A Comparative Study of Maximum Power Point Tracking Techniques for Solar Systems

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Abstract— **The solar power is getting attention globally because of being clean and renewable in nature. However, the power extraction limit from solar cell depends on the solar irradiance and temperature. The solar radiation keeps varying the whole day and thus making the solar power generation fluctuating in nature. Resultingly, the solar energy from the solar panel is always less than the maximum possible generation limit of the solar panel. The solution to this problem is the maximum power point tracking (MPPT) algorithm, enabling maximum power extraction from the solar panel. This work presents a comparative study of various MPPT techniques under constant and varying irradiance conditions. This work shows the solar MPPT control by perturbation and observes (P&O), incremental conductivity (IC) and Gaussian and triangular fuzzy logic controller (FLC) techniques. The efficiency comparison for MPPT by these techniques has also been presented in this work. The evaluation of performance for these techniques has been performed to determine the best possible technique for MPPT. The comparative study shows that the triangle-based FLC is superior to the other FLC technology and remaining conventional technologies for MPPT.**

Keywords: *MPPT, Photovoltaic (PV), Fuzzy logic control, Membership functions, Solar power*

I. Introduction

Rise in demand of electricity is resulting in fossil fuels depletion at a faster rate. This alarming situation has forced to look for alternate and clean energy resources i.e., solar, wind, bio fuel and geothermal etc. Among various renewable sources, PV is the most popular because of its simplicity and abundance of sunlight. In addition to that PV energy is clean, environment friendly, free, inexhaustible and easily available source of energy. It is worth noting that the solar energy production depends on various factors such as solar irradiance and atmospheric conditions. However, the solar irradiance keeps varying the whole day, which results in solar cell to underperform than its maximum possible energy generation limit. It can be concluded then the energy production is non-linear in nature and for that reason the operating point of PV module is not able to track the maximum power limit [1]. Unfortunately, in solar panels, the maximum power point is constantly changing due to changes in solar irradiance and seasons through the year. This results in the need of MPP tracking at each instance to collect the possible maximum energy from the solar panel and to improve its efficiency. To meet the needs of MPPT, there are various tracking algorithms/techniques being used in previous works to set the working point of the PV module at MPPT. All these technologies may differ in hardware design, response speed, efficiency and cost [2]-[4]. These techniques usage can also vary depending on atmospheric and weather conditions. Every technique has its own pros and cons. For that reason, classification of different MPPT techniques can be made on the basis of hardware design, efficiency, cost and sensitivity.

Perturbation-and-observe is one of the first method being explored for MPPT in solar panels [5]-[9]. The bestselling point of this technique is that the required sensor is simple and small in number. In addition, this technique can work well even without previous information about the properties of the photovoltaic module. However, the main drawback is: when it reaches MPP, the system swings around it, resulting in a loss of performance. Later some other computational techniques like artificial neural network (ANN), Incremental conductivity (IC) and fuzzy logic controllers were analyzed in solar MPPT [10]-[13]. The prime advantage of IC technique is timely detection of atmospheric changes and this property makes it ideal candidate for rapidly changing weather conditions. However, it has associated problem of complexity and thus high price of the whole technique [14].

In this work our focus is on MPPT by using FLC technique. This work provides a comparison study of MPPT by FLC and other

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conventional techniques. The gaussian and triangular FLC membership functions are explored for MPPT. FLC technique has advantage of fast tracking of MPPT and reduction in voltage fluctuations after achievement of Maximum power point. Simulation models have been generated using MATLAB/Simulink environment for comparison purposes. The results present the performance superiority of triangular FLC over its counterpart under different atmospheric conditions [15]-[17].

II. BASIC MODEL AND OPERATION

A solar generation system is typically composed of these components i.e., solar panel, DC-DC converter, MPPT controller and load. All reported solar systems in literature are based on components as described earlier. Solar panel is the main generation unit responsible for energy generation by converting solar energy to electric energy. DC-DC converters are generally for voltage regulation purposes. The brief detail for every component in a basic solar power generation system is given below.

