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Enhancing the Efficiency of Grid Connected Bifacial PV System Using Artificial Neural Network MPPT

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***Abstract*— To meet the world's growing energy demands, countries are increasingly promoting the installation of photovoltaic (PV) systems to reduce reliance on fossil fuel imports. However, conventional monofacial PV modules typically achieve only 20-25% efficiency, which poses challenges for maximizing power output. In contrast, advanced bifacial PV panels can capture sunlight from both sides, enhancing the overall efficiency of the system. It is crucial to operate PV systems at their maximum power point (MPP) to optimize performance. This paper proposes an advanced neural network-based maximum power point tracking (MPPT) system for bifacial PV systems. By integrating the advantages of bifacial PV modules with artificial neural networks, this approach aims to address the challenges associated with solar energy utilization effectively. To evaluate the effectiveness of the proposed method, it was compared with a monofacial PV module and the traditional Perturb and Observe algorithm. The results indicate that the proposed method achieves higher output power, greater tracking efficiency, lower total harmonic distortion (THD), and reduced settling time.**

***Index Terms*— PV, Bifacial PV module, MPPT, ANN**

I. INTRODUCTION

In recent years, electricity generation from renewable sources has gained popularity worldwide. These renewable sources are cleaner and produce electricity without emitting pollutants into the environment. Renewable sources such as solar, wind, and biomass provide alternatives energy sources that significantly reduce harmful gas emissions and decrease dependence on finite resources like coal, oil, and natural gas. Among these, solar energy is one of the most widely utilized sources for electricity generation.[1]

The PV system offers several advantages, including clean energy production and reduced electricity costs. However, if these systems operate without an MPPT (Maximum Power Point Tracking) controller, their efficiency is significantly lower. This is because PV systems have nonlinear characteristics, and maintaining optimal power output is crucial for improving overall efficiency [2]-[4].

Several MPPT methods have been implemented for controlling PV power, ranging from traditional hill-climbing techniques, also known as Perturb and Observe (P&O), to machine learning-based artificial neural network (ANN) MPPT. Advanced techniques provide better control over PV power due to their sophisticated control strategies, which effectively manage the inherent nonlinearities in the PV system and improve tracking efficiency. The commonly used method for controlling PV power is the Perturb and Observe (P&O) technique, also known as the hill-climbing method. However, this approach has some limitations, including power oscillation around the maximum power point (MPP) and reduced tracking efficiency in rapidly changing environmental conditions.[5]-[8]

Conventional monofacial PV modules capture sunlight only from the top side of the panel. In contrast, bifacial modules can absorb sunlight from both the top and back surfaces, due to their transparent backside which absorbs reflected sunlight, thereby enhancing the energy harvesting efficiency of the PV system.[9]

Emerging techniques such as fuzzy logic and artificial neural networks (ANN) have shown promise in improving the performance of solar PV systems. Unlike traditional methods, these AI-based strategies offer more sophisticated and adaptable control options.[10]-[12]

In this paper, we implement a grid-connected Bifacial PV system with ANN and P&O MPPT techniques. The performance of the proposed methods is evaluated based on parameters, including the power output from both types of modules, MPP tracking efficiency, power waveform ripple, and total harmonic distortion (THD). This study aims to make a significant contribution to solar energy technology by assessing effective MPPT techniques for bifacial PV modules, ultimately enhancing energy harvesting efficiency and overall system reliability.

