# FUZZY LOGIC CONTROLLER BASED-GLOBAL MAXIMUM POWER POINT TRACKING ALGORITHM FOR PV ARRAY UNDER PARTIAL SHADING CONDITIONS

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**ABSTRACT:**

**This paper develops a Maximum Power point Tracking (MPPT) algorithm for optimizing solar array performance that is robust to rapidly varying weather conditions. The power voltage characteristic of photovoltaic (PV) arrays operating under partial-shading conditions exhibits multiple local maximum power points (MPPs). In this paper, a new method to track the global MPP is presented, which is based on controlling a dc/dc converter connected at the PV array output, such that it behaves as a constant input-power load. The proposed method has the advantage that it can be applied in either standalone or grid-connected PV systems comprising PV arrays with unknown electrical characteristics and does not require knowledge about the PV modules configuration within the PV array. The simulation results verify that the proposed global MPP method guarantees convergence to the global MPP under any partial shading conditions.**

**Here we are using the fuzzy controller compared to other controllers i.e. The fuzzy controller is the most suitable for the human decision making mechanism, providing the operation of an electronic system with decisions of experts. In addition, using the fuzzy controller for a nonlinear system allows for a reduction of time to track the GMMP in the system and improves the efficiency.**

***Index Terms:- Extremum seeking control; GMPPT; photovoltaic system; Maximum power point tracking; partial shading condition; Fuzzy logic controller (FLC).***

## I. INTRODUCTION:

Development of solar energy worldwide in the last ten years has brought into purview the maximum power point tracking and module mismatch losses. Such losses are mainly occurred by partial shading of the solar panel and various kinds of solar modules. These losses can be reduced by different parameter analysis. PV is the method of generating electric power conversion i.e. solar radiation into electrical power using semiconductor devices exhibiting the photovoltaic effects. The analysis of current over voltage and power over voltage characteristics at varying solar irradiation levels and temperatures has been obtained. Traditional control system design deals with the problem of stabilization of a system where the reference is known- easily determined or generated- while reaching certain design criteria.

However, in some cases it can be very difficult to find an appropriate reference value. For illustration, the energy efficiency of photovoltaic system depends on the irradiation, the temperature and the other climatic changes. If one desires to maintain optimal efficiency, it is necessary to change one of these variables. Extremum seeking control is a family of control design approaches whose purpose is to autonomously find optimal system behaviour for the closed-loop system and for nonlinear map, while at the same time maintaining stability of signals. Extremum seeking control is therefore largely used to realize real-time optimization for dynamic systems and tracking a varying maximum or minimum (extremum, or optimum value) of a performance function. It is a very interesting methodology in practice because it does not necessitate any knowledge of the process dynamics or model of the system.

A basic photovoltaic system includes generally three main components; a PV generator, a DC-DC converter with MPPT control and a load which could be a battery as shown in fig.1. As it is known, the power characteristic of a photovoltaic (PV) array is nonlinear.

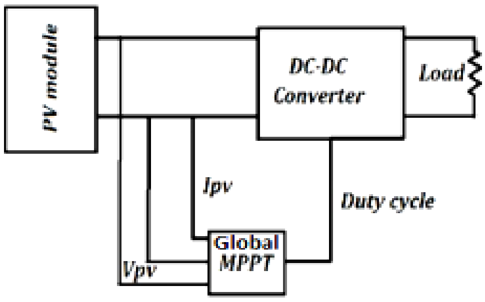



Fig.1. Schematic proposed control system of a Photovoltaic system.

The PV system exhibits only one maximum power point (MPP) on the Power-Voltage (P-V) curve which varies apparently with irradiance, temperature and other environmental condition [1].

