

# Tracking of photovoltaic power system with new Fuzzy Logic Control strategy

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**Abstract** A new intelligent technique of tracing the peak power point of a standalone photovoltaic (PV) module using Fuzzy Logic Control (FLC) is presented in this paper which exploits the effects of the characteristic of PV module. Partial shaded and change in weather conditions produces numerous local maximum peak points (MPP), which makes the tracing of the multiple global peak power a challenging task. Furthermost of traditional tracing technique fail to operate correctly under these non-uniform irradiance situations. The real traditional FLC search based maximum power point tracking (MPPT) flops to trace the peak power under partial shaded situations. This paper advances the technique by considering the wide range of search and power ripple so that the designed FLC technique traces maximum power for all the situations. It is tested for dissimilar weather condition through Matlab simulation and verified laboratory experimentally. In this paper, the merits of using a novel FLC is also offered. Three inputs and single output fuzzy rules are developed. From the Matlab simulation outcomes, it is observed that the FLC controlling technique decreases error and it provides rapid reaction to environmentally friendly variations. The competence of the designed technique has closely coordinated with the true maximum power point (MPP) and the successful laboratory experimental results attained with a 100 Watt photovoltaic module specify that the method can be favourably realized for photovoltaic standalone system.

**Index Terms** – Maximum Tracking, Photovoltaic, Fuzzy Logic Control, DC to DC buck-boost Zeta converter

## I. INTRODUCTION

Considering the great initial capital investment cost of a solar photovoltaic panel and its low energy conversion efficiency, it is necessary to operate the photovoltaic panel at MPP so that possible power can be produced. Numerous MPPT arrangements have been suggested by different authors [1–11]. Among them widespread tracing schemes are incremental conductance, perturb and observe (P&O), open-circuit voltage, and short circuit current [1]. Some altered methods have also been recommended, with the knowledge of developing the performance and decreasing the hardware [2]. The tracing systems stated above are real and stage tested under unchanging solar irradiance, where the voltage (V) versus power (P) graph of solar photovoltaic module shows only one peak power point (PPP) for a specified environmentally friendly situations [3]. Under change in weather conditions and partial shading a distortion occurs in the complete voltage vs. power curve [4]. That is voltage vs. power graphs often display several local maxima at diverse places, which may also consequence in fairly strange ratios between universal maximum peak voltage and open circuit voltage [5]. These issues can present a substantial trouble to the correct process of a MPPT. The occurrence of several peaks decreases the effectiveness of the earlier peak power tracking systems, which consider a single PPP on the voltage vs. power

characteristic [6]. The occurrence of different weather and partially shadow circumstances being quite mutual (e.g., due to birds, trees, and clouds, etc.), there is an obligation to develop unusual MPPT structures that can trace the global peak under these environments. In this paper the different method for peak power tracking using three inputs and single output Fuzzy Logic Controller (FLC) search controlling technique is proposed [7]. The designed FLC technique can find peak power by doing wide range of illumination and temperature variations [8]. In common, solar photovoltaic source is worked along with a DC to DC stage converter, whose pulse width modulation (PWM) duty cycle (D) is altered in order to path the instant PPP of solar photovoltaic source. The voltage to current ratio for the load is obvious on other concerns. However voltage to current ratio for the solar photovoltaic module is directed by PPP of the module. To match these dissimilar necessities, DC to DC power converter is interpolated between solar PV panel and the load. The voltage to current ratio on the output and input sides of the DC to DC stage converter will be the equal whereas current and voltage values detected on the two sides may be diverse [9].

For regulatory the DC to DC stage converters numerous control approaches are described in the literature. These controlling techniques are easy to design and simple to implement. Conversely, there are some limitations [10] that delay the traditional controllers, such as need for alteration of control parameters against variations in load and supply voltage parameters, performance related on the functioning point, stabilization problems and difficult proposal of control parameters, etc. To overcome selected of the drawback stated above, Fuzzy Logic Controllers are approaching up in developed processes outstanding to their experiential nature related with effectiveness and simplicity for both nonlinear and linear structures. FLC use has been prosperous in numerous areas, mainly in the area of power electronics to control the DC to DC power converters and PWM inverters, etc. [11]. This FLC is adaptive and nonlinear nature, which provides it robust enactment under load, supply voltage (Vs) disturbances, and parameter variation [12]. In this paper, a new Fuzzy Logic Control has been

utilized to trace the global peak from the buck-boost zeta converter delivered solar photovoltaic module system. The controller inputs to the designed Fuzzy Logic Controller are three, while the production is the alteration of control signal for pulse width modulation generator. Use of adaptive Fuzzy Logic Controllers for the solar photovoltaic schemes will relieve the load involved in the proposal of DC to DC controller parameters. Further, proposed FLCs controllers will expand the tracing performance as matched with traditional controllers. To increase the tracing speed additional, the FLC rules have been enhanced using artificial intelligent in its place trial and error [13]. In this paper, with proposed a new FLC search controlling technique, the performances of P&O are compared.

