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Solar PV System Based on Fuzzy Logic MPPT Algorithm

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Abstract**—**This paper talks about the MPPT controller based on FLC, which is used to get as much energy from the sun as possible from a solar PV module. The goal of this paper on an MPPT-based fuzzy-logic controller (MPPT-FLC) is to find good reference current and voltage values. MPPT-FLC compares the switching frequency values to the real the PV system's current and voltage in order to control them. The switching frequency value is used to change the angle of the ignition switch on the Step-up converter (MOSFET gate). The switching frequency of the switch device tells the step-up converter how much to boost-up the output voltage. The proposed controllers change its switching frequency of the Step-up converter switches to keep trace of the optimum power of a solar photovoltaic (PV) array.

Keywords*— photo-voltaic system, MPPT, Step-up converter, Fuzzy-logic controller.*

1.INTRODUCTION

As a result of industrialization and population increase, the world's demand for energy is expanding tremendously. It is essential to note that emerging countries have significantly contributed to the two billion-person population surge in just one generation. Avoiding energy shortage is among the most common problems of the twenty-first century. As a result, energy demand is rapidly rising to fulfill global population growth needs Different nations around the world utilize their approaches, methods, regulations, and control mechanisms to make a name for themselves. The globe's resources are near to finish as a result of population growth and modernization ambitions [1]. It is necessary to consider energy sources because they are essential to meeting the needs of the globe's population. Numerous factors, including the nature of the country's technological advancement and its development profile, contribute to the insufficiency of energy availability. Ecosystems are badly affected by emission of hazards gases from the combustion of non-renewable energy source that are readily available and regularly exploited to supply the global energy demand[2]. Due to their high growth of population and efforts to achieve economically and ecologically sustainable development, developing countries are under pressure to seek out energy sources [3]. Since energy consumption is inversely correlated with economic growth, it increases with economic growth. Despite the fact that numerous strategies for increasing energy production capacity have been given, a lot of people still reside in without electricity regions of emerging nations. Using non-heritable energy sources, which are a finite and exhaustible source of energy, would not totally satisfy energy demand. Each nation should be able to use its resources to create an environment conducive to the long-term existence of humans. Because various countries rely more heavily on nonrenewable energy than on renewable power sources, it isn't now standard practice to carry out such responsibilities. It is a well-known fact that there are multiple controversial issues producing significant disasters in various countries as a result of dominant parties vying for access to regions with abundant fossil fuel reserves. In addition, the prolonged use of nonrenewable energy sources could give rise to climate change, it might ultimately result in catastrophic natural disasters that endanger the ecosystem of the world [4]. Carbon molecules produced by the combustion of fossil fuels are damaging to the ozone layer. Carbon compound is toxic to humans and other creatures. The carbon compound damages the ozone layer as a result of increases in the earth's temperature and unexpected changes in the weather, among other things. It is essential to consider renewable resources like as solar-energy, wind-energy, hydro-energy, and geothermal-energy because they are beneficial to the environment. Solar energy, however, maybe the best choice for the futuristic world for several reasons. First, solar-energy is the most available source of renewable-energy[5], releasing $3.8*10^{26}$ W every second, of which the earth absorbs approximately $1.8*10^{17}$ W [6]. Heat and light are two ways that solar energy reaches the planet. The majority of this energy is lost owing to dispersion, reflections or absorbing by clouds as it moves. Solar energy is a cost-free, abundant, green energy source, pollution-free, clean, noise-free, and naturally occurring source of energy, according to studies [7][8][9][10]. The solar photovoltaic (PV) module transforms solar radiation into

electrical energy. There are numerous types and price ranges of photovoltaic devices. 14-19% [11][12]is the solar energy conversion efficiency of commercially available multicrystalline (Si) solar cells. Voltage and current are applied simultaneously to electricity generated by solar PV modules. Voltage and current produced by the solar photovoltaic (PV) module[13] are reliant on cell temperature and solar irradiance. Maximum power point tracking is a technique for bringing out optimum power from a solar photovoltaic (PV) arrays under all conditions of cell temperature and sun radiation. This study describes a technique for maximizing efficiency of a solar photovoltaic (PV) arrays system using an MPPT algorithm. Fuzzy-logic controller technique on a Step-up converters device. The suggested approach comprises fine-tuning the switching frequency of the step-up converter switch to track peak power and maximize the effectiveness of a solar photovoltaic (PV) array. Intelligent controller techniques based on fuzzy-logic controllers are connected with increased energy conversion efficiency, as explained in this research. The tool of Matlab Simulink is employed to simulate the controller approach.

2. SOLAR PHOTOVOLTAIC SYSTEM

Most modern technology uses solar photovoltaic technology. The two key climatic variables of temperature and sun irradiation determine the characteristics of all PV module. The voltage - current , voltage – power characteristics of PV arrays with a specific temperature of 25°c and five distinct sun irradiations of 1, 0.8, 0.6, 0.4, and 0.2 kW/m^2 are shown in Fig.1. When the irradiance increases, the current across the panel increases considerably but the voltage scarcely changes, increasing the quantity of power produced. When a result, as the sun's irradiation rises, so will the energy generated[14].

