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An Efficient MPPT Technique using Fuzzy/P&O Controller for PV Applications

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ABSTRACT

A PV array's output power is maximized by using the maximum power point tracking (MPPT) technique, which also improves the system's stability and reliability. The maximum output of a PV module changes with the temperature and amount of solar radiation. Using a Maximum Power Point Tracker (MPPT), photovoltaic (PV) systems continuously extract and deliver as much power as they can. A DC-DC Converter and a controller are components of an MPPT. Many different MPPT algorithms have been proposed, but most of them have drawbacks in terms of efficiency, accuracy, and adaptability. Conventional controllers cannot give the optimal response due to the nonlinear current-voltage characteristics of PV modules and the nonlinearity of DC-DC converters because of switching in large parameter changes and line transients.

To track a PV system's maximum power point, the authors designed and modeled a fuzzy/P&O controller. The proposed method shows improved performance in terms of oscillations about the maximum power point, speed, and sensitivity to parameter variation. The PV system's performance was assessed using a variety of test scenarios that included signals for temperature and solar irradiance variables. The MATLAB/Simulink simulation results showed that the proposed method worked well at the operating point in terms of settling time, power loss, and oscillations.

KEYWORDS – PV system, DC-DC converter, MPPT, Fuzzy logic, P&O.

INTRODUCTION

Most renewable energy resources, such as solar PV systems, wind turbines, and hydropower, come from the sun, wind, and quickly flowing water, respectively. A solar PV system is one of the most attractive renewable energy options since it provides long-term, clean, and safe power [1]. As an added bonus, it can be placed virtually anywhere with varying capacity and has a minimal ongoing cost. The output power of a PV system is primarily determined by irradiance and temperature, i.e. by weather conditions, which demonstrates the current-voltage (I-V) characteristic of a PV array. This shows that the generation of PV power increases when the input irradiance increases, but it drops when the operating temperature is high. The location of the maximum power point (MPP) changes with the seasons and climate [2]. The tracking efficiency of the PV controller is computed from the difference between the theoretical maximum power and the actual maximum power of a PV module. A PV system's equipment failure can occur owing to unintentional incidents, just like with any other electrical device. When the weather changes suddenly, the DC voltage of a PV array changes dramatically, this is the most prevalent cause of PV system failure. When a hot-spot develops on a PV array, it can cause damage to the PV power conversion system, as well as shorten the array's lifespan [3].

PV power systems have a poor penetration because of their inefficiency and high cost per watt when compared to traditional power sources. As a result, substantial effort needs to be done to improve the efficiency and reliability of PV systems. Modeling and simulation are the initial steps in understanding and discussing ways to increase the efficiency of PV modules [4]. You can come up with several approaches to optimize the operation of the system when you've got a good PV module modeling and simulation under your knowledge [7]. Current approaches do have some limitations, however, such as low efficiencies and response times as well as low accuracy. In order to deal with these challenges, control systems have been devised to improve the average tracking efficiency, stability and management of a PV generation's power flow under various weather circumstances [5]. There have been a variety of strategies explored to create this control system, but artificial intelligence-based MPPT is the most effective for nonlinear systems like the PV system [6]. An off-grid PV system's fuzzy/P&O controller and dc-dc converter are being designed, modeled, and simulated in this study. It'll be implemented in two stages, with the fuzzy/P&O controller as a reference for input and output variables and defuzzification evaluated during the modeling stage. In addition, the dc-dc converter will be constructed in accordance with the analytical model.

