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Fuzzy Logic Controller Based Maximum Power Point Tracking of Photovoltaic System using CUK Converter

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***Abstract*— Today, the energy crisis in the world has led to the increase use of renewable energy sources. With the improvement in power electronic tools, the solar photovoltaic energy has been considered as an important renewable energy resource because it is clean, reduce green house effect and pollution free. The efficiency and performance of the photovoltaic system may be increased by using Maximum Power Point Tracking (MPPT) techniques. A number of algorithms are developed to track the maximum power point effectively. This paper proposed an fuzzy logic controller (FLC) based CUK converter for maximum power point tracking (MPPT) of a photovoltaic (PV) system under variable operating conditions. The FLC projected that the Unsymmetrical membership function gives faster response than the symmetrically distributed membership functions. The fuzzy logic controller for the CUK MPPT scheme shows smooth change of current and no change (Constant) of Voltage in variable-load, represented in little steady state error and overshoot. Here in this paper, intelligent control method uses a Fuzzy Logic Controller applied to a DC-DC converter device. The performance of the converter is tested in MATLAB simulation at different operating conditions.**

***Keywords*— Photo voltaic System, Maximum Power Point Tracking (MPPT), DC-DC CUK Converter, Fuzzy Logic Controller, P&O Algorithm.**

I. INTRODUCTION

One of the major concerns in the power sector is the day to day rising power demand but the lack of enough resources to meet the power demand using the conventional energy sources. The frequent use of fossil fuels has caused the fossil fuel deposit to be reduced and has considerably affected the environment depleting the biosphere and cumulatively adding to global warming [6]. Demand has increased for renewable sources of energy to be utilized along with conventional systems to meet the energy demand. Thus the growing demand on electricity, the limited supply and increasing cost of conventional sources such as coal, fossil fuels and petroleum etc has lead to the use of renewable energy sources. Utilization of renewable energy resources is the demand of today and the requirement of tomorrow. With advancement in power electronic technology, solar power generation system has attracted more attention due to the energy crisis and environment pollution problem. The extraction of maximum available power from a photovoltaic module is called Maximum Power Point Tracking and is done by Maximum Power Point Tracking methods.. The efficiency of the photovoltaic system may be substantially increased by using Maximum Power Point Tracker (MPPT) [5]. PV power generation systems have one big problem that the amount of electric power generated by PV module is always changing with weather conditions. i.e., irradiation. Therefore, a Maximum Power Point Tracking (MPPT) method to achieve maximum power (MP) output at real time becomes necessary in PV generation systems. The amount of power generated by a PV depends on the operating voltage of the array. A PV's maximum power point (MPP) varies with solar temperature and Irradiation. Its Voltage-Current and Voltage-Power characteristic curves denote a unique operating point at which maximum possible power is reached. At the Maximum Power point, the PV operates at maximum efficiency. Therefore, many methods have been introduced to determine MPPT for a particular value. The conventional MPPT methods are generally classified into the following groups such as Perturbation and observation (P&O) methods, Incremental conductance methods, Constant current or constant voltage etc. Among them the P &O method has drawn much attention due to its simplicity.

II. MAXIMUM POWER POINT TRACKING

A typical solar panel converts only 40 to 50 percent of the incident solar irradiation into electrical energy. MPPT technique is used to improve the efficiency of the PV panel. Maximum Power Transfer theorem says, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance. When a PV module is directly connected to a load, see fig.1.

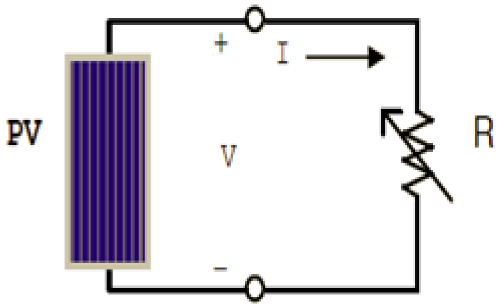


Fig 1. Direct Coupled Load

method, Short Circuit Current method, Perturbation and observation (P&O) methods, Incremental conductance methods, Constant current or constant voltage Feedback of power variation with voltage technique, Feedback of power variation with current technique etc [1-4].Among this P&O method is widely used due to its simplicity. The P&O algorithm is the simplest method, which results in low cost of installation and it may be competitive with other Maximum Power Point Tracking algorithms.

