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Design of boost converter based on maximum power point resistance for photovoltaic applications

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ABSTRACT

The design of the boost converter for the maximum power point tracking (MPPT) is complex due to the nonlinear characteristics of Photovoltaic (PV) modules. In addition, PV modules are irradiance and temperature dependent, which further increases the complexity of the boost converter design. This paper proposes a new approach that eases the design of the boost converter specifically for MPPT applications. This approach represents the maximum power point of the PV module as resistance to simplify the boost converter design, which specifies the design according to the PV module parameters. The derived equations require nine parameters to determine the inductance, input capacitance, and output capacitance of the MPPT boost converter. In this paper, the single diode PV model and the hill climbing MPPT algorithm have been applied in the simulation using MATLAB/Simulink®. The results show that the simulations of the boost converter followed the desired requirements. This proves that the calculated inductance, input capacitance, and output capacitance using the proposed method are accurate.

1. Introduction

The Maximum Power Point Tracking (MPPT) converter is a device that obtained the maximum power from the Photovoltaic (PV) module. There are three parts in the MPPT converter, which are the MPPT method, the controller for the power converter, and the power converter. There are various types of MPPT method has been introduced by the researcher throughout the years (Kamarzaman and Tan, 2014; Karami et al., 2017; Seyedmahmoudian et al., 2016). This includes the Hill Climbing Method or Perturb and Observe Method, the Incremental Conductance Method, the Particle Swarm Optimization Method, and much more. The function of the MPPT method is to search the maximum power point of the PV module. The MPPT method commonly produces the duty cycle or the voltage reference as their output. The duty cycle produced by the MPPT method is connected to the Pulse Width Modulation (PWM). While voltage reference produced by the MPPT method is fed into the controller for the power converter. The controller for the power converter produces the duty cycle for the PWM. This controller for the power converter improves the transient response of the MPPT converter. The conventional and non-conventional controller for the power converter used in the MPPT converter is the Proportional-Integral (PI) controller (Ahmed and Salam, 2015; Kwan and Wu, 2017; Na et al., 2017) and Fuzzy Logic controller (Kumar et al., 2015) respectively.

The power converter used in the MPPT converter includes the buck converter (Balasankar et al., 2017), the boost converter (Kchaou et al., 2017; Palaniswamy and Srinivasan, 2016), the buck-boost converter (Kwan and Wu, 2017), the SEPIC converter (Kiranmai and Veerachary, 2005), and many more. The power converter used for the MPPT converter is usually connected to the PV module as the input source and operates based on the switching pulses produced by the PWM. The design of the power converter is done to determine the inductance and the capacitance used in the MPPT converter. The inductance is calculated to maintain the MPPT converter in the continuous current mode. Maintaining continues current mode is important for the controller to maintain a stable output. If the inductance is too small, the MPPT converter operates in the discontinuous current mode. While if the inductance is too large, the MPPT, the MPPT converter becomes bulky and has a slow transient response. The capacitance is calculated to ensure the voltage ripple is maintained within the desired specification. If the capacitance is too small, the voltage ripple becomes large. While if the capacitance is too large, the transient response of the MPPT converter becomes slow.

The design of the power converter commonly not the main focus on the development of the MPPT converter and the research conducted is more toward the development of the MPPT method. However, there is still research on the power converter for the MPPT converter (Başoğlu and Çakır, 2016; Bennett et al., 2012; Enrique et al., 2007; Nayak et al.,

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2017). Nevertheless, the study is focused on choosing the optimum power converter topology for the MPPT converter. One of the research is analysing the relationship of the PV Resistance - Output Resistance - Duty Cycle (R_{pv}-R_o-D) (Başoğlu and Çakır, 2016; Nayak et al., 2017). This research determines the power converter suitable for the MPPT converter based on the PV module and the load. Another research on the power converter for the MPPT converter is analysing the MPPT converter as the variable resistance emulator (Enrique et al., 2007). However, there is no derivation of the inductance and capacitance for the MPPT converter in their research.

Several approaches have been taken to design the power converter for the MPPT converter. This includes designing the power converter in the MPPT converter based on the conventional design of the power converter (Dubey and Shah, 2017; Farhat et al., 2017; Yilmaz et al., 2018). This design procedure is inaccurate since the MPPT converter has a non-linear source, which is PV module, and not a linear voltage source. Some of the MPPT converter design is not even shown (Boukenoui et al., 2016; Harrag and Messalti, 2015; Rezk and Eltamaly, 2015). There is also the MPPT converter design that only includes the small signal analysis of the MPPT converter, but not included the inductance and capacitance calculation (Chatrenour et al., 2017; Mendalek and Al-Haddad, 2017). Besides, the derivation of the inductance and capacitance for the MPPT converter is incomplete, which could not be used to calculate the inductance and capacitance (Abusorrah et al., 2013; Rezkallah et al., 2015; Yatimi and Aroudam, 2016).