## II. PROPOSED SYSTEM

Maximum tracking can be recognized using multiple converter topologies. In this work DC to DC buck-boost Zeta converter is utilized to its high effectiveness. The transfer function of DC voltage is written by Eq.(1)

$$V_o/V_s = D / (1 - D) \quad (1)$$

$$C = \frac{D}{2fr} \quad (2)$$

$$L = \frac{(1-D)^2 D r}{2f} \quad (3)$$

Where, output voltage (Vo), source voltage (Vs), and Duty cycle (D). The acute values of the capacitance and inductance can be find out using the Eq.(2) and Eq.(3). Where, f is the frequency in 20Khz. The capacitance and inductance are designed as C= 220 micro Farad, L is 100 micro Hendry. The R value is 100 ohms. The maximum tracking search technique execution is done in embedded Matlab function block is available in the Simulink software. Generally the requirement of load voltage is either higher or lower than input source voltage based on their applications. Normally series strings in solar photovoltaic array may outcomes in high power loss under change in partial shaded situation. Hence the buck-boost converter is suitable to match the load impedance with the source impedance thus delivering possible peak power to the load. Fig.1 illustrates the proposed block diagram for implementing the designed MPPT search technique with DC to DC buck-boost Zeta converter. The output of DC to DC converter block provides the output

voltage, which is in turn matched with the actual voltage at which solar photovoltaic panel is functioning. The error signal (E) is fed to the designed FLC controller block and the consequential signal is lastly matched with the triangular wave signal to yield gating (G) pulses to the DC to DC converter switch [14].

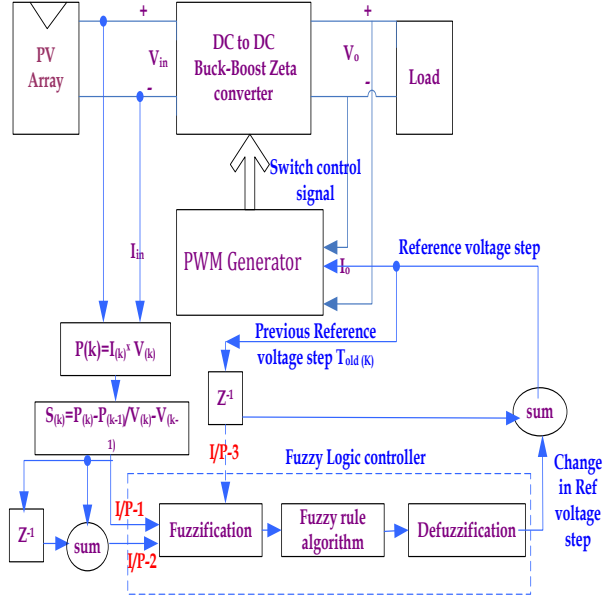


Fig.1 Block diagram of designed FLC based MPPT using DC to DC zeta converter.

## 2.1 Equivalent circuit of PV system

In the literature different models of solar photovoltaic cell are presented: single diode and single resistance model [15], single diode and two resistances model [6] and more than one diode models [16]. In this paper, one diode and one resistance model is prepared and shown in Fig.2.

As most of PV manufacturers give only three operating points: such as short circuit current, the maximum power point defined as maximum power current and maximum power voltage, open circuit voltage and since this work is not based on a PV intrinsic study, the one diode model is considered satisfactory and easy to implement under MATLAB Simulink software. From the equation describing the voltage versus current (V-I) cells characteristic, and taking into account the  $N_p$  number of PV system parallel branches and the  $N_s$  number of cells in series inside the PV panel, the Eq. (4) gives the PV system voltage ( $V_{pv}$ ) as a function of output current ( $i_{pv}$ ). We consider the PV system  $N_p=1, N_s=36$ .

$$V_{pv} = 2nN_sV_T \ln \left( \frac{N_p i_L - i_{pv}}{N_p i_o} + 1 \right) - \frac{2N_s R}{N_p} i_{pv} \quad (4)$$

The photovoltaic  $I_L$  is given by Eq(5) and the diode saturation current  $i_o$  is given by Eq.(6).

$$i_L = \frac{T}{G^*} I_{sc} (1 + K_o (T - T^*)) \quad (5)$$

$$i_o = I_o^* \left( \frac{T}{T^*} \right)^{3/n} \left[ \frac{1}{\exp \left( \frac{V_{GC} T^*}{n V_T} \left( \frac{1}{T} - \frac{1}{T^*} \right) \right)} \right] \quad (6)$$

where  $n$  is the diode ideality factor (generally between 1 and 2, the value 1 is for an ideal diode);  $V_T = kT^*/q$  is a constant with  $T^*=298$  K the reference temperature,  $q=1.6022 \times 10^{-19}$  C the elementary charge and  $k = 1.38 \times 10^{-23}$  J/K the Boltzmann's constant. The variables are the input light irradiance  $G$  ( $W/m^2$ ) with  $G^*=1000$   $W/m^2$  the reference irradiance and the cell temperature  $T$ (K) with  $K_o=0.0044$  A/K the temperature coefficient for current. For polycrystalline cells, the band gap energy semiconductor, here noted as  $V_G$ , is equal to 1.12 eV. Under the  $G^*$  reference irradiance and the  $T^*$  reference temperature, the diode saturation current is calculated by Eq. (7).

$$I_o^* = \frac{I}{\exp \left( \frac{V_{oc}}{n V_T} \right) - 1} \quad (7)$$

Based on the above equations and using the electrical specifications presented in Table-I, the PV system model has been implemented using MATLAB Simulink.

