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전류원형 PWM 인버터를 이용한 태양광 시스템과 계통 연계를 위한 연구

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Interface between Photovoltaic System and Utility Line using Current-Source PWM Inverter

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ABSTRACT

This paper presents a current-source-inverter based on a buck-boost configuration and its application for residential photovoltaic system. The proposed circuit has five switches. Among them, only one switch acts as chopping, and the other determine the polarity of output; therefore, it can reduce the switching loss. Because the input inductor current is operated on the discontinuous conduction mode, high power factor can be achieved without additional input current controller. So the overall system shows a simple structure. The operational modes are analysed in depth, and then it was verified through the experimental results using a 150 W prototype.

Keywords: Photovoltaic system (PV), buck-boost converter

I. INTRODUCTION

In recent year, the utilization of natural energy has become an attractive alternative to fossil fuels because of their environmental problems and energy saving. Among them, solar energy is especially concerned because it does not generate any poisonous or dirty substances that are polluting the water, air, or land somewhere, and it is abundant and inexhaustible. In the photovoltaic (PV) systems, the cost reduction of solar cells and interface circuit between the solar array and the utility line is still major issues. In general, photovoltaic system smaller than 1 kW supplies lower voltage than that of AC line; therefore, it requires additional boost converter or a transformer to feed such low voltage into the high AC utility line, and commonly connected in series with a voltage-source-inverter (VSI). The lower efficiency due to the cascaded connection and large size of the transformer are resulted in cost increase. Several inverter topologies to solve the cost problem were presented [1]-[6]. Among them, a single-phase utility interactive photovoltaic system including a current-source PWM inverter was presented [1]. The best advantage of this photovoltaic system can supply the utility with maximum power corresponding to the isolation with sinusoidal current waveform at unity power factor, and there is no need for any current feedback control; nevertheless, it has a cost problem.

In addition, new five inverter topologies using two converters with buck/boost voltage characteristics connected in parallel-series-connection were proposed in order to avoid the drawbacks of commonly used voltage-source-inverter configuration [2]. The presentable achievement of these five topologies is an enormous reduction in volume; however it shows low efficiency due to the switching loss.

In this paper, we present a novel current-source PWM inverter based on buck-boost topology as the interface circuit in order to reduce the overall system cost, and to achieve high efficiency. The proposed inverter can obtain high power factor without additional current controller. It shows a simple configuration compared with conventional PV systems. The circuit configuration and its operational mode will be described, and then the validity will be verified through the experimental results using a 150 W prototype.

II. PROPOSED CURRENT-SOURCE PWM INVERTER

Fig. 1(a) shows the basic configuration of proposed current-source PWM inverter as an interface circuit for photovoltaic system. It consists of five switches, one inductor, a small capacitor, and LC filter. Among five switches, only Q_A is used for chopping, and the other determines the output polarity; therefore, this switching scheme can considerably reduce the switching loss. Since the proposed circuit is based on the buck-boost converter, it has an advantage compared with the boost or buck topology in output waveform generation. In the case of buck topology, the output voltage never becomes higher than the input voltage; therefore, in order to feed such low voltage into the high AC utility line, it requires additional boost converter or a transformer. On the other hand, boost topology can generate higher voltage amplitude than that of input; however, lower voltage under the input level could not be obtained. So there has a drawback that it becomes a reason of higher waveform distortion in the near zero cross range. But the proposed circuit can generate either higher or lower than input voltage according to the duty ratio.

Fig. 1(b) shows expected output voltage, output and input inductor current waveforms according to the gate signals. The proposed inverter can obtain the sinusoidal current waveform without input current sensing because the input inductor is operated in the discontinuous conduction mode; therefore, the current peak will automatically follow the voltage waveform. Consequently, it only requires the feedback signal to control in phase with the utility line. As shown in Fig. 1(b), in the positive half cycle of output signal Vs, the polarity selection switches Q_1 and Q_2 are turned on, and the PWM signal to generate a sinusoidal waveform is applied to Q_A. In contrast, when Q_3 and Q_4 are conducting, the output is generated as negative. Because the inverter operates in DCM, a sinusoidal AC output with constant power can be obtained from the photovoltaic system.

