Comparative Analysis of Adaptive P&O and Fuzzy Logic Controller Technique for MPPT in Solar PV System

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Abstract— In this paper Adaptive Perturb and Observe using Fuzzy logic controller is used to improve the efficiency and faster response compared to the P & O technique. The PV cell module is connected to the boost converter and MPPT techniques. P & O with fixed perturb either conventional or modified suffers from disadvantages such as oscillations around maximum power point technique. It is known that the P&O method exhibits erratic behavior under rapidly changing irradiance level that causes incorrect or slow maximum power tracking. To overcome P & O oscillations I go for Adaptive P & O maximum power point tracking (MPPT) is proposed to track the maximum power under sudden changes in irradiance. Adaptive P&O tracking method without having oscillations around the MPPT. To enhance the performance of the P & O algorithm, this project presents the application of adaptive perturb and observe technique using fuzzy logic controller. Here the input variables of the controller are transformed into linguistic variables which associate with a set of rules results the displacement of the operation around MPPT form the photo voltaic cell to the load. Hence, the proposed method offers better output results with reduced oscillations. The simulation and experimental studies show that the proposed algorithm gives faster response than the conventional p and o algorithm. In this paper MATLAB simulink is used for analysis efficiency.

Key words: Solar PV Panel, Boost Converter, Perturb and Observe, Fuzzy Logic Controller

I. INTRODUCTION

The global demand for electrical energy has increased continuously over the last few decades. In today's world energy and environment have become serious concerns. Hence alternative sources of energy became more important. Among all renewable energy sources PV sources will have biggest contribution to electric power generation in coming years because installation capacity of PV sources is increasing year by year. In 2009 , 7.4GW of new PV capacity was added worldwide and new PV installations grew by a massive 130% to reach 17.5GW in 2010.Installations could see double digit growth in 2011 to reach 20.5GW making a total capacity of 58GW by the end of the year. IMS research predicts that installation of 35GW will come up by 2014.

Stand-alone applications include water pumping, domestic and street lighting, electric vehicles, military and space applications whereas grid connected configurations include hybrid systems and power plants etc..In general there is only one point on P-V and V-I curve called the maximum power point. At this point only PV system operates with maximum efficiency and produces maximum output power.

A common MPPT Technique is well known as power feedback method which measures the power of PV array and uses it as feedback variable. Based on power feedback there are three important tracking techniques used in PV systems. They are the Perturbation and Observation (P&O), the hill climbing method, the incremental conductance method. In both P & O and Incremental conductance methods the voltage at maximum power point (Vmpp) is continuously tracked till it satisfies the equation dp/dv=0 where P represents PV array output power and V is voltage. But in hill climbing method Vmpp is tracked by making dp/dv=0 where D is duty cycle.

Among all MPPT methods P&O techniques are widely used because of simplicity and good performance. But P&O techniques suffer with speed versus oscillations trade off problem because of using fixed perturb value. Hence for improved performance adaptive P&O using fuzzy logic controller are used. These techniques are simulated under varying weather conditions.

II. BLOCK DIAGRAM OF PV SYSTEM

It consists of PV array, Boost converter, MPPT block, and finally load. Combination of Series and parallel solar cells constitute PV array. Series connection of solar cells boost up the array voltage and parallel connection increases the current.

In order to change the input resistance of the panel to match the load resistance (by varying the duty cycle), a DC to DC converter is required. Boost converter is used to obtain more practical uses from solar panel.

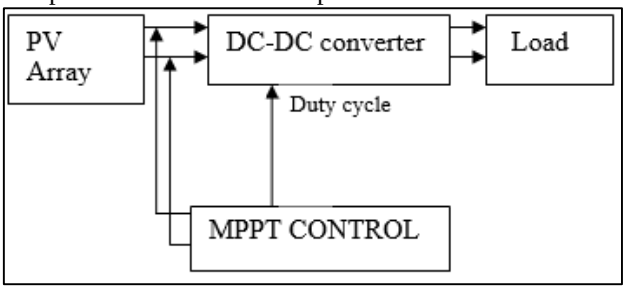


Fig 1. Block Diagram

The input of boost converter is connected to PV array and output is connected to load. MPPT block receives and signals from PV array. The output of MPPT block is series of pulses. These pulses are given to boost converter. Converter works based on these pulses to make the PV system operate at Maximum power point (MPP).