A. Photovolatic panel model

The generic model of solar cell array is derived from diode physical properties, also called as single diode model. A photovoltaic unit cell can be represented by the equivalent circuit provided in Figure 1. Diode voltage-current characteristics are usually explained by Schokley diode equation as explained below.

$$I_D = I_{Sat}\left[exp^{\left(\frac{V_D}{nV_T}\right)} - 1\right]$$

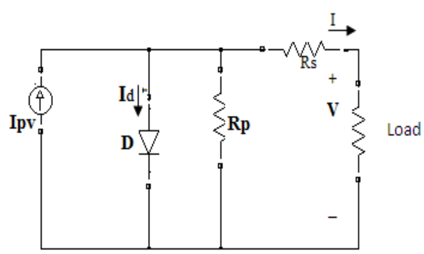


Fig. 1. Photovoltaic Cell Equivalent Circuit

I_D and $I_{sat,}$ are representing diode current and reverse saturation current, while V_D and V_T are showing diode voltage and thermal voltage respectively. The thermal voltage V_T is represented below:

$$V_T = \frac{KT}{q}$$

T is representing temperature in kelvins, K stands for Boltzmann constant, and q is for electron charge. So, PV array model can also be derived from Figure 1. The array currents I for PV panel is given below.

$$I = I_{PV} - I_O\left[exp\left(\frac{V + R_s I}{V_t a}\right) - 1\right] - \frac{V + R_s I}{R_{sh}}$$

Here, the I_{PV} is solar light current, Rs and R_{sh} shows series and parallel resistances for PV array. Current I_{PV} generated by light strike depends on solar light intensity and environmental temperature. Since light keeps varying the whole day, so it is not possible to extract maximum light current from panels. This issue arises the need of MPPT algorithm in solar panels.

B. DC-DC Converter

The generated output DC voltage from solar panel is fluctuating in nature, which requires voltage regulation before using it for load. PV panels are usually connected to boost converter for voltage regulation. DC-DC converters adjusts the generated voltage level by pulse width modulation to MPP.

C. Algorithms for Maximum Power Point Tracking(MPPT)

Maximum power point tracking controller is the central brain of a solar system as it helps in maximum power extraction from system under varying atmospheric and weather conditions. The idea behind MPPT is transmission of maximum power to the load under varying solar irradiance and temperature levels. Maximum power transfer is possible only if the PV panel impedance matches with the impedance of load. The whole solar system with PV panel, DC-DC converter, MPPT controller and load is provided in Figure 2.

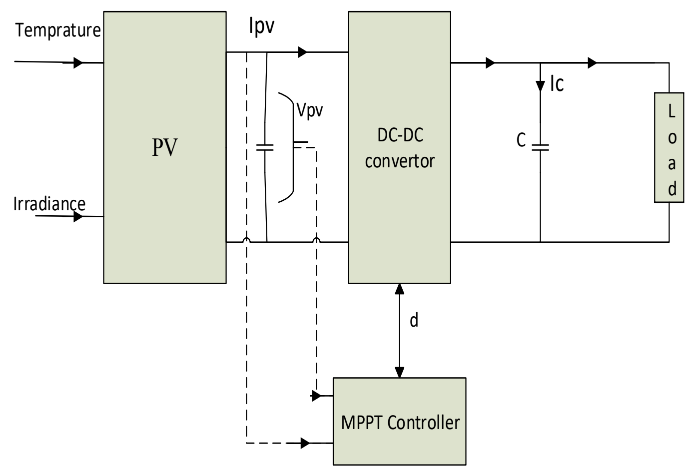


Fig. 2. MPPT System

III. PROPOSED METHOD

Figure 3 shows the block diagram for the proposed solar system installed with FLC. MPPT control in this work is achieved by FLC due to its higher speed. The whole system is composed of photovoltaic array, DC-DC boost converter and fuzzy controller. Generated voltage and current values by PV module are used by FLC for MPPT. Reference voltage for pulse width modulation signal is determined by FLC, with reference to $\frac{dP}{dV}$ and $\Delta\frac{dP}{dV}$ values.

