Dual-Fuzzy MPPT in Photovoltaic-DC Analysis for Dual-load Operation with SEPIC Converter

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Abstract — In this paper, dual-fuzzy based maximum power point tracking (MPPT) is proposed for standalone photovoltaic (PV) system, working for dual-load operation. The proposed MPPT consists of two different fuzzy logic controllers (FLCs) to support operation of single ended primary-inductor converter (SEPIC) in buck and boost conditions, by depending on irradiance conditions. To realize dual-operation of SEPIC, dual-load approach has been applied by selecting suitable load resistance, which could achieve maximum power point (MPP) with specific irradiance and duty cycle. Then, relationship between irradiance, load resistance and duty cycle has been discussed in details. The dual-fuzzy based MPPT together with PV module of Kyocera KD210GH-2PU connected to SEPIC was simulated in MATLAB-Simulink, and further the laboratory prototype with TMS320F28335 eZdsp board was implemented. Each load was connected to direct current (DC) supply to ensure continuity of the supply to both loads. Both simulation and experimental results and comparison analysis (with P&O) have been presented. From the results and analysis, dual-fuzzy based MPPT with dual loads shows that by switching from PV to DC, there is no change in output voltage, but during the switching from DC to PV, there are significant changes that can be noticed according to the irradiances.

Keywords — fuzzy logic; dual loads; SEPIC dc-dc converter; MPPT; photovoltaic.

I. INTRODUCTION

Among the long list of renewable energy, photovoltaic (PV) from solar is much preferable due to easiness to implement with less maintenance. In recent days, PV systems have been never ending demand due to its enormous potential to be the nearest solution we have right now to slowly substitute our dying fuel energy. When the PV panel is exposed to solar irradiation, it could generate direct current electricity without any environmental impact and contamination. The only drawbacks regarding it, is the cost to manufacture PV panel is too high with small range of efficiency which is about 15-20% [1].

PV panel has nonlinear output characteristics and the main factors affecting PV output power are solar irradiation, temperature and load impedance [2, 3]. When solar irradiation rises, PV current increases; however, the temperature of PV module has more significant effect on PV voltage operation [4]. Due to nonlinear output characteristic of PV panel, an algorithm is needed to track the maximum power point (MPP) of the PV curve to deliver maximum power and it is called maximum power point tracking (MPPT).

Fig.1a Block diagram of PV system with dual-MPPT and dual-load operation.
The operation of MPPT is basically to find the operating voltage $V_{MPP}$ and the operating current $I_{MPP}$ at which PV operates to obtain MPP. There have been many MPPT methods developed and implemented [5, 6]. Among them are perturb and obverse (P&O), incremental conductance (IC), artificial neural network (ANN), fuzzy logic controller (FLC), constant voltage, three point weight comparison, short current pulse, and open circuit voltage. Specifically for FLC, it does not require an accurate mathematical model and is known to be very efficient in handling problems that have non linearity variables as in PV [6, 7].

As dc-dc converters such as buck-boost and CUK converters have inverted polarity in their output value, single ended primary-inductor converter (SEPIC) is much more preferable because polarity of its output is not inverted [8, 9]. However, till date, previous reported works only covered either boost or buck conditions, or both buck and boost in their converter operations with only a single load. Therefore, in this paper, two FLCs with each having their own independent control are proposed to handle switching of the two loads depending on the PV output current and it is called as load switching controller. Both controllers and load changing controller are clearly shown in the block diagram of dual-fuzzy MPPT PV system with dual-load operation. Meanwhile, voltage and current are measured and used by dual-fuzzy MPPT to produce duty cycle to operate IGBT in SEPIC [7].

The proposed standalone PV system consists of four main components: PV panel, SEPIC, MPPT and controllers, as shown in Fig. 1. The controllers consist of load changing controller and intermediate controller. The function of intermediate controllers is to control the connection between SEPIC and loads. Threshold current is set in the controller. Once the input current is more than the threshold value, SEPIC converter will be connected to load 2 by load changing controller. If the current is less than the threshold value, it remains as default, where the load changing controller connects load 1 to SEPIC converter. The function of intermediate controllers is to control the connection of loads to either DC supply or SEPIC. When the irradiance is low, the current delivered from the PV panel will be lower and FLC, as further explained later with higher duty cycle will be selected. With higher duty cycle, SEPIC performs boost action and thus higher resistor (load 1) will be connected to be associated with the low current supply and to obtain high output voltage at the load side. When the sun irradiance is higher, the input current from PV will increase. Now the targeted load will be lower resistor (load 2), so high current could flow through it and of course the load voltage will be lesser, so SEPIC will perform buck action resulting from the lower duty cycle.

