A Comparative Study between Monofacial and Bifacial PV modules using Fuzzy Logic based MPPT

Mohd Talha Zubair [1], Paradesi Sowmya [2], Korsa Mohini [3], Ahmad Ramin [4]
M.tech Student [1,2,3,4]
Electrical and Electronics Engineering [1,2,3,4],
[1,2,3,4] JNTUH College of Engineering and Technology, Hyderabad, India

Abstract - Solar Photovoltaics (PV) is crucial to meeting the energy needs of the current generation. Bifacial PV modules can generate high power density and higher energy yield with cost-effective operation due to their diffused and reflected irradiance capturing capability. The power output of the PV system varies with varying temperatures and solar irradiance. The bifacial solar cell takes the independent value of irradiance for the front side and rear sides of the cell. Bifacial solar cells, like any other solar cell, are variable sources and their power output must be controlled, which is accomplished using the maximum power point tracking (MPPT) control techniques. Various Artificial Intelligence (AI) based algorithms are available for maximizing the power of the PV systems. AI-based methods have huge applications in PV systems to provide better responses. To get the Bifacial PV module's maximum operational power, this study proposes AI-based, fuzzy logic MPPT control with boost converter topology.
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Index Terms – Solar PV module, monofacial, bifacial, MPPT, Fuzzy logic.

I. INTRODUCTION

Photovoltaic (PV) system efficiency enhancement research has grown increasingly significant in the PV industry. The lack of efficiency in conventional PV modules has led to different cell designs and various cell manufacturing technologies. The nonlinear characteristics of PV panels are a major disadvantage. The surrounding weather conditions influence the power obtained from the PV system.

Various maximum power point tracking (MPPT) control strategies have been presented to address this drawback, the traditional methods for tracking the maximum power are simple and easy but cannot handle nonlinearity. Artificial intelligence (AI) based fuzzy logic control is one such optimization approach that can handle non-linearity. It improves the speed, precision, and efficacy of the panel.

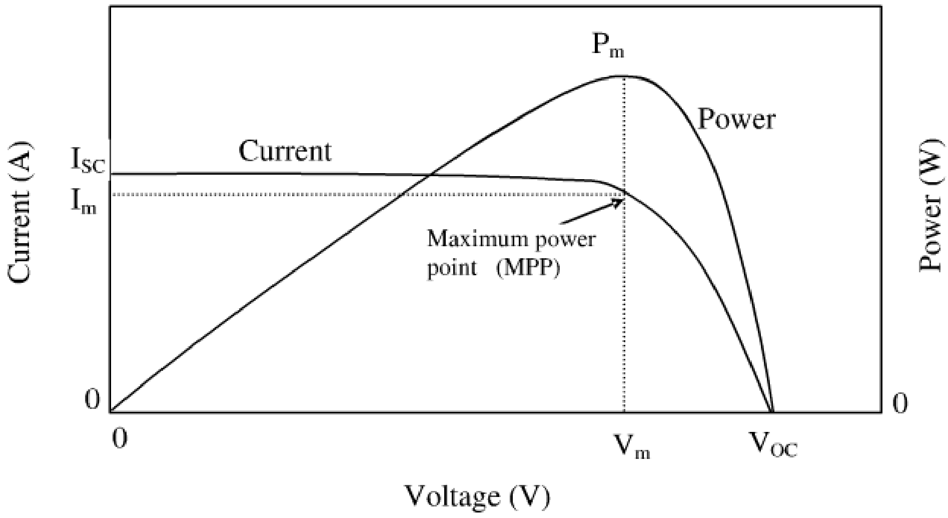
Unlike mono-facial PV modules, bifacial PV modules produce power from the front side as well as the back side of the module because of the transparent backside that captures the sunlight. They can greatly enhance power-generating performance when compared to mono facial/conventional modules.

The power output of the bifacial PV system depends majorly on albedo, the height of the panel from the ground, and the orientation/tilt of the panel. The front and rear-side power collection capability of bifacial PV cells allow them to be used in applications where the reflected light can be fully captured by the back side of the cell. It is difficult to accurately assess the performance of the bifacial solar cell because of the external contribution of sunlight from the sides.

The proposed model is based on the assumption that the front side of the module captures the direct irradiance and the rear side captures the reflected and diffused irradiance.

Irradiance and temperature are variable parameters in the bifacial PV module, which makes it a variable source and generates nonlinear characteristics curves.

