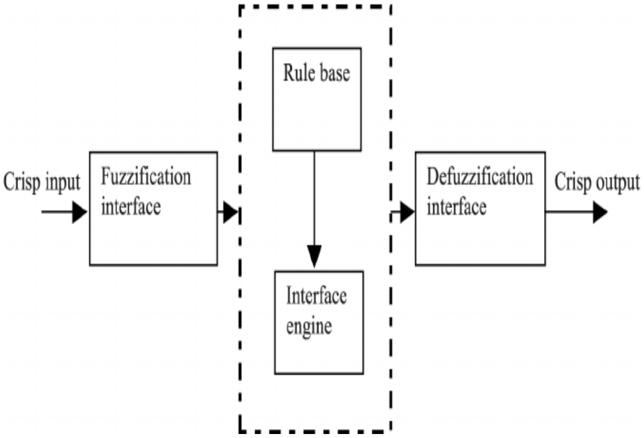

Fig.8 Structure of Fuzzy Logic Controller

V.RESULTS AND DISCUSSIONS

In order to reasonably compare, all methods are implemented through a CUK converter circuit, the sampling time is0.01 s, and the voltage disturbance in the P&O method is 0.1 V. The disturbanceΔV_{large} of the rapid global scanning algorithm is 13.3 V (60% of$V_{OC\ module}$).The performance of the proposed algorithm under gradually varying shading conditions. The irradiance level in the time range0–3s is, 1000W/m^2 .That means entire array receives uniform insolation. During this period, the P&O method can work well and there is no partial shading of the array. The irradiance level on the shaded module becomes 400W/m^2. At this time, "GMPP track subroutine" begins to look for GMPP. First, the P&O method traces the LMPP, and detects weather the partial shading condition existed or not. Then, the reference voltage of the left peak is set to *35.5 V.(80%(1-M/N)***V_{oc}*,M=2,N=4,*V_{oc}*=88.8*).

Afterward, the new GMPP is tracked down and replaces the original LMPP at t=4.1s. The whole process takes 1.1s. When the whole array is covered in shadow at t=13s, the "GMPP track subroutine" stops, and the P&O method finds a new MPP. By comparing the two proposed algorithm, the P–V curve periodic scanning algorithm takes more time and loses more energy in the process of scanning. The rapid global scanning algorithm has good performance in place of tracking speed and can track the GMPP in only 1.2 sec, but some low-power work points still exist in the tracking process. Further, when the whole array is covered in shadow (at t=13sec), neither the P–V curve periodic scanning algorithm nor the rapid global scanning algorithm cannot determine the presence of partial shading. So, periodic scan sequence or "GMPP track subroutine "cannot stop operating, and cause more energy loss. The results of PV curve periodic scanning (PSA) and rapid global scanning (RGSA) are shown in the fig 9,10,11,12.

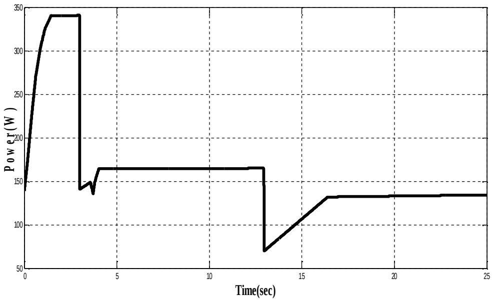

Fig.9 Output power of PV module under partial shading with PSS

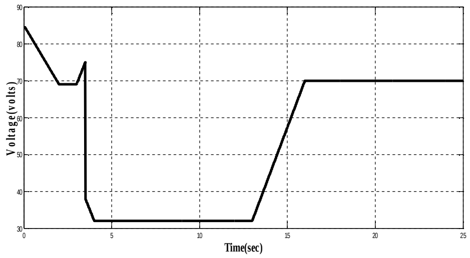

Fig.10 Output voltage of PV module under partial shading with PSS

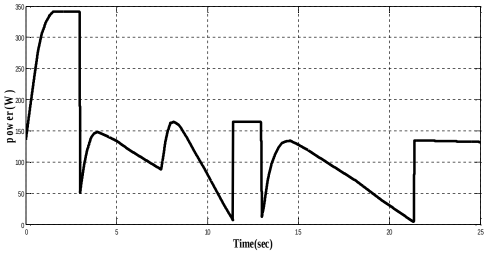

Fig.11 Output power of PV module under partial shading with RGSA

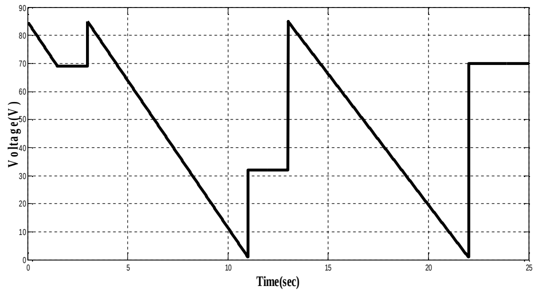

Fig.12 Output voltage of PV module under partial shading with RGSA

The FLC is proposed to improve the MPPT dynamic performance under varying environmental operating conditions, by considering the duty cycle in the FLC output. In the proposed FLC, the triangular membership functions, is used. They are selected for the input E(k),CE(k) variables and output variable D(k). The peak values of each fuzzy set in the membership functions will influence the overshoot, stability, and steady-state error of system responses.