Due to this nonlinearity on this curve a Maximum Power Point Tracking (MPPT) must be applied. The researchers have proposed many algorithms in this case that demonstrate good performance such as the searching resolution, tracking accuracy and speed. Some of those algorithms are: perturb and observe (P&O) and Hill Climbing (HC)[2-3] photovoltaic generator is constituted by several cells connected in series and/or parallels[4-5]thus, a cell presents the elementary component of a photovoltaic array. The effects and the examination of partial shading on the characteristics of PV array [6-9]. Extremum Seeking Control (ESC) is real-time optimization algorithm[10]and adaptive control tool , which resolves the problem of tracking a varying maximum or minimum of a performance function; generally, it attempts to determine the extremum value of an unknown nonlinear performance function. [11-14].

This paper is organized as follows: Section 2 demonstration of PV cell and PV generator. Segment 3 will be held to demonstrate the impact of the shadow on the PV exhibitions. ESC calculation will be talked about and the execution markers, for example, the seeking determination and following precision are uncovered in area 4. The outcomes got for the execution markers are specified in Section 5 that is about fuzzy logic controllers. At long last, last area finishes up the paper.

## II. PHOTOVOLTAIC CELL:

A photovoltaic generator is constituted by several cells connected in series and/or parallels thus, a cell presents the elementary component of a photovoltaic array, and consequently the study can be limited to model one cell.

The photovoltaic cell is represented in the figure 2 by the electrical equivalent circuit, which consists of a current source modelling the luminous flux; the losses in the cell are modeled by two resistors, a shunt resistor and a series resistor. The model involves the following five unknown parameters: n, $I_{ph}$, $R_s$, $R_{sh}$ and $I_s$.

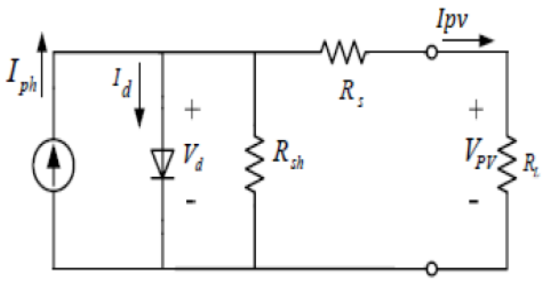



Fig. 2. Equivalent circuit of PV module.

The characteristic equation is deduced directly from Kirchhoff's law:

$$I_{pv}=I_{ph}-I_d-I_{sh} \quad \text{... (1)}$$

The final equation for the model of the photovoltaic cell based in the relationship between the output voltage, Vpv, and the current, I through the equation:

$$I_{pv}=I_{ph}-I_s(\exp((V_{pv}+I_{pv}*R_s)/V_t)-1)-(V_{pv}+I_{pv}*R_s)/R_{sh} \quad \text{...(2)}$$

Where:
$I_{ph}$ is the light current,
$I_s$ is the reverse saturation current of diode,
$R_s$ is the series resistance,
$R_{sh}$ is the shunt resistance,
$V_t$ is thermic voltage.

## III. PARTIAL SHADING OF PV SYSTEM

It is not possible to have uniform irradiance of PV panel all the time because of buildings or trees shades, atmosphere fluctuation, existence of clouds and daily sun angle changes [1].

Fig.3. PV panel for without and with partial Shading conditions.

Each photovoltaic generator has a unique operating point at which it can provide the maximum power and this power depends mainly on the radiation intensity. If some module of a string within a PV generator is in the shade, their electrical property will be changed [6-10]. The effects and the examination of partial shading on the characteristics of PV array.

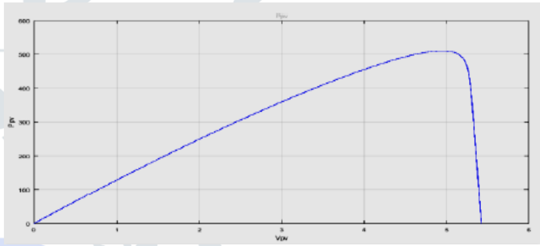


Fig. 4. Power characteristic of PV Panel without partial shading

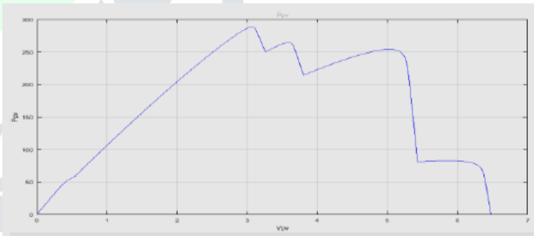


Fig.5. Power characteristic of PV Panel with partial shading.

