Design and Simulation of Fuzzy Logic Controller forMaximum Power Point Tracking in Solar PV System

Sonawane Madhuri S.*, Dharaskar Vedika R., Jadhav Rashmi H., Wagh Priyanka Y.
Electrical Department, K. K. Wagh Institute of Engineering Education and Research, Nashik, Maharashtra, India
****Corresponding Author***
E-Mail Id: madhurisonawane3033@gmail.com

ABSTRACT

This project proposes a microcontroller- based control method for the maximum power point tracking (MPPT) of a photovoltaic (PV) system under variable temperature and insolation conditions. Fuzzy Logic algorithm is implemented to improve the performance and to reduce the tracking time. To maximize efficiency, PV systems use a MPPT to constantly extract the highest power that can be produced by a solar panel and then deliver it to load. MPPT finds and maintains operations at the maximum power point (MPP) using a tracking algorithm during various weather conditions. Fuzzy logic controllers are preferred to tolerate the nonlinear behaviour of PV module. The study system includes a PV array, a PWM controlled DC-DC converter and sensor circuits. The designed controller regulates the converter output voltage by varying duty cycle of the PWM signal using MPP algorithm and it maximizes the output power extracted from PV array.

Keywords: *Fuzzy logic, maximum power point tracking, microcontroller, photovoltaic*

INTRODUCTION

Energy demands are increasing day by day as well as upcoming shortage of fossil fuels, dependency on the other countries for primary energy is an alarming situation. So, a step forward is a must for sustainable development. Renewable energy is the key source and most promising. This paper deals with PV systems.

It is important to track MPP (Maximum Power Point) for optimize use of energy. The maximum power of a PV module varies due to changing temperature, solar radiation, and load. Hence a MPPT algorithm along with Fuzzy logic is introduced to continuously extract maximum power from PV module. Installation cost is more. Running and maintenance cost is low.

Figure 1 shows Maximum power varying with different cell temperature at the same insolation and Figure 2 shows Maximum power varying with different insolation at the same temperature. The main objective is to achieve the peak that is the MPP (Maximum Power Point) also known as operating point.

To achieve MPP fuzzy logic algorithm is implemented and a microcontroller-based control method for the maximum power point tracking (MPPT) of a photovoltaic system under changing insolation conditions, sun irradiation, temperature, angle of inclination of solar panel and partial shading on the panel [1].

For the reduction of tracking time, fuzzy logic control algorithm is implemented with the embedded microcontroller for improved performance as compared to conventional techniques in power efficiency and swift maximum power point tracking. The system includes a photovoltaic array, a PWM controlled DC to DC converter and sensor circuit [2].

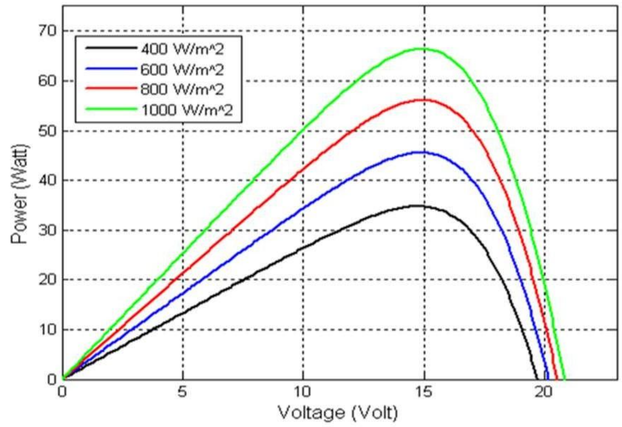

Fig. 1: *Maximum power varies with different cell temperature at the same insolation [1]*

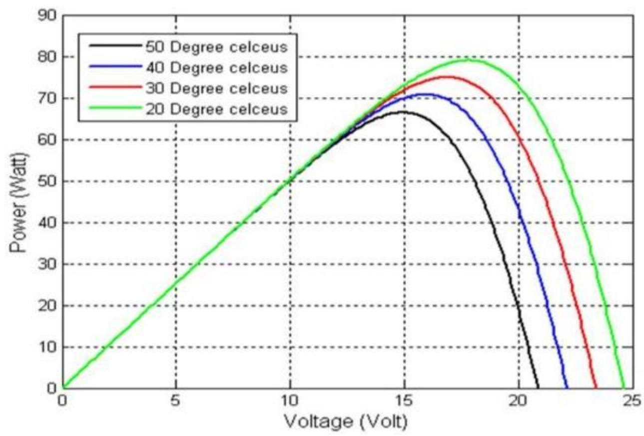

Fig. 2: *Maximum power varies with differentisolation at the same temperature [1]*

