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Photovoltaic maximum power point tracking under fast varying of solar radiation

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HIGHLIGHTS

- An INC-MPPT technique is improved for PV plant.
- Dynamic efficiency of the basic INC under a gradual irradiance profile is improved.
- Energy conversion efficiency is increased by approximately 5%.
- Stringent irradiance profile with different shapes is selected as in EN50530.
- A robust tracker is proposed for variable irradiance, temperature and load.

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ABSTRACT

Perturb and Observe (P&O) and Incremental Conductance (INC) are widely used as Maximum Power Point Tracking (MPPT) techniques in Photovoltaic (PV) systems. But, they fail under rapidly varying of sunlight levels. This paper proposes a new MPPT technique, which can make a distinction between perturbation in the reference voltage and sudden-changing of sunlight and thus optimize the PV system efficiency. This method consists on a modified INC algorithm, which is used to fine-tune the duty cycle of the DC/DC converter in order to avoid divergences of the maximum power point (MPP) when using basic INC under fast varying of luminosity levels.

The proposed PV-MPPT system, which is composed by a step-up converter as the interface to feed the load, is tested by simulation within the Matlab/Simulink software by taking into account the luminosity, the temperature and the load variation. The simulation results are satisfactory and demonstrate that the improved INC technique can track the PV maximum power at diverse operating conditions with the most excellent performance, the energy conversion efficiency is increased by approximately 5%.

1. Introduction

The solar energy has many advantages compared with fossil-fuel energy. It is inexhaustible, free of charge, naturalness, clean, no ecological pollution, and with modular character, which allows construction of the solar array at different power levels. On the other hand, it has an important disadvantage, which is the low efficiency of conversion of light to electrical energy [1]. Moreover, the power harvested by a PV generator depends on a number of factors, such as the luminosity, the temperature, and the load in that it is connected. In each operating condition, there is just one and unique particular point that makes the PV array in functioning at its maximum power. In most PV applications (stand-alone system, hybrid system and public grid connected system), it is very important to exploit the peak power provided by the photovoltaic generator. To achieve this goal, a power electronics device with an adequate MPPT technique is needed [1–5]. Many of these MPPT algorithms have been published in several references [6–9]. These methods vary in many aspects such as the necessary sensors, the complexity, the cost, the efficiency, the convergence rapidity, the accurate tracking when temperature and/or luminosity vary, and equipment required for the implementation or popularity [10]. A full analysis of 30 different MPPT algorithms can be found in [6].

Among these techniques, Perturb and Observe [11–17] and Incremental Conductance [2,17–21] are algorithms most

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commonly used in the literature due to their simplicity of implementation and independence to PV array parameters. Other techniques based on different principles are fractional short circuit current that estimates the optimal current by short circuit current [22], fractional open circuit voltage that estimates the optimal voltage by the open circuit voltage [23], the neural network [24], the fuzzy logic [10,25] and the Sliding Mode Control-based MPPT (SMC) [1,26–29]. Most of these algorithms are iterative, based on the disruption of the cyclic ratio of the converter by a small increment. These techniques can track the MPP with great precision under stable conditions. But it still reveals compromise between speed pursuit and the reliability of prosecution when the values of load or weather conditions change rapidly. A lot of researchers made changes to these algorithms in the objective to improve them. In Ref. [30], two different implementations for the INC algorithm were applied to PV pumping system; the first one is with reference voltage perturbation in combination with a PI regulator to regulate the power converter duty cycle; the second one is without PI controller in which the duty cycle is employed straight as the control parameter. It was found that the direct duty cycle control exhibits better energy efficiency than the first control by about 2%. The INC direct duty cycle control was firstly implemented in solar array using Cuk converter by Safari et al. [31]. This last method is considered in the present paper as basic INC. It perturbs the duty ratio until the peak power is reached with a fixed step size. However, it suffers from the low speed tracking and the losing tracking direction when rapid changes occurred in environmental conditions. For that reason, many researchers introduce the variable step size in INC MPPT [32,33]. Basic and variable step size INC techniques are also not capable to respond precisely in fast-changing of solar radiance [2]. That is why the authors of [2] have proposed a variant of variable step size INC method with a permitted error $\left(\left|I_{pv} + V_{pv}\frac{dI_{pv}}{dV_{pv}}\right| < 0.06\right)$ to mitigate inaccurate answers of the conventional INC (fixed step size) during sudden changes in sunlight levels. But this last work should be checked with a profile of gradual change of irradiance. Therefore, this paper proposes a new and simple INC to reduce the probability of losing tracking direction that may be occurred and thus to enhance the energy efficiency of the PV system.

