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Optimal Power Extraction from Solar PV Panels using Fuzzy Logic and Artificial Neural Network based Maximum Power Point Tracker

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ABSTRACT

Solar energy is among most impactful type of renewable energy because of the reliable amount of sunlight the Earth receives. By installing the solar modules one can easily reduce the dependency on electrical grid and utilize the clean energy locally. One of the main disadvantages is that the solar irradiance varies even at the same place throughout the day. Due to the variation in solar irradiance photovoltaic energy generation is not constant throughout the entire day. As the operating point changes due to change in irradiation it becomes necessary to identify instant by instant that specific operating point of I-V characteristics of solar module where the maximum amount of power is getting generated. The conventional techniques to identify this maximum power point MPP are popular, simple and easy to implement, but they can only track single MPP under the uniform solar irradiance. Conventional techniques require long time and also has low tracking accuracy. Soft computing techniques are a little complex in comparison to conventional techniques but all of them are flexible as well as reliable. Soft computing techniques provide optimal solution with high efficiency. The paper design and compare Fuzzy Logic and Artificial Neural Network based MPPT for PV applications.

KEYWORDS
Solar photovoltaics
MPPT: Maximum power point tracker
Conventional
Soft computing
Fuzzy Logic

1. INTRODUCTION

In recent years, renewable energy has attracted good amount of attention for household or residential applications and power generation [1-3]. One of the problems of the renewable energy resource is that they have low energy conversion efficiency [4-6]. Many forms of renewable energy resources such as solar energy, hydro power, tidal, wind energy, tidal, etc are available. However, solar or photovoltaic systems are the simplest, environment friendly as well as easy to install. But photovoltaics system's efficiency is very less. So, in order to replace conventional energy sources with renewable energy sources which is a more environmentally friendly option, it is imperative to extract maximum power and deliver it to desired load at the minimum cost [7-10].

For capturing the maximum power from the photovoltaic module, the module will operate at its optimal power points. For this purpose, a controller called MPPT is used. The output of photovoltaic array depends on the terminal operating voltage and the photovoltaic array exhibits non-linear I-V characteristics [11-12]. Therefore, the purpose of MPPT is to compensate for the varying I-V curve of the solar cell. The function of MPPT is to modify the output voltage and to accurately track the constantly varying point at which maximum power can be acquired [13-15]. The conventional techniques like Perturb & Observe have some drawbacks such as oscillation around the maximum power point as well as low efficiency. Soft computing based MPPT methods, such as FLC or ANN model can be used to improve the conventional method based MPPT model [16-21]. Soft computing techniques are complex as compared to the conventional techniques, but they are flexible as well as reliable. Soft computing techniques provide optimal solutions with high efficiency [22]. This paper focusses on two of the soft computing techniques i.e. artificial Neural Network and Fuzzy Logic. An MPPT has been designed using both techniques separately and their performances have been compared. It is established that the soft computing based MPPT scheme produces better efficiency for the solar panel compared to the conventional Perturb and Observe based MPPT controller. In the next sub section, detailed mathematical modeling of solar panels is presented to prepare the mathematical base for MPPT algorithm.

2. MATHEMATICAL MODELING OF THE SOLAR PV PANEL

Equivalent circuit of a PV cell is shown in Fig. 1, in which current source is antiparallel with a diode and nonidealities are represented by series and parallel resistances and respectively [23]. PV cells are connected in series and parallel configuration to form PV module and PV arrays. Mathematical equations governing I-V characteristics of PV panel are given in (1)-(4).

$$I_{ph} = \left[I_{scr} + K_i\left(T - 298\right)\right] * \left(G/1000\right) \qquad (1)$$

$$I_{rs} = I_{scr}\left[\exp\left(qV_{oc}/N_S AKT\right) - 1\right] \qquad (2)$$

$$I_o = I_{rs}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{qE_{go}}{Bk}\left\{\frac{1}{T_r} - \frac{1}{T}\right\}\right] \qquad (3)$$

$$I_{PV} = N_P * I_{ph} - N_P * I_O \left[\exp\left\{ \frac{q(V_{PV} + I_{PV} R_S)}{N_S A k T} \right\} - 1 \right] \quad (4)$$

Where I_{PV} and V_{PV} represent the output PV current and voltage, I_{ph} is photo-current, I_{rs} is reverse saturation current, q is the electrical charge $(1.6 \times 10^{-19} C)$, k is Boltzmann constant $(1.38 \times 10^{-23} J/k)$, T is temperature and G is the PV module illumination in (W/m^2). With the aforementioned equations given in Table I, the modelling has been carried out using MATLAB.

