Maximum Power Point Tracking without Current Sensor for Small Scale Photovoltaic Power System

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Abstract— **This paper presents a maximum power point tracking without a current sensor for a small scale photovoltaic power system. The small scale photovoltaic power systems are used in parallel, and so the cost and the reliability are strongly demanded. In the proposed inverter, the current is controlled with open loop, and then the power of photovoltaic array is calculated by the equation using the voltage of the photovoltaic array. Therefore, the system can obtain the power by detecting only the voltage of the photovoltaic array. As a result, we may obtain the performance of the MPPT with a current sensor as well as with a current sensor.**

I. Introduction

It is necessary to produce the pollution-free natural energy and to obtain that photovoltaic power systems have been developed for home usages. The voltage-power characteristic of photovoltaic array is not liner because of the variation, which caused by a solar intensity and a temperature, and we cannot adopt the liner control theory easily to obtain the maximum power of the photovoltaic array. The perturbation and observation method is often used for the maximum power point tracking (MPPT) in many photovoltaic power systems[1]. The method moves the operating point toward the maximum power point by periodically increasing or decreasing the voltage of photovoltaic array. Usually, by increasing or decreasing the duty ratio of on-state of switching device, the maximum power point is tracked. It is necessary for the MPPT to calculate the input power. In an ordinary system, the input power is calculated as the product the voltage and the current of the photovoltaic array. The small scale photovoltaic power systems are used in parallel, and so the cost and the reliability are strongly demanded.

We had proposed the inverter consists of two sets of buck-boost type chopper circuit[4]. The merit of the system lies in the fact that the main circuit is rather simple and the number of switching devices which are used in the system is less than that in the conventional system. A transformer is not necessary for the system and an inductor which links to a utility grid line is smaller than the conventional system. In the system, there is no earth-leakage current at all in the theoretical base, because the grand level between the photovoltaic array and utility line is same.

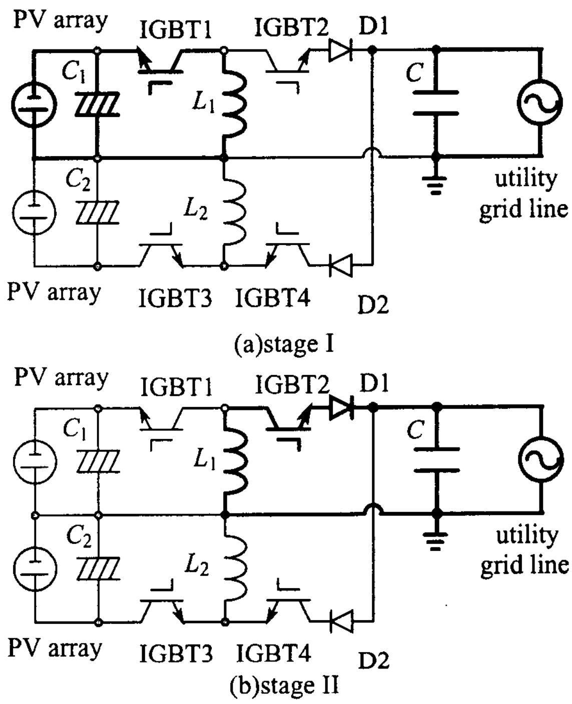


Fig. 1. Inverter consists of two sets of buck-boost type chopper circuit.

This paper presents a maximum power point tracking without a current sensor for a small scale photovoltaic power system. In the proposed inverter, the current is controlled with open loop, and then the power of the photovoltaic array is calculated by the equation using the voltage of the photovoltaic array. Therefore, the system can obtain the power by detecting only the voltage of the photovoltaic array. As a result, we may obtain the performance of the MPPT with a current sensor as well as with a current sensor. Simulations and Experimental results are shown using the inverter using back-boost chopper circuits.

II. Inverter using Buck-Boost Chopper Circuits

Usually, the interface circuits between the photovoltaic arrays and the utility grid lines consist of a voltage source inverter. However, the current source inverter and the

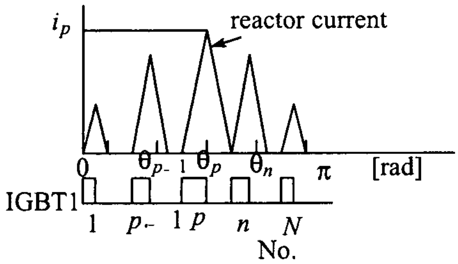


Fig. 2. Current wave form of inductor and switching pulses.

power inverter were adopted in photovoltaic power systems[2].

