

Modified incremental conductance MPPT algorithm to mitigate inaccurate responses under fast-changing solar irradiation level

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Abstract

During the increment of solar irradiation, the conventional incremental conductance algorithm responds inaccurately at the first step change in the converter duty cycle. This paper presents the conventional algorithm confusion and proposes a modified incremental conductance algorithm that responds accurately when the solar irradiation level increases. Moreover, the proposed algorithm shows zero oscillation in the power of the solar module after the maximum power point (MPP) is tracked. MATLAB simulation is carried out with the modified incremental conductance algorithm under a fast-changing solar irradiation level. Results of the modified, conventional and variable step size incremental conductance algorithms are compared. Finally, the hardware implementation, consisting of a single-ended primary-inductor converter (SEPIC) and a PIC controller, is applied as the maximum power point tracking (MPPT) controller. The simulation and experimental works showed that the proposed algorithm performs accurately and faster during the increment of solar irradiation level.

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1. Introduction

Electricity generation using solar energy has gained increasing popularity in recent years (Mekhilef et al., 2011, 2012). However, electricity generated by photovoltaic (PV) panels is an unstable energy source because of its firm dependence on factors such as solar irradiation level and surrounding temperature. Therefore, maximum power point tracking (MPPT) controller is needed to improve the efficiency of the PV system by ensuring that the PV module continuously supplies maximum power despite changes in weather conditions (de Cesare et al., 2006; Houssamo et al., 2010).

To ensure the high efficiency of the PV system, numerous MPPT algorithms have been developed, such as Fractional Open-Circuit Voltage (FOCV), Fractional Short-Circuit Current (FSCC), Fuzzy Logic, Neural Network, Perturbation and Observation (P&O), and Incremental Conductance (Reza Reisi et al., 2013; Gounden et al., 2009; Chaouachi et al., 2010; Altas and Sharaf, 2008; Faranda et al., 2008; de Brito et al., 2011; Ishaque et al., 2012). The simplest algorithms are FOCV and FSCC, which use the linearity of open-circuit voltage or short-circuit current to the maximum power point (MPP) voltage or current. However, these algorithms require intermittent disconnection of the PV module to obtain the open-circuit voltage or short-circuit current. Thus, overall efficiency of the PV system is lower because of the power losses during the disconnection (Qiang et al.,

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2011). Alternatively, Fuzzy Logic or Neural Network is chosen to obtain an accurate MPPT algorithm because of their ability to handle the non-linearity and dispensability of an accurate mathematical model, but these algorithms highly dependent on user experience on the PV module characteristics (Gounden et al., 2009; Chaouachi et al., 2010; Altas and Sharaf, 2008; Liu et al., 2013; Whei-Min et al., 2011). The PV module's characteristics change along with time because of degradation. Therefore, the algorithm parameters need to be updated.

