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Analysis of PWM Converter for V-I Output Characteristics of Solar Cell

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ABSTRACT

Recently, photovoltaic system has been studied widely as a renewable energy system, because it does not produce environmental pollution and it has infinity energy source from the sun. A study on photovoltaic system has a lot of problems like as reappearance and repetition of some situation in the laboratory experiment for development of MPPT algorithm and islanding detection algorithm, because output characteristics of solar cell are varied by irradiation and surface temperature of solar cell. Therefore, the assistant equipment which emulates the solar cell characteristics which can be controlled arbitrarily by researcher is require to the researchers for reliable experimental data. In this paper, the virtual implement of solar cell (VISC) system is proposed to solve these problems and to achieve reliable experimental result on photovoltaic system. VISC system emulates the solar cell output characteristics, and this system can substitute solar cell in laboratory experiment system. To realize the VISC, mathematical model of solar cell is studied for driving converter and the DC/DC converters are compared in viewpoint of tracking error using computer simulation. Output dynamic characteristic of PV array is varied by irradiation and PWM converter performance is studied using PSIM simulator.

Keywords: Photovoltaic system, virtual implement of solar cell (VISC) system, the interpolation model (IM)

1. Introduction

Because of the request for renewable energy system, public attention has concentrated on photovoltaic system. This system does not produced pollution on the energy conversion process and generated electrical energy from infinite solar energy. But, the output characteristics of the photovoltaic system are varied by weather conditions as solar irradiation, cell temperature, light incidence angle and so forth.

Therefore, many researchers has been studied for the improvement of the power conversion efficiency of photovoltaic system using the maximum power point tracking (MPPT) method[1][2].

In the study on MPPT algorithm, the comparative experiment in same condition is requisite for the verification on the proposed algorithm and for comparison between the existing algorithm, but it is impossible using actual solar cell because the weather condition changes every moment.

In this paper, the virtual implement of solar cell (VISC) system is proposed to solve these problems and to achieve reliable experimental result on photovoltaic system. The VISC system emulates the solar cell output characteristics, and it can substitute solar cell in laboratory experiment

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system.

To construct VISC system, the mathematical model of solar cell and DC/DC power conversion part was studied in this paper. For the power conversion part, the buck and buck-boost converter were designed and compared in a view of output characteristics. For the mathematical model of solar cell, the interpolation method was considered and verified using computer simulation.

2. Solar Cell Modeling

The irradiation level and temperature are the major factors for the electrical output characteristics of the solar cell which are shown in Fig. 1 and Fig. 2. In Fig. 1, the output current varies from lower current to the higher level as solar irradiation goes high. Fig. 2 shows the output curve for variation of cell temperature. It moves to the higher voltage level as increasing cell temperature.

The mathematical model of solar cell must include the characteristics mentioned above. The parametric mode (PM) may be available when the theoretical parameters are known already[3]. But it is difficult to achieve all the parameters of solar cell and to match real solar cell.

In this paper, the interpolation model IM) is considered because the interpolation model is very simple mathematically, and it can be applicable in real time controller for VISC[2].

The interpolation model needs the data set of three point only. One is the open circuit voltage, another is the short circuit current and the other is the maximum power point voltage and current.

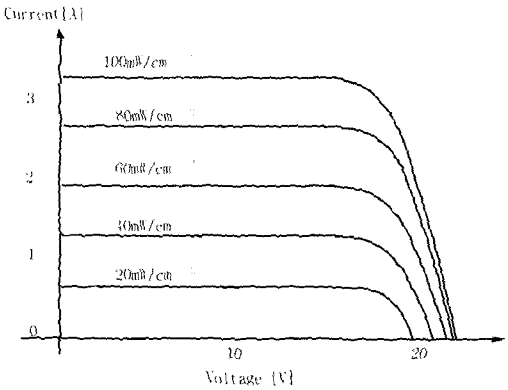


Fig. 1. V-I characteristics on varying illuminations.

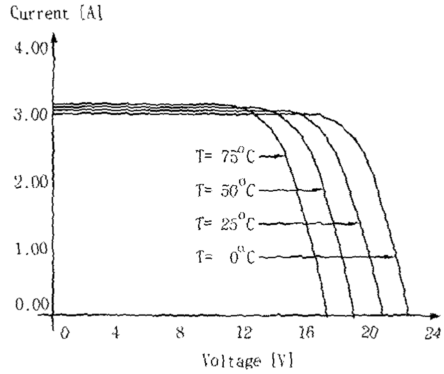


Fig. 2. V-I characteristics on varying temperature.