MPPT control based on fuzzy logic is getting attention because of its simplicity. MPPT control by fuzzy is simple and easy in implementation and can be effectively used for both nonlinear and linear systems. This method works well even for fast changing environment conditions. In this work FLC based MPPT has been explored for varying irradiance condition. It is worth mentioning that the speed of response in FLC is also better than other control methods as in FLC no precise input or mathematic model is needed [13]. FLC usually operates in the four steps:

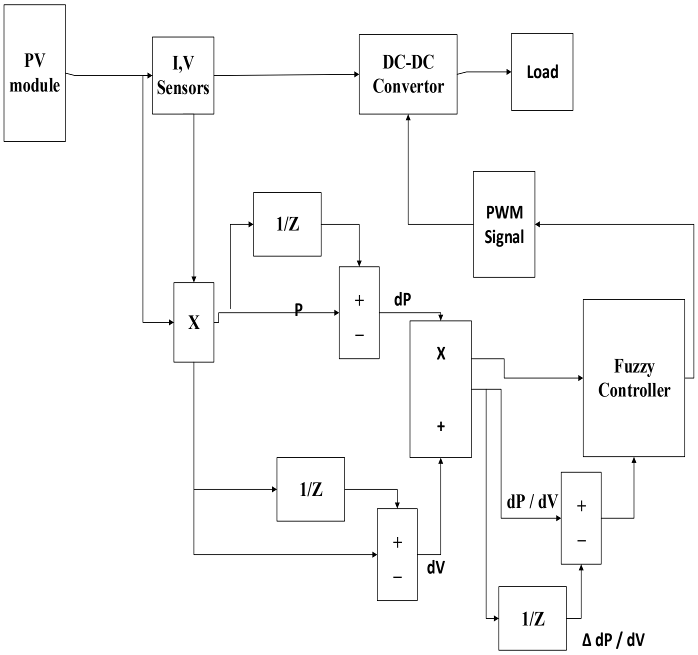


Fig. 3. Fuzzy logic based MPPT solar system

1) Fuzzification

This is the basic step in FLC and in this step real input or output values are converted into fuzzy notation by linguistic levels. This can be performed by various fuzzifiers available for this purpose, also called as membership functions.

2) Knowledge Base

In this step database and rule base are identifies. Database contains the basic date which is needed in fuzzification. Rule base are the rules defining the possibilities of output with various inputs. The base rules are usually made by if & then statements.

3) Inference Engine

This step involved plotting inputs for an output using FLC. Interface engine step fires all these rules and computer executes them for fuzzy control signal generation.

4) Defuzzification

In the final step a crisp value is generated from fuzzy output, this step is called as defuzzification.

B. Proposed Fuzzy Logic Control

In this work the proposed FLC for MPPT has two inputs and one output and the proposed FLC is relying on linguistic variables [13-16]. We have taken change in error and error as variables for input.

Case A: Gaussian Membership Function

For this approach gaussian type membership functions are chosen. Membership functions are being shown by following linguistic variables: (i) small negative value (SM) (ii) big negative value (BM) (iii) small positive integer (SI) (iv) big Positive Integer (BI) (v) zero (ZE). Fuzzy rules for gaussian membership function are enlisted in Table 1 and resulting E, CE and output variable are plotted in Figure 4.