Fig.1 shows the current-voltage (IV) and power-voltage (PV) curves of a solar cell. MPPT gives the operating DC power output that a PV system can generate. Maximum power occurs when the PV module is operating at maximum current and maximum voltage. The maximum power is extracted from a PV module when the load impedance is equal to the source impedance as per the Maximum Power theorem. The module's impedance varies with the environment and therefore most MPPT systems necessarily need a DC-DC converter, to optimize the match between source and load impedance for maximum power transfer. It is also known that the traditional MPPT method fails to reach maximum power point during abrupt changes in irradiance or temperature and therefore fuzzy controller is used for the bifacial PV module to enhance its efficacy



. Fig1: P-V I-V characteristics of solar cell

II. Literature survey

[1] Senthilkumar, S., et al. modelling of solar cell using single diode and analysis in different weather condition. Generation of high power density and higher energy yield with cost effective operation due to their diffused and reflected irradiance capturing capability.
[2] A. J. Alrubaie, MPPT for tracking maximum power from solar cell. The power output of bifacial solar cell must be controlled. This is accomplished using MPPT techniques.
[3] S. A. Raj and G. G. Samuel, AI based techniques for maximum power tracking in different irradiance and temperature conditions. AI based algorithms are used for maximizing the power of PV system.
[4] Raina, Gautam, Rohit Vijay, and Sunanda Sinha. Detailed analysis of bifacial PV module.
[5]Kumar comparison between conventional MPPT techniques and Fuzzy logic based MPPT. AI based methods have huge applications in PV systems to provide better responses.

III. Block Diagram

Fig 2. Block diagram

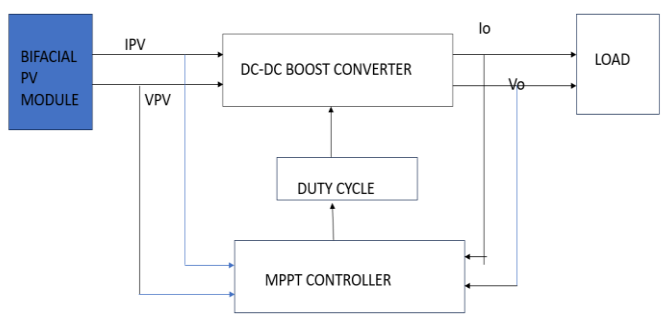


Fig.2 depicts a block representation of MPPT control for a solar panel. The solar panel is linked with a converter circuitry, the converter topology chosen depends on the application of the solar PV system. The converter interrupts the voltage/current as required. The MPPT controller controls the switching of the converter circuit to achieve maximum operating power. The proposed model uses a boost converter and fuzzy logic controller for power tracking of the bifacial module.

By using FLC, it is guaranteed that the maximum power for both monofacial and bifacial modules is tracked under both standard and variable conditions. It is well known that traditional MPPT methods produce fluctuating outputs; in contrast, the FLC approach provides a smoother tracking of the maximum power point and minimizes oscillation-related losses.

IV. MODELLING OF BIFACIAL PV MODULE

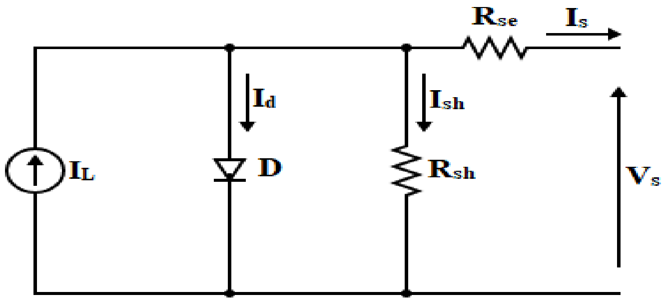


Fig 3: Model of PV Cell

The generated open circuit output voltage of a Solar PV System is given by following equation

$$V_{OC} = V_s = \frac{nkT}{q}\, ln\left(\frac{I_L}{I_o} + 1\right)$$

$$I_{o2} = I_{o1} * 2^{\left(\frac{T_2 - T_1}{10}\right)}$$

Where, n = ideality factor of diode
k = Boltzmann constant (J/K)
T= Temperature (K)
I_L = Light generated current or Photovoltaic current (A)
I_o = Reverse saturation current of diode (A)
q = Charge of electron (Coulombs)
T_2 = Final Temperature (K)
T_1 = Initial Temperature (K)
It can be seen that voltage increases linearly with temperature but the effect of variation reverse saturation current I_o with temperature is more than the linear dependency of voltage on temperature.

So, the effect is decrease in voltage due to increase in temperature and vice versa.
The net output current of a PV system is given as

$$I_S = I_L - I_O\left(exp\left(\frac{q * V_s}{n * k * T}\right) - 1\right) - \frac{V_s + I * R_{se}}{R_{sh}}$$

V_s = PV cell output voltage (V)
I_s = PV Cell output current (A)

MODELLING OF BIFACIAL PV MODULE

The equivalent circuit of a bifacial cell in Fig.4 shows the total bifacial cell current I as the combination of currents from the front side and rear side. By applying KCL, the equation for total current can be written as: $I = I_f + I_r$

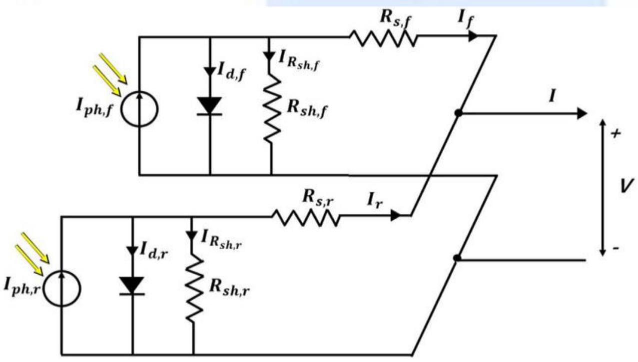


Fig 4: Bifacial PV model

$$I[A] = |Iph - I_0\,[exp\,((V{+}IRs)/\,nVT) - 1]\,|\,Front \rightarrow + |Iph - I_0\,[exp\,(V{+}IRs)/\,nVT) - 1]\,|\,Rear \leftarrow$$