Among the aforementioned algorithms, P&O and incremental conductance are frequently used. These two algorithms work in accordance with the power against voltage (P – V) curve of the PV module. Both algorithms tune the DC–DC converter duty cycle in the PV system to ensure that the latter operates at the MPP. For P&O, steady-state oscillation occurs after the MPP is reached because the perturbation continuously changes in both directions to maintain the MPP (Weidong and Dunford, 2004; Weidong et al., 2007; Fermia et al., 2007; Femia et al., 2005; Abdelsalam et al., 2011). Steady-state oscillation causes system power losses. For incremental conductance, the slope of the P – V curve is used for MPPT. The conventional incremental conductance algorithm determines the gradient of the P – V curve. In addition, the duty cycle of the converter is tuned in fixed step size until the peak (gradient is equal to zero) of the P – V curve is reached. However, the algorithm speed is slow when fixed step size is used. Therefore, Rahman et al. (2013) and Fangrui et al. (2008) introduced the variable step size in MPPT. In the algorithm, the fixed step size is multiplied with the slope of the P – V curve. Thus, the duty cycle step size becomes smaller when the PV system operates near to the MPP (peak of the P – V curve). Meanwhile, the step size is larger and possesses faster tracking speed when the PV system operates far from the MPP. Theoretically, when the peak of the P – V curve is found, no further perturbation of duty cycle or no oscillation in the power of the PV module (Qiang et al., 2011; Rahman et al., 2013; Fangrui et al., 2008; Kakosimos and Kladas, 2011) occurs. However, during implementation, the zero value is rarely obtained on the slope of the P – V curve because of the truncation error in digital processing. Conventional and variable step size incremental conductance algorithms are also unable to respond accurately at the first step change in the duty cycle of the converter after the increase in solar irradiation level (Zbeeb et al., 2009). Therefore, the present paper introduces new tracking steps to identify the changes in solar irradiation level. The variations in current (dI) and voltage (dV) of the PV module are used to track the increase in solar irradiation instead of the slope (dP/dV) of the P – V curve. The proposed algorithm can respond accurately during the changes in solar irradiation level. Moreover, a small permitted error is used in the proposed algorithm to ensure that no steady-state oscillation occurs. The results of both simulation and hardware implementation are provided. The results of the proposed algorithm are compared with

those of the conventional algorithm. The comparison reveals that the proposed algorithm performs better by eliminating the steady-state oscillation and by responding faster and accurately to the variation in solar irradiation level. Fig. 1 shows the block diagram of the PV system.

1.1. PV module characteristic

PV module is a current source that comprises a number of solar cells connected in series or parallel to generate electrical energy when there is sunlight. Solar cell is a type of semiconductor that produces electricity when sunlight is emitted onto it (Bennett et al., 2012). To understand solar cell characteristics, mathematical models have been developed. Few types of models have been created, such as single-diode and two-diode models (Bennett et al., 2012; Ishaque and Salam, 2011; Ishaque et al., 2011; Gonzalez-Longatt, 2005). For simplicity, some models ignore the shunt resistance R_{sh} , which is normally very large and can be considered as an open circuit. In this paper, single-diode model from Gonzalez-Longatt (2005) is chosen to model the solar cell. The mathematical expression for the equivalent electric circuit used in the model is shown below:

$$I = n_p I_{sc} - n_p I_o \{ \exp[q(V/n_s + R_s I)/nkT_k] - 1 \} \quad (1)$$

where V is the output voltage of PV module, I the output current of PV module, R_s the series resistance of cell, q the electron charge, I_{sc} the light-generated current, k the Boltzman constant, T_k the temperature (K), n the diode ideality factor, n_s the number of PV cells connected in series, n_p the number of PV cells connected in parallel, and I_o the reverse saturation current.

As shown in Gonzalez-Longatt (2005), I_{sc} is affected by temperature and solar irradiation while I_o is only affected by temperature. The PV module model is generated using Eq. (1) and the Newton–Raphson method in MATLAB.

The maximum power available from the PV module depends on the surrounding temperature and solar irradiation level. Fig. 2 shows the two main characteristic curves, namely, current against voltage curve (I – V curve) and P – V curve. These curves are used to investigate the effect of temperature and solar irradiation level on the PV module. When a load is connected to the PV module, a load line is imposed on the I – V curve. The voltage and current of

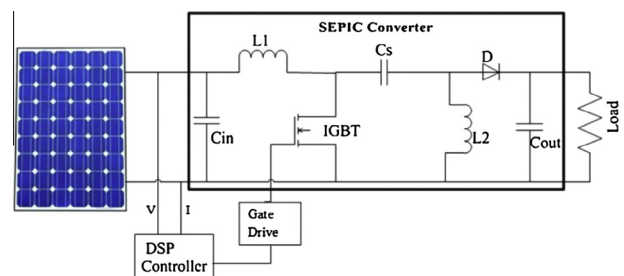


Fig. 1. Block diagram of the PV system.

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