TABLE 1: FUZZY RULE TABLE FOR GAUSSIAN MEMBERSHIP FUNCTIONS

CE \ E	BM	SM	Z	SI	BI
BM	Z	Z	BI	BI	BI
SM	Z	Z	SI	SI	SI
Z	SI	Z	Z	Z	BM
SI	BM	BM	BM	Z	Z
BI	BM	SM	SM	Z	Z

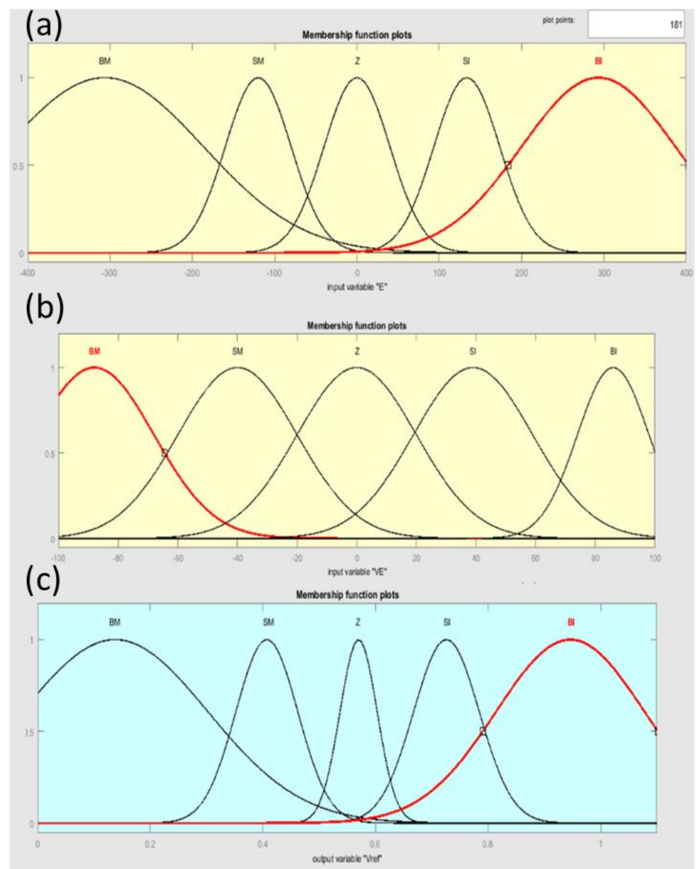


Fig. 4 (a) The Error "E" (b)The Variation in Error signal "CE" and (c) The Output Variable "Vref".

Case B: Triangular Membership Function

In a similar fashion the E, CE and Vref were plotted using triangular membership functions. Fuzzy rules have been provided in Table 2 for this case and resulting waveforms are given in

Figure 5. Triangular rules are better than gaussian as they choose the right control action. Controller reads the input values and then fuzzy rules are fired to create a suitable control surface. Control surface resulting by this method is called fuzzy set (controller output).

TABLE 2: FUZZY RULE TABLE FOR TRIANGULAR MEMBERSHIP FUNCTIONS

CE \ E	BM	SM	Z	SI	BI
BM	SM	BM	BM	BM	Z
SM	SM	BM	BM	Z	SI
Z	BM	BM	Z	SI	BI
SI	BM	Z	SI	SI	BI
BI	Z	SI	SI	BI	BI

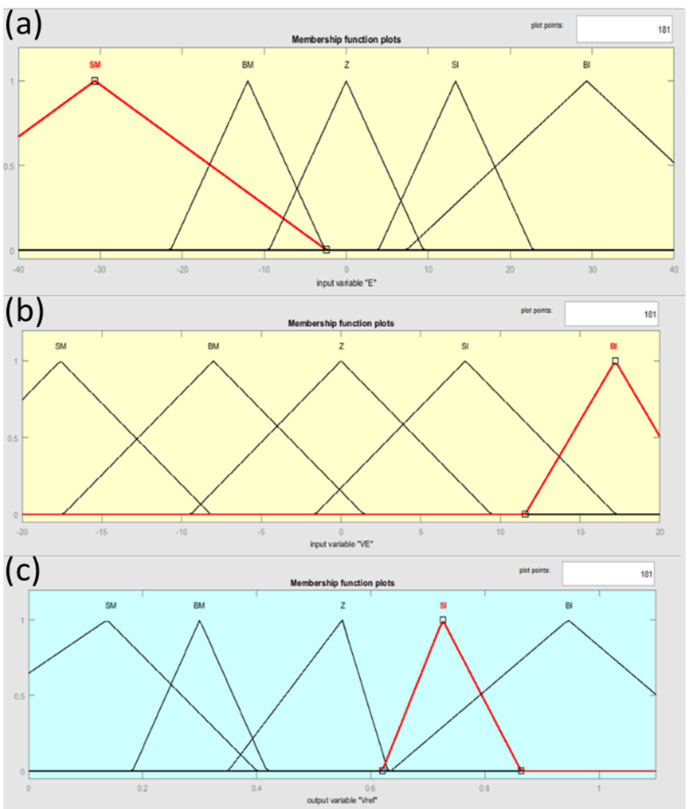
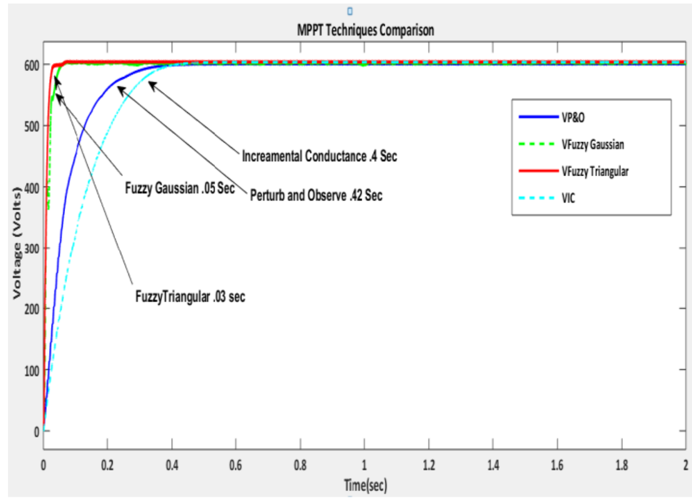


