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Design of an ANFIS based MPPT controller for a solar photovoltaic system under partial shading condition

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Abstract-
One of the essential approaches in the photovoltaic (PV) is to generate maximum power through Maximum Power Point Tracking (MPPT) approaches. In this work, the technique of MPPT representing Adaptive Neuro Fuzzy Inference System (ANFIS) along with the proposed MPPT method has been suggested in the PV system under partial shading conditions. The effectiveness of the suggested Neural network (NN) based MPPT approach is compared with other studied method at various atmospheric conditions. The system was developed in the MATLAB/Simulink software. As per the simulation outcomes, the proposed ANFIS based MPPT method can extract maximum power and decreases the power losses as compared to PI controller along with proposed MPPT algorithm .Furthermore, the proposed method has enhanced the PV system performance under various Partial Shading Conditions.

Keywords:
Photovoltaic (PV), Maximum Power Point Tracking, Neural network, Fuzzy Logic (FL) Partial Shading conditions, Global maxima power point (GMPP).

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I. INTRODUCTION

As the conventional energy sources which are available are decreasing day by day, it becomes a challenge for mankind to generate power from conventional energy sources. Solar energy is one of the traditional energy sources, which is freely available and is pollution free .Its installation cost is high .A solar PV system should be operated at its peak efficiency. The power produced by PV depends on the amount of irradiance falling on the PV array. At STC (1000W/m^2) the level of irradiance is high, so power generation is maximum. Apart from STC, there is a condition of partial shading which may cause due to trees, clouds, and buildings which results in reduction of solar irradiation falling on the panel. Therefore power generated by PV system decreases. When a part of array is subjected to shading condition the power voltage (PV) curve exhibits non linear characteristic and have more than one peak point, which are called as local maxima's(less than MPPT). For the PV system to work at its peak efficiency an MPPT algorithm is required, that is capable of operating at MPP which is higher than local maxima's. Therefore a MPPT algorithm which can track the GMPP among local maxima's should be developed.

However, traditional MPPT algorithms like perturb and observe, Incremental conductance [1]-[3] are able to deal with uniform shading condition only. The traditional algorithms are not able to track GMPP hence it becomes important to develop new algorithm which can efficiently track Maximum power point under partial shading condition. Few algorithms that work efficiently under partial shading conditions are proposed [4]-[6]. By using sensors at the output side of PV system in duty cycle control method that traces the GMPP effectively even for changing load and climatic conditions. A study on P-V characteristics under non Standard Test Condition was reported, and it was observed that the MPP occurred almost at the multiples of 80% of open circuit voltage. The magnitude of PV curve peaks shows the rising before the GMPP and decreasing after the GMPP [7]. This work explains how an improved MPPT algorithm works under PSC.

II. PARTIAL SHADING CONDITION

Figure.1exhibits a Photovoltaic array which consists 4 PV modules associated in sequence under similar insolation conditions. Current (I) versus Voltage (V) and Power (P) versus Voltage (V) Characteristics of a PV array is shown below. when the solar module terminals are shorted, the voltage is zero, as well as the current produced by PV panel is maximum and it was known as short circuit current and it is denoted by Isc When the solar array terminals are open circuited, the current is zero and the voltage found across the terminals

is maximum and it was termed as Open Circuit Voltage. The PV characteristics are plotted between these two extremes (Voc, Isc).Current is indicated on the vertical Y-axis and Voltage is indicated on the horizontal X-axis. The P-V Curve of a photovoltaic device is shown below. At the peak point on the power voltage curve, the peak power output is located and it is the MPP. The current and voltage at this MPP are denoted by I_{MP} and V_{MP} and Where $V_{MP}=0.85*V_{OC}$,$I_{MP}=0.9*I_{sc}$.

The output power of PV array is affected by PSC. The module covered by shadow is at low voltage when compared with module under no shading condition. As current flows from higher to lower potential, the module which is subjected to partial shading consumes power instead of producing and this phenomenon give rise to hotspot formation [15]. The bypass diode is used to protect PV cell against hotspot effect. The PV curve shows linear characteristics under STC's. Under the partial shading conditions PV curve shows non linear characteristics. The non linear characteristics are due to formation of multiple local maxims' out of which one is Global Maximum Power Point. The total number peak points are alike to the number of different irradiation levels on the Photovoltaic array and any maximum point may represent GMPP. So in order to use PV system at maximum efficiency, the system is to be operated at a particular voltage where MPP is obtained. MPPT technique is implemented with help of algorithm to extract peak power from the PV panel such that it would deliver maximum power output which corresponds to PV curve.

