A FASTER MAXIMUM POWER POINT TRACKER USING PEAK CURRENT CONTROL

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Abstract- This paper focuses on alternatives for implementing variable size perturbations in peak current controlled perturbation and observation (P&O) maximum power point trackers (MPPT). Implementations of P&O algorithms based on peak current control and on instantaneous sampled values have shown to provide very fast transients and small oscillations around the maximum power point (MPP). However, operation with fixed variation of the reference current results in a tradeoff between speed of response and maximum power yield in the steady state. Variable variation of the reference current can be successfully done with Fuzzy logic. This paper discusses a Fuzzy logic based P&O MPPT with peak current control with variable variation of the reference current for improved transient as well as steady-state performance. The Fuzzy logic based scheme presents a faster rise time of 0.27 ms as compared to 0.32 ms for the standard scheme with fixed $\Delta I_{REF}$. Simulation results show a 15 % gain in the transient response and decrease of the power loss in the steady state.

Keywords: PV systems, MPPT, Perturbation & Observation (P&O), Peak Current Control, Fuzzy logic.

I. INTRODUCTION

It is evident that the output characteristics of the PV panel are non-linear in nature and vary with atmospheric conditions namely temperature, irradiance and etc. Tracking the maximum power point (MPP) of a photovoltaic (PV) array is usually an essential part of a PV system. As such, many MPP tracking (MPPT) methods have been developed and implemented [1-3]. An MPPT is a control algorithm that can be included in the PV panel connections in order to track the maximum power point, which is going to be different from the STC (Standard Test Conditions) rating under almost all situations [4]. MPPT Algorithms can be basically classified into two categories On-line and Off-line methods. On-line methods measure operating voltage and/or current and compare the present value of power with the previously obtained values and appropriate changes in the reference value are made so as to cause a further increase in power ultimately tracking the operating point that operates at maximum power. Online methods are usually more expensive due to extra circuitry employed and are usually only used in large PV systems. However, with the availability of low-cost based microcontrollers and field programmable gate arrays (FPGAs) these methods can also be applicable to module based power electronic interfaces [5-8]. Off-line methods rely on the measurement of parameters like irradiance, panel temperature, short circuit current, open circuit voltage of the PV array etc. and the use of prior training data to set the reference signal corresponding to operation at the maximum power point (MPP). This methods present reduced implementation costs, but sub-optimum performance [9-13].

Fuzzy logic is being increasingly used in present times as a convenient tool to model and control systems, which are nonlinear in nature, the solar PV array being no exception. In this paper we use a Fuzzy logic based controller along with instantaneous values of PV voltage and current and peak current control for determining not only the direction of the next perturbation (variation of reference current) but also its magnitude, by which one can enhance both transient and steady-state operation simultaneously. The modified membership functions and Rule base are presented in this paper. This could provide an advantage in terms of computational time. The Paper is organized as follows: Section II describes the proposed Fuzzy logic based MPPT scheme and the design of the Fuzzy controller, membership functions, rule base and etc. Simulations run with MATLAB/Simulink for both the fixed increment peak current control and the Fuzzy based peak current controller are presented in Section III and comparisons are drawn.

II. FUZZY LOGIC CONTROLLER

A subjective Fuzzy model of the system is designed based on prior expert knowledge of the system. The Fuzzy logic controller (Fig.1) is divided into four sections: Fuzzification, Rule base, Inference and Defuzzification. The inputs to the
Fuzzy logic controller are change in PV array power ($\Delta P_{PV}$) and change in PV array current ($\Delta I_{PV}$) and the output is the step change in converter reference current ($\Delta I_{REF}$).

![Rule Base Diagram](image)

### A. FUZZIFICATION

Input variable 1 ($\Delta P_{PV}$) is divided into seven Fuzzy sets: PB (Positive Big), PM (Positive Medium), PS (Positive Small), ZZ (Zero), NS (Negative Small), NM (Negative Medium) and NB (Negative Big). As opposed to [14] where the Fuzzy set PS assumes a membership value greater than zero beginning at the origin, in the present model the Fuzzy set PS is offset from the origin in order to speed up the startup process and at the same time prevent variation of the reference current at the MPP. Additional Fuzzy sets PM and NM has also been added to improve the control surface and allow a smooth transition from the transient to the steady-state. Input variable 2 ($\Delta I_{PV}$) is divided into 3 Fuzzy sets: N (Negative), Z (Zero) and P (Positive). The output variable ($\Delta I_{REF}$) is divided into 7 Fuzzy sets: PB (Positive Big), PM (Positive Medium), PS (Positive Small), ZZ (Zero), NB (Negative Big), NM (Negative Medium) and NS (Negative Small). The Fuzzy sets PM, PB and NM, NB of the output variable associated with the transient response are constructed separate from the rest of the membership functions which are associated with the steady-state response. This enhances both the transient and the steady state performance providing a larger step variation of current during the transient phase and an almost zero step variation of current in the steady-state. The membership functions for the input and output variables are displayed in the Fig.2. The membership functions for the input and output variables were designed to model the unsymmetrical nature of the PV panel $P_{PV} \times I_{PV}$ curve. The Membership functions are denser at the center to provide greater sensitivity in the region near the MPP. Input membership functions are normalized and suitable tuning gains are used to match the inputs to the respective universes of discourse.