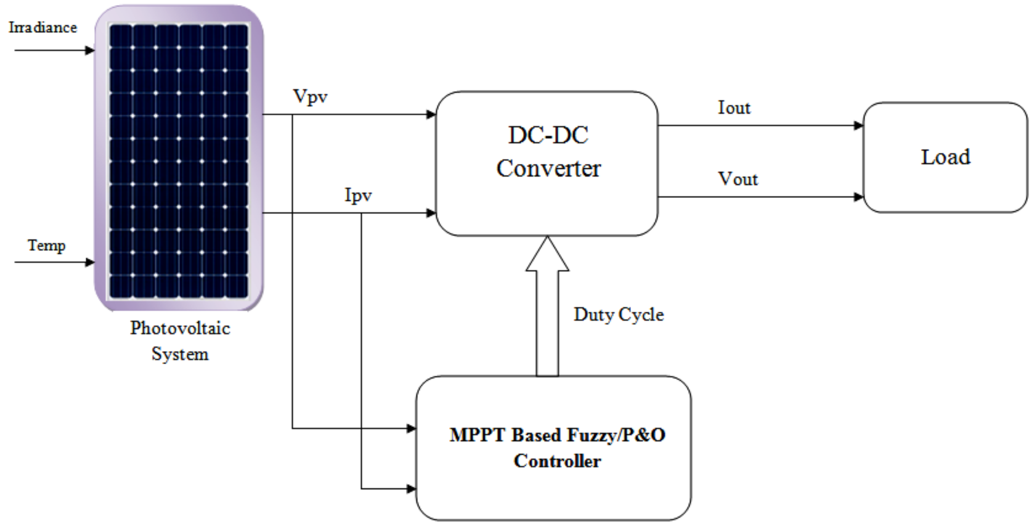


Fig.1: Block diagram of MPPT Controller Based PV System

SYSTEM CONFIGURATION

In this paper, Fig.1 shows the proposed system configuration. The photovoltaic system generates voltage and current, which are then transformed via a DC-DC converter to match the load. Using an MPPT-based Fuzzy/P&O Controller, the duty cycle value of the DC-DC converter is modified to maximize the amount of power coming from the solar panel.

A. PV System Modeling

Several solar cells are connected in series and parallel to form a PV module, which is then installed on a single panel. The objective is to compute the power output of a PV module using an analytical model that defines the current-voltage relationships based on the electrical properties of the module. Using a one-diode model as given in the theory section below, the current-voltage curve particular to a PV module can be established. Simulink software is used to develop a PV module model based on theory. The output power can be influenced by the level of solar radiation and the temperature of the cells using this model.

Fig.2 shows an equivalent photovoltaic circuit using the mathematical equations Eq. (1)-(5),

$$I_T = N_p I_L - N_p I_{sat}[\exp\left\{\frac{q(V_{mpp}+(I_{mpp}.R_s))}{N_s.A_D.k.T_{pv}}\right\} - 1] \quad (1)$$

$$I_L = [I_{sc} + K_i(T_{pv} - T_r)]\frac{\lambda}{1000} \quad (2)$$

$$K_i = \frac{I_{sc} \cdot I_{scTC}}{100} \quad (3)$$

$$I_{sat} = I_{rs}[\frac{T_{pv}}{T_r}]^3 \exp\left[\frac{qo.Eg}{A_D.k}\left\{\frac{1}{T_r} - \frac{1}{T_{pv}}\right\}\right] \quad (4)$$

$$I_{rs} = \frac{I_{sc}}{[\exp\left\{\frac{q.V_{OC}}{N_S.A_D.k.T_{pv}}\right\} - 1]} \quad (5)$$

With I_T as the total current generated, I_L as the current generated photovoltaic, I_{sc} as the short circuit current, I_{scTC} as the short circuit current in the coefficient temperature, I_{sat} as the saturation current of the diode, I_{rs} as module reverse saturation current, λ as irradiance, T_{pv} as photovoltaic temperature, T_r as temperature reference = 298.15°K, A_D as ideality factor, E_g as band gap, K_i as photovoltaic module short circuit current, N_s as the number of cells in 1 module (series), N_p as the number of cells in 1 module (parallel), I_{mpp} as the current at maximum power, V_{mpp} as the voltage at maximum power, q as the electron charge = 1.6 x 10^{-19}C, q_o as the constant = 1.6 x 10^{-19}J/eV, k as Boltzmann constant = 1,3805x10^{-23}J/K, V_{oc} as a voltage in the open circuit, R_S as a series resistance, and R_{sh} as parallel resistance.