Fig.4. shows the presence of one maximum on the power curves when the panel is not covered by clouds or generally does not be under shade (PV have uniform distribution of irradiance). However, when a portion of the panel is shaded, then the power characteristic has several peaks and presents a lot of local MPP, as it is shown on Fig.5 One of these peaks presents the Global maximum power point.

## IV. EXTREMUM SEEKING CONTROL SCHEME:

There is the need of much advanced level environmental friendly technology in order to meet the growing energy need of the world. There is a need of sustainable development i.e. The kind of development which fulfill present generation needs without compromising with the capability and the ability of the coming generation to meet theirs.

**Extremum-Seeking Control Principle:**

Illustrated in Fig.6. is a block diagram of an ESC system. It shows the simplest way to find the maximum point by ESC method i.e., the MPP on the solar cell P-V curve. The current balance point is identified by a gradient detector, subsequent to which modification toward the next instant is determined, and the current signal, stored into memory, is assessed for alteration at the next instant via a switching element. An internal signal is obtained as the multiplication of an integrator gain K by the current signal, and is compared with a triangular waveform to form a PWM.

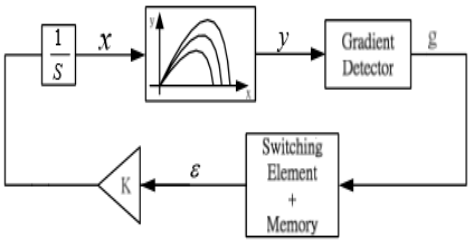



Fig.6. A block diagram of an ESC system

Extremum Seeking Control (ESC) is real-time optimization algorithm [11-15] and adaptive control tool, which resolves the problem of tracking a varying maximum or minimum of a performance function; generally, it attempts to determine the extremum value of an unknown nonlinear performance function. As it is known conventional control algorithm deals with the problem of equilibrium of a system about a known reference trajectory or easily determined, while reaching certain design criteria. However, in some cases it can be very difficult to find a reference value. Between the various applications of ESC we can found Global Maximum Power Point Tracking which can seek and track the MPP.

There are a lot of methods to implement Maximum power Point Tracking in PV field. Researchers have proposed different approaches that have the objective of extracting the operating point of power under varying conditions of weather (temperature and irradiance), the famous traditional algorithms are: Perturb and observe (P&O) and the Hill Climbing (HC)[3] .

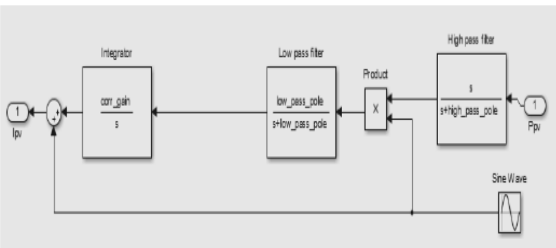



Fig. 7. ESC scheme.

The performance of a PV array is nonlinear and the power characteristic presents several peaks especially when the PV panel is in the partial shading conditions that why it is necessary to find the global MPP. By using conventional MPPT, we may fall on one of these peaks, not obligatory on the highest one, which refer to Global MPP. ESC algorithm resolves this problem without knowing the internal parameters of the system.

The scheme employs a sinusoidal perturbation sine wave which additively enters the system. The measured output $P_{PV}$ is then passed through a high pass filter and multiplied by the same perturbation signal, sine wave generating an estimate of the derivative at the input of the integrator. The Low-Pass Filter (LPF) used after the demodulation block is not necessary but it is helpful in filtering out the effect of dither (damping) signal. The High pass filter is just more effective in eliminating the DC component of the system. The gain parameter of integrator controls the speed of convergence. Relative to conventional MPPT approaches, the adoption of ESC achieves a faster response, and then the task of a MPPT controller is analysed in this work.