![Membership Functions](image)

### B. RULE BASE

The rule base for the Fuzzy logic controller is designed based on the rule base provided in Table I. The Fuzzy algorithm tracks the maximum power based on the master-rule: "If the last change in the reference current ($I_{REF}$) has caused the power to increase keep changing the reference current in the same direction; else if it has caused the power to drop, move it in the opposite direction" which is the basic principle of the P&O Method [15]. A rule base consisting of 19 rules is designed. The master rule is converted into the first 12 rules displayed in Table I. Additional rules are required to compensate for the change of the PV array characteristic.
curves with atmospheric conditions, leading to an overall drift of the optimum point. Rules 13-16 are designed for this purpose. Rules 17-18 are also designed to prevent the stabilizing effect in a region other than that of true peak power. Finally, a single rule 19 is provided to stabilize the operation of the system at the MPP. Weights are generally added to rules to improve the reasoning accuracy and to reduce undesirable consequent [15]. Different rule weights have been used to cover varying conditions. The highest weights are given to the first set of 12 rules as they represent the normal system operation. Rules 13-18 are used to account for special conditions and hence are given a lower weight. Rule 19 is activated only when the system operates at the MPP and hence needs only a light weight.

Table I. Rule base for the Fuzzy model

<table>
<thead>
<tr>
<th>Rule No.</th>
<th>If ΔPREF is... And ΔIREF is... Then ΔIREF is...</th>
<th>Rule weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PB</td>
<td>PB</td>
</tr>
<tr>
<td>2</td>
<td>PM</td>
<td>P</td>
</tr>
<tr>
<td>3</td>
<td>PS</td>
<td>P</td>
</tr>
<tr>
<td>4</td>
<td>PB</td>
<td>N</td>
</tr>
<tr>
<td>5</td>
<td>PM</td>
<td>N</td>
</tr>
<tr>
<td>6</td>
<td>PS</td>
<td>N</td>
</tr>
<tr>
<td>7</td>
<td>NB</td>
<td>P</td>
</tr>
<tr>
<td>8</td>
<td>NM</td>
<td>P</td>
</tr>
<tr>
<td>9</td>
<td>NS</td>
<td>P</td>
</tr>
<tr>
<td>10</td>
<td>NB</td>
<td>N</td>
</tr>
<tr>
<td>11</td>
<td>NM</td>
<td>N</td>
</tr>
<tr>
<td>12</td>
<td>NS</td>
<td>N</td>
</tr>
<tr>
<td>13</td>
<td>PB</td>
<td>Z</td>
</tr>
<tr>
<td>14</td>
<td>PM</td>
<td>Z</td>
</tr>
<tr>
<td>15</td>
<td>NB</td>
<td>Z</td>
</tr>
<tr>
<td>16</td>
<td>NM</td>
<td>Z</td>
</tr>
<tr>
<td>17</td>
<td>ZZ</td>
<td>P</td>
</tr>
<tr>
<td>18</td>
<td>ZZ</td>
<td>N</td>
</tr>
<tr>
<td>19</td>
<td>ZZ</td>
<td>Z</td>
</tr>
</tbody>
</table>

C. INFERENC
The inference method determines the output of the Fuzzy controller. Mamdani's inference method has been used in our system along with the max-min composition method. This is because this method is computationally more efficient and has better interpolative properties than other inference methods such as those based on the Compositional Rule of Inference (CRI) and Generalized Modus Ponens (GMP) and Sugeno inference methods. However, Mamdani's inference method is usually popular for most control engineering applications [16].

D. DEFUZZIFICATION
The output of the Fuzzy controller is a Fuzzy set. However, a crisp output value is required. Moreover, the output of the Fuzzy controller should be defuzzified. The centroid method is one of the commonly used defuzzification methods and is the one we will employ for the proposed system. This method has good averaging properties and simulation results showed that it provided the best results as compared to other defuzzification methods such as bisector, Middle of Maxima (MOM) and etc [16].