In order to get the interpolation model of the solar cell characteristics. The geometric approximation method was used[4].

$$\left(\frac{V_{cell}}{V_{oc}}\right)^m + \left(\frac{I_{cell}}{I_{sc}}\right)^n = 1 \qquad (1)$$

where, V_{cell}, I_{cell}: Solar cell output voltage and current

V_{OC}, I_{SC} : Solar cell open circuit voltage and current

m, n: Positive real number.

The maximum power point voltage and current, V_{mp} and I_{mp} are placed on the curve which can be drawn using Eq (1). And it is known that the differential of the P-V curve on the maximum power point is zero, then the slop of I-V curve at the point (V_{mp}, I_{mp}).

$$\left.\frac{dI}{dV}\right|_{(V_{mp}, I_{mp})} = -\frac{I_{mp}}{V_{mp}} \qquad (2)$$

Because Eq. (2) is feasible on the V-I curve too, it can be substitute to the differentiated equation of Eq. (1), then the solution of that equations followed to be Eq. (3) and (4).

$$V_{mp} = V_{oc} \sqrt[m]{\frac{n}{n+m}} \qquad (3)$$

$$I_{mp} = I_{sc} \sqrt[n]{\frac{n}{n+m}} \qquad (4)$$

where, V_{mp} , I_{mp} : The voltage and current on the maximum power point.

3. PWM Converter and Controller[5]

The virtual implement for solar cell requires the power conversion circuits which has the circuit topology of DC/DC converter. We compare the characteristics of two circuits topology, buck and buck-boost converter, to conclude power conversion circuit of VISC. Because the boost converter cannot output lower voltage than source voltage, it was excluded in comparative study on controllability and dynamics between the topologies. Analysis and design of buck and buck-boost converter is made of same design specification and the converters are designed in the continuous current mode (CCM).

The controller is consist of the PV model block, the voltage controller and the current controller. The PV model block makes the output voltage command by converter output current, and then the output voltage is regulated to follow the voltage command by use of two controllers, one is the voltage controller and the other is the current controller.

3.1 Buck Converter

The buck conveter is the step-down converter. For the emulation of the solar cell, the output voltage may varies from zero to open circuit voltage. Therefore, the source voltage must be higher than the open circuit voltage of solar cell array. The inductance and capacitance of buck converter can be designed using Eq. (4) and (5), (6). Fig. 3 shows the buck converter circuit and the control blockdiagram.

$$\frac{V_{cell}}{V_s} = D \tag{5}$$

$$\Delta V_{cell} = \frac{V_s D(1-D)}{8LCf_s^2} \tag{6}$$

$$\Delta I_{cell} = \frac{V_s D(1-D)}{f_s L} \tag{7}$$

where, D : duty ratio

V_s : Input source voltage

ΔV_{cell} : Output ripple voltage

ΔI_{cell} : Output ripple current

L : Inductance.

3.2 Buck-Boost Converter

Because the buck-boost conveter can opeate as the step-down converter and the step-up converter, the input voltage can be designed to a lower voltage than open circuit voltage of solar cell. In that case, the buck-boost converter operates in step-up mode and shows poor transient response. So, silmillar to a buck converter, the source voltage must be designed higher voltage than the open circuit voltage of solar cell array. The buck-boost converter is shown in Fig. 4 with it's controller. The system parameters of buck-boost converter can be designed using Eq. (8) and (9), (10).

$$\frac{V_{cell}}{V_s} = -\frac{D}{1-D} \tag{8}$$

$$\Delta I_{cell} = \frac{V_s D}{f_s L} \tag{9}$$

$$\Delta V_{cell} = \frac{P}{(V_{cell} - V_S)Cf_S} \tag{10}$$

where, P : Rated output power of converter.

4. Computer Simulation

In order to analyze on output characteristics of the buck and the buck-boost converter, the output ripple and model tracking error are defined in this section. Then the simulation results are compared between each converter.

The voltage and current ripple ratio are defined as Eq. (11), (12) at given operating point (V_{cell} , I_{cell})

$$R_V = \left.\frac{\Delta V}{V_{mp}}\right|_{V_{cell}} \times 100[\%] \tag{11}$$

$$R_I = \left.\frac{\Delta I}{I_{mp}}\right|_{V_{cell}} \times 100\ [\%] \tag{12}$$

where, ΔV: Peak-to-peak voltage ripple

ΔI : Peak-to-peak current ripple

V_{mp} : Voltage in the peak power point

I_{mp}: Current in the peak power point.

Model tracking error (ε_{mt}) is defined as the difference current between the solar cell output and the converter output at given operating point V_{cell}.