Fig. 5 (a)The error signal "E" (b)The variation in error "CE" and (c) The Output variable "Vref".

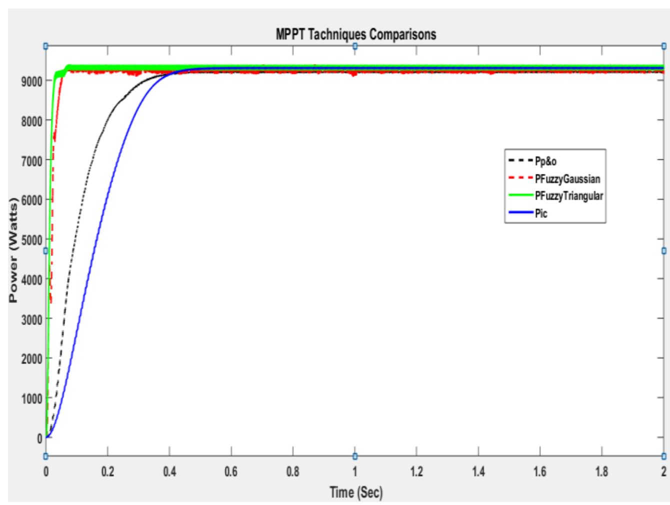
IV. SIMULATION RESULTS

In the end the MPPT by FLC (gaussian and triangular) was compared to P&O and IC methods. In this work the MATLAB /Simulink environment has been used to model the whole MPPT system by FLC assuming constant temperature of 25°C. For fair comparison the solar irradiance is kept same initially i.e., 1000 W/m^2. Figure 6 shows the comparison of voltage, current and power of P&O, IC and FLC.

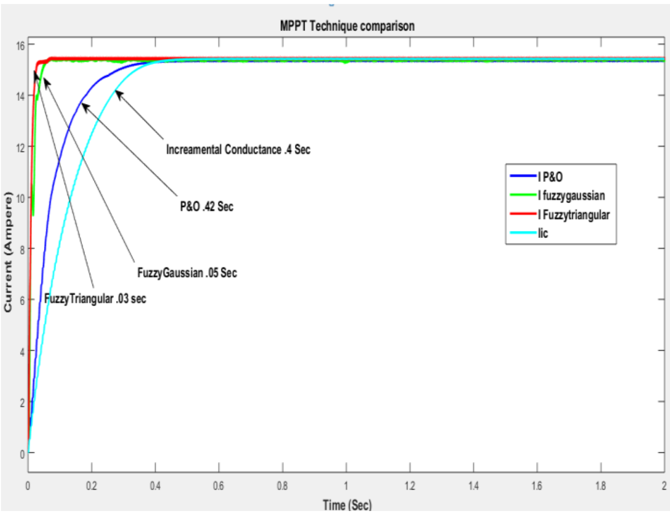
This is evident that triangular FLC has high tracking speed of 0.03s than other techniques and as a result generated voltage is more constant than remaining techniques. P&O and IC track maximum power point at 0.42s and 0.4s respectively, that is less than FLC for MPPT. Although Gaussian FLC also behaves better than P&O and IC but underperforms than triangular FLC.



