Design of the power generator system for photovoltaic modules

Sung-Joon Park*★

Abstract

In this paper, a dc-dc power converter scheme with the FPGA based technology is proposed to apply for solar power system which has many features such as the good waveform, high efficiency, low switching losses, and low acoustic noises. The circuit configuration is designed by the conventional control type converter circuit using the isolated dc power supply. This new scheme can be more widely used for industrial power conversion system and many other purposes. Also, 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. The FPGA based DC-DC converter operates at high switching frequency to make the output current a sine wave, whereas the full-bridge inverter operates at low switching frequency which is determined by the ac frequency. As a result, we can get a 1.72% 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 0.53W.

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

Key words: DSC, photovoltaic, photovoltaic power generator

I. Introduction

Recently, there are many researches about the alternate energy sources as the increase of the concern about the global environment protection and the demand for the pollution-free natural energy. We have already been confronted with serious global environmental problem, such as Greenhouse effect and environmental pollution. To overcome these problems, development of renewable, clean energy technologies which include photovoltaic, solar thermal, wind turbines, hydro-power, wave and tidal power etc. are imperative common challenges for mankind to live in the future[1]-[2].

Especially, the solar energy is one of the positive choices. Above all, dye sensitized solar cells(DSC) are expected to become popular solar cells because of their advantages of cost and efficiency. A photovoltaic system consists of solar cells and ancillary components such as power-conditioning equipment and support structures. Solar cells utilize the energy from the sun by converting solar radiation directly into electricity. The potential of the sun as an energy resource is enormous as about 1×1018 kWh strike the earth's surface yearly. This can be compared to the total world energy consumption of 1×1014 kWh in 2000.

In this study, the 50W load connected solar power system is schematically classified into three different types; an alternative three-phase full bridge switching, an isolated high frequency transformer DC link and a transformer-less direct AC link. The topologies of three-step shifter dc-dc converter are

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advantageous for safety and reliable viewpoint due to the function of exact gate signal. Also, there is a fascination about it because of lower hysteresis loss, mutual inductance and high frequency scheme. This method is used for the transformer magnetic circuit to reduce the core losses. This paper presents a high frequency transformer connected three-step phase-shifted 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[3]. 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 areproposed from an experimental point of view.

II. Real photovoltaic modeling of the PV modules

Fig. 1 represents the simplified equivalent electric circuit of a PV module defined by the following equations[4]:

$$I = I_{SC}[1 - \exp(\frac{V + V_{OC} + IR_S}{V_t}) - 1] - \frac{V + R_S I}{R_P} \quad \text{(Eq-1)}$$

$$V_t = \frac{mkT}{q} \quad \text{(Eq-2)}$$

where I, V are the PV module output voltage and current, I_{SC} is the ideal PV module short-circuit (A), V_{OC} is the ideal PV module open-circuit voltage (V), V_t is the thermal voltage (V), m is a nonideality factor, k is the Boltzmann constant, T is the absolute cell temperature (K), q is the electron charge and R_S, R_P are the series and parallel resistance, respectively, of the PV module.

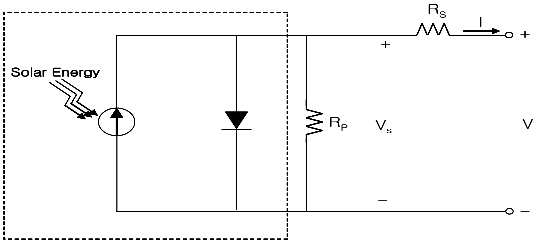


Fig. 1. The PV module equivalent circuit.

