In this paper, a fuzzy logic control (FLC) is proposed to control the maximum power point tracking (MPPT) for a photovoltaic (PV) system. The proposed technique uses the fuzzy logic control to specify the size of incremental current in the current command of MPPT. As results indicated, the convergence time of maximum power point (MPP) of the proposed algorithm is better than that of the conventional Perturb and Observation (P&O) technique.

The simulation results have been used to verify the effectiveness of the algorithm. The proposed method produces good efficiency with low switching loss. The nonlinearity and adaptiveness of fuzzy controller provided good performance under parameter variations such as solar irradiation. Tracking of the maximum power point (MPPT) plays an important role in photovoltaic(PV) power systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize they module efficiency. This work presents a fuzzy logic controller based MPPT algorithms using design of dc to dc new buck converter for photovoltaic applications. The introduction of fuzzy controller solution has given very good performance and whatever the parametric variation of the system.

Keywords: photovoltaic system, MPPT, P&O, Fuzzy Logic Control, Buck converter,

Introduction

In our world today, the problems caused by global warming and pollution effect become the important issues for research. Renewable energy sources are considered as a technological option for generating clean energy. Among them, photovoltaic (PV) system has received a great attention as it appears to be one of the most promising renewable energy sources. Recently, due to its development and cost reduction, PV system becomes an efficient solution PV system cannot be modeled as a constant DC current source because its output power is varied depending on the load current, temperature and irradiation.

A photovoltaic generator can operate over a wide range of voltage and current output, but in case you want to Maximize the energy produced (connected to UPS, battery charger, irrigation, motor-pump set, water pump, etc.) it is interesting to include a search of maximum power point in converters[1]. In fact the current vs. voltage depend on the solar irradiance and temperature. These climatic variations result in fluctuations in the maximum power point. Because of these fluctuations, it often inserts one or more controlled static

converted static converters for the furtherance of the maximum power point. These commands are known as maximum power point tracking(MPPT) associated with the choppers, which provides coupling between PV module receivers, forcing the first to deliver its maximum power[1-4].

This area makes up our days the subject of extensive research to improve the command to the pursuit of maximum power point. In this work we present fuzzy logic (FLC) based maximum power point tracking controller

Generally, MPPT is adopted to track the maximum power point in the PV system. The efficiency of MPPT depends on both the MPPT control algorithm and the MPPT circuit. The MPPT control algorithm is usually applied in the DC-DC converter, which is normally used as the MPPT circuit. Typical diagram of the connection of MPPT in a PV system is shown in Fig. 1.

One of the most popular algorithms of MPPT is P&O (Perturb and Observe) technique; however, the convergence problem and oscillation are occurred at certain points during the tracking. To enhance the performance of the P&O algorithm, this paper presents the application of Fuzzy Logic Control
(FLC) to the MPPT control. The simulation study in this paper is done in MATLAB and Simulink.

**Photovoltaic Equivalent Circuit**

The model of solar cell can be categorized as p-n semiconductor junction; when exposed to light, the DC current is generated. As known by many researchers, the generated current depends on solar irradiance, temperature, and load current. The typical equivalent circuit of PV cell is

![Typical circuit of PV solar cell](image)

The basic equations describing the I-V characteristic of the PV model are given in the following equations:

\[
0 = I_{SC} - I_D - \frac{V_D}{R_p} \cdot I_{PV} 
\]  
(1)

\[
I_D = I_0(e^{V_{oc}/V_T} - 1) 
\]  
(2)

\[
V_{PV} = V_D - R_s I_{PV} 
\]  
(3)

**Maximum Power Point Tracking Techniques**

**A. Perturb and Observation (P&O)**

One of the most simple and popular techniques of MPPT is the P&O technique. The main concept of this method is to push the system to operate at the direction which the output power obtained from the PV system increases. Following equation describes the change of power which defines the strategy of the P&O technique.

\[
\Delta P = P_n - P_{n-1} 
\]  
(4)

If the change of power defined by (4) is positive, the system will keep the direction of the incremental current (increase or decrease the PV current) as the same direction, and if the change is negative, the system will change the direction of incremental current command to the opposite direction. This method works well in the steady state condition (the radiation and temperature conditions change slowly). However, the P&O method fails to track MPP when the atmospheric condition is rapidly changed. Flow chart of the P&O method is described in Fig. 3.

