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A Comparative Analysis of MPPT Schemes for PV Systems Operating Under Non Uniform Irradiance and Partial Shaded Conditions

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Abstract
The performance of PV system under non uniform irradiance and partial shading condition is analyzed with help of conventional perturb and observe method and improved Incremental Resistance algorithm. The outputs are generated using MATLAB/SIMLUNK. Partial Shading of modules is given importance in this work. The Perturb and observe method is evaluated along with fuzzy controller and the output of the system is compared with Incremental Resistance method. The system with fuzzy logic controller was found to be more efficient and attains stability much faster than any other controller. But the power output of system with INR method was found to be more stable and with boosted value. The comparison of the two MPPT schemes is done in this paper and the performance of the schemes is analyzed.
Key words – *PV system, MPPT, partial shading, Perturb and Observe method, Fuzzy controller,Incremental resistance method.*

1. Introduction

Energy crisis is the world's major concern in the present scenario.Renewable energy sources have led its helping hand to the human society as a promise for future development. The simple conversion step in PV system has made its way to electricity generation easier. The advancement in power electronics engineering helped in improvement of applications depending on PVsystem. If all theincoming solar irradiance can be efficiently utilized, the whole population can be powered up for years to come with ideal systems. The efficiency of the system was improved from 8% to 44% with help of many Maximum power point tracking schemes. The analysis of PV system is categorized on structure of semi-conductor, converter topology, MPPT algorithms, and loads structure and so on. Thus the PV system is a field of elaborate study.

As years pass by the performance of PV panel may not meet the guarantee period of about 20-25 years offered as in data sheet.Since they are exposed to dust, atmosphere and other pollutions, the panels may show only poor performance. Also there are chances of having any plant near the panels that offers shade as it grow in to tree as years pass by. Thus the area of MPPT algorithm is being expanded, considering not just the incoming solar irradiance, but also the system and load.

Typically the Perturb and observe method were mostly employed, but the oscillation obtained at the MPP reduced its efficiency [1]. Similarly incremental conductance method is one of the recognized algorithms. For system withthenon-linear characteristics, incremental conductance method was initially used [6].With variation on load characteristics the usual methods become insufficient. Controllers for tuning the MPP without oscillations were included. Then the parameter of observation was changed to improve the dynamics of control to obtain incremental resistance method [7].

As system complexity increased, the requirement of better analysis of the system became mandatory. The standard test condition is not enough for guaranteeing the best performance of PV system throughout years. Due to the generation of more than one maximum power point from a single panel, in partial shaded condition, the regular algorithms will not provide an efficient working.Lots of survey is been made under various design aspects, to find a proper technique to be adopted in these peculiar conditions[4]. In general papers have analyzed only one condition of either non uniform irradiance or partial shaded condition. An effort is taken through this work to make a comparative performance analyzeof fuzzy controller and Incremental resistance algorithm on the PV system under various irradiance and partial shaded condition.

The general study on PV without controller is made in section 3. In section 4 the validation of fuzzy controller is made. The incremental resistance method is briefed in section 5, followed by the results.

2. PV system modeling

In general the solar cell isconsidered as a current source. The characteristics of solar cell mainly depend upon the solar irradiance and temperature.

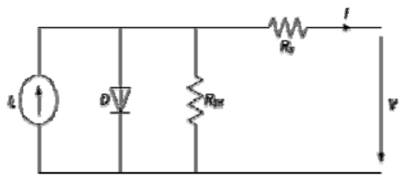

Fig. 1.Electrical Equivalent circuit of solar cell

The major equations of solar cell involve the effect of irradiance.The characteristicequations involve both the temperature co-efficient termsand diode characteristics equation.

$$I = I_L N_p - I_O N_p \left(e^{\frac{\left(V + IR_S \frac{N_S}{N_P}\right)}{V_t N_S a}} - 1 \right) \qquad (1)$$

Where, a represents the diode factor of 1.2 and k is the Boltzmann constant (1.38×10^{-23}).