The boost converter is commonly used for the MPPT converter (Qi et al., 2014; Rajesh and Mabel, 2014; Ramos-Hernanz et al., 2017). However, the input capacitor needs to be added parallel with the input source of the boost converter for the MPPT converter. The research shows the boost converter does not operate at the maximum power point of the PV module without the input capacitor (El-Saady et al., 2014). This resulting in a lower power obtained from the PV module. Even though it is common to add an input capacitor to the MPPT boost converter (Ding et al., 2016; Patel and Agarwal, 2008; Vangari et al., 2015), there are MPPT boost converter that does not have the input capacitor, which lead to a large PV voltage ripple (Abusorrah et al., 2013; Farhat et al., 2017). To reduce the PV voltage ripple without adding an input capacitor, the inductance needed is very large (Alik and Jusoh, 2017). There are equations to calculate the input capacitor for the MPPT boost converter (Elmehdi et al., 2017; Vangari et al., 2015). However, the derivation of the equation is not shown and the accuracy of the calculation is not proven.

The review of the MPPT converter shows there is no specific calculation of the inductance and the capacitance needed by the power converter with the PV module as the non-linear input source. This calculation is important to keep the inductance and capacitance used in the MPPT converter as small as possible without the MPPT converter operates in the discontinuous current mode, has an output voltage ripple within the desired specification, and maintaining the operation around the maximum power point. Although a high value of inductance and the capacitance can be used, it produces a slow transient response for the MPPT converter.

This paper derives the inductance and the capacitance calculation for the MPPT boost converter with the PV module as the non-linear input source. The derivation of the MPPT boost converter is based on the ideal condition and operates in the continues current mode. The derivation is done based on three different resistive load condition. The objective of the derivation is to produce the simple equations to calculate the input capacitance, the output capacitance, and the inductance for the MPPT boost converter. The single diode model is used to simulate the 50 W PV module. The MPPT method used for the simulation is the Hill Climbing Method. The derivation is proven by comparing the theoretical value obtained from the derived equation with the simulation results of the MPPT boost converter obtained from MATLAB/Simulink®.

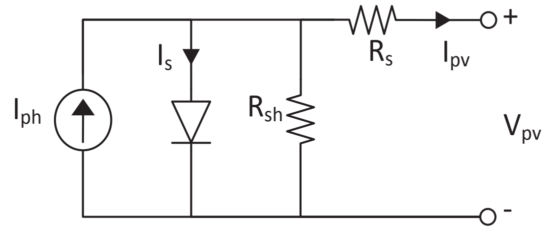

Fig. 1. The single diode model.

2. Components modelling for MPPT boost converter

2.1. PV model

The PV model is one of the components in simulating the MPPT boost converter. The function of the PV model is to produce the Current-Voltage I-V characteristic curve of PV module. The PV model used is based on the electrical circuit model called the single diode model, as shown in Fig. 1. Using Kirchhoff Current Law, the equation of the PV current, I_{pv}, is derived, as shown in (1) (Balato et al., 2016). Since (1) is an implicit equation, it requires an iteration method to solve the equation. The iteration method used to solve (1) is the Newton-Raphson Method (Xenophontos et al., 2014).

$$I_{pv} = I_{ph} - I_s\left(e^{\frac{(V_{pv}-I_{pv}R_s)}{AV_T}} - 1\right) - \frac{(V_{pv}-I_{pv}R_s)}{R_{sh}} \tag{1}$$

$$V_T = \frac{kT}{q} \tag{2}$$

where I_{ph} is the photocurrent (A), I_s is the saturation of dark current (A), V_{pv} is the PV module voltage, R_s is the series resistance (Ω), A is the ideality factor, V_T is the thermal voltage, k is the Boltzmann constant (1.38×10^{-23} J/K), T is the temperature of p-n junction (K), q is the electron charge (1.6×10^{-19} C), and R_{sh} is the parallel resistance (Ω).

I_{ph} produces depends on the irradiance and the temperature. The high irradiance or temperature increases I_{ph}. I_{ph} is calculated using (3) (Kadri et al., 2012). While I_s only depends on the temperature and it is calculated using (4) (Ickilli et al., 2012). R_s and R_{sh} affect the maximum power point produces by the PV model. These two parameters need to be adjusted carefully and resulting in an accurate PV model. R_s and R_{sh} are calculated using the Parameter Estimation Method based on the characteristic of the PV panel shown in Table 1 (Chin et al., 2015).

$$I_{ph} = \frac{G}{G_{stc}}(I_{sc} + K_i(T - T_{stc})) \tag{3}$$

$$I_s = \frac{I_{sc} + K_i(T-T_{stc})}{e^{\left(\frac{V_{oc}+K_V(T-T_{stc})}{AV_t}\right)}-1} \tag{4}$$

where G is the irradiance (W/m^2), STC is the Standard Test Condition (1000 W/m^2 and 25 °C), G_{stc} is the irradiance under STC (1000 W/m^2), α is the temperature coefficient of I_{sc}, T_{stc} is the temperature under STC (25 °C), and β is the temperature coefficient of V_{oc}.

Table 1
The technical parameters of the Solar Power MartSPM050-M PV panel (Mono-Crystalline 50Wp Solar Module SPM050-M).

Parameter	Value
Open Circuit Voltage, V_{oc} (V)	22.53
Short Circuit Current, I_{sc} (I)	2.97
Maximum Power Point Voltage, V_{mp} (V)	18.68
Maximum Power Point Current, I_{mp} (I)	2.77
Temperature Coefficient of V_{oc}, K_v (°C/V)	−0.0789
Temperature Coefficient of I_{sc}, K_i (°C/mA)	0.1485