3. MAXIMUM POWER POINT TRACKER ALGORITHM

An electrical device which is used to convert light energy or sunlight into electricity by using photovoltaic effect is called a solar cell. The electrical qualities of a solar cell change when it's exposed to light. When multiple solar cells are arranged in one plane it is called solar module. As per the dependency on size for solar cell, the output current is directly proportional to its area. The voltage of the solar cell, however, remains constant irrespective of the area of the solar cell. When we connect PV modules in series, voltage gets added up. When we connect dissimilar PV modules in parallel, current gets added up. Generally, solar cells are connected in series as in case of parallel arrangements of solar cells, shadow effect can cause the solar cell which is getting less illumination to shut down resulting in loss of power. MPPT is used when power source is variable like sunlight in case of solar, to maximize the extraction of energy. It is mostly used with solar or PV systems, however it can also be used with other renewable resources in order to extract maximum energy. The major problem that the MPPT tackles is the efficiency of the transfer of power from solar cells as this efficiency depends upon the availability of sunlight, temperature of the solar panel as well as the electrical characteristic of the load. In case these conditions vary the maximum power point changes. The non-linear relation between the total resistance and temperature of the solar module is analyzed based on I-V curve which is shown below in Figure 2 for different values of irradiation at 25°C. The MPPT basically varies the load resistance to obtain the MPP.

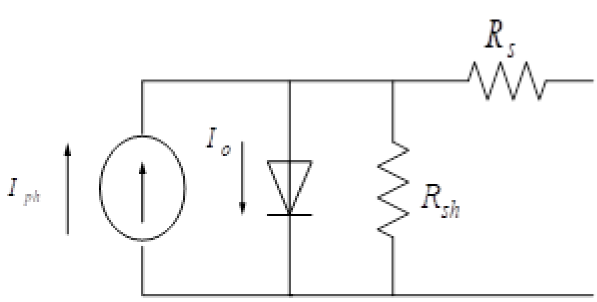


Fig. 1 A single diode model of PV cell

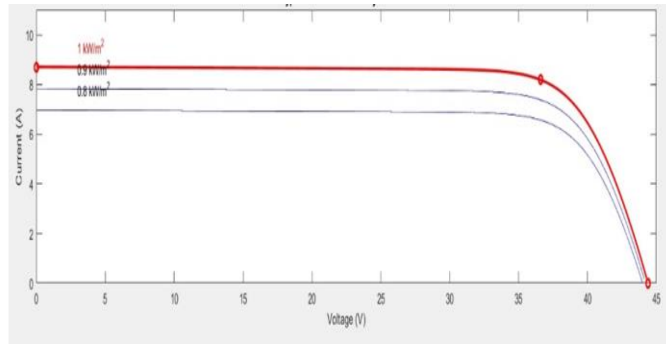


Fig. 2 I-V characteristics of solar panel

3.1 Fuzzy Logic based MPPT for photovoltaic supply

In the year 1965, Lotfi A. Zadeh', a professor in Computer Science from University of California, Berkley introduced concept of the Fuzzy Logic (FL). The most important features of FL are that it doesn't necessarily require accurate mathematical structure to work as it works well using inexplicit inputs. FL is quite robust as well as accurate as compared to older non - linear controllers. FL control operation can be done in three steps which are [24-26]:

1. The Fuzzification
2. The Inference Engine
3. Defuzzification

The Fuzzification: The Fuzzification is defined as a process of transforming numerical variables into linguistic variable with the help of defined membership function ZE, zero; NS, negative small; NB, negative big; PB, positive big; PS, positive small are basically the linguistic variable which is used in this project. The linguistic variable mentioned above is described using the desired mathematical function. In this project triangular shaped membership function is used to implement FLC membership function for both input and output.

The Inference engine: Fuzzy rules and sub blocks are used to link input and output variables in Fuzzy Logic Designer. Here Mamdani's Fuzzy Inference technique is used. This technique uses minimum-maximum operation and fuzzification of actual input value is done before the rule given below is used. The purpose of using this rule is to control the boost converter to reach MPP. This rule is used to find closer points of MPP by decreasing and increasing the duty-ratio of boost-converter. The rule base mentioned above is described in Figure 3.