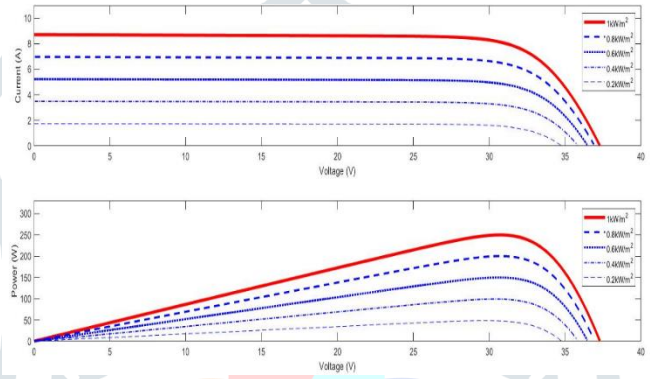

Fig.1:- Photovoltaic array voltage - current and voltage – power characteristics at constant temperature (25°c) and Variable Solar Irradiation

The voltage - current ,voltage – power characteristics of a solar photovoltaic(PV) array with a temperature range of 15°c, 25°c,35°c and 45°c with fixed illumination of 1000 W/m^2 presented in Fig. 2 show that when the voltage drops as the current increases. A minimal fluctuation in temperature in the current decreases the array's power. Thus at extremely high temperatures, the PV array is inefficient and won't produce high energy[15].

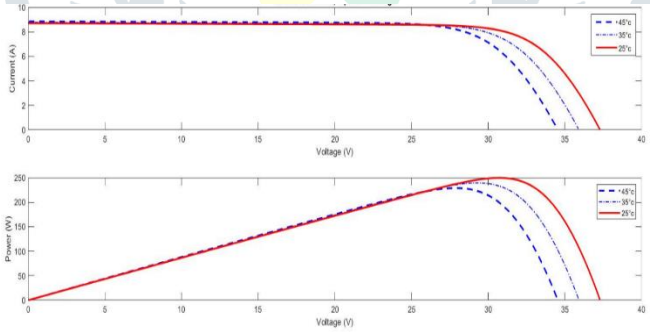

Fig.2:- Photovoltaic array voltage - current and voltage – power characteristics with a constant 1000W/m^2 solar irradiation and variable temperatures

3. MPPT-FLC System

The control method comprises of a solar Photovoltaic (PV) array coupled to a step-up converter, with regulated output voltage. The MPPT-FLC controller modifies the step-up converter input switching frequency of the switch to collect the optimum quantity of power from the solar photovoltaic (PV) array[16].

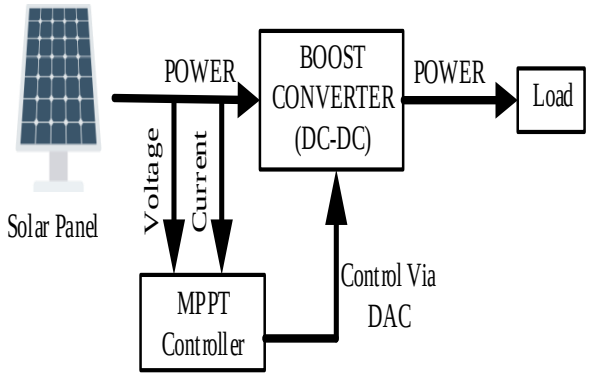

Fig.3:-Block Diagram of MPPT-FLC system

A. Model of Solar photovoltaic (PV) module

Solar photovoltaic (PV) module technology is based on P-N junction semiconductors.When the solar panel is exposed to light, the DC varies linearly with the solar PV irradiance. The analogous electrical circuit of an idealized solar Photovoltaic (PV) array may be conceived of as a current source in parallel with the diode[17][18].

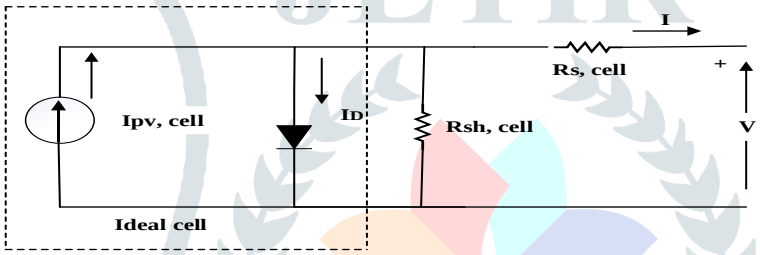

Fig.4:- Schematic diagram of a solar PV module

The semiconductor theory fundamental equation that arithmetically defines the V-I characteristics of an idealized Photovoltaic module is:

$I=I_l-I_D-I_{sh}$ (1)

Where, $V_j = V+IR_s$ (2)

$I_D=I_0\{\exp^{[V_j/nV_T]}-1\}$ (3)

$I_{sh}=V_j/R_{sh}$ (4)

Therefore, $I = I_l-I_0\{e^{[V_j/nV_T]}-1\}-((V+I*R_s)/R_{sh})$ (5)

I_l: current in PV cell (Amp.)

I_D: current in diode (Amp.)

I_{sh}: Shunt Current (Amp.)

I: Output Current (Amp.)

V_j: Diode and resistance R_{sh} across voltage (Volts)

V: Voltage in output terminal (Volts)

I: Current in output terminal (Amp.)

R_s: Resistor in series (Ohm)

I_0: Saturation current in reverse (Amp.)

n: Ideality factor of diode (1 for an idealized diode)

k: Boltzmann's constant

R_{sh}: Resistor in parallel

V_T: Thermal Voltage (at 25°c).

When solar photovoltaic (PV) array are attached in parallel, the current increases, and when solar photovoltaic (PV) array are attached in series, the output voltage increases.

