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# Performance Enhancement of Solar PV System under Partial Shading Environment

**P. Sivaraman, J. S. Sakthi Suriya Raj**

***Abstract:*** ***Partial Shading is an important challenge in photovoltaic (PV) systems which affects the quality and quantity of the Output Power. The regular fluctuation of condition and the decreased productivity of PV Array is a noteworthy hindrance in the quick development of the solar based power generation A Solar PV framework comprises of PV array linked with an Inverter through a dc-dc converter and the yield of the Inverter is connected with the load. Be that as it may, addition to PV modules, and array configuration, control electronic converters are likewise basic parts for a solar based power production. It is imperative to comprehend the impact of partial shading to create effective and solid Photovoltaic energy conversion framework. PV array arrangement, converter setup and MPPT control method are the three fundamental regions where the energy extraction from PV cluster can be enhanced under partial shaded condition. A point by point examination study is directed among Central and Micro-Inverter based PV Systems and distinctive MPPT control procedures were contemplated and thought about under partial shaded condition utilizing MATLAB/Simulink.***

***Keywords: Photovoltaics, Partial Shading, Maximum Power Point Tracking, Neural Network***

## I. INTRODUCTION

Solar oriented PV framework comprises of a PV generator that produces electric power from daylight and power converters for energy extraction and a reinforcement storage device, for example, battery. There are three fundamental regions where the energy extraction from PV array can be enhanced under partial shaded condition.

The first incorporates diverse array setups for interconnecting PV modules, specifically series– parallel, Total-crosstie (TCT), and Bridge-Linked (BL) designs [1]. Unlike solar thermal panels solar PV panels are very sensitive to shading. Under partial shaded condition the shaded cell does not have any flow of electrons. Hence the shaded cell acts as a load and consumes the current generated by the adjacent cells. Hence there occurs the hot spot which could permanently damage the cell [2]. Permanent damage of single cell can affect the whole PV module. To bypass the current flowing through the shaded cells, Bypass diodes are utilized which keep the cell from damage.

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But bypass diode for each solar cell will increase the cost of the module [3]. Thus for high proficiency and to lessen the cost bypass diodes can be connected for each three cells linked in series. Thus if any of the three cells is shaded the current produced by the contiguous two cells will just flow through it. To evade partial shading early written works are centered around the arrangement of the PV modules with Bypass diode which are in module level only. Later research are made on using bypass diode on every cell has been focused which reduces the shading effect drastically. The Photovoltaic cluster setup framework is utilized to enhance generation at Partial Shaded Condition (PSC) [4].

The second classification incorporates distinctive PV framework structures, to be specific Centralized design, String inverters and Micro-inverters. Most regularly utilized inverter is a centralized inverter, it connects several solar panel strings via a dc-bus [5]. The drawbacks of centralized architecture causes a complete loss of power due to mismatch of strings and blackouts during inverter fault. The following famous configuration is string inverter that comprises of single inverter for each string. Micro-inverter gaining progressively prominent design on rooftop installation and to limit the partial shading [6].

The third classification incorporates Maximum Power Point Tracking (MPPT) systems, for example, dividing rectangles techniques, the power increment technique, instantaneous operating power optimization, Perturb and Observe method (P&O),Modified P&O, Incremental conductance (IC) method, Fibonacci search, Neural Networks(NN), and particle swarm optimization [7]. Since PV module is non-linear it is important to show it for the design and recreation of MPPT for PV system application [8] and [9].

In this paper NN based MPPT algorithm is used to analyze partial shading effect in Central and Micro-Inverter based PV Systems. Further the NN based MPPT algorithm is simulated using simulink and compared with the P&O and IC method and its results are presented.

## II. REVIEW OF VARIOUS CONVERTER CONFIGURATION

The energy extraction characteristics of every converter structure are similar but under partial shaded condition the maximum power captured are strongly depends upon the converter configuration. The central and micro inverter configurations are discussed below.

*Central converter configuration*

A large single inverter is used to convert the whole DC power generated by array called as central inverter. The inverter configuration relies on the sizing of the PV array, thus sizing of array is an essential factor in Central inverter configuration. Central converters are commonly used converter in early days. In this type of configuration all the solar panels are linked to a common inverter through DC-DC boost converter integrating with MPPT control technique. The Fig. 1 shows the block diagram of Central inverter.

