A TRANSFORMER-LESS SINGLE PHASE INVERTER USING A BUCK-BOOST TYPE CHOPPER CIRCUIT FOR PHOTOVOLTAIC POWER SYSTEM

Nobuyuki Kasa and Takahiko Iida
Department of Electronic Engineering, Faculty of Engineering
Okayama University of Science
1-1 Ridai-Cho Okayama-City 700-0005 Okayama Japan
phone: +81-86-256-9521, fax: +81-86-255-3611
e-mail : kasa@ee.ous.ac.jp, e-mail : iida@ee.ous.ac.jp

ABSTRACT–This paper presents a newly developed transformer-less single phase inverter for a photovoltaic (PV) power system. In the proposed system, there is no earth-leakage current at all in the theoretical base, and the main circuit of this system is rather simple and it is expected the higher efficiency will be realized. The system is operated by a digital signal processor (DSP) which makes it more flexible in the control. From the experimental results, it is found that this new inverter supplies the AC power to utility grid line with the power factor of nearly unity.

1. INTRODUCTION

It is necessary to produce the pollution-free natural energy. Then, photovoltaic power systems have been developed for home usages. Usually, the interface circuits between the PV arrays and the utility grid lines consist of a voltage source inverter. However, the current source inverter and the power inverter were adopted PV power systems. The power inverter has some features[1]. A reactor which links to a utility grid line is not necessary for the system.

Some PV power systems are operated by a DSP, and it makes the system more flexible in the control[2][3]. The detection of a power outage of utility grid line and the maximum peak power tracking (MTTP) are implemented by a DSP.

Recently, transformer-less inverters have been proposed to reduce sizes and costs of photovoltaic power systems. However, in such conventional inverters, there is an inevitable potential difference between the PV array and the grand level of utility grid line. Then it causes the earth-leakage current and rises some serious problem in the system.

This paper presents a newly developed transformer-less single phase inverter for a PV power system which is applied for the home usage. The proposed power inverter is a buck-boost type chopper circuit, and the number of switching device which are used in the system are less than that in the conventional system. A transformer and a reactor which links to a utility grid line are not necessary for the system. In the system, there is no earth-leakage current at all in the theoretical base. And also the main circuit of this system is rather simple and it is expected the higher efficiency will be realized. In this paper, simulated and experimental results are shown using the prototype systems whose power is 500W.

2. PROPOSED INVERTER USING BUCK-BOOST TYPE CHOPPER CURCIUT

Principle of operation

Figure 1 shows the main circuit diagram of the proposed power system. In this circuit, two sets of PV arrays and Buck-Boost type chopper circuits are connected in anti-parallel to the output capacitor C, which generates the AC voltage. Both choppers are operated at the fixed frequency in discontinuous current mode (DCM)[4]. This system has four stages of the operation which are shown in figure 2.

The stage I is defined as the duration that IGBT1 is on-state and all of the other IGBTs are off-state. In other words, the PV array energy is transferred to the reactor L_1

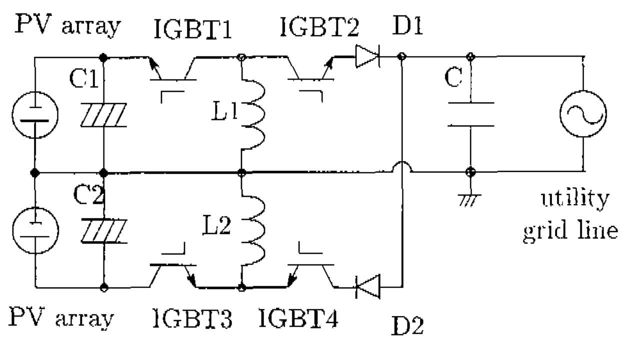

Fig. 1. Main circuit of proposed inverter.