The connections of resistor loads with intermediate controllers and load changing controller are clearly shown in the block diagram. Meanwhile, Fig 1b shows the operation of the controllers when SEPIC is connected to load 1 and however, only intermediate controller 2 is attached to load 2 for connecting it to DC supply, as shown in Fig 1b. The default settings of the controllers have been made based on irradiance 200W/m$^2$ as load changing controller and intermediate controller 1 are attached to load 1, and however, only intermediate controller 2 is attached to load 2 for connecting it to DC supply, as shown in Fig 1b. Meanwhile, Fig 1c shows the operation of the controllers when SEPIC is connected to load 2.
intermediate load 1 connects load 1 with DC supply. All the connections of the controllers have been tabulated accordingly in Table 1.

<table>
<thead>
<tr>
<th>Load changing controller</th>
<th>Intermediate controller 1</th>
<th>Intermediate controller 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>OFF (default)</td>
<td>Connects load 1 to SEPIC</td>
<td>Connects load 2 to DC Supply 2</td>
</tr>
<tr>
<td>(during low irradiance)</td>
<td>DC Supply 1 is disconnected</td>
<td>DC Supply 2 is connected</td>
</tr>
<tr>
<td>ON (during high irradiance)</td>
<td>Connects load 1 to SEPIC</td>
<td>Connects load 2 to DC Supply 2</td>
</tr>
<tr>
<td></td>
<td>DC Supply 1 is connected</td>
<td>DC Supply 2 is disconnected</td>
</tr>
</tbody>
</table>

### III. DUAL FUZZY LOGIC CONTROLLERS (FLCs)

Two FLCs are configured as MPPT in this system to perform buck and boost operations for dual loads. One FLC has been set to give lower duty cycle and another FLC has been set to higher duty cycle. The inputs for both FLCs are same and the difference is the output duty cycle. Both FLCs use two inputs; error E and change of error CE at sample time k, which are defined by (5) and (6) [12, 13].

\[
E(k) = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \quad (5)
\]

\[
CE(k) = E(k) - E(k-1) \quad (6)
\]

Basically, operation of FLC can be classified into four basic elements: fuzzification, rule base, inference engine and defuzzification [11-14]. During fuzzification, inputs of the fuzzy, CE and E variables are calculated and converted into linguistic variables based on the membership function. The output D is generated by looking up in a rule base table. The fuzzy output is converted back to numerical variable from linguistic variable during defuzzification. According to the Fig.4, both selections of duty cycle and switching of the load controller are based on input current. When the input current is higher than the threshold value that has been set in the algorithm itself, FLC with lower duty cycle will be selected. At the same time, load switching controller will be switched to load 2 which have low resistance.

The concept of designing the controller is based on P-V curve. In each FLC, 7 membership functions are configured for all inputs. All the membership functions are set as triangular shapes with both ending sides of the universe of discourse companied by trapezium shape to show the continuous of the controller. Seven-term fuzzy sets, Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), Positive Big (PB), are defined to describe each linguistic variable. The fuzzy method is Mamdani where the maximum or minimum composition technique for the inference is used. Center-of-gravity methods are used in the defuzzification process. Fig. 3 shows membership patterns for the following inputs of E and CE and output voltage reference. Table 2 shows the rules implemented for both controllers. From these seven membership functions, zero (ZE) membership is representing MPP, which divides left and right sides according to the curve gradient. The positive membership functions (PB, PM and PS) are focused at left side of MPP based on positive gradient with PB is the most left region. However, the negative membership functions (NB, NM and NS) are focused at right side of MPP based on negative gradient with NB is the most right region. The areas of PS and NS are rather smaller as compared to the rest of the membership functions in order to make the controller becomes more sensitive towards ZE which determines the duty cycle of the controller.