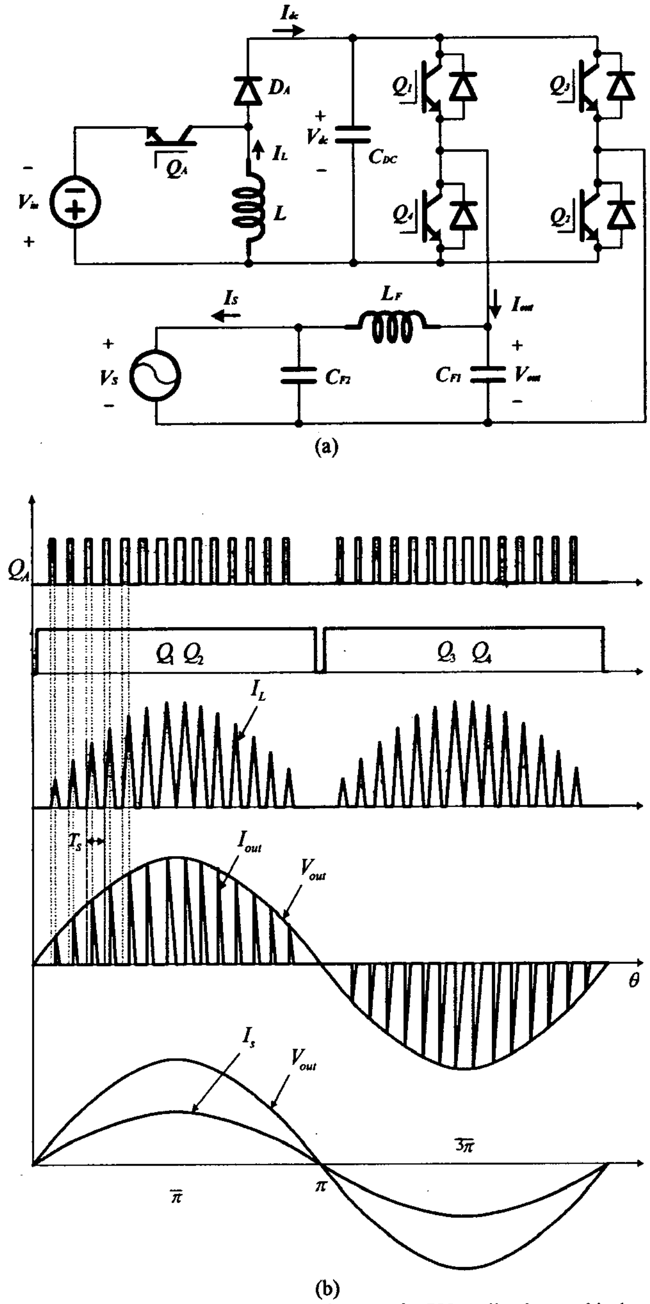


Fig. 1. Proposed current-source PWM inverter for PV application, and its key waveform according to the gate signals. (a) Configuration of proposed interface circuit for the photovoltaic system. (b) Each gate signal, output voltage, output and input inductor current.

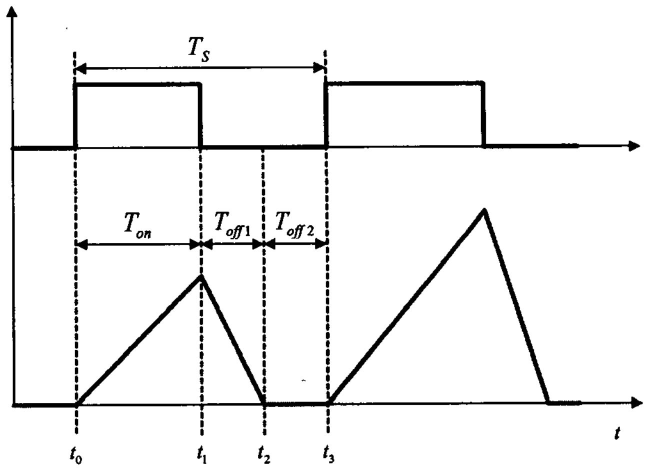


Fig. 2. Magnified inductor current with a QA gate signal.

The proposed inverter has three operational modes in each polarity. Fig. 2 shows the operational modes. It is magnified waveform of Fig. 1(b). To simplify the mode analyses, several assumptions were given. We only consider the positive cycle. All switching devices and components are ideal; therefore, the stray factors are ignored. The ripple component of input voltage V_{in} is very small so it is equal to constant DC voltage, and the load is a pure resistance. Before mode 1, there is no current flowing through the inductor. To form a positive output, Q_1 and Q_2 are conducting.