To improve the performance of solar cell in wide range of temperature a modified Io current equation is formulated [5]. G denotes the solar irradiance value. The suffix n represents the nominal values of parameters.

$$I_L = I_{pvn} + k_I (T - T_n) \frac{G}{G_n} \qquad (2)$$

$$I_O = \frac{I_{scn} + k_I \Delta T}{\exp\left(\frac{V_{ocn} + k_V \Delta T}{a V_t}\right) - 1} \qquad (3)$$

Where$(T - T_n) = \Delta T$

I_{pvn} is the nominal PV current value obtained from the data sheet. Thecurrent temperature coefficient $k_I$andvoltage temperature coefficient k_V is included.

Analysis is made on PV system for non uniform irradiance and partially shaded situation to make the study more effective. This paper make an effort to bring an analysis on system with and without controller schemes, to verify the correctness.

3. Simple scheme without controller

The simulation of PV is made in MATLAB by choosing certain parameter criterions. A PV array KC200GT is taken for the analysis at STC with A. M 1.5. Equations 1,2 and 3 is used for the simulation.The non uniform irradiance condition is simulated by providing varying irradiance for all three modules for particular time intervals and the performance characteristics were plotted.

Table 1: Specifications of PV panel

Parameter	Values
I_{mpp}	7.61 A
V_{mpp}	26.3 V
P_{max}	200 W
I_{sc}	8.21 A
V_{oc}	32.9
k_V	-0.1230 V/K
k_I	0.0032 A/K
N_s	54

(1)

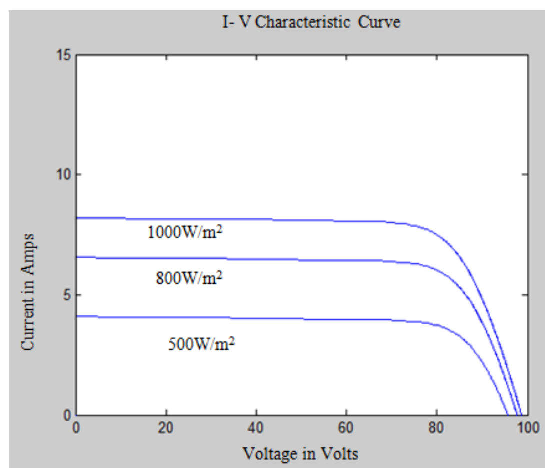

Fig. 2. (a) I-V Characteristics at non-uniform irradiance

The Figure 2 shows the relation between current and varying irradiance. Its seen that with irradiance, current also varies linearly. But as temperature increases with irradiance the performance of the system reduces. Thus with non uniform irradiance the power curve keeps on changing.

Similarly figure 3 shows the effect of partial shading condition on PV system without controller. At a particular time period it generates more than one peak, which makes it difficult to find the optimum power point.