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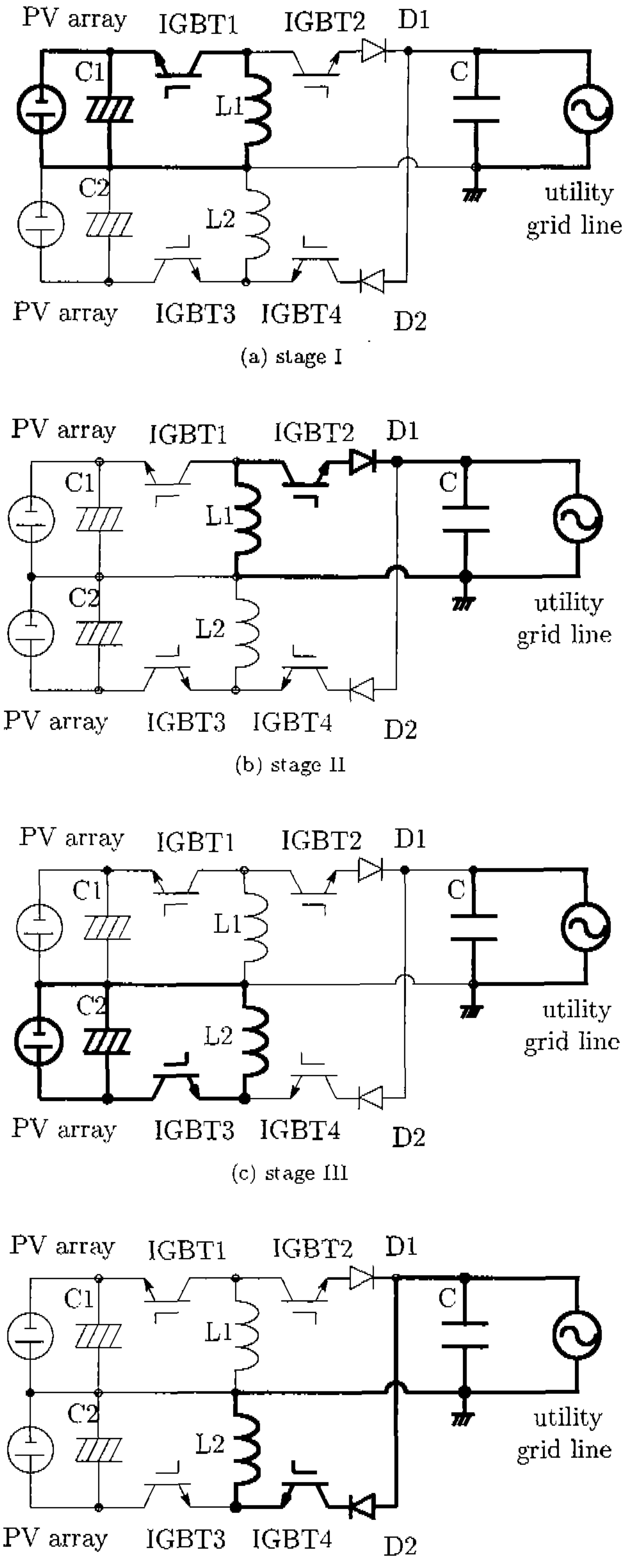

(a) stage I

(b) stage II

(c) stage III

(d) stage IV

Fig. 2. Stages of operation.

and the stored energy in C is discharged to the utility grid line giving positive polarity. The stage II is defined as the duration that IGBT2 is on-state and the rest are off-state, or that both the stored energies in C is released to the AC utility grid line giving positive polarity. The stages III and IV are the negative polarity conditions against the stages I and II, respectively.

Analisys of circuit

When the equivalent resistances of the stages I and II are R_1 and R_2, the state equations of these are expressed as follows:

$$L_1 \frac{di_1(k)}{dt} + R_1 i_1(k) = V_{DC} \quad (1)$$

$$-L_1 \frac{di_2(k)}{dt} - R_2 i_2(k) = \sqrt{2} V_{AC}(k) \quad (2)$$

where, k is a number of the switching. When $i_1(k) = i_2(k-1)$ on eq.(1) and $i_2(k) = i_1(k)$ on eq. (2) at the time $t = 0$, the above equations are solved as follows:

$$i_1(k) = \frac{V_{DC}}{R_1} + \{i_2(k-1) - \frac{V_{DC}}{R_1}\} \exp\{-\frac{R_1}{L_1} t_{ON}(k)\} \quad (3)$$

$$\begin{aligned} i_2(k) &= -\frac{\sqrt{2} V_{AC}(k)}{R_2} \\ &+ \left\{ i_1(k) + \frac{\sqrt{2} V_{AC}(k)}{R_2} \right\} \exp\{-\frac{R_2}{L_1} t_{OFF}(k)\} \quad (4) \end{aligned}$$

In the proposed inverter, the reactor current is not continuous (DCM). Then the above equations are expressed as follows:

$$i_1(k) = \frac{V_{DC}}{L_1} t_{ON}(k) \quad (5)$$

$$i_2(k) = \frac{\sqrt{2} V_{AC}}{L_1} t_{OFF}(k) \quad (6)$$

$$t_{ON} + t_{OFF} = \frac{1}{2Nf} \quad (7)$$

where, f is the frequency of utility grid line and N is the number of the switching times in the term of $1/f$. The stored energy of L_1 is calculated by the next equation.

$$\frac{1}{2} L_1 i_1^2(k) = \frac{V_{AC} I_{AC}}{Nf} (2 \sin^2 \theta_k - \sin^2 \theta_{k-1}) \quad (8)$$

In the term which includes the peak point of i_1, the peak current is shown as I_P. Figure 3 shows the wave form of the reactor current in the term when the current is peak. The value of L_1 is determined by solving the related equations in this term.

