Type-2 Fuzzy Logic Approach of a Maximum Power Point Tracking Employing SEPIC Converter for Photovoltaic System

Ahmad H. El Khateb, Nasrudin Abd Rahim, and Jeyraj Selvaraj

***Abstract*—This paper introduces a type-2 fuzzy logic controller (FLC) as a maximum power point tracker (MPPT), which can handle the uncertainties of the rules under high variations in weather conditions. The MPPT employed single-ended primary-inductor (SEPIC) converter. The new controller improves maximum power tracker search method by rules fuzzifying. An accurate and fast converging to maximum power point is offered by type-2 fuzzy tracker during both steady-state and varying weather conditions compared to conventional fuzzy MPPT methods. The performance of the proposed maximum power point tracker is demonstrated in MATLAB simulation at different operating conditions.**

***Index Terms*—Fuzzy logic controller (FLC), Maximum power point tracker (MPPT), Photovoltaic (PV).**

I. Introduction

Type-2 fuzzy set was introduced in [1] as an upgrading of the ordinary fuzzy logic set which is called type-1 fuzzy set. The characterization of type-2 fuzzy set is that the membership value for each element of this set is a fuzzy set in [0,1], not a crisp set like type-1 set. Type-2 fuzzy set can handle linguistics uncertainties as well as numerical uncertainties. FLC needs dispersion to measure more about rule uncertainties than a single number. Type-2 FLC provides this dispersion and it is considered a fundamental to the design of systems that include linguistic and numerical uncertainties. [2]-[3]

The PV power and voltage characteristics are nonlinear and affected by the irradiance and temperature variations. The applied MPPT uses a type of control and logic to look for the knee, which in turn allows the SEPIC converter to extract the maximum power from the PV array. The tracking method provides a new reference signal for the controller and extracts the maximum power from the PV array. Literature has proposed many MPPT techniques. The incremental conductive method is based on the derivative of power over voltage being zero at the MPP, positive on the left of the MPP, and negative on the right. This method requires complex computation to give good performance under rapidly varying weather conditions. Furthermore, the tracking time is relatively long for small step size [4]. Hill climbing method works by perturbation of the PV system changing the power converter duty cycle and observing it on the output power, and then deciding the new direction of the duty cycle to extract maximum power. The hill climbing method has slow response especially under varying weather conditions because the MPPT gives the decision directly for the duty cycle declaring a controller of error signal. The voltage-based MPPT method uses the fact that the ratio between the maximum power voltage and the open circuit voltage under different weather conditions, are linearly proportional [5] and current-based MPPT approximates the ratio between the maximum power current and the short circuit current under different weather conditions [6]. Perturbation and observation (P&O) method are the commonly used due to its ease of implementation, and low cost [7]. P&O works effectively under varying weather conditions where it can reach to the error signal due to its separation between the MPPT method that control the reference signal and the duty cycle resulting of changing the reference signal. Therefore, P&O employs the MPPT for the reference signal while the power converter can be controlled separately.

Among different intelligent controllers, fuzzy logic is the simplest to integrate with the system. Recently, fuzzy logic controller (FLC) has received an increasing attention to researchers for converter control, motor drives, and other process control as it provides better responses than other conventional controllers [8]-[13]. The imprecision of the weather variations that can be reflected by PV arrays can be addressed accurately using fuzzy controller. In order to take the advantages of fuzzy logic algorithm, the MPPT algorithm is integrated using FLC so that the overall control system can always provide maximum power transfer from PV array to the inverter side in spite of the unpredictable weather conditions. The drawback of most of the fuzzy-based MPPT algorithms [14]-[18] is that the tracking point is located away from the maximum power point when the weather conditions change. Furthermore, the MPPT control depending on duty-cycle changes causes neglecting in power converter error signal control. However, there is a need to control the duty cycle of the power converter and to track the maximum power point depending on reference signal not duty-cycle.

This paper presents a type-2 fuzzy-based technique for MPPT in standalone PV system. The implementation of this FLC involves the operations of fuzzification, inference, and output processing. The output process consists of type-reduction and defuzzification. Type-reduction method is an extended version of defuzzification. Type-reduction catches more information about rule uncertainties than does the crisp value. Type-2 FLC provides better performance for

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maximum power point tracker especially for noisy and fast changing irradiations. The MPPT is designed by converting the P&O algorithm into 16 fuzzy rules, after the controller inputs and output have been divided to four fuzzy subsets. As the proposed method always transfers maximum power from PV arrays, it optimizes the number of PV modules.

II. The Proposed System

Fig. 1 is the circuit diagram of the SEPIC DC-DC converter together with the MPPT type-2 fuzzy controller. The design of type-2 fuzzy controller was done using Mamdani method. The PWM changes its duty cycle according to the control signal, configuring a feedback from the output voltage signal.

The input variables of the FLC are divided to four fuzzy subsets for two input variables which can generate sixteen fuzzy logic rules. The fuzzy rules mimic the behavior of P&O method. The shapes and fuzzy subset partitions of the membership function in both input and output shown in Fig. 2 depend on the behavior of the controller output and input signals.