II. PV CELL MODELING

A. Monofacial PV

The equivalent Circuit of PV cell is shown in Fig.1

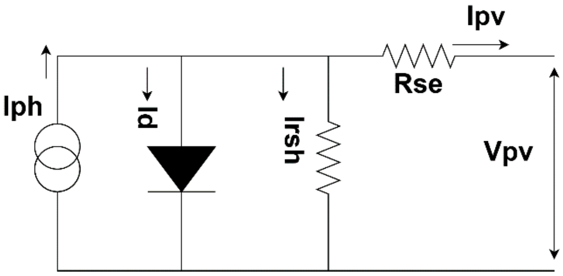

Figure 1 Equivalent Circuit of PV cell

The Current of PV cell is given as

$I_{PV} = I_{ph} - I_d - I_{rsh}$

$$I_{PV} = I_{ph} - Io\left(e^{\left(\frac{Vpv+Ipv*Rse}{Nd*Kb*T}\right)} - 1\right) - \left(\frac{Vpv + Ipv * Rse}{Rsh}\right)$$

I_{ph} = photon current

I_{rsh} = current through shunt resistance

I_{PV} = PV output current

V_{PV} = output voltage of PV cell

I_o= reverse saturation current

N_d = diode ideality factor

K_b= Boltzmann constant

T= cell temperature

B. Bifacial PV module

The bifacial PV module can be represented as two monofacial PV module connected in parallel as shown in Fig.2.

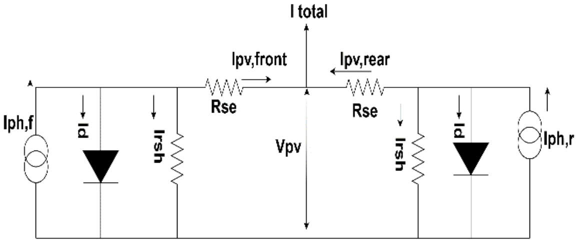

Figure 2 Equivalent Circuit of Bifacial PV module

The equation for output PV current will become as

$$Total\ Current = I(front) + I(rear)$$

$$I, total = Iph, f - Io\left(e^{\left(\frac{Vpv+Ipv,front*Rse,front}{Nd*Kb*T}\right)} - 1\right) - \left(\frac{Vpv + Ipv, front * Rse, front}{Rsh, front}\right) + Iph, r - Io\left(e^{\left(\frac{Vpv+Ipv,rear*Rse,rear}{Nd*Kb*T}\right)} - 1\right) - \left(\frac{Vpv + Ipv, rear * Rse, rear}{Rsh, rear}\right)$$

The ability to capture the reflected sunlight increases the PV output current. The amount of sunlight reaches to the back surface of the panel depends upon the reflectivity of the surface and mounted angle. The irradiance value reaches to the rear surface is given as

$G_{rear} = \alpha * G_{toltal}$

Where "α" is Albedo Value. Table.1 shows the albedo values for different surfaces.

Table 1 Albedo Values for different surfaces

Type of surface Solar PV mounted	Reflected irradiance Value (α)
Concrete	0.3-0.6 %
Grass	0.25-0.30%
Ice	0.27-0.47%
Sand	0.38-0.42%

The Current-Voltage, Power-Voltage characteristics of PV module is illustrated in Fig.3. from the Fig it can be noticed that the PV module exhibits nonlinear characteristics and it varies by changing in environmental factors such as irradiance and temperature. Hence a control algorithm is needed to operate the system at maximum power point.

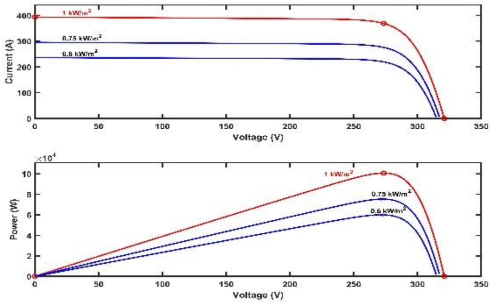

Figure 3 I-V and P-V characteristics

III. MAIMUM POWER POINT TRACKING TECHNIQUES

A. Perturb and Observe (P&O)

Fig. 4 shows how the P&O MPPT algorithm operates. The algorithm is based on varying the PV voltage or current operating value and tracking the change in PV power that occurs. The algorithm will lower the converter's duty cycle if the operating point perturbation raises PV power.