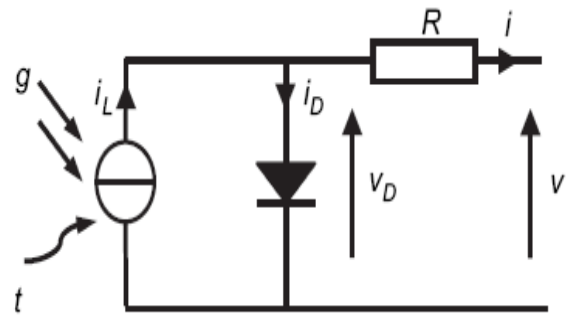


Fig.2. simplified PV equivalent circuit model

From equation we notice that the output of PV cells is a complex variable, it depends on the PV insolation and the junction temperature of the cell. Solar energy production devices have a complex relationship between the produced power, the load that they supply and the efficiency of delivery. The time and speed it takes to convert energy from the solar PV device into current varies from cell to cell since the conversion of photons into electron depends on many factors. Which are not

unique for all the PV devices. The voltage versus power characteristics for a typical PV device at different temperatures are presented in Fig.3.

Table-I Electrical specifications of PV panel “KL100”KL Solar Pvt Ltd, Coimbatore.

Electrical specifications	Values
Typical peak power( $P_p$ )	100 $W_p$
Voltage at peak power( $V_{pp}$ )	17.1 V
Current at Peak power( $I_{pp}$ )	5.85 A
Short circuit current( $I_{sc}$ )	6.55 A
Open circuit voltage( $V_{oc}$ )	21.5 V
Power [ $P_{max}$ ]	-0.43%/K
Short circuit current( $I_{sc}$ )	+0.06%/K
Nominal operating cell temperature(NOCT)	45 <sup>o</sup> C
No.of cells	36
Tolerance of $P_{max}$	± 10%

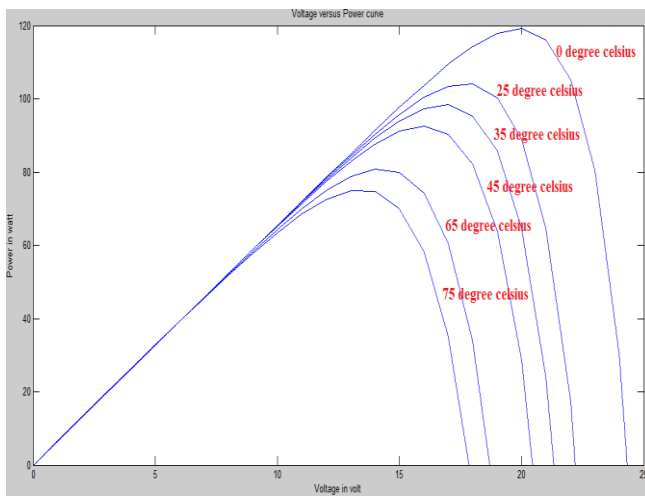


Fig.3 voltage versus power characteristics for a typical PV device at different temperatures

## 2.2 Design of DC to DC buck-boost Zeta Converter

The ZETA dc to dc converter is similar to the buck-boost topology varies the above and below the output voltage. This converter needs two inductors and one series capacitor, sometime this capacitor is called a flying capacitor. The zeta converter basically is configured from a buck controller that drives a high side PMOSFET. The zeta converter is one more option for regulating a nonlinear input power supply, like low cost wall wart. In the design of the converter to minimize board space, a coupled inductor can be used.