The system is designed and analyzed on MATLAB software as it is a better platform to study fuzzy logic algorithm, The Fuzzy toolbox which is readily available in MATLAB can be used to plot the input and output membership functions (MF) depicted in Figure 8. The fuzzy rules are also presented, can alsobe written using the same toolbox. The designed controller regulates the converter output voltage by varying duty cycle of the PWM signal using maximum power point (MPP) algorithm and it maximizes the output power extracted from photovoltaic array, we observed that the implementation of the fuzzy logic algorithm in a microcontroller is capable of rapidly locking into the MPP for a photovoltaic panel under variable temperature and insolation conditions [3].

The system includes a photovoltaic array, the generation rate of the solar panel is low and can be improved with the help of MPPT techniques. When sunlight falls on the PV panel, the output from solar panel is measured by the voltage and current measuring devices. These output values are then sent to the fuzzy based MPPT block, here all the processing takes place. [4] Then a PWM controlled DC-DC converter, the system is analyzed with a boost converter to step up the voltage level and achieve optimum voltage, So, a MPPT controller with a DC- DC converter is connected between the source and the load as shown, in general, the conversion efficiency of dc-to-dc converter is reading 90% Fuzzy based MPPT block compares the present and past values from the solar panel with the help of algorithm written.

Comparing the values, it sends a signal to the DC-DC converter block depending on the output received from the panel. Based on the signal received from the fuzzy controller the DC-DC converter boosts the value of the output to meet the preset values. Thus, trying to maintain the output to meet the required standards of the load/storage device [5] and sensor circuits.

Fuzzy Logic algorithm and its flowchart is prepared to get maximum output power. Fuzzy logic algorithm helps to solve a problem after considering all available data. Then it takes the best possible decision for the given the input. The concept of maximum power point tracking proves its worth in these cases. A controller that can be dedicated to this function, so that the maximum available power from the panel can be drawn, there by maximizing the utilization factor of the system. It is clear that the peak power point for different irradiations corresponds to different voltages levels [1,6]. The system is designed according to algorithm and all the required blocks are studied [7].

It is analysed that Fuzzy logic method is the most accurate, most efficient and flexible method rather than Perturbation and observation (P&O) methods, Incremental Conductance (IC) methods, a controller using fuzzy logic has been used widely on the last decade since fuzzy logic can handle the problem of not precision input, does not require an accurate mathematical modeling and able to handle nonlinearity.

The results for the Fuzzy Logic Controller are compared with that for the other techniques like Perturb & Observe and Incremental Conductance, and suitable conclusions are made on factors like PV array dependence, Oscillations at the maximum power point, Algorithm complexity and Convergence speed [8]. The basic concept of MPPT is thoroughly studied and a system is designed. The results show that the proposed MPPT is able to detect and reach the MPP in a short time accurately under both slow and fast changes in irradiance. [9].

