Analysis of Series and/or Parallel Converter for V-I Output Characteristics of Solar Cell

J.-H. Yoo, J.-M. Han, T.-G. Ryu, J.-S. Gho, G.-H. Choe , Y.-M. Chae*

Department of Electrical Engineering Konkuk Univ. Seoul, Korea

Delta Products Corporation Power Electronics Laboratory*

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. And this system is consisted a lot of solar cell unit.

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. And then analysis of parallel and series characteristics was done for combination of VISC model.

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 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. And compared the series and parallel characteristic for expansion of solar cell output power. 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 Fig2. 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 model(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. 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

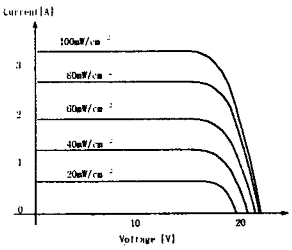


Fig. 1 V-I characteristics on varying illuminations.

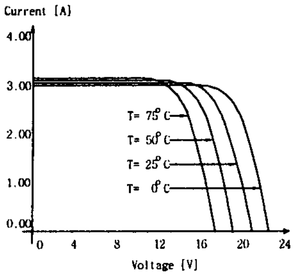


Fig. 2 V-I characteristics on varying temperature.

The maximum power point voltage and current, V_{mp} and I_{mp} are placed on the curve which can be drawn using (1). And it is known that the differential of the P-V curve on the maximum power point is zero, then the slop of V-I curve at the point (V_{mp}, I_{mp}). Because Eq.(2) is feasible on the V-I curve too, it can be substitute to the differentiated equation of (1), then the solution of that equations followed to be (3) and (4).

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

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

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

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 circuit 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 (5), (6) and (7). 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 operate 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 (8), (9) and (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.

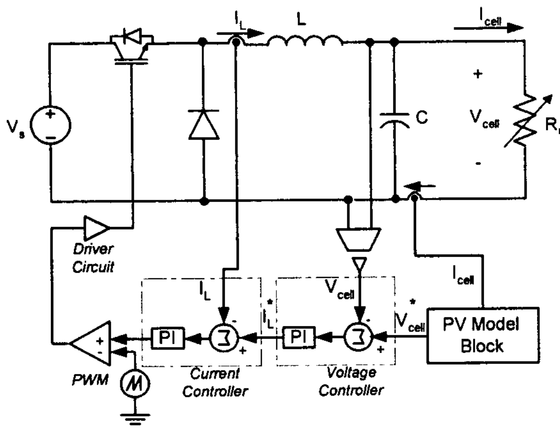


Fig. 3 Buck converter circuit and controller.

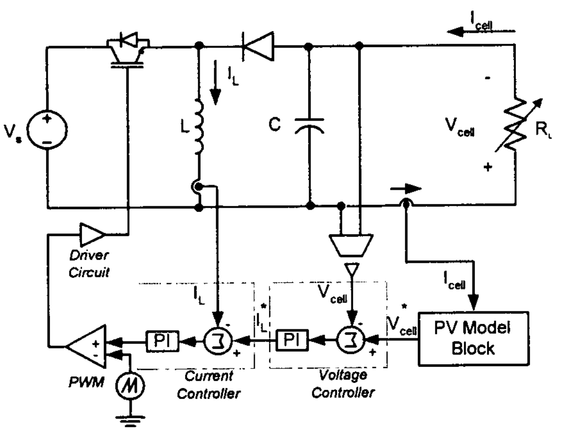


Fig. 4 Buck-boost converter circuit and controller.

Table. I 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}	16.8[V]	
I_{mp}	2.97[A]	
V_{OC}	21[V]	
I_{SC}	3.23[A]	
P	50[W]	

3.3 Buck Converter Connected Series and Parallel.

To analyze the series and parallel operating characteristics, two buck converters are connected series or parallel. Fig.5 shows buck converter circuit connected series and controller, also fig.6 shows converters connected parallel and controller. In figure 5 and 6, there are one controller. But in fact, each converters were controlled by controllers respectively.

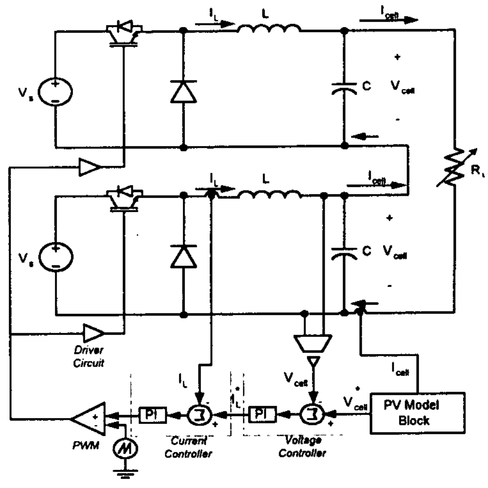


Fig. 5 Buck converter circuit connected series.