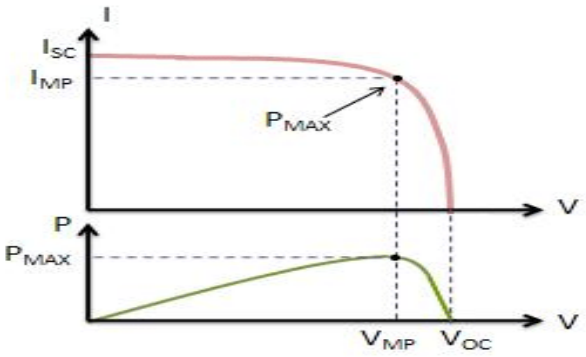


Fig1: P-V Curve

A. General shading pattern of PV string

Case1: All modules are exposed to same irradiation i.e. irradiation=1000W/m2.
Case2: A part of array is subjected to partial shading Condition i.e. irradiation=400W/m2 and remaining part subjected to 1000W/m2.
Case3: All the modules are under shade i.e. irradiation=400W/m2.

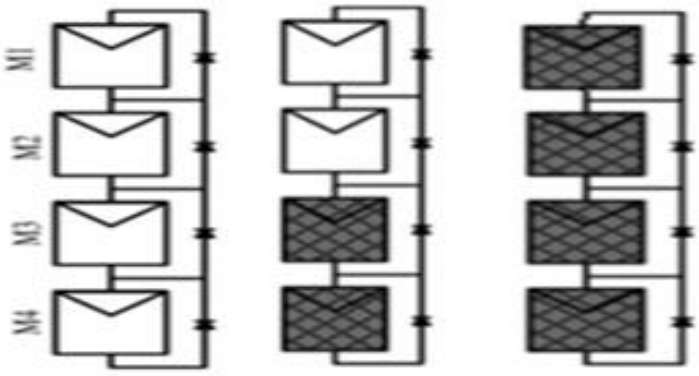


Fig2: Three different cases of shading

B. In detail explanation of P-V curve peaks formation:-

The output of PV system is pure DC voltage. So, P&V characteristics as follows, a linear rise in slope as in figure3. The highest power point that can be observed from PV Curve is known as MPP.

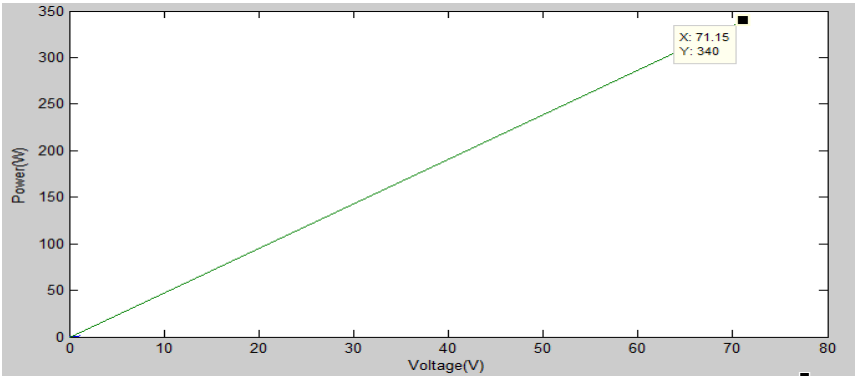


Fig 3: PV Curve under STC

During shading condition, the panels under shade are isolated, due to this there is dip in the voltage of the array and the P&V Characteristic is displayed in fig.4.
As in figure 4, the first peak is due to full irradiance or STC. The second peak is due to partial shading, the PV curve during partial shading is due to decreased voltage.