Defuzzification: Fuzzy subset is the output of FLC so defuzzification should be done because the real systems need crisp value which is obtained after defuzzification. Defuzzification is the method which is employed in order to transform linguistic value or linguistic fuzzy sets back into its mathematical equivalent magnitude. It is needed so as to add crisp value of the FLC to the previous value of the duty cycle ratio. After this resultant output of duty-ratio is sent to gate of MOSFET in the boost converter. The implementation and designing of FLC based MPPT is done by MATLAB (r2021a). The PV system consists of 12 Tata Power Solar System TP300LBZ solar panel in which there are 2 parallel panel and 6 series panel. The specifications are given in Table I.

Table .1 Solar PV Panel Specification

Characteristics of Parameter	Specifications
Maximum Power Point (P_{MPP})	300.12 x12= 3601.4 W
Voltage at MPP (V_{MPP})	36.6 x 6= 219.6 V
Current at MPP (I_{MPP})	8.2 x 2= 16.4 A
Open Circuit Voltage (V_{OC})	44.4x 6 = 266.4 V
Short Circuit Current (I_{OC})	8.69 x 2= 17.38 A

To maintain the voltage at the output, a DC-DC boost converter is applied, whose parameters are given in Table II.

Table. 2 DC-DC Boost converter Specification

Switching Frequency	5000 Hz
Capacitance	400 µF
Inductance	3.2mH
Resistance	50Ω

FLC based MPPT Control algorithm adopted here can be summarized by the flowchart given below,

3.2 The Artificial Neural Network Based MPPT for PV Applications

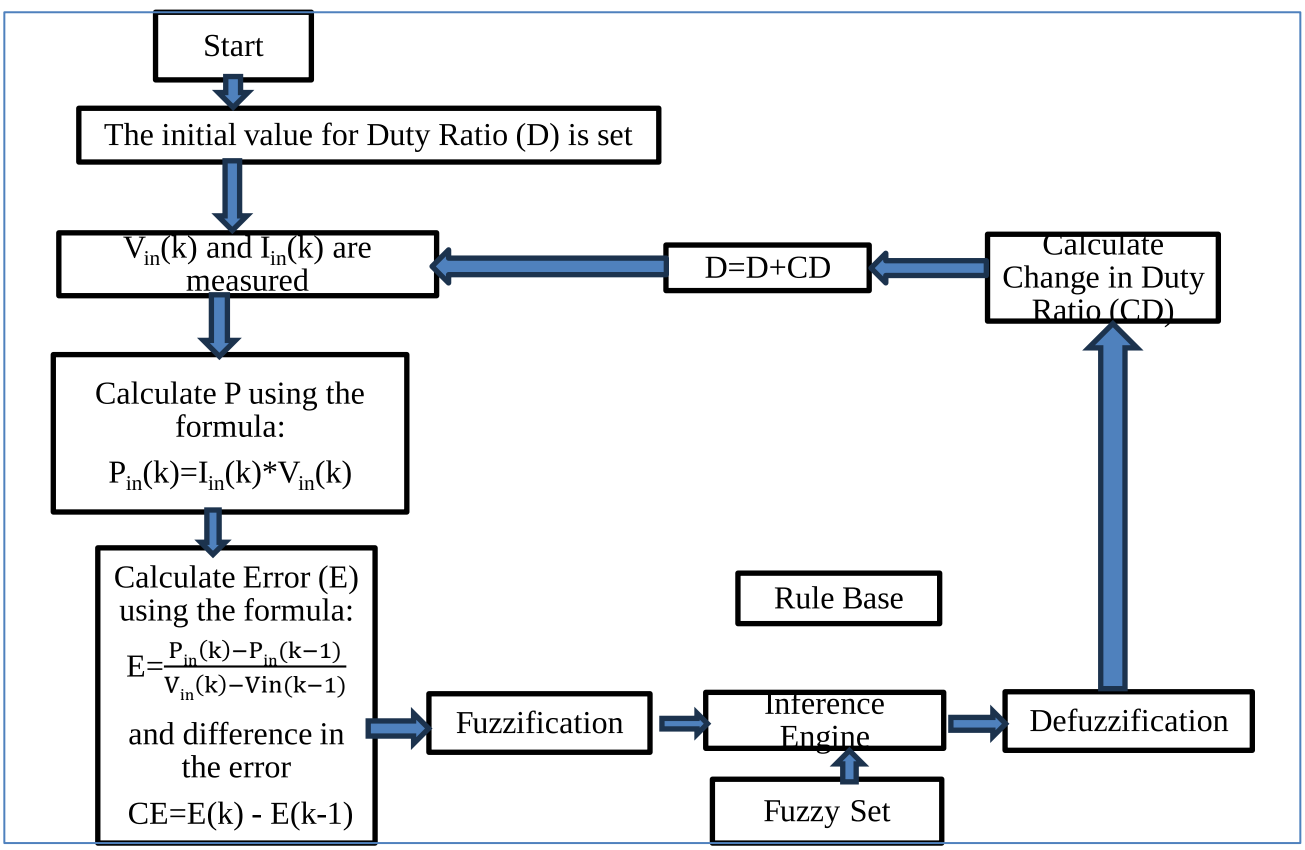
Neural network is works in similar way like human brain, which contain the set of artificial neurons i.e., it learns and grasps from experiences to store data or information in terms of patterns. ANN consists of interconnection of artificial neurons and processes information with the help of these interconnection. Neural network is categorized into 3 parts or layers named as, input layer, output layer, and hidden layer. As per application hidden layer might or might not be used [27-30].