Mode 1 (t_0 - t_1): At t_0, Q_A is turned on, and D_A is reverse-biased. With the input voltage V_{in} across inductor L, inductor current linearly ramps up at a rate as:

$$\frac{di_L}{dt} = \frac{V_{in}}{L} \tag{1}$$

During on time T_{on}, inductor current reaches to:

$$I_{Lpeak} = \frac{V_{in}T_{on}}{L} \tag{2}$$

Therefore, the stored energy become as:

$$E = \frac{1}{2}LI_{Lpeak}^2 \tag{3}$$

Mode 2 (t_1 - t_2): At t_1, Q_A is turned off, voltage across the inductor reverses; thus I_{Lpeak} flows to the output. Because all the energy stored in L is delivered to the load before the next Q_A turn-on. When Q_A turns off, the inductor current does not flow through the input source. So the only power transferred to the load can be expressed as:

$$P = \frac{LI_{Lpeak}^2}{2T_S} \tag{4}$$

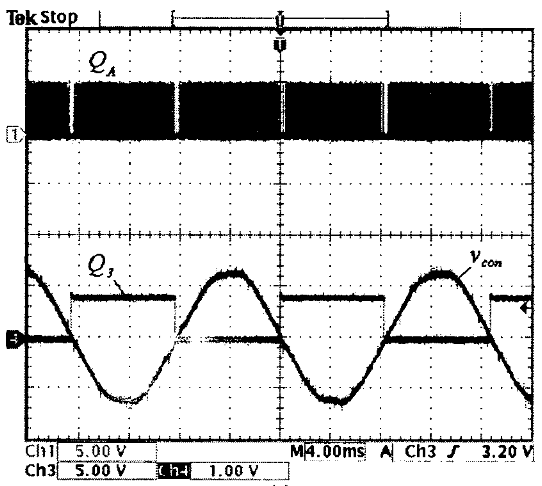
Assuming that there is no loss, and a minimum output resistance R_o, output power can be written as:

$$P_{out} = \frac{V_{out}^2}{R_o} = \frac{LI_{Lpeak}^2}{2T_S} \qquad (5)$$

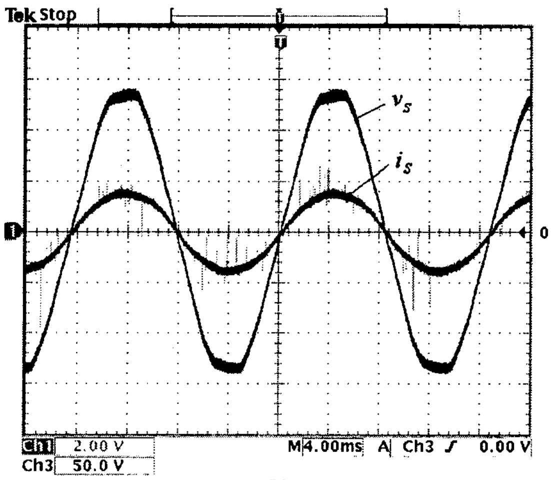
Mode 3 (t_2 - t_3): Q_A is off state, and there is no power transferred to the load from the input. Because the inductor current is discontinuous, in order to make the output current I_{out} continuous, a low pass filter composed of an inductor L_F and a capacitor C_F is required between utility line and the inverter.

III. EXPERIMENTAL RESULTS

To verify the validity of proposed current-source-inverter as the interface circuit for photovoltaic system, a 150 W prototype was manufactured and tested in the laboratory. The operating frequency of proposed circuit was set to 10 kHz. The used components were listed in the Table I.



(a)



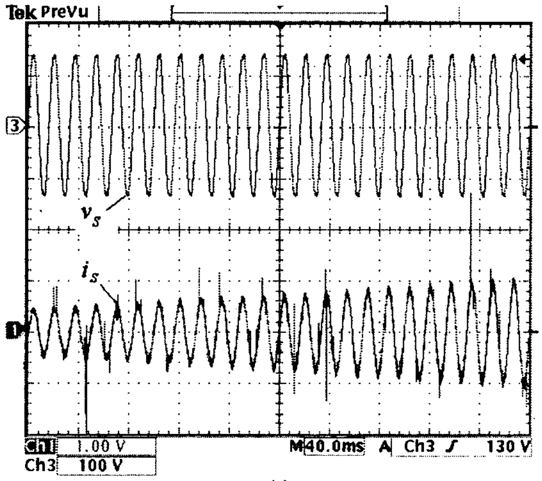
(b)

Fig. 3. Experimental waveforms. (a) Gate signals of QA, and Q3 with its control signal. (b) Utility line voltage and supplied current from the photovoltaic system through the interface circuit.

