Fuzzy Logic Controller with Maximum Power Point Tracking using Creative Design of DC to DC Buck Converter for Photovoltaic Power System

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Abstract. The studies on the photovoltaic (PV) generation are extensively increasing, since it is considered as an essentially inexhaustible and broadly available energy resource. However, the output power induced in the photovoltaic module depends on solar radiation and temperature of the solar cells. Therefore, to maximize the efficiency of the renewable solar energy system, it is necessary to track the maximum power point of the PV panel. In this paper, a maximum power point tracker using fuzzy set theory is presented to improve energy conversion efficiency 96.5%. The new method gives a very good maximum power operation of any PV module under different conditions such as changing insolation and temperature. The simulation studies show the effectiveness of the proposed algorithm.

Keywords: Fuzzy Logic Controller, Maximum Power Point Tracking, Photovoltaic Energy System, DC to DC Converter, Creative Buck Converter, Renewable Solar Energy, Fuzzy Set Theory, Insolation, Temperature.

I. INTRODUCTION

The rapid increase in the demand for electricity and the recent change in the environmental conditions such as global warming led to a need for a new source of energy that is cheaper and sustainable with less carbon emissions [1-10]. We have shining sun all the year, so we can use standalone photovoltaic (PV) powered system to equalize the power demand. Unfortunately, the actual energy conversion efficiency of PV module is rather low [2]. So to overcome this problem and to get the maximum possible efficiency, the design of all the elements of the PV system has to be optimized. In order to increase this efficiency, maximum power point tracking (MPPT) controllers are used. A significant number of MPPT control have been elaborated since the eighties, starting with simple techniques such as hill climbing, current, voltage feedback based MPPT [5], power feedback based MPPT such as perturb and observe (P and O), incremental conductance technique, recently intelligent based controls MPPT have been introduced. In this paper, an intelligent control technique using fuzzy logic control is associated to an MPPT [2, 5] novel design of dc to dc buck converter controller in order to improve energy conversion efficiency.

II. THE PROPOSED TECHNIQUE

In the system, the renewable photovoltaic (PV) power is taken as the primary source is used as a backup and

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storage system. This system can be considered as a complete green power generation system because the main energy sources and storage system is all environment friendly. The proposed isolated generation system mainly consists of PV generator, analysis of dc to dc buck converter, intelligent based MPPT controller and dc load as shown in Fig.1. The system is very simple and the following subsections, a mathematical model for device is developed and they combined together to form the complete model. This is to be used in the controller design and simulation studies.

![Fig.1. A typical standalone PV system](image)

### A. PV Module

The photovoltaic (PV) generator consists of solar cells normally connected in series and parallel fashion to provide voltage and current required by the load. This PV generator exhibits a nonlinear voltage versus current characteristic that depends on the insolation of solar radiation as given by (1). KL020 PV module is chosen for a MATLAB simulation model. The module provides 20W of nominal maximum power. Table 1 shows its electrical specification.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Peak power (P_{mp})</th>
<th>Peak voltage (V_{mp})</th>
<th>Peak current (I_{mpp})</th>
<th>Open circuit voltage(V_{oc})</th>
<th>Short circuit current(I_{sc})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specification</td>
<td>20Watt</td>
<td>17.1V</td>
<td>1.17A</td>
<td>21.5V</td>
<td>1.30A</td>
</tr>
</tbody>
</table>

\[
V_g = \frac{1}{A_g} \ln \left[ \frac{G I_{phg} - I_g + I_{og}}{I_{og}} \right] - I_g R_{sg} - - - - (1)
\]

Where \(V_g\) is the PV generator voltage, \(I_g\) is the PV generator current, \(A_c=\lambda/N_s\) is the PV generator constant, \(\lambda=q/(e^*Z^*U)\) is the electron charge, \(Z=1.38*10^{-23}J/K\) is Boltzmann constant, \(U=298.15'C\) the absolute temperature, \(\varepsilon=1.1\) is the completion factor, \(N_s=36\) is the series connected solar cells, \(N_p=1\) is the parallel paths, \(R_{sg}=R_s*(N_s/N_p)\) is the PV generator series resistance, \(I_{phg}=I_{ph}^*G\) is the insolation dependent photo current of the PV generator, \(G\) is the solar insolation in per unit and 1.0 per unit, of G(or S)=1000 W/m²[9-11]. Using the equivalent circuit of a solar cell (Fig.2) and the pertinent equation the nonlinear (V-I) characteristics of a solar panel are extracted, neglecting the series resistance.

\[
I_I = I_{ph} - R_s \exp \left( \frac{q V_I}{KTA} \right) - 1 - \frac{V_I}{R_{sh}} - - - - (2)
\]