The effect of temperature and irradiation change can be seen clearly on the power panel signal. FLC MPPT technique provides a good tracking speed and less variation around the MPP. It is clearly determined that by using the FL controller in the MPPT system, we have a significant energy gain with FLC as shown in fig 13, 14, 15, and 16.

These results show that the less instantaneous efficiencies corresponding compared to PV curve periodic scanning method (PSS) and Rapid Global Scanning Algorithm (RGSA) with FLC. They are considerably improved by the proposed MPPT technique. The MPPT using fuzzy logic controller gives better results than the proposed method in several areas of the tracking curve. The Fuzzy Logic Controller reduces the ripple power compared with PSS and RGSA controller. The Fuzzy Logic Controller is faster than the traditional PI controller in the transitional state. Comparison of three techniques power, voltages as shown in table 2

Table.2 comparison of the three techniques voltage and power.

	PPS	RGSA	FLC
OUTPUT VOLTAGE	83V	83V	93V
OUTPUT POWER	347W	347W	360W

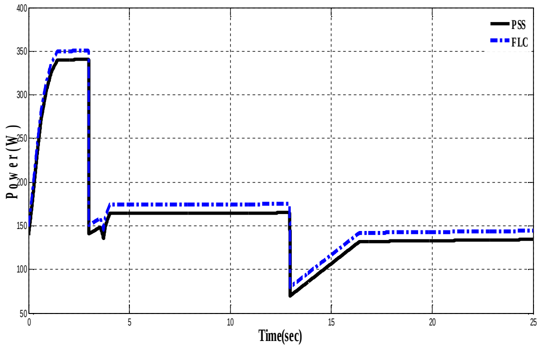

Fig.13 Comparison of PSA and FLC powers

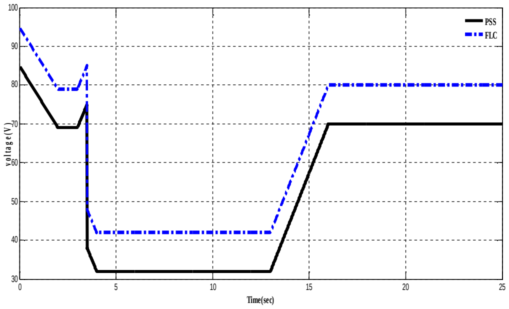

Fig.14 Comparison of PSA and FLC voltages

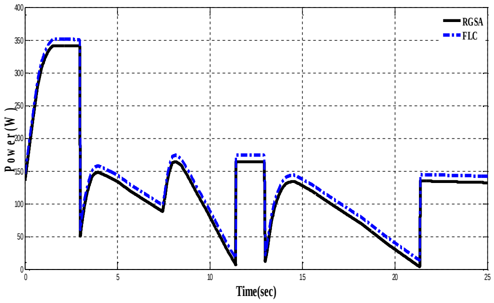

Fig.15 Comparison of RGSA and FLC powers

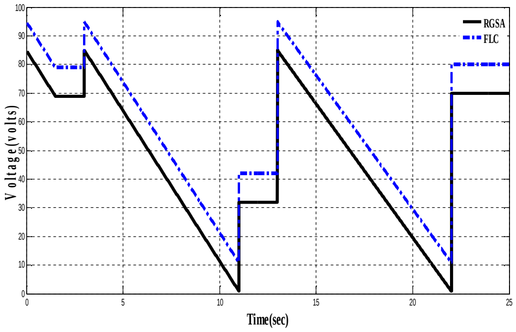

Fig.16 Comparison of RGSA and FLC voltages

VI. CONCLUSION

In this thesis, improvement of the solar module efficiency under partial shading conditions by using PSA and RGSA is described. These techniques are modified form of basic Perturb and Observe MPPT technique. PI controller is used for comprising the solar output with reference voltage and pulse width modulator (PWM) produces pulses with equal intervals of time. So the basic P&O subroutine run four times and gives the maximum power operating point under different types of partial shading conditions in the PSA. This algorithm gives better results compared to conventional techniques. But for rapidly varying environmental conditions this will not give good results. For such type of problems we introduce a small change in the proposed algorithm and produced results. The new algorithm is called RGSA. It gives better results compared to PV curve periodic scanning technique but there still exists in low power points and also did not track when all modules under shading conditions.

To reduce this low power points fuzzy logic controller is introduced instead of PI controller. This fuzzy logic controller gives good tracking speed, reduce lower power points and also increase over all power value.

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