“Research Note”

DESIGN, SIMULATION AND IMPLEMENTATION OF A FUZZY-BASED MPP TRACKER UNDER VARIABLE INSOLATION AND TEMPERATURE CONDITIONS*

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Abstract– A new microprocessor based fuzzy maximum power point tracker (MPPT) for photovoltaic applications under different thermal and insolation conditions is proposed. The photovoltaic system includes a solar panel, a fuzzy MPPT (to compute the optimal duty cycle) and a resistive load. Fuzzy controller input parameters are dP/dI and its variations (to improve accuracy) as well as the variation of a converter duty cycle (to improve dynamic characteristics). Theoretical and experimental results demonstrate fine performance as compared to the usual PV systems with direct connections of solar panel and load. The main contribution of this paper is the inclusion of temperature variations in the MPPT algorithm.

Keywords – Photovoltaic, maximum power point tracker, fuzzy, temperature

1. INTRODUCTION

Many maximum power point tracking (MPPT) techniques are proposed and implemented. These techniques include look-up table methods [1-2], perturbation and observation (P&O) methods [3-4] and computational methods [5-7]. One of the computational methods which has demonstrated fine performances under variable insolation conditions is the fuzzy-based MPPT technique [8-9]. Recently the application of fuzzy control has been successful in photovoltaic applications [10-17].

This paper considers the simultaneous impact of insolation and temperature variations and presents a new fuzzy MPP tracker that uses dP/dI and its variations, as well as the history of duty cycle variations as the inputs and computes the optimal MPPT converter duty cycle. A photovoltaic system including a silicon solar panel, the proposed fuzzy MPP tracker and a resistive load is designed, simulated and constructed.

2. THE PHOTOVOLTAIC SYSTEM

The nonlinear V-I characteristics of a solar panel (M parallel strings with N series cells per string) is

\[
v_{SA} = \frac{N}{\lambda} \ln \left( \frac{I_{ph} - i_{SA} + M I_o}{M I_o} \right) - \frac{N}{M} R_S I_{SA}
\]

where \(v_{SA}\) and \(i_{SA}\) are the output voltage and current of the solar cell, respectively, \(I_{ph}\) is the generated current under a given insolation, \(I_o\) is the reverse saturation current (Fig.1), \(\lambda\) is a constant coefficient that depends on temperature and \(R_S\) is the series resistance of the solar cell.

The V-I characteristics depend on the operating temperature and insolation [18]

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\[
\Delta T = T_{SA} - T_{SAr}, \; \Delta i = \alpha \left( \frac{I_{sc}}{I_{scr}} \right) \Delta T + \left( \frac{I_{sc}}{I_{scr}} - 1 \right) I_{scr}, \; \Delta v = -\beta \Delta T - R_s \Delta i, \; v_{SAr}^{new} = v_{SA} + \Delta v, \; i_{SAr}^{new} = i_{SA} + \Delta i \tag{2}
\]

where \( T_{SA} \) and \( T_{SAr} \) are the operating and the rated (nominal) solar panel temperatures, respectively, \( \alpha \) is the current-temperature coefficient, \( \beta \) is the voltage-temperature coefficient, and \( I_{sc} \) and \( I_{scr} \) are the operating and the rated solar panel short circuit currents, respectively. For the silicon solar panel (\( M=1, N=36 \)) used for the theoretical and experimental analysis of this paper [7] (manufactured by the Iranian Optical Fiber Fabrication Co. (OFFC)), Eq. (2) can be written as

\[
v_{SA} = k \ln \left( \frac{I_{ph} - i_{SA} + I_o}{I_o} \right) - i_{SA} \tag{3}
\]

Parameters of Eq. (3) will change under different temperature and/or insolation conditions (Table 1). Computed (Eq. (3)) V-I characteristic for the silicon solar panel of [7] are shown in Fig.2.

**Table 1. Parameters of Eq. (3) for the OFFC silicon solar panel under different temperature and insolation levels**

<table>
<thead>
<tr>
<th>( \left( \frac{I_{sc}}{I_{scr}} \right) ) [%]</th>
<th>Temp. [°C]</th>
<th>( k )</th>
<th>( I_{sc} ) [A]</th>
<th>( I_o ) [A]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>-20</td>
<td>2.13</td>
<td>2.83</td>
<td>4.84 \times 10^{-5}</td>
</tr>
<tr>
<td>100</td>
<td>25</td>
<td>1.764</td>
<td>2.926</td>
<td>5 \times 10^{-3}</td>
</tr>
<tr>
<td>100</td>
<td>70</td>
<td>1.505</td>
<td>3.02</td>
<td>5.16 \times 10^{-3}</td>
</tr>
<tr>
<td>60</td>
<td>-20</td>
<td>2.134</td>
<td>1.699</td>
<td>2.9 \times 10^{-4}</td>
</tr>
<tr>
<td>60</td>
<td>25</td>
<td>1.767</td>
<td>1.756</td>
<td>3 \times 10^{-4}</td>
</tr>
<tr>
<td>60</td>
<td>70</td>
<td>1.507</td>
<td>1.812</td>
<td>3.1 \times 10^{-4}</td>
</tr>
<tr>
<td>20</td>
<td>-20</td>
<td>2.138</td>
<td>0.566</td>
<td>9.68 \times 10^{-5}</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
<td>1.77</td>
<td>0.585</td>
<td>1 \times 10^{-4}</td>
</tr>
<tr>
<td>20</td>
<td>70</td>
<td>1.509</td>
<td>0.604</td>
<td>1.03 \times 10^{-4}</td>
</tr>
</tbody>
</table>