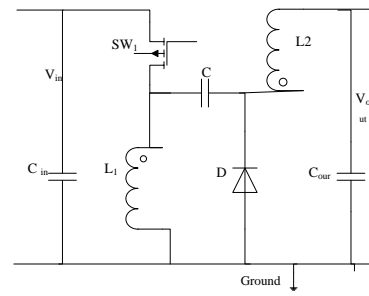


Fig.4. DC to DC buck-boost zeta converter

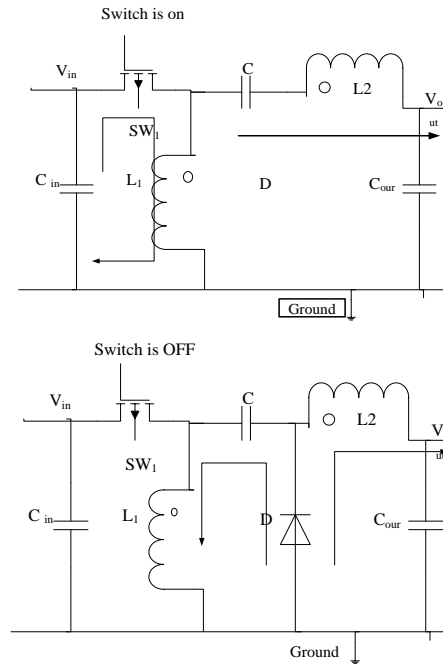


Fig.5. Converter circuit diagram (a) switch is on (b) switch is off

### 2.2.1 Modes operation of zeta converter

The illumination of Fig.4 shows a simple circuit of a ZETA converter, containing of an input capacitor,  $C_{in}$ , an output capacitor,  $C_{out}$ , coupled inductors  $L_1$  and  $L_2$ , an AC coupling capacitor  $C$ , a power MOSFET,  $SW_1$ , and a diode,  $D$ . Fig.5 shows the ZETA converter operating in the continuous conduction mode (CCM) when  $SW_1$  is on and when  $SW_1$  is off. To recognize the voltages at the various circuit nodes, it is essential to analyse the circuit at DC when both switches are off and not switching. Capacitor ( $C$ ) will be in parallel with  $C_{out}$ , so  $C$  is charged to the output voltage,  $V_{out}$ , during steady state CCM. Fig.5. illustrations the voltages across  $L_1$  and  $L_2$  during CCM operation. When  $SW_1$  is off, the voltage across  $L_2$  must be  $V_{out}$  since it is in parallel with  $C_{out}$ . Since  $C_{out}$  is charged to  $V_{out}$ , the voltage across  $SW_1$  when  $SW_1$  is off is  $V_{in} + V_{out}$ . therefore the voltage across  $L_1$  is  $-V_{out}$  relative to the drain of  $SW_1$ . When  $SW_1$  is on, capacitor

C, charged to  $V_{out}$ , is connected in series with  $L_2$ , so the voltage across  $L_2$  is  $+V_{in}$ , and diode D sees  $V_{in} + V_{out}$ . The duty cycle D for a zeta converter operating in CCM is given by

$$D = \frac{V_{out}}{V_{in} + V_{out}} \quad (8)$$

This can be rewrite as

$$\frac{D}{1-D} = \frac{I_{in}}{I_{out}} = \frac{V_{out}}{V_{in}} \quad (9)$$

$D_{max}$  occurs at  $V_{in(min)}$  and  $D_{min}$  occurs at  $V_{in(max)}$ . These five parameters (L1, C, L2,R) can be calculated following the parameter estimation procedure given above, and the result are shown in Table-II.

Table-II Parameter estimations for the PV modules

Parameter	L1	C	L2	R
Values	100 mH	220 $\mu$ F	100 mH	100 $\Omega$

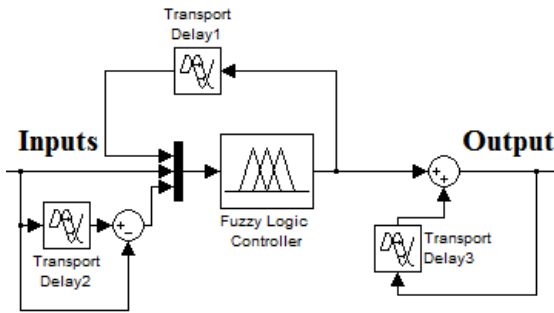


Fig.6. Block diagram of the designed 3x1 FLC controller

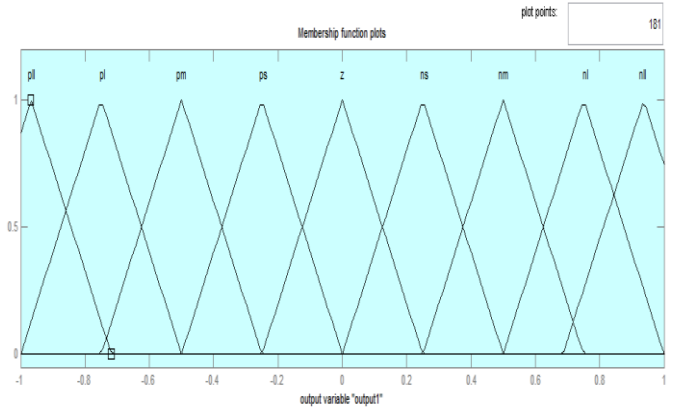


Fig.8. Output membership functions of the fuzzy control system.

### III. A NEW 3x1 FUZZY LOGIC CONTROLLER DESIGN

The fuzzy sets idea was suggested by Zadeh in the year 1965 [14]. The fuzzy logic algorithm can create human information into the rule base to controller a plant with linguistic explanations. It trusts on skilled experience as a replacement for mathematical models. The merits of fuzzy logic control comprise high faults tolerance, good popularization, and Suitability for nonlinear system control. A fuzzy logic controller design has four major parts: fuzzification, defuzzification, control rule base, and fuzzy inference. The block diagram of the new dfuzzy control system design is shown in Fig.6. At first, the solar photovoltaic output voltage and current are sensed and fed into ADC blocks. This analog signal converted into digital signal by ADC (Analog to Digital converter) applied into FLC block. Then, a feedback analog voltage and current signal will be generated and converted into a digital signal through an ADC. When the voltage and current in the westward-eastward track or the northward-southward track is dissimilar, the variances will be supplied into the fuzzy logic controller. Then, the FLC produces gate pulses to the semiconductor devices. Note that if the measured variances of sensors are zero, i.e., the sun is vertical position to the photovoltaic panel; the FLC does not operate. Since the sun changes gradually, high speed