Figure 1 shows the main circuit diagram of the proposed photovoltaic power system. In this circuit, two sets of photovoltaic array (PV array) and Buck-Boost type chopper circuit are connected in anti-parallel construction with the output capacitor C, which generates the AC voltage. Both choppers are operated at the fixed frequency in the discontinuous conduction mode (DCM), because the whole power of the photovoltaic arrays is transferred to utility line in the term of one switching.

The stage I is defined for the situation where IGBT1 is in on-state and all the other IGBTs are at off-state condition. In other words, the PV array energy is transferred to the inductor L_1 and the stored energy in C is discharged to the utility grid line giving a positive polarity. The stage II is defined for the duration when IGBT2 is in on-state and the rest are at off-state condition, implying that both the stored energies in C is released to the AC utility grid line giving a positive polarity. The stages III and IV are the negative polarity conditions against the stages I and II, respectively.

Figure 2 shows the waveform of inductor current and the switching pulse for IGBT1. f is the frequency of utility grid line and N is the number of the switching times in the term of $1/2f$. When we control the output current to unity power factor, θ_p is $\pi/2$. In the p-th term when the inductor current includes the highest peak point, the highest peak current i_p is given by

$$i_p = \frac{v_{DC}}{L}t_{on} = \frac{\sqrt{2}V_{AC}}{L}t_{off}. \qquad (1)$$

The widths of switching for the p-th term are expressed as follows:

$$t_{on} = \frac{i_p L}{v_{DC}}. \qquad (2)$$

$$t_{off} = \frac{i_p L}{\sqrt{2}V_{AC}}. \qquad (3)$$

When above equations are substituted to the next equation

$$t_{on} + t_{off} = \frac{1}{2Nf}. \qquad (4)$$

i_p is expressed by

$$i_p = \frac{\sqrt{2}V_{AC}v_{DC}}{2NfL(v_{DC}+\sqrt{2}V_{AC})}. \qquad (5)$$

where, V_{AC} is the voltage of utility grid line and it is constant value.

The output energy W which is supplied to the utility grid line is given by

$$W = V_{AC}\sin\theta_p I_{AC}\sin\theta_p \frac{1}{Nf}. \qquad (6)$$

We design the reactance L, with the actual energy stored in the inductor equal to the energy that must be stored in it.

$$\frac{1}{2}Li_p^2 = W \qquad (7)$$

When the relation of energy given in (6) is substituted in the above equation, we obtain

$$\frac{1}{2}Li_p^2 = \frac{V_{AC}I_{AC}}{Nf}\sin^2\theta_p. \qquad (8)$$

Solving for L, we get

$$L = \frac{V_{AC}v_{DC}^2}{4NfI_{AC}(v_{DC}+\sqrt{2}V_{AC})^2\sin^2\theta_p}. \qquad (9)$$

The inductance L as given in the above equation is utilized in the following equation to calculate the width of switching for the n-th term.

$$i = \frac{v_{DC}}{L}t_{ON(n)} \qquad (10)$$

The energy which is stored in the inductor is expressed as follows:

$$\frac{1}{2}Li^2 = \frac{V_{AC}I_{AC}}{Nf}\sin^2\theta_n \qquad (11)$$

Then, the width of switching for the n-th term is expressed as the next equation.

$$t_{ON(n)} = \sqrt{2LV_{AC}I_{AC}\sin^2\theta_n / Nfv_{DC}^2} \qquad (12)$$

III. Maximum Power Point Tracking without Current Sensor

The voltage-power characteristic of photovoltaic array is not liner because of the variation which caused by a solar intensity and a temperature as shown in figure 3, and we cannot adopt the liner control theory easily to obtain the maximum power of the photovoltaic array. The characteristics are measured on 1 p.m. and 3 p.m. The maximum power point, which is located at knee of the P-V curve (b), is moved by a solar intensity and a temperature. The perturbation and observation method is often used for

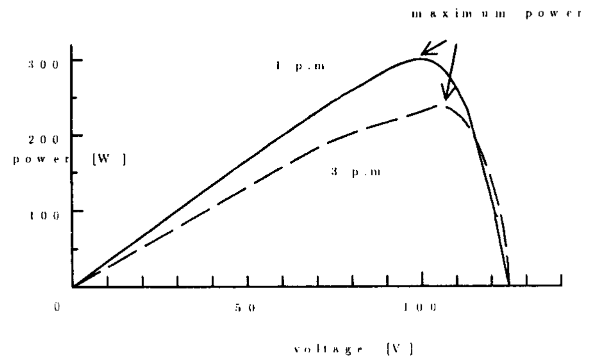


Fig. 3. PV characteristics.