The modeling of the bifacial cell can be done by using the conventional solar cell model while modeling the current equation of the bifacial cell, the equation stands true when two conventional cells are connected in parallel, using different irradiance values for each cell and standard temperature value
(298K), one cell represents the front face of the bifacial cell and the other represents the rear side of the cell.

V. MPPT (MAXIMUM POWER POINT TRACKING) TECHNIQUE OF PV:

The MPPT control is used to maximize the operating power of a variable source system. Three methods—changing impedance, observing power output, and setting the ratio of maximum voltage and open-circuit voltage can be used to track the maximum power point. By injecting a small current signal into the module bus, load impedance can be modified to a value equal to the source impedance.

The second method is used in many hill-climbing MPPT algorithms. At the maximum operating power point, the slope of the PV curve is zero. The power is monitored and the voltage is changed until the slope dP/dV is zero. If the slope is positive the voltage is increased and if the slope is negative the voltage is decreased. The voltage is left unaltered once the slope is zero.

In the third method, the operating voltage is set to k times the open-circuit voltage, where k is 0.2 for the silicon cell and is defined as the proportion of maximum voltage and open-circuit voltage.

The conventional MPPT algorithm generates an oscillating output to overcome this disadvantage many modifications have been done in the conventional MPPT algorithms. The AI-based MPPT approach has no restrictions in terms of sensing the module's voltage, current, or power.AI based MPPT controllers can handle nonlinearity, imprecise, input, and give minimal oscillations around maximum power point.

Thus, improving the overall response of the photovoltaic system the output of the bifacial module (I, V) is controlled by a DC-DC boost converter power circuit and fuzzy logic-based control circuit to ensure maximum power output.

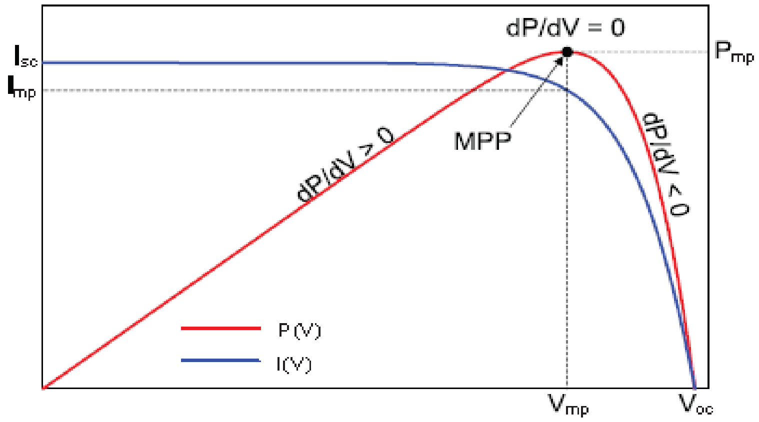


Fig 5: Slope of dp/dv on PV characteristic

VI. FUZZY LOGIC BASED MPPT

Fuzzy Logic controller (FLC) works with fuzzy sets and logical assertions to mimic real-world human-like reasoning difficulties. A fuzzy set, unlike a conventional set, contains all of the set's items with membership values ranging from 0 to 1.

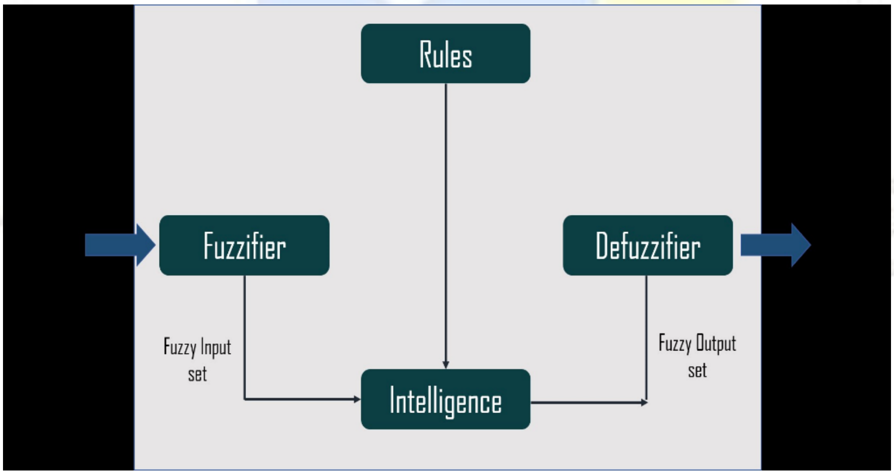


Fig 6: Fuzzy logic architecture

The fundamental concept of the fuzzy logic system is shown in Fig.6. The fuzzy logic system is first configured with PV input current and voltage values, then member functions and fuzzy rules are set up, and finally, the output is calculated.