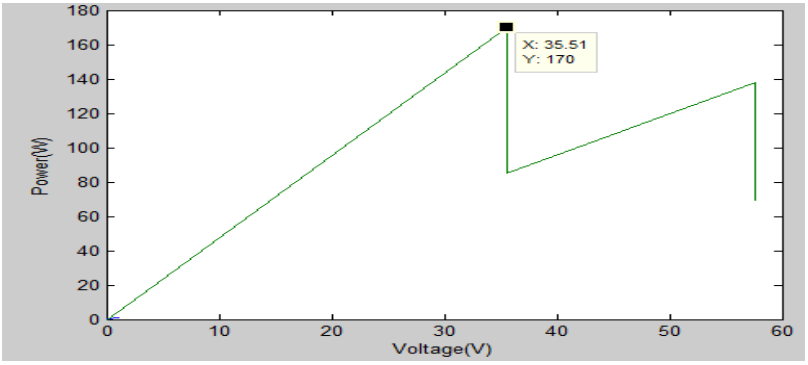


Fig4: PV Curve under Partial Shading Condition

III. PV system Block Diagram:-

A.PV system

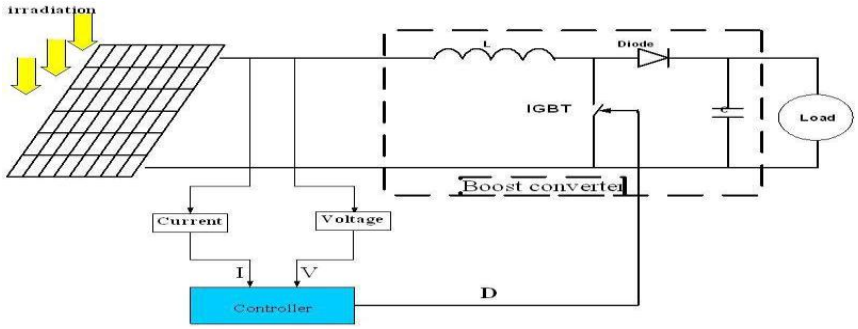


Fig 5: P-V system Block diagram with proposed algorithm

When a group of PV panels are linked to the MPPT integrated circuit, the voltage and current developed by the group is noticed by relevant sensors and is given to this controller which checks whether the input voltage and current values match the user-defined reference values, and then provides power switch with accurate established pulses based on these values.

B. The GMPP track Subroutine MPPT Controller method:

It is the modified type of P&O method. P&O method works well under no shadow. P&O Algorithm is the easiest technique of MPPT to implement. In this technique power output of system is compared by changing the voltage. On raising the voltage, if power rises then farther 'change in voltage' is increased. Same as, on decreasing voltage if power rises then change in voltage is decreased. The above process is repeated to reach maximum power point. The MPP occurred at a particular voltage value and it is taken as reference point (V_{ref}).

The P and O algorithm is shown in the fig.6. But it fails to show correct or exact reference voltage during shading condition. So the improved version of P and O is used for MPPT during PSC.The modified P&O algorithm is shown in flowchart. It consists of two subparts 1) Main program 2) GMPP track Subroutine. The main program has P&O algorithm and the regular shade is checked by comparing the voltages of PV modules. As the shading occurs, the voltages of modules change, this difference of voltage indicates the occurrence of shading. Then the main program calls the GMPP track Subroutine which has already been mentioned earlier as shading occurs, the PV curve exhibits multiple power peaks .It is necessary to track GMPP for effective utilization of PV system.

The tracking of GMPP is obtained by changing the voltage references with the help of GMPP track subroutine algorithm. The algorithm has the ability to separate or isolate the modules which are under shade from the modules which are under no shade from the modules. The modules under shade are isolated, then grouped and labelled as modules with lower voltage level, it is denoted by letter 'M'.This count of lower voltage modules are used for setting new reference voltage value which was further used for tracing of GMPP by implementation of P&O method. So, whole improved version plays a crucial role in setting or changing the voltage reference value that exactly helps to track GMPP under partial shaded condition.

***C*.GMPPT algorithm for severe shading conditions:**

In the proposed algorithm, the modules are isolated, under shaded conditions these modules are exposed to 400W/m^2. The peaks that are formed within the algorithm are tracked to obtain the GMPP out of local MPP [16].