![Fig.2. Equivalent circuit of a solar cell](image)
The photocurrent $I_{ph}$ depends on the solar radiation and the cell temperature as stated in the following.

$$I_{ph} = \left( I_{scr} + k_i(T - T_r) \right) \frac{S}{100} - -(3)$$

Where $I_{scr}$ is the PV panel short circuit current at reference temperature and radiation (A), $k_i$ is the short circuit current temperature coefficient (A/K) and $S$ is the solar radiation (mW/cm²). The reverse saturation current $I_s$ varies with temperature, according to the following.

$$I_{rs} = I_{rr} \left( \frac{T}{T_r} \right)^{3/2} \exp \left[ \frac{1.115}{k' A} \left( \frac{1}{T_r} - \frac{1}{T} \right) \right] - -(4)$$

Where $T_r$ is cell reference temperature, $I_{rs}$ is the reverse saturation current at $T_r$, $K$ is Boltzmann’s constant in eV/K and the band gap energy of the semiconductor used in the cell is equal to 1.115[4]. Finally, the next equation was used in the computer simulation to obtain the open circuit voltage of the PV panel [4].

$$V_{oc} = \frac{AKT}{q} \ln \left( \frac{I_{ph} + I_{rs}}{I_{rs}} \right) - -(5)$$

From (3) to (5), we get

$$I_{rr} = \frac{\left( I_{scr} + k_i(T - T_r) \right) \frac{S}{100}}{\exp \left[ \left( \frac{V_{oc}}{AKT} \right) - 1 \right]} - -(6)$$

And from (2)

$$R_{sh} = V_{oc} \frac{I_{rs} \exp \left[ \left( \frac{V_{oc}}{k' A} \right) - 1 \right]}{I_{rs}} - -(7)$$

B. MPPT By Fuzzy Logic Controller

The control objective is to track and extract maximum power from the PV panel for a given solar insolation level. The maximum power corresponding to the optimum operating point is determined for a different solar insolation level. Recently fuzzy logic controller has been introduced in the tracking of the MPP in PV system [5]. They have the advantage to be robust and relatively simple to design as they do not require the knowledge of the exact model. They do require in the other hand the complete knowledge of the operation of the PV system by the designer. The proposed system in this paper consist of two input variables: error (E) and change of error (CE), and one out variable, duty ratio or duty cycle (D).

**Fuzzification.** Membership function values are assigned to the linguistic variables, using five fuzzy subsets: NB (negative big), NS (negative small), ZE (zero), PS (positive small) and PB (positive big), the partition of fuzzy subsets and the shape up to appropriate system. The value of input error (E) and change of error (CE), are normalized by an input scaling factor. In this system the input scaling factor has been designed such that input values are between -1 and 1. Normally the triangular shape of the membership function of this arrangement presumes that for any particular input there is only one dominant fuzzy subset [5]. We chose the number of fuzzy subset depending on the required accuracy, some papers using seven subset for the same problem but the increasing in accuracy is very small. The input variable error (E) and change of error (CE) for the fuzzy logic controller can be calculated as follows:

$$E(K) = \Delta I \frac{I}{V} = \frac{\Delta P}{V} = \frac{\Delta P}{\Delta I} \frac{\Delta I}{\Delta V} = \frac{\Delta P}{\Delta V}$$

$$CE(K) = E(K) - E(K - 1)$$

Where $I$ is the output current from PV panel $I : I(k) - I(k-1)$. $V$ is output voltage from PV panel $V : V(k) - V(k-1)$. Table 2 shows the rule table for fuzzy logic controller.

**Table 2. Fuzzy Rule Table**

<table>
<thead>
<tr>
<th>CU</th>
<th>CE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>NB</td>
</tr>
<tr>
<td>NS</td>
<td>NZ</td>
</tr>
<tr>
<td>ZE</td>
<td>NS</td>
</tr>
<tr>
<td>PS</td>
<td>PS</td>
</tr>
<tr>
<td>PB</td>
<td>PB</td>
</tr>
</tbody>
</table>
Duty ratio, the output of fuzzy logic control uses to control through PWM which generated pulse to control MOSFET switch in DC to DC converter.

C. Novel Buck DC to DC Converter

The controller is used to obtain the PV maximum power using a proper control tracking technique algorithm because of the nonlinear nature of this source. A direct connection between the PV and the load also works well. However, there are no guarantees that the PV would supply the maximum power. The efficiency of the electrical converter is assumed to be 100%. It receives variable input voltage, which is the output of PV panels and yields constant output voltage across its output capacitor where the loads can be connected [9]. Instead of constant duty cycle [7] in the controlled buck converter utilized in this paper, the duty cycle is controlled based on the input voltage and loading conditions Duty cycle is varied using a pulse width modulation technique [12]. Hence the system under study in this section is as shown in Fig.3.