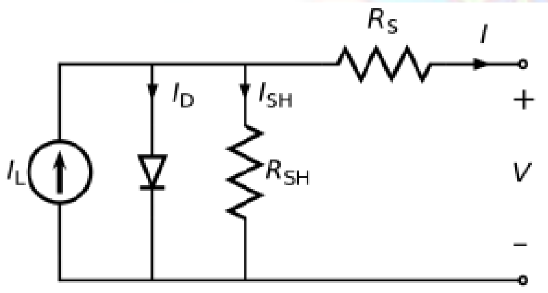


Fig.2: PV equivalent circuit.

Several solar cells are connected in series and parallel to form a PV module, which is then installed on a single panel. The objective is to compute the power output of a PV module using an analytical model that defines the current-voltage relationships based on the electrical properties of the module. Using a one-diode model as given in the theory section below, the current-voltage curve particular to a PV module can be established. Simulink software is used to develop a PV module model based on theory. The output power can be influenced by the level of solar radiation and the temperature of the cells using this model.

B. DC-DC Converter

Fig.3 illustrates a dc-dc converter's schematic layout. It alters the dc input voltage $V_g(t)$ to produce a dc output voltage $V_o(t)$ that differs from the input voltage. It's ideal if the converter suffers little losses during the conversion process.

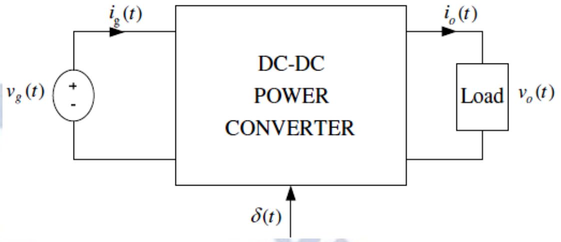


Fig.3: Structure of DC-DC converter

In dc-dc converters, resistors are avoided to obtain minimal losses. Instead of resistors and diodes, capacitors and inductors are employed since they have zero losses. Topologies, the terms used to describe the various ways in which electrical components can be assembled and connected to one another, are diverse. To summarize, there are three main types of converter topologies: boost, buck, and boost-buck. The output voltage of the buck converter is lower than the input voltage, the output voltage of the boost converter is greater than the input voltage, and the output voltage magnitude of the buck-boost converter can be larger or lower than the magnitude of the input voltage.

C. Fuzzy Controller Design

The degree of truth is used in fuzzy logic, which is a computer approach. The degree of truth and linguistic factors used by a fuzzy logic system are used to produce a specific output. The type of the output is determined by the condition of this input.

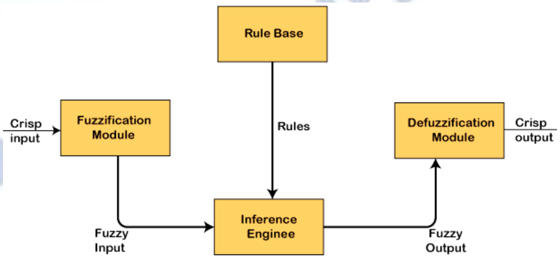
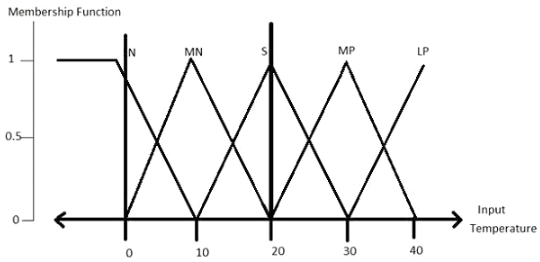


Fig.4: Structure of fuzzy logic system

Rules that link the inputs of an expert with the desired outcomes are used in fuzzy logic to designate and implement solutions. Fuzzy sets, membership functions, linguistic variables, and fuzzy rules all have a significant impact on fuzzy logic. This function is used to estimate or compute how much a given input element belongs to an abstract set, such as a fuzzy set. The x-axis depicts the Universe, while the y-axis shows the degrees of membership in that Universe. An illustration of a membership function can be seen in the diagram below.



