A novel design of DC-DC converter for photovoltaic PCS

Sung-Joon Park*, *Member, KIMICS*

Abstract— Renewable energy resources will be an increasingly important part of power generation in the new millennium. Besides assisting in the reduction of the emission of greenhouse gases, they add the much needed flexibility to the energy resource mix by decreasing the dependence on fossil fuels. Due to their modular characteristics, ease of installation and because they can be located closer to the user, PV system have great potential as distributed power source to the utilities.

In this paper, a dc-dc power converter scheme with the push-pull based technology is proposed to apply for solar power system which has many features such as high efficiency, stable output, and low acoustic noises.

DC-DC converter is used in proposed topology has stable efficiency curve at all load range and very high efficiency characteristics.

This paper presents the design of a single-phase photovoltaic inverter model and the simulation of its performance.

Index Terms— DSC, photovoltaic power system, solar generator

I. INTRODUCTION

As the conventional fossil fuel is depleting at a faster rate while the cost of electrical energy is increasing due to growing consumer demand, photovoltaic energy becomes a promising renewable alternate source. The emerging renewable energy, solar and wind are expected to play a major role in supplying at least 5-10% of total electrical energy demand worldwide. Over 2 billion people in the developing world have no access to electricity. For these people, PV is probably the most economical and abundant power source today[1-2].

Still the PV modules have relatively low conversion efficiency; so more price can be reduce using high efficiency power conditioner that are designed to extract the maximum power from the PV module. The performance of a PV array system depends on the operating conditions as well as the solar cell and array design quality.

A photovoltaic system consists of solar cells and ancillary components such as power-conditioning equipment and support structures

In this study, various power control technique of photovoltaic dc-dc converter has been designed as adjusting the trigger time interval of each module and high efficiency DC-DC converter using a sinusoidal pwm inverter and push-pull circuit has been used to find out the optimal parameters of photovoltaic PCS such as a blocking capacitor, a total input energy, and switching frequency.

This paper presents a high frequency transformer connected push-pull based technology by using FPGA interface to personal computer for the residential PV power system, which delivers the single-phase 2 wire type 60Hz AC output into the AC power grid. And we also describe the whole system configuration of a new utility interactive DC modulated converter for solar power system with a high solar energy conversion efficiency. Its operating principle and related RTOS(real time operating system) computer control schemes are proposed from an experimental point of view.

II. Simplified equivalent circuit model for photovoltaic cell

PV cells can be modeled as a current source in parallel with a diode. When there is no light present to generate any current, the PV cell behaves like a diode. As the intensity of incident light increases, current is generated by the PV cell.

To understand the electronic behavior of a solar cell,

Manuscript received November 17, 2008 ; revised March 14, 2009.

* Corresponding author Sung-Joon Park is with Power Generation Division, Korea Hydro-Nuclear Power, Busan, 619-711, Korea (Tel: +82-51-782-6080, Fax:+82-51-200-3235, Email: co2laser@chol.com)

it is useful to create a model which is electrically equivalent, and is based on discrete electrical components whose behavior is well known. An ideal solar cell may be modelled by a current source in parallel with a diode; in practice no solar cell is ideal, so a shunt resistance and a series resistance component are added to the model. The resulting equivalent circuit of a solar cell is shown on the left. Also shown, on the right, is the schematic representation of a solar cell for use in circuit diagrams[3-5].

The simplest way to describe a photovoltaic generator is to depict is as an ideal current source, which produces a current (I_F) approximately proportional to the incident light power, in parallel with a diode, as shown in Fig. 1.

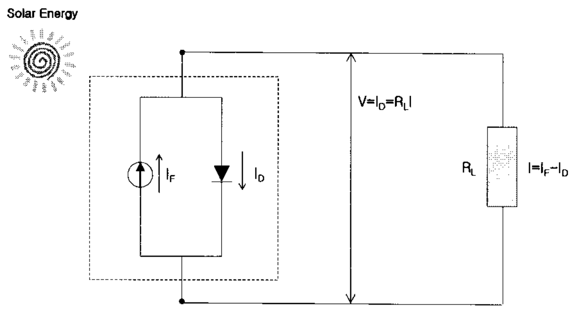


Fig. 1. The PV module equivalent circuit.

