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A Comparative Study on Efficiency Enhanced Solar Energy Harvesting Systems

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Abstract

The consumption of electrical energy is increasing day by day; in the power generation from the conventional energy sources, the environment and ecology was highly affected due to the emissions of carbon gases from fossil fuel, owing to protect the environment, the only option left is the renewable energy. In last few years there is a tremendous increase in attention towards the use of solar energy. These papers presents a meticulous comparison of fuzzy and perturb and observe algorithms implemented solar energy harvesting systems to get more electric power from the solar energy without affecting the environment and ecology. In this work the photovoltaic cells are widely used for electrical power conversion because of its non-linear Power-Voltage characteristics and the maximum power point tracking algorithm enhance to provide improving energy stability, increasing energy sustainability, and conversion-reduction and enhance the system efficiency.

Keywords: Maximum power point tracking, Photovoltaic system, Renewable energy, solar energy.

INTRODUCTION

In a Present days the continuous increase in the level of greenhouse gas emissions and the fluctuation of rising fuel prices are the main driving forces behind efforts to utilize various sources of renewable (Non-Conventional) energy. The energy needs of industrialized societies as well as developing countries are constantly multiplying. This production has tripled since the 1960's to the present. The main concern in the power sector is the day-to-day increasing power demand and the unavailability of enough resources to meet the power demand using the conventional energy sources. Demand has increased for renewable sources of energy to be utilized along with conventional systems to meet the energy demand. Renewable sources like wind energy and solar energy are the prime energy sources which are being utilized in this regard [2]. The continuous use of fossil fuels has caused the fossil fuel deposit to be reduced and has drastically affected the environment depleting the biosphere and cumulatively adding to global warming. Solar energy is abundantly available that has made it possible to harvest it and utilize it properly. Solar energy can be a standalone generating unit or can be a grid connected generating unit depending on the availability of a grid nearby. Thus it can be used to power rural areas where the availability of grids is very low. Another advantage of using solar energy is the portable operation whenever and wherever necessary. In a comparative study on the world energy consumption released by International energy agency shows that in 2050 solar array installations will supply around 45% if energy demands in the world. In order to tackle the present energy crisis one has to develop an efficient method in which maximum power has to be extracted from the incoming solar radiation. The power conversion mechanisms have been greatly reduced in size in the past few years. The development in power electronics and Renewable Energy (RE) systems has helped engineers to come up with very small but powerful systems to withstand the high power demand. But the disadvantage of these systems is the increased power density [3, 10]. The use of power optimization mechanisms called the Maximum Power Point Tracking (MPPT) algorithms has led to the increase in the efficiency of operation of the solar modules and thus is effective in the field of utilization of renewable sources of energy.

In this paper a comprehensive review of major MPPT techniques used in the PV standalone system are presented and gives a detailed review on various MPPT techniques used in the literature. Simulation of a PV standalone system with both the MPPT schemes and the results of simulation are presented. The I-V & P-V characteristics with different irradiation and temperature variation are shown in Figure 1&2.

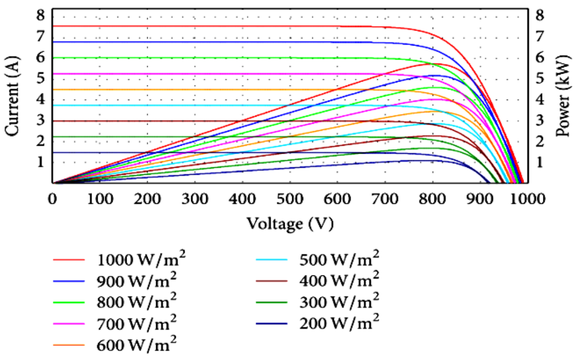

Figure 1. I-V and P-V - curve with different irradiation.

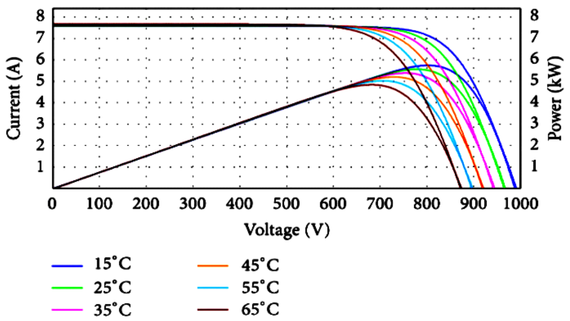

Figure 2. I-V and P-V curve with temperature variation.

