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Application of PCCS Method to PV Generation System with Half Bridge Inverter

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Abstract. A Power Conditioning System (PCS) for a PV power generation system obtains the maximum power from a photovoltaic (PV) array by Maximum Power Point Tracking (MPPT), but losses in the inverter are a factor in lowering the power obtained by the MPPT. The generation of harmonic currents is also a problem for PCS. This paper proposes the application of the Peak Current Control Switching (PCCS) method in PCS for PV Generation System using a half bridge inverter. The half bridge inverter improves efficiency by reducing the number of switching elements and further suppresses harmonic currents by controlling them using the PCCS method. In this paper, a comparative simulation of the conventional Hysteresis Current Control (HCC) method and the proposed PCCS method is performed using a half bridge inverter. The results of harmonic analysis and comparative simulation of total harmonic distortion (THD) show that the PCCS method generates harmonic components near the switching frequency, and that the proposed PCCS method always has a lower distortion rate than the conventional HCC method.

1 Introduction

In recent years, research on renewable energy has been active due to the problems of energy resource depletion and global warming caused by carbon dioxide emissions. Photovoltaic (PV) generation system directly converts solar energy into electrical energy without emitting any carbon dioxide and toxic substances, and PV arrays are widely used for power sources these days[1]-[2].

A Power Conditioning System (PCS) for PV generation system converts Direct Current (DC) power obtained from PV arrays into Alternating Current (AC) power. The switching elements used at that time incur losses due to slight ON resistance and switching losses. The PCS obtains the maximum power from a PV array by Maximum Power Point Tracking (MPPT), but losses in the inverter are a factor in lowering the power obtained by the MPPT. In addition to the above problems, the generation of harmonic currents is also a problem for PCSs for PV power generation. Harmonic currents can cause overheating and overvoltage in electrical equipment, noise and image distortion in communication equipment, and there is a strong need to reduce harmonic currents, for example by setting guidelines for harmonic suppression measures[3].

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Various methods have been studied to reduce these harmonic problems[4]-[11]. Of these, the Hysteresis Current Control (HCC) method is the most frequently studied. The advantages of this method are its simplicity of execution and fast response time. However, it has the disadvantage that the switching frequency varies over a wide range, making filter design difficult. To solve this problem, the authors have previously proposed a peak current control switching (PCCS) method using a full-bridge inverter[12]. This method minimizes the difference between the input peak current and the reference current at a constant switching frequency, reducing harmonic currents and limiting the frequency of the generated harmonic currents.

Therefore, this paper proposes to apply the PCCS method to a photovoltaic system with a half bridge inverter in order to improve efficiency and to suppress harmonic currents and limit frequency. Comparative simulations between the conventional HCC method and the proposed PCCS method show that the PCCS method is effective for half bridge inverters.

2 Conventional circuit configuration

Figure 1 shows the circuit configuration of a conventional PCS. The output of a solar array changes its maximum power point with changes in solar radiation intensity and panel surface temperature. Therefore, by using MPPT control with the DC-DC converter, it is always operated at the maximum power point. S_0-S_4 represent switching elements, V_D is the input DC voltage, V_N is the grid voltage, and I_N is the grid current. The current direction is shown here with respect to the grid power supply, so that the grid voltage and grid current are in opposite phases during reverse power flow. The conventional circuit, a full-bridge inverter, uses four switching elements, and losses due to slight ON resistance and switching losses are generated by the switching elements. Thus, the power obtained from the inverter will be decreased by these switching elements.