SYSTEM DESCRIPTION
MPPT

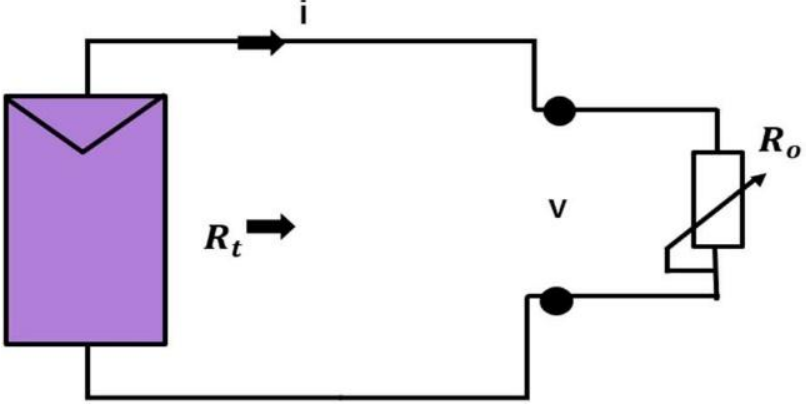

Fig. 3: *Schematic diagram [10]*

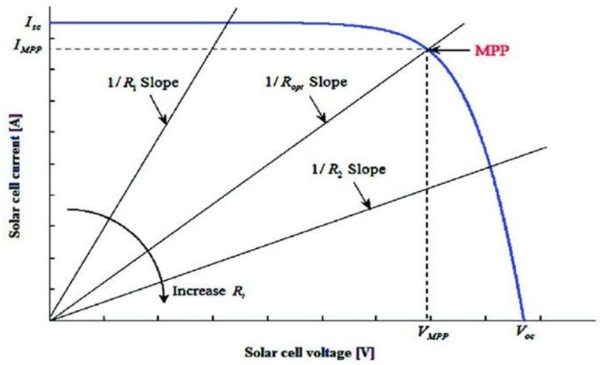

Fig. 4: *V-I characteristics [10]*

The Figure 3 show the schematic diagram in which solar panel is connected to the load R0 which is variable. Current 'i' is the output current from PV module and 'v' is the voltage obtained. Rt is the resistance viewed from PV module side.

It is not advisable to connect the terminals of panel to load as maximum power may not be extracted, a power interface is a must to extract maximum power. The Figure 4 shows the V-I characteristics of the Figure 3.

The load line is plotted on the V-I characteristics. It isobserved from Fig.4

$V_{MPP}\ X\ I_{MPP} = P_{max}$ …… (1)

As the load is not constant and is continuously varying, the slope of load line is not constant. The equation (2.1) indicates the formula to calculate the Pmax.

Case-1: If R_t increases as a result R_0 increases, slope decreases and load line is shifted to right.

Case-2: If R_t decreases as a result R_0 decreases, slope increases and load line is shifted to left.

In both the above cases maximum power is not drawn. Maximum power drawn is only when $R_t = R_0$. To satisfy this condition, a power interface is to be introduced so that R_t is always at operating point whatever may be the value of R_0.

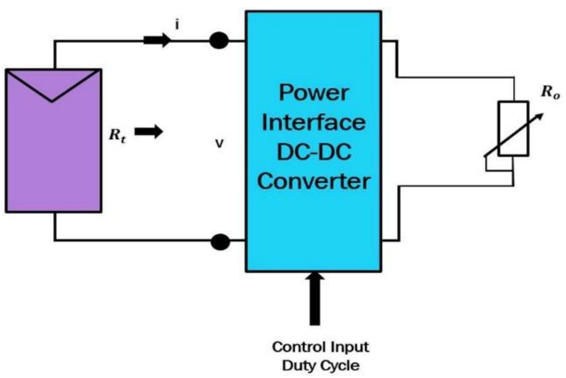

Fig. 5: *Power Interface [10]*

The Fig.5 shows the power interface needed to achieve MPPT and satisfy the condition:
$R_t = R_0$Duty cycle is the control input. Control input will change as the value of R_0 change, and R_t will remain constant.

Fuzzy Logic
The term fuzzy refers to things which are not clear or are vague. Fuzzy logic is used when we can't determine the state is true or false, as in Boolean Logic. Boolean Logic refers to either true or false. But Fuzzy logic refers to less, little, much. The membership function helps determine the degree of the state. The value of membership function is between 0 to 1.

Fig. 6: *Implementation of Fuzzy logic [3]*

The Figure 6 shows the Implementation of Fuzzy logic in which the first step is fuzzification followed by decision making and then defuzzification. An algorithm will be designed in order to vary duty cycle and according to its output will be obtained.

Variation in lighting intensity causes these trackers to deviate from the maximum power point when lighting conditions change, the tracker needs to response within a short time to the change to avoid energy loss. Therefore, it is not easy to track the maximum power point of the PV cell quickly and effectively in the real application.