III. MODELING OF PV CELL

The PV cell model is represented by equivalent electrical circuit. The model contains a current source I_{ph}, diode, series resistance Rs, shunt resistance R_{sh} and load. The current source produces I_{ph} which depends on radiation. The output

current is the difference between photo current I_{pv} and diode current I_o.

$$I_{pv} = I_{ph} – I_o - I_{rs}$$

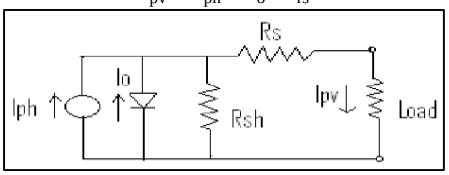


Fig 2. PV Cell Model

The equations of PV module are as follows:

Current output of PV module is given by,

$$I_{pv} = N_p * I_{ph} – N_p * I_o [\exp (q (V_{pv} + I_{pv} * R_s) / NSKTCA) – 1] - V_{pv} + I_{pv} * R_s / R_{sh}$$

Output voltage of PV cell is given by,

$$V_{pv} = NSAKT/q [\ln (N_p * I_{ph} – I_{pv} / N_p * 10) + 1] – I_{pv} R_s$$

The PV cell output voltage is a function of the photocurrent that mainly determined by load current depending on the solar irradiation level during the operation.

Module photo current is given by,

$$Iph = [Isc + ki (T – 298) * \lambda / 100$$

Module reverse saturation current is given by,

$$I_{rs} = I_{sc} / \exp (q * V_{oc} / NSAKT – 1)$$

Module saturation current is given by,

$$I_o = I_{rs} * [T / T\gamma] 3 \exp \{q * E_{go} / B*K [1 / T_r – 1 / T_k]\}$$

Where,

I_{ph} - Light generated current in a PV cell
I_o - PV cell Saturation current in (A)
I_{pv} - Output current of PV cell in (A)
V_{pv} - Output voltage of PV cell in (V)
N_s - Number of cells connected in series
N_p - Number of cells connected in parallel
A - Ideality factor =1.6
K - Boltzmann constant = 1.3805e-23Nm/K
T - Cell operating temperature in Kelvin
T_γ - Reference temperature in Kelvin
Q - Electron charge=1.6e-19 coulombs
K_i - Temperature coefficient
I_{sc} - Short circuit current in (A)
I_{rs} - Reverse saturation current in (A)
E_{go} - Band gap energy for silicon = 1.1 eV
R_s - Series resistance of PV cell in (Ω)
R_{sh} - Shunt resistance of PV cell in (Ω)
λ - PV cell illumination (MW/m2) = 1000 MW/m2
B - Ideality factor =1.6

k and t should have same temperature unit either in Kelvin or Celsius and ideality factor A is used to make the I-V characteristics to fit the curve actual characteristics. Full array voltage is calculated by multiplying the voltage of PV cell with number of cells connected in series. Similarly array current is obtained by dividing cell current with number of cells connected in parallel. The I-V and P-V curves for a solar cell are given in the following below figure. It can be seen that the cell operates as a constant current source at low values of operating voltages and a constant voltage source at low values of operating current.

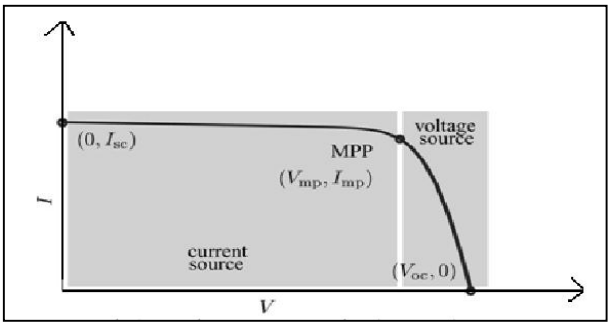


Fig. 3: Maximum Power Point (Vmp , Imp)

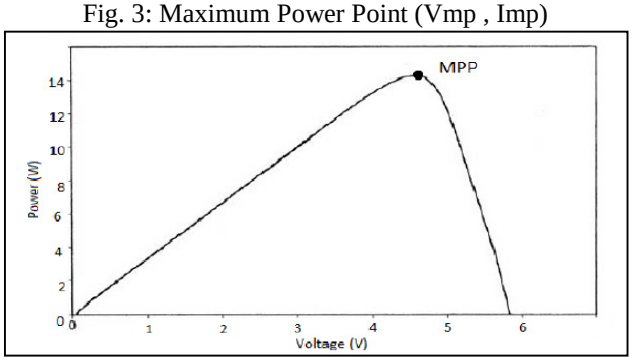


Fig. 4: P-V characteristics of a solar panel

Characteristic V-I curve of a practical PV device with three remarkable points shown in figure no 3.These are short circuit (0,Isc), MPP (Vmp, Imp) and open circuit (Voc, 0). V-I curves has only one maximum power point (Vmp, Imp). If load operating point coincides with this point maximum power is delivered by PV array.