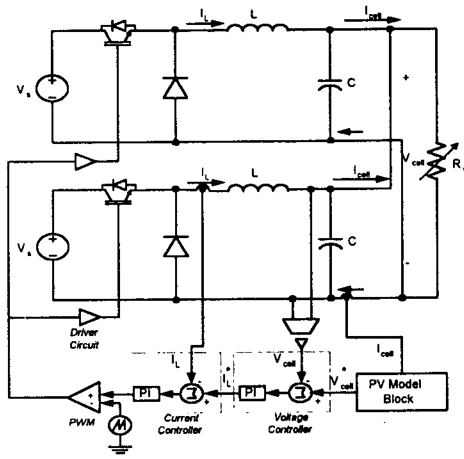


Fig. 6 Buck converter circuit connected parallel.

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 (11), (12) at given operating point(V_{cell}, I_{cell}). 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}.

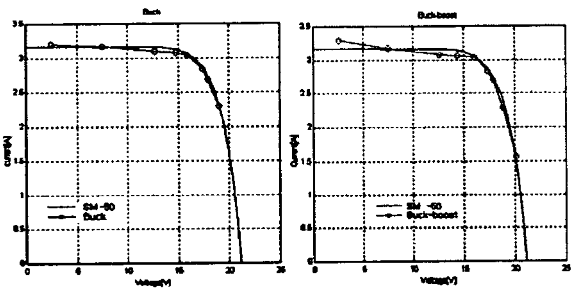
$$R_v = \left.\frac{\Delta V}{V_{mp}}\right|_{V_{cell}} \times 100\,[\%] \quad (11)$$

$$R_I = \left.\frac{\Delta I}{I_{mp}}\right|_{I_{cell}} \times 100\,[\%] \quad (12)$$

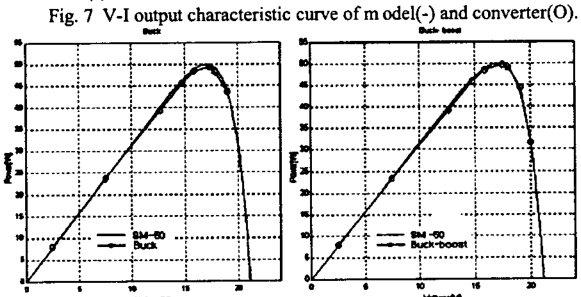
$$\varepsilon_{mt} = \left.\frac{I_{model} - I}{I_{model}}\right|_{V_{cell}} \times 100[\%] \quad (13)$$

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
I_{model} : Current desirable current ,
I : Converter output current

Fig.7 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.8 is P-V output curve of model power and converter, and it shows a little deviation from the model output power. Fig.9 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. Fig.10 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.10(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.



(a) Buck converter (b)Buck-boost converter.
Fig. 7 V-I output characteristic curve of model(-) and converter(O).



(a) Buck converter. (b)Buck-boost converter.
Fig. 8 P-V characteristic of IM model(-) and converter(O).

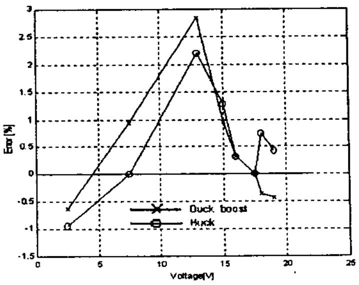
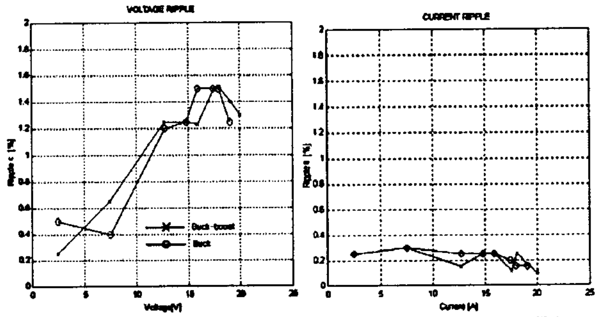
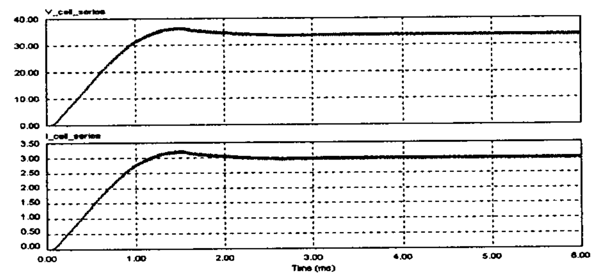


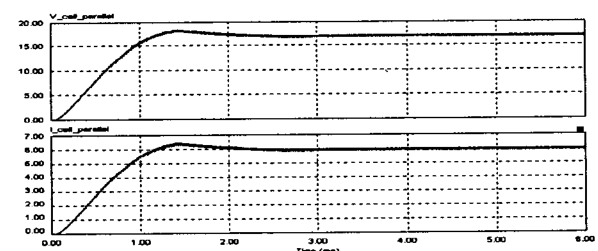
Fig 9. Model tracking error curve.