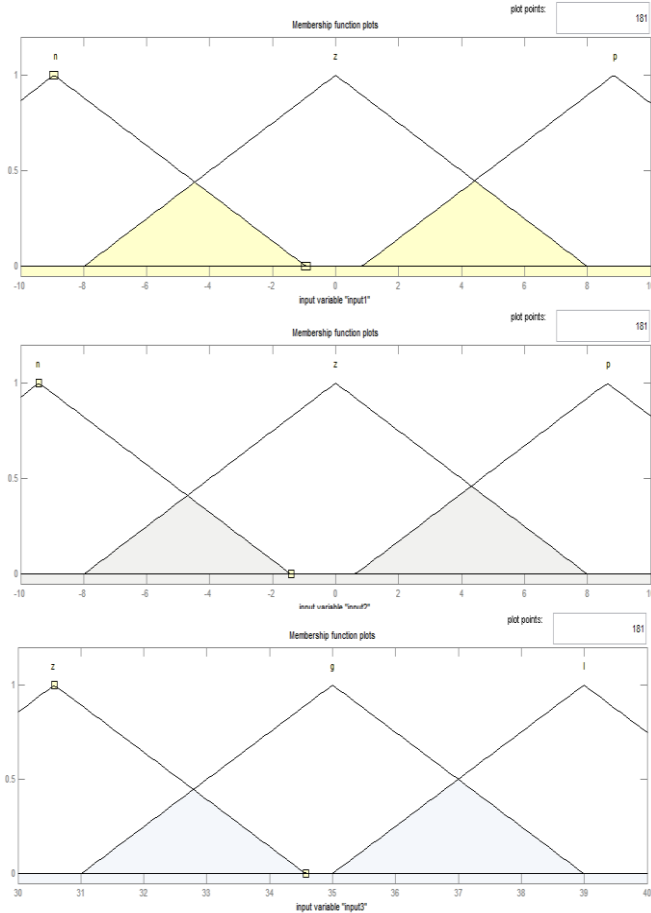


Fig.7. Input membership functions of the fuzzy control system.

alternation of the tracking system is not needed. By FLC technique, few merits are takes place such as reducing consuming power and smooth operation can be realized. Hence, the FLC technique has sufficient to attain decided goal. Since the corresponding voltage and current sensors can operate freely and organized independently. The membership functions are shown in Fig.7 and Fig.8. As shows fuzzy membership functions consists of three inputs and single output. The terms n,p,l,z and g transfer negative, positive, little, zero and great respectively. The output membership functions are nominated as PLL transfer positive double large, PL transfer positive large, PM transfer positive medium, PS transfer positive small, Z transfer zero. NS transfer negative small, NM transfer negative medium, NL transfer negative large, NLL transfer negative double large respectively. The extent of membership functions parameters are given as input 1 as{-10,10},input 2 as {-10,10}, input 3 as {30,40} and output as {-1,1}.Eighteen fuzzy control rules are used, as shown in the following.

Table-III Fuzzy controls rules

S.No	Input-1 “A”	Input-2 “B”	Input-3 “C”	Output “D”
1.	n	N	z	ps
2.	n	N	g	pll
3.	n	Z	z	pm
4.	n	Z	g	pll
5.	n	P	z	z
6.	n	P	g	ps
7.	z	N	z	ps
8.	z	N	g	pl
9.	z	Z	z	z
10.	z	P	l	nl
11.	z	P	z	ns
12.	z	P	g	ps
13.	p	N	l	nm
14.	p	N	z	z
15.	p	Z	l	nm
16.	p	Z	z	ns
17.	p	P	l	nll
18.	p	P	z	nm

Rule 1: If A is n, and B is n, and C is z, then Dis PS.

Rule 2: If A is n, and B is n, and C is g, then Dis PLL  
.....

....Rule 18: If A is p, and B is p, and C is z, then Dis NM.

In the fuzzification block the process numerical input variable is transformed into a linguistic variable output. The designed FLC has three controlling inputs are used such as Error one for  $e = \Delta P / \Delta V$ , Error two is change in error ( $\Delta e$ ) and Error three is FLC output. Which are discrete by

$$e(z) = \frac{P(z) - P(z-1)}{V(z) - V(z-1)} \quad (10)$$

$$\Delta ce(z) = e(z) - e(z-1) \quad (11)$$

The following nine fuzzy levels are selected for the controlling inputs of the FLC (error1 (e1) ,error2: change of error ( $\Delta e$ ) and error3: output FLC ) in the fuzzification: ns-negative small, nm-negative medium, nll-negative double large, nl-negative large, z-zero, ps- positive small, pl- positive large, pll-positive double large, and pm-positive medium. Membership functions for controller the FLCs inputs, i.e., E1(e), E2( $\Delta e$ ), E3( $\Delta O-1$ ), and incremental variation in the controlling output ( $\Delta O$ ) are distinct on the general normalized range of [-1, 1].