The usage of FLC involves initial duty cycle where the initial duty cycle applied is difference for both low irradiance and high irradiance. Without the initial duty cycle, the result of FLC is highly unpredictable and it could affect the power converter by triggering high duty cycle into the converter resulting in high output voltage. The duty cycle can be increased and decreased but with a certain range. So for both buck and boost operation, two FLC are being implemented.
VI. HARDWARE IMPLEMENTATION

Laboratory prototype was developed to investigate the performance of the proposed dual-fuzzy based MPPT with dual-load operation. Solar simulator is used instead of solar panel due to the experimental needs of changing the irradiances frequently. The solar simulator used is Chroma 62100H-600S; programmable DC power supply 600V/25A/15KW with Solar Array Simulation. The parameters in the solar simulator have been set according to the PV module Kyocera KD210GH-2PU. Dual-fuzzy based MPPT is implemented through a microcontroller TMS320F28335 eZdsp board. The MPPT algorithm was designed by using MATLAB/Simulink and by using Code Composer Studio (CCS); the control code was generated before it was downloaded into DSP.

Fig.4 Flow chart of proposed dual-fuzzy MPPT.
Fig. 5 shows the input voltage from PV. For the change from irradiances 700 W/m² to 200 W/m², the input voltage remain the same as shown in Fig. 5a, but there is a significant voltage drop during the switching from low irradiance (200 W/m²) to high irradiance (700 W/m²). By using dual-fuzzy, voltage drop of about 4V and settling time of 0.3s are obtained, which are lower than P&O MPPT with voltage drop of 15V and higher settling time in about 0.35s with very high ripples, as illustrated clearly in Fig. 5b.

Fig. 6 shows the PV input powers for the change from 200 W/m² to 700 W/m² and the change from 700 W/m² to 200 W/m². Larger voltage drop and high ripples occur when P&O MPPT is used, resulting in poor quality in input power. Due to high voltage drop during step down at time of 10s as shown in Fig. 6c, the input power of PV when using P&O is also affected. At period of 10s, P&O causes the power drop nearly 20W and then high ripples and high oscillations take place throughout the experimental operation. When dual-fuzzy is in use, power drop is only about 3W with lesser ripples.

Fig. 7 shows the output voltages at load 1 and load 2. Whenever the intermediate controllers switch the loads to different supplies (PV supply and DC supply), output voltages of the loads have been observed. All the results are presented together by comparing P&O and dual-fuzzy. Fig 7a shows output voltage at load 1 during switched from PV supply to DC supply.

However, Fig 7b shows output voltage at load 1 during switched from DC supply to PV supply. Output voltage at load 2 which was switched from PV supply to DC supply and DC supply to PV supply was presented in Fig. 7c and Fig. 7d respectively. Table 3 shows the comparison of dual-fuzzy and P&O in terms of percentage of ripples, overshoot, and rising time.
Fig. 7 Effect of dual-fuzzy and P&O algorithms in output voltages during switched from a) PV supply to DC supply at load 1, b) DC supply to PV supply at load 1, c) PV supply to DC supply at load 2, and d) DC supply to PV supply at load 2.

Table 3. Output voltage characteristics of both dual-FLC and P&O algorithms.

<table>
<thead>
<tr>
<th></th>
<th>Dual-fuzzy</th>
<th>P&amp;O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage drop at input voltage</td>
<td>0.06% (1.6V drop)</td>
<td>48% (13V drop)</td>
</tr>
<tr>
<td>Power drop at input power</td>
<td>0.136% (6W power drop)</td>
<td>37.5% (25W power drop)</td>
</tr>
<tr>
<td>Ripple in load 2 and load 1</td>
<td>0.018% (0.4V)</td>
<td>14.2% (2.5V)</td>
</tr>
<tr>
<td>Voltage overshoot in load 2</td>
<td>3% (0.5V)</td>
<td>43% (7.5V)</td>
</tr>
<tr>
<td>Rising time in load 1 (output voltage)</td>
<td>0.05 seconds</td>
<td>0.2 seconds</td>
</tr>
</tbody>
</table>

VII. CONCLUSION

This paper presents dual-fuzzy based MPPT for SEPIC with dual loads by ensuring maximum power transfer could happen either in low or high irradiances. Higher duty cycle is more suitable to be applied during lower irradiance and must be connected to higher resistance load. However, lower duty cycle is preferred to be switched when the irradiance is high and lower resistance load must be connected to it in order to obtain MPP. Dual-fuzzy based MPPT is needed in order to perform boost and buck operations separately in two different loads. Analyses of the output voltages obtained at load 1 and load 2 shows that during the switching from DC supply to PV supply, if the irradiance is high, there will be high overshoot voltage due to high current of PV and if the irradiance is low, there will be voltage drop due to low current supply by PV.

REFERENCES