A. Perturb and Observe Algorithm

In this method a small perturbation is introduced to the system. Due to this perturbation the module power changes. If the power increases due to the perturbation then the perturbation is continued in the same direction. After the maximum power is reached the power at the next instant decreases and hence after that the perturbation is reversed. When the steady state is reached the above algorithm oscillates around the maximum point. In order to keep the variation of power is small the perturbation size should be kept very small as shown in Fig2.

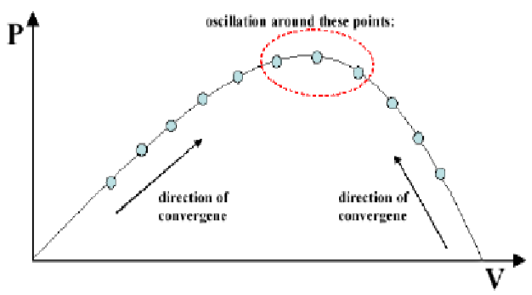


Fig. 2. Perturb and Observe Algorithm

The flow chart of the above algorithm is shown in the Fig. 3. The algorithm measures the value of current and voltage from the solar photovoltaic module. Power is calculated from the PV current and Voltage. The value of power and voltage at k^{th} instant are stored. Then next values at $(k+1)^{th}$ instant are measured again and power is calculated from measured values. The voltage and power at $(k+1)^{th}$ instant are subtracted with the values from k^{th} instant. If we monitor the power voltage curve of the solar pv module we observe that in the right hand side of the curve where the voltage is almost constant and the slope of power voltage is negative (dP/dV<0) whereas in the left hand side of the slope is positive.(dP/dV>0). The right hand side curve is for the lower duty cycle (nearer to zero) where as the left hand side curve is for the higher duty cycle (nearer to unity). Depending on the sign of dP (P (k+1) - P (k)) and dV (V (k+1) -V (k)) after subtraction the algorithm decides whether to increase the module voltage or to reduce it [12].

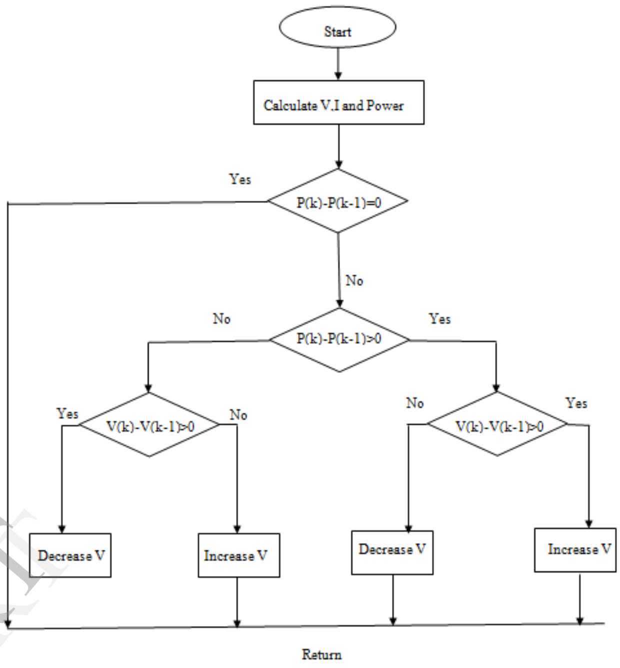


Fig.3 Flow Chart of Perturb and Observe.

Table 1 The Operation of P&O Algorithm

ΔP_{PV}	ΔV_{PV}	**Perturbation**
>0	>0	Increase V
>0	<0	Decrease V
<0	>0	Decrease V
<0	<0	Increase V

Table 1 summaries the operation of the P&O algorithm. From the above table the change in power and voltage increases or decreases means perturbation of the voltage increased and kept in the same direction to reach maximum power point. The change of power increases and voltage decreases and vice-versa means the perturbation of voltage reversed to reach MPPT.