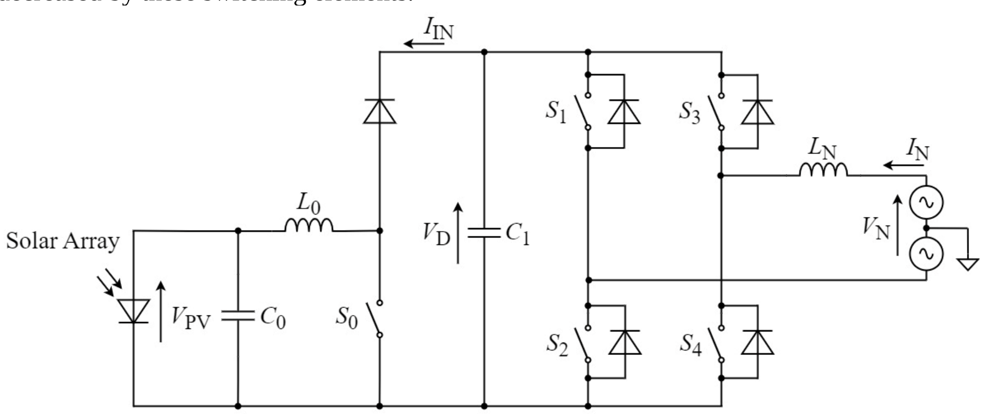

Fig. 1. Circuit configuration of conventional PCS

3 Proposal of a new circuit configuration

Figure 2 shows the circuit configuration of the proposed system. The conventional single-phase full-bridge inverter uses four switching elements, whereas the half bridge inverter used here uses two switching elements, reducing the number of components.

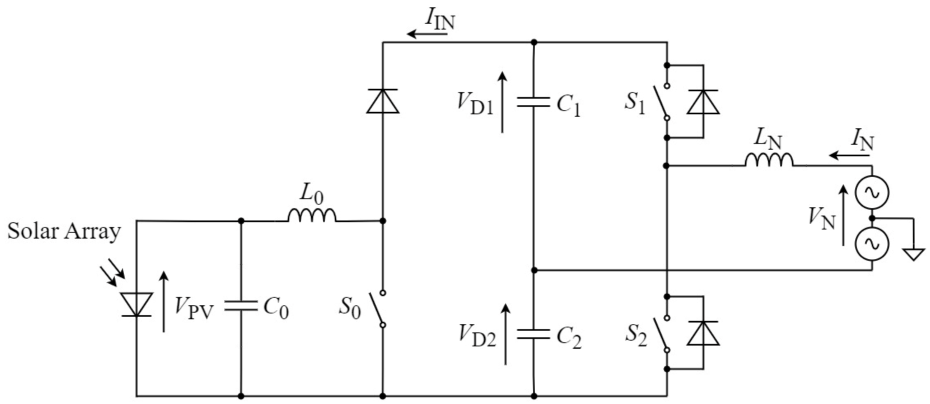

Fig. 2. Circuit configuration of the proposed PCS

Assuming that mode 1 is when S_1 is off and mode 2 when S_2 is off, the circuit equation can be expressed by the following equations.

mode 1)

$$\begin{cases} \dfrac{dI_N}{dt} = \dfrac{V_N + \dfrac{q_2}{C_2}}{L_N} \\ \dfrac{dq_1}{dt} = -I_{IN} \\ \dfrac{dq_2}{dt} = -I_N - I_{IN} \end{cases}$$

mode 2)

$$\begin{cases} \dfrac{dI_N}{dt} = \dfrac{V_N - \dfrac{q_1}{C_1}}{L_N} \\ \dfrac{dq_1}{dt} = I_N - I_{IN} \\ \dfrac{dq_2}{dt} = -I_{IN} \end{cases}$$

The current value rises in mode 1 and falls in mode 2. By periodically switching between mode 1 and mode 2, DC power is converted to AC power.