The I-V characteristics of a commercially available PV module for various cell temperature and incident solar irradiance conditions are shown in Fig. 2(a and b), respectively. The short-circuit current, I_{SC}, is proportional to the solar irradiance, G(W/㎡), incident on the module, while the open-circuit voltage, V_{OC}, is usually considered to depend only on the PV module cell temperature, T_C (℃), thus neglecting the effect of the incident solar irradiance on the open-circuit voltage[5]:

$$I_{SC} = I_{SC.STC} \frac{G}{1000\,W/m^2} \quad \text{(Eq-3)}$$

$$V_{OC} = V_{OC.SOC} - K_T(T_C - 25℃) \quad \text{(Eq-4)}$$

$$T_C = T - 273K = T_A + \frac{NOCT - 20℃}{800\,W/m^2} G \quad \text{(Eq-5)}$$

where, $I_{SC.STC}$ is the short-circut current (A) under standard test conditions (STC, cell temperature = 25℃ and solar irradiance = 1kW/㎡), $V_{OC.STC}$ is the open-circuit voltage (V) under STC, K_T is the open-circuit voltage temperature codfficient (V/℃), T_C is the cell temperature (℃), T_A is the ambient temperature (℃) and NOCT is the normal operating cell temperature(℃). The values of $I_{SC.STC}$, $V_{OC.STC}$, K_T and NOCT are specified by the PV module manufacturer. The effect of the cell temperature on the short-circuit current is assumed negligible.

The effect of the parallel resistance, R_P, is usually neglected, resulting in the following, simplified, I-V characteristic equation:

$$I = I_{SC}[1 - \exp(\frac{V - V_{OC} + IR_S}{V_t})] \quad \text{(Eq-6)}$$

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[6]:

$$I = I_{SC}[1 - \exp(\frac{V_S - V_{OC}}{V_t})]$$
$$= I_{SC}\left[1 - \exp\left\{C_T\left(\frac{V_S}{V_{OC}} - 1\right)\right\}\right] \quad \text{(Eq-7)}$$

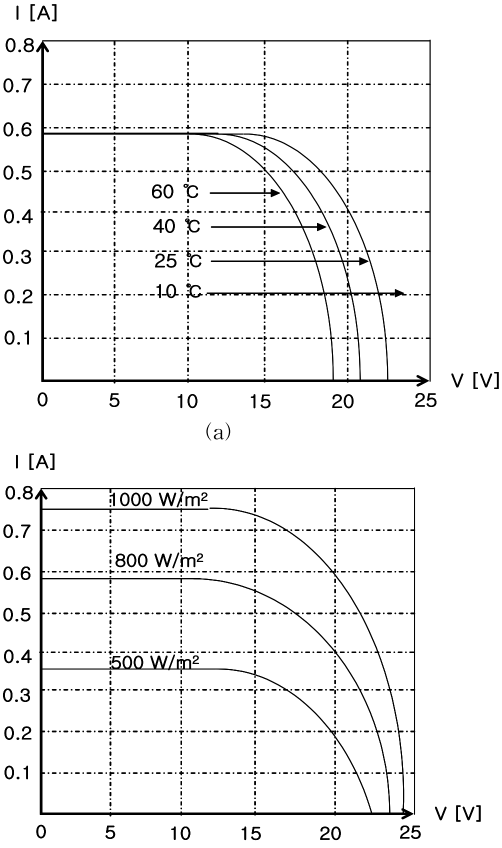


Fig. 2. The current-voltage characteristics of a PV module with temperature and irradiance.

$$C(T) = \frac{V_{OC}}{V_t} \quad \text{(Eq-8)}$$

$$0 \le V_S \le V_{OC} \quad \text{(Eq-9)}$$

where V_S is the ideal PV module output voltage.

Using the values of I calculated using, Eq.(Eq-7), the corresponding values of the PV module output voltage, V , are calculated using the following equations:

$$V = V_S - IR_S \quad \text{(Eq-10)}$$

$$0 \le V \le V_{OC} \quad \text{(Eq-11)}$$

Considering the values of V_{OC} and V_t for various commercially available PV modules, operating under the temperature conditions of typical PV energy production applications, the temperature sensitivity of C_T in Eq. (Eq-7) is neglected in the proposed method. The ideal PV module modeling based on this approximation has the advantage of reduced calculation complexity[7].