## V. FUZZY LOGIC CONTROLLER:

Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalve logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree.

The general structure of the FLC is shown in Fig. 8. The FLC is composed of fuzzification, membership function, rule base, fuzzy inference, and defuzzification [16-19].

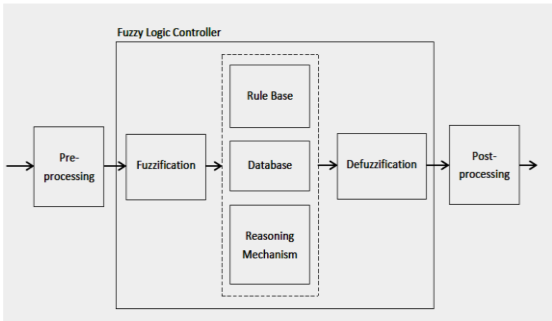
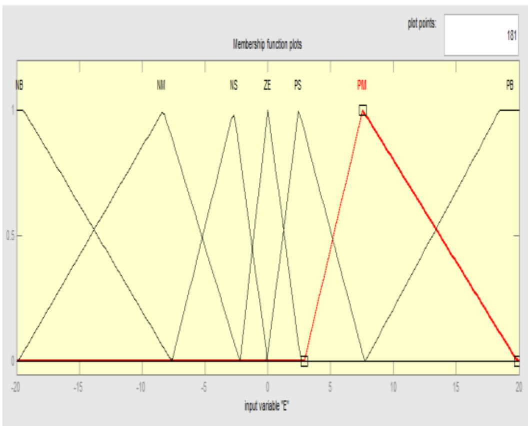



Fig.8. Block diagram of FLC.

The fuzzification comprises the process of transforming crisp values into grades of membership for linguistic terms of fuzzy sets. The membership function is used to associate a grade to each linguistic term. For fuzzification, the triangular membership functions with overlap are used for the inputs and output fuzzy sets as shown in figure 9.



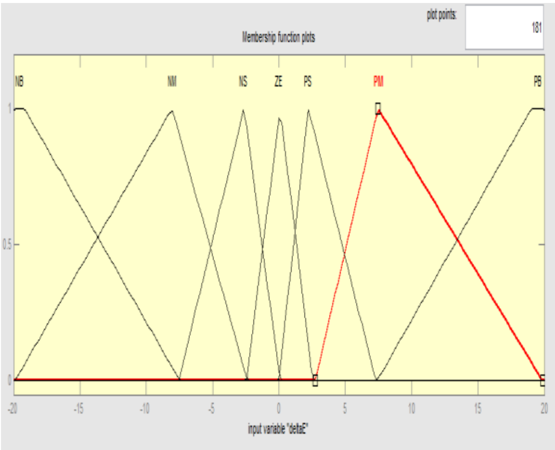



Fig. 9. Membership functions

In which linguistic variables are represented as NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZO (Zero), PS (Positive small) PM (Positive Medium), and PB (Positive Big).The rules of fuzzy mapping of the input variables to the output are represented in Table I. There are total 49 rules in the table. The Membership Function Editor is used to define the shapes of all the membership functions associated with each variable. The Rule Editor is for editing the list of rules that defines the behavior of the system. The Rule Viewer and the Surface Viewer are used for looking at, as opposed to editing, the FIS. They are strictly read-only tools. The Rule Viewer is a MATLAB-based display of the fuzzy inference diagram shown at the end of the last section. Mamdani type fuzzy inference is used in this study.