STANDALONE PHOTOVOLTAIC SYSTEM

A system feeding a load or connected to a load and which is not connected to the grid is called a Standalone or Isolated system. Standalone system requires a battery in some cases but with grid connected system battery is not needed as the deficit power could be obtained from the grid itself. Both standalone and grid connected photovoltaic systems use MPPT to obtain the maximum possible output power from the PV array. [1-4] Photovoltaic cells consist of a silicon P-N junction that when exposed to light releases electrons around a closed electrical circuit. From this premise the circuit equivalent of a PV cell can be modeled through the circuit shown in Fig. 3. Electrons from the cell are excited to higher energy levels when a collision with a photon occurs. These electrons are free to move across the junction and create a current. This is modeled by the light generated current source Iph. The photocurrent Iph generated in the PV cell is proportional to level of solar illumination, I is the output current of photovoltaic cell. The current Id through the diode varies with the junction voltage and the cell reverse saturation current Is V is the output of the photovoltaic cell, Rsh and Rs are the parallel and series resistances, respectively. Parallel resistance Rsh is very large while the series resistance Rs is small. When the number of cell in series is Ns and the number of cell in parallel is Np.

A. Equivalent Circuit of PV Cell

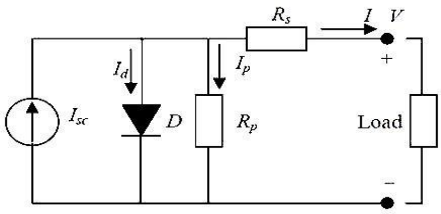

Figure 3. Equivalent Circuit of Photovoltaic Cell.

$$I = N_P\ I_{Ph} - N_P\ I_s * \left[exp\left\{q\,\frac{(V+I.R_S)}{N_S\,AkT}\right\} - 1\right] \quad (1)$$

$$I_{SC} = I_{Ph}\ (T_{ref})[1 + a(T - T_{ref})] \quad (2)$$

$$I_{Ph}\ (T_{ref}) = I_{SC}\ (T_{ref}) * \frac{E}{E_0} \quad (3)$$

$$a = \frac{I_{SC}(T_2) - I_{SC}(T_1)}{I_{SC}(T_1)} * \frac{1}{T_2 - T_1} \quad (4)$$

$$I_d = I_s * \left[exp\left\{q\,\frac{(V+I.R_S)}{AkT}\right\} - 1\right] \quad (5)$$

$$I_s = I_{so} * \left(\frac{T}{T_{ref}}\right)^{\frac{3}{A}} * exp\left[\left(-\frac{E_g}{Ak}\right) * \left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right] \quad (6)$$

$$I_{so} = \frac{I_{sc}\ (T_{ref})}{\left(exp\left(q\frac{V_{OC}(T_{ref})}{AkT_{ref}}\right) - 1\right)} \quad (7)$$

$$R_s = -\frac{d_v}{dI_{Voc}} - \frac{1}{X_V} \quad (8)$$

$$X_V = I_{so} * \frac{q}{AkT_{ref}}\,exp\left(q\,\frac{V_{OC}(T_{ref})}{AkT_{ref}}\right) \quad (9)$$

Here,
V - Output Voltage of a PV cell [V].
I – Output Current of a PV Cell [A].
Ns – Sum of segments linked in series.
Np – Sum of segments linked in parallel.
Iph – Light Stimulated Current in a PV Cell.
Is – PV cell Saturation Current.
Rs – Series Resistance of a PV cell.
A – Ideality Factor.
B – Boltzmann Constant.
T – Cell Temperature.
q – Electron charge.
Tref – Reference Temperature.
Isc – PV short circuit Current.
A – Short circuit current temperature coefficient.
Rsh – Shunt resistance of a PV cell.

B. DC-DC Power Boost Converter:

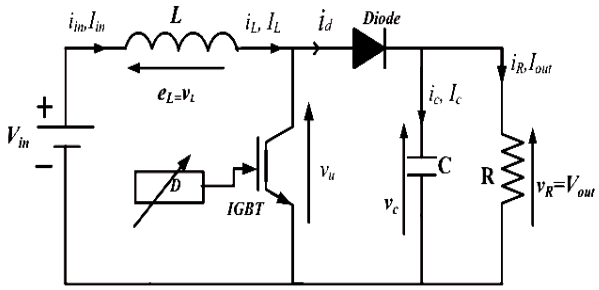

Figure 4. Equivalent Circuit Diagram of Boost Converter.