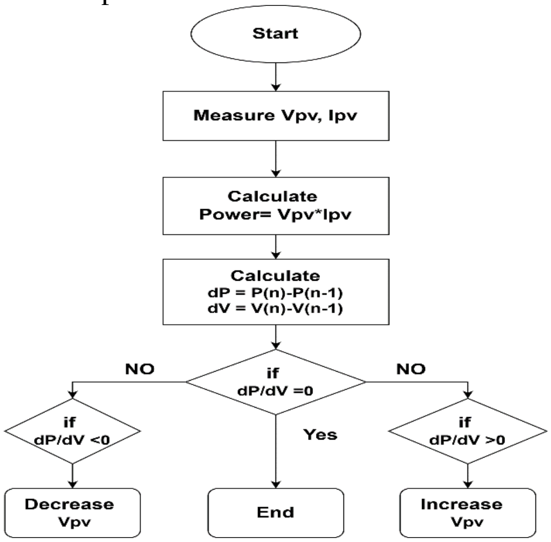

Figure 4 P&O MPPT

B. Artificial Neural Network MPPT

A feedforward Neural Network shown in Fig. can be used for PV MPPT application. The purpose of employing ANN algorithm is to make a relation between inputs(irradiance,Temperature) and one output(Vmp). By training the network, it predicts the Vmp value based on the inputs(irradiance and temperature).

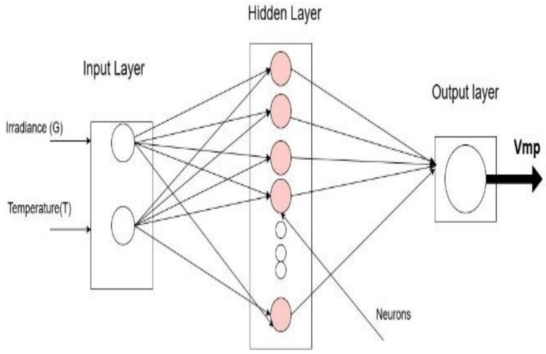

Figure 5 Feedforward Neural Network

The procedure for implementing ANN MPPT is illustrated in Fig.6. the data is obtained by simulating the PV modules. The data is then used for training the network. Levenberg-Marquardt algorithm is used for training.