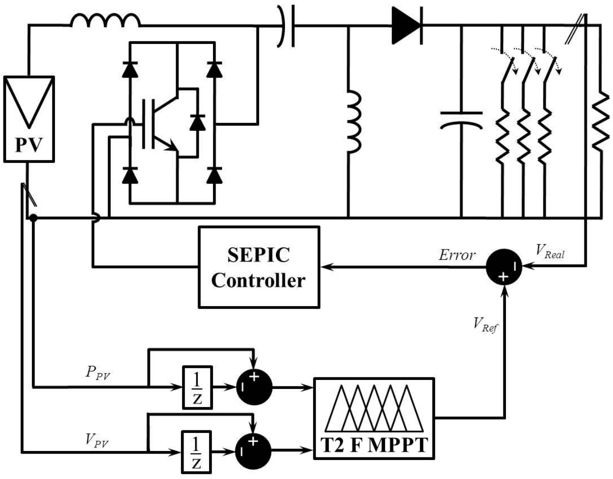

Fig. 1. Circuit diagram of the proposed system.

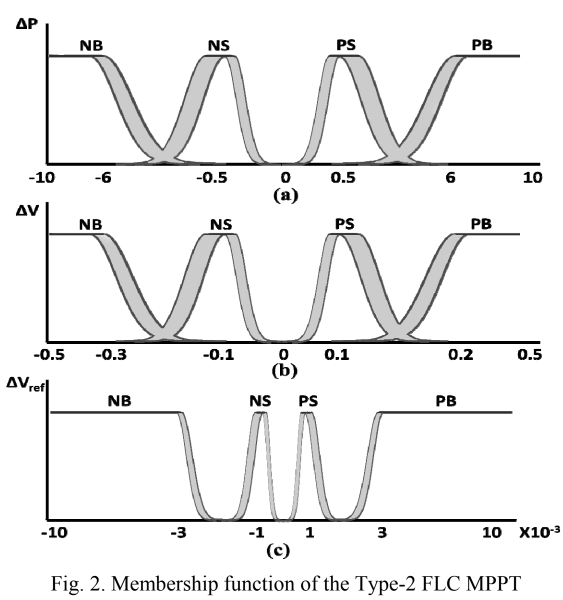

Fig. 2. Membership function of the Type-2 FLC MPPT

T2FLC consists of four elements: type1 fuzzification, fuzzy rule-base, the inference producer, and type1 defuzzification. The fuzzy rule-base is a collection of rules, which are combined in the inference producer to produce a fuzzy output. Type1 fuzzyfier maps the crisp input into type1 fuzzy sets, which are subsequently used as inputs to the inference producer, whereas the type1 defuzzification maps the type1 fuzzy sets produced by the inference producer into crisp numbers.

A T1FLCs are unable to handle rule uncertainties directly, because they use type1 fuzzy sets that are certain. On the other hand, T2FLC is very useful in uncertainties measurement. Type2 fuzzy set models and minimizes the effects of uncertainties in rule base FLC. Unfortunately, type2 fuzzy sets are more difficult to use than type1 fuzzy sets; hence, their use is not widespread yet.

In fuzzy logic controller design, one should identify the main control variables and determine the sets that describe the values of each linguistic variable. The proposed P&O searching algorithm is designed to achieve the advantage of P&O simplicity and eliminate all aforementioned drawbacks. The change in PV array output power and the change in PV array output voltage are the inputs of the FLC. The increment of the reference voltage is the output of the FLC where the increment is added to the previous reference voltage to produce the new reference voltage. The inputs and the outputs of the FLC are shown in the equations from (1) to (3)

$$\Delta P = P(k) - P(k-1) \tag{1}$$

$$\Delta V = V(k) - V(k-1) \tag{2}$$

$$\Delta V_{ref} = V_{ref}(k) - V_{ref}(k-1) \tag{3}$$

The advantage of this modification in P&O is that the output of the FLC changes the reference voltage only. Therefore, the duty cycle of the SEPIC converter can further be controlled using specific controller. Furthermore, the SEPIC controller ensures that the PV output power does not diverge from the maximum power point during varying weather conditions or variable load.

The input variables of the FLC are divided to four fuzzy subsets which are: positive big (PB), positive small (PS), negative small (NS), and negative big (NB). These four fuzzy subsets for two input variables can generate sixteen fuzzy logic control rules. Also, the membership functions of the output variables are four-term fuzzy sets, negative big (NB), negative small (NS), positive small (PS), and positive big (PB). The fuzzy method used here is Mamdani, where the maximum of minimum composition technique is used for the inference and the center-of-gravity method is used for the defuzzification process to convert the fuzzy subset reference voltage changes to real numbers as presented in (4).