If the solar cell terminals are connected by an external load resistor R, part of the current produced by solar radiation will flow through the resistor (external current I) and the other part will flow through the diode (diode current I_D). The external current I is thus given by

$$I = I_F - I_D \qquad \text{(Eq-1)}$$

Fig.2-6 also shows that, for the ideal photovoltaic generator, the voltage V applied on the resistor is equal to the voltage on the diode V_D:

$$V = V_D \qquad \text{(Eq-2)}$$

The diode is a non-linear conducting element which current × voltage curve is given, in a general way, by

$$I_D = I_S[\exp(\frac{V}{V_t}) - 1] \qquad \text{(Eq-3)}$$

where I_S and V_t are characteristic of the particular generator, with V_t a function of temperature.

Using (Eq-2) in (Eq-3), and this result in (Eq-1), we obtain the function that describes the $I \times V$ characteristic curve of the ideal photovoltaic generator (Fig. 2.):

$$I = I_F - I_D = I_F - I_S[\exp(\frac{V}{V_t}) - 1]$$

$$(\because V_t = V_D) \qquad \text{(Eq-4)}$$

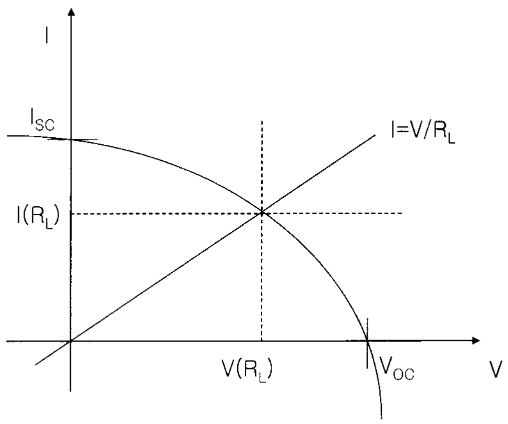


Fig. 2. $I \times V$ characteristic curve of the ideal photovoltaic generator.

The fact that we have drawn an $I \times V$ graph should not give us the wrong impression that the voltage (or the current) is a variable that can be independently varied; as a matter of fact, the independent variables in the situation of Fig. 1 are the incident light power and the external resistance R_L. This situation is found in the experimental determination of the $I \times V$ characteristic curve, where the load resistance R_L is varied, maintaining a constant light intensity, and the values of the (I , V) pair that correspond to each tested value of resistance are measured and plotted in a graph where R_L do not appear explicitly.

Truly, the external current I and the external voltage V are related, in (Eq-4), by

$$V = R_L \qquad \text{(Eq-5)}$$

allowing to eliminate one of them from (Eq-4) and to write the other as function of R_L, for constant light intensity. This is a transcendental function that can be determined as shown in Fig. 2. For each value of resistance there corresponds a (I , V) pair over the characteristic curve, the coordinates of the point where the curve is intercepted by the $I = \frac{V}{R_L}$ straight line.

The values I_{SC} of the short circuit current ($R_L = 0$) and V_{OC} of the open circuit voltage ($R_L = \infty$), which correspond to the points where the characteristic curve intercepts $V = 0$ and the $I = 0$ axes, respectively, are shown bellow:

i) Ideal photovoltaic generator in open circuit

$$V_{OC} = V_t \ln\left[\frac{I_F + I_S}{I_S}\right] \quad \text{(Eq-6)}$$

ii) Ideal photovoltaic generator in short circuit

$$I_{SC} = I_F \quad \text{(Eq-7)}$$

The PV module mathematical modeling presented above, has the drawback that the output current , I, appears on both sides of Equations. (Eq-1) and (Eq-6). In order to avoid the corresponding calculation complexity, in this charter, the ideal PV module output current is calculated as follows:

$$I = I_{SC}[1 - \exp(\frac{V_S - V_{OC}}{V_t})]$$
$$= I_{SC}[1 - \exp\{C_T(\frac{V_S}{V_{OC}} - 1)\}] \quad \text{(Eq-8)}$$

III. DC-DC converter design concept

As illustrated in Fig. 3, the proposed PV simulator is composed of two subsystem:

(i) the switched-mode DC/DC power converter and

(ii) the control system, consisting of the FPGA unit, the push-pull converters and the voltage and current sensors.