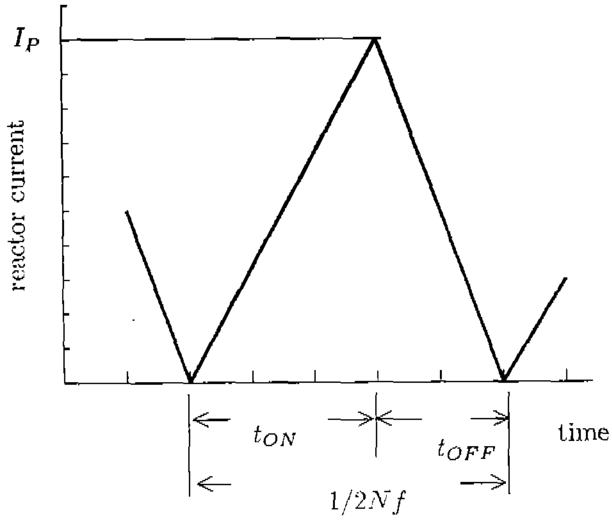

Fig. 3. Current wave form of reactor.

When the relation of eq. (5) and (6) is considered, the peak current I_P is calculated by the next equation.

$$I_P = \frac{\sqrt{2}V_{AC}V_{DC}}{2NL_1 f(V_{DC} + \sqrt{2}V_{AC})} \quad (9)$$

Then, the reactor L_1 is designed by the next equation.

$$L_1 = \frac{V_{AC}V_{DC}^2}{4NI_P(V_{DC} + \sqrt{2}V_{AC})^2(2\sin^2\theta_k - \sin^2\theta_{k-1})} \quad (10)$$

When the difference of voltage is ΔV, the capacitor C is given by the next equation.

$$\frac{1}{2}(\sqrt{2}V_{AC})^2 = \frac{V_{AC}I_{AC}\sin^2\theta_P}{Nf} + \frac{1}{2}C\Delta V^2 \quad (11)$$

$$C = \frac{2V_{AC}I_{AC}\sin^2\theta_P}{Nf(\sqrt{2}V_{AC} - \Delta V)^2} \quad (12)$$

The widths of switching are expressed as the next equations, by using eqs. (5),(6) and (8).

$$t_{ON}(k) = \sqrt{\frac{2LV_{AC}I_{AC}(2\sin^2\theta_k - \sin^2\theta_{k-1})}{NfV_{DC}^2}} \quad (13)$$

$$t_{OFF}(k) = \sqrt{\frac{2LI_{AC}(2\sin^2\theta_k - \sin^2\theta_{k-1})}{NfV_{AC}}} \quad (14)$$

Then, we design the parameters of the main circuit as follows: $L_1 = L_2$ =106 μH, C=120μF, f=60Hz, N=20, V_{DC} =48V, V_{AC}=100V.

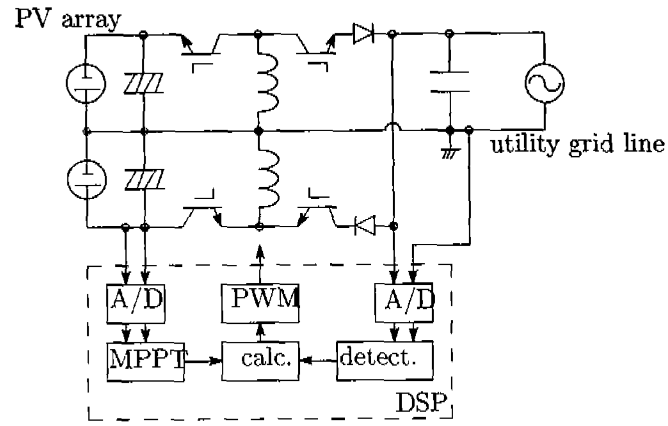

Fig. 4. Experimental system.

3. SIMULATED AND EXPERIMENTAL RESULTS

Experimental system

Figure 4 shows our experimental system. The DSP type TMS320C31 of TI was used to control the whole power system and calculate each switching pattern of IGBT. The switching frequency of the IGBTs which is 2.4 kHz is synchronized to the frequency of the utility grid line.