During the first step of fuzzification, crisp sets of membership functions are used to turn the input parameters into linguistic variables. The number of member functions used influences the controller's accuracy. Seven fuzzy levels are used namely Positive small, medium, and large are denoted by PS, PM, and PB, respectively. Negative small, medium and big are denoted by NS, NM, and NB, respectively, and, Z (zero). MF is membership function.

The fuzzy levels and membership functions are used to determine the accuracy of the fuzzy-based system. The fuzzy rules are shown in Table1 fuzzy controller has two incoming ports and one outgoing port. The fuzzy rule algorithm joins the fuzzy inputs and outputs. Mamdani's fuzzy inference system is the second stage that creates a control system by using a set of rules to formulate the mapping from a given input to an output.

The last process is defuzzification which produces the required duty ratio output by the centroid method. At this stage, quantifiable values are generated, by converting the fuzzy set values into crisp output. The controller behavior is defined by the set of IF-THEN statements.

MF	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Table 1. fuzzy logic rule

VII. DC- DC BOOST CONVERTER

Boost Converters sometimes, also known as step-up choppers are the type of chopper circuits that provides such an output voltage that is more than the supplied input voltage. In the case of boost converters, the dc-to-dc conversion takes place in a way that the circuit provides a high magnitude of output voltage than the magnitude of the supply input.

It is given the name '**boost**' because the obtained output voltage is higher than the input voltage.

The figure given below is the circuit representation of the boost converter:

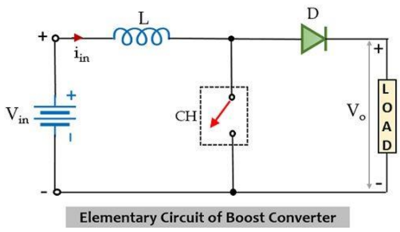


Fig 7: Circuit diagram of Boost converter

The circuit here is an elementary form of step-up chopper which necessarily requires a large inductor L in series connection with the voltage source. The whole circuit arrangement operates in a way that it helps in maintaining a regulated dc signal at the output. Initially, when the chopper CH is in on state, then in the presence of supply dc input current begins to flow through the closed path of the circuit i.e., passing through the inductor as shown in the figure below.

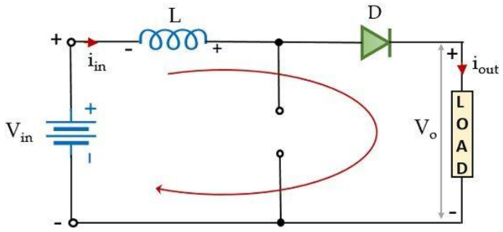


Fig 8: Mode1

Here, the polarity of the inductor will be according to the direction of the flow of current. In this particular case, the diode in the configuration is in reverse biased condition and so current will not be allowed to flow through that particular part of the circuit during on state of the chopper. Resultantly, the voltage across the chopper will appear across the load.

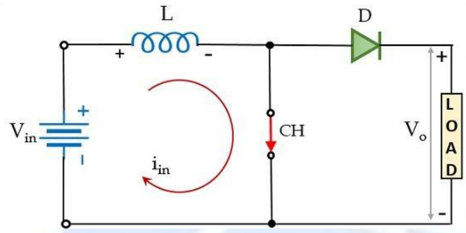


Fig 9: Mode2

Furthermore, at the instant when CH is in the off state, then the part of the circuit through which the current was flowing earlier will not be active in this case. However, as the inductor stores, the energy in the form of a magnetic field and so the current through it will not die out instantly.

Thus, the total voltage across the load will be given as: $V_{out} = V_{in} + V_L$

This means that the output voltage exceeds the applied input voltage. Thus, performs step-up conversion as the energy stored within the inductor during the T_{on} period is released during the T_{off} period.

During the T_{on} period, the voltage across the inductor will be given as: $V_L = L\frac{di}{dt}$

Since we know, $T = T_{on} + T_{off}$, therefore,

$$V_{out} T_{off} = V_{in} T$$

$$V_{out} = V_{in} \frac{T}{T_{off}}$$

$$V_{out} = V_{in} \frac{T}{T - T_{on}}$$

$$V_{out} = V_{in} \frac{1}{\left(\frac{T}{T} - \frac{T_{on}}{T}\right)}$$

- INDUCTOR VALUE $L = \frac{V_{i\eta} * D}{F_S * \Delta \bar{I}_m}$
- DUTY CYCLE $D = \frac{v_0 - v_{in}}{v_0}$
- is the input minimum voltage, D is the duty cycle, Fs is the switching frequency and is the ripple current. The value of the output capacitor can be found using the equation:

  CAPACITOR VALUE $C = \frac{I_0 m * D}{F_S * \Delta v_C}$

VIII. SIMULATION DIAGRAM OF BIFACIAL PV MODULE

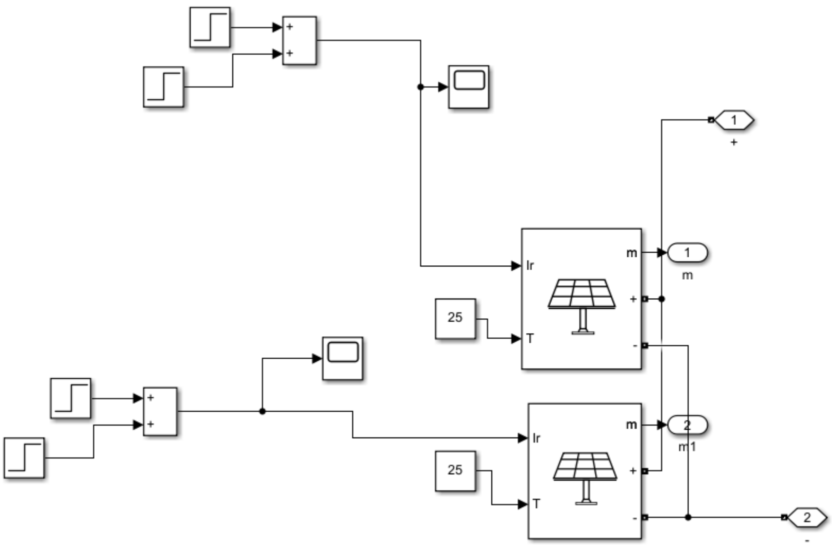


Fig 10: Simulation model of bifacial PV

The proposed bifacial PV module can be simulated in MATLAB _ Simulink by connecting two Monofacial PV module in parallel with each other.

Electrical Parameters	Values
No. of cells	60
Short circuit current	10.4A
Open circuit voltage	49.3V

Table 2. electrical parameters for PV module modelling

IX. . SIMULATION MODEL OF BIFACIAL PV WITH FUZZY LOGIC CONTROLLER AND DC-DC CONVERTER

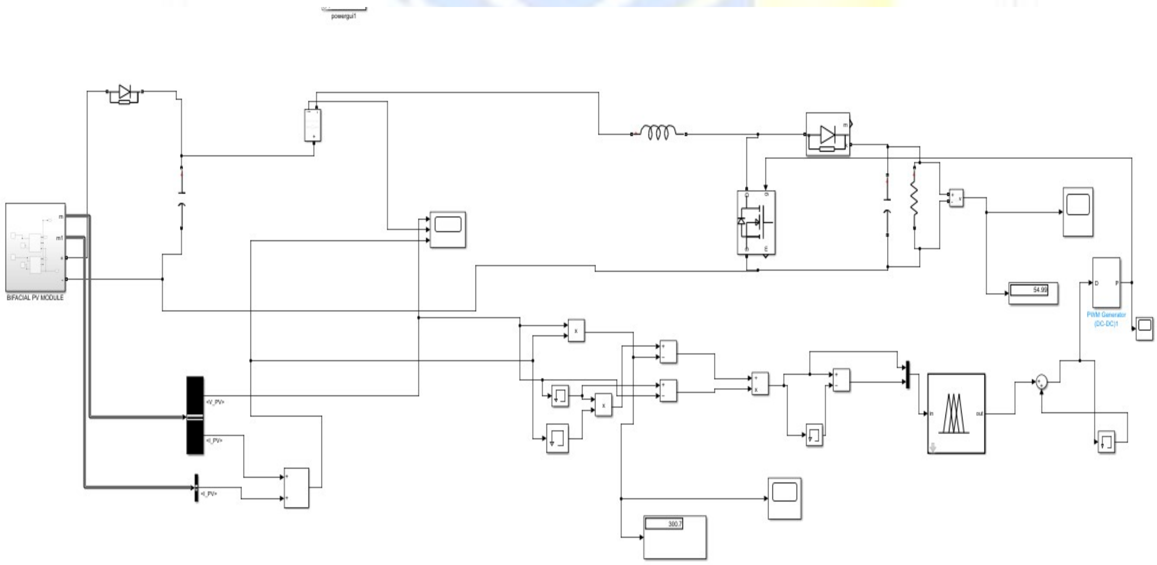


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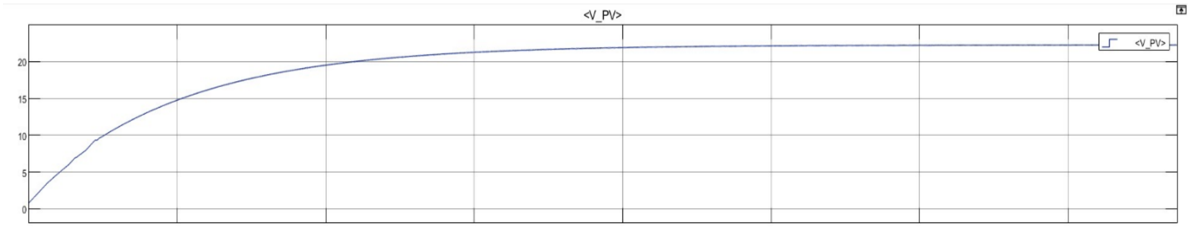
FIG 11: SIMULATION MODEL of proposed project

The output of PV module is connected to DC-DC boost converter to step up the PV voltage. The values of L and C of boost converter is obtained from equation which are given in previous section.