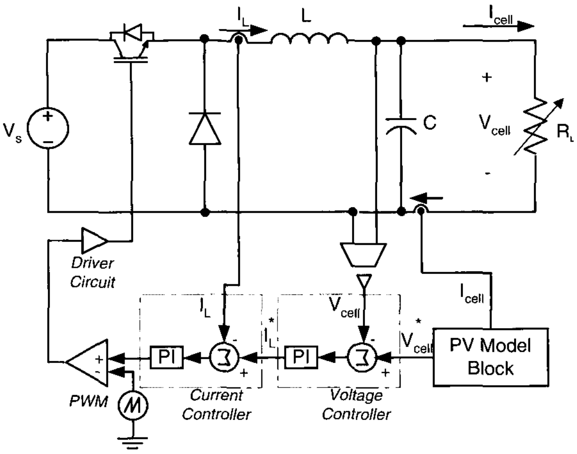


Fig. 3. Buck converter circuit and controller.

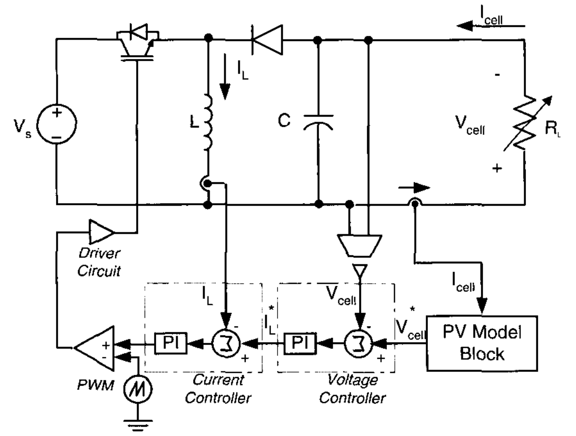


Fig. 4. Buck-boost converter circuit and controller.

Table. 1. Condition for Simulation.

	L(mH)	C(uF)
Buck-boost	0.8	7.6
Buck	0.8	6.25
f_s	20 [KHz]	
V_S	34[V]	
V_{mp}	17[V]	
I_{mp}	2.9[A]	
V_{oc}	21[V]	
I_{sc}	3.1[A]	
P	50[W]	

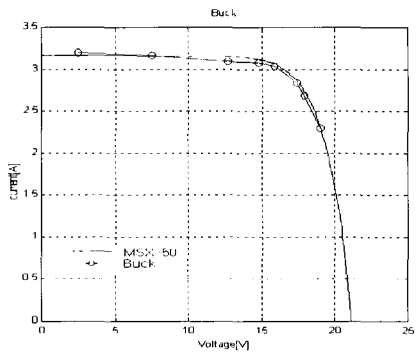
$$\varepsilon_{mt} = \left. \frac{I_{model} - I}{I_{model}} \right|_{V_{cell}} \times 100[\%] \tag{13}$$

where, I_{model} : Current desirable current

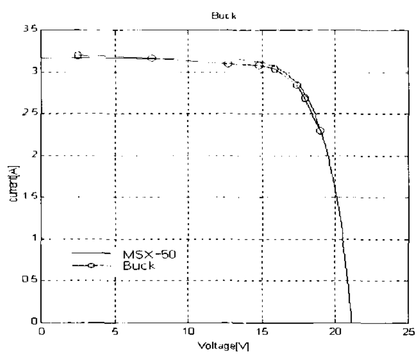
I : Converter output current.

Fig. 5 shows that V-I curve of model output and converter. Because the model output current is the current command value of converter, the output of converter must follow that of model. From the plot of V-I, it seems that the output characteristics of the two converters are very similar to the model output characteristics and the output current of each converter stands aside of model output current. Fig. 6 is P-V output curve of model power and converter, and it shows a little deviation from the model output power.

Fig. 7 is the model tracking error of converter. At the region above 13[V] the figure shows similar tracking error but at the apposite region it shows the different tracking errors of the buck and buck-boost converter, 2% and 3% each.

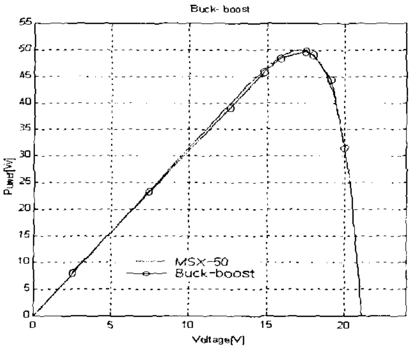


(a) Buck-boost converter

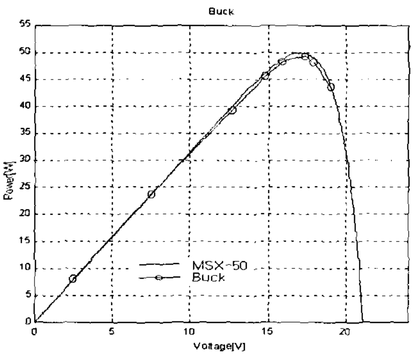


(b) Buck converter

Fig. 5. V-I output characteristic curve of model(-) and converter(O).



