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An improved maximum power point tracking method for a photovoltaic system

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ABSTRACT

In this paper, an improved auto-scaling variable step-size Maximum Power Point Tracking (MPPT) method for photovoltaic (PV) system was proposed. To achieve simultaneously a fast dynamic response and stable steady-state power, a first improvement was made on the step-size scaling function of the duty cycle that controls the converter. An algorithm was secondly proposed to address wrong decision that may be made at an abrupt change of the irradiation. The proposed auto-scaling variable step-size approach was compared to some various other approaches from the literature such as: classical fixed step-size, variable step-size and a recent auto-scaling variable step-size maximum power point tracking approaches. The simulation results obtained by MATLAB/SIMULINK were given and discussed for validation.

1. Introduction

Nowadays, renewable energy systems have attracted much attention because of their clean nature and decreasing cost. Amongst these, PV system receives great attention because of its technology development, reduced cost and reliable sun source [1].

However, PV systems have a major problem: the amount of electrical power generated by a PV panel is dependant with a weather conditions [2]. This results in the probable mismatch between the operating characteristics of the load and the PV panel. The operating point, when the PV panel is connected directly to a load, is not necessarily the maximum power point (MPP) that can be provided. A precious amount of energy is then lost. To overcome this problem, most of the time a converter controlled by an MPPT algorithm, is inserted between the PV panel and the load as illustrated in Fig. 1. By varying the duty cycle (D) of the converter (through the transistor Q), the input impedance of the converter can match the output impedance of the PV panel in order to lead the system to the MPP. Thus, the MPPT algorithm moves and maintains the operating point to the MPP even with PV panel output power change [3].

Lately, a large number of MPPT methods have been proposed and implemented [1–21]. Fractional open-circuit voltage and short-circuit current [4,5] methods provide a simple way to peak the maximum power. However, to measure the open-circuit voltage or short-circuit current as a reference, these methods require periodical disconnection or short-circuit of the PV modules, resulting in more power loss. Due to their simplified control structures and ease of implementation, algorithms such as Hill Climbing [6–8] and Perturb and Observe (P&O) [9–14] were widely applied in the MPPT controllers. While P&O is a perturbation in the operating voltage of the PV array, Hill Climbing introduces a perturbation in the duty cycle of the converter [7,12,15]. Nevertheless, for these two methods, the perturbation generates oscillations at the steady-state: the power loss may be increased. Incremental conductance (INC) method is based on the fact that the slope of the PV array power versus voltage curve is zero at the MPP. This method has been proposed to improve the dynamic performance under rapidly varying conditions and the tracking accuracy [16,17]. In theory, since the derivative of the power versus the voltage vanishes at MPP, the steady oscillations would be eliminated. However, due to the resolution of digital implementation, the value zero of the slope of the PV array power versus voltage curve seldom occurs. Although the INC method is a little more complicated compared to the P&O and Hill Climbing methods, it can be easily implemented due to the progress of digital signal processors (DSPs) [18].

In addition, research works on the variable step-size methods have also been proposed [19–21]. In the conventional method of Hill Climbing, P&O and INC, a fixed step size is applied to track the MPP. The use of a fixed step-size causes some problems because the step-size cannot be changed in the vicinity of the MPP. Although the MPP can be reached, the system cannot produce stable output power when too large step size is used; it results in a reduction in the power produced by the overall system. To achieve

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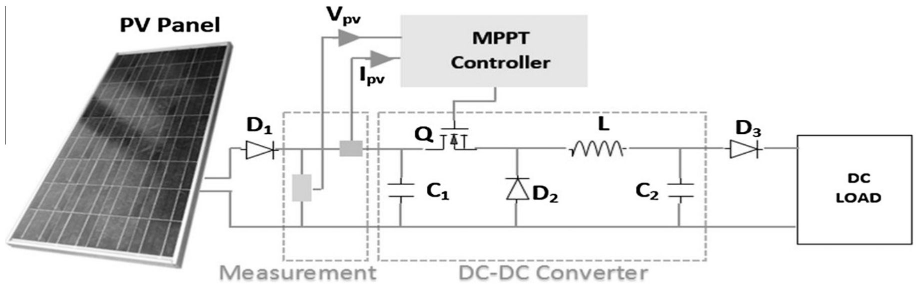

Fig. 1. The scheme of the PV system.

a stable output power near the MPP, a small step size can be used, but it can cause a slow dynamic response. To solve the above dilemma, the variable step-size method was introduced. With the variable step-size concept, stable output power and fast dynamic response can be obtained simultaneously.