The Fuzzy Logic Controller provide the required duty cycle to the converter so that the PV output power is maximum. Fuzzy logic controller compares previous value of change in slope of PV curve and present value. If the change in slope is positive it will increase the duty cycle value otherwise it will decrease it. If the slope is zero then it will store the previous duty cycle value.

X. . OUTPUT WAVEFORMS

Fig 12: PV voltage



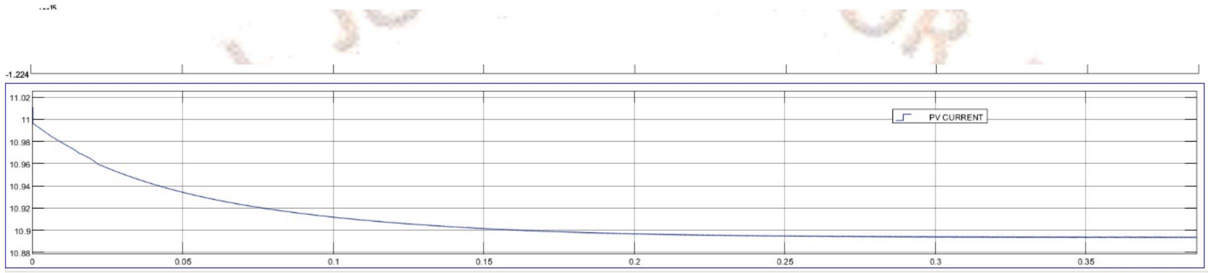


Fig 13: PV current

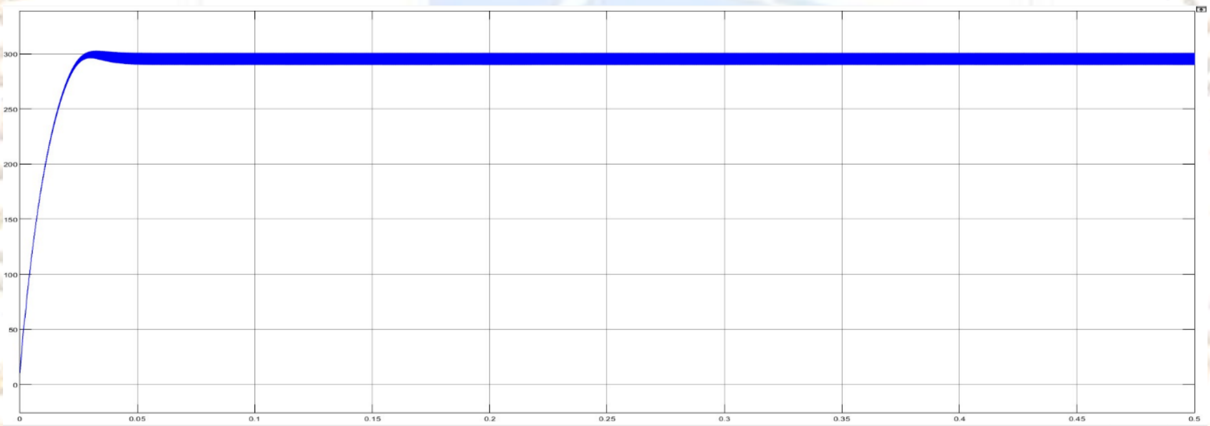


Fig 14: Output voltage

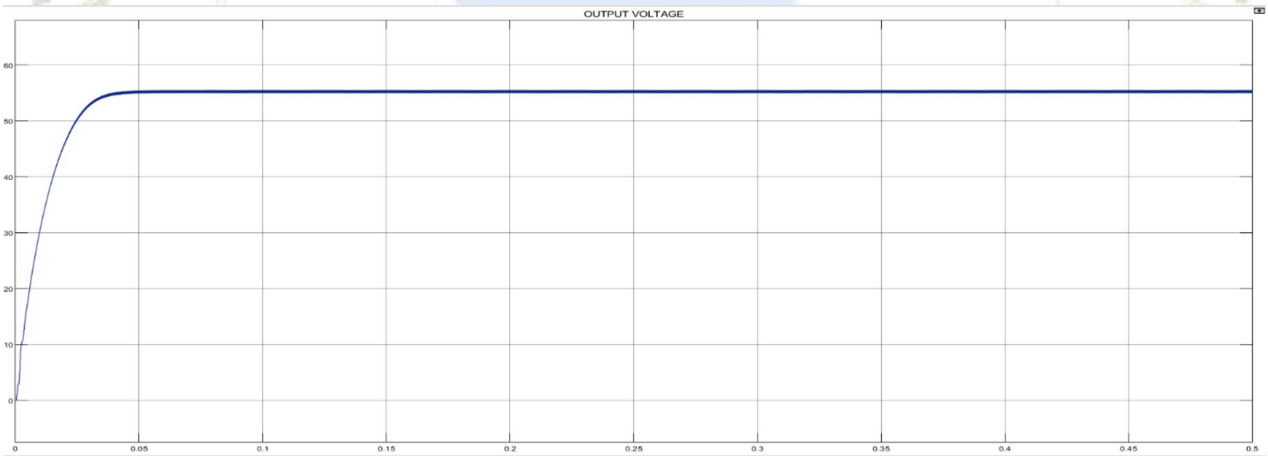


Fig 15: Output power of Bifacial PV module

XI. . SIMULATION MODEL OF MONOFACIAL PV WITH FUZZY LOGIC CONTROLLER AND DC-DC CONVERTER

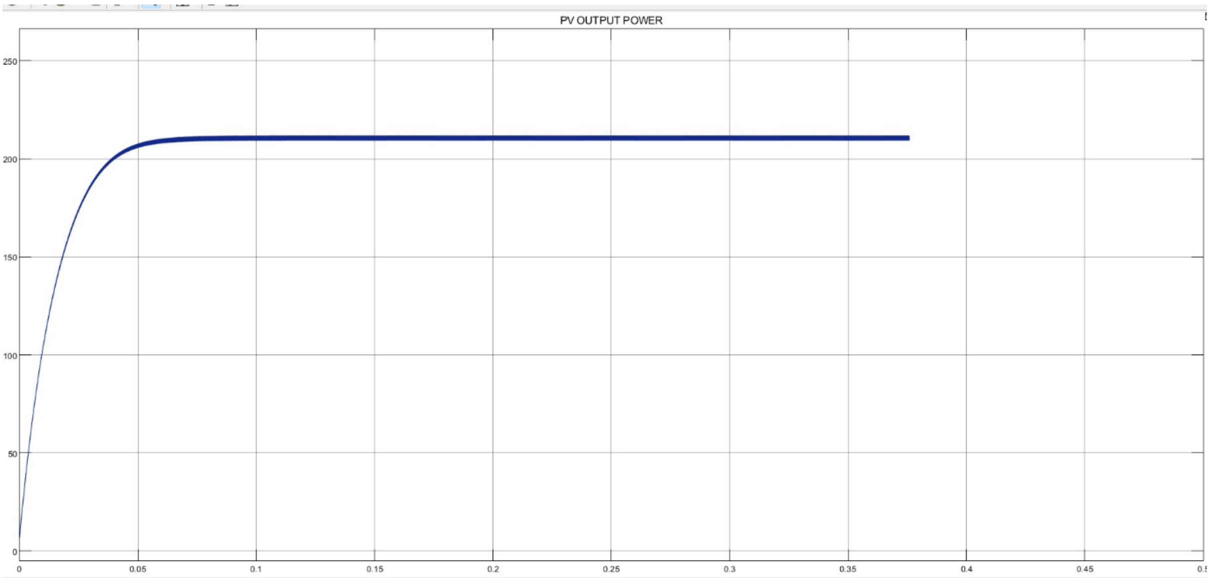
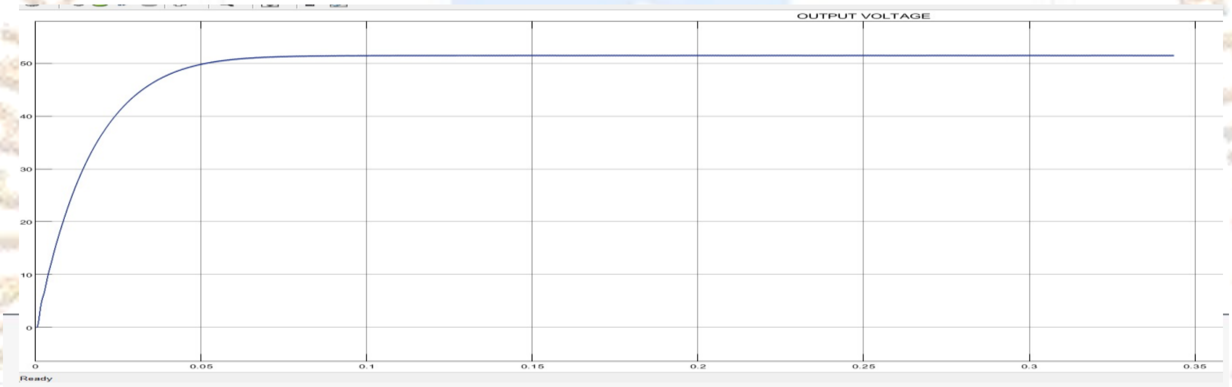