B. Step-up converter

A step-up converter is one that uses a minimum input voltage to boost the voltage output. In this instance, the source current is greater than the output current. It is achieved in this suggested approach utilizing a DIODE or a MOS-FET. The converter's functioning may be divided into two states. When the transistor is operating state, the current in the step-up inductor grows linearly, while the diode is in the off state[19]. Whenever the transistor is switched turn-off, the inductor store power is discharged to the source load via the diode[20]. The fundamental interrelation betwixt both source voltage and load voltage of a step-up converter at constant state is provided by.

$$\frac{VL}{VS} = \frac{1}{1-D} \quad (6)$$

D is the switching frequency and value of switching frequency is (0 and 1).

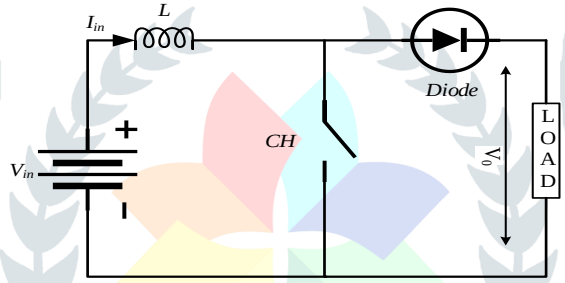

Fig.5:-Step-up converter circuit

C. MPPT (Maximum power point tracker)

The operational point of a solar photovoltaic (PV) array based on the load to which it has been attached when it is used in a process[21]. The operational point of a Photovoltaic systems module and the amount of solar radiation it receives change during the course of the day. Only 30 to 40 percent of solar irradiation is transformed into electricity by a photovoltaic array. Sun tracing involves manually moving solar photovoltaic (PV) arrays to capture the optimal energy output under a certain circumstance, whereas MPPT involves using electrical circuitry to transmit the optimum quantity of energy generated to the load. Utilizing an algorithm as well as an electrical device, that mechanism for monitoring the maximum power employs both to trace the optimum power. The method is based on the concept of impedance matching, which is required for optimum energy transfer betwixt the load and the solar photovoltaic (PV) array[22]. Consequently, the difficulty of locating the optimum point of power is reduced to a problem of impedance matching. Utilizing a step-up converter, the switching frequency (D) of the switch is adjusted to achieve this impedance matching[23][24]. Voltage and current are measured to determine the solar module's output power. This power is fed into the algorithm that also modifies the switching frequency of the switch, thereby adjusting the specular reflection load impedance based on the PV array's power output. MPPT techniques are derived from solar photovoltaic (PV) systems, such as the fuzzy-logic controller[25][26]. The FLC is a digital implementation algorithm with high speed, high complexity, and medium reliability. Due to the influence of array temperature and solar irradiance on the maximum power point (MPP) of a photovoltaic system, the MPP of a solar PV array must be continuously monitored. This paper concentrated on the MPP control algorithm for calculating the solar array's maximum power. Simulation is used to examine the efficacy of the most popular algorithms in depth.

D. Fuzzy logic approach for SPV system

A set of rules that were created from qualitative descriptions make up the fuzzy system. Fuzzy inferencing can be used to some extent in fuzzy systems to fire rules, but in typical expert systems, a rule either executes or does not execute. To the solar Rule, definitions are made to determine the energy estimation precision measured by absolute relative error. In the opinion of global solar energy at a certain place while maintaining a set of multiple-antecedent fuzzy rules, and parameters as constants have been created. Fuzzy-logic controllers use fuzzy logic to make decisions and regulate the controller's output. The key elements of a fuzzy-logic controller based MPPT controller are as follows: Fuzzifier, rule base, inference engine, defuzzifier are all terms used in controller.

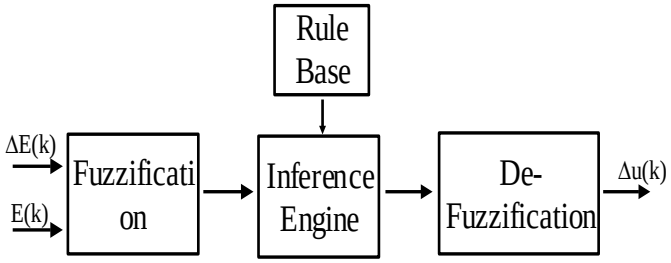

Fig.6:- Architecture diagram of a fuzzy-logic controller

The controller receives two input parameters. Error E (k) and correction in error ΔE (k). Fuzzification is a procedure that converts sharp inputs into fuzzy inputs. The rules are developed in a rule repository and implemented in the inference-engine. Defuzzifier transformed fuzzy outputs into crisp outputs. Defuzzification process uses the center of gravity calculate the outputs of all this fuzzy-logic controller, which represents the switching frequency change. The Fuzzy controller obtains two inputs: variations in solar photovoltaic (PV) module power (ΔP_{PV}) and variations in solar photovoltaic (PV) module current (ΔV_{PV}) obtained at the different sampling times instant. The 2 input parameters are processed by the fuzzy-logic controller, whose output is the gradual reference current (ΔVref). This output is received by the step-up converter.

The input1 variable (ΔP_{PV}) of the fuzzy-logic controller is split into five fuzzy set: Positive-Big, Positive-Small, Zero, Negative-Small, and Negative-Big. The rules are shown in Table 1.

The input2 variable (ΔV_{PV}) of the fuzzy-logic controller is split into five fuzzy set: Positive-Big, Positive-Small, Zero, Negative-Big, and Negative-Small. The rules are shown in Table 1.

The output variable (ΔVref) is split into five fuzzy set: Positive-Big, Positive-Small, Zero, Negative-Big, and Negative-Small [27][28]. The rules are arranged in according to Table 1.