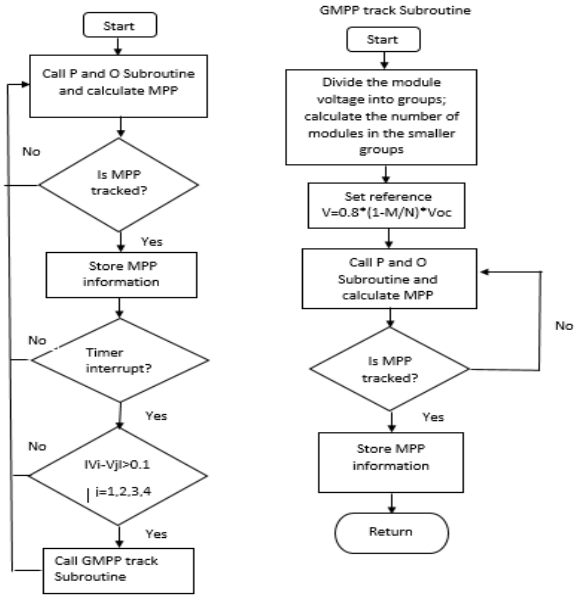


Fig 6: Improved MPPT Algorithm

During Case1: As all the modules are under STC, i.e., when exposed to 1000W/m^2 .The P and O algorithm is able to trace the MPP by setting reference voltage as 0.8*V_{oc} where V_{oc} is Open circuit voltage of array [15].

During Case2: As two modules of the array are exposed to partial shading, now the P&O algorithm goes into inactive position and GMPP Track subroutine comes into active position and set new reference voltage value which is obtained by isolating PV modules that are under shaded condition and the same P&O method was used to trace GMPP (maximum power point).

During Case3: All the modules are exposed to 400W/m^2, at this condition GMPP track subroutine fails as it isolates the modules completely, it leads to loss of the available power in NON-STC's from the PV System.

IV. ANFIS BASED MPPT ALGORITHM

Blending of learning capability of neural network and knowledge representation ability of fuzzy logic (FL) leads to fuzzy neural networks. ANFIS is a fusion of FL and NN. So it has the compensation of both the techniques. In ANFIS, fuzzy rules are formulated reliant on the inputs and NN redefines the initial membership functions and rule base by the process of training. Two input and one output data set are used for training the ANFIS controller [24].The parameters of the ANFIS network used for MPPT are chosen depending on the minimum Root mean Square Error [25]. The inputs of this controller are errors and change in errors. The effect is the duty ratio variation of DC-DC Boost converter.. When using the ANFIS function, create or load the

INPUT data and pass it to the training data input argument. When using neuro fuzzy designer, in the load data section, selecting training and then to load data from a file, select file. For loading data in to workspace, from MATLAB select workspace.

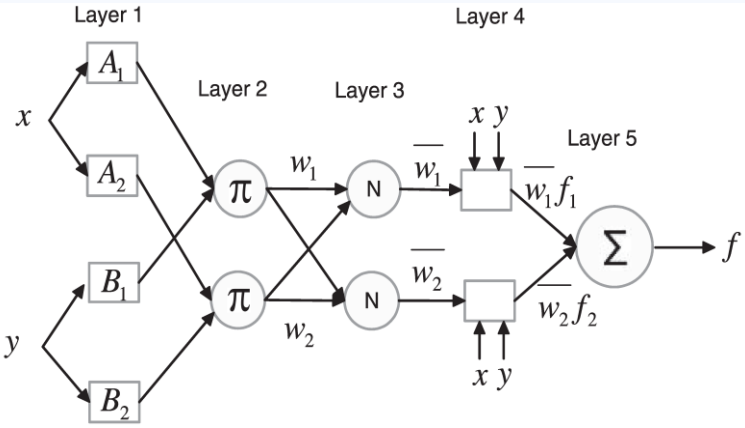


Fig. 7 ANFIS model.