Fig. 2. Nonlinear V-I and P-I characteristics of one OFFC silicon solar panel at different insolation and temperature levels

**3. THE FUZZY MPP TRAKER**

To determine the operating point corresponding to maximum power for different insolation and temperature levels (Eq.(3)), a fuzzy logic controller (FLC) for adjusting the duty cycle of the DC/DC converter is used (Fig.3). Inputs of the fuzzy processor (FP) include \( dP/dt \) and its variations (to improve accuracy), as well as the variations of a converter duty cycle (to improve dynamic characteristics). \( U(K) \) and \( \Delta U(k) \) denote the
outputs of the controller and FP, respectively. Input and output variables of FLC are related by the following equations:

\[
\frac{dP}{dt}(k) = \frac{p_{S_A}(k) - p_{S_A}(k-1)}{i_{S_A}(k) - i_{S_A}(k-1)}, \quad \Delta \left( \frac{dP}{dt} (k) \right) = \frac{dP}{dt} (k) - \frac{dP}{dt} (k-1)
\]

\[
\Delta DC(k) = \Delta U(K-1), \quad U(k) = U(k-1) + \Delta U(k)
\]

where \( p_{S_A}(k) \) and \( i_{S_A}(k) \) are the power and current of the solar panel, respectively, and \( U(K) \) is the duty cycle of a buck converter.

The fuzzy processor includes three functional blocks: fuzzification (thirteen fuzzy subsets for input variables and five fuzzy subsets for output variable), fuzzy rule algorithm (75 fuzzy control rules and Mamdani's inference method with max-min operation fuzzy combination) and defuzzification (using center of area (COA) algorithm).

4. SIMULATION AND CONSTRUCTION OF THE FUZZY MPP TRACKER

For the simulation of a fuzzy MPPT with solar panel and resistive load, the Matlab/Simulink software is used (Fig.4). For the experimental investigation, a microprocessor-based tracker (Fig. 5) with the following capabilities was constructed and used: (a) Implementing the fuzzy MPPT technique, (b) Continual control of the buck converter according to the fuzzy tracking method, (c) On-line measurements of solar panel voltage, current and temperature, as well as computing the FP input parameters (Fig.3).

5. ANALYSIS OF SIMULATED AND MEASURED RESULTS

Two cases are investigated: Case 1- without the MPP tracker (e.g., direct connection of the solar panel and the load). Case 2- with the MPP tracker (placed between the solar panel and the load).
**Insolation Analysis:** Figure 6 demonstrates the impact of insolation variations on the performance of the fuzzy MPP tracker. These results indicate a considerable increase in the panel power level, about 350% for high insolation (Figs.6a-c) and about 275% for low insolation (Figs. 6d-f) in the presence of the fuzzy MPPT.

**Temperature Analysis:** Figure 7 demonstrates the impact of temperature variations on the present of the fuzzy MPP tracker. Figs.7a-c show measured waveforms for a high temperature condition (e.g., $T_S = 40^\circ C$). The maximum PV output power increases about 400% in the presence of the proposed fuzzy MPP tracker. Figs. 7d-f show measured results for a low temperature condition (e.g., $T_S = 17^\circ C$). Demonstrating the outstanding performance of the MPP fuzzy tracker, which increases the PV maximum output power from 6 W to about 24 W.
6. CONCLUSIONS

This paper presents a new microprocessor based fuzzy MPP tracker for photovoltaic applications under different temperature and/or insolation conditions. The main conclusions are as follows:

- The proposed fuzzy tracker performs satisfactorily in the presence of insolation and temperature variations.
- Considerable increase in solar output power is achieved under different insolation (e.g., about 350%, Fig.6) and temperature (e.g., about 400%, Fig.7) conditions.
- Solar panels generate more power under low temperature conditions (Fig.7).
- The proposed fuzzy tracker performs an online adaptive search of solar panel maximum power.
- The proposed tracker is robust to environmental (e.g., insolation, temperature) and parameter variations.
- The proposed tracker does not require any external sensor (or a dummy solar panel) for detecting solar intensity and temperature.

REFERENCES


PERSIAN TRANSLATION OF ABSTRACTS