D. P&O Controller Design

The P&O algorithm measures the output power before and after perturbing the PV module's operational point by increasing or reducing the duty cycle of a dc-dc converter. Because of this, a higher power increase has a similar effect as a lower power increase. Fig.5 depicts the four possibilities that are offered throughout the tracking of the MPP, with point 1 representing the previous location and point 2 representing the current position of each case (A, B, C, and D).

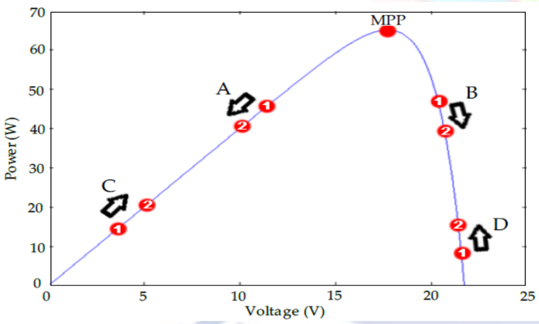


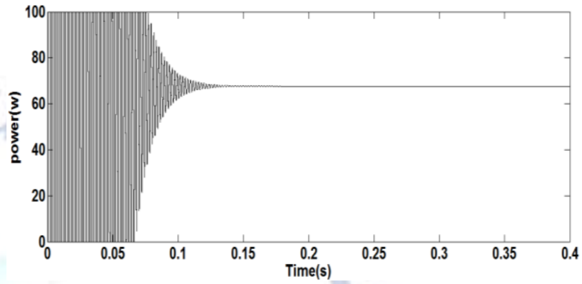
Fig.5: Movement of MPP on P-V curve of PV module.

SIMULATION RESULTS

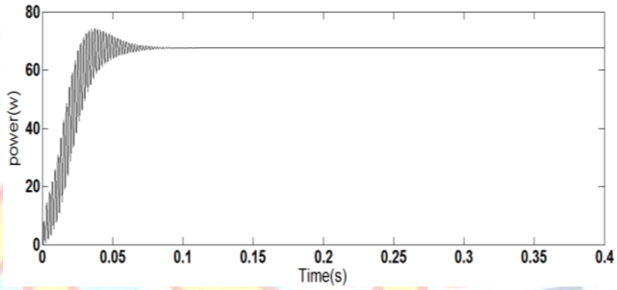
MATLAB/Simulink was used to test the PV system's performance under various conditions. There are four scenarios that simulate unexpected variations in solar irradiation and PV module operating temperature.

Case.1: standard test conditions

Here the system performance can be evaluate by taking parameters as an ideal conditions in this case i.e., solar irradiance (1000 W/m^2) and temperature (25^{0}c). Here we can observe in the waveforms (Fig.6), we are getting more oscillations and large settling time in output power of PV module i.e., before controlling system. When we implement MPPT technique (fuzzy/P&O) in the system, we get less oscillations and less settling time in output power of the system.