IV. MAXIMUM POWER POINT TRACKING TECHNIQUES

The photovoltaic module operation depends strongly on the load characteristics, to which it is connected. Indeed, for a load with an internal resistance iR, the optimal adaptation occurs only at one particular operating point, called Maximum Power Point (MPP) and noted in our case max P. Thus, when a direct connection is carried out between the source and the load, the output of the PV module is seldom maximum and the operating point is not optimal. To overcome this problem, it is necessary to add an adaptation device, MPPT controller with a DC-DC converter, between the source and the load. So the MPPT controller is also required to track the new modified maximum power point in its corresponding curve whenever temperature and/or insulation variation occurs.

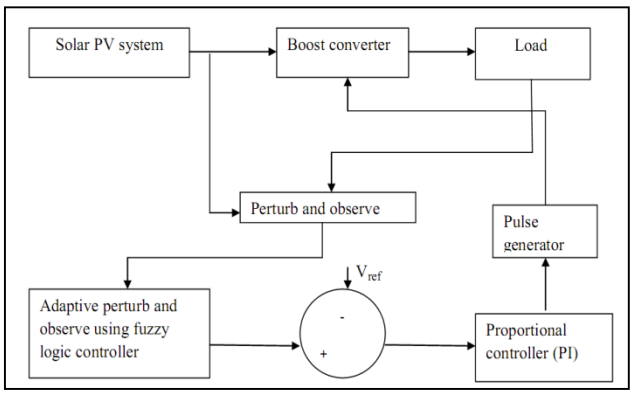


Fig. 5: Block diagram

The efficiency of a solar cell is very low. In order to increase the efficiency, methods are to be undertaken to match the source and load properly. One such method is the maximum power point tracking (MPPT). In photovoltaic systems the I-V curve is non-linear, thereby making it difficult to be used to power a certain load. This is done by utilizing a boost converter whose duty cycle is varied by using an MPPT algorithm. A boost converter is used on the load side and solar panel is used to power this converter.

A. Perturb and observe

A P&O method is the most simple, which moves the operating point toward the maximum power point periodically increasing or decreasing the PV array voltage by comparing power quantities between in the present and past. If the power increased, the perturbation is continuous in the same direction in the next perturbation cycle, otherwise the perturbation direction is reversed.

This way, the operating point of the system gradually moves towards the MPP and oscillates around it in steady-state conditions. Large perturbation step sizes yield fast tracking of the MPP under varying atmospheric conditions but result in reduced average power conversion in steady state due to large oscillations around the MPP.

It was proved that the P&O MPPT control system sometimes deviates from the maximum operating point in case of rapidly changing atmospheric conditions, such as broken clouds.

Another disadvantage is that this simple tracking method has difficulty in providing good performance in both dynamic and steady-state responses. Hence the famous tradeoff problem between faster response and steady-state oscillations is inherent. Moreover, the perturbation is not generic. For fixed perturb values the oscillations in steady state are proportional to perturb value.

If perturb value is high oscillations are high, if perturb value is low the output response is very slow. Hence with fixed perturb value tradeoff problem exists between faster response and steady state oscillations. Hence to increase performance a variable perturb is used.