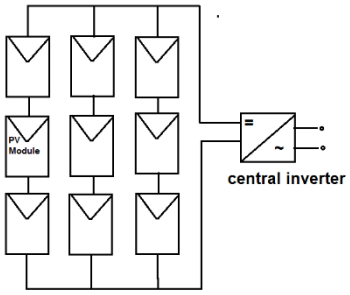


**Fig. 1: Block diagram of Central Inverter**

The drawback of central inverter setup is size of the inverter and space required for eretion is expansive and appropriate cooling framework is required. Also it has large power loss because of shading of adjacent PV modules inside the array.

*Micro-inverter configuration*

At recent day's Micro inverter are used since the efficiency of the micro inverter is high under partial shaded condition when compared with above converter configuration. Here each PV module is connected with a small inverter called as Micro-inverter. The Fig. 2 shows the block diagram of Micro inverter.

Micro-inverter has many favorable position over Central inverter, for example, ease installation in short time. It additionally flexible since the power generation capacity can be increased easily. PV modules of various brands and models can be incorporated over a period.

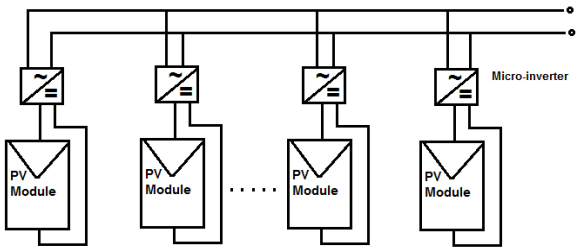


**Fig. 2: Block diagram of Micro-inveter**

Each Micro-inverter possess an individual Maximum Power point tracker enhances the power generation. At the point when comes to cost factor Micro-inverter are high cost and increased in number of fault nodes that are difficult monitor and troubleshoot.

## III. REVIEW OF MAXIMUM POWER POINT TRACKING

Since the efficiency of the solar cell is low it is important to enhance the power generation utilizing additional electronic device such as MPPT. Maximum Power Point tracking (MPPT) is an electronic system used to follow the maximum power accessible under changing resource and extract it with the assistance of a DC-DC converter. MPPT tracking is very surprising from mechanical following, it is an electronic framework that changes the electrical operating point of the module to extricate the Maximum accessible power. A basic block diagram of MPPT control is appeared in Fig. 3.

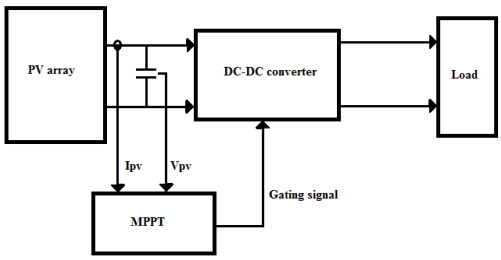


**Fig. 3: Block diagram of MPPT control**

*Perturb and Observe*

A standout amongst the most incredible calculation to track MPPT is Perturb and Observe technique. In this strategy the MPP got is continually perturbed to follow the maximum power point. The primary disadvantage of the framework is that it doesn't settle at Global maxima that accomplished however it constantly perturbing the framework fluctuating forward and backward of GMPP. Accordingly it requires a Error limit or hold up function to decrease the wavering on GMPP which builds the multifaceted nature of the calculation.

*Incremental Conductance method*

Incremental Conductance algorithm is utilized to follow the MPP at quick fluctuating atmosphere condition which is a disadvantage of P&O technique. This strategy quits perturbing once the operating point achieves the GMPP by observing the condition is fulfilled. On the off chance that the condition in the algorithm isn't fulfilled, the operating point is perturbed right or left of MPP accordingly. It additionally can track the MPP in a quick fluctuating irradiance condition quicker than P&O system with higher exactness.

*Neural Network*

Neural networks (NN) is very flexible and powerful hence, it have been intensively used for solving non-linear and complex systems. Hence the NN can be used to track MPP under varying irradiance conditions. General Regression Neural Network (GRNN) is used for simulation. Simulink model of General Regression Neural Network shown in Fig. 4 below.


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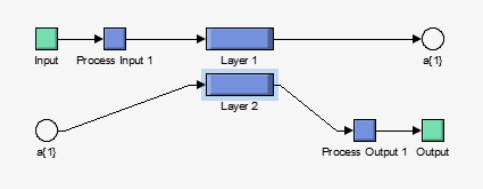


**Fig. 4: Simulink model of General Regression Neural Network**

The structure of GRNN comprises of two layers Pattern and summation layers. The input enters the Pattern layer the corresponding connection between the input and the response is remembered and stored in the framework. Accordingly the system can gain from the preparation information in a fraction of time it gives relating output in the output terminal. GRNN unlike feed forward system it can ready to track to a Global solution and won't be caught by local maxima [12]. The exactness is relies on the quantity of training data gave along these lines by giving required measure of training data the GMPP can be tracked quicker. Here the input data given is Irradiance and the output is the reference signal value. Hence for change in Irradiance level the corresponding pulse are generated and fed to the switch of the Boost Converter. This technique can Track the Maximum Power Point faster.