To overcome this drawback, many MPPT algorithms were suggested for tracking the MPP of solar module. As shown in Figure 5, based on the use of conventional DC-DC converter, where combination of voltage and power feedback control system is implemented with the use of artificial intelligence algorithm which results in a two-dimensional tracking strategy that makes tracking response faster and maximizes the power extracted from the solar module and the power delivered to the load. Maximum power point tracking is assured by varying duty cycle of the PWM signal to control MOSFET switch applied to a boost converter.

The control logic is implemented to a microcontroller with the use of fuzzy logic algorithm. Designing a conventional controller presents problems since modelling the system is very difficult due to its non- linearity. For controlling such a complicated system, fuzzy logic control can be the best solution. However, fuzzy technique, which has gained popularity in recent years, looks very promising for this application.

The use of fuzzy logic in gate signals control in MPPT is tackled, analyzed, and implemented in this paper where MATLAB/SIMULINK simulation and experimental results are described.

MPPT Tracking
Power is differentiated with respect to voltage and equated to zero to achieve MPP.

$$\frac{dP}{dV} = \frac{P(n)-P(n-1)}{V(n)-V(n-1)} \ldots\ldots (2)$$

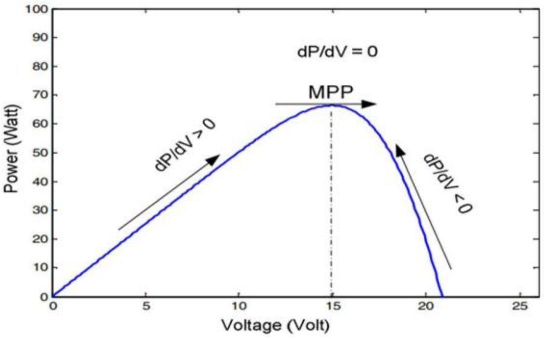

Fig. 7: *Optimum Point Tracking [1]*

Case-1: When $\frac{dP}{dV}$ = 0 operation point (MPP) is achieved.

Case-2: When $\frac{dP}{dV}$ > 0, operation point is on the left
Case-3: When $\frac{dP}{dV}$ < 0, operation point is on the right

ALGORITHM AND FLOWCHART

Table 1: *Algorithm [1].*

ΔVpv*[o/p]	ΔVpv[i/p]					
		NB	NS	ZE	PS	PB
	NB	PS	PB	NB	NB	NS
	NS	PS	PS	NS	NS	NS
ΔPpv[i/p]	ZE	ZE	ZE	ZE	ZE	ZE
	PS	NS	NS	PS	PS	PS
	PB	NS	NB	PB	PB	PS

ΔPpv[i/p] denotes Input-1, ΔVpv[i/p] denotes Input-2
ΔVpv*[o/p] denotes outputMembership function:
NB- Negative Big, NS- Negative SmallZE- Zero, PS- Positive Small
PB- Positive Big

Rules

1. If ΔPpv is NB and ΔVpv is NB then ΔVpv* is PS.
2. If ΔPpv is NB and ΔVpv is NS then ΔVpv* is PB.
3. If ΔPpv is NB and ΔVpv is ZE then ΔVpv* is NB.

4. If ΔPpv is NB and ΔVpv is PS then ΔVpv* is NB.
5. If ΔPpv is NB and ΔVpv is PB then ΔVpv* is NS.
6. If ΔPpv is NS and ΔVpv is NB then ΔVpv* is PS.
7. If ΔPpv is NS and ΔVpv is NS then ΔVpv* is PS.
8. If ΔPpv is NS and ΔVpv is ZE then ΔVpv* is NS.
9. If ΔPpv is NS and ΔVpv is PS then ΔVpv* is NS.
10. If ΔPpv is NS and ΔVpv is PB then ΔVpv* is NS.
11. If ΔPpv is ZE and ΔVpv is NB then ΔVpv* is ZE.
12. If ΔPpv is ZE and ΔVpv is NS then ΔVpv* is ZE.
13. If ΔPpv is ZE and ΔVpv is ZE then ΔVpv* is ZE.
14. If ΔPpv is ZE and ΔVpv is PS then ΔVpv* is ZE.
15. If ΔPpv is ZE and ΔVpv is PB then ΔVpv* is ZE.
16. If ΔPpv is PS and ΔVpv is NB then ΔVpv* is NS.
17. If ΔPpv is PS and ΔVpv is NS then ΔVpv* is NS.
18. If ΔPpv is PS and ΔVpv is ZE then ΔVpv* is PS.
19. If ΔPpv is PS and ΔVpv is PS then ΔVpv* is PS.
20. If ΔPpv is PS and ΔVpv is PB then ΔVpv* is PS.
21. If ΔPpv is PB and ΔVpv is NB then ΔVpv* is NS.
22. If ΔPpv is PB and ΔVpv is NS then ΔVpv* is NB.
23. If ΔPpv is PB and ΔVpv is ZE then ΔVpv* is PB.
24. If ΔPpv is PB and ΔVpv is PS then ΔVpv* is PB.
25. If ΔPpv is PB and ΔVpv is PB then ΔVpv* is PS.