Table 1:-Matrix for the prediction of fuzzy rule for mppt

$\Delta Vref * (o/p)$	$\Delta Vpv(i/p)$ (change in Voltage)					
		NB	NS	ZE	PS	PB
$\Delta Ppv(i/p)$ (Change in Power)	NB	PS	PB	NB	NB	NS
	NS	PS	PS	NS	NS	NS
	ZE	ZE	ZE	ZE	ZE	ZE
	PS	NS	NS	PS	PS	PS
	PB	NS	NB	PB	PB	PS

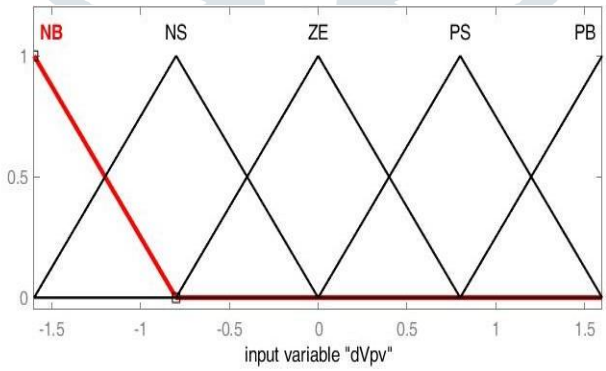

Fig.7:- Fuzzy subset membership functions for change in voltage

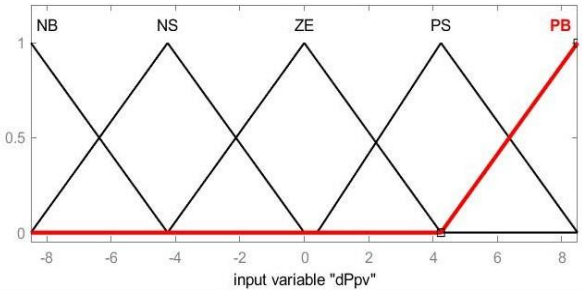

Fig.8:-Fuzzy subsets membership functions for change in Power

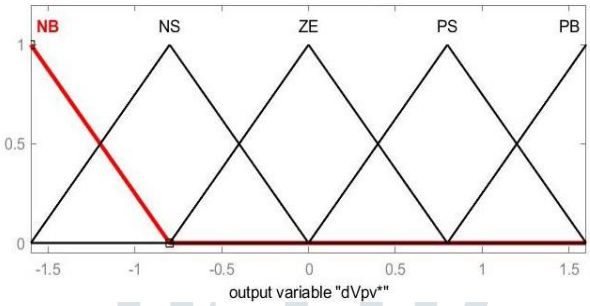

Fig.9:- Fuzzy Subset membership Functions for change in output Voltage

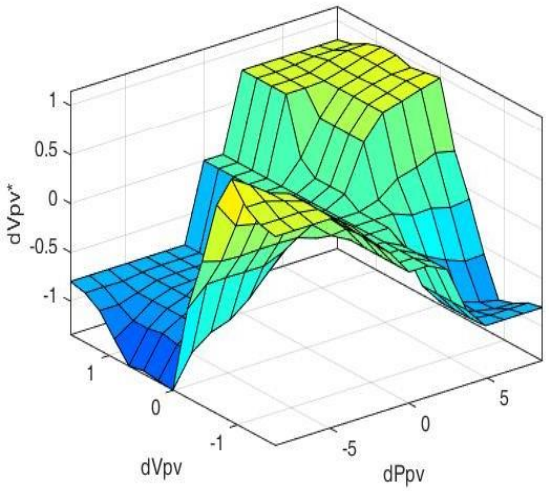

Fig.10:- Graphical representation of fuzzy rules

4. Calculation of MPP of a solar photovoltaic (PV) module

The values of voltage and current at MPP operating under various temperatures and irradiance calculate the power P_{inp} (k)

$$P_{inp}(k) = I_{inp}(k) * V_{inp}(k) \quad (7)$$

Where k is the discrete system (not continuous) and $V_{inp,}$ Iinp is the voltage, current produced by the solar photovoltaic (PV) array. Then calculate the value of error (E).

$$E = \left\{ \frac{(Pinp(k)) - (Pinp(k-1))}{(Vinp(k)) - (Vinp(k-1))} \right\} \quad (8)$$

$$\Delta E = [E(k) - E(k-1)] \quad (9)$$

Error is the ratio of the power and voltage value difference between the current and previous value, and the value of error is sent to the fuzzification block, which applies the fuzzy rule and then changes the switching frequency depending on the optimum power output collected by the solar photovoltaic (PV) array.