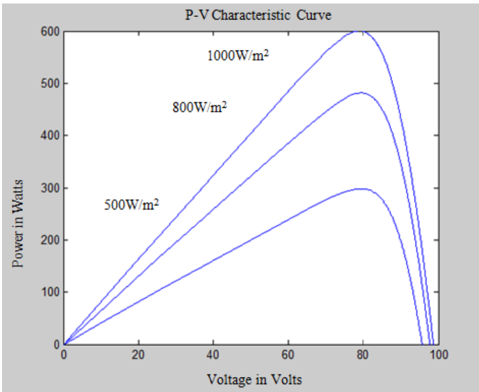

Fig. 2.(b) P-V Characteristics at non-uniform irradiance

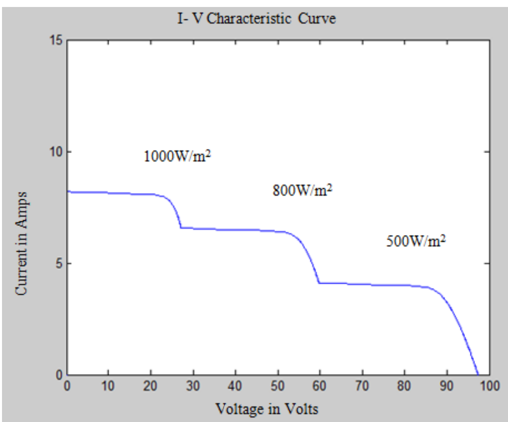

Fig. 3. (a) I-V characteristics curve at Partial shading

With the characteristics curve obtained it is clear that to implement a system for supplying a load, a proper controller is required to ensure the constant maximum power output.

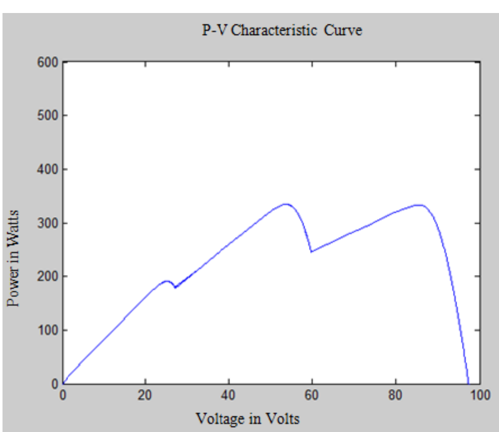

Fig. 3. (b) P-V characteristics curve at Partial shading

3. P&O with Fuzzy Controller

The conventional perturb and observe method is considered as the MPPT controller for a PV system with DC-DC converter.

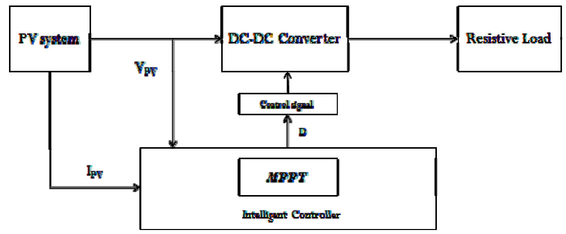

Fig.3. The Basic block diagram of the system.

The controller is the major part of concern that helps in proper tuning of the output. The system parameters are chosen by considering many factors as temperature and irradiance.

3.1 DC- DC Boost converter

The system is regulated with a DC-DC boost converter to maximize the obtained output. The boost converter specifications can be obtained from the equations involving the duty cycle Dand the switching frequency of value 30KHz.

$$\frac{V_O}{V_{in}} = \frac{1}{1-D} \tag{4}$$

The Capacitor and inductor valuesare calculated as from equations 5 and 6.

$$C = \frac{D}{f \times R_O \times (\frac{\Delta V_O}{V})} \tag{5}$$

$$L = \frac{V_{in} \times D}{f \times \Delta I} \tag{6}$$

Table 2: Converter Specifications

Parameter	Values
C	500µF
L	5mH
C_{filter}	470µF
L_{filter}	3mH
R_o	300Ω

3.2 MPPT controller

Many algorithms have been developed in the recent years, for maximum power point tracking applications.

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Hill climbing methodis the early developed and the simplest one. But with expansion in the field, the need for better algorithm increased.
The P&O has shown a very good performance, but for the oscillation shown when reaching the MPP, better tuning controllers are required.