III. PROPOSED SYSTEM

The system consists of a PV panel connected to a CUK converter to enhance and regulate the output voltage [11]. It drives the DC load by using the power tracked from the solar panel. The MPPT is used to track the maximum power from solar panel. The block diagram of the proposed system is shown in Fig.4

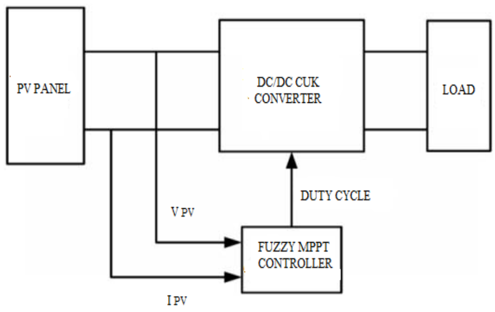


Fig.4 Block diagram of the proposed system

A. *Photovoltaic System*

Photovoltaic (PV) are solid-state, semi-conductor type devices which produce electricity when it observes light. The word PV means "electricity from light." The building block of a solar panel is solar cell. A photovoltaic module is formed by connecting many solar cells in series and parallel. The equivalent circuit of a solar cell is shown in Fig. 5.

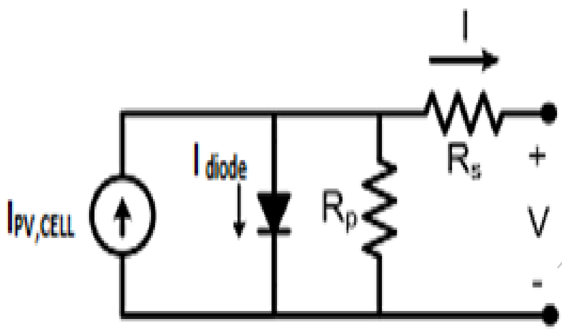


Fig 5: Equivalent circuit of a solar cell

The modeling of this solar cell can be developed based on equation (2.1),

$$I = I_{PV,CELL} - I_{diode} = I_{PV,CELL} - I_{0,CELL}\left[EXP\left(\frac{q * V}{\propto * k * T}\right) - 1\right]$$

Where ,

- $I_{PV,cell}$ is the current produced by the incident light.
- I_{diode} is the Shockley diode equation.
- I_0,cell [A] is the reverse saturation or leakage current of the diode [A].
- q is the electron charge [1.60217646 *10^{-19}C].
- k is the Boltzmann constant [1.3806503 *10^{-3}J/K].
- T [K] is the temperature of the P-N junction.
- α is the diode ideality constant which lies between 1 and 2 for mono crystalline silicon.

The characteristic equation of a solar module is dependent on the number of cells in connected in parallel and series [7]. The current variation occurs is less dependent on the shunt resistance and is more dependent on the series resistance. Fig.6 shows the P-V, I-V curve of a solar panel. It can be seen that the cell operates as a constant current source at minimum values of operating voltages and a constant voltage source at low values of operating current [8].

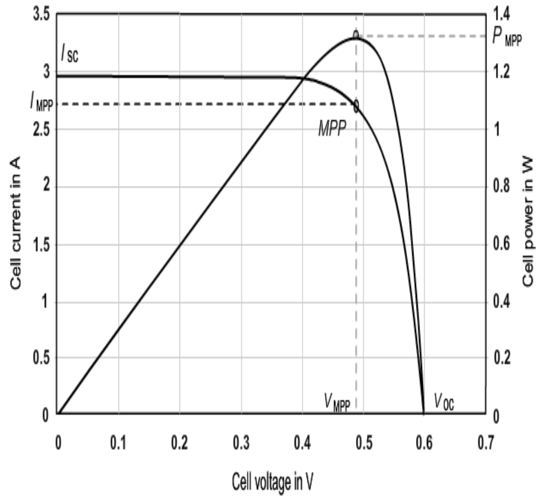


Fig.6: P-V I-V curve of a solar cell at given temperature and solar irradiation

B. CUK Converter

The Cuk converter is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is essentially a boost converter followed by a buck converter with a capacitor to couple the energy. The non-isolated Cuk converter can only have opposite polarity between input and output. It uses a capacitor as its main energy-storage component, unlike most other types of converters which use an inductor. The circuit of the Cuk converter is shown in Figure 3.1 It consists of dc input voltage source Vg, input inductor L_1, controllable switch Q_1, energy transfer capacitor C_1, diode D_1, filter inductor L_2, filter capacitor C_2, and load resistance R.