B. Flowchart for Perturb and Observe

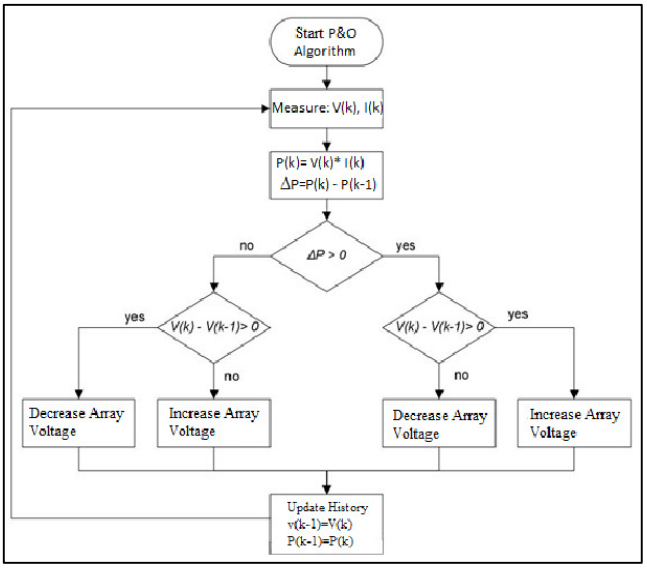


Fig. 6: Flowchart for perturbs and observe

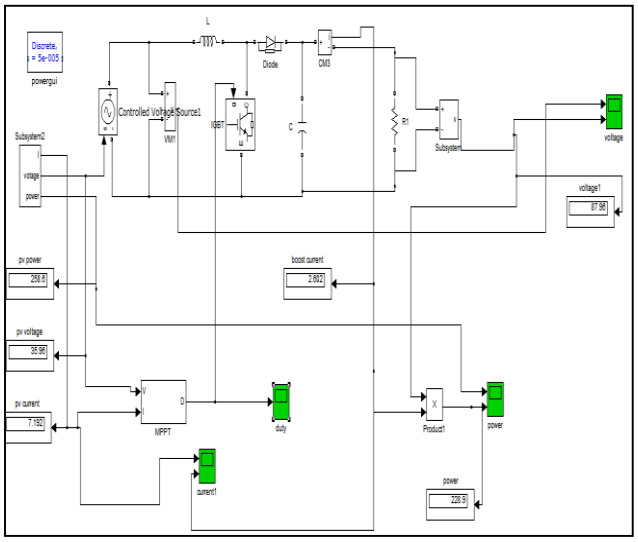


Fig. 7: Perturb and Observe

C. Adaptive perturb and observe

The P&O involves perturbation in the array operating voltage or current. Perturbing means either incrementing or decrementing PV array voltage. If PV array voltage is increased, power of PV array increases. Hence in the next perturbation also voltage is increased. This process is continued till power reaches Maximum Point. At maximum point if voltage is increased further PV array power decreases.

Hence perturbation is made negative at this point that means voltage is decreased. The system oscillates at this maximum point. To reduce these oscillations the perturbation size is decreased but this smaller perturbation size slows down the system. Hence speed versus oscillations problem exists with P&O method with fixed Perturb value. To avoid this problem adaptive perturb method is used.

The main idea behind this technique is that at the start of any hill climbing technique, large perturb steps are needed to quickly reach the MPP, and as the MPP is approached, the perturb value needs to be decreased to avoid large oscillations around this maximum output power operating point.

This adaptive technique utilizes the error between two successive array power signals calculated from the measured array voltage and current signals to create an adaptive perturb and observe.

Basically, at the start of the hill climbing process, this error is large and decreases as the maximum power operating point is approached at steady state. Therefore, this error can be treated like an error signal in a closed-loop system that needs to be minimized at steady state, prevented from overshoot at startup, and free from steady-state oscillations.

The simplest clue to achieve all these targets is to treat this error signal using a conventional PI controller, which is the main core of this technique. Even though perturb is adaptive, still there without oscillations around MPP and gives faster response.

V. PROPORTIONAL INTEGRAL (PI) CONTROLLER

The system also employs a PI controller. The task of the MPPT algorithm is just to calculate the reference voltage V_{ref} towards which the PV operating voltage should move next for obtaining maximum power output. This process is repeated periodically with a slower rate of around 1-10 samples per second. In this project, K_p is taken to be 0.00423 and K_i is taken to be 150. A relatively high KI value ensures that the system stabilizes at a faster rate. The PI controller works towards minimizing the error between Vref and the measured voltage by varying the duty cycle through the switch. The switch is physically realized by using an IGBT with the gate voltage controlled by the duty cycle.

VI. FUZZY CONTROLLER

A. Fuzzy Control System Design

Fuzzy logic control has found many applications in the past decade. This is so largely because fuzzy logic control has the capability to control nonlinear, uncertain system even in the case where no mathematical model is available for the control system.

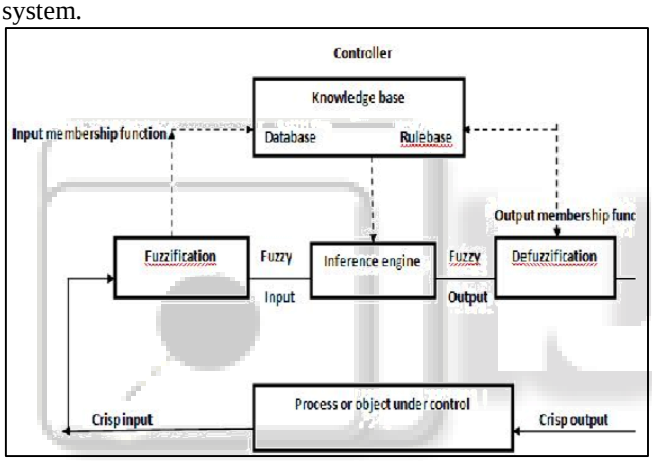


Fig. 8: Block diagram for fuzzy logic controller

Fuzzy logic is one of the most powerful control methods. It is known by multi-rules-based resolution and Multivariable consideration. Fuzzy MPPT is popular for over last decade. Fuzzy logic controllers (FLC) have the advantages of working with imprecise inputs, no need to have accurate mathematical model, and it can handle the nonlinearity. It consists of two inputs and one output. The two FLC input variables are the error (E) and change of error (CE) that expressed by,

