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Improved control strategy for photovoltaic emulator using resistance comparison method and binary search method

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ABSTRACT

The current Resistance Comparison Method uses a fixed-step size in the iteration process to determine the operating point of the photovoltaic emulator. The weakness of the fixed-step size is the inaccuracy of the produced operating point and that it requires a high number of iterations to converge, which can burden the controller processor. This paper proposed a Resistance Comparison Method with an adaptable step size using the Binary Search Method for the photovoltaic emulator. The advantages of this control strategy are the fast operating point tracking capability, highly accurate operating point, and no readjustment is needed for the controller of the closed-loop converter system (robust). The simulation of the photovoltaic emulator system is conducted in the MATLAB/Simulink® using current-mode controlled buck converter with a Proportional-Integral compensator and a single diode photovoltaic model with a series resistor. The results obtained are compared to the conventional control strategy of the photovoltaic emulator. The proposed control strategy demonstrates an average of iteration convergence of 26 times better and 21 times more accurate compared to the conventional Resistance Comparison Method.

1. Introduction

The photovoltaic (PV) emulator is a device that emulates the characteristics of the PV module, as shown in Fig. 1. It generally consists of a power converter, such as the buck converter, and a controller. The controller oversees the control strategy, the PV Mathematical Model (PVMM), the Proportional-Integral (PI) compensator, and the pulse width modulator (PWM). The output of the PV emulator is the output voltage, V_o, and the output current, I_o. The PV emulator is used during the development processes of PV devices such as Maximum Power Point Tracking (MPPT) devices and PV inverter. During the development process, these PV devices are connected to the actual PV panels and testing is conducted using the irradiance from the sunlight or the solar simulator. Some disadvantages of this method are that a large space is required to place the PV panels, this method can also damage the PV panels if the PV component does not operate correctly, and the repeatability of the condition to test the PV components is hard to achieve. Because of these disadvantages, a PV emulator is more suitable for testing PV components.

The function of the control strategy is to determine the operating point of the PV emulator. It affects the accuracy, dynamic performance, stability, and processing power requires for the PV emulator. The common control strategy for the PV emulator is to use the PVMM as the reference input for the closed-loop converter system operation (Di Piazza et al., 2010; Ickilli et al., 2012; Koran et al., 2014; Vijayakumari et al., 2012). This type of control strategy is called the Direct Referencing Method (DRM) and it is a simple control strategy since no additional algorithm is needed. The DRM uses the dynamic characteristic of the power converter and PI compensator to obtain the operating point of the PV emulator. Since the PVMM has a nonlinear characteristic, at a certain condition, it produces an unstable operating point for the closed-loop converter system. As a result, the output of the system becomes oscillated and unstable. The stability of the operating point is improved by overdamped the compensator for the closed-loop converter system which results in a poor dynamic performance or using the output resistance, R_o, as the input for the PVMM.

There are two types of DRM which are the current-mode controlled system (Koran et al., 2014, 2010) and the voltage-mode controlled system (Algaddafi et al., 2015; Di Piazza et al., 2010). The DRM with the current-mode controlled system produces a stable output when operates in the constant current region and an unstable output when operates in the constant voltage region. While the DRM with the voltage-mode controlled system produces

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Nomenclature

A	ideality factor
e	closed-loop system error
e_i	current error (%)
G	irradiance (W/m^2)
G_c	transfer function of the pi compensator
G_p	transfer function of the buck converter
I_{pvref}	reverence photovoltaic current (A)
$I_{sc(ref)}$	reverence short circuit current (A)
K	Boltzmann constant (1.38×10^{-23} J/K)
K_{gv}	irradiance coefficient for V_{oc} (V/°C)
k_{ref}	reference constant (Ω)
α	temperature coefficient for I_{sc} (A/°C)
β	temperature coefficient for V_{oc} (V/°C)
q	electron charge (1.602×10^{-19} C)
r_{Io}	output current ripple factor (%)
R_{pv}	photovoltaic resistance (Ω)
r_{Vo}	output voltage ripple factor (%)
T	temperature (°C)