![Flow Chart of the P&O Method](image)

**A. MPPT Using Fuzzy Logic Control**

MPPT using Fuzzy Logic Control gains several advantages of better performance, robust and simple design. In addition, this technique does not require the knowledge of the exact model of system. The main parts of FLC, fuzzification, rule-base, inference and defuzzification, are shown in figure. The current reference is the command for controlling the current drawn from the PV. Flow chart of the proposed FLC is shown in Fig. 5. The equations for \( \Delta P_{PV} \) and \( \Delta I_{PV} \) are given as follows:

\[
P_{PV}^k = V_{PV}^k \cdot I_{PV}^k 
\]  
(5)

\[
\Delta P_{PV}^k = P_{PV}^k - P_{PV}^{k-1} 
\]  
(6)

\[
\Delta I_{PV}^k = I_{PV}^k - I_{PV}^{k-1} 
\]  
(7)
The control rules are indicated in Table 1 with \((\Delta P_{pv})\) and \((\Delta V_{pv})\) as inputs, while \((\Delta V_{pv, \text{ref}})\) represents the output. These inputs and output variables are expressed in terms of linguistic variables (such as BN (big negative), MN (means negative), SN (small negative), Z (zero), SP (small positive), MP (means positive), and BP (big positive)). From these linguistic rules, the FLC proposes a variation of the reference voltage \(\Delta V\) according to Eqs. (4–6), where \(P_{pv[k]}\) and \(V_{pv[k]}\) are the power and voltage of the photo-voltaic generator at sampled times (k), and \(V_{pv,\text{ref}[k]}\) the instant of reference voltage.
Proposed System

In the proposed design, the universe of discourse for the first input variable ($\Delta P_{pv}$) is assigned in terms of several linguistic variables by using seven fuzzy subsets, which are denoted by NB (negative big), NM (negative medium), NS (negative small), Z (zero), PS (positive small), PM (positive medium) and PB (positive big). The membership functions for the variable are shown in Fig. 6. Fig. 7 shows the universe of discourse for the second input variable ($\Delta I_{pv}$), which is classified into 3 fuzzy sets, namely, Negative (N), Zero (Z) and Positive (P).

Fig. 5 shows the control surface of the output variable, $\Delta I_{ref}$. The MOSFET is controlled by a PWM signal generation circuit that uses a microcontroller. T is the period of the control signal and d is the duty cycle. The switch is closed for the time $dT$ and opened for the time $(1-d)T$ during each period. In searching for the MPP and tracking this point in order to minimize the spread between the operating power and the optimal power in the event of change of the weather conditions, the control circuit of the buck converter will be in the opposite direction. Intelligently perturbs periodically the operating point of the PV module. The resulting output voltage and current of the PV module are then used by the control circuit to increase or decrease the duty cycle of the buck converter in order to change the operating point of the PV module. If the power is thereby increased, then the next perturbation will be in the same direction otherwise the next perturbation will be in opposite direction.
Generalized Building and Simulation

Building of Generalized PV Model

A model of PV module with moderate complexity which includes the temperature independence of the photocurrent source, the saturation current of the diode, and a series resistance is considered based on the Shockley diode equation. It is important to build a generalized model suitable for all of the PV cell, module, and array, which is used to design and analyze a maximum power point tracker. Being illuminated with radiation of sunlight, PV cell converts part of the photovoltaic potential directly into electricity with different output characteristics. A generalized PV model is built using MATLAB/Simulink. The proposed model is implemented and shown in figure 7.

The renewable solar photovoltaic energy sources are accurately and effectively controlled. A photovoltaic panel of 36 cells with exponential connected to dc load through a new design chopper is used with fuzzy logic controller. The tracking MPPT standard conditions and variable real value input apply to the photovoltaic. Fig.7. shows the schematic circuit of proposed system with FLC based MPPT converter produce the constant output voltage, current is generally faster than the controller based on classical MPPT algorithms. The fuzzy controller has been very good improvements against the ripples in steady, it can eliminate them. The MPPT fuzzy logic control has better performance compared to each other at the time of response and stability. Increasing the temperature always involves a decrease in power.
Conclusion
The different results with different robustness test confirms the proper functioning of fuzzy controller with good performance in the atmospheric variations of illumination and temperature thereby reducing power losses, with better dynamics results. The fuzzy controller with satisfaction at the sharp variations of temperature and illumination and a fast response time. This eliminates the fluctuations in the power, voltage and duty ratio in steady state. The fuzzy logic controllers are more effective for the nonlinear systems because there is more flexibility. A fast and steady fuzzy logic MPPT controller was obtained. It makes it possible indeed to find the point of maximum power in a shorter time runs.

References
[10]In-Hwan Oh,”A soft switching synchronous buck converter for zero voltage switching(ZVS) in Light and Full load