**TABLE. No. I: Fuzzy Rules**

| Change in error | Error | | | | | | |
|---|---|---|---|---|---|---|---|
| | NB | NM | NS | Z | PS | PM | PB |
| NB | PB | PB | PB | PM | PM | PS | Z |
| NM | PB | PB | PM | PM | PS | Z | Z |
| NS | PB | PM | PS | PS | Z | NM | NB |
| Z | PB | PM | PS | Z | NS | NM | NB |
| PS | PM | PS | Z | NS | NM | NB | NB |
| PM | PS | Z | NS | NM | NM | NB | NB |
| PB | Z | NS | NM | NM | NB | NB | NB |

In which linguistic variables are represented as NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZO (Zero), PS (Positive small) PM (Positive Medium), and PB (Positive Big).The rules of fuzzy mapping of the input variables to the output are represented in Table.No.I. There are total 49 rules in the table. The Membership Function Editor is used to define the shapes of all the membership functions associated with each variable. The Rule Editor is for editing the list of rules that defines the behavior of the system. The Rule Viewer and the Surface Viewer are used for looking at, as opposed to editing, the FIS. They are strictly read-only tools. The Rule Viewer is a MATLAB-based display of the fuzzy inference diagram shown at the end of the last section. Mamdani type fuzzy inference is used in this study.

## VI. SIMULATION AND DISCUSSION:

In this section, we will present the result of simulation, where we use a PV module model based on module data-sheet parameters of six PV panels in series. This model has Ipv input, which is suitable for series connections. The pannel characteristics are:

- Short-circuit current = 5.45 A
- Open-circuit voltage = 22.2 V
- Current at maximum power = 4.95 A
- Voltage at maximum power = 17.2 V

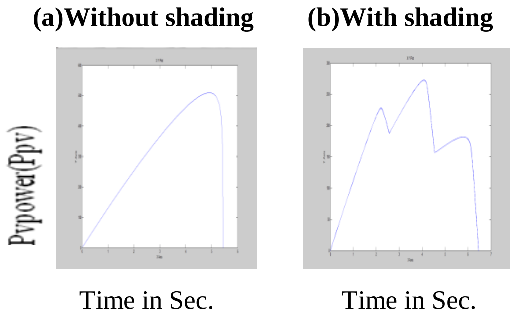


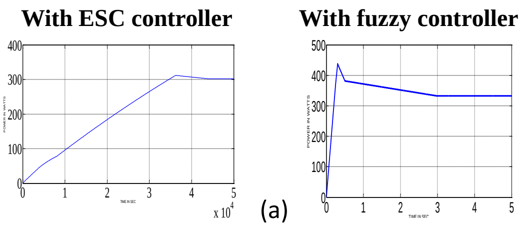

Fig. 10. Power characteristic of PV Panel at uniform irradiance and at under partial shading conditions.

By applying the proposed ESC algorithm (Fig. 10) to the PV panel with and without partial shading conditions, we obtained this result for different values of parameters in function of time.

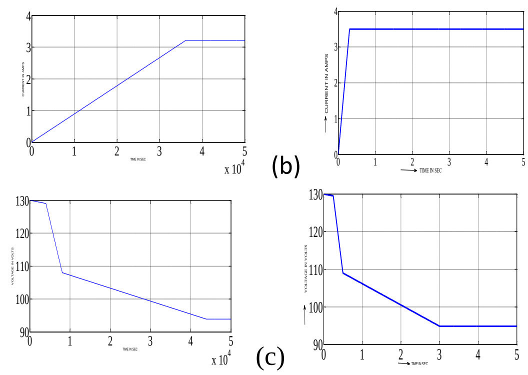
**FOR ANALYSING THE PARTIAL SHADING CONDITIONS FOLLOWING CASES ARE CONSIDERED:**

**CASE (i): Fd=1000Hz, Kd=0.001, Fh=800Hz, Fl=60Hz**

**(A). With Partial Shading Condition:** In these fig. 11 first we give different irradiations to the pv system because it is under partial shading conditions so we insert different irradiation values 1000W/$m^2$,700 W/$m^2$and 400 W/$m^2$.Then the outputs of pv system is given to the input of MPPT controller.In this we give ESC controller.The output of these ESC controller given to the boost converter.It is given to the load.




(a)



Time in Sec.