Subscript

stc	standard test condition
ref	reference

Abbreviation

1D1R	single diode model with series resistor
BSM	binary search method
DRM	direct referencing method
ICD	input change detection
MPPT	maximum power point tracking
PI	proportional-integral
PV	photovoltaic
PVMM	photovoltaic mathematical model
PWM	pulse width modulator
RCM	resistance comparison method
SMPS	switched-mode power supply

an unstable output when operates in the constant current region and a stable output when operates in the constant voltage region. The Hybrid-Mode Controlled Method (HMCM) combines two DRMs to produce a stable output in any regions of the I-V characteristic curve (Kim et al., 2013; Mai et al., 2017; Yuan et al., 2009). However, this control strategy is very complex since two different control systems are used. The system can be costly if two power supplies are used in the PV emulator (Kim et al., 2013).

The Hill Climbing (HC) and the Perturb and Observe (P&O) methods are commonly used in the MPPT due to the simplicity of the method (Kamarzaman and Tan, 2014). These two methods are also implemented in the control strategy of the PV emulator. The HC method for the PV emulator does not need the PI controller (Erkaya et al., 2015; Gonzalez-Llorente et al., 2016). V_o changes according to the step size of the duty cycle. As a result, the dynamic response of the PV emulator is poor. The P&O method for the PV emulator includes the PI controller in the control strategy (Ö et al., 2016). Therefore, the dynamic response of this method is better than the HC method.

The Analog Based Method (ABM) is one of the control strategies of the PV emulator. There are several ways to implement the ABM. The Photovoltaic Amplifier Method uses the linear power supply and the PV cells to emulate the PV I-V characteristic (Armstrong et al., 2005; Midtgard, 2007). Instead of using the PV module, the I-V characteristic of the PV cell is amplified using the linear power supply. This method suffers from a low efficiency due to the used of the linear power supply. Another ABM is the Unilluminated Photovoltaic Method (Zhou et al., 2014). The method eliminated the irradiance from the PV module and adding a parallel current source at the terminal of the PV module. As a result, the controllable artificial light is not needed and this simplifies the PV system testing process. However, this method is not flexible since the PV panel is required during emulation process. The Transistor Based Method is one of the ABM (Zegaoui et al., 2016). The advantages of this method are the ability to emulate partial shading condition, requires a low number of components, and does not need a complex controller. However, the Transistor Based Method is highly inefficient. The transistors require the cooling system or radiators since a large power dissipation occurs at the transistor.

The R_o is calculated digitally using the ratio of the output voltage, V_o, to the output current, I_o. This ratio produces a fixed value equal to R_o even if there are any disturbances to V_o and I_o. Therefore, the operating point produces by the PVMM does not oscillate and is more stable. However, the conventional PVMM has the voltage or current as the input. To allow the PVMM to receive the resistance as the input, the Resistance Comparison Method (RCM) is used. The RMC compares R_o with the PV resistance, R_{pv}, obtained by dividing the PV voltage, V_{pv}, over the PV current, I_{pv} from the

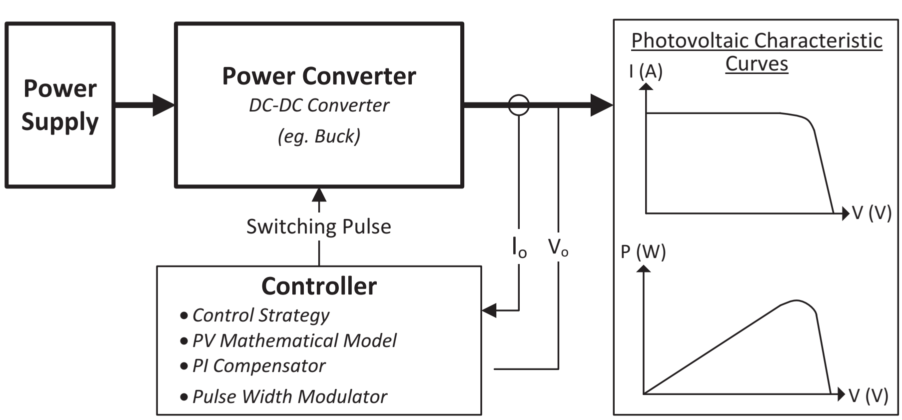

Fig. 1. The general block diagram of the PV emulator.