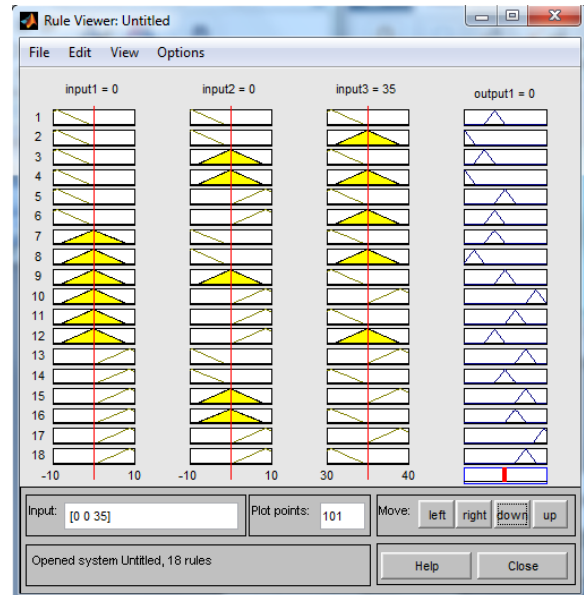


Fig.9 Rule viewer of the proposed FLC system

In this paper, product inference is functional for fuzzy inference. The center of gravity mode is embraced for defuzzification to attain a practical functional value. Usually defuzzification technique is applied by digital circuits. The defuzzification equation is shown as.

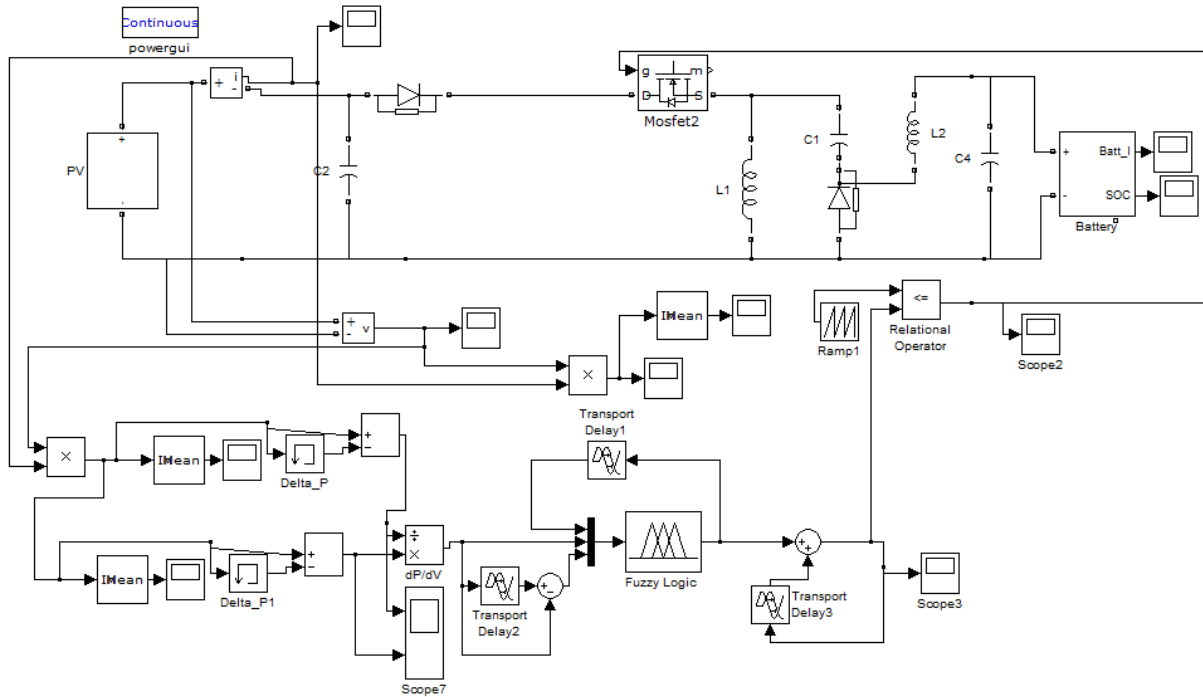


Fig.11 Schematic diagram of proposed system

$$\Delta D = \frac{\sum_{i=1}^{18} x_1 y_1 z_1}{\sum_{i=1}^{18} x_1} = x_1 y_1 z_1 + x_2 y_2 z_2 \dots x_{18} y_{18} z_{18} \quad (12)$$

Fig.9 shows the rule viewers; here we are used three inputs and one output. If there is any change takes place in the given three inputs automatically output also changed according to the change in the input. Fig.10 shows the four fuzzy surface waveform, which shows the variation of three inputs and one output [19], [20].