$$E(j) = P_{pv}(j) - P_{pv}(j-1) / V_{pv}(j) - V_{pv}(j-1)$$

$$CE(j) = E(j) - E(j-1)$$

Where Ppv, Vpv are the PV power and voltage respectively at instant j. E (j) shows if the load operating point at the instant j is located on the left or on the right of the maximum power point on the P-V characteristic where it is equals to zero at MPP. While the change of error CE (j) expresses the moving direction of this point. Where the control action duty cycle D used for the tracking of the maximum power point by comparing with the saw tooth waveform to generate a PWM signal for the boost converter.

B. Fuzzification

The fuzzification is the process of converting the system actual inputs values E and CE into linguistic fuzzy sets using fuzzy membership function. These variables are expressed in terms of four linguistic variables such as VL (Very low), L(Low), M (medium) and H (high) using basic fuzzy subsets.

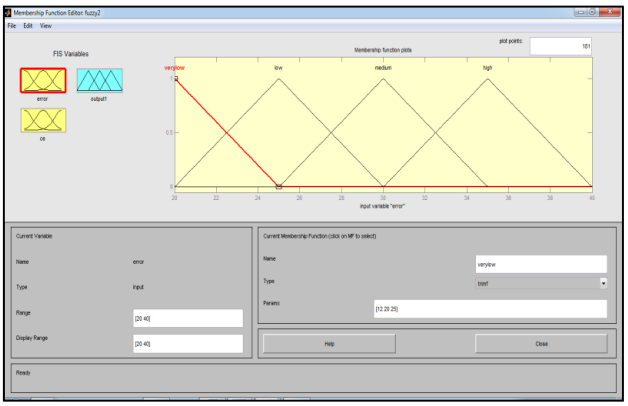


Fig. 9: Membership function editor

C. Rule base and Inference Engine

Fuzzy rule base is a collection of if-then rules that contain all the information for the controlled parameters. The fuzzy rule algorithm includes 16 fuzzy control rules.

Fuzzy inference engine is an operating method that formulates a logical decision based on the fuzzy rule setting and transforms the fuzzy rule base into fuzzy linguistic output. Basically a linguistic controller contains rules in the If-then format. Here used four variables for one input, then totally 16 rules.

For example

- If error is VL and change in error rate is VL then output is H
- If error is VL and change in error rate is L then output is M
- There is four linguistic variables create 16 rules.

D. Defuzzification

Defuzzification of the inference engine, which evaluates the rules based on a set of control actions for a given fuzzy inputs set. This operation converts the inferred fuzzy control action into a numerical value at the output by forming the union of the outputs resulting from each rule. The center of area (COA) algorithm is used for defuzzification of output duty control parameter. If E is VL and CE is VL then crisp D is VH, it means that if the operating point is far away from the MPP by the right side, and the variation of the slope of the curve is almost Zero; then increase the duty cycle.

VII. SIMULATION RESULTS

The PV array is simulated by using matlab/simulink environment. The P-V and V-I curves of PV array at temperatures and irradiances are shown in figures