Above 25 rules are to be set in MATLAB Simulinkfor the working of algorithm.

The fuzzification of inputs will take place and according to the rules decision will be taken by thesystem followed by the output.

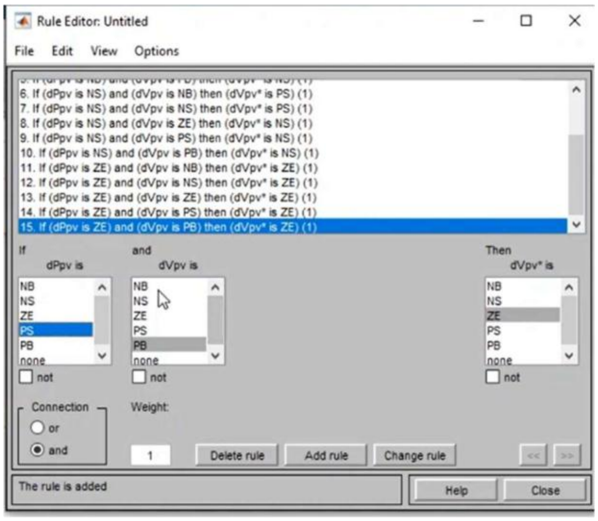

Fig. 8: *Rule Editor-MATLAB*

Figure 8 shows the Rule Editor toolbox available

MATLAB Simulink Library. The inputs and outputs are defined as given in the algorithm above. Rule base is defined so that the fuzzy controller takes the appropriate decision. The inputs and outputs are in the form of Membership functions those are NB, NS,ZE, PS, PB.

Following is the flowchart followed by the system to change the duty cycle of the system according to the reference and feedback and error.

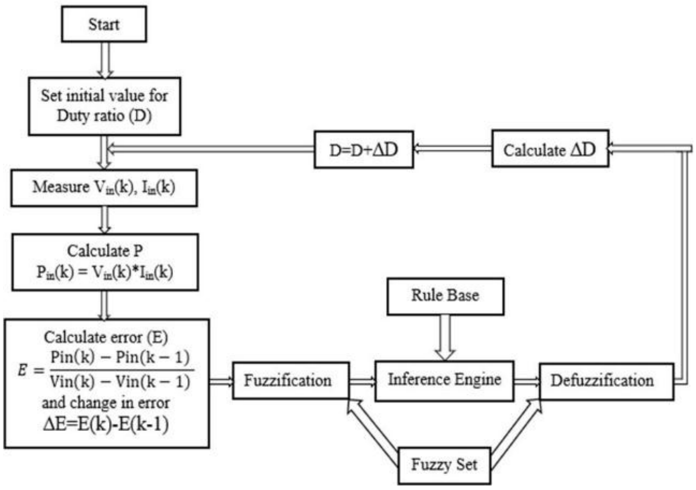

Fig. 9: *Detailed Flowchart [1]*

The Figure 9 shows the flowchart and the working of system along with the algorithm.

Step 1: Start the system. Assume the PV- module is delivering power at any point of working.

Step 2: Initialize the value of duty ratio (D). In the begin let it be equal to zero. Duty cycle is the controlling parameter and will be responsible for change in required output.

Step 3: Calculate the Power (P) which is initially obtained after starting the system. To calculate Power, following formula is used, assume DC system.

$P_{in}(k) = V_{in}(k)*I_{in}(k)$ ....(3)

Where $P_{in}(k)$ is Input power
$V_{in}(k)$ is Input voltage to system
$I_{in}(k)$ is Input current.