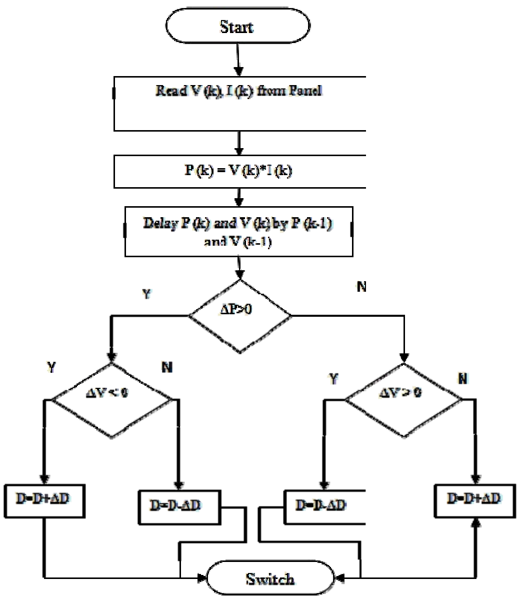

Fig 4. Flowchart for perturb and observe method

3.3 Fuzzy logic controller

The fuzzy logic controller is implemented here to tune the maximum power point as it does not require a well established mathematical model. The parameters used for FLC are an error signal and change in error signal. The member ship functions and rules determine the clarity of the output and its stability. Mainly five member ship functions are used [3] NB (negative big), NS (negative small), ZE (zero), PS (positive small), and PB (positive big). The inference table is formed with help of the function plot and 17 rules.

Table 3: Fuzzy inference table

E / dE	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	NB	NB	NB	ZE	ZE

The major equations concerned is

$$E(k) = \frac{P(k)-P(k-1)}{I(k)-I(k-1)} \quad (7)$$

$$dE = E(k) - E(k-1) \quad (8)$$

Where, P_{pv} and I_{pv} are power and current of the PV system.

4. Incremental Resistance MPPT Algorithm

The algorithms so far implemented were efficient for standard test conditions. Varying nature of climate tend to change the behavior of parameterinvolved. The Incremental conductance method wasmodified for the partial shaded analysis. But it was implemented only for fixed scaling factor[11].

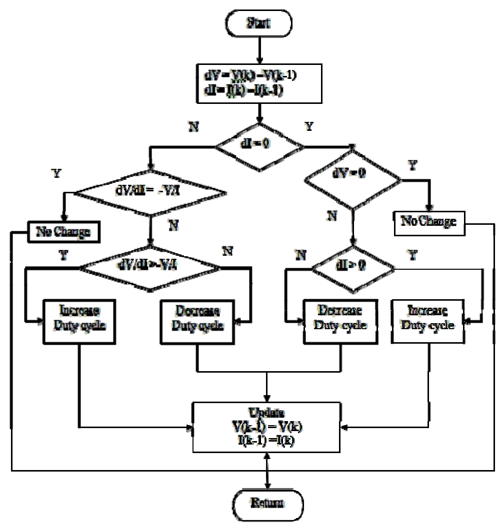

Fig 5. Flowchart ofIncremental Resistance method.

The scaling factor also needed to be changed, for highly varying irradiance nature.[12] The signals are changed in to discrete domain to achieve a varying scaling factor property.

$$\frac{dP_{PV}}{di_{PV}} = \frac{d(V_{PV} \times i_{PV})}{di_{PV}} = \frac{dV_{PV}}{di_{PV}} \times i_{PV} + V_{PV} \quad (9)$$

$$e = \frac{dP_{PV}}{di_{PV}} + \frac{V_{PV}}{i_{PV}} \quad (10)$$

Since duty cycle is the required output from the controller to the converter, the error signal is multiplied with the scaling factor to obtain new duty cycle.

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The maximum power point is tracked by checking on to these three conditions.

$$D(k) = D(k-1) + N \times |e(k)|\,; \quad e(k) > 0$$
$$D(k) = D(k-1)\,; \quad e(k) = 0$$
$$D(k) = D(k-1) - N \times |e(k)|\,; \quad e(k) < 0$$

It is clear that the scaling factor is an important parameter. With the change in scaling factor the power linearization is also varied. Afixed scaling factor is chosen in this paper.