4 Basic concept of PCCS method

Figure 3 shows a conceptual waveform diagram of the PCCS method in reverse current flow operation. The blue dashed line represents the reference current I_{Nref}. The current value rises in mode 1 and falls in mode 2. The ratio m is determined by obtaining the values of input voltage V_{D}, reference current I_{Nref}, and grid voltage V_{N} at each switching cycle T_{S} and minimizing the square of the error (I_{N1}-I_{Nref}) and (I_{N2}-I_{Nref}). The equation for the ratio m is given below.

$$m = \frac{\alpha\beta + \gamma\delta}{\beta^2 + \delta^2} \ (0 \leq m \leq 1.0) \tag{4.1}$$

where

$$\alpha = I_{Nref} - I_{N0},\ \ \beta = \frac{V_{D1} + V_N}{L_N} T_S,\ \ \gamma = \alpha + \frac{V_{D1} - V_N}{L_N} T_S,\ \ \delta = \frac{2V_{D1}}{L_N} T_S \tag{4.2}$$

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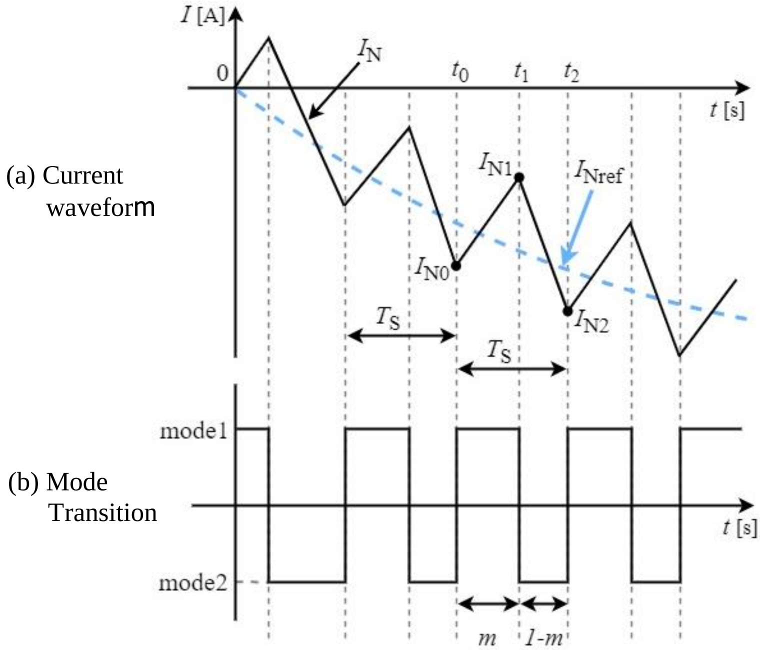

Fig. 3. Waveform conceptual diagram of PCCS

This allows switching at a constant switching frequency.

5 Simulation results

In this section, a comparative simulation between the conventional HCC method and the proposed PCCS method is performed to confirm the effectiveness of the PCCS method using a half bridge inverter.

5.1 Simulation conditions of the proposed method

Figure 4 shows a control system diagram of the PCCS method for simulation. Where, the PV side including the DC-DC converter is assumed to be the current source I_N, and IGBTs are used as switches in this simulation. The input voltage V_D (V_{D1}+V_{D2}) is adjusted with the input reference voltage V_{Dref} and the power factor 1 is executed. The error between V_{Dref} and V_D is amplified by a PI controller and multiplied by a signal proportional to the grid voltage V_N to synchronize the phase and generate a reference current I_{Nref}. The error between the measured I_N and the reference current I_{Nref} is controlled through PCCS and the ratio *m* is obtained by calculation. The output of the PCCS is compared to the carrier wave to generate a PWM signal.