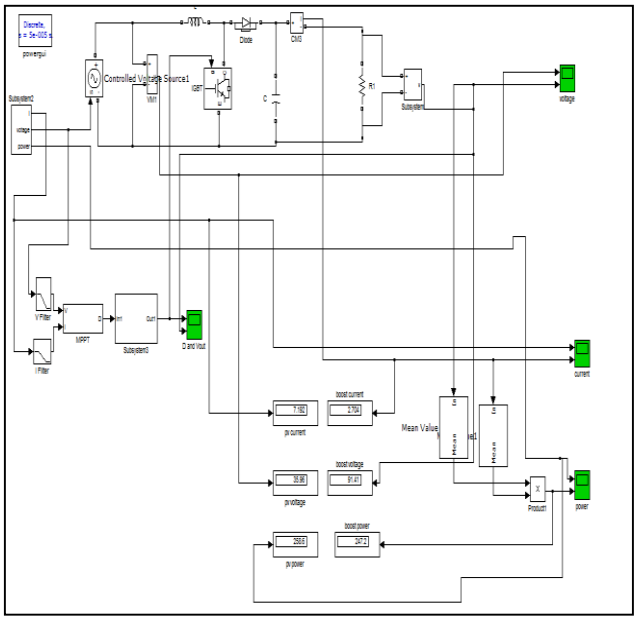


Fig. 10: Adaptive perturb and observe using FLC

A. Specification of 300w Solar PV Panel

Parameter	Specification
Short circuit current(Isc)	7.34A
Opencircuitvoltage(Voc)	48V
Current at P_{max} (I_{max})	7.192A
Voltage at P_{max} (V_{max})	35.96V
Maximum power (P_{max})	258.6W

Table 1: Specifications of PV panel parameter

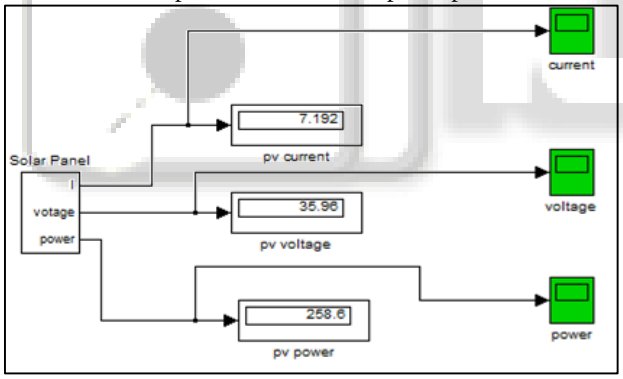


Fig. 11: Solar photovoltaic systems

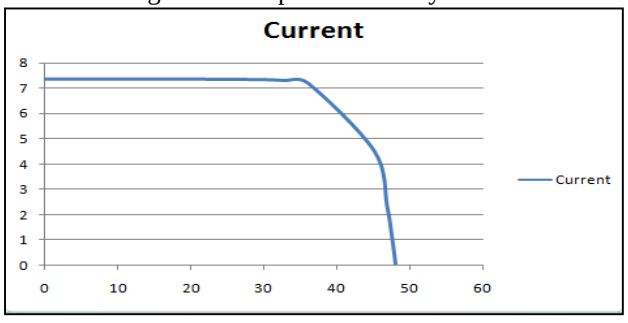


Fig 12 V-I Characteristics

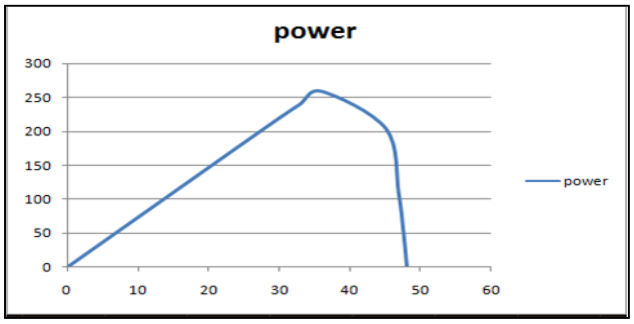
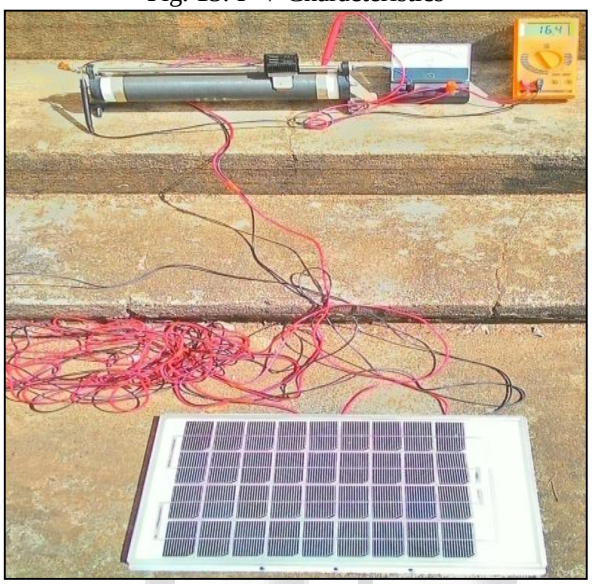


