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Research paper

Photovoltaic system with quantitative comparative between an improved MPPT and existing INC and P&O methods under fast varying of solar irradiation

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ABSTRACT

This work aims firstly to extract parameters lacked in the manufacturers' datasheet by using a simple tool provided by PSIM and then model the PV panel. This model is validated using experimental data. In addition, this work presents the effect of solar irradiation and temperature on the performance of the PV panel. Next, this work will demonstrate that existing algorithms such as perturb and observe and incremental conductance respond inaccurately when solar irradiation is increased. For that a modified incremental conductance algorithm is presented, the latter can respond accurately when solar irradiation is increased and reduce the steady-state oscillations. Finally, 'software-in-the-loop' simulation for the conventional and the modified algorithms is made. Thus a quantitative analysis on the amount of energy loss for rapid change of environmental conditions in the modified method with existing INC and P&O methods is done. The results show that the modified algorithm makes an accurate response once the solar irradiation is increased with fast response and high efficiency. Hence, the loss of energy is minimized.

1. Introduction

The PV panel output power depends on solar irradiation and temperature (Patel and Agarwal, 2008; El Hammoumi et al., 2018). Thus, the load imposes its own characteristic on the power supplied by the PV panel (Motahhir et al., 2015). Therefore, to predict and analyze the impact of these parameters on PV power, firstly a PV panel model must be studied in accordance with the behavior of the PV panel (Wu et al., 2017b, 2016, 2017a). Therefore, various models were suggested in the literature, in Rauschenbach (1980) a single diode model is used, in Barth et al. (2016) a two diodes model is proposed to describe the impact of the recombination of carriers, and in Nishioka et al. (2007) a model of three diodes is used to present the effects which are neglected by the two diodes model. However, the single-diode model is the most widely used photovoltaic model in view of its good simplicity and accuracy (Yıldıran and Tacer, 2016). Moreover, manufacturers offer only some characteristics of PV panel. Thus, others characteristics required to model PV panel are lacked in the manufacturers' datasheet, as the light-generated current, the diode saturation current, the diode ideality factor and the series and shunt resistors (Ishaque et al., 2012). Hence, different methods have been proposed by researchers in Yıldıran and Tacer (2016), Ishaque et al. (2012), Ishaque and Salam (2011) and AlHajri et al. (2012) to extract the lacked characteristics based on the datasheet values, but these methods require an implementation and this can increase the time taken in the development of a PV system. Therefore, this work aims firstly to extract parameters lacked in the manufacturers' datasheet by using a simple tool provided by PSIM (PSIM Tutorial, 2014) and then model the PV panel. For simplicity, the single diode model is used in this work. The latter gives a high compromise between accuracy and simplicity (Carrero et al., 2007) and several researchers have used it in their works (Radjai et al., 2014; Ahmed and Salam, 2016). In addition, this work presents the effect of solar irradiation and temperature on the performance of the PV panel.

On the other hand, the maximization of the PV power always remains a major challenge in the literature. Researchers have proposed different MPPT algorithms to maximize PV power, namely Fractional Short-Circuit Current (FSCC), Fractional Open-Circuit Voltage (FOCV), Fuzzy Logic, Neural Network, Perturb and Observe (P&O), and Incremental Conductance (INC) (Amir et al., 2016; El-Khozondar et al., 2016). FSCC and FOCV are the simplest MPPT techniques, which are based on the linearity of short-circuit current or open-circuit voltage to the maximum power point current or voltage. However, these techniques isolate the PV panel to measure the short-circuit current or open-circuit voltage. Therefore, the loss of power is increased due to the periodic isolation of the PV panel (Verma et al., 2016). On the other side, Fuzzy Logic and Artificial Neural Network are knowledge-based controllers

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Nomenclature

a	: Diode's ideality factor
I	: Panel output current [A]
I_s	: Diode saturation current [A]
I_{ph}	: Panel photocurrent [A]
G	: Solar irradiation [W/m^2]
K	: Boltzmann constant [J K^{-1}]
K_v	: Temperature coefficient of open circuit voltage [V/°C]
K_i	: Temperature coefficient of short circuit current [A/°C]
N_s	: Number of cells connected in series
$P_{\max}$	: Maximum power of the panel [W]
q	: Electron charge [C]
R_s	: Series resistance [Ω]
R_{sh}	: Shunt resistance [Ω]
T	: Junction temperature [K]
V	: Panel output voltage [V]
Offset	: Step size