5. Simulation and Results

The System considers a nominal residential load powered by a PV array of KC200GTmodel. A3 module array is simulated with help of MATLAB/SIMULINK. The system is incorporatedwith the P&O algorithm and fuzzy controller, and then a comparison is made with the adaptive incremental resistance algorithm for both non uniform irradiance and partial shaded condition
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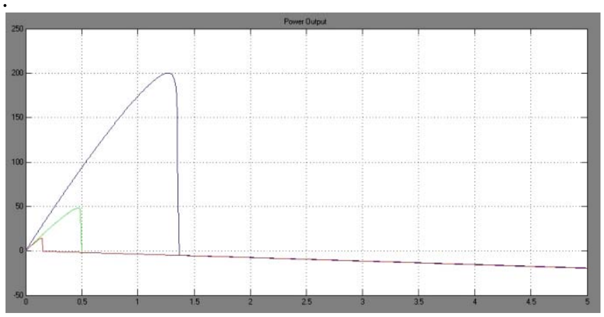

Fig.6. Power Output for partial shading without controller.

The power output obtained during any variation in the incoming solar irradiance other than the standard test condition is shown in .Figure 6. It can be noted that the power output is highly non linear and do not sustain for longer period. Thus the importance of algorithms and controllers for maximum power point tracking can be understood

The Fuzzy controller is used to reduce the oscillation at MPP with P&O methodIt is seen that from Fig. 7 with fuzzy controller, the output is stabilized within seconds after a small disturbance. A varying irradiance of $1000 w/m^2$ for 2 seconds, and reduced to $500 w/m^2$ for 4 seconds later a $800 w/m^2$ till 5 second were given.

The power output is reduced with respect to the irradiance applied. The peak power is about 550W. The partial shading mode is analyzed by applying varying irradianceof$1000 w/m^2$, $800 w/m^2$ and $500 w/m^2$to the three modules respectively. The Each module generate different peak.

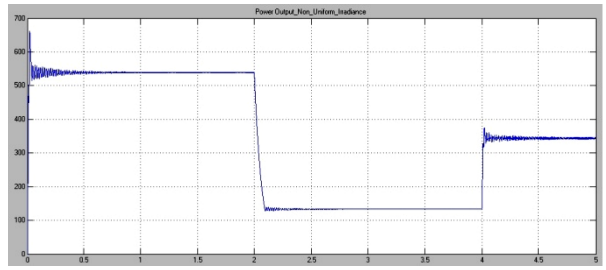

Fig. 7. Power output for non-uniform irradiance with $1000 w/m^2$, $500 w/m^2$ and $800 w/m^2$ irradiance

Now Fig 8 denotes the power output obtained for partial shading with fuzzy controller. It is seen that power is maximized and more stable, but a compromise is needed to be made when considering the STC. The fuzzy controller with centroid defuzzification method could find the global power point.

It can also be noted that The Power output is maintained to an optimum of 320W after a peak transient up to 0.01 seconds. This transient can be avoided by using better design.

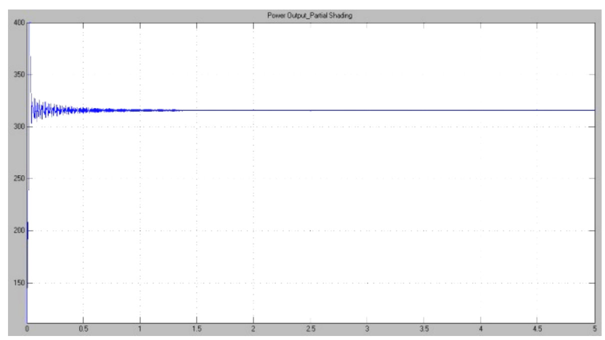

Fig. 8 Power output of partially shaded PV panels with Fuzzy controller

The major advantage of using INR along with boost converter is the ability to achieve a boosted power about 1kW. The algorithm is also able to tune well during any variation in the weather.

