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Design and Simulation of a Photovoltaic Emulator System based on a Full-Bridge Structure

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Abstract. In this paper, the design and simulation of a photovoltaic (PV) emulator are presented. The output characteristic and I-V curve are produced based on mathematical engineering PV module, so that they are similar to the practical curves. The proposed system consists of a single-phase full-bridge PWM rectifier and a DC/DC buck converter, which can reduce the voltage ripple and improve the power factor near the grid. The rectifier uses double-loop control strategy and the buck circuit uses the formula of the PV module to control output voltage and load current. Using Matlab simulation, the result proves feasibility and good performance of this scheme, and simulation waves can reflect the change of temperature and light intensity.

Ⅰ. INTRODUCTION

With falling prices of solar cells and rising prices of fossil fuel, solar energy plays a more significant role in our daily life. The output characteristic of solar cell is nonlinear, so it is susceptible to the effects of light, temperature, load etc. Therefore, it is essential to build a PV emulator to simulate the output characteristics under the condition of different temperature and light intensity. That makes possible to perform different PV energy production systems' tests under work conditions and without depending on weather or much more expensive and huge systems. And the PV emulator can also shorten the development cycle and improve the working efficiency.

Combining with the power electronic and control technology, PV emulators based on mathematical engineering module of solar cells have been designed and developed rapidly recently in medium and high power occasions.

This paper is organized as follows: First of all, section II describes the mathematical engineering PV module. Secondly, section III presents the PV emulator's structure and the control method. Then, Section IV shows the simulation model and explains the simulation results. Finally the conclusions of this project are exposed.

Ⅱ. MATHEMATICALAL ENGINEERING PV MODULE

The parameters of physical PV module are difficult to calculate, so the mathematical engineering PV module is proposed to meet the practical needed. We just need four important parameters of solar cells: open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), maximum power point voltage (V_m) and maximum power point current (I_m); whose equations can be expressed as:

$$I_L = I_{sc} \bullet [1 - C_1 \bullet (e^{\frac{V_L}{C_2 \bullet V_{oc}}} - 1)] \tag{1}$$

$$C_1 = (1 - \frac{I_m}{I_{sc}}) \bullet e^{\frac{-V_m}{C_2 \bullet V_{oc}}}, \quad C_2 = (\frac{V_m}{V_{oc}} - 1) \bullet [\ln(1 - \frac{I_m}{I_{sc}})^{-1}] \tag{2}$$

Eq.1 and Eq.2 describe the I-V curve with standard temperature (T_{ref}=25℃) and irradiation (S_{ref}=1000W/m^2).

If the curve reflects the change of temperature and irradiation, Eq.3, Eq.4 and Eq.5 correct the four above-mentioned parameters. They can be described as:

$$\Delta S = \frac{S}{S_{ref}} - 1 \quad , \quad \Delta T = T - T_{ref} \tag{3}$$

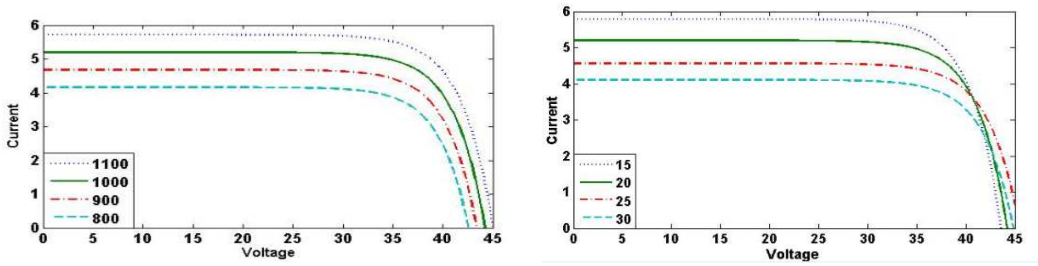
$$V_{oc} = V_{oc} \bullet (1 - \gamma \bullet \Delta T) \bullet \ln(1 + \beta \bullet \Delta S) \quad , \quad V_m = V_m \bullet (1 + \gamma \bullet \Delta T) \bullet \ln(1 + \beta \bullet \Delta S) \tag{4}$$

$$\mathrm{I}_m = \mathrm{I}_m \bullet \frac{S}{S_{ref}} \bullet (1 + \alpha \bullet \Delta T) \quad , \quad I_{sc} = I_{sc} \bullet \frac{S}{S_{ref}} \bullet (1 + \alpha \bullet \Delta T) \tag{5}$$

The typical values of α, β, γ are: α =0.0025/℃, β =0.5, γ=0.00288/℃.

First of all, select a group of temperature and irradiation and calculate the results of Eq.3-5. Then put them into Eq.1 and Eq.2, the curve is for a given temperature and given solar irradiation. [2]

The I-V curve of a PV module is depicted in the Fig. 1. (a) reflects the change of irradiation under 25℃ and (b) reflects the change of temperature under 1000 W/m^2 irradiation, which are consistent with the I-V curves. [3]



(a) (b)

(a) 25℃ with different irradiation (b) 1000 W/m^2 irradiation with different temperature

Figure.1. I-V curves with different irradiation and temperature

Ⅲ. DESCRIPTION OF EMULATOR

A. Structure of Emulator

The main circuit of emulator is composed of a rectifier circuit and a power circuit. In this paper, the rectifier circuit uses a single-phase full-bridge structure with PWM principle, and the power circuit utilizes buck circuit. A full-bridge rectifier can't only increase the power factor near the grid and reduce the ripple of output voltage, but also enhance the performance of power circuit.[1] Buck circuit is a no isolated circuit which contains one switch of device. Therefore it is easy to control and it is suitable for medium and high power system. Fig. 2 shows the structure of PV emulator.