Choppers are static DC-DC Converters for generating variable DC voltage source from fixed Voltage Source. The DC-DC converter consists of capacitors, inductors, and switches to bring up or bring down a DC electrical voltage to another. In this work the boost converter will hold the PVG maximum working point through a controller called MPPT. All the devices connected in the system are in ideal case only they don't consume electric power. The equivalent circuit diagram of Boost Converter is shown in Figure.4.In a DC-DC Boost converter, by using the Averaging concept, the input output voltage relationship for continuous conduction mode is given by:

$$V_{out} = \frac{1}{1-D} V_{in} \quad (10)$$

Based on the assumption where $P_{in} = P_{out}$ it can be deduced that

$$R_{pv} = (1 - D)^2 R_{out} \quad (11)$$

The Data sheet details of the boost DC/DC converter are given in Table: 1

Table 1. Component values of dc to dc boost converter.

Description	Rating
L	350 [μH]
C	560 [μF]
R	50 [Ω]

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MAXIMUM POWER POINT TRACKING (MPPT):

The MPPT control is a fundamental phase in order to obtain a good performance in a PVG system. In the MPPT techniques evolved solar can be categorized either direct or indirect methods. The direct approach of MPPT algorithm is liberated from erstwhile knowledge of PV characteristics. There are several types of Direct Method algorithms as follows, Perturb & Observe (P&O), Fuzzy Logic Method, Neural Network Method, and Incremental Conductance Method (IN Cond). In indirect approach needs previous appraisal of PVG it is based on Scientific Relationship obtained from pragmatic Data. In this paper the effectiveness of two different control algorithms P&O and Fuzzy Logic algorithms are reviewed.

A. Perturb and Observe (P&O) Method:

In the Solar Power conversion System the P&O algorithm is widely used to track the maximum power from photovoltaic generator. It is an iterative method of obtaining MPP. The block diagram of Perturb and Observe implementation system is shown in figure.5. In this P&O method the word Perturb meant, by increasing and decreasing V_{ref} or by adjusting the duty cycle of the converter directly and observing the effect on output of the PV panel. If the present value of the P (k) of the PV panel is higher than its Past value P (k-1) then we keep the same direction of disturbance otherwise it is reversed [9].

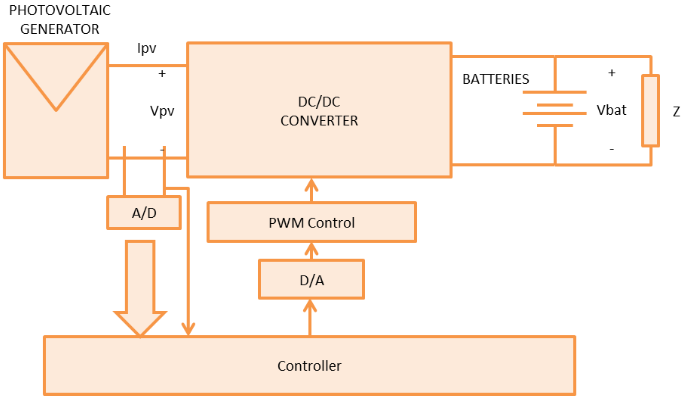


Figure 5. Perturbation and Observe implementation system

The P&O Algorithm can be detailed below:

- When the ratio $\Delta P/\Delta V$ is positive the voltage must be increased, this yields…

$$D(K) = D(K-1) + \Delta D \tag{12}$$

When the ratio $\Delta P/\Delta V$ is negative the voltage must be decreased through…

$$D(K) = D(K-1) - \Delta D \tag{13}$$

The ΔD crisp value is chosen by trail and tests in simulation. If the crisp value ΔD is very large or small we may lose the information.

The P&O method has the following problems,

- The PV system always operates in an oscillating mode.
- The poor convergence of the algorithm in the case of sudden changes in temperature, illumination.

B. MPPT controller based on Fuzzy Logic:

In the recent MPPT method are widely used in PV power conversion system. The block diagram of fuzzy logic algorithm is shown in figure.6. These controllers are independent of the process model. Fuzzy systems (FS) are based on fuzzy set theory and associated techniques in 1965 by Lotfi A.Zadeh, Professor in computer science at the University of California in Berkeley. [7].