Simulated results

P-SPICE was used to verified the operation of the proposed inverter. Figure 5 shows the simulated output current and voltage wave-forms at the output power condition of 500W. It seems that the output current wave-form was distorted at the zero cross point, however, it was clear that the power factor was nearly unity. The current wave-form will become sinusoidal by improving the switching pattern of the IGBT1.

Experimental results

Figure 6 shows the experimental output current and voltage wave-forms of the newly constructed photovoltaic power system inverter. In this experiment, the lead battery was used instead of the PV array for the DC inverter source, in order only to verify the operation of the newly developed inverter system. In this, the wave-form of the voltage of the between capacitor C and the output current of the utility grid line are shown, when the output power of the inverter is 400 W. As the result, it is found that this new inverter supplies the AC power to utility grid line with the power factor of nearly unity.

Figure 7 shows the efficiency and power factor in this circuit, when the output power is changed from 100 to 400

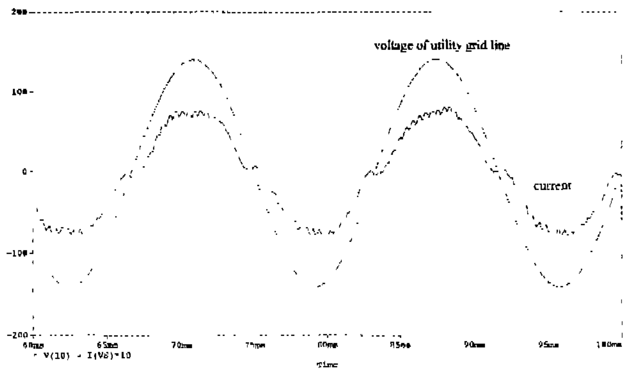

Fig. 5. Simulated result.

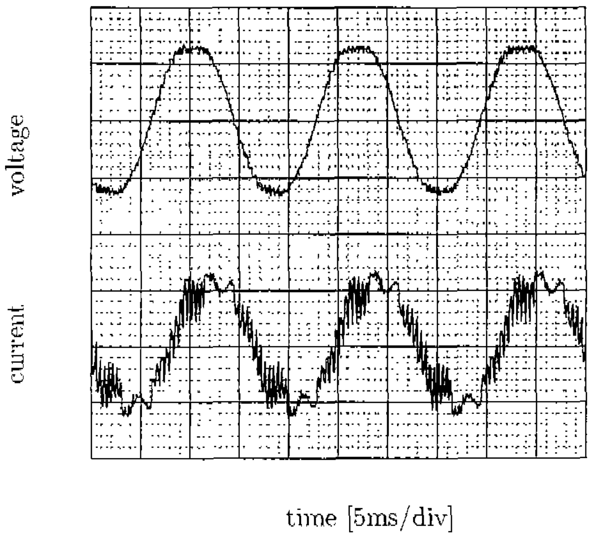

Fig. 6. Experimental result.

W. On the right load condition, the charge current of the capacitor C is bigger, and the power factor is not unity. In this experiment, the switching frequency is very low and then the value of capacitor is large. If the switching frequency is higher, the power factor becomes nearly unity.

4. CONCLUSION

It is proposed that a new transformer-less single phase inverter using Buck-Boost type chopper circuit is applicable to photovoltaic power system. The features of this new system are that the grand level between PV array and AC utility grid line is same, the main circuit configuration is simple and the whole power system is controlled by a DSP.

From the experimental results which were obtained from the newly proposed power system, the power of the PV array can be transferred to the utility grid line with the nearly unity power factor. Then, it can be concluded that

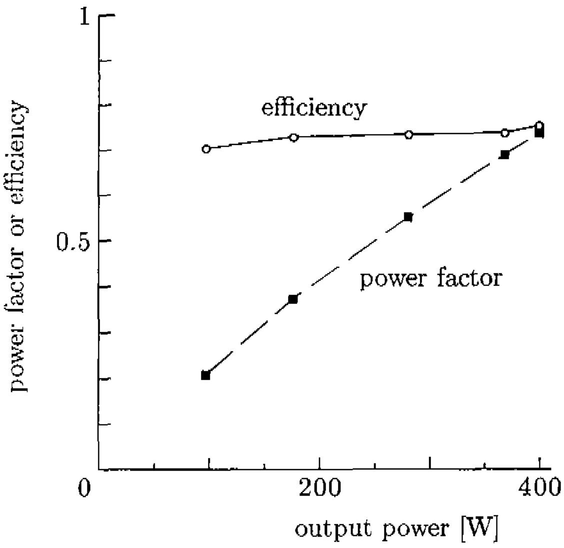

Fig. 7. Power factor and efficiency.

the proposed inverter is suitable to the PV power system for home usage.

5. ACKNOWLEDGMENT

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