III. 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 analog to digital(A/D) converters and the voltage and current sensors.

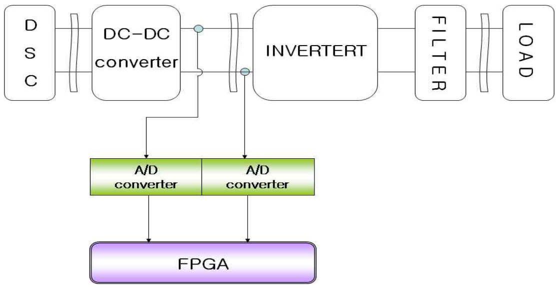


Fig. 3. The block diagram of the PV module.

The power 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 duty cycle value, D, as follows:

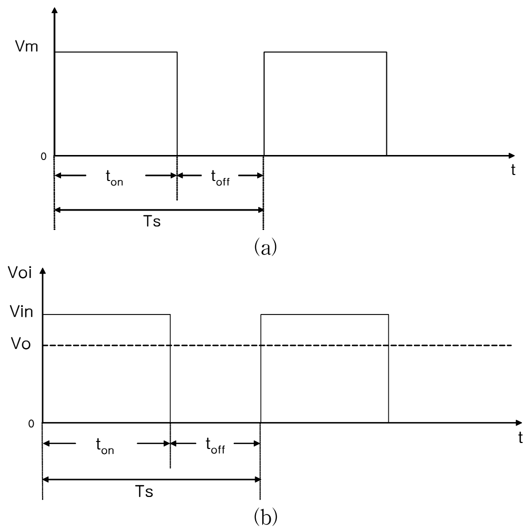


Fig. 4. The DC to DC converter principal waveform

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

where t_{on} is the duty signal ON time and T_S is the switching period.

The switching frequency is adjusted by the V_O 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.

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.

Fig. 5 shows the controller circuit schematic for dc-dc converter. 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.

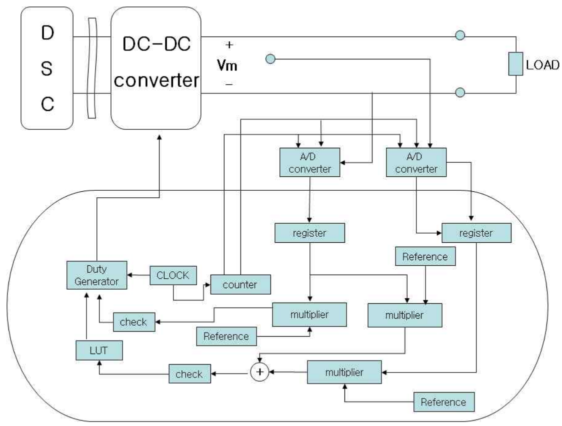


Fig. 5. Controller circuit for dc-dc converter.

Ⅲ. inverter design concept

Fig.6 shows waveforms of the proposed sine-pwm. Because duty is controlled by sine wave, it is reduced harmonics distortion and increased power efficiency.

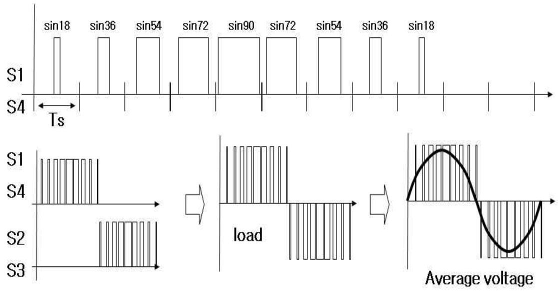
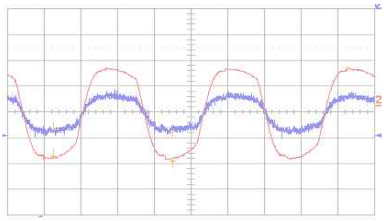
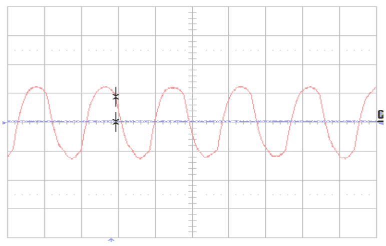


Fig. 6. Gate signal waveforms of sine PWM method.