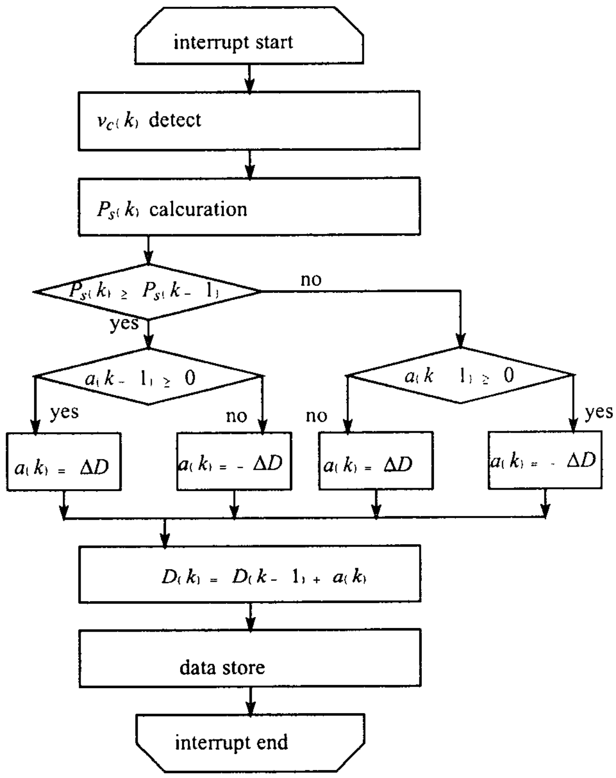


Fig. 4. Flowchart of MPPT.

the maximum power point tracking (MPPT) in many photovoltaic power systems. The method moves the operating point toward the maximum power point by periodically increasing or decreasing the voltage of photovoltaic array. Usually, by increasing or decreasing the duty ratio of on-state of switching device, the maximum power point is tracked.

We adopt the perturbation and observation method to the inverter using Buck-Boost type chopper circuits. In our system, we can calculate the current of the PV array by next equation, and then we can obtain the power of the PV array using only the voltage of the PV array.

The average reactor current presents $i/2$ [3],and we can

TABLE I

CIRCUIT PARAMETERS

L_1	118μH	C	12μF
L_2	118μH	C_1, C_2	4700μF
f	60Hz	V_{AC}	100V
N	80	f_{sw}	9.6kHz

calculate the average current of the PV array as follows:

$$i_s = f/2\int_0^{1/f} i/2dt = \sqrt{2LV_{AC}I_{AC}f/NL} \qquad (13)$$

The output power of PV is expressed as

$$P_s = v_{DC}i_s. \qquad (14)$$

Here, i_s includes only the variable value I_{AC} and the other ones are constant values. I_{AC} is the commanded value for the inverter and it is directly proportional to $D(k)$ which is the commanded value of the MPPT. Then, we can calculate of the power, which is product of v_{DC} and $D(k)$, without detecting the current of the PV array.

Figure 4 shows the flowchart of proposed maximum power point tracking. First, the voltage of PV array is detected through A/D converters. The input power $P_s(k)$ is calculated by the detected voltage and compared the one which were calculated at the previous sampling $P_s(k-1)$. Here, a is the increased or decreased value of duty ratio and $a(k-1)$ is the same at the previous sampling. The relationship between $a(k)$ and $a(k-1)$ decides increase or decrease of the duty ratio. In this way, the maximum power point is tracking based on the perturbation and observation method.

IV. EXPERIMENTAL RESULTS

Figure 5 shows our experimental system configuration. Six photovoltaic arrays are used in our system and the rated power is 654W. The TI TMS320C31 digital signal processor (DSP) is used to track the maximum power point, control the whole power system and calculate each pulse width of IGBT. The data of pulse width is outputted through the digital out and the data is encoded to the pulse width by digital circuits on a programmable logic device (CPLD). In this experimental system, we detect the voltage of the PV2 v_{DC} for the MPPT. The switching frequency of the IGBTs (9.6 kHz) is synchronized to the frequency of the utility grid line (60 Hz). The circuit parameters are listed in table I.