1. Inp

2. ut layer (input node) –In order to derive conclusions, the information from outer world is provided to train the model and conclude from it. This layer passes the information to the next layer which is the hidden layer.

3. Hidden layer – This is the layer where all the computation are performed with set of neurons on input data. In neural network number of hidden layers can be as desired, but the single hidden layer is the simplest layer.

4. Output layer – After all the computation, output layer of the model is derived. In output layer there can be single and multiple nodes. Output node is one when we have binary classification and output node can be more than one when there is multi class classification. Flowchart of the process of training of ANN is given below.



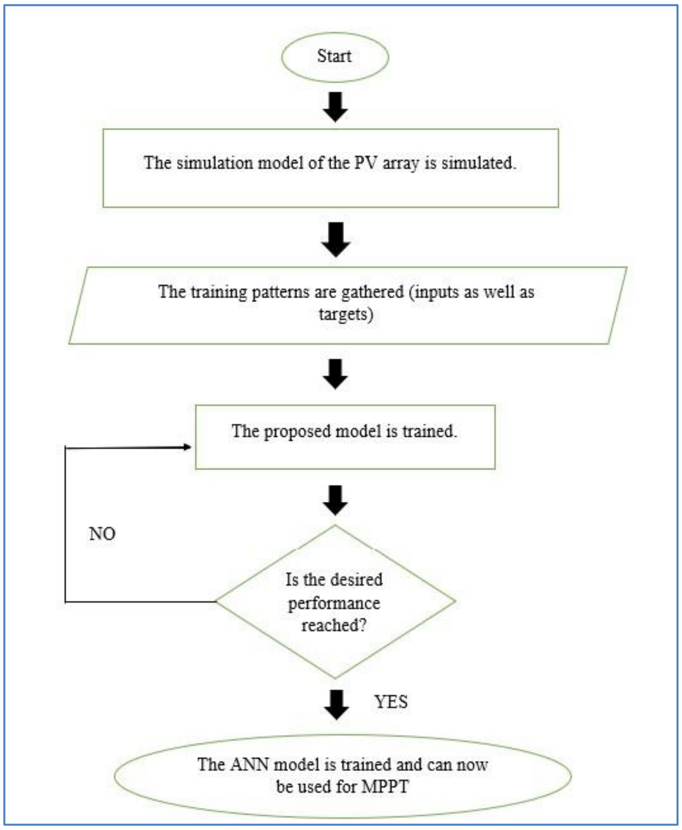


Fig. 3 Flowchart of the MPPT based on ANN

4. RESULT AND DISCUSSION

The performance of above MPPT techniques have been checked with the helop of MATLAB based simulation. A PV panel with specification as mentioned in table 2 is taken for solar power generation at the varying solar incidence condition. In order to maintain the output voltage at MPP, the ANN and FL based scheme has been implemented which maintains the output voltage at Vmpp with the help of DC-DC Boost converter. The specification of the Boost converter is mentioned in table 3. ANN and FL both are training based algoritm platform. In FL based scheme, MPPT method has two input variable namely The Error (E), The Change in Error (CE) and one output variable which is The Change in Duty-Cycle (CD). So, FL Designer will be used for fuzzification as shown in below figure.