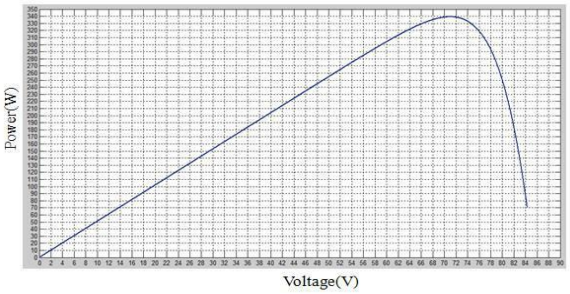
V. SIMULATION OUTCOMES

A. Multiple Peaks Formation:

Simulation results were obtained with Matlab environment. The results obtained by simulation of circuit to observe shading effect on P-V Curves as shown in Fig8 is as follows. The below figures 8,9 shows the P-V Characteristics curve under STC i.e. irradiance of 1000W/m2and NON-STC'S, i.e., irradiances of 400W/m2.The rating of solar PV array is shown in below table1.

Table1: Rating of solar PV array:

Parameters	Values (simulation)
Voc	0.69V
Isc	0.4125A
Vmpp	88.32V
Impp	4.7A
Pmpp	414W



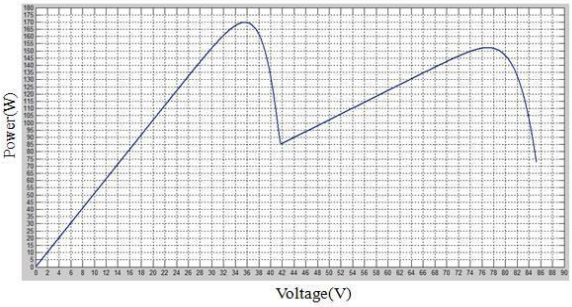


Fig.8 P-V Curve under Standard Test Condition.Fig.9 multiple peaks observed during partial shading.

The results show that P-V Curve of array possesses multiple maxima under partial shaded condition. There are two observed peaks in P-V Curve of figure 9. The highest point is GMPP, while other is LMPP. In order to keep output of PV array significantly higher, the operating point obtained by algorithm should be GMPP.

B. With P&O algorithm:

The output achieved by P&O process alone under NON-STC is shown in Fig10, 11 is as follows. The below figures 10,11shows the voltage at which GMPP occurs and power i.e. GMPP at NON-STC'S, i.e., irradiances of 400W/m2.

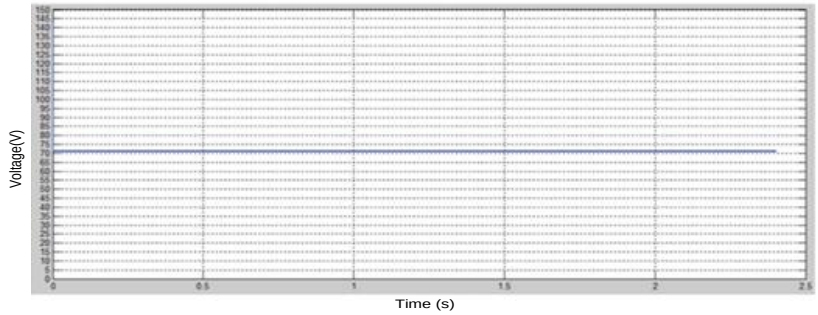


Fig.10 Voltage Tracked by the P and O Algorithm under Partial Shaded Condition

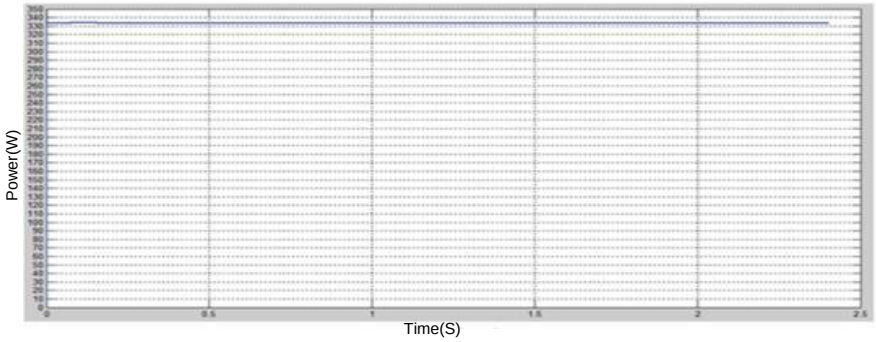


Fig.11 Power Tracked by the P and O Algorithm under Partial Shaded Condition

C. with GMPP track subroutine (Improved) MPPT algorithm:

The highest power obtained in three cases as mentioned in 3 section is traced by the modified version of P&O method i.e., Improved MPPT method and the obtained results are as shown in the figures 12,13 below. The figure 12 shows the voltage references generated by the algorithm where GMPP has occurred and figure 13 shows the maximum power that is available in all three conditions.