Fig. 13: P-V Characteristics



B. Boost Converter Specifications

D=0.8; r=13Ω; L=0.4MH; C=340µf

Simulation output for perturb and observe at irradiance 1000 W/m^2

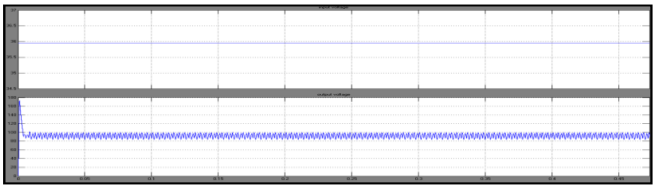


Fig. 14: Voltage output

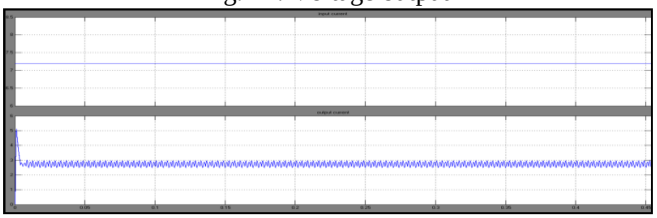


Fig. 15: Current output

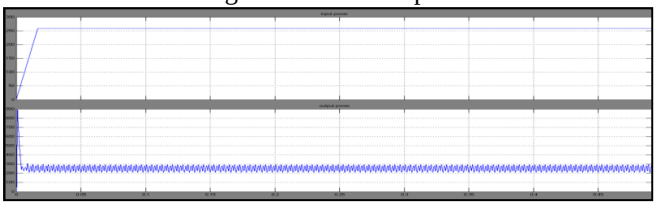


Fig. 16: Power output

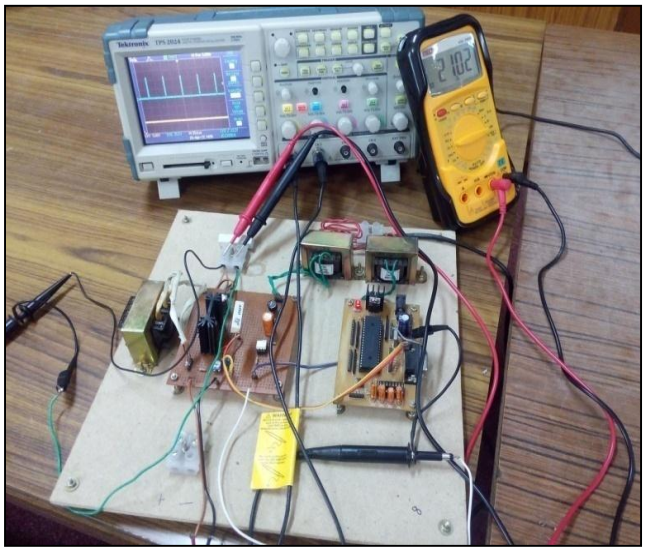


Fig. 17: Hardware output for Adaptive Perturb and Observe during that time solar panel irradiance level.