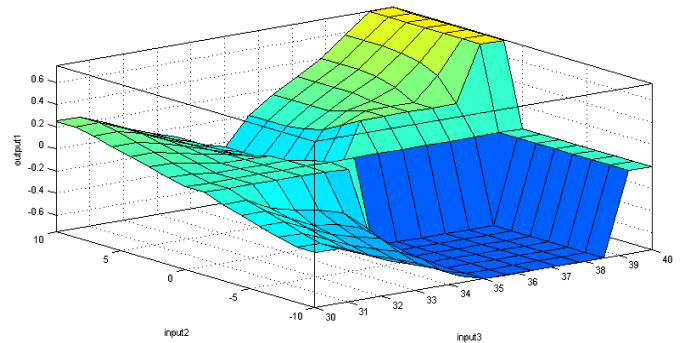
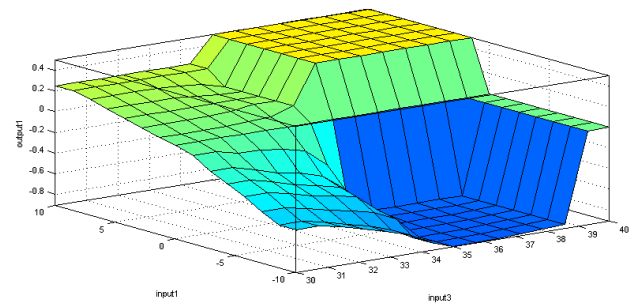
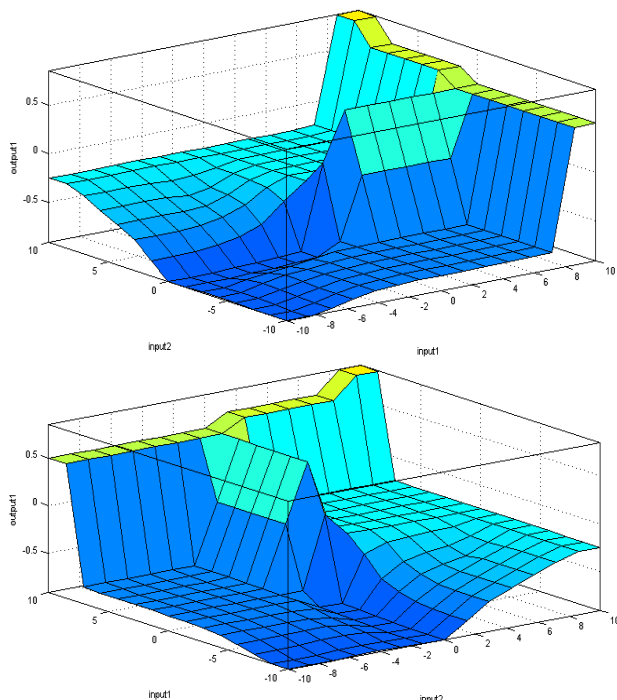


Fig.10. Different of the surface viewer

- (a) X-axis:Input-1, Y-axis:Input-2,Z-axis:output
- (b) X-axis:Input-2, Y-axis:Input-1,Z-axis:output
- (c) X-axis:Input-3, Y-axis:Input-1,Z-axis:output
- (d) X-axis:Input-3, Y-axis:Input-2,Z-axis:output

#### IV. SIMULATION AND HARDWARE IMPLEMENTATION OF DESIGNED FLC CONTROLLER

The schematic circuit diagram of the projected scheme is shown in Fig.11. In Straight coupled scheme the solar photovoltaic panel is directly joined across the resistive



load. The PPP is not transmitted to the load because the source and load are not properly matched. A DC to DC converter buck-boost converter serves the resolve of transporting PPP from the solar PV panel to the load resistance [21]. The DC to DC buck-boost zeta converter acts as a boundary between the photovoltaic panel and the resistive load [22].

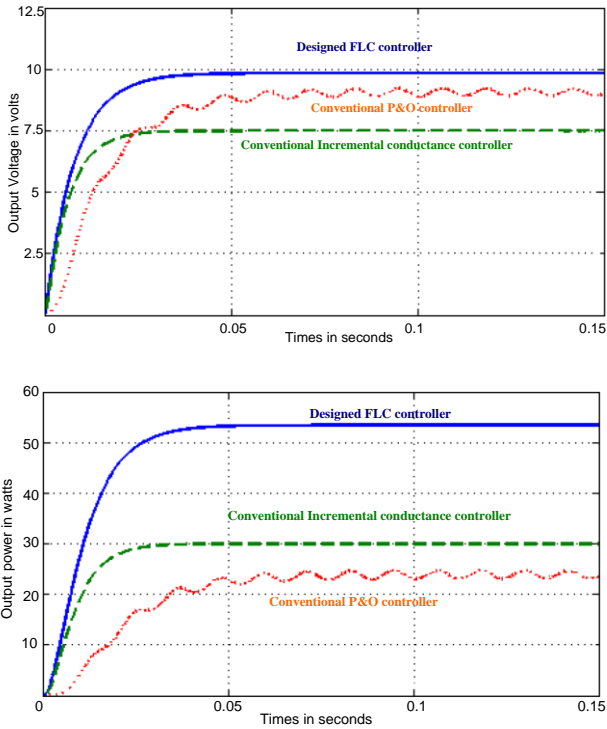


Fig.12.Solar illumination of 500 W/m<sup>2</sup> (a) Output voltage  
(b) Output power