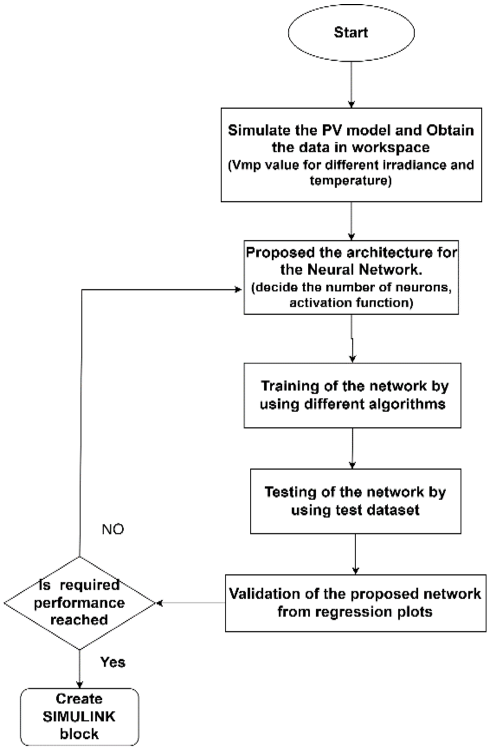

Figure 6 ANN MPPT algorithm

IV. SIMULINK DIAGRAM AND DESCRIPTION

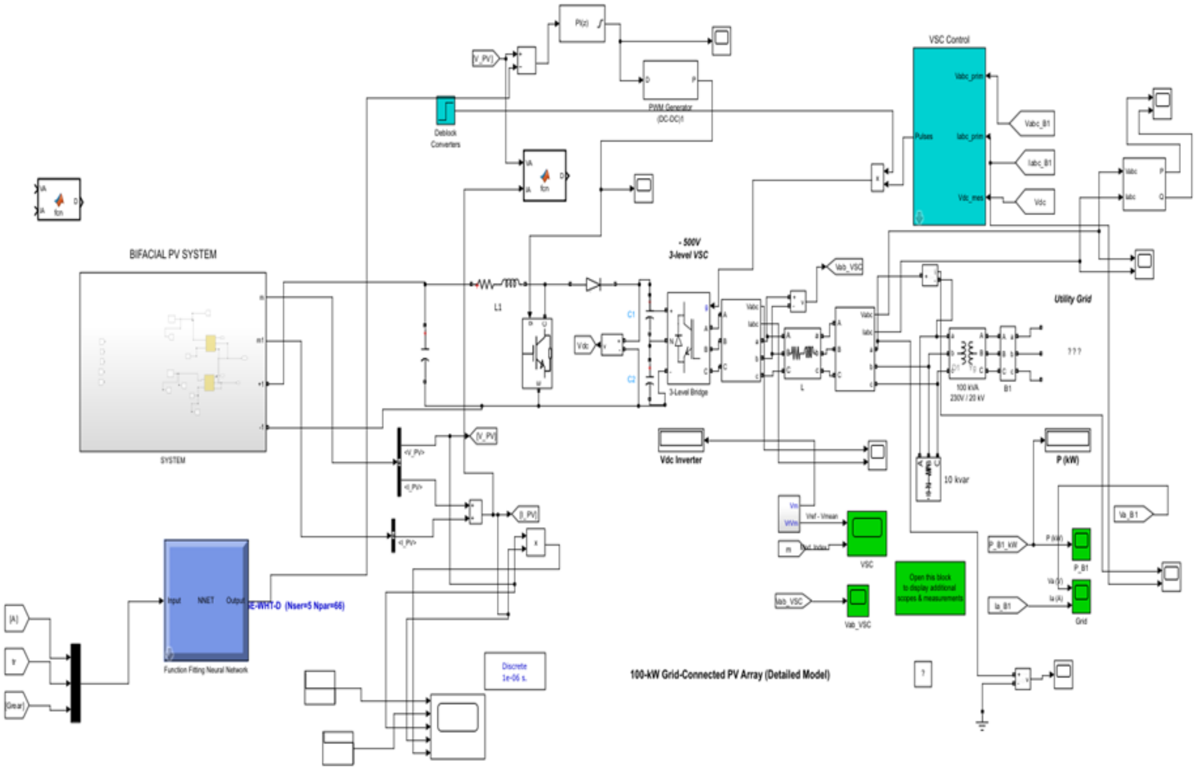

Figure 7 SIMULINK diagram

Fig.7 represents The Simulink Diagram of grid connected bifacial PV system with ANN MPPT

From the Simulink Diagram it can be noticed that the Bifacial PV panels takes front side irradiance (G,front) as well as rear side i.e. reflected irradiance (G,rear). The ANN MPPT gives the Vmp value based on network training with respect to inputs. The actual PV voltage Vpv is compared with voltage at maximum power point (Vmp) and the resultant error value is given to the controller. The Controller provides the duty cycle of the boost converter in order to maintain the operation at MPP.

In effective grid integration, Inverter and transformer is needed to converting the DC output of PV into AC to match with the grid voltage value.

The ratings of the Component is shown in Table.2.

Table 2 Ratings of components

Components	Rating
Maximum power of one PV module	305.226 Watts
maximum voltage	54.7V
maximum current for Monofacial	5.58Amps
Maximum current for bifacial PV module	5.58-7.4 Amps
Parallel Strings	66
modules per string connected in series	5
Monofacial PV array Maximum Power	100KW
Bifacial PV Array maximum Power	133KW
DC-DC Converter	500V, 5KHz
Inverter	3-Phase , 3-level
Step-up transformer	200V/20KV
Grid	20KV

V. SIMULATION RESULTS

The system is simulated using MATLAB/SIMULINK. The fig.8,9 represents the PV output voltage, current and Power with ANN and P&O MPPT. The irradiance on front surface of the panel is considered as 1000,800,600 wb/m^2 and on backside of the panel as 360,340,300 wb/m^2.