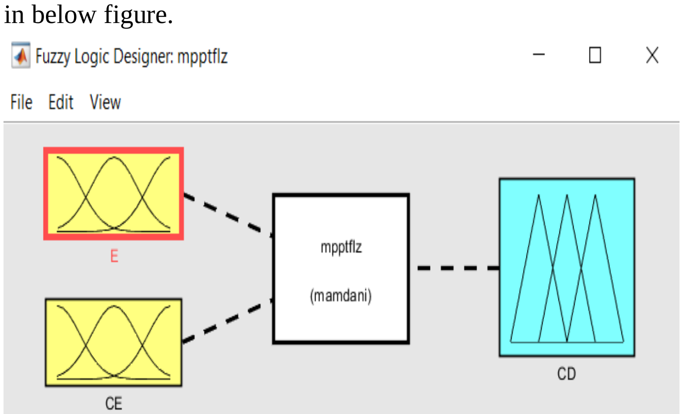


Fig. 4 Fuzzy Logic Designer

Based on above fuzzification scheme implemented with FL based MPPT algorithm, the PV output has been obtained at 1000 W/m^2 and 900 W/m^2.

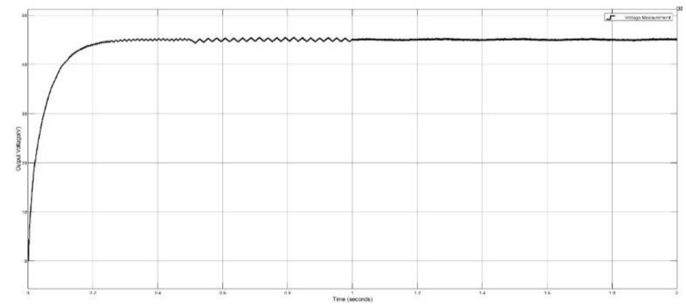


Fig 5. Output Power Waveform for 1000 W/m^2 irradiance for FLC based MPPT

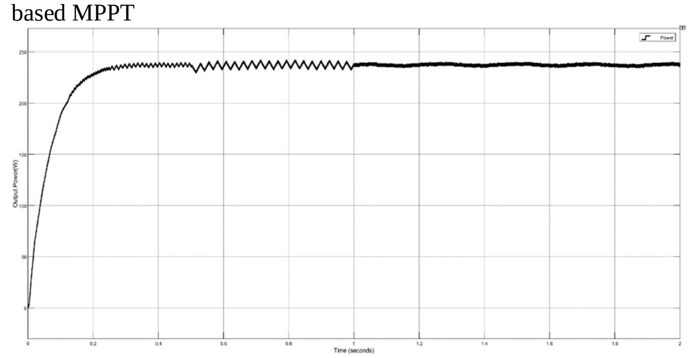


Fig. 6 Output Power Waveform for 900 W/m^2 irradiance for FLC based MPPT

For ANN based implementation of MPPT algoritm, training is performed in a specific order. The order is explained below.

In the first way i.e., supervised training, output value is known so input can be given according to required output so that resulting output and desired output can be compared to resulting output to generate the error value. After obtaining the error value, propagating data is enabled and the process named as 'training set'. In this project, for the purpose of training of the model, supervised training is used.. In another way of training i.e., unsupervised training, the desired output is not basically not predictable so the training is done with the random input, so the process is named as 'self-organization'. Back propagation is the process used to update as well as find the optimal values of the coefficient so that the error in the model can be minimized. After training of the network, Neural Network Training Regression (plot regression) is obtained along with their respective value of R (regression).