## IV. PV MODULE

Solar cells are the fundamental unit of PV framework that are linked in series to form a module or panels. Solar panels are comprised of Solar cells orchestrated in way to catch sunlight and furthermore canvassed by a Glass in the best to secure the cells and furthermore to enable the sunlight to fall on PV, the glass has the property of diminishing the warmth which enhances the semiconductor to work productively. These panels are connected in series/parallel to form an array depending upon the required voltage on the output terminal [13] [14].

Solar cells are commonly linked in series since the voltage rating of a solitary solar cell is low interfacing in series gives the additive of voltage. Parallel connections are done to increase the current rating that are done in module level. Mismatch in solar cell because of partial shading cause power loss as well as cause permanent damage to the cell. PV module is built by utilizing mathematical modeling by the equation 1. The Fig. 5 demonstrates the Equivalent circuit diagram of PV array.

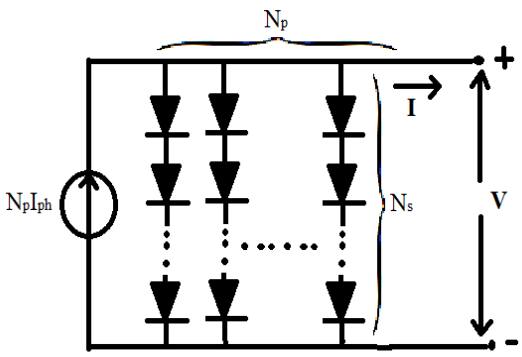


**Fig. 5: Equivalent circuit of PV module**

$$I = N_p I_{ph} - N_p I_s[\exp(qV_{oc}/N_s K T_c A) - 1] \quad (1)$$

Np - cells in parallel
Ns - cells in series
Iph - Photocurrent
Is - saturation current
Voc - open circuit voltage
q - (= 1.6 ×10−19C) magnitude of charge
k - (= 1.38 ×10−23J/K) is Boltzmann's constant
Tc - Operating temperature

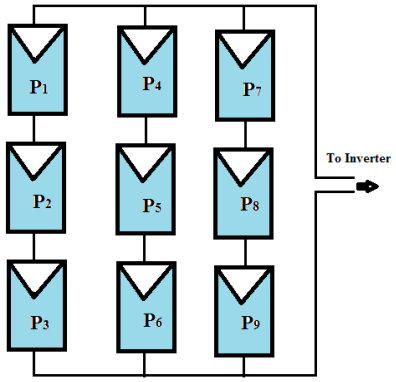


**Fig. 6: Block diagram of series parallel connected PV array**

Power rating of the panels are decided by the power they can deliver at Standard Testing Conditions (STC): 1000 W/m2 irradiance, and a cell temperature of 25°C.

*Reference PV module*

**STP250S - 20/Wd** PV Module is a commercially available from SUNTECH, has taken as the reference module for Simulation. The subtleties of maker's information of this module are given in Table I.

**TABLE I Data sheet of reference module**

| Characteristics | Specifications |
|---|---|
| Optimum Operating Voltage (Vmp) | 30.7V |
| Optimum Operating Current (Imp) | 8.15A |
| Open Circuit Voltage (Voc) | 37.4V |
| Short Circuit Current (Isc) | 8.63A |
| Maximum Power at STC (Pmax) | 250W |
| Module Efficiency | 15.2% |
| No. of Cells | 60 (6 × 10) |
| The electrical details are under test states of irradiance of 1000 W/m2, cell temperature of 25°C and AM of 1.5 Allowable scope of Error is ±3% | |

## V. SIMULATION AND RESULTS

*Simulink model of Central inverter*

Simulation of a Central Inverter is given in Fig. 7. Here a 3x3 PV array is arranged in series, parallel as shown in Fig. 6


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is connected to a common inverter called Central inverter through a boost converter by MPPT control technique. The outcome of the inverter is connected to a resistive load R through an LC filter. THD level for the outcome voltage waveform is calculated using Fast Fourier Transform (FFT) analysis.