(a) Buck-boost converter



(b) Buck converter

Fig. 6. P-V characteristic of IM model (-) and converter (O).

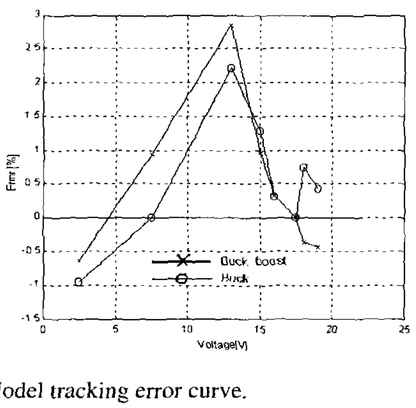
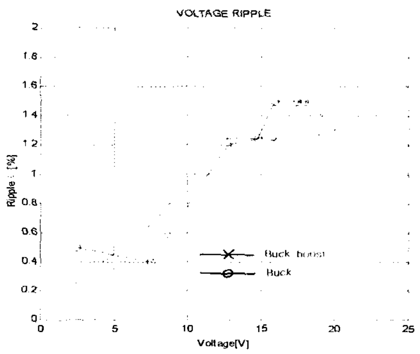


Fig. 7. Model tracking error curve.

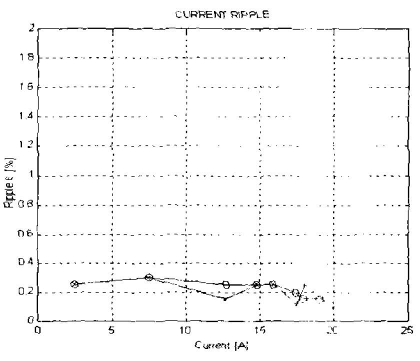
Fig. 8 shows ripple rates of output voltage and current, these are designed 5[%], which are satisfied with desirable value. With increasing the output voltage the voltage ripple rate appears increase, whereas the current ripple rate appears decrease in Fig. 8(b).

Because the simulation results are substantially same for the buck and buck-boost converter, it is possible that both of converters can be applicable on VISC.

In Fig. 9 and Fig. 10, the transient response time of the both converter system is 2~3[ms] for the step illumination change. If the buck-boost converter is designed to have lower source voltage than open circuit voltage, the transient time will increase greatly than that of the buck converter.



(a) Ripple rate of output voltage (R_V)



(b) Ripple rate curve of output current (R_I)

Fig. 8. Output voltage and current ripple rate.

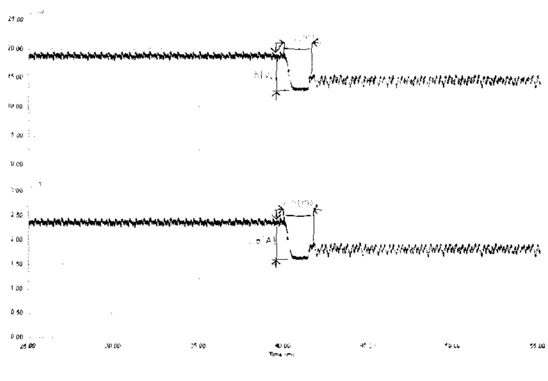


Fig. 9. Transient voltage and current waveforms when illumination changed from 100% to 50%.

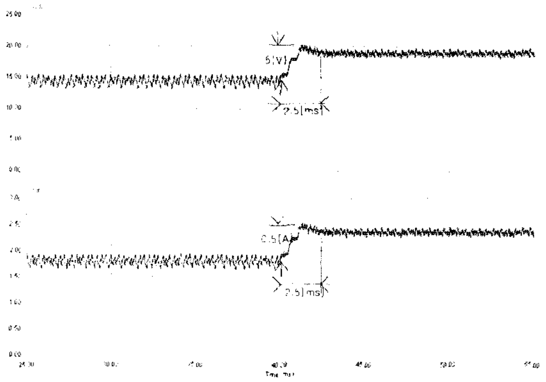


Fig. 10. Transient voltage and current waveform when illumination changed from 50% to 100%.

5. Conclusion

Interpolation model for solar cell was used to simulate solar cell and comparative study on the switching converters was done for implement VISC system. Using computer simulation tool, PSIM, the proposed model and PWM converter was tested at the view of model tracking error and output ripple.

When comparing the model curve and actual output curve of two PWM converters it was match very closely, so both of PWM converter, buck and buck-boost converter, may be applicable for the VISC system. And it was warned that the source voltage must be chosen higher value than open circuit voltage of cell model in case of buck-boost converter because of its latent long transient time.

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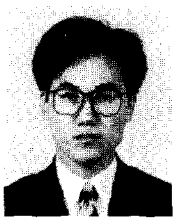

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