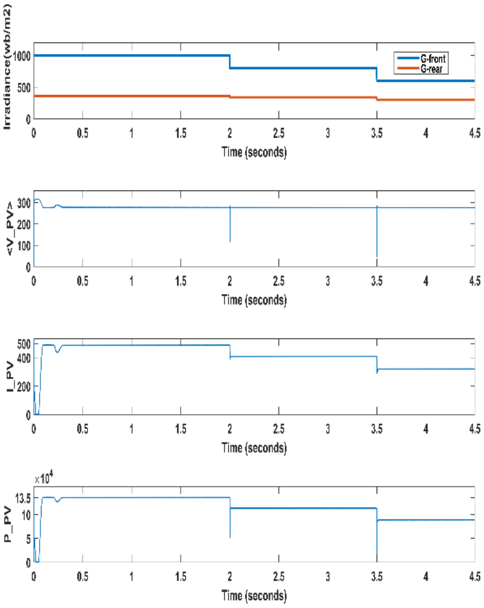

Figure 7 PV output with ANN MPPT

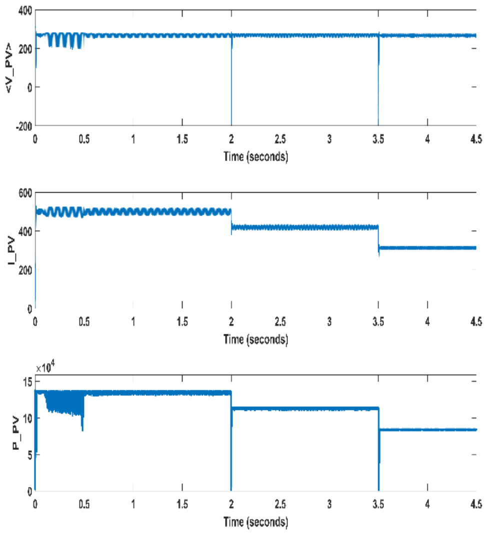

Figure 8 PV output with P&O MPPT

The results indicates that proposed MPPT for Bifacial PV system effectively control the PV power in varying irradiance condition with high tracking efficiency, less ripple content and lower settling time compared to P&O MPPT shown in Fig.10.

The voltage from the DC-DC boost converter is converted to AC by using 3-phase, 3-level inverter shown in Fig.11. In grid integration the voltage of the inverter should match the grid voltage level. The step-up transformer is employed which match the inverter output with grid voltage. As shown in fig. the transformer output matches the grid voltage level of 20KV. Hence the system can be effectively integrate with the existing grid for injecting the power generated by solar PV system.