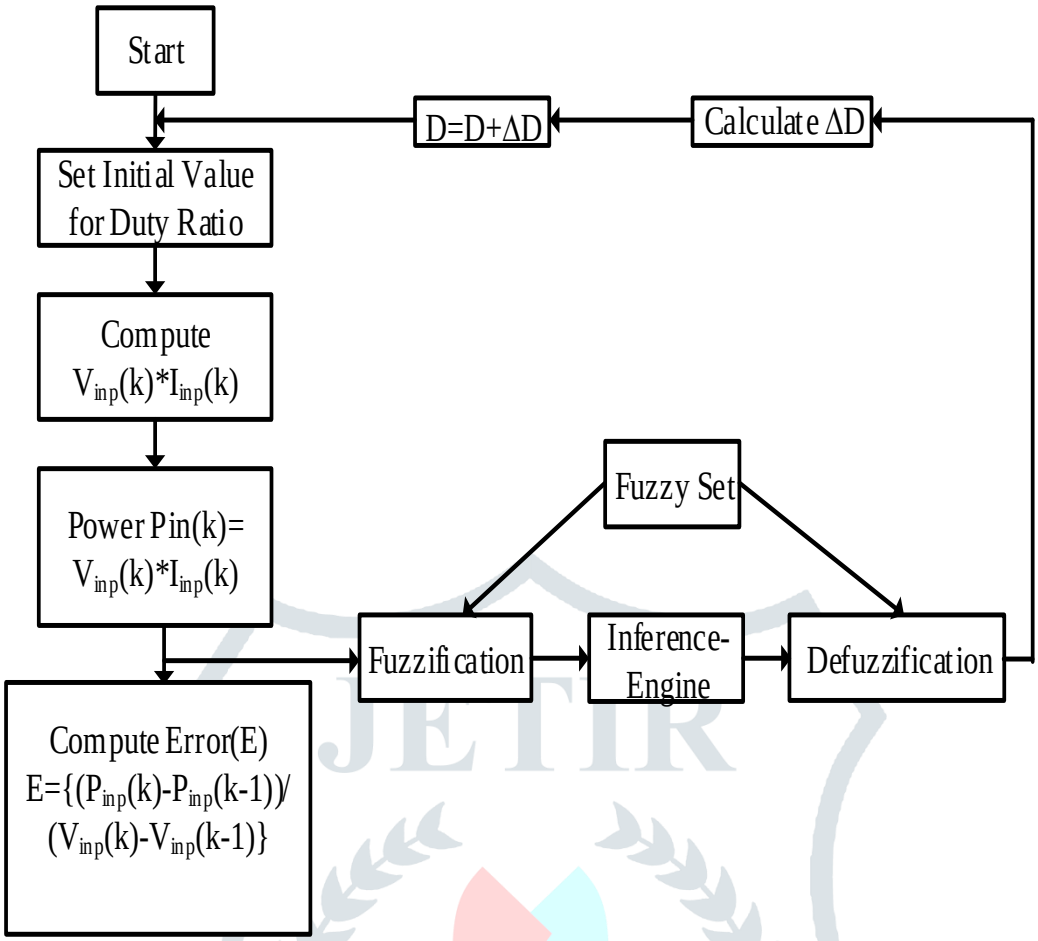

Fig.11:-Fuzzy logic algorithm flow chart

5. PERPOSED MODEL

Fig.12 represents a model of the proposed Fuzzy Logic Control-basedMPPT. The Photovoltaic module specification used in this simulation is tabulating.

Table.2:-Specification of Photovoltaic module

$I_{short\text{-}circuit,}$ (Amp.)	8.66
$V_{open\text{-}circuit,}$ (Volt.)	37.3
Current at MPP, (Amp.)	8.15
Voltage at MPP, (Volt.)	30.7
Maximum Power, (Watt)	250.205
No.of cells(N_{cell})	60

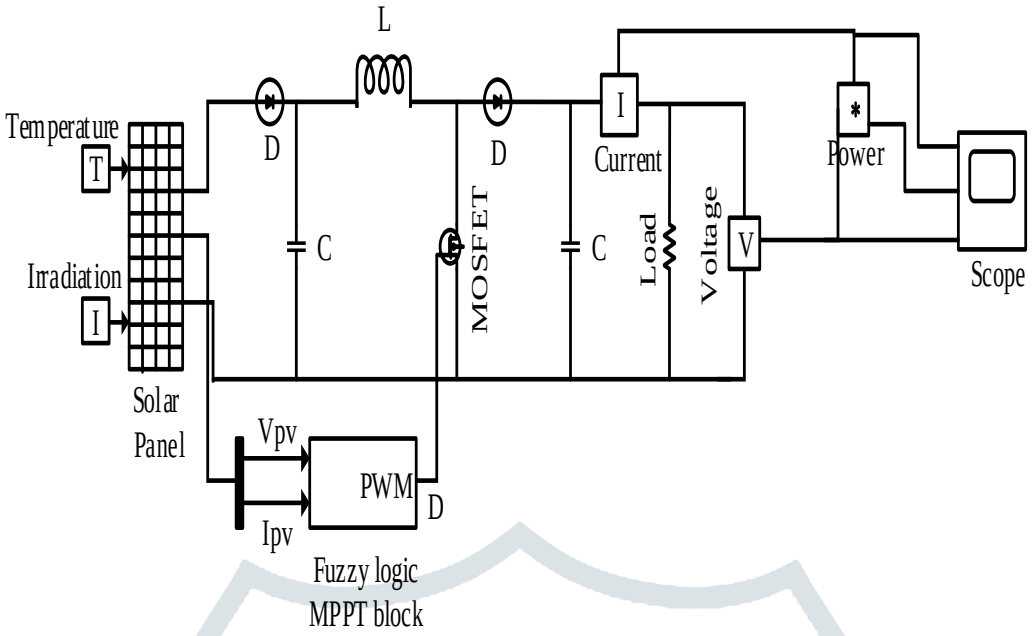

Fig.12:-Simulink Model of fuzzy logic control based MPPT

Table.3:- Maximum power point of a solar photovoltaic (PV) array with fluctuating irradiance at temperatures of 25°c and 45°c

Tempature (°c)	Time,(sec)	Irradiation,(W/m^2)	V_{MP}, (V)	I_{MP}, (A)	P_{max},(W)
25°c	(0-0.5)	200	6.635	0.884	5.870
	(0.5-1)	400	13.25	1.766	23.403
	(1-1.5)	600	19.84	2.645	52.46
	(1.5-2)	800	26.4	3.52	92.92
	(2-2.5)	1000	32.94	4.392	144.65
45°c	(0-0.5)	200	6.75	0.90	6.07
	(0.5-1)	400	13.49	1.79	24.221
	(1-1.5)	600	20.18	2.69	54.30
	(1.5-2)	800	26.86	3.58	96.16
	(2-2.5)	1000	33.5	4.467	149.64

Table.3 describes irradiation, cell temperature, voltage, current, and total output power of MPP. Table.3 column first describes the temperature of a solar cell, the second column describe the time period the third column describes the various irradiation, the fourth column describes the voltage across MPP, the fifth column describes the current across the MPP and the sixth column describes the total power output across the MPP.