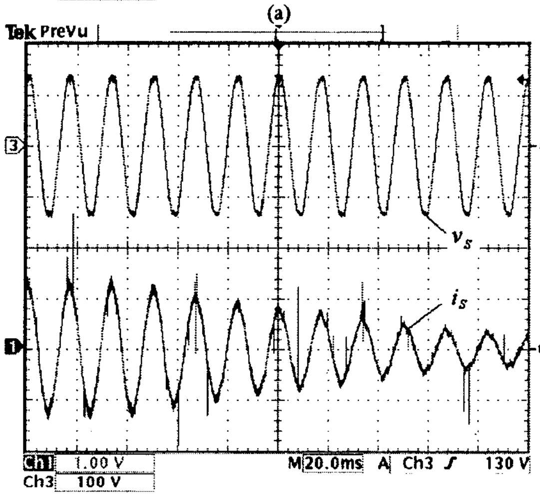
Fig. 3 shows the experimental waveform of proposed current- source PWM inverter. Fig. 3(a) shows the gate signals of Q_A, Q_3 used for polarity selection, and its reference. As a controller, digital signal processor TMS320F241 was used. Dead-time between positive and negative selection switches was set to 5 [μs]. Fig. 3(b) shows the utility line voltage and the supplied current from the photovoltaic system. Both waveforms are in phase showing high power factor.

Table I
Component list of proposed interface circuit

Symbol	Value or Type	Symbol	Value or Type
Q_A	2SK2198	L_F	3 [mH]
Q_1-Q_4	IRF830	C_{F1}	300 [nF]
D_A	RF607	C_{F2}	300 [nF]
C_{dc}	10 [nF]	V_{in}	DC 50 [V]
L	300 [μH]	V_s	AC 100 [V]



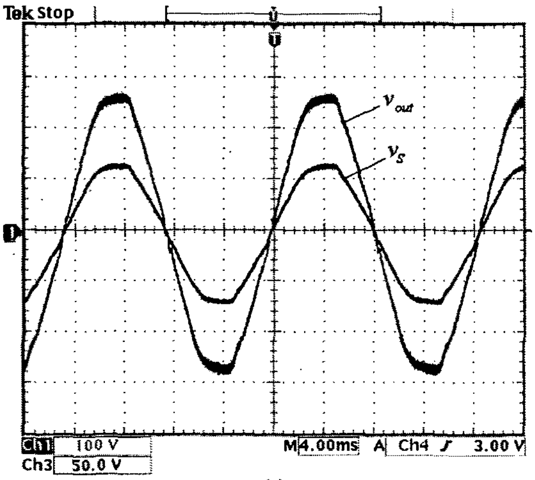
(a)



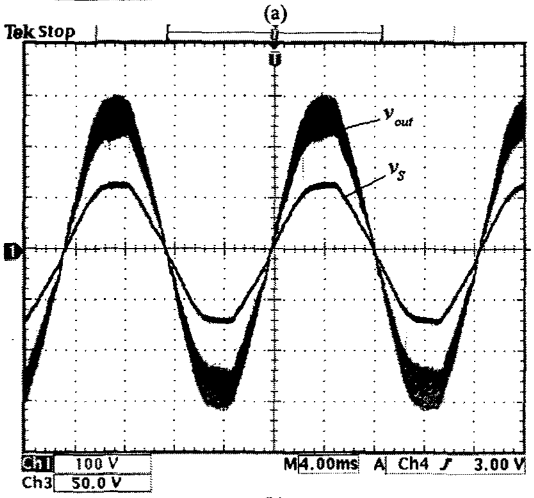
(b)

Fig. 4. Dynamic characteristic of proposed circuit.
(a) With the sun rising. (b) Eclipse of the sun.