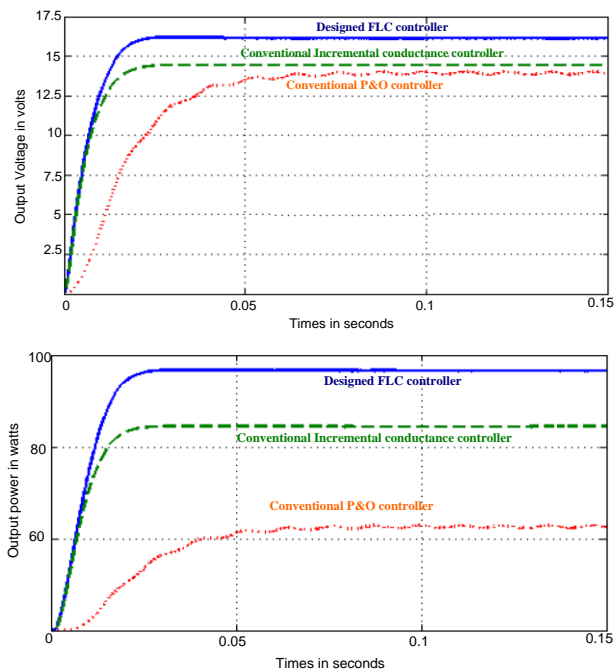


Fig.13.Solar illumination of 950 W/m<sup>2</sup> (a) Output voltage  
(b) Output power

The Matlab simulation result shows in Fig.12 and Fig.13 are obtained when different irradiance and temperature. In Fig.12 shows the output voltage and output power of DC to DC converter, the panel receive uniform illumination of 500 watt per square meter thus indicating the three controllers such as conventional P&O, conventional incremental conductance controller, and designed FLC technique. In further detail analysis of the proposed system change the illumination of PV panel from 500 watt per square meter into 950 watt per square meter thus indicating the output voltage and power of the same three controllers is illustrated in Fig.13.



Fig.14. Laboratory setup of solar PV modules

In order to transfer the functioning point of the PV module panel to the PPP, a closed loop structure must be executed to sense the current and voltage. After detecting V & I of the two parameters, an FLC algorithm must be applied to produce the error (E) signal. The E is normally in digital form is send into the digital to analog converter (DAC -0808) which changes it to the consistent analog pulses. This analog signal is then matched with a great frequency triangular wave single of 20 kHz. The pulse created is fed to the gate terminal of the power semiconductor (Mosfet) device, thereby varying the D of the converter. This produced pulse must be intelligent to initiate the semiconductor MOSFET of the DC to DC power circuit. Thus the load impedance is synchronized with the source impedance and peak power is moved. The experimental setup of the designed system is illustrated in Fig.11. Some results acquired from the Matlab Simulation were confirmed. Fig.14 displays a setup of solar PV panels connected in series arrangements. The panel is tilting stand preparation is used. Digital Storage Oscilloscope (DSO) was utilized to track the real PV



characteristics. From the experimental results conclude that the solar illumination has been observed as proportional to short circuit current. Fig.15. shows the gate pulses generated by PIC microcontroller with different weather conditions are introduced [22].

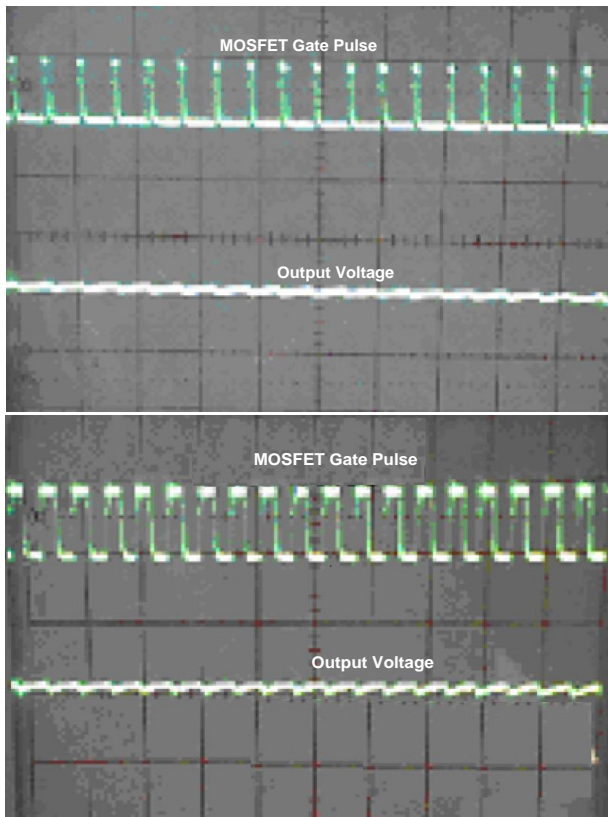


Fig.15. Experimental waveform of gate pulse and output voltage with various illumination conditions.

### V. Conclusion

In this paper, a new FLC search maximum tracking technique is used to trace the peak power under partial shaded situation. Characteristics of the solar photovoltaic system have been offered for emerging the accurate model of solar PV module. It is verified that the a new FLC search technique trace the peak power when numerous peaks exist in the I-V and V-P characteristics using Matlab simulation and practical experimental. Here purely implemented in the electrical tracking technique. In addition, it is also confirmed that the optimized FLC control advances the tracing performance matched with the traditional P&O which eludes the modification of controller parameters. Using the designed optimized Fuzzy Logic controller enhanced standalone photovoltaic module tracing performance is realized under different weather conditions. The merits of the designed artificial intelligent FLC techniques like various weather

conditions and variance evolution for modification the fuzzy rules need to be inspected.

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