(a) Ripple rate of output voltage (R_V) (b) Ripple rate of output current (R_I).
Fig. 10 Output voltage and current ripple rate.



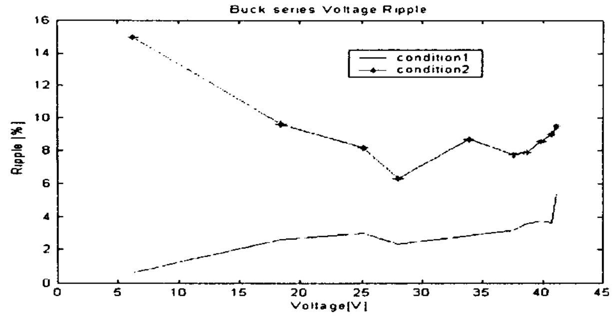
(a) Voltage, Current wave form of Converter connected series



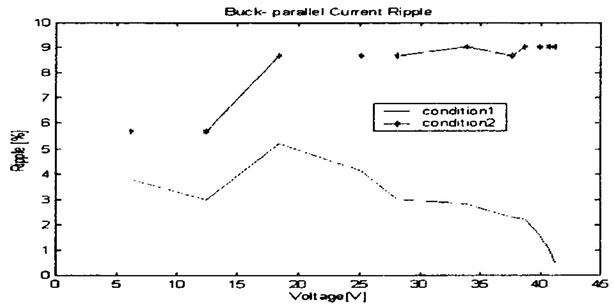
(b)Voltage,Current wave form of Converter connected parallel
Fig. 11 Voltage, Current Wave form of Converter of connected series and parallel

Table 2. Condition of Converter connected series, parallel

	Converter 1		Converter 2	
Condition	L(mH)	C(uF)	L(mH)	C(uF)
1	0.8	3.3	0.8	3.3
2	0.96	3.96	0.64	2.64



(a) Voltage Ripple rate on converter connected series.



(b)Current Ripple rate on converter connected parallel.

Fig. 12 Output voltage and current ripple rate on converter connected series and parallel.

Fig. 11 show wave form of voltage and current, when converter is connected series and parallel. Fig.11(a) show series operation characteristics which voltage increase 2 times and fig.11(b) show parallel operation characteristics which current increase 2 times. When made converter, in some cases, value of L or C make a difference of each converters. This difference caused difference output characteristics of converters connected series and parallel.

The controller is designed according to condition 1 of Table 2. The value of L,C resonance frequency is distinguished condition 1 from condition 2. In condition 2, converter 1 is higher 20% than the converter of condition 1 and converter 2 is lower 20%.

Fig.12 results of simulation on condition of Table 2. Figure 12(a) is R_V(voltage ripple ratio) of converters connected series, (b) is R_I(current ripple ratio) of converters connected parallel. When changed L, C value (condition 2), R_V is 5% higher than condition 1 at converter connected series, R_I is 5% higher than condition 1 at converter connected parallel.

5. CONCLUSION

Interpolation model(IM) for solar cell was utilized for simulation of 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.

The output characteristics of converters connected series and parallel were similar to solar cell array's. but, when the value of L, C resonance frequency is changed, voltage and current ripple rate is at least 5% increased

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.

ACKNOWLEDGEMENT

This work was supported by Korea Research Foundation Grant. (KRF-2000N-PV03-P-01)

REFERENCES

[1] Lilington D., Kukulka J., Mason A., Sanchez J." Optimization of silicon 8 ㎝×8 ㎝ wrap through space station cells for on orbit operation". In Proceedings of 20th IEEE PV Specialists Conference, pp.934-204, 1988

[2] Mikihiko Matsui., Tatsuya Kitano., De-hong Xu., Zhong-qing." A New Maximum Photovoltaic Power Tracking Control scheme Based on Power Equilibrium at DC Link". Conference Record of the 1999 IEEE, Vol. 2, pp.804-809, 1999

[3] Mrig L., DeBlasio R., O'Sullivan G. A., Tomko T. "An advanced PV system simulator to demonstrate the performance of advanced PV cells and devices" Proceeding of 16th IEEE PV Specialists Conference. San Diego, pp 199-204, 1982

[4] Y. Iida. Y. Fuchikami and Y. Neba "Analysis of step-up chopper with photovoltaic array". IEEE Japan Annual Meeting Vol4, No.841, pp.4/180. 1999

[5] Mohan N., Underland T.M and Robbin W.P "Power Electronics: Converters, Applications and Design" pp. 69-73. John Wiley&Sons, New York, 1989