Greek Letters

α	: Duty cycle

Abbreviations

P & O	: Perturb and observe
INC	: Incremental Conductance
MPP	: Maximum Power Point
MPPT	: Maximum Power Point Tracking
PV	: Photovoltaic
STC	: Standard Test Conditions

where they require a detailed knowledge while implementing them. Fuzzy Logic and ANN are effective in tracking MPP and they obtain a consistent MPPT algorithm due to their ability to treat the nonlinearity of the PV Panel. But they require large memory for rules implementation or training respectively. In particular, the fuzzy logic method requires the designer to have some prior knowledge of how the output responds qualitatively to the inputs, and it suffers from a severe drawback that the rules cannot be changed, once it is defined. ANN presents many disadvantages like the fact that the data needed for the training process has to be specifically acquired for every PV panel and location, also the PV characteristics change with time, so the neural network has to be periodically trained. Hence, since the amount of training involved is quite high for this algorithm, this makes its implementation even more complex (Ram et al., 2017). P&O and INC are mostly used due to their medium complexity. These methods use the (P–V) characteristic of the PV panel. For P&O, steady-state oscillations occur after the MPP is reached due to the perturbation made by this technique to maintain the MPP, which in turn this increases the loss of power (Motahhir et al., 2016). For INC, it is founded in point of fact that slope of the power curve is zero at the MPP, and theoretically, there is no perturbation after the MPP is reached (Sekhar and Mishra, 2014; Jately and Arora, 2017; Motahhir et al., 2017). Therefore, steady-state oscillations are minimized. However, during implementation, the zero value is rarely found on the slope of the P–V characteristic because real values cannot be precisely represented using binary floating-point numbers (Motahhir et al., 2018). Moreover, P&O and INC methods can make an inaccurate response, when solar irradiation is suddenly increased (Motahhir et al., 2018; Tey and Mekhilef, 2014). Therefore, this work aims also to present and implement a modified INC algorithm, which can overcome the wrong response made by the conventional algorithms (P&O and INC) when the irradiance is suddenly increased. The modified algorithm uses the variations in voltage (ΔV) and current (ΔI) of the PV panel to identify the increase in solar irradiation instead of the slope ($\Delta P/\Delta V$) of the P–V characteristic, and then it can make a correct response in duty cycle. Besides, a mini error is accepted to assert that the slope is near to zero and minimize the steady state oscillations.

This paper is organized as follows. Following the introduction, section two presents the modeling of PV panel and investigates the effect of solar irradiation and temperature. Section three illustrates conventional and modified algorithms. 'software-in-the-loop' simulation and quantitative analysis on the amount of energy loss for rapid change of environmental conditions in the modified method with existing INC and P&O methods are elaborated.

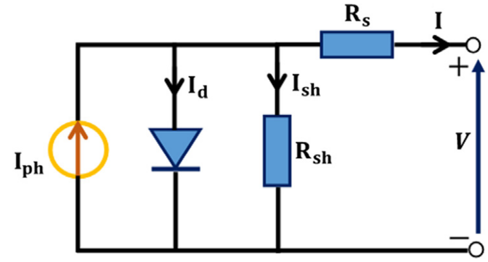

Fig. 1. Single diode model of PV panel.

2. Modeling of photovoltaic panel and array

2.1. Model of photovoltaic panel

Solar cells are semiconductor with a P–N junction made of a thin plate or a semiconductor layer. When exposed to light a photocurrent proportional to the solar irradiation is generated, if the photon energy is greater than the bandgap. I–V output characteristic of a solar cell has an exponential characteristic similar to that of a diode (Villalva et al., 2009). Not that a PV panel is a set of PV cells, the electric model of literature Kaiser and Reise (Liu and Dougal, 2002) is used in this work, which consists of a source photon current, connected with bypass diode and two resistors bound in series and in parallel. Fig. 1 shows the electrical model of the PV panel, and its characteristic is presented in Eqs. (1)–(3).

$$I = I_{ph} - I_s\left(\exp\frac{q(V+R_sI)}{aKTN_s} - 1\right) - \frac{(V+IR_s)}{R_{sh}} \tag{1}$$

where:

$$I_{ph} = (I_{sc} + K_i(T - 298.15))\frac{G}{1000} \tag{2}$$

$$I_s = \frac{I_{sc} + K_i(T - 298.15)}{\exp\left(\frac{q(V_{oc}+K_v(T-298.15))}{aKTN_S}\right) - 1}. \tag{3}$$

2.2. Parameters identification of MSX-60 PV panel

As shown in Fig. 2, some parameters required to model a PV panel are missed in the datasheet. Therefore, these parameters should be determined in advance to simulate a given PV panel. To do that, a utility provided by PSIM is used in this paper due to its simplicity (PSIM Tutorial, 2014); the latter is presented in Fig. 3 and is called 'solar module utility' and it must be used as follows.

This utility extracts initial values of model parameters from the three kinds of user input data groups: One is the datasheet