![Fig.3. Design DC to DC Novel Buck Converter Topology](image)

III. RESULTS AND DISCUSSION

A simple model is proposed which is, however, sufficient to accurately evaluate the behavior of the configuration from the energy standpoint [6]. Thus, the power and energy aspects are considered, while the voltages and the currents of the devices will not be dealt with:

A. Photovoltaic Generator

PV is modeled by a gain converting weather data (i.e., solar insolation) into electrical power. This gain, \( G_{pv} \), is given by Equation (10), where \( A_{pv} \) is the PV area in m\(^2\) and \( \eta_{pv} \) is the PV efficiency [6].

\[
G_{pv} = \eta_{pv} * A_{pv} = \frac{P_{pv}}{\text{insolation}} \]

B. 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 cells, which is used to design and analyze a maximum power point tracker.

Figs.4 gives the voltage versus power (V-P) characteristic curves of a PV panel at different radiation with constant temperature, respectively. From Figure it is observed that the radiation changes mainly affect the output current. From the figure the solar panel behaves as a current source at the left of MPP, and it assumes voltage source behavior at the right of MPP[8]. Considering that most of the loads supplied by PV system usually operate under constant voltage, so it is necessary to track the MPP of the solar panels regardless the load voltage.

C. Simulation Results and Interpretations

In this section, a simulation with MATLAB/Simulink MPPT of 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 input apply to the photovoltaic [10]. Fig.5. Show that the FLC based MPPT converter produce the constant output voltage, current is generally faster than the controller based on classical MPPT algorithms [11]. The fuzzy controller has been very good improvements
against the ripples in steady state. The MPPT fuzzy logic control has better performance compared to each other at the time of response and stability [12,13]. Increasing the temperature always involves a decrease in power.

Fig.4. Influence of different illumination on the characteristic voltage vs. power

Fig.5. Structure of the proposed system

Fig.6. The relevant waveforms($V_o, I_o, V_{in}, I_{in}$,Pulse,$V_{sw}, I_d$)
The fuzzy controller has a response almost perfect continuation algorithm while P&O and INC are late and they present some fluctuations. The fuzzy controller has a response almost perfect continuation algorithm while P&O and INC are late and they present some fluctuations. We also note that the fuzzy MPPT controller is faster [13,14]. Structure of the proposed system is shown in Fig.5. Fig 6-8 show the simulation results behavior of the system, variation of insulation with constant temperature. The result show that the fuzzy controller following the deposit with less fluctuation. The relevant waveforms of output voltage and current, input voltage and current, pulse, voltage across switch and diode current are shown in fig.6. Voltage across switch and Switch stress across voltage and current waveforms are shown in fig.7.

![Voltage across switch](image1)

![Switch stress across voltage and current](image2)

**Fig.7 Switch waveforms**
(a) voltage across switch (b) switch stress across voltage and current

### D. Fuzzy Logic Control Simulation in MATLAB/Simulink

Fig.8. shows details of FLC block in MATLAB/SIMULINK. As we mentioned in beginning of this section. FLC for MPPT have two input variable and one output variables. The first step in shown block is to calculate the input variable using Equation (8) and (9), then using FLC block which programmed as mentioned in previous sections to calculate duty ration which is the pulse width modulator input.

### E. Observations

The overall proposed system efficiency 96.51%. The controlled voltage source input voltage and current are 20, 5.217. Converter output voltage and current are 19.3, 5.216. Input and output power are 104.3watts, 100.6watts. Solar cell photovoltaic: voltage-20.01volts, current-0.598amps for 11.95watts-power. MPPT factor varies from ~1 to 1.6 as per the environment conditions.

![Fuzzy logic controller block](image3)

**Fig.8. Fuzzy logic controller block**

### IV. CONCLUSION

A novel method for maximum power point tracking was presented in this paper. The method combines a fuzzy MPPT with an appropriately designed fuzzy logic control to speed up the procedure of reaching the accurate maximum power point of the photovoltaic panel under changing weather conditions. The method presents very good results. The methodology can be applied on any photovoltaic module of the market. Due to the existence of the fuzzy logic control the method could track and adapt to any automatic variations of the photovoltaic module through time. The proposed system could get a comparatively better efficiency when compared to the results in [11]. Therefore, the method is guaranteed to present its very good performance independently of these variations.
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