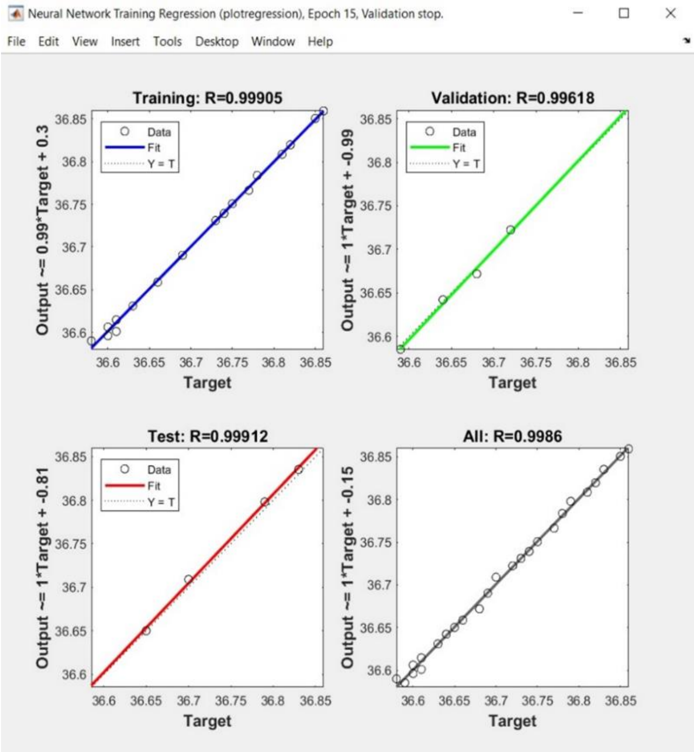


Fig. 7 Neural Network training regression plot

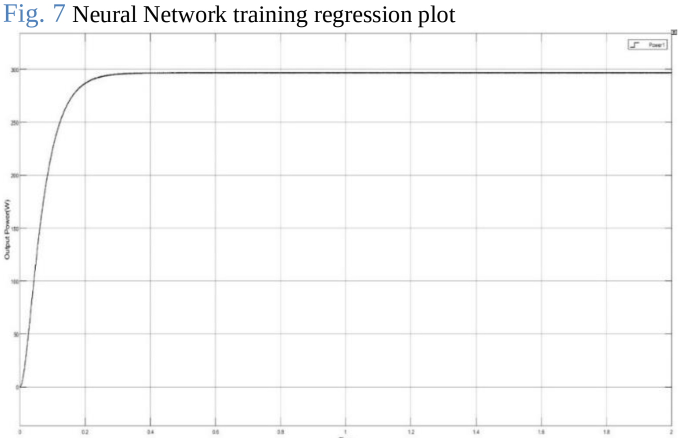


Fig 8. Output Power Waveform for 1000 W/m^2 irradiance for ANN based MPPT.

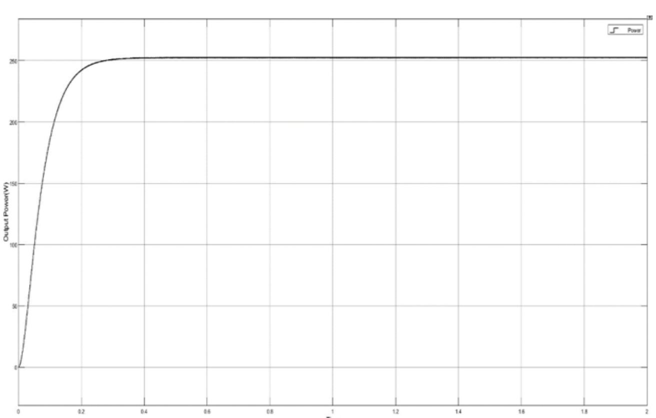


Fig. 9 Output Power Waveform for 900 W/m^2 irradiance for ANN based MPPT.

The tables shown below provides the efficiencies which is calculated for two MPPT techniques under two different values of insolation that is 1000 W/m2 and 900 W/m2.

Table. 3 Efficiency calculation of FLC based MPPT

Irradiance (W/m2)	**1000 W/m2**	**900 W/m2**
Efficiency [η](%)	Poutput= 291.5 W Pgraph= 300.12 W η=97%	Poutput= 241.2 W Pgraph= 260.08W η=93%.

Table. 4 Efficiency calculation of ANN based MPP

Irradiance (W/m2)	**1000 W/m2**	**900 W/m2**
Efficiency [η](%)	Poutput= 296.9 W Pgraph= 300.12 W η=98%	Poutput= 252.6 W Pgraph= 260.08 W η=97%

5. CONCLUSION

FLC and QANN based MPPT model was designed as well as implemented in MATLAB/Simulink. The output waveform is obtained by using two different values of irradiance that is 1000 AW/m2 and 900 AW/m2 at 225°C. As per the Power-Voltage characteristic graph for different values of irradiation (which provides the value of Power at MPP at different values of irradiances), efficiency is also calculated. As per the efficiency table and the output power waveform ANN base MPPT controller is smooth and contains less oscillation. By repeated training of the network the model become more accurate. In this project, the total number of data sets that were used was 16. Large number of data set can also be used to train the network to make the controller more accurate.

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