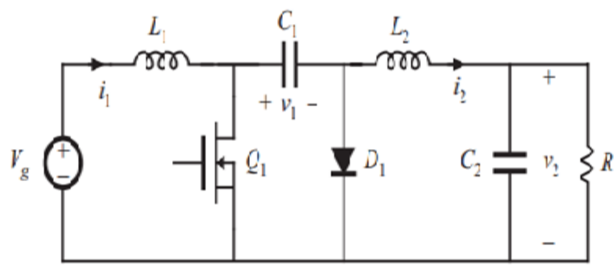


Fig.7 Circuit Diagram of CUK Converter

when the switch is closed (ON), and it is conducting as a short circuit. In this mode, the current through L_1 rises. And at the same time the voltage of C_1 reverse biases diode

D_1 and turn it off. The capacitor C_1 discharges its energy to the circuit C_1-C_2-load-L_2.

when the switch is open (OFF), the diode is forward-biased and conducting energy to the output. The capacitor will start to charge from input supply V_g and the energy stored in the inductor transferred to the load. The capacitor C_1 is the medium for transferring energy from source to load.

$$V_0 = \frac{-V_s D}{(1-D)} \qquad (1)$$

The above equation (1) is called output voltage equation of a converter. CUK converters has low switching losses yields maximum output power, we can assume that input power equal to out-put power.

$$V_s I_s = -V_0 I_0 \qquad (2)$$

$$I_0 = \frac{I_s(1-D)}{D} \qquad (3)$$

The above equation (3) is called output current equation of a converter. Due to low switching losses CUK converter have high efficiency.

IV. FUZZY LOGIC CONTROLLER

Fuzzy logic control is a convenient way to map an input space to output space. Fuzzy logic uses fuzzy set theory, in which a variable is a member of one or more sets, with a specified degree of membership. Fuzzy Logic Controller(FLC) have been introduced in the tracking of the MPP in PV systems [9]. They have the advantage to be robust and relatively simple to design as they do not require the knowledge of the accurate model. They do require in the other hand the complete knowledge of the operation of the PV system by the designer. The design of fuzzy controller was done using Mamdani method for the converter. Fig 7 shows the block diagram for Fuzzy Logic Controller.

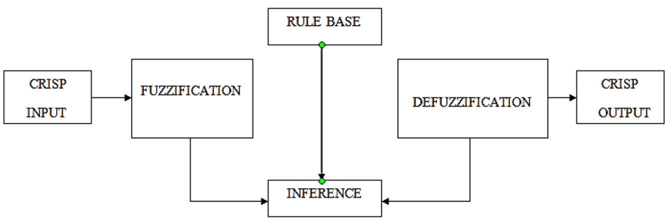


Fig 7: Block diagram for fuzzy logic controller

A fuzzy logic controller basically includes three blocks. They are Fuzzification, Fuzzy Inference and Defuzzification. The FLC requires that each input/output variable which define the control surface be expressed in fuzzy set notations using linguistic levels. The process of converting input/output variable to linguistic levels is termed as Fuzzification. The behaviour of the control surface which relates the input and output variables of the system are governed by a set of rules.

A typical rule would be–"If x is C THEN y is D" [10]. When the rules are fired, the resulting control surface is expressed as a fuzzy set to represent the constraints output. This process is termed as inference. Defuzzification is the process of conversion of fuzzy quantity into crisp quantity. Many methods available for defuzzification. The most commonly used is centroid method.

A. Proposed Fuzzy Logic Controller

Fuzzy logic is implemented to obtain the MPP operating voltage point faster and also it can minimize the voltage fluctuation after MPP has been recognized. The proposed fuzzy logic based MPPT controller has two inputs and one output. The Sign and V_{PV} are the input variables to Fuzzy Logic Controller and The output of the Fuzzy Logic Controller is duty cycle (D) which should be given to the CUK converter.Fig.8 represents the Structure of Fuzzy Logic Controller.