The INC algorithm is among the Hill-Climbing techniques [34]. Through adjusting the duty ratio of the converter, it drives up the operating point on the power versus voltage curve to achieve the MPP which is at the top. This method offers advantages such as simple implementation, fast convergence speed, high efficiency and low cost [6,19,31], but also some disadvantages: The first one is the incessant unwanted oscillating of the operating point around the MPP [35,36], once the tracking control reaches the vicinity of the PV panel maximum power. As a result, this steady-state undulation causes the energy losses. The second one is that the algorithm can lose its tracking direction, i.e. it can deviate away from the MPP, when the change in the luminosity is rapid [19,35], especially if the irradiation varies according to a slope. For the reason that the algorithm is not capable to determine if the change in the power is due to the perturbation of the voltage or due to the change in the irradiance. This divergence also causes the power loss and thus a decrease in the efficiency. Another problem to consider is that many researchers test their algorithms with simple irradiance profile (constant or step). Consequently, the improvements in performance cannot be truthfully demonstrated. In order to reduce the effect of these drawbacks, this paper proposes a new MPPT control based on a modified incremental conductance. The proposed tracker is similar to the old one, but it incorporates two tests consisting in change in current and voltage with same signs. The added part is for the fast-varying of the sunshine. Therefore, the new INC can distinguish between perturbation in the reference voltage and sudden-changing of sunlight and thus avoid divergence from the MPP. An additional contribution is the selecting of stringent profile for the irradiance variation as suggested by EN 50530 [17,37]. This irradiance profile consists on different shapes such as the ramp up, the step down, the step up and the ramp down. These diverse shapes are capable to confirm truthfully the efficacy of the proposed tracker under static and dynamic states. As a result, this work is done to improve the dynamic efficiency of PV conversion chain with a modified INC that can decrease the probability of diverging away from the peak power. To compare the proposed tracker with the basic one, the tracking efficiency parameter is taken into account.

This paper is organized as follows. PV panel and boost chopper models are given in Sections 2 and 3 respectively. Then Maximum Power Point Tracking Algorithms are introduced in Section 4. Subsequently, the basics of classical and modified INC techniques are given. Thereafter, Section 5 depicts the results of simulation. Finally, the conclusion section summarizes highlights the achievements of this study.

2. Equivalent circuit and characteristics of PV panel

The solar cell is the basic elementary component, which can transform directly the sunlight into electricity. Assembly of cells in series forms a module. The equivalent circuit of the PV module is illustrated in Fig. 1 [20,21]. A series-parallel assemblage of modules forms an array. The PV panel can be described mathematically by the following set of equations as in [38,39].

$$I_{pv} = N_p I_{ph} - N_p I_s \left[exp\left(\frac{V_{pv} + (\frac{N_s}{N_p}) R_s I_{pv}}{n_s a v_t} \right) - 1 \right] - \frac{V_{pv} + \left(\frac{N_s}{N_p}\right) R_s I_{pv}}{\left(\frac{N_s}{N_p}\right) R_p} \quad (1)$$

where I_{pv} is the PV array output current (A), V_{pv} is the PV array output voltage (V), N_s and N_p are the number of PV modules connected in series and parallel, respectively, n_s is the number of PV cells connected in series in one string, R_s and R_p are respectively the PV module series and parallel resistances (Ω), a is the p-n junction ideality factor.

The photo-current I_{ph} depends on solar irradiance G and temperature T as follows:

$$I_{ph} = [I_{sc}^* + k_i(T - T^*)] \frac{G}{G^*} \quad (2)$$

where k_i is the short circuit current temperature coefficient, I_{sc}^* is the short circuit current at standard test conditions (STC) that are: solar irradiance $G^* = 1000\ \text{W/m}^2$, cell temperature $T^* = 298$ K and a spectral distribution AM 1.5.

The reverse saturation current I_s varies with temperature according to the following expression:

$$I_s = \frac{I_{sc}^* + k_i(T - T^*)}{exp\left(\frac{V_{oc}^* + k_v(T - T^*)}{n_s v_t}\right) - 1} \quad (3)$$

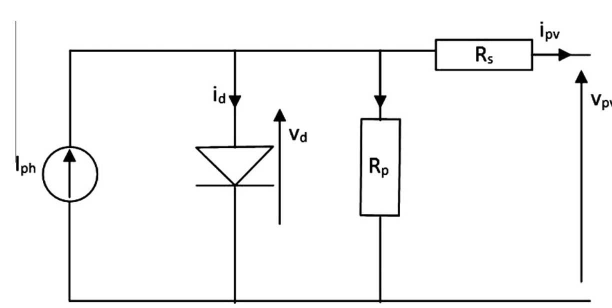

Fig. 1. Solar module equivalent circuit.