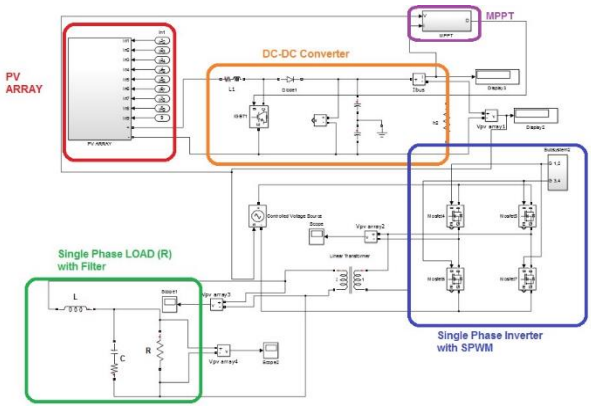


**Fig. 7: Simulink model of Central inverter**

*Simulink model of Micro inverter*

Simulink model of Micro Inverter is given below in Fig. 8. Here each PV module is connected to a separate inverter called Micro inverter through a boost converter by MPPT control technique. The output of the each inverter is connected in parallel to a resistive load R through an LC filter.

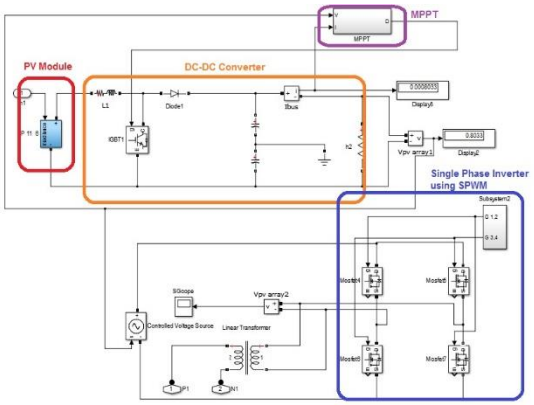


**Fig. 8: Simulink model of a Micro inverter configuration**

In this way output of the nine Micro inverter are linked in parallel THD level for the output voltage waveform is determined utilizing FFT investigation

*Output of Micro inverter*

The Fig. 9 gives the THD value for output waveform of Micro inverter. Similarly THD is calculated for various Shading patterns and comparison is made between central and Micro inverter.

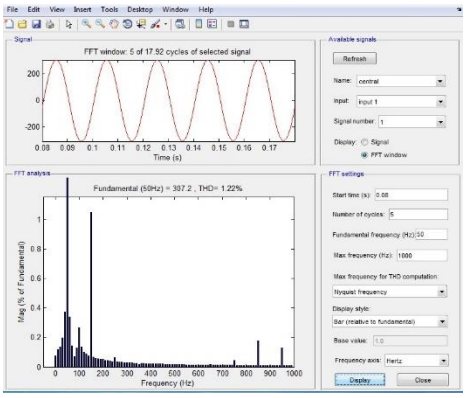


**Fig. 9: FFT analysis of Central Inverter**

*THD value under different shading scenarios*

THD value obtained for Central and Micro inverter under same shading conditions for all panels i.e., same value of irradiance for all the PV panels are presented below in Table II.

**TABLE II THD value under different shading condition**

| Irradiance 1000W/m$^2$ | THD (%) | |
|---|---|---|
| | Central Inverter | Micro-Inverter |
| 1000 | 1.22 | 4.44 |
| 800 | 1.35 | 4.44 |
| 600 | 2.31 | 4.49 |
| 400 | 6.15 | 6.86 |
| 200 | 13.22 | 13.97 |

The above Table II gives the estimations of THD under consistent shading condition for all modules differed from 1000W/m2 to 200W/m2 [15] [16].

*Partially shaded PV modules*

PV Modules P1, P2, P3, P4, P7, P5, P9, are shaded successively by maintain 200W/m2 as the Irradiance level. The below table VI demonstrates the THD esteem acquired by FFT examination under different Shaded condition.

Micro-inverter in shaded condition and has Low transmission loss and high Efficiency than central inverter. The generation capacity of the Plant can be expanded effectively in Micro Inverter setup. The Power produced in one panel won't influence by the neighboring panels under Shading caused. In Micro-Inverter increment in extensive number of PV arrays fundamentally expands the quantity of semiconductor switches, making them cost restrictive.