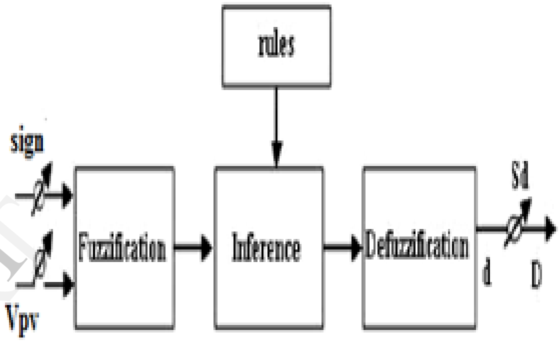


Fig.8. Structure of proposed Fuzzy logic controller

B. FLC for Cuk Converter

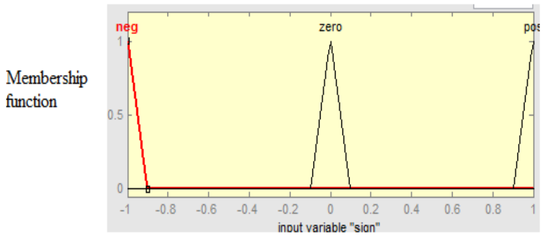
The input variables of the FLC are the sign error and the voltage V_{pv}. The output of the FLC is the duty cycled (D), of the PWM signal, which regulates the output voltage. Figs. 10 shows the membership functions of the inputs and the outputs of the CUK side FLCs. The triangular membership functions are used for the FLC for easier computation.

The universe of discourse for input variable 1 (sign) is divided into three Fuzzy sets Negative (n), Zero (z), Positive(p).The universe of discourse for input variable 2 (Vpv) is divided into 3 Fuzzy sets Low (l), Optimum (o) and high (h) is defined to describe each linguistic variable. The universe of discourse for the output variable (d) is divided into 5 Fuzzy sets: Low negative(ln), High optimum negative(hon), Zero(z), Low optimum positive (lop) and High positive(hp).The fuzzy rules of the proposed PV CUK DC-DC converter can be represented in an un symmetric form as shown in Table 2. Unsymmetrical membership function offers faster response than the symmetrical membership function. Furthermore, as in Figs. 9 the Mamdani fuzzy inference method is used for the proposed Fuzzy logic controller, where the maximum of minimum composition technique is used for the fuzzy inference and the center-of-gravity method is used for the defuzzification method.

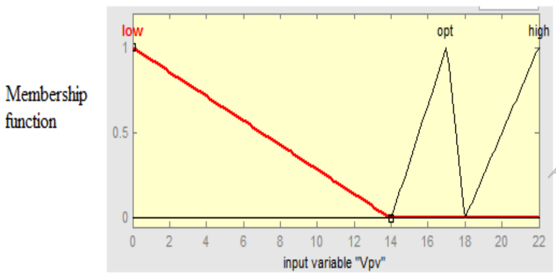
For example, IF (Sign is neg) and (V_{pv} is low) THEN (output is ln)

Table-I
Fuzzy Rule-Based Matrix

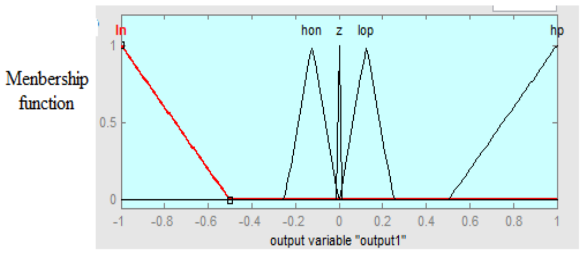
Sign / Vpv	Negative n	Zero z	Positive p
Low l	ln	z	lop
Optimum o	hon	z	lop
High h	hon	z	hp



(a)



(b)



(c)

Fig. 10 Unsymmetrical membership function of the proposed FLC (a) sign (b) Vpv (c) Output

V. SIMULATION AND RESULTS

The simplest model of a Simulation of PV cell consists of an ideal current source in parallel with an ideal diode. It is seen that the temperature and irradiation changes affect the PV output current and voltage. The best conditions are the "standard operating conditions happen at Irradiance equal to 1000W/m², cells temperature equals to 25°C and spectral distribution Air Mass (AM) is equal to 1.5. Fig 11 shows the simulation of PV model Here, Irradiance and temperature are considered as the inputs of the PV system. Table 3 represents the proposed electrical characteristics data of the solar at 25 °C, 1.5AM, 1000W/M^2.