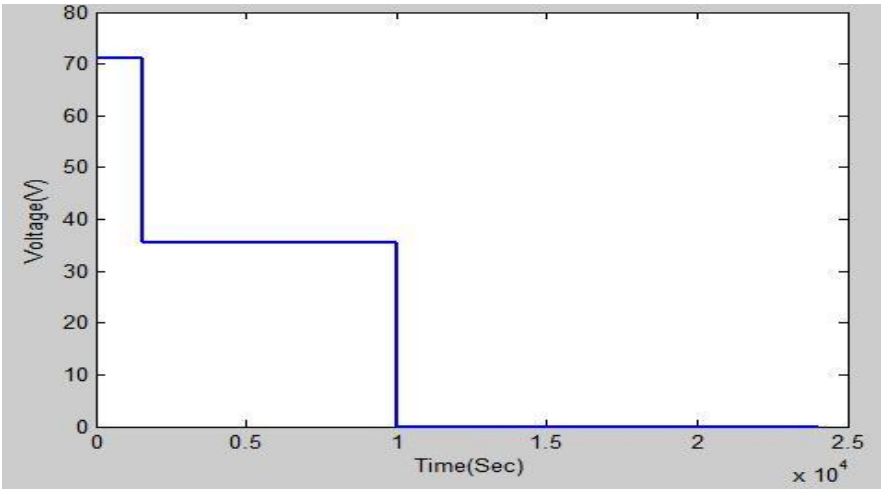


Fig.12 Voltage Tracked by the Improved P&O MPPT Algorithm under Partial Shaded Condition

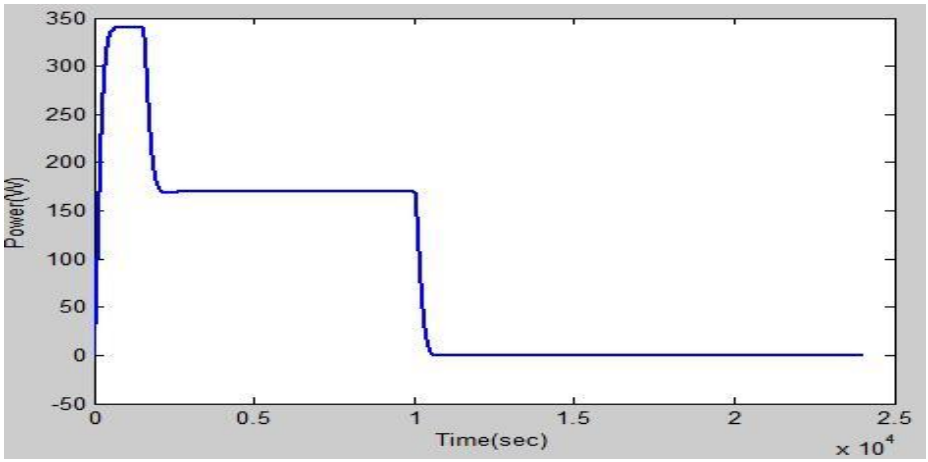


Fig.13 GMP Tracked by the Improved P&O Algorithm under Partial Shaded Condition

By observing the graphs, so obtained from P&O method and Improved MPPT method, P&O algorithm, which is a part of GMPP track subroutine algorithm, is failed, since it presenting not varying power references indicator regardless of NON-STC. The results obtained either from P&O method or GMPP track subroutine method will be same under STC's i.e. irradiances of 1000W/m2.

P&O works on the present instant of Voltage and current's it does not depend on state of system(shade condition).GMPP track subroutine is also same as P&O but here it considers condition or state of system that means whether the shading presented or not. under shaded condition PV modules are isolated and based on the irradiation it divides modules into subgroups, and generates new reference's voltage based on the Upper (darken) situations, which was used further to provides pulses to converter with the help of this generated voltage reference.