The power dc-dc converter input voltage, Vin, is an unregulated DC voltage. A constant frequency duty control signal, V_m , depicted in Fig. 4(a), is producted by the FPGA unit and it is used to control the power switch, S, in order to modulate the DC input voltage into a high-frequency wave, V_{oi}, shown in Fig. 4(b), which then passes through a lowpass L-C filter producing the DC output voltage, V_O. The DC output voltage is regulated to the desired value by adjusting the duty signal cycle value, , as follows[6]:

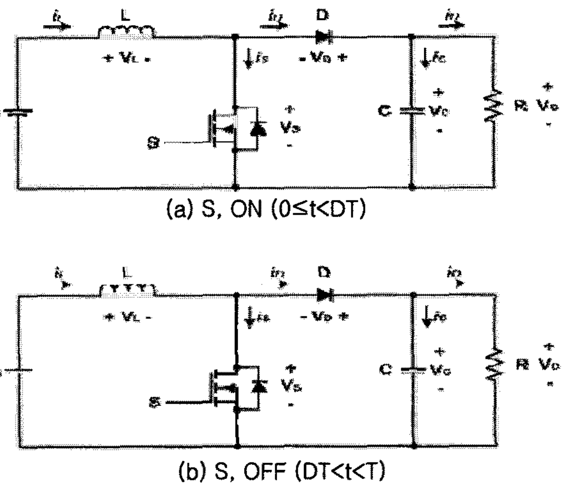


Fig. 3. Equivalent circuits of operation modes for the boost converter.

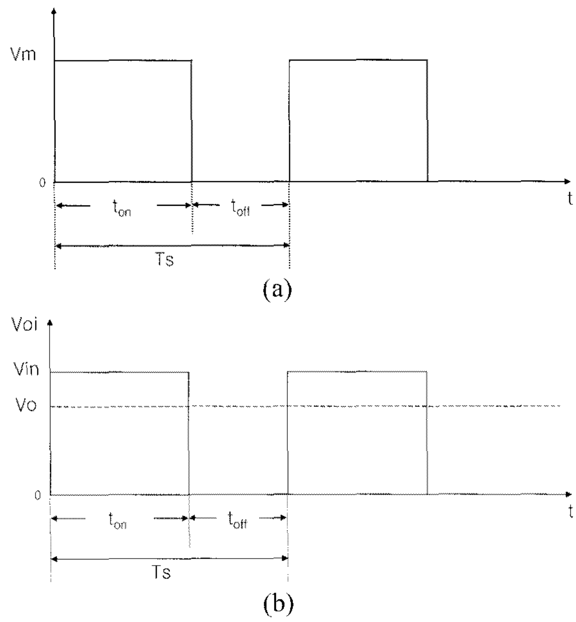


Fig. 4. The DC to DC converter principal waveform

Fig. 5. depicts the experimental waveform for the boost converter.

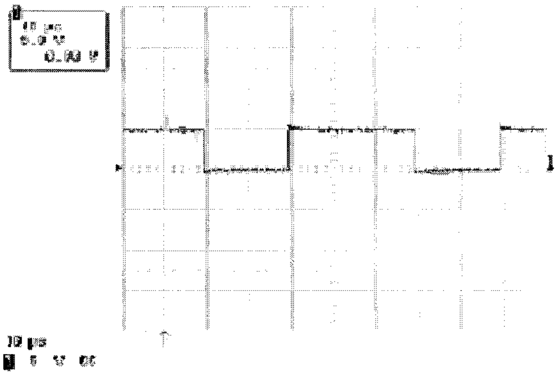


Fig. 5. Boost converter control signal.

$$V_O = DV_{IN} = \frac{t_{ON}}{T_S} V_{IN} \qquad \text{(Eq-12)}$$

where t_{on} is the signal ON time and T_S is the switching period. The inductor, L, is wound on a ferrite core and its value is selected such that the converter operates in the continuous conduction mode[5].

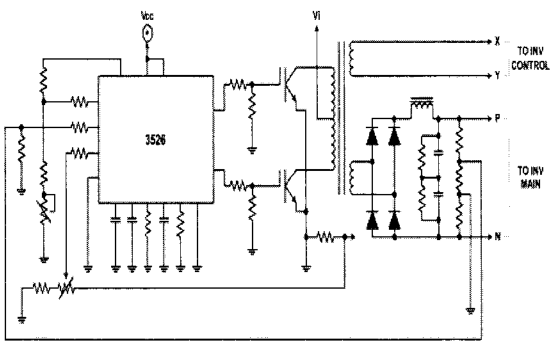


Fig. 6. DC-DC converter for photovoltaic PCS using push-pull converter.

The push-pull DC-DC converter can be implemented using current feedback on the basic circuit in Fig. 6.

Fig. 7 shows a stable waveforms of the series connected push-pull DC-DC converter.

The switching frequency is adjusted by the Vout and DC converter out voltage. The comparator sends a signal to ROM in FPGA. The interval for dc-dc step converter is determined by the signal of the reference value comparing with the DC voltage.