Fig 16: simulation model of monofacial PV

Fig 17: output power of Monofacial PV module



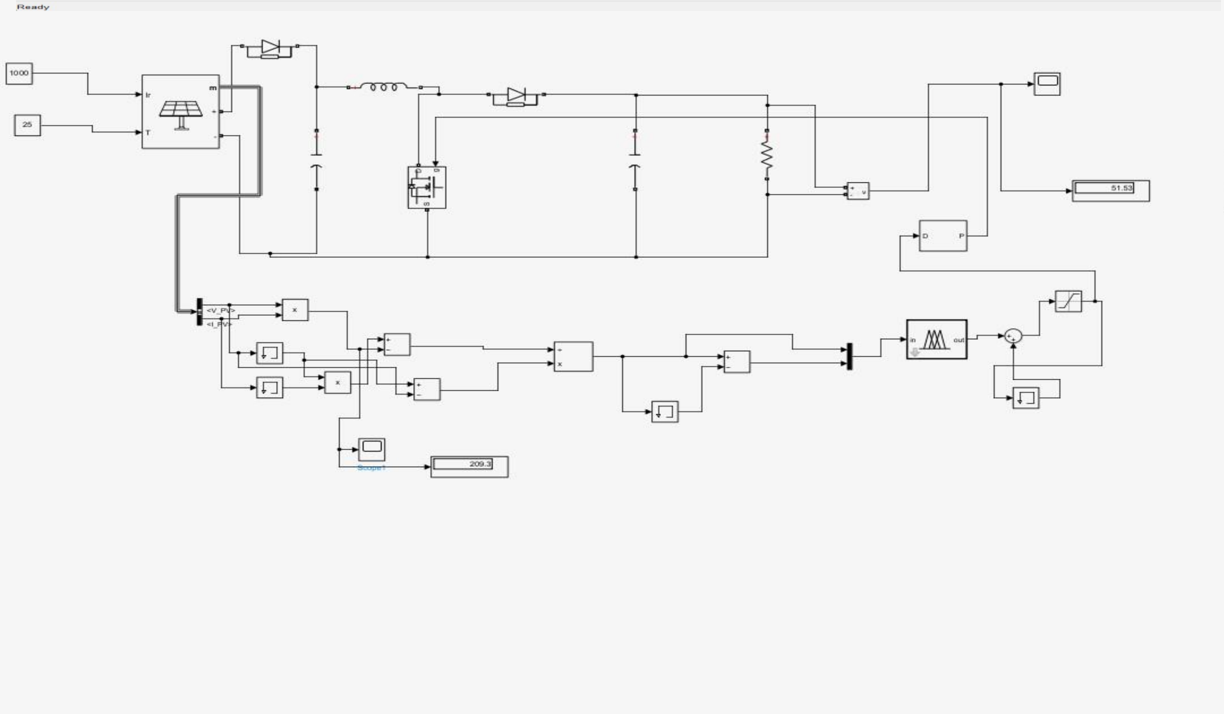


Fig 18: Output voltage

COMPARISON BETWEEN MONOFACIAL AND BIFACIAL PV MODULE

PARAMETER	MONOFACIAL	BIFACIAL
MAXIMUM POWER POINT	211W	300W
VOLTAGE AT MPP	51V	59V
CURRENT AT MPP	7.0A	10.2A
EFFICIENCY	18.8%	26%

Table3. Comparison between monofacial and bifacial PV

XII. CONCLUSIONS

It can be concluded from Table 3 that the performance efficacy of the bifacial module is better than the monofacial module. The bifacial modules utilize the diffused and reflected sunlight falling on the back side of the module. The additional light-absorbing ability of bifacial modules enhances the power yield and efficiency of the solar panels.

By using FLC, it is guaranteed that the maximum power for both monofacial and bifacial modules is tracked under both standard and variable conditions. It is well known that traditional MPPT methods produce fluctuating outputs; in contrast, the FLC approach provides a smoother tracking of the maximum power point and minimizes oscillation-related losses. It is preferable to reduce losses for bifacial modules since there are extra losses caused by the power imbalance between the front and back sides.

XIII. REFERENCES

[1] Senthilkumar, S., et al. "Analysis of single-diode PV model and optimized MPPT model for different environmental conditions." International Transactions on Electrical Energy Systems 2022 (2022).

[2] A. J. Alrubaie, A. Al-Khaykan, R. Q. Malik, S. H. Talib, M. I. Mousa and A. M. Kadhim, "Review on MPPT Techniques in Solar System," 2022 8th International Engineering Conference on Sustainable Technology and Development (IEC), 2022

[3] S. A. Raj and G. G. Samuel, "Survey of AI based MPPT algorithms in PV systems," 2022 4th International Conference on Smart Systems and Inventive Technology (ICSSIT), 2022, pp. 597-604, doi: 10.1109/ICSSIT53264.2022.9716521.

[4] Raina, Gautam, Rohit Vijay, and Sunanda Sinha. "Study on the optimum orientation of bifacial photovoltaic module." International Journal of Energy Research 46.4 (2022): 4247-4266.

[5] Kumar, Jaldeep, Bhuvnesh Rathor, and Prakash Bahrani. "Fuzzy and P&O MPPT techniques for stabilized the efficiency of the solar PV system." 2018 International Conference on Computing, Power and Communication Technologies (GUCON). IEEE, 2018.).