(a)

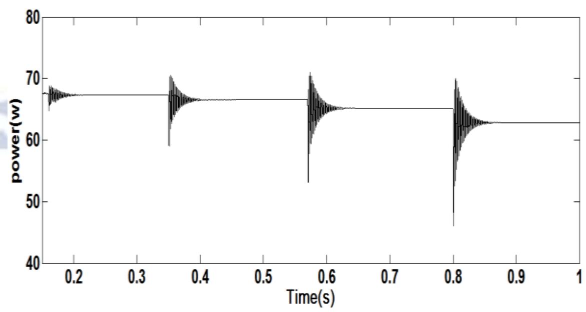


(b)

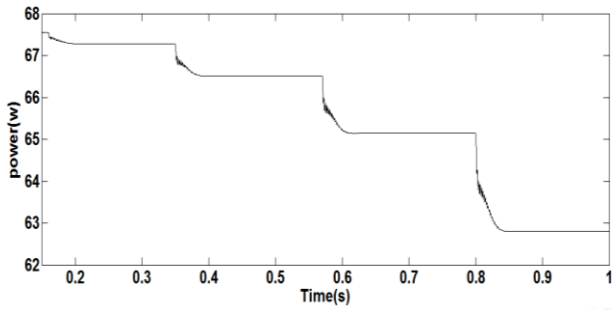
Fig.6: output power (a) Before MPPT Controller, (b) After MPPT Controller (Ideal conditions)

Case.2: Changes in solar irradiance

In this condition, the operating temperature is placed at 25^{0}c and solar irradiance changes as increases & decreases. Here we can observe in the waveforms (Fig.7 & 8), we are getting more oscillations and large settling time in output power of PV module i.e., before controlling system. When we implement MPPT technique (fuzzy/P&O) in the system, we get less oscillations and less settling time in output power of the system.

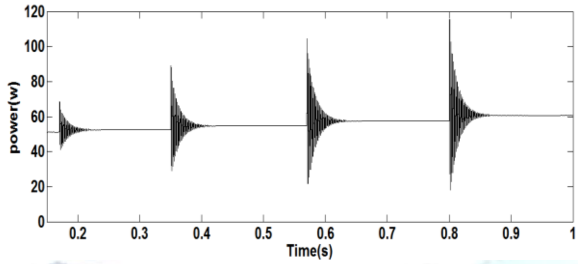


(a)

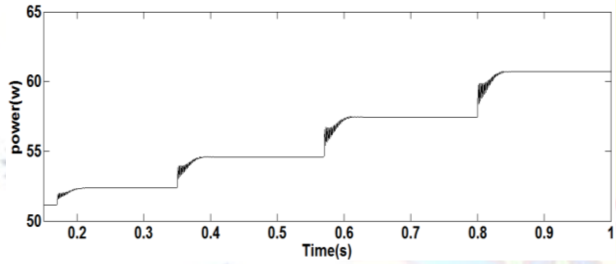


(b)

Fig.7: output power (a) Before MPPT Controller, (b) After MPPT Controller (decreases in solar irradiance)



(a)

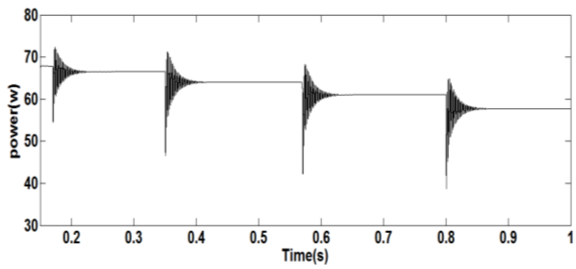


(b)

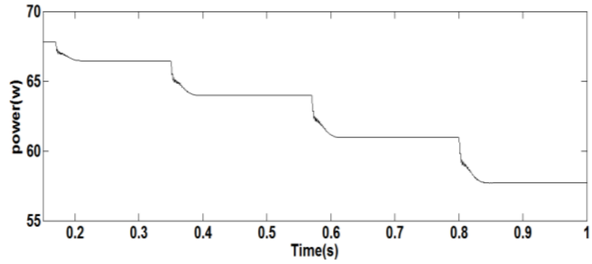
Fig.8: output power (a) Before MPPT Controller, (b) After MPPT Controller (increases in solar irradiance)

Case.3: Changes in temperature

In this condition, the operating temperature is changes as increases & decreases and solar irradiance will be maintained as constant. Here we can observe in the waveforms (Fig.9 & 10), we are getting more oscillations and large settling time in output power of PV module i.e., before controlling system. When we implement MPPT technique (fuzzy/P&O) in the system, we get less oscillations and less settling time in output power of the system.