**TABLE IV THD value obtained by FFT analysis under various Partially Shaded condition**

| Irradiance 1000 W/m$^2$ | THD (%) | |
|---|---|---|
| For Shaded PV panel 200 W/m$^2$ | Central Inverter | Micro-Inverter |
| P1 | 1.39 | 7.75 |
| P1,P2 | 1.42 | 16.03 |


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| | | |
|---|---|---|
| P1,P2,P3 | 1.49 | 20.48 |
| P1,P4 | 2.90 | 16.03 |
| P1,P4,P9 | 5.47 | 20.48 |
| P1,P5 | 2.90 | 16.03 |
| P1,P5,P9 | 5.47 | 20.48 |

*Simulink model of MPPT control*

PV array is connected to a Resistive load through Boost converter. The boost converter boost the output voltage by switching ON and OFF the switch, here the switch used is Integrated Gate Bipolar Transistor (IGBT). Output waveform generated for various irradiance patterns is given below in Fig. 10.

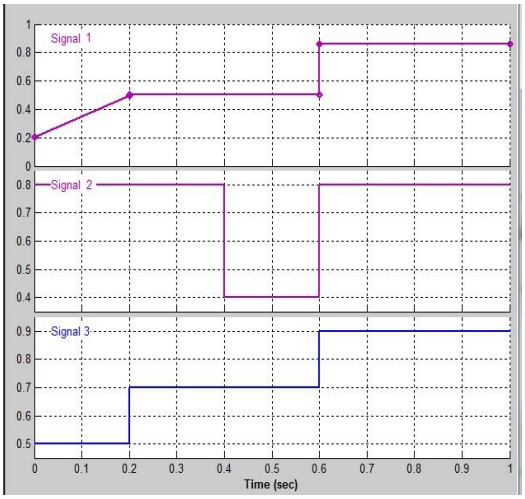


**Fig. 10: Different Shading patterns**

The output Power curve for various partial shaded patterns are shown below in Fig. 11 and values obtained are tabulated in Table V.

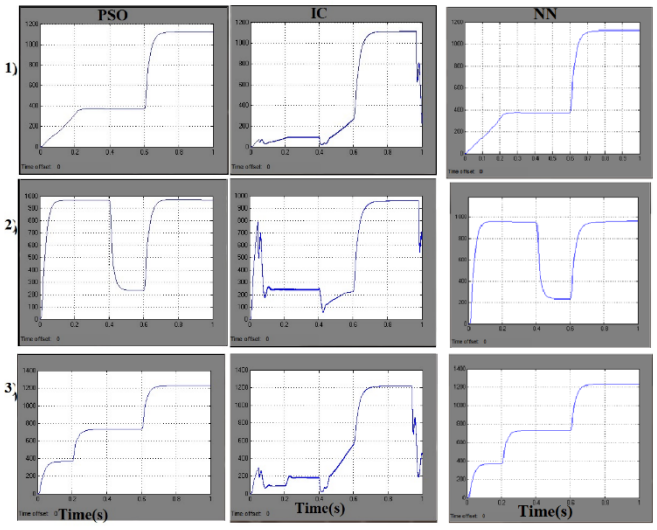


**Fig. 11: output power waveform for P&O and IC**

**TABLE V Comparison between P&O, IC and NN**

| Shading pattern | MPPT | Voltage (V) | Current (A) | Power (W) | Settling Time(s) |
|---|---|---|---|---|---|
| 1 | P&O | 51.13 | 21.93 | 1122 | 0.076 |
| | IC | 51.05 | 21.78 | 1112 | 0.076 |
| | NN | 51.13 | 21.93 | 1122 | 0.075 |
| 2 | P&O | 47.47 | 20.36 | 966.6 | 0.07 |
| | IC | 47.37 | 20.21 | 957.4 | 0.15 |
| | NN | 47.47 | 20.36 | 966.6 | 0.03 |
| 3 | P&O | 53.56 | 22.97 | 1231 | 0.05 |
| | IC | 53.22 | 22.79 | 1213 | 0.08 |
| | NN | 53.56 | 22.97 | 1231 | 0.04 |

## VI. CONCLUSION

Under the steady shaded condition Central inverter is faster to track the general MPPT and the value of THD when contrasted with Micro inverter is low. Micro-inverter in other hand has numerous different points of interest, for example, less power loss of DC transmission, Spacing required, erection and adaptability of Modules, the THD got is little higher. Along these lines for a large Power generation Central inverter performs well, amount and intensity yet this not same for small and Distributed generation where Micro-inverter has overwhelming execution. The two most commonly used MPPT algorithms P&O and IC are compared with NN based MPPT control method under partial shaded condition, the output shows that NN has same energy extraction characteristics as that of the P&O but has faster tacking with reduced output power oscillations. Hence Neural Network based MPPT control technique can track the maximum power fast and accurate.

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