6. RESULTS & DISCUSSIONS

In this graph show the relation between voltage and time. According to this graph we are changing the irradiance value in w/m^2.Which causes change in output (desired) voltage. It means that various level of irradiance we get various value of voltage. The fluctuation is minimize because of the FL-MPPT controller method is used which is are main motive of this research.

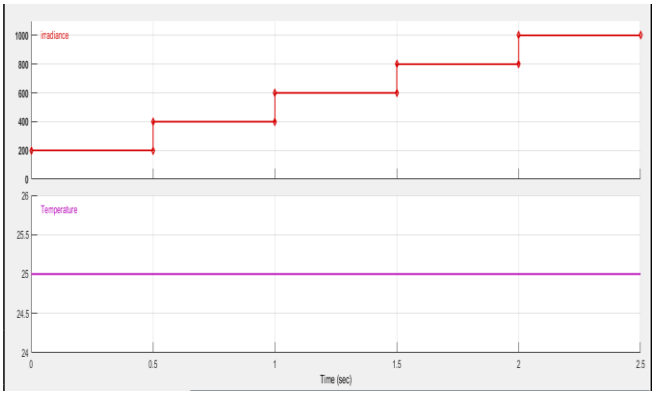

Fig.13:-Input values of various irradiance at constant temperature (25°c) with time period.

This Fig.13 shows various values of irradiance are taken into consideration range from 200w/m^2 to 1000w/m^2.These values are increased stepwise. The constant temperature value are kept at 25°c Various sets of readings on taken based on these temperature(25°c).

Fig.14:- Output voltage under varied irradiation conditions at (25 °c)

This Fig.14 shows output voltage output voltage under varied irradiation conditions at 25 °c. The output voltages shows stepwise increase at 25°c from 6.635v to 32.94v.The output voltage is showing Oscillation due to noise, environmental condition, changing in temperature, cloudy conditions.

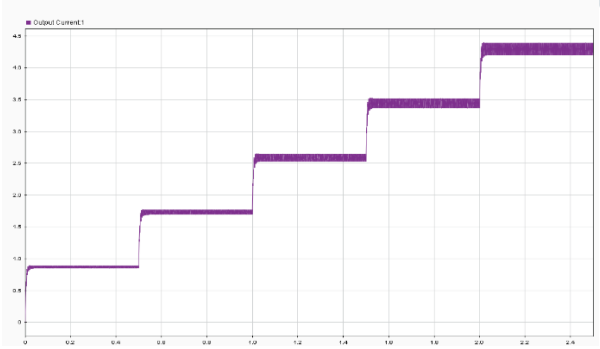

Fig.15:- Output current under varied irradiation conditions at (25 °c)

This Fig.15 shows Output current under varied irradiation conditions at (25 °c).The output current shows stepwise increases at 25°c from 0.884A to 4.392A.The output current is showing Oscillation due to noise, environmental condition, rapidly change in irradiance value and cloudy condition.

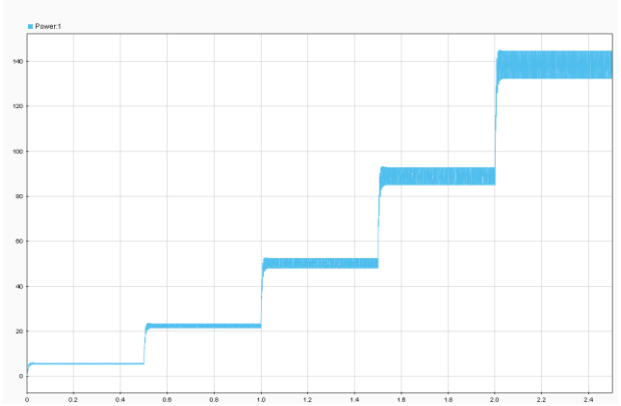

Fig.16:- Output power at various levels of irradiation at a Constant temperature (25 °c)

This Fig.16 shows output power at various levels of irradiation at a constant temperature (25 °c).The output current shows stepwise increases at 25°c from 5.870W to 144.65W.The output current is showing Oscillation due to noise, environmental condition, rapidly change in irradiance value and cloudy condition.

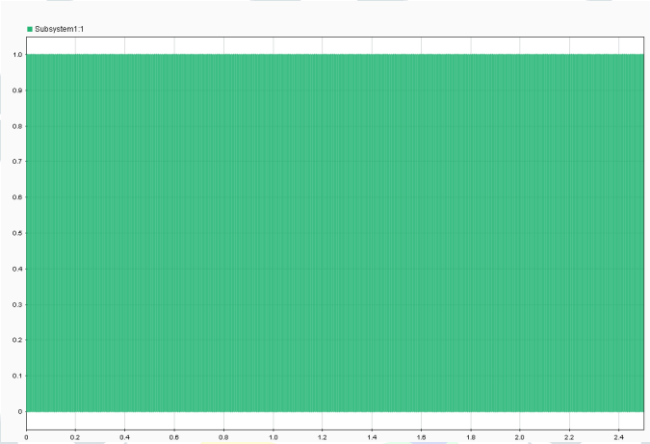

Fig.17:- PWM output at constant temperature (25°c) for fuzzy logic control

This Fig.17 shows the characteristics of PWM generator which applied at the controlled switch of step-up control.