Shading can be more complicated if due to a permanent reason, the analysis on the occurrence is also important. When considering fast moving clouds, the irradiance level is continuously varied. The power output then tends to settle in little lesser point than that of the maximum output, which can be seen as in figure 9. The movement of clouds can be very random in nature, thus the power generated reduces with irradiance gradually from about 700W. That is power is generated respective to the value of irradiance, unless as fuzzy controller were the power obtained is of the minimum optimum value.

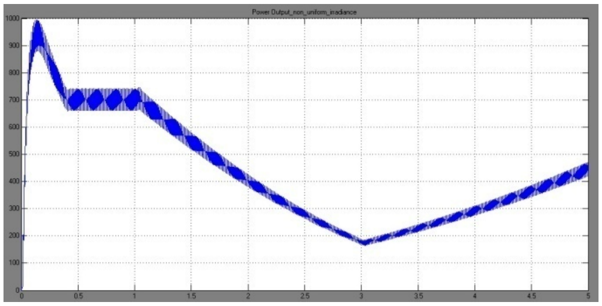

Fig. 9. Power output due non uniform irradiance using INR.

When implementing the incremental resistance method with nominal scaling factor for different irradiance at each module, a stabilized output is obtained. The scaling factor helps in maintaining a very high output power. The controller can be used to tune the power output between various peaks and ultimately finding the global maxima of the system.

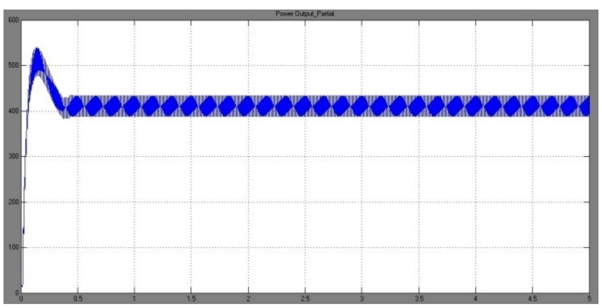

Fig. 10. Power output due to partial shaded modules using INR.

From figure 10 it can be noted that the power output reaches a value of 0.5kW during the partially shaded condition of modules after a slow decrease from a transient.Without the controller the power output will be the power output of the single module, with the INR MPPT controller the output is maintained the next highest possible value of the whole system capacity. Here the power variation is linear and with less transients.

5.1 Comparison of Results

The partial shaded condition is considered as the dominant issue in this paper. Hence the comparison is made under the analysis for shading only. The power output obtained under three conditions are observed and noted. The analysis shows that incremental resistance method show better performance with boosted power value.

Table 4: Comparison of Results

Sl. No.	PV system	Power Output	
		Non-Uniform Irradiance	Partial shaded Condition
1	Without Controller	600W (STC)	200W
2	P&O with FLC	550W	320W
3	INR Method	**710W**	**450W**

Considering the power rating that can be obtained from PV system, Fuzzy controller shows 53% efficiency and system with INR controller provides 75% efficiency along with the boosted output. For a system requiring boosted output value INR method can be chosen, but for system whose priority is stability instead of power output value Fuzzy controller can be considered.

5. Conclusion

The growing energy crisis leads us to focus on renewable energy sources. Photovoltaic system being the more energy efficient is been widely used on many application. Photovoltaicsystem requires less stages of conversion making it much more reliable. Maximum power point tracking algorithms are used to improve system efficiency.From the developed algorithms proper choice of method is necessary to obtain the required outcome.In this paper an effort is made to analyze the effect of varying irradiance along with partial shaded condition with help of perturb and observe method and fuzzy controller . A comparative study is made with incremental resistance method for all parameter variations. With the Implementation of fuzzy controller, output could be stabilized faster but the peak overshoot obtained in the output was further reduced by implementing INRmethod.

For partial shading condition both fuzzy controller and incremental resistance algorithm shows better performance, but the power output can be boosted to very high value without disturbing the design aspect of the system with Incremental Resistance method.

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