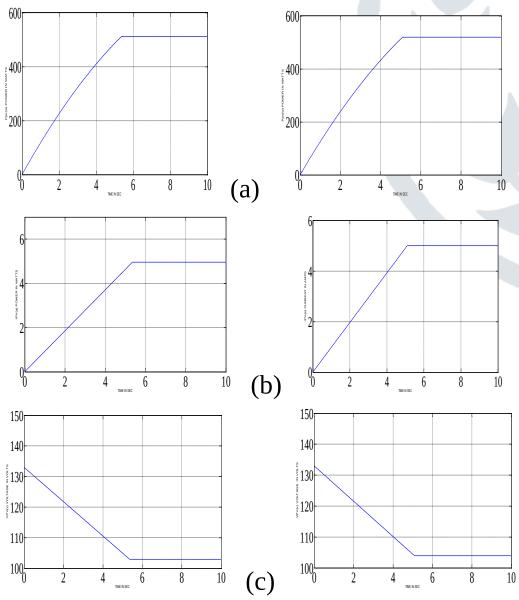
Fig. 11: Tracking the GMPP and optimal values of (a) power , (b)current , (c)voltage of PV panel under partial shading conditions

By applying ESC controller to the PV system, the voltage,current and power values are 310W at 3.6sec, 3.2Aat 3.6sec, 94v at 4.4sec then for the proposed system,i.e Fuzzy controller is adopted for the same PV system power at 420w at 0.3 sec,current at 3.5a at 0.3 sec,voltage at 95v at 3 sec are carried out and compared to the ESC controller.Fuzzy gives the better performance and reduced the time.

### (B).Without Partial Shading Condition:

In without partial shading condition we will give only one irradiation constant at the maximum power that is 1000 W/$m^2$.

**With ESC controller** **With fuzzy controller**



Time in Sec.

Fig.12: Tracking the GMPP and optimal values of(a) power ,(b) current,(c)voltage of pv panel without partial shading conditions.

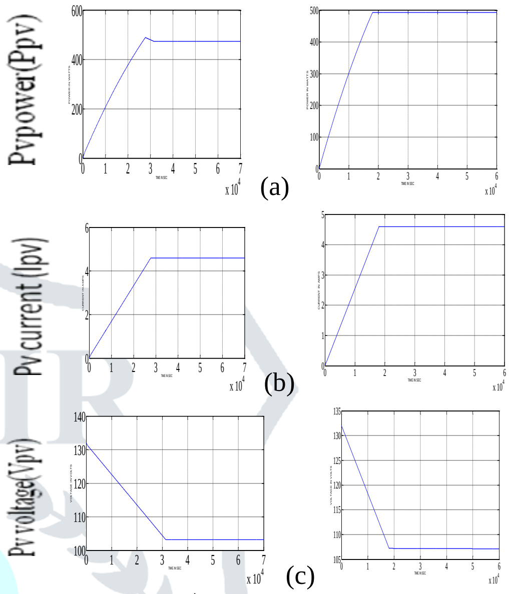
In fig.12. first we will see power,current,voltage with ESC controller then will see throught fuzzy logic controller.In ESC we will observe power,current ,voltage at 510W at 5.2sec, 4.9A at 5.3sec, 102V at 5.2sec.Where as in fuzzy controller we oserve Power at 520w at 5 sec,Current at 5a at 5 sec,Voltage at 104V at 5 sec.

### CASE (ii): Fd=1000Hz, Kd=0.001, Fh=900Hz, Fl=30Hz.

### (A).Without Partial Shading Condition:

In fig.13.without partial shading condition we will give only one irradiation constant at the maximum power that is 1000 W/$m^2$.This is given to pv system,the outputs of this is given to mppt controller.the output of mppt controller given to boost converter and it is connected to load.

**With ESC controller** **With fuzzy controller**



Time in Sec.