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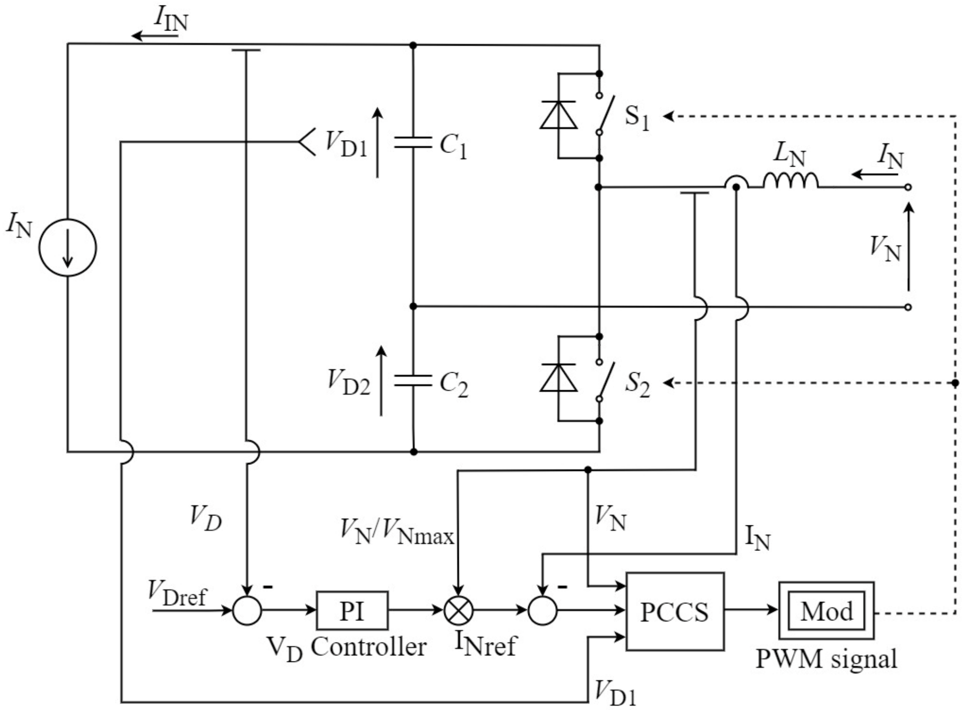

Fig. 4. Control system diagram of the PCCS method

Table 1 shows the circuit conditions. Comparative simulations of the HCC and PCCS methods are performed with the maximum frequency of the conventional HCC method and the switching frequency of the proposed PCCS method set at 20 kHz, and with two input power levels of 2 kW and 4 kW.

Table 1. Circuit conditions

Input power	P	2kW/4kW
Input current	I_{IN}	2.5A/5A
Input reference voltage	V_{Dref}	800V
Grid voltage	V_N	200V(rms)
Power supply frequency	f	50Hz
Switching frequency	f_S	20kHz
Grid inductance	L_N	1.8mH
Capacitance	C_1, C_2	50mF

5.2 Simulation using MATLAB/Simulink

Simulation was performed using MATLAB/Simulink with the control system diagram in Figure 4. Figure 5 shows the Simulink model for the PCCS method. The model in Figure 5 was calculated using equation (4.1), where Alpha, Beta, Gamma, and Delta were calculated using equation (4.2).