Table 3 Electrical Characteristics Data of the Solar at 25 °C, 1.5AM, 1000W/M^2

Maximum Power (Pmax)	60 W
Open-circuit voltage (Voc)	21.1 V
Short-circuit current (Isc)	3.8 A
Voltage at Maximum Power (Vmp)	17.5 V
Current at Maximum Power (Imp)	3.5 A

In fig. 12 & 13 shows the P-V and I-V characteristics of a PV system and it represents the three remarkable points Voc=21.1V, Isc=3.8A and maximum power point (Pmax=60W, Vmp =17.5V, Imp =3.5A) are shown.

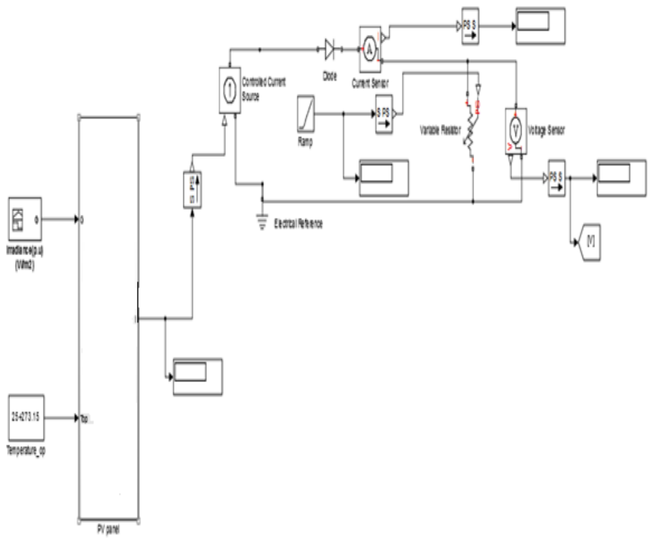


Fig. 11 Simulation of PV cell

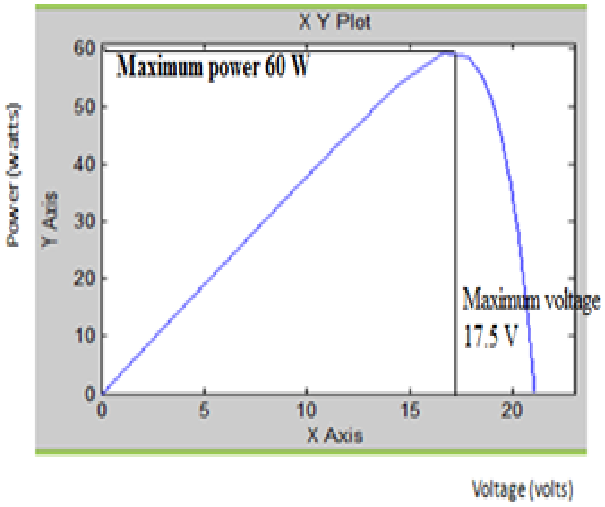


Fig. 12 P-V Characteristics

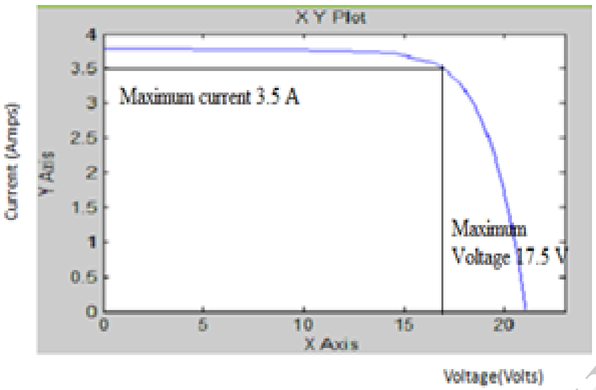


Fig.13 I-V Characteristics

The simulation has been done for a gradual change of solar radiation from 300 to 1000W/m^2 as shown in fig. 14. The fig.15 shows the PV output Voltage (V) ,Current (A) and Power (W). The PV output power (60W) is maintained constant whenever load changes and the corresponding CUK converter output voltage and inductor current is 75 V and 0.75A shown in fig.16.