III. SIMULATION RESULTS
Simulations were run in Matlab/Simulink environment to verify the performance of the proposed scheme with simplified models of a PV panel, boost converter and a battery. The parameters are shown below.

PV panel (at rated solar irradiation levels)

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2</td>
<td>21.8</td>
<td>3.3</td>
<td>18.9</td>
<td>62.37</td>
</tr>
</tbody>
</table>

Boost converter and battery bank

<table>
<thead>
<tr>
<th>L [mH]</th>
<th>Fsw [kHz]</th>
<th>Vd[V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>24</td>
</tr>
</tbody>
</table>

Simulations of the algorithm using fixed variation of reference current are also provided for comparison purposes. Figures 3 and 5 show the start-up process under rated ambient conditions and the response to a step variation of irradiance to 50% of the initial value for the standard scheme with fixed ΔIREF and the Fuzzy logic based scheme with variable ΔIREF. Figures 4 and 6 show the detailed steady-state waveforms for the above-mentioned peak current control based algorithms. It must be stated that optimum tuning gains have been used for the fuzzy controllers which is 2.8 for the ΔIREF input and 5 for the ΔVREF. As seen from Fig.5 the Fuzzy logic based scheme presents a faster rise time of 0.27 ms as compared to 0.32 ms for the standard scheme with fixed ΔIREF because the use of the Fuzzy logic controller allows the use of a larger variation of reference current during the transient state. In the simulations the refresh rate for the reference current was same as the switching frequency which was chosen to be 100 kHz, while in the experimental case the refresh rate for the reference current is approximately 250Hz due to the constraints of the DSP microcontroller, which requires a larger time-step to process the MPPT algorithm in real time. The rise time in the case of the simulations was 0.27 ms. Thus the expected rise time in the experimental case should be 108 ms, which is close to what we have experimentally. In [16] it was seen that if the peak current control logic was implemented in the DSP, in the case of the standard scheme with a fixed ΔIREF, the switching frequency was restricted to 10kHz in order to have a good enough resolution of duty cycle. In addition the computation time required by the DSP to process the Fuzzy controller block in the schemes involving Fuzzy logic, places a further restriction on the switching frequency of the boost converter, if the peak current control logic was implemented in the DSP. The fuzzy logic based variable ΔIREF scheme also presents a reasonable response. As seen in Fig.6 the Fuzzy based schemes present lowest power drops and peak-to-peak ripple in Ipv (0.045A) in the steady-state as opposed to 0.15A for the fixed variation of reference current, because ΔIREF = 0 A in the steady-state. The current ripple for these cases is only due...
to the intrinsic switching of the converter and does not include the variations of $I_{\text{REF}}$ that appear in the case of the fixed variation of reference current. For further increasing the power drawn from the PV array one should reduce the current ripple. This can be done by using a higher value of inductance for the Boost inductor, increasing the switching frequency or using interleaved boost converters.

![Fig. 3](image1.png) **Fig. 3** Start-up of the MPPT system under rated ambient conditions and response to sudden step-down of irradiance for standard scheme with fixed $\Delta I_{\text{REF}}$

![Fig. 4](image2.png) **Fig. 4** Detailed steady-state for standard scheme with fixed $\Delta I_{\text{REF}}$

![Fig. 5](image3.png) **Fig. 5** Start-up of the MPPT system under rated ambient conditions and response to sudden step-down of irradiance for Fuzzy logic based scheme with variable $\Delta I_{\text{REF}}$

![Fig. 6](image4.png) **Fig. 6** Detailed steady-state for Fuzzy logic based scheme with variable $\Delta I_{\text{REF}}$

IV. **CONCLUSIONS**

This paper has proposed the use of a Fuzzy Logic based controller to output an incremental reference current that varies with both magnitude and direction depending on the operating point of the system on the PV panel $V_{PV}\times I_{PV}$ characteristic. This way, one achieves very fast transient responses as well while reducing the oscillations around the MPP in the steady-state. The remaining power loss in the steady-state is due only to the current ripple. Implementation of the peak current control based MPPT systems in an FPGA or a faster microcontroller to be able to operate the power converter at a higher frequency, what should reduce the size of the passive components and further increase the speed of response of the MPPT system. So, operation at higher switching frequencies is possible in spite of the computational constraints of the DSP microcontroller.

**REFERENCES**