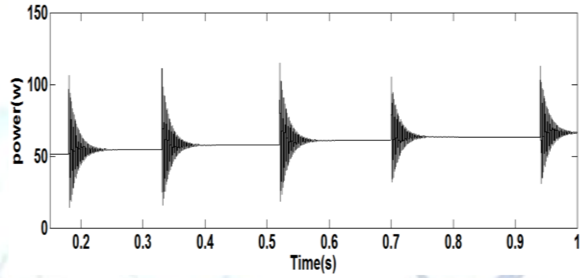


(a)

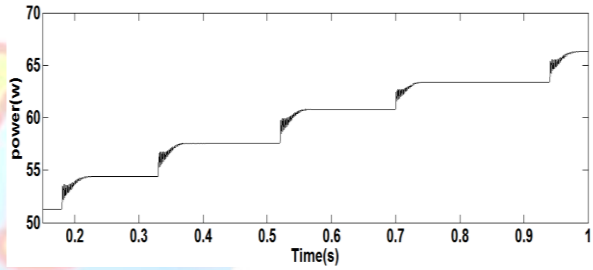


(b)

Fig.9: output power (a) Before MPPT Controller, (b) After MPPT Controller (decreases in temperature)



(a)

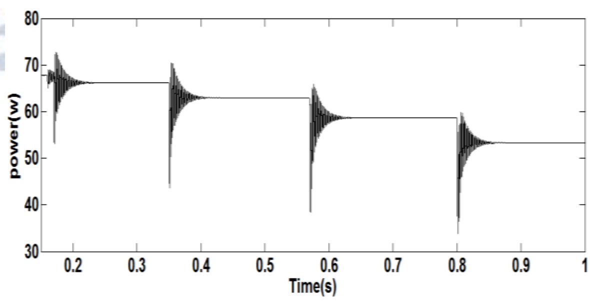


(b)

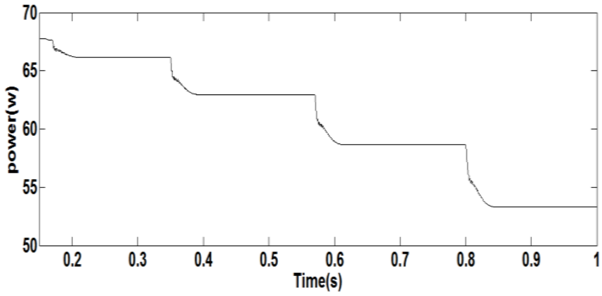
Fig.10: output power (a) Before MPPT Controller, (b) After MPPT Controller (increases in temperature)

Case.4: Changes in temperature & solar irradiance

In this condition, the operating temperature and solar irradiance is changes. Here we can observe in the waveforms (Fig.11), we are getting more oscillations and large settling time in output power of PV module i.e., before controlling system. When we implement MPPT technique (fuzzy/P&O) in the system, we get less oscillations and less settling time in output power of the system.



(a)



(b)

Fig.11: output power (a) Before MPPT Controller, (b) After MPPT Controller (changes in irradiance and temperature)

CONCLUSION

A fuzzy/P&O controller for tracking a PV module's maximum power point was presented in this paper. The PV system's performance was assessed using a variety of test scenarios that included signals for temperature and sun irradiance variables. MPPT controller has been shown to enhance PV output power, shorten convergence time, and minimize MPP fluctuations when used with a PV system. So the average tracking efficiency of the PV system as well as the stability and dependability of PV generating are improved when it connects to the load. As future work, the Adaptive Neural- Fuzzy Inference System (ANFIS) was used with a real photovoltaic dataset to develop an effective maximum power point tracking technique.

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