Step 4: The next step is to calculate Error (E), Error is the difference between present state(k) and the previous state(k-1) in discrete domain. Error is
Calculated by:

$$E = \frac{\mathrm{Pin(k)-Pin(k-1)}}{\mathrm{Vin(k)-Vin(k-1)}} \ldots\ldots (4)$$

Also calculate ΔE (change in error),

$\Delta E=E(k)-E(k-1)$ ………..(5)

Step 5: This error signal is given to the controller where the fuzzy logic is been embedded.

Fuzzification of the error signal is done and broken down into membership functions. The Inference Engine is the decision-making block. Decision is made according to the algorithm those are the rules embedded in the Rule base. After deciding the output membership function according to the input, defuzzification takes place and final output is calculated.

Step 6: Finally, ΔD is calculated that is the difference between previous and present value, to know the change in duty ratio and then new Duty ratio is calculated by D= D + ΔD and output is updated. If the duty cycle is not according to the desired value the process is repeated.

IMPLEMENTATION AND TESTING

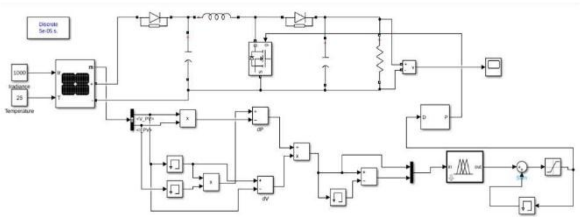

Fig. 10: *Simulink.*

Fig.10 shows the simulation of study system. The working is as follows: The Solar Irradiation is obtained on the panel, then the light energy is converted to the electrical energy by the cells. A boost converter is used ahead to step up the voltage. The duty cycle is the varying parameter. By controlling duty cycle VMPP at the output is received, measured by the voltage measurement block. At the initial point, product of voltage and current is needed from the PV-Module, hence by using the product block Power is calculated. Further memory elements are needed to hold the previous value. Previous values are needed to calculate the error so as to obtain required output.

By using subtract block the instantaneous value and previous value of power and voltage is obtained, that is dP and dV are calculated. Further by using division and multiplication block, error (E) is calculated as stated the flowchart.

$$E = \frac{Pin(k) - Pin(k-1)}{Vin(k) - Vin(k-1)} \ldots\ldots (4)$$

These blocks are further connected to fuzzy logic controller so as to implement algorithm. The process will be as follows:

Fuzzification, Decision making and later Defuzzification.

Then further it is connected to saturation block to limit the output from -1 to +1 as the system is designed for fuzzy logic controller. The output of saturation block is given to PWM generator to obtain desired duty cycle.

The Simulink model is tested for the following cases:
Case-1 Constant temperature, variable irradiation Case-2 Constant irradiation, variable temperature Case-3 Random

inputs

Case-1 Constant temperature, variable irradiation:

In this case the model is tested when the temperature is kept constant and the irradiation is changed. It is observed that the VMPP is achieved even if there is change in irradiation. Hence the main motive is achieved.

Table 2: *Observation at Constant temperature, variable irradiation.*

Srno.	Temperature(°C)	Irradiation (W/m^2)
1	25	400
2	25	600
3	25	800

Here observations are obtained for three different irradiations those are 400 W/m^2, 600 W/m^2, 800 W/m2 keeping the temperature constant at 25° C. Same graph is obtained for all the three inputs from the table. The output of the model is given below:

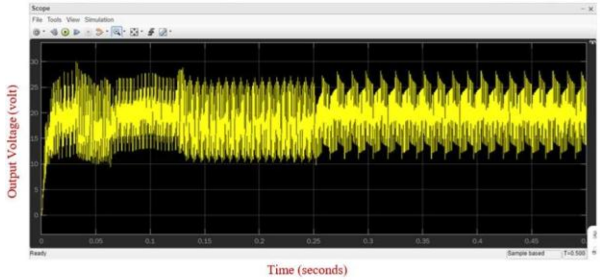

Fig. 11: *Output Voltage at 25°C and 400 W/m^2*

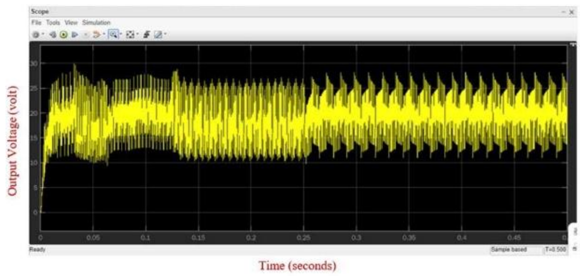

Fig. 12: *Output Voltage at 25°C and 600 W/m^2.*

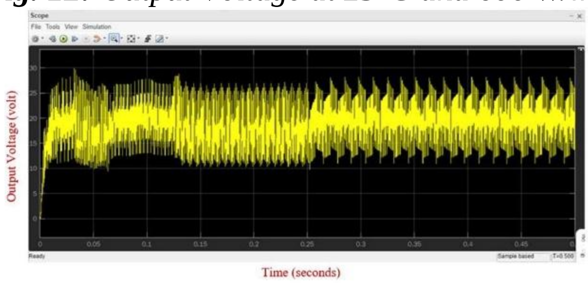

Fig. 13: *Output Voltage at 25°C and 800 W/m^2.*

Case-2 Constant irradiation, variable temperature:

In this case the model is tested when the irradiation is kept constant and the temperature is changed. It is observed that the VMPP is achieved even if there is change in temperature. Hence the main motive is achieved.

Table 3: *Observation at Constant irradiation, variable temperature.*

Srno.	Temperature(℃)	Irradiation (W/m^2)
1	25	800
2	27	800
3	29	800

Here observations are obtained for three different temperatures those are 25°C, 27°C and 29°C keeping the irradiation constant at 800 W/m^2. Same graph is obtained for all the three inputs from the table. The output of model is given below:

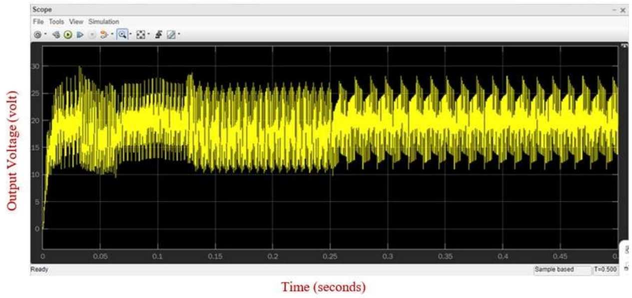

Fig. 14: *Output Voltage at 25°C and 800 W/m^2.*

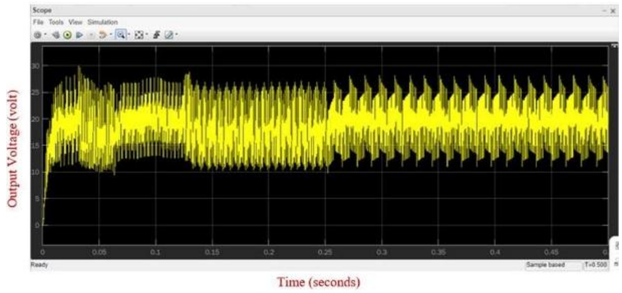

Fig. 15: *Output Voltage at 27°C and 800 W/m^2.*

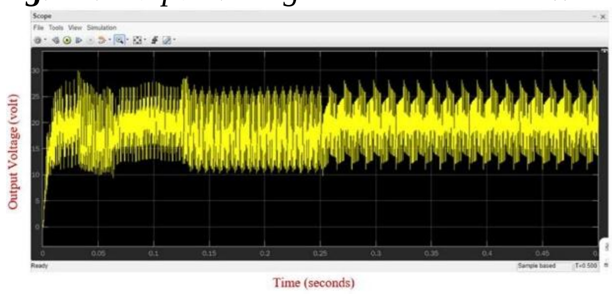

Fig. 16: *Output Voltage at 29 °C and 800 W/m^2.*

Case-3 Random inputs:
In this case random inputs are taken as shown in the below table. Temperature is varied from 30° C to 50° C for rigorous testing. Whereas the irradiation is varied from 600 W/m^2 to 1000 W/m^2. It is observed that the VMPP is achieved even if there is change in temperature. Hence the main motive is achieved.