Figure 6 shows the output current and voltage waveforms of the prototype photovoltaic power system. Here, the above waveform is the voltage of the intermediate capacitor C. The below waveform is the output current of the inverter, with the output power of the inverter being 500 W. It is found that the proposed inverter supplies the

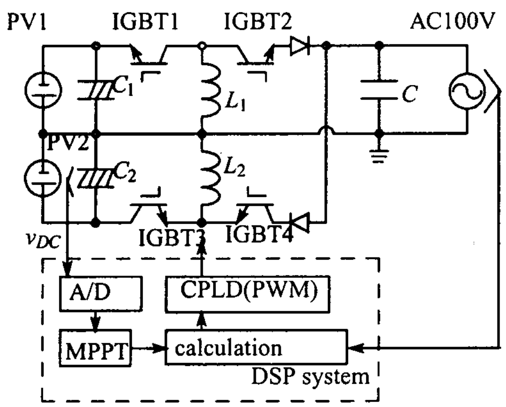


Fig. 5. System configuration.

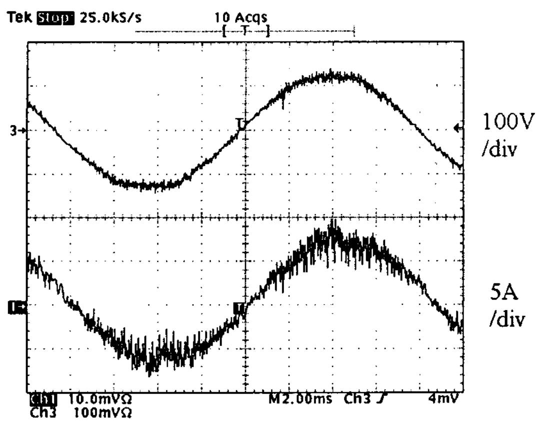
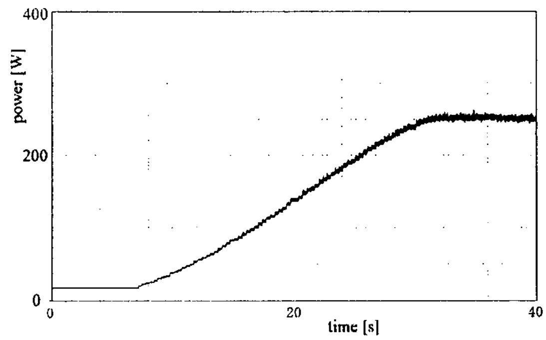
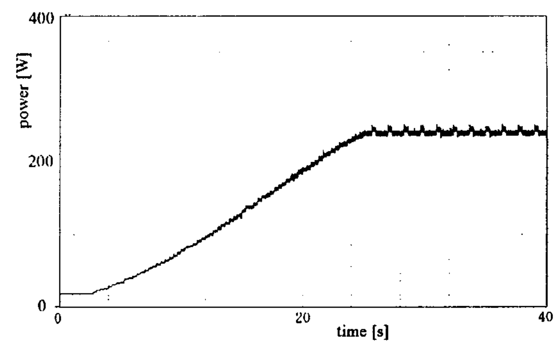


Fig. 6. Waveforms of output voltage and current.



(a) with current sensor



(b) without current sensor

Fig. 7. Behavior of MPPT.

AC power to the utility grid line with the power factor of nearly unity.

Figure 7 shows the behaviors of the MPPT. The maximum power is about 250W. The starting response of the MPPT by the perturbation and observation method with a current censor is shown in (a) and the method without a current sensor shown in (b). As a result, the proposed method can track the maximum power point as well as a perturbation and observation method with a current sensor. The maximum power in figure 7(b) is 5W smaller than in figure 7(a), because of the influence of the assumption which the current of the PV array is proportional to the duty ratio.

V. Conclusion

We propose a maximum power point tracking without a current sensor for a small scale photovoltaic power system. The proposed inverter can controls the output current with the open loop, and we can calculate the power with detecting the voltage. Then we can track the maximum power point without a current sensor as well as with a current sensor. From the experimental results which were obtained from the proposed system, the power of photovoltaic array can be transferred to the utility grid line with nearly unity power factor at the maximum power point without a current sensor. All the observation and experimental results lead to the fact that our proposed inverter is suitable to the photovoltaic power system utilized for the small scale system, whose rated power is under 1kW.

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