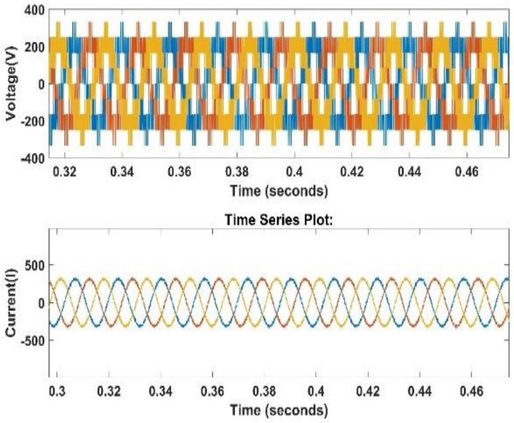

Figure 9 Inverter output voltage and current

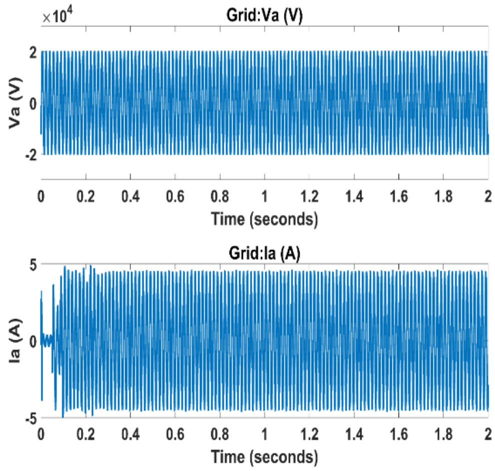

Figure 10 Voltage and Current injected into the Grid

The power injected into the grid from solar PV systems must meet quality standards to ensure reliable performance. Fig.12 represents the power injected by using P&O and ANN MPPT. The power with P&O having more ripple content which may reduce the grid stability by injecting harmonics.

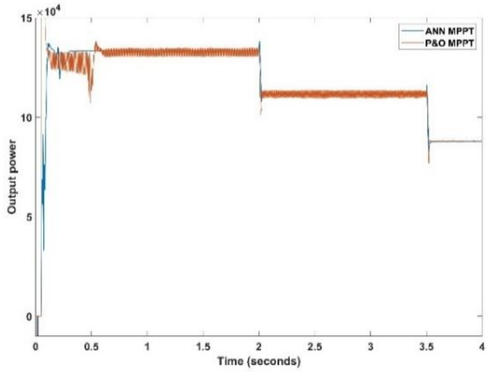

Figure 11 Injected power with MPPT techniques

Table.3 gives the detail comparison of MPPT techniques

Table 3 Comparison of MPPT techniques

Comparing factors	ANN MPPT	P&O MPPT
Ripple content in PV power(%)	0.05	6.5
Settling time(sec)	0.28	0.55
PV power obtained at 1000wb/m^2	135KW	Fluctuates 132-135KW
Total harmonic distortion(%)	3.6%	11%

The purpose of using Bifacial PV module is to increase the power generation from the PV panels, improving the efficiency of the solar module and increasing the reliability of the PV system. The comparison of Conventional Monofacial and advanced Bifacial PV module is illustrated in Fig.13.

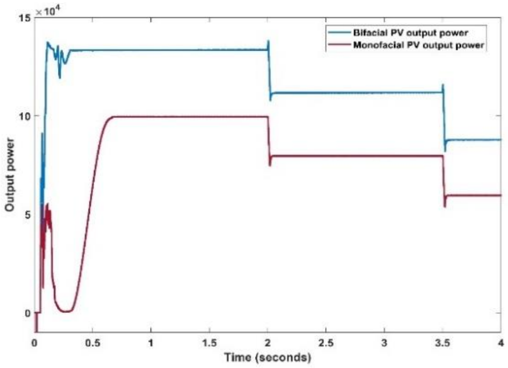

Figure 12 Comparison between PV modules

VI. CONCLUSION

In this paper, an ANN-based MPPT (Maximum Power Point Tracking) algorithm is implemented to improve the efficiency of grid-tied bifacial PV modules. The use of bifacial PV technology aims to enhance the energy conversion efficiency of the PV system. The proposed technique is compared with the conventional (P&O) algorithm. The results indicate that, despite the inherent nonlinearities in the PV system due to varying environmental factors, the proposed MPPT effectively tracks the maximum power with high tracking efficiency, exhibiting low ripple content and a lower total harmonic distortion (THD) value.

Furthermore, a comparison between PV modules has been performed. One of the drawbacks of conventional monofacial PV modules is their lower energy conversion efficiency. In contrast, bifacial modules overcome this limitation by generating a higher amount of power while occupying the same space as monofacial modules. The capabilities of bifacial PV modules significantly enhance energy harvesting efficiency and overall system reliability.

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