The conventional variable-step method achieves good tracking performance but also has a convergence problem encountered in the above mentioned algorithms; a constant value is more often needed to be multiplied in the tracking method. To maintain a stable output power and exhibit the fast dynamic response, the choice of this constant value is very important. The system oscillates with a poor choice of the constant value, thereby reducing the power generation. Another problem with the use of this constant value involves significant changes in the irradiation, which cause the power–voltage curve of the PV panel to vary significantly. The dynamic response of the PV system will be slow when the irradiation exhibits a large variation. This constant value cannot be adjusted with the variation in weather.

This papers presents an approach of MPPT which adjusts automatically the variable step-size using an improved scaling function without the constant value mentioned above. As a second improvement, abrupt changes of the irradiation are studied and taken into account to avoid wrong decision. This new approach is compared with some classical and recently used approaches in a PV system under weather sudden changes for the validation.

2. Fixed and variable step-size MPPT principles

Typical tracking methods are the P&O, Hill-Climbing method and the INC [22–24]. They are widely used because of their easy implementation. Based on a simple criterion, P&O and INC methods however operate around the MPP by oscillating. The oscillations cause a loss of power which depends on the step-size used by MPPT algorithm to command the converter. This step-size is fixed in the conventional P&O and INC methods. The variable step-size MPPT methods have been developed to solve this problem [25,26].

2.1. Criterion of decision making

To be able to track the maximum power, the fixed step-size MPPT methods, such as P&O/Hill-climbing and INC, use the criterion which shows if the current operating point is on the left, the right or at the MPP on the curve of power versus voltage. The P&O method criterion is the derivative of the power dP/dV (or dP/dD for the Hill-Climbing) at the MPP [3]:

$$\frac{dP}{dV} = 0 \tag{1}$$

On the left of the MPP, $\frac{dP}{dV} > 0$ and $\frac{dP}{dV} < 0$, on the right of the MPP. The INC method uses another criterion, replacing the power P by the product V by I as following:

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = \frac{VdI}{dV} + I \tag{2}$$

$$\frac{dI}{dV} = -\frac{I}{V} \tag{3}$$

Then on the left of the MPP, $\frac{dI}{dV} > -\frac{I}{V}$ and $\frac{dI}{dV} < -\frac{I}{V}$ on the right of the MPP [27].

Since the side of the current operating point is determined, the decision is taken to move toward the MPP. Thereby, the value of the duty cycle is updated by adding or subtracting the fixed step ΔD to the previous value of the duty cycle D_{k-1} as follows [26]:

$$D_k = D_{k-1} \pm \Delta D \tag{4}$$

2.2. Fixed step-size MPPT principle

Fig. 2a illustrates how the tracking of the MPP is performed in general by a fixed step size MPPT algorithm. Assuming at the start the system operates at the point A1, a fixed step-size based MPPT controller trains the operating point with a fixed step ΔD toward the MPP. Therefore, as depicted in Fig. 2a, the operating point moves from A1 to A2, from A2 to A3, from A3 to B3, from B3 to A3 and then around the MPP, it keeps oscillating between A3 and B3. The oscillations result in a loss of power depending on the size of the step ΔD. If a larger step ΔD is used, the MPP may be tracked faster but the amplitude of the oscillations will also be larger. On the other hand, a use of a smaller step results in a slower dynamic response but a smaller loss of power. This is the dilemma with the use of fixed step-size MPPT methods [25,26].

2.3. Variable step-size MPPT principle

To solve the dilemma previously described in the case with conventional fixed step-size MPPT method, the variable step-size MPPT method adjusts the step-size as illustrated in Fig. 2b. Considering that A1 is the starting operating point, the MPPT controller leads the operating point A1 toward the MPP as in the case of the fixed step-size MPPT method (A1–A2–A3–A4–B4) described previously with a variable step-size: a larger step-size is given when the operating point is far from the MPP, and smaller step-size is applied when the operating point is near the MPP. The tracking can be achieved simultaneously with a faster dynamic response and a stable steady-state (smaller loss of power indeed).

The research work in [20] proposed a variable step-size MPPT method based on the slope of Power–Voltage curve of the PV panel. The scaling of the step-size is given by:

$$\Delta D = N \times \frac{dP}{dV} \tag{5}$$

where N the scaling factor. This scaling factor is constant and has to be carefully chosen in order to achieve good tracking performances. However, with a significant changes in the weather, the PV panel