Same graph is obtained for all the six inputs from the table. The output the model is given below:

Table 4: *Random inputs.*

Srno.	Temperature(℃)	Irradiation (W/m^2)
1	30	600
2	30	600
3	40	800
4	40	800
5	50	1000
6	50	1000

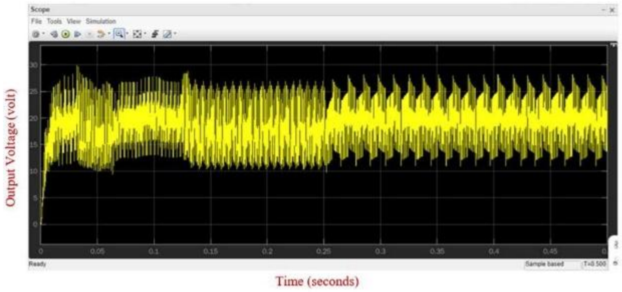

Fig. 17: *Output Voltage at Random inputs.*

CONCLUSION

The work carried out in the report can be summarized briefly as follows. The theoretical base of MPPT and Fuzzy system is critically studied. According to the algorithm flowchart is designed. Mathematical Modeling and system parameters have been designed as per the required output. Simulink of the system is performed on MATLAB. Fuzzy rules have been defined by studying the algorithm. Special care of input and output is taken so as there is no mislead to Fuzzy controller.

The fuzzy controller can manage to work with non-linearity in the system. Even if rough data is available, it can compute the output. It does not require the exact values. Hence by using a power interface along with controlling parameter (duty cycle) maximum power can be achieved. Fuzzy Logic is a technique derived from artificial Intelligence which helps reducing the tracking time and handle non-linearity. It is observed that the output that is the graph and VMPP does not change at any of the cases discusses above.

REFERENCES

1. Khan, S. A., & Hossain, M. I. (2010, December). Design and implementation of microcontroller based fuzzy logic control for maximum power point tracking of a photovoltaic system. In *International Conference on Electrical & Computer Engineering (ICECE 2010)* (pp. 322-325). IEEE.
2. Prasad, C. B., Sonam, S. K., Reddy, B. R. G., & Harika, P. (2017, June). A fuzzy logic based MPPT method for solar power generation. In *2017 International Conference on Intelligent Computing and Control Systems (ICICCS)* (pp. 1182-1186). IEEE.
3. Raj, M. P., & Joshua, A. M. (2017, September). Design, implementation and performance analysis of a LabVIEW based fuzzy logic MPPT controller for stand-alone PV systems. *In 2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI)* (pp. 1012-1017). IEEE.
4. Canny, D., & Yusivar, F. (2018, August). Maximum power point

tracking (MPPT) algorithm simulation based on fuzzy logic controller on solar cell with boost converter. In *2018 2nd International Conference on Smart Grid and Smart Cities (ICSGSC)* (pp. 117-121). IEEE.

5. Corcau, J. I., & Dinca, L. (2019, September). Modeling and analysis of a fuzzy type MPPT algorithm. In *2019 International Conference on Electrical Drives & Power Electronics (EDPE)* (pp. 230-234). IEEE.
6. Roshan, A., Dwivedi, P., & Kumar, H. (2019, August). Fuzzy Based MPPT and Energy Management Strategy. In *2019 IEEE 10th Control and System Graduate Research Colloquium (ICSGRC)* (pp. 14-19). IEEE.
7. Hayder, W., Abid, A., Hamed, M. B., & Sbita, L. (2020, July). Intelligenit MPPT algorithm for PV system based on fuzzy logic. In *2020 17th International Multi-Conference on Systems, Signals & Devices (SSD)* (pp. 239-243). IEEE.
8. Dabboussi, M., Hmidet, A., & Boubaker, O. (2020). An efficient fuzzy logic MPPT control approach for solar PV system: A comparative analysis with the conventional perturb and observe technique. In *2020 6th IEEE International Energy Conference (ENERGYCon)* (pp. 366-371). IEEE.
9. MATLAB/ SIMULINK, 2021. *(Software)*
10. NPTEL Lectures. *(Online Videos)*