$$\Delta V_{ref} = \frac{\sum_i^n \Delta V_{ref_i} \mu\left(\Delta V_{ref_i}\right)}{\sum_i^n \mu\left(\Delta V_{ref_i}\right)} \tag{4}$$

where ΔV_{ref} is the fuzzy output and ΔV_{refi} is the output membership function center of max-min inference composition. ΔV_{ref} is a monotonic increasing function with respect to V_{ref}. The left most point V_{refL} and the right most point V_{refR} can be expressed as follow:

$$\Delta V_{refL} = \frac{\sum_i^n \Delta V_{refL_i} \mu\left(\Delta V_{refL_i}\right)}{\sum_i^n \mu\left(\Delta V_{ref_i L}\right)} \tag{5}$$

$$\Delta V_{refR} = \frac{\sum_i^n \Delta V_{refR_i} \mu\left(\Delta V_{refR_i}\right)}{\sum_i^n \mu\left(\Delta V_{refR_i}\right)} \tag{6}$$

Referring to [19], the defuzzified crisp output from the interval type-2 fuzzy system is the average of V_{refL} and V_{refR} which is:

$$\Delta V_{ref} = \frac{\Delta V_{refR} + \Delta V_{refL}}{2} \tag{7}$$

The fuzzy rules mimic the behavior of P&O method. The fuzzification of the P&O technique with the rules is shown in Fig. 3. The shapes and fuzzy subset partitions of the membership function in both input and output shown in Fig. 2 depend on the behavior of the controller output and input signals.

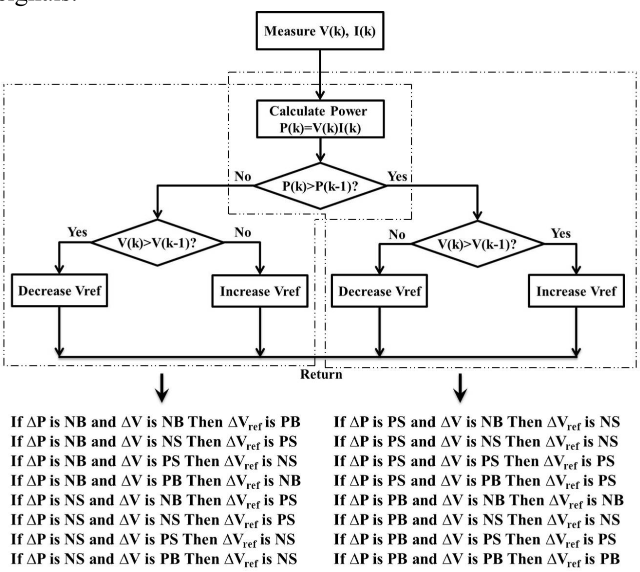

Fig. 3. Fuzzification of the modified P&O rules

The T2FLC deals with variable step size to increase or decrease the reference voltage, therefore the tracking time becomes short and the system performance during steady-state conditions is much better than with conventional P&O technique.

III. Results

The results introduced in Fig. 4 belong to power, voltage, and current under constant radiation. It is clear that the drawback of the conventional P&O method appears where the reference loses the optimum point at sudden radiation changing. Furthermore, at gradually radiation varying, Fig. 5 shows that the conventional P&O loses the optimum point and cause oscillations in the steady state while these drawbacks have been solved for the proposed T2FLC based MPPT technique. In both previous cases, the proposed FLC based MPPT shows faster response in the transient response and stable steady state. Moreover the oscillations become disappear comparing with the conventional P&O method.

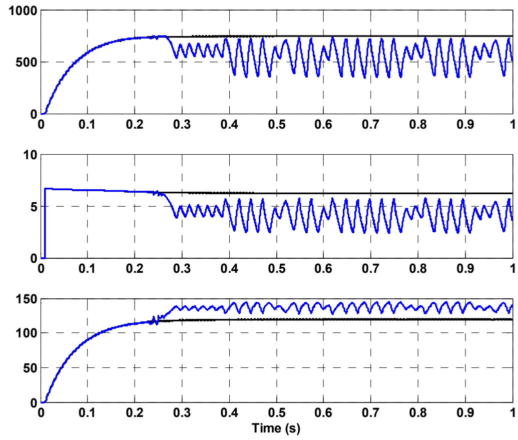

Fig. 5. Power, current, and voltage under constant radiation

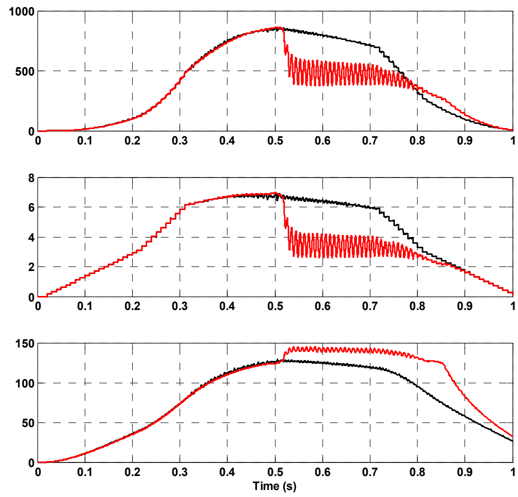

Fig. 6. Power, current, and voltage under varying radiation

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