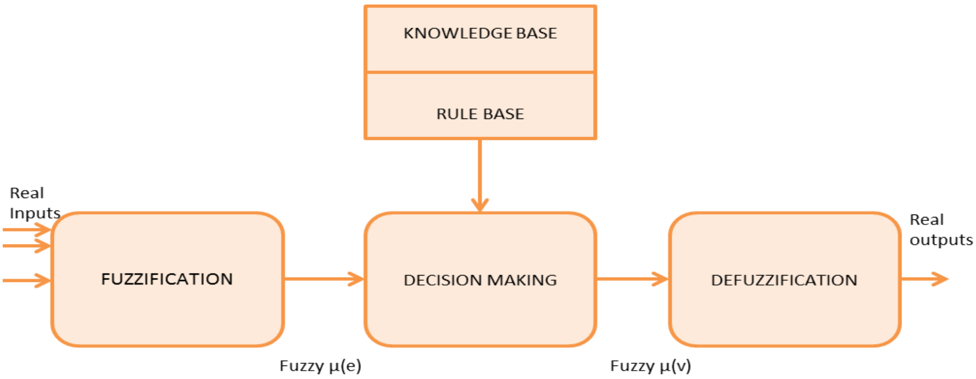


Figure 6. Block Diagram of Fuzzy Logic Algorithm.

The process of fuzzy logic control can be categorized into four elementary components.

- Fuzzification.
- Rule Base.
- Inference Engine.
- Defuzzification.

In this study, the inputs of FLC are error, E and change in error, dE at sample time k, the output of FLC is the duty cycle, D.

The two input variables are described by:

$$E(k) = \frac{P_{pv}(k) - P_{pv}(k-1)}{I_{pv}(k) - I_{pv}(k-1)} \qquad (14)$$

$$dE(k) = E(k) - E(k-1) \qquad (15)$$

Where,

$P_{pv}(k) - Power\ of\ the\ PV\ module.$

$I_{pv}(k) - Current\ of\ the\ PV\ module.$

In membership function standards are assigned to the linguistic variables, using five fuzzy subsections:

NB – Negative Big,

NS – Negative Small,

ZO – Zero,

PS – Positive Small,

PB – Positive Big.

The partition of Fuzzy Subsets and the shapes of membership function,

The graphical representation of five fuzzy subsets is shown in figure.7

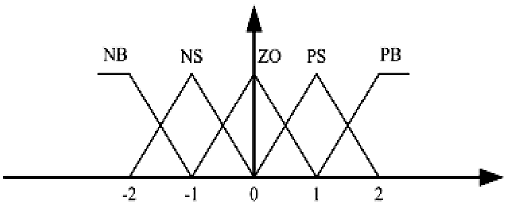


Figure 7. Graphical Representation of Five Fuzzy Subsections.

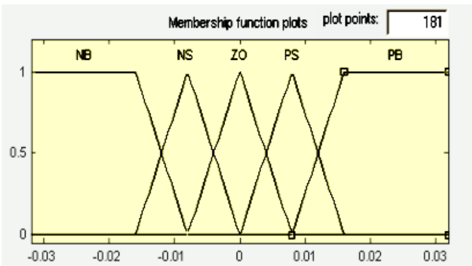


Figure 8(a). Membership Function plots for 'E'.

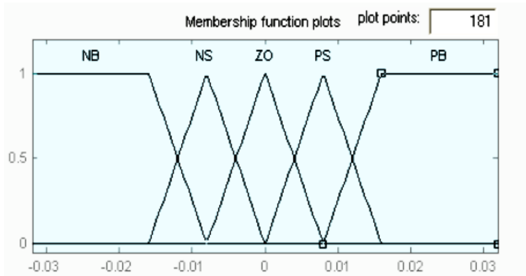


Figure 8(c). Membership Function plots for 'D'.

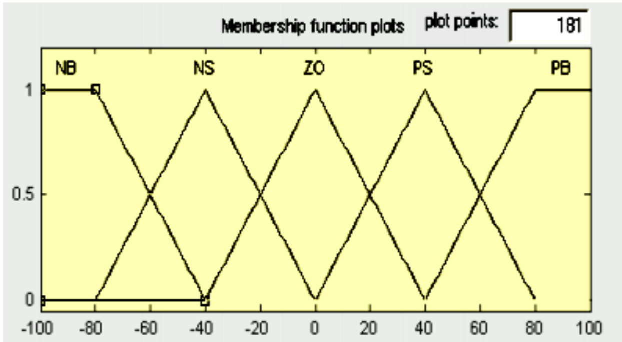


Figure 8(b). Membership Function plots for 'delta E'.

Table 2: Fuzzy Inference Table.