(a) Comparison of voltage for different MPPT Techniques

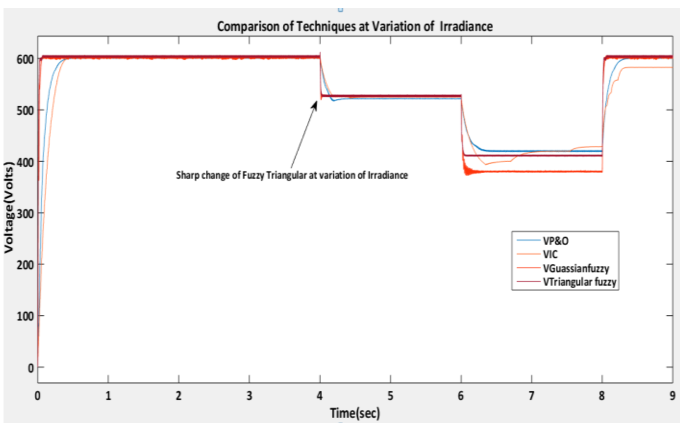


(b) Comparison of power for different MPPT Techniques

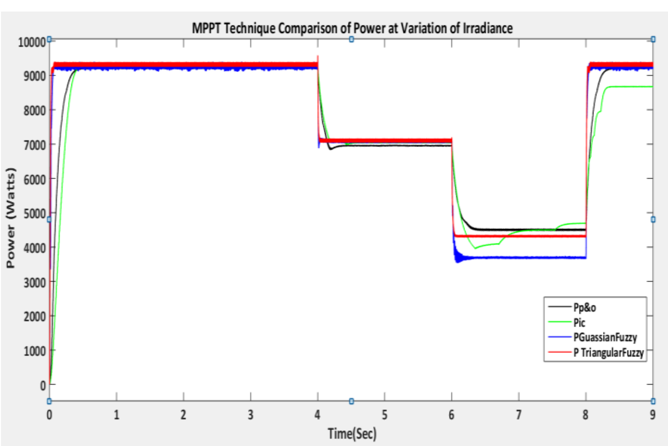


(c) Comparison of current for different MPPT Techniques

Fig. 6: P&O, Incremental Conductance, Gaussian Fuzzy and Triangular fuzzy comparison at standard Irradiance of 1000 W/m^2.



(a): Voltage comparison at varying Irradiance



(b) Power Comparison at varying Irradiance

Fig. 7: P&O, Incremental Conductance, Gaussian Fuzzy and Triangular fuzzy comparison at varying Irradiance

At second stage of experimentation, the efficiency and response of reported techniques is compared under varying irradiance condition. Figure 7 shows voltage and power waveforms for different MPPT techniques. It is worth noting that triangular FLC has fast and sharp changes during irradiance variation instant, thus making DC link stable more quickly as compared to other techniques. P & O and IC both have slow response to irradiance variation and lags the triangular and gaussian FLC in terms of performance. We can conclude then that triangular FLC is faster in speed and performance when compared to P&O and IC and gaussian FLC.

V. Conclusions

This work presents the importance and implication of MPPT in a solar power generation system. There are various MPPT algorithms for tracking maximum power point in solar systems like P&O, IC and FLC. This work presents a comparison between above reported techniques with assistance of MATLAB/Simulink environment. It was found that FLC for MPPT outperformed as compared to conventional MPPT algorithms.

FLC is preferable for MPPT because of its simplicity and moreover no mathematical model is required in FLC. It was also noted that triangular FLC has high response speed and performance under constant and varying irradiance conditions as compared to P&O, IC and gaussian FLC. Triangular FLC also showed less voltage fluctuations under varying atmospheric conditions.

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