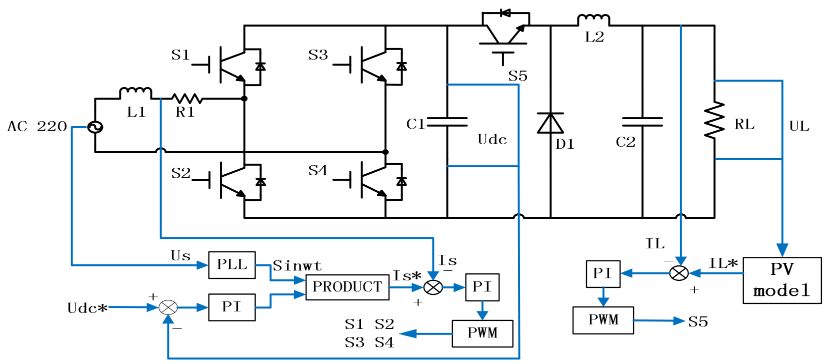


Figure.2. Structure and control of PV emulator

B. Control Method

Double-loop control is often used for a control method in the single-phase PWM rectifier control system. The target of outer loop is to control the output voltage of rectifier, and inner loop is for control sine wave current of grid according to result of the outer. In order to reduce the steady-state error and keep rapid performance, the system uses PI controllers to regulate. The advantages of this method are fast dynamic response, small input harmonic current of grid and stable output voltage.

Single current loop is used to control buck circuit. First, take sample of load voltage. Then utilize the mathematical engineering PV model to transfer the voltage to current. Finally make up a current loop to regulate the output of PI controller. It is important to regulate PI parameters, because the appropriate PI parameters make entire system work well. The control method is also shown in Fig. 2.

Ⅳ. MATLAB SIMULATION

In Matlab simulink environment, the simulation tools are used to build up the PV emulator model according to the structure and the control method. The related circuit parameters are listed in Table 1. And the simulation model is shown in Fig. 3, which includes a main circuit and control parts. Ideal MOSFET and universal bridge with 2 arms are used in the simulation.

Table 1 The related circuit parameters are listed

Input Inductance(L1)	10mH	Input Voltage	220V
Filter Inductance(L2)	2mH	DC Load	15Ω
Fundamental Frequency	50Hz	I_{sc}	5.2A
Input Resistance	0.6Ω	V_{oc}	44.2V
Capacitance(C1,)	5600μF	I_m	4.95A
Capacitance (C2)	3300μF	V_m	35.2V
Rectifier Output Voltage(Udc)	400V	Temperature	25℃
Switching Frequency	10kHz	Irradiation	1000 W/m^2

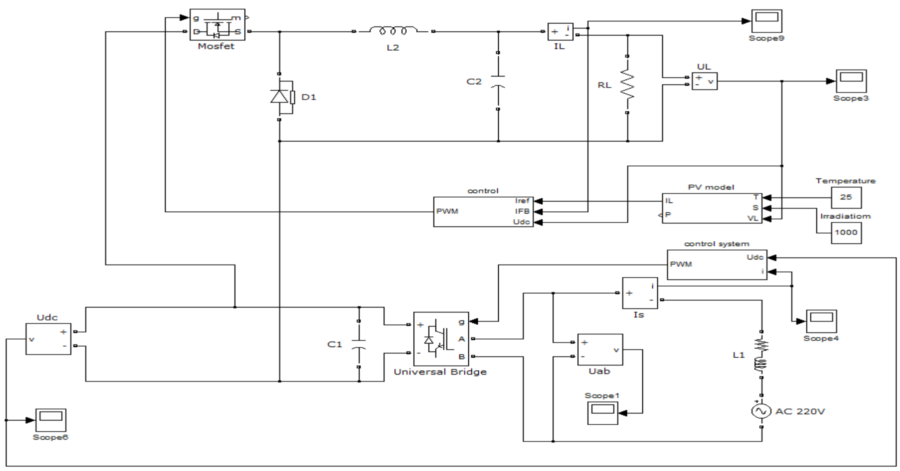


Figure.3. Simulation model

Fig.4 shows the results of simulation. Former two pictures present output current and voltage which conform to the I-V relation of PV basically. And the last picture represents the wave of Udc. From the wave, the system has a rapid dynamic response and small static error.

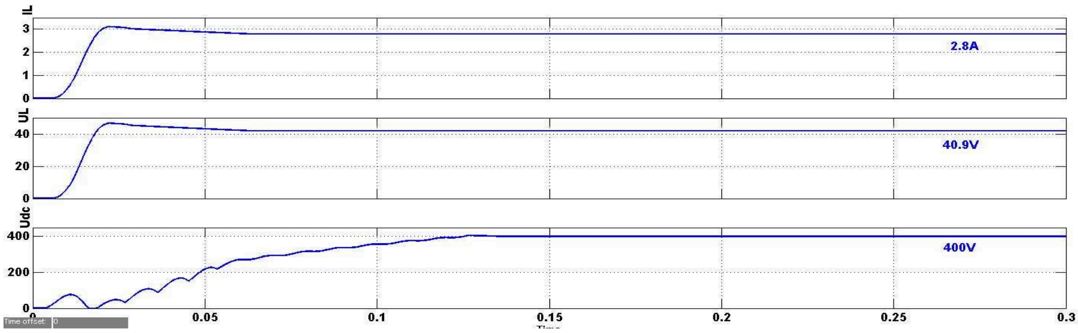


Figure.4. Simulation wave

V. CONCLUSIONS

This paper describes design and simulation the PV emulator system based on a single-phase full-bridge PWM rectifier and buck structure. Mathematical engineering PV module reflects the change of temperature and irradiation in practical condition. And the result of simulation shows a good performance of control method. To prove the feasibility of the entire control scheme, further experiments are carrying out.

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