E	dE	NB	NS	ZE	PS	PB
	NB	ZE	ZE	PB	PB	PB
	NS	ZE	ZE	PS	PS	PS
	ZE	PS	ZE	ZE	ZE	NS
	PS	NS	NS	NS	ZE	ZE
	PB	NB	NB	NB	ZE	ZE

FLC contains four main components:

a) The fuzzifier that maps crisp values into input fuzzy sets to activate rules.

b) The rules which define the controller behavior by using a set of IF-THEN statements.

c) The inference engine which maps input fuzzy sets into output fuzzy sets by applying the rules, and

d) The defuzzifier that maps output fuzzy values into crisp values. The membership function plots for fuzzy logic are shown in fig.8.

Defuzzification: Defuzzification is the process of producing a quantifiable result in the Centre of the gravity to calculate the result of this FLC which is the duty ratio (cycle). This is very simple and very fast method in fuzzy logic algorithm.

Gravity rule of Defuzzification,

$$D = \frac{\sum_{j=1}^{n} \mu(D_j) - (D_j)}{\sum_{j=1}^{n} (D_j)} \qquad (16)$$

The Simulation configuration of the Perturb & Observe (P&O) is shown in Figure.09 and Fuzzy Logic Controller (FLC) are present in Figure.10.

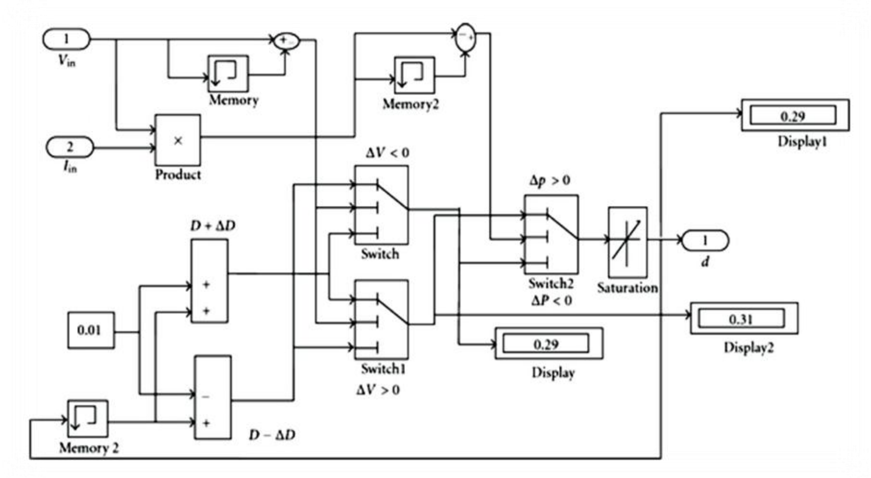


Figure 9. Simulation diagram of MPPT based on Perturbation and Observe algorithms

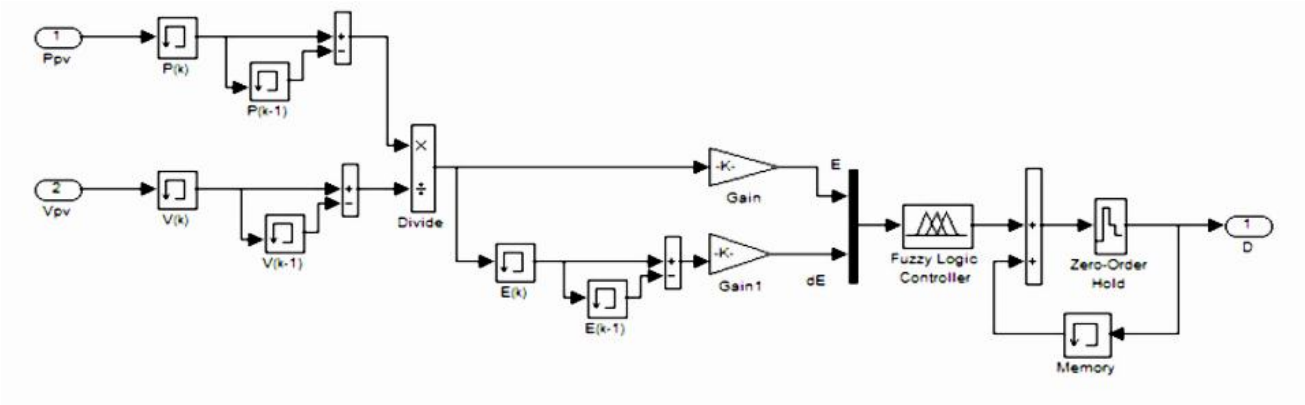
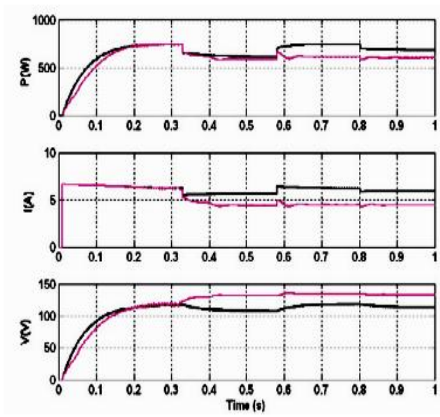