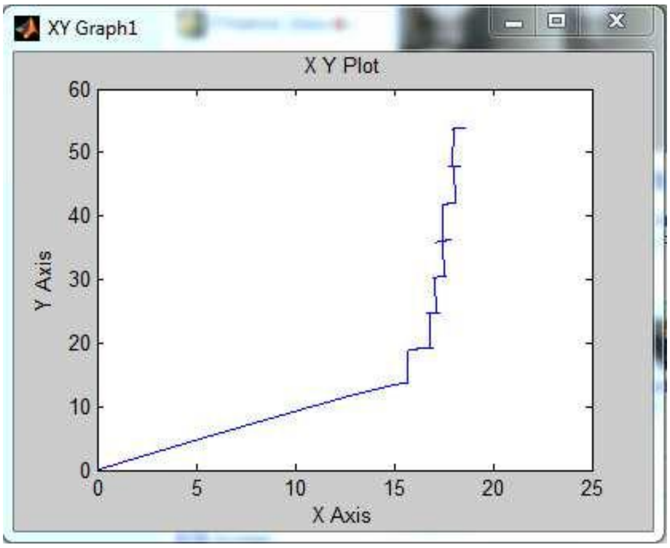


Fig. 14 Maximum Power Point Tracking By Perturb And Observe Algorithm for 300,400,500,600,700,800,900,1000w/M2 Irradiances.

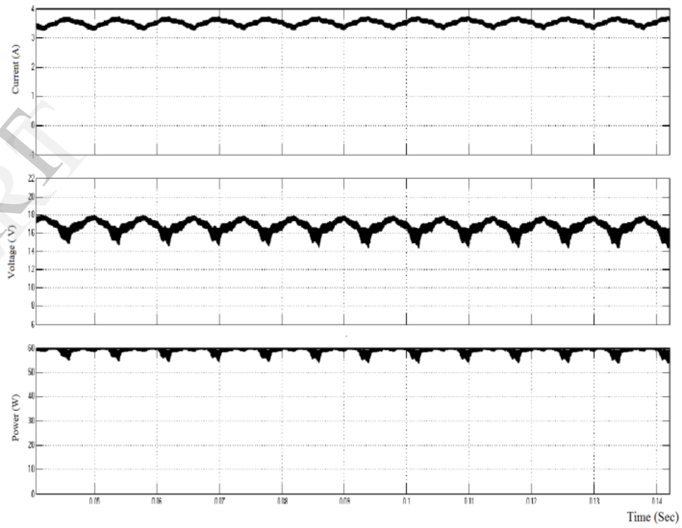


Fig.15 PV Panel Output

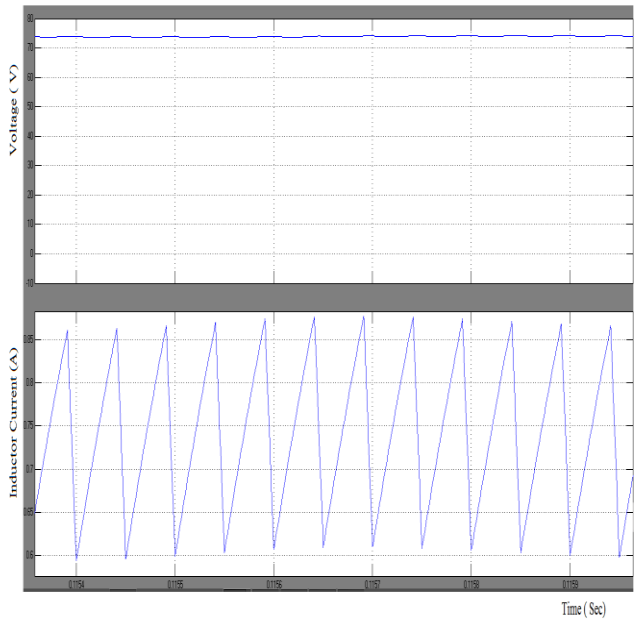


Fig.16 CUK converter Output

VI. CONCLUSION

In this paper a standalone PV system has been simulated by MATLAB/Simulink. Perturb and observe(P&O) algorithm has been used for maximum power point tracking. The proposed Fuzzy Logic MPPT system to track the voltage with respective to the maximum power output. It results shows in increasing the efficiency of the PV panel and reducing the effects of weather changing as much as possible. So, the controller's performance of the CUK converter can be improved i.e constanat voltage and smooth current transition is acheived. This type of control suitable for variable-load systems as it not only addressed steady-state response, but also improved transient response.

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