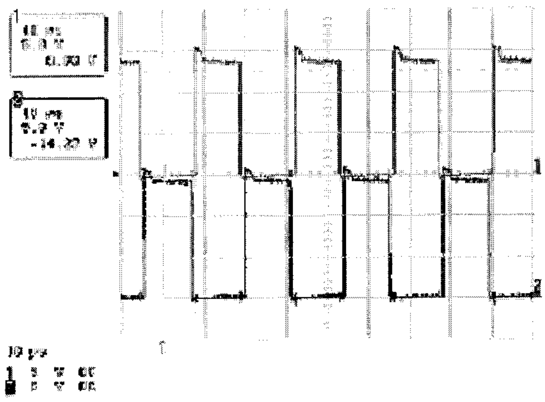


Fig. 7. The waveform of push-pull converter controller.

The appropriate frequency from that is also sent to the FPGA. The main elements of the driving signal are designed to diminish the saturation energy.

The control circuit consists of three part. One is computer keyboard for being taken information of desirable duty ratio and frequency.

To drive dc-dc converter, we can determine duty ratio and frequency. Another is duty ratio and switching frequency display part to show operational time in PC monitor. The resulting output voltage and current measurements are interfaced in digital format to the FPGA unit through the corresponding 8-bit A/D converters. The DC/DC converter output voltage and current are related, in case of ohmic load, according to the linear The simulated PV module I-V characteristic, which is calculated by the control circuit implemented in the FPGA unit.

This controller is digitally implemented on the FPGA(ACEX-EP1K100_208PQFP type) and interfaced with PC parallel port. The on-board clock running at 12MHz was used. An over-current detection faculty is added to protect the system under fault situations.

IV. Inverter Design Concept

Fig.8 shows waveforms of the proposed sine-pwm. Because duty is controlled by sine wave, it is reduced harmonics distortion and increased power efficiency.

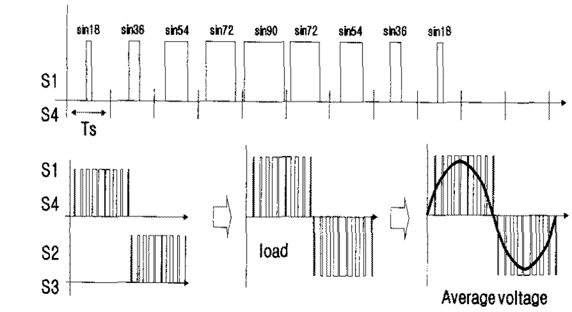
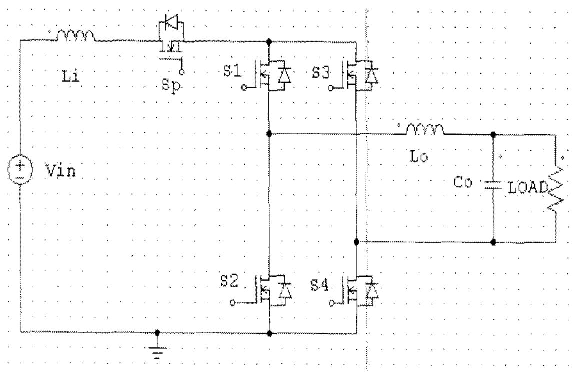
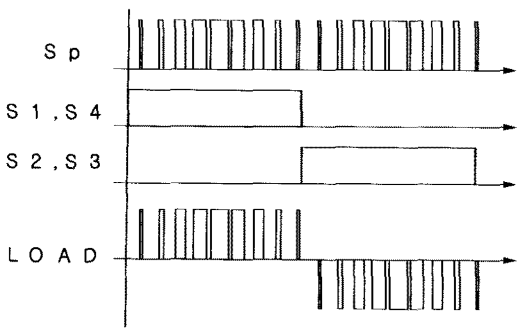


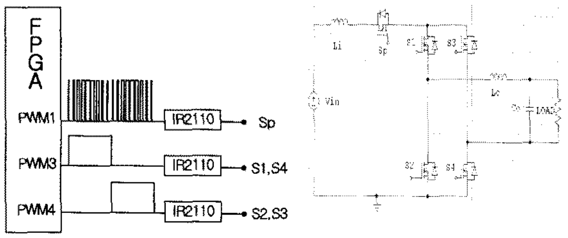
Fig. 8. Gate signal waveforms of sine PWM method.



(a)



(b)



(c)

Fig. 9. The proposed stepping control method inverter topology: (a) Stepping control method inverter, (b) Gate singal waveforms Sp, S1~S4. (c) Stepping drive inverter circuit and control signal.