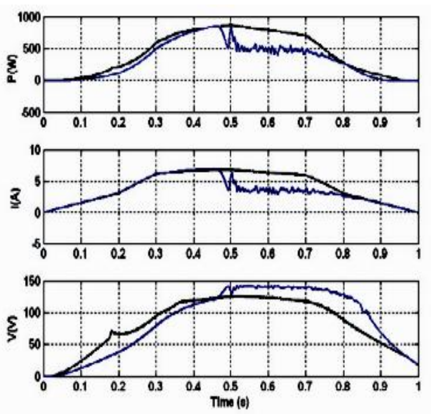
Figure 10. Simulation diagram of MPPT based on Fuzzy Logic algorithms

SIMULATION RESULTS AND DISCUSSION:

The results belonged to power, voltage and current under step radiation varying. It is clear that the drawback of the conventional P&O method appeared where the reference loses the optimum point at sudden radiation changing. Furthermore, at gradually radiation varying, the conventional P&O lost the optimum point and caused oscillations in the steady state while these drawbacks have been solved for the proposed FLC-based MPPT technique. In both previous cases, the proposed FLC-based MPPT showed faster response in the transient response and stable steady state. Moreover, the oscillations disappeared, comparing with the conventional P&O method.

It is noticed that both P&O MPPT and fuzzy logic MPPT can track the maximum power operating voltage point. For practical implementation, the FLC must be selected for its higher performance compared to the P&O controller [4-8]. Hence the FLC has better performance and closed to the P&O. FLC has better response time, less oscillation and much more accurate tracking at each step.





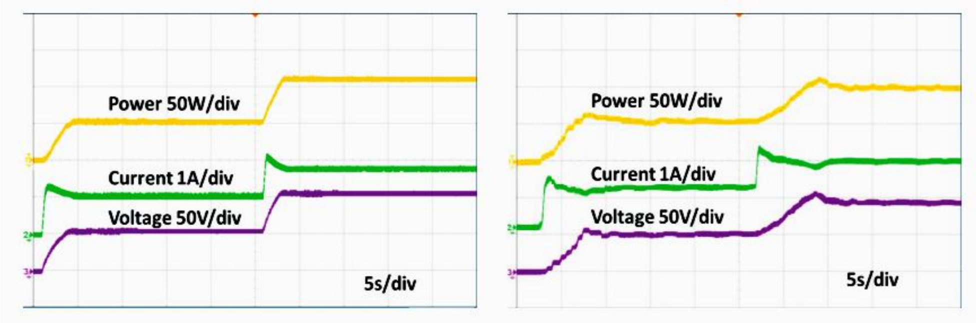


Figure 12. Power voltage current under P&O and Fuzzy Logic Control Method.

CONCLUSION

The solar power systems are reliable substitute to be used as Eco-Friendly energy conversion systems with reduced emissions of greenhouse gases. They are environment friendly and economically competitive compared to all other traditional power conversion methodology. In this paper a new power electronics technology plays a very important role in the integration of RE sources into the grid. It is effectively and feasible approach for the system operating in remote regions. The Photovoltaic model was analyzed and simulated for testing the performance improved MPPT techniques with P&O and Fuzzy Logic algorithm. In this work, the aim was to control the duty cycle of the boost converter in order to obtain the maximum power possible from a PV generator, whatever the solar insolation and temperature conditions. Based on the simulation it can be concluded that with the both controllers the PV panel can deliver the maximum power. However, the performance of fuzzy logic MPPT is better than the traditional controllers for the nonlinear systems, it has the capability of reducing perturbed voltage when MPP has been recognized. This action directly preserves a more stable output power compared to the conventional MPPT where the output power fluctuates around MPPT. The solar energy systems are assumed as the power supply (or) applied directly to the various Industrial applications, solar vehicle, solar water heater, solar power satellite, Solar Distillation, Solar pumping System etc.,

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