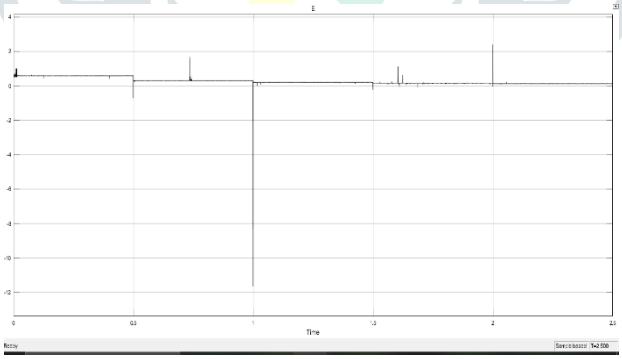

Fig.18:- Error signal of Fuzzy MPPT controller system at constant temperature (25°c).

This fig.18 shows the error is generated due to the sudden change in the irradiation value and various weather conditions due to generating an error in the output of solar photovoltaic (PV) array.

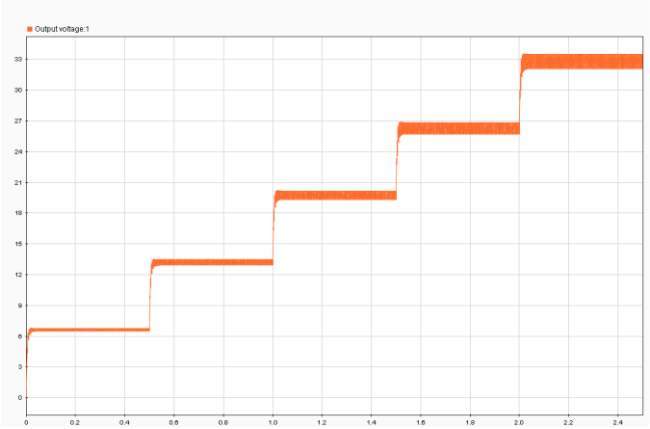

Fig.22:- Output voltage under varied irradiation conditions at (45°c)

This Fig.22 shows output voltage under varied irradiation conditions at (45°c).The output voltages shows stepwise increase at 45°c from 6.75v to 33.5v.The output voltage is showing Oscillation due to noise, environmental condition, changing in temperature, cloudy conditions.

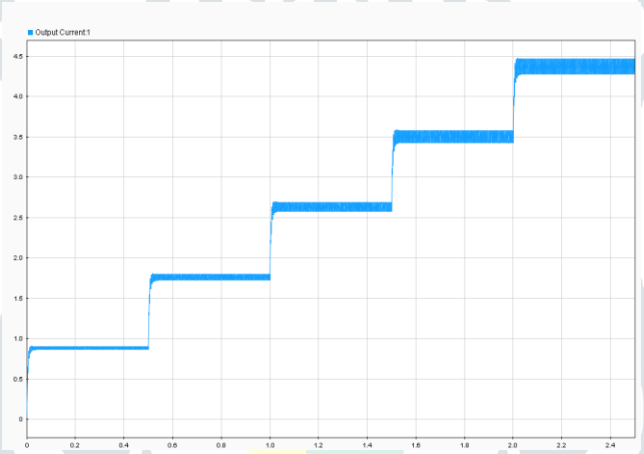

Fig.23:- Output current under varied irradiation conditions at (45°c)

This Fig.23 shows output current under varied irradiation conditions at (45°c).The output current shows stepwise increases at 45°c from 0.90A to 4.467A.The output current is showing Oscillation due to noise, environmental condition, rapidly change in irradiance value and cloudy condition.

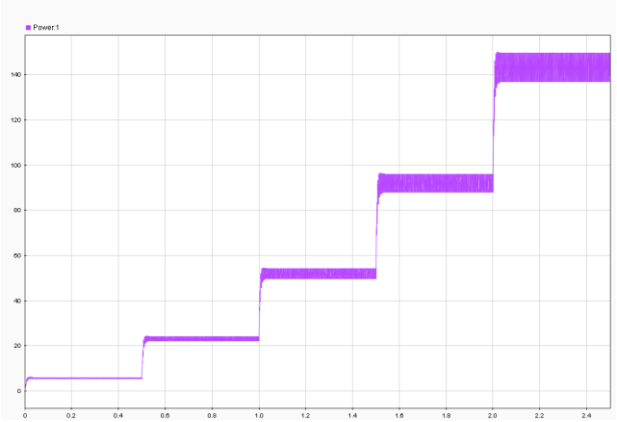

Fig.24:- Output power at various levels of irradiation at a constant temperature (45°c)

This Fig.24 shows output power at various levels of irradiation at a constant temperature (45°c).The output current shows stepwise increases at 45°c from 6.07W to 149.64W.The output current is showing Oscillation due to noise, environmental condition, rapidly change in irradiance value and cloudy condition.