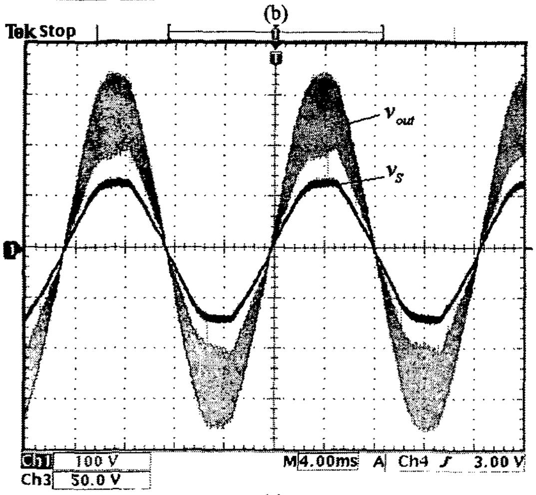
Fig. 4(a) and (b) show the dynamic characteristic of proposed current-source PWM inverter. The output power of photovoltaic system is very changeable according to the weather. It shows well the dynamic characteristic of proposed circuit. It shows high power factor regardless of the variation of weather. Fig. 4(a) shows the output current supplied from the photovoltaic system with output voltage when the sun is rising, and Fig. 4(b) shows the output characteristic with the eclipse of the sun. Due to the variation of power of solar cell, the supplied energy is changing, but they show near unity power factor.



(a)



(b)



(c)

Fig. 5. Characteristic of output filter according to the supplied power. (a) When low power is transferred. (b) When middle power is transferred. (c) When high power is transferred.

The proposed current-source PWM inverter can obtain the sinusoidal current waveform without input current sensing because the input inductor is operated in the discontinuous conduction mode. Since the inverter operates in DCM, a sinusoidal AC output with constant power can be obtained from the photovoltaic system. However, due to this reason, it requires some filters in order to make the output current I_{out} continuous. In this experiment, a low pass filter composed of an inductor L_F and two capacitors is used between utility line and the inverter. Fig. 5(a), (b) and (c) show the characteristic of employed filter. Regardless of transferred power level, it shows good characteristics.

Fig. 6 shows the power dissipation of all switches by switching losses. Switching loss of Q_A used as chopping is higher than that of the sum of others. Regardless of transferring energy, the switching losses by Q_A and others are shown as 1.22 W and 0.96 W, respectively. FFT result of the proposed circuit is shown in Fig. 7. Harmonic currents are increased proportional to the quantity of transferring energy; but it is not severe as shown in Fig.7.

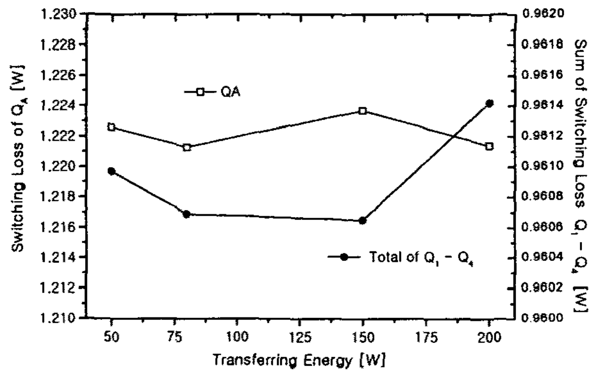


Fig. 6. Power consumption by switching losses of Q_A switch and others.

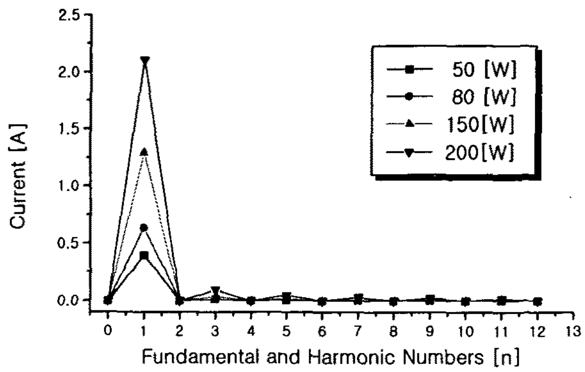


Fig. 7. FFT results according to the transferring energy.

IV. CONCLUSION

In this paper, we proposed a current-source-inverter based on a buck-boost configuration, and tested its possibility for residential photovoltaic system. The proposed circuit has five switches. Because only one switch acts as chopping, and the other determine the polarity of output, it can reduce the switching loss. Because the input inductor current is operated on the discontinuous conduction mode, near unity power factor can be achieved without additional input current controller. So the overall system shows a simple structure. The operational modes were analysed, and it was verified through the experimental results using a 150 W prototype.

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