D.Comparison outputs of ANFIS with PI controller:

The PV system Power and voltage Tracked by using conventional algorithm along with ANFIS and PI controller under PSC are shown in below figure 14 and 15.

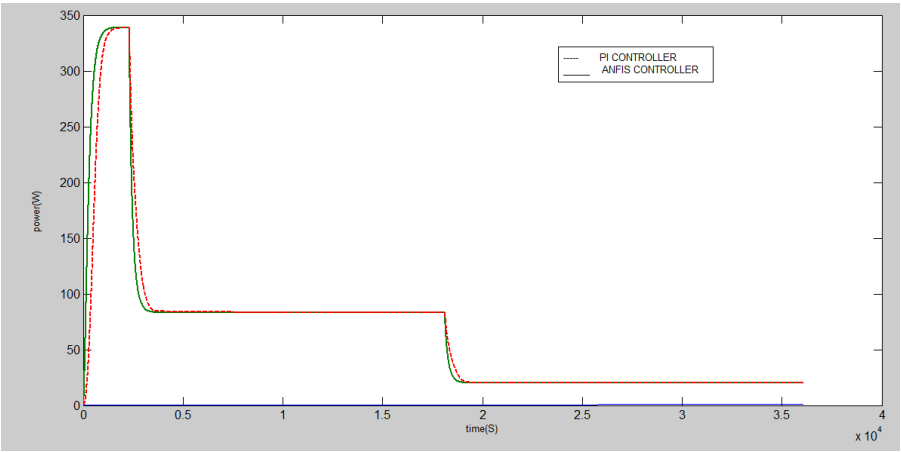


Fig 14: GMP Tracked by the Improved P&O Algorithm under Partial Shaded Condition by using ANFIS and PI controller

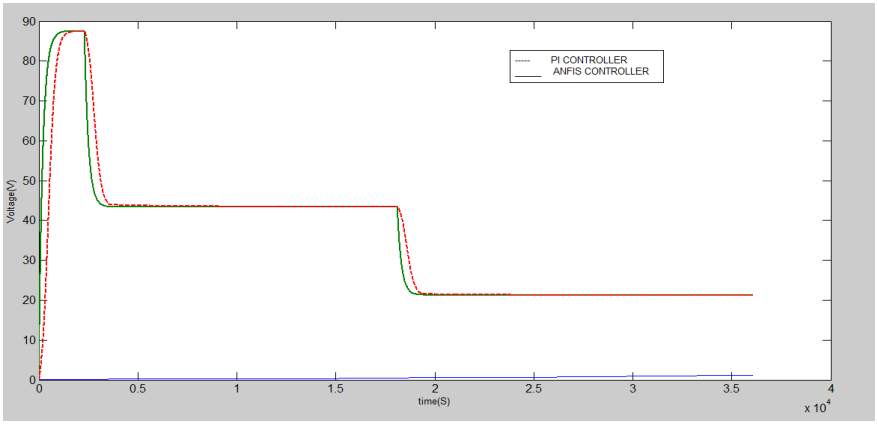


Fig 15: Voltage Tracked GMP Tracked by the Improved P&O Algorithm under Partial Shaded Condition by using ANFIS and PI controller

From observing the above two graphs, it is clear that the PV system has been examined with improved P&O algorithm based MPPT method along with PI and ANFIS controller under different partial shading conditions, the simulation results reveal the superiority of the proposed control schemes. The performance of our proposed system is shown in below table.

Table2: Performance of different controllers along with algorithms:

Parameter	Improved P&O with PI controller	Improved P&O with ANFIS controller
Response time	High	Low
Oscillations	High	Low
Steady-state variations	High	Low
Power loss	High	Low
Algorithm complexity	Low	High
Overall performance	Moderate	Excellent

VI. CONCLUSION

In this work, the issues encountered in improved P&O method have been examined. Here a better solution is suggested, known as adaptive neuro fuzzy inference system (ANFIS) along with the proposed method. .The main objective of ANFIS is to minimize the fluctuations as fast as possible. The merit of ANFIS is verified via MATLAB simulation. The exhibition of ANFIS correlated with another state of the art method (improved P&O) which informs that the accomplishment of ANFIS is outstanding corresponding to the up-to-date methods.

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