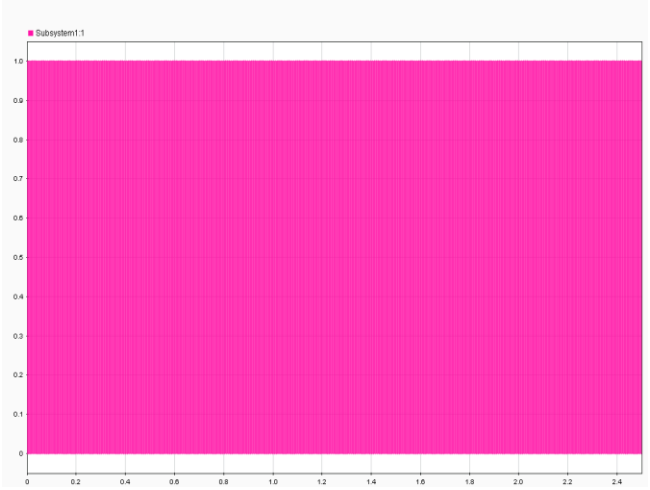

Fig.25:- PWM output at constant temperature (45°c) for fuzzy logic control

This Fig.25 shows the characteristics of PWM generator which applied at the controlled switch of step-up controller.

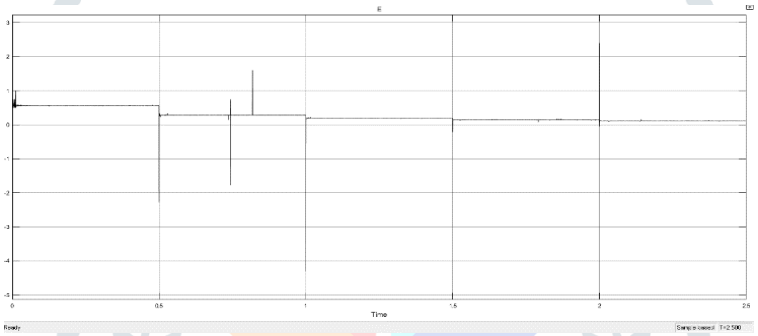

Fig.26:- Error signal of Fuzzy MPPT controller system at constant temperature (45°c)

This fig.26 shows the error is generated due to the sudden change in the irradiation value and various weather conditions due to generating an error in the output of solar photovoltaic (PV) module.

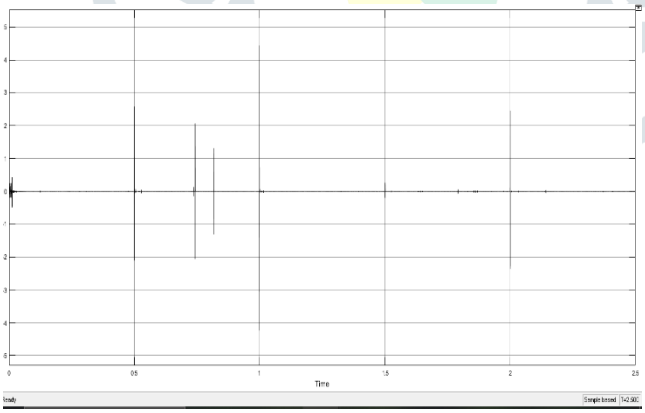

Fig.27:- Feedback error signal of Fuzzy MPPT controller system at constant Temperature (45°c)

This fig.27 shows the feedback error signal is given the error correction block for changing the total error.

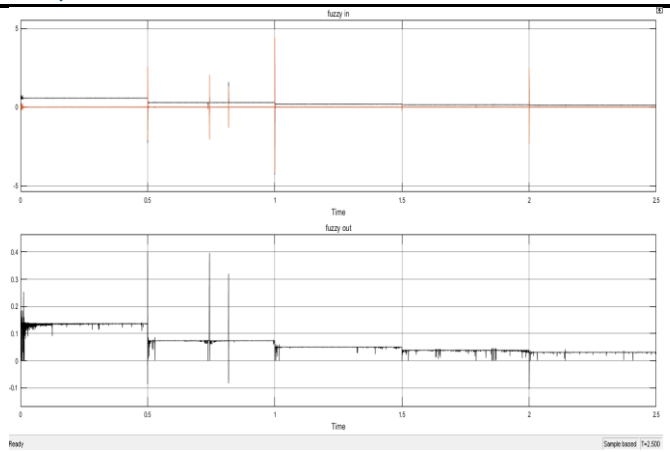

Fig.28:-Input of error signal & Output of error signal of Fuzzy Controller at constant temperature (45°c)

This fig.28 shows the correction of the error signal given to the fuzzification process, and using the fuzzy rule decreases the error value, and changes the switching frequency of the switch.

7. CONCLUSION

This paper shows the construction of a maximum power point tracker based on fuzzy- logic that can respond to various conditions. The findings of the modeling of solar photovoltaic (PV) arrays indicate that the output characteristics of solar photovoltaic (PV) arrays are nonlinear and that their output power is more sensitive to temperature and solar irradiance. MPPT control algorithms are used to operate solar photovoltaic (PV) arrays at their maximum operating point when the maximum amount of power produced can be transferred to the load connected across the output terminals of the step-up converter. According to simulation results, the maximum power point tracker based on fuzzy logic provides superior MPP tracking and faster response speed. Due to its changing step size, fuzzy MPPT maintains a constant MPP tracking response even when PV module specifications alter. Simulation results illustrate the higher performance of the intelligent MPPT technique based on fuzzy logic. The complete system was simulated using the Fuzzy-logic MPPT algorithm, and the simulation results show that using an MPPT-FLC increases the efficiency of the solar photovoltaic (PV) module. The Maximum power point tracking-based fuzzy-logic controller enhances output power, reduces fluctuations, & responds quickly to changing weather conditions.

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