C. Simulation Output For Adaptive Perturb and Observe Using Fuzzy Logic Controller for Irradiance 1000 W/M²

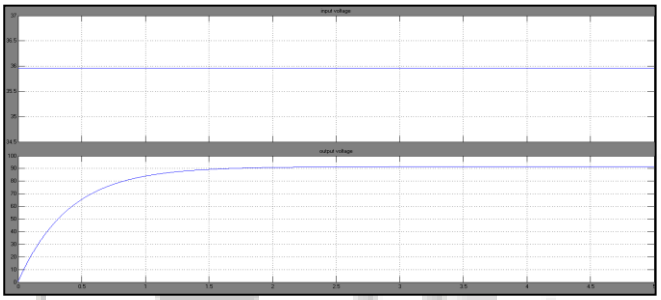


Fig. 18: Output voltage

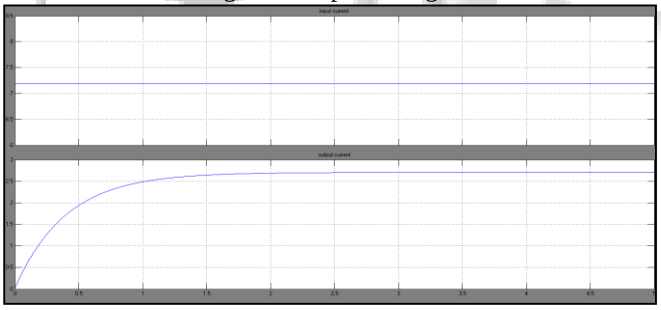


Fig. 19: Output current

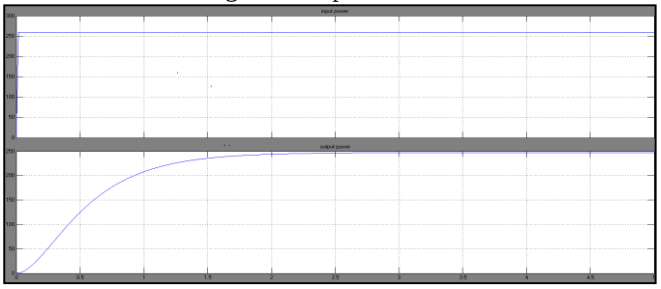


Fig. 20: Output power

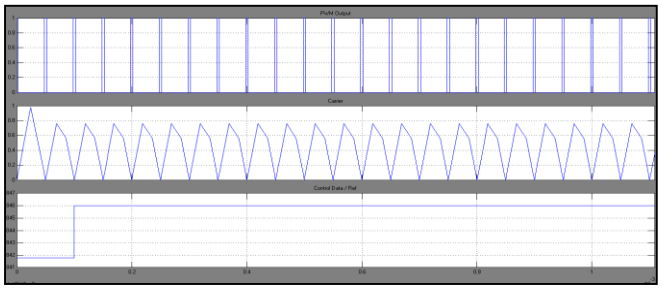


Fig. 21: PWM output

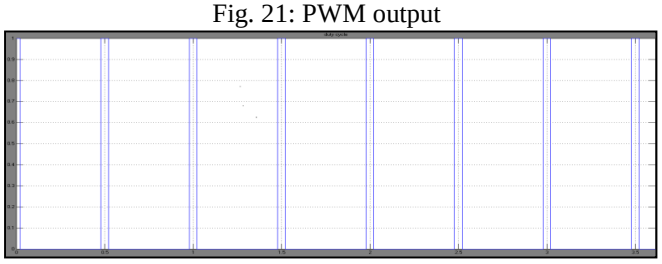


Fig. 22: Duty cycle output

D. Hardware Output For Adaptive Perturb and Observe using Fuzzy Logic Controller During That Time Solar Panel Irradiance Level.

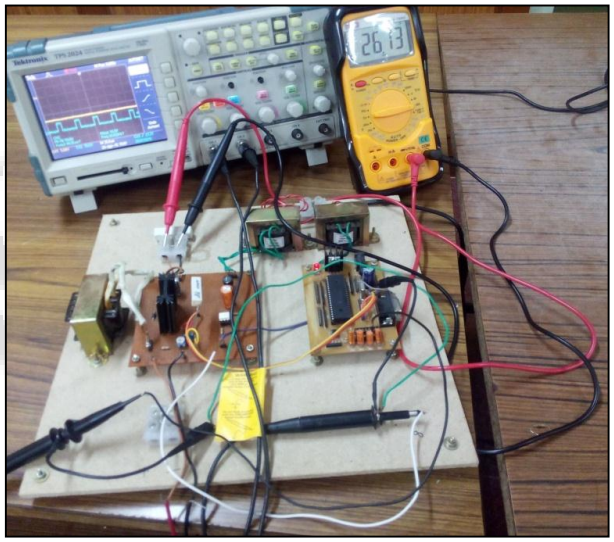


Fig. 23: Hardware output for adaptive perturb and observe using fuzzy logic controller

E. Comparison of Software and Hardware MPPT Techniques at a Temperature of 25°C and Irradiance of 1000 w/m2

S.no	Mppt techniques	Voltage	current	power
1	P &O	87.96	2.602	228.9
2	AP &O using fuzzy logic controller	91.41	2.704	247.2
3	P &O (Hardware)	21	1.504	31.584
4	AP &O using fuzzy logic controller (Hardware)	26	1.98	51.48

Table II:

VIII. CONCLUSION

The proposed MPPT algorithm is verified for sudden changes in irradiance through digital simulations using MATLAB have been verified with hardware results. Reduces the

oscillations and tracks the MPPT faster response, irrespective increase or decrease in irradiance. The proposed adaptive P & O with fuzzy logic based MPPT technique can track the maximum power point faster compared to the P & O based MPPT technique. Fuzzy logic can improved the dynamic performance of the system. The result of simulation and experimental studies show the efficiency of the adaptive p&o with fuzzy logic controller in maintaining the stable maximum power point tracking. The computational efforts caused due to the derivatives as explained in Incremental conductance method are absent. Hence, the proposed method offers better output results with reduced oscillations. The simulation and experimental studies show that the proposed algorithm gives faster response than the conventional p and o algorithm.

IX. FUTURE WORK

In future analysis can be extended for hardware and their performance is analyzed under varying irradiance conditions. Further work is needed to assess the impact of the converters in solar photovoltaic system which should be accounted for the economic analysis.

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