(a)



(b)

Fig. 7. The output waveform: (a) linear PWM inverter, (b) sine-PWM inverter.

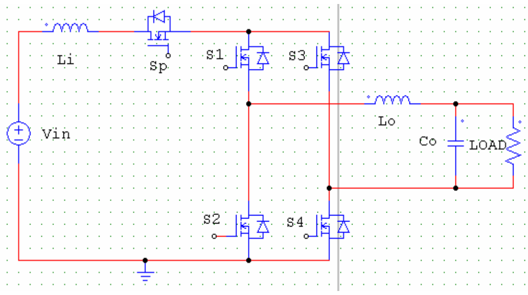
Fig. 7(a) shows the waveform used for the linear control PWM. Fig. 7(b) presents the waveform of sine PWM method.

Also, I propose a photovoltaic module inverter system using stepping control method and full-bridge circuit. Fig 8(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.

Fig. 8(b) shows the operational waveform for each input gate signal(Sp, S1~S4).

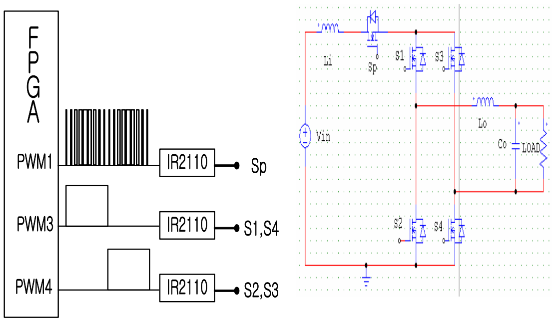
As shown in Fig. 8(b), during a positive half cycle of the ac utility voltage, the polarity selection, S1 and S4, are conducting, and a pulse width modulated switching signal to synthesize a sinusoidal current wave is applied to Sp. In contrast, a case where S2 and S3 are conducting, the current obtained by the dc-dc converter is transferred to the negative direction of the utility line voltage.

The control signal is shown in Fig. 8(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.



(a)

(b)



(c)

Fig. 8. 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.

Fig. 9 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 trun off. In order to voltage change, the switching pattern is reversed, switches S1 and S4 is turn off, S2 and S3 is turn on.

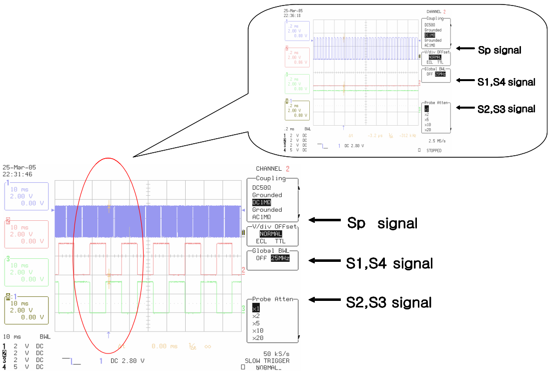


Fig. 9. Experimental gate signal.

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 1.72% 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 0.53W.

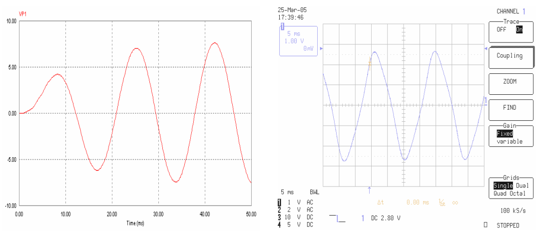


Fig. 10. The proposed inverter output waveform: (a) simulation waveform, (b) experimental waveform

4. Results and discussion

In this study, 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 1.72% 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 0.53W.

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