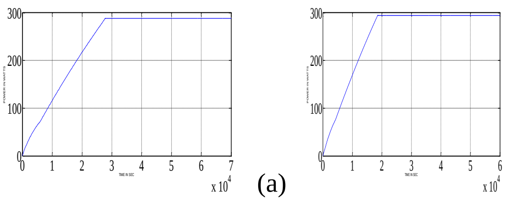
Fig 13: Tracking the GMPP and optimal values of (a) Power, (b) current and (c)voltage of PV panel without partial shading conditions.

The dither(damping) frequency is Fd=1000Hz, the dither amplitude is Kd=0,001, the cut-off frequency of the HPF is Fh=900Hz, and the cut-off frequency of the LPF: Fl=30Hz.In ESC we will observe power,current ,voltage at 480W at 3.1 sec,4.6A at 2.8 sec, 103Vat 3.1 sec.Where as in fuzzy controller we oserve power at 490w at 1.8 sec,current at 4.7a at 1.8 sec,voltage at 107v at 1.8 sec.When compared to ESC results fuzzy controller results gives better power,current,voltage values in reduced time.

### (B).With Partial Shading Condition:

In this case different irradiations values are given to the pv system because it is under partial shading conditions so we insert different irradiation values 1000W/$m^2$,700 W/$m^2$and 400 W/$m^2$.Then the outputs of pv system is given to the input of mppt controller.In this we give ES controller.The output of these ES controller given to the boost converter and followed by the load.

**With ESC controller** **With fuzzy controller**



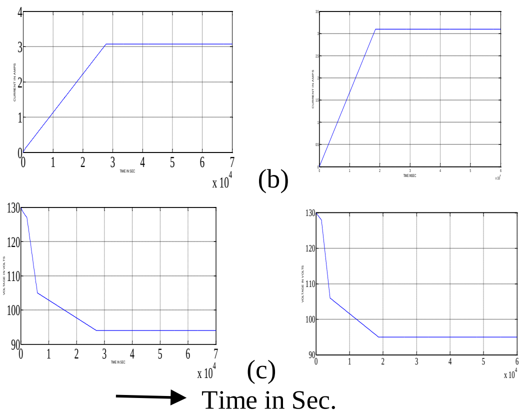



Fig. 14: Tracking the GMPP and optimal values of (a) power , (b)current and(c) voltage of PV panel under partial shading conditions.

The dither frequency is Fd=1000Hz, the dither amplitude is Kd=0,001, the cut-off frequency of the HPF is Fh=800Hz, and the cut-off frequency of the LPF: Fl=60Hz.in this first we will see power,current,voltage with ESC controller then will see throught fuzzy logic controller.In ESC we will observe power,current ,voltage at 280W at 2.8sec,3.1Aat 2.8sec,94v at 2.7sec.Where as in fuzzy controller we oserve power at 290w at 1.8 sec,current at 3.2a at 1.8 sec,voltage at 95v at 1.8 sec.When compared to ESC results fuzzy controller results gives better power,current,voltage values in reduced time.

**TABLE NO : II**

| Condition | With ESC | | With fuzzy Controller | |
|---|---|---|---|---|
| | **Power** | **Time** | **Power** | **Time** |
| Without Partial shading | 510 W | 5.2 Sec | 520 W | 5 Sec |
| With Partial shading | 310 W | 3.6 Sec | 420 W | 0.3Sec |

## CONCLUSION:

The detection of global MPP is indispensable in order to maximize the PV system energy production in the case of PV array partial shading. In this paper, a new method has been presented to track the global MPP of PV arrays. In this paper has the advantage that it can be applied in PV arrays with unknown electrical characteristics and does not require knowledge of the PV modules configuration with in the PV array. By using the Fuzzy logic controller along with incremental conductance method the power, voltage and current characteristics are increased and its execution time also reduced by comparing with ESC. The simulation results verify that the proposed method guarantees convergence to the global MPP under any partial shading conditions. So fuzzy controller gives better system performance than ESC method.

## FUTURE SCOPE:

Artificial neural network (ANN) characteristics can be used for providing better power, current and voltage characteristics in reduced execution time under partial shading conditions.

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