I propose a photovoltaic module inverter system using stepping control method and full-bridge circuit. Fig. 9(a) shows the structure of a proposed interface circuit. It consists of five switches, an inductor, and LC filter at output port. Sp operates at a high switching-frequency to make the output current a sinusoidal wave, and S1~S4 switches determine the polarity of the ac output voltage. Therefore, compared with general full-bride PWM inverter that performance complete chopping, this system reduces the switching loss[8].

Fig. 9(b) shows the operational waveform for each input gate signal(Sp, S1~S4).

As shown in Fig. 9(b), during a positive half cycle of the ac utility voltage, the polarity selection, S1 and S4, are conducting, and a pulse width modulated switching signal to synthesize a sinusoidal current wave is applied to Sp. In contrast, a case where S2 and S3 are conducting, the current obtained by the dc-dc converter is transferred to the negative direction of the utility line voltage.

The control signal is shown in Fig. 9(c). It shows gate signals of Sp and S1~S4 from FPGA. By using this programming digital circuit, it can determine the switching sequence of the full-bridge switches.

Fig. 10 shows FPGA output signal. In this signal waveform, the switching patterns of the controlled switches S1~S4 are decided by its direction. When S1 and S4 is turn on, S2 and S3 is fully turn off. In order to voltage change, the switching pattern is reversed, switches S1 and S4 is turn off, S2 and S3 is turn on.

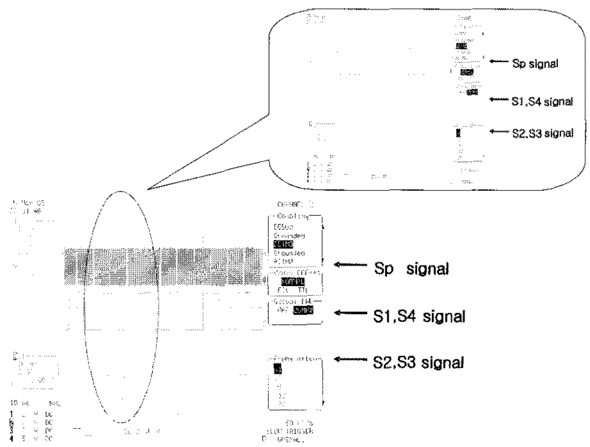


Fig. 10. Experimental gate signal.

Fig. 10 shows simulation waveform and experimental waveform. These experimental results are similar to simulations results. As we can use sine PWM control method, we can get a 1.852% low THD in present state using booster converter control method.

Moreover, we can use stepping control method, we can obtain the switching losses by Sp measured as 0.37W.

V. Results and discussion

In this study, the push-pull converter based dc-dc converter for photovoltaic power has been suggested.

In addition, I proposed an efficient photovoltaic power interface circuit incorporated with a FPGA based DC-DC converter and a sine-pwm control method full-bridge inverter. We have investigated operational characteristics of this solar power system as a function of FPGA based controller. As a result, we can get a 1.852% low THD in present state using linear control method. Moreover, we can use stepping control method, we can obtain the switching losses by Sp measured as 0.37W.

REFERENCES

[1] International Energy Agency, "Renewables in Global Energy Supply An IEA Fact Sheet," 2002.

[2] Brittish Petroleum Statistical, "Review of World Energy," 2003.

[3] Green, M.A., "Photovoltaics: technology overview," *Energy Policy*, vol. 28, pp. 989-998, 2000.

[4] M. G. Jaboori, M. M. Saied, and A. A. Hanafy, "A contribution to the simulation and design optimization of photovoltaic systems," IEEE Trans. Energy Conv., vol. 6, pp.401-406, Sept. 1991

[5] G. Vachtsevanos and K. Kalaitzakis, "A hybrid photovoltaic simulator for utility interactive studies," IEEE Trans. Energy Conv., vol. EC-2, pp. 227-231, June 1987.

[6] H. D. Maheshappa, J. Nagaraju, and M. V. Krishna Murthy, "An improved maximum power point tracker using a step-up converter with current locked loop," Renewable Energy, vol. 13, no. 2, pp. 195-201, 1998

[7] Sung-Joon Park, "Modeling of a novel power control scheme for photovoltaic solar system, International Journal of KIMICS, vol. 6, no 4, pp 417-420, Deccember 2008

Sung-Joon Park
He received his B.S. degree in Electrical Engineering from Dongeui University in 2000. He received his M.S. degree and the ph.D degree in Electrical Engineering from Pusan National University, Korea in 2002 and 2009 respectively. He worked at the LG Electronics Institute of Technology as a research engineer(LG Elite). At present, he is employed by the Korea Hydro-Nuclear Power(KHNP) Company.