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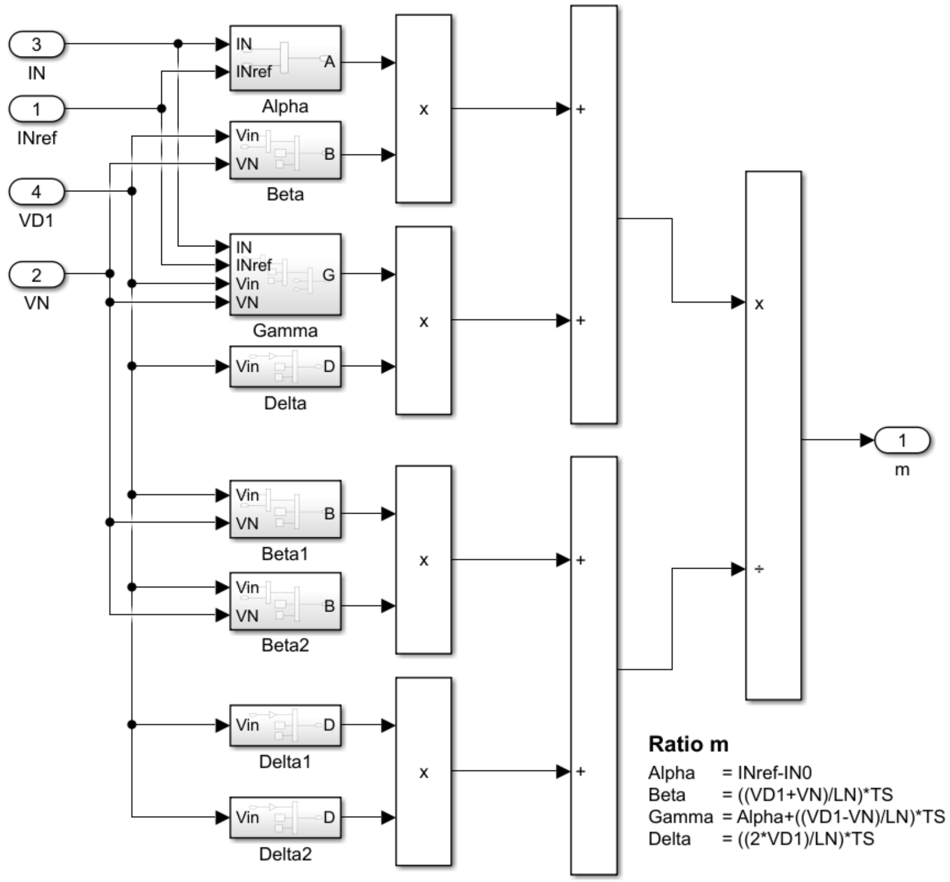
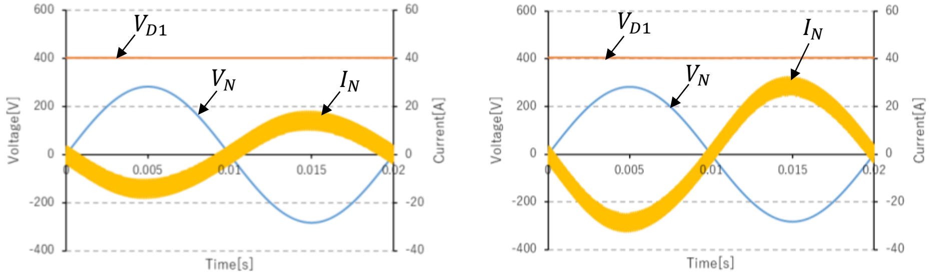


Fig. 5. Simulink model of PCCS method

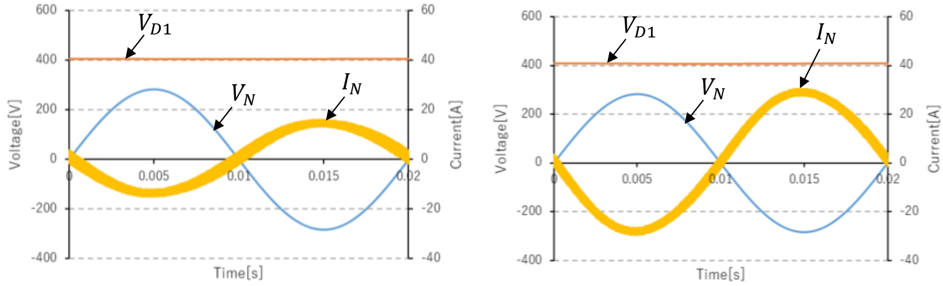
5.3 Results

Figures 6 and 7 show the waveforms of I_N, V_N, and V_{D1} at steady state when simulations are performed using the HCC and PCCS methods. From these figures, it was confirmed that the I_N formed a sinusoidal waveform and that reverse power flow was taking place. It can also be seen that the PCCS method suppresses the ripple of the grid current I_N more than the HCC method.



(a) Input power = 2kW (b) Input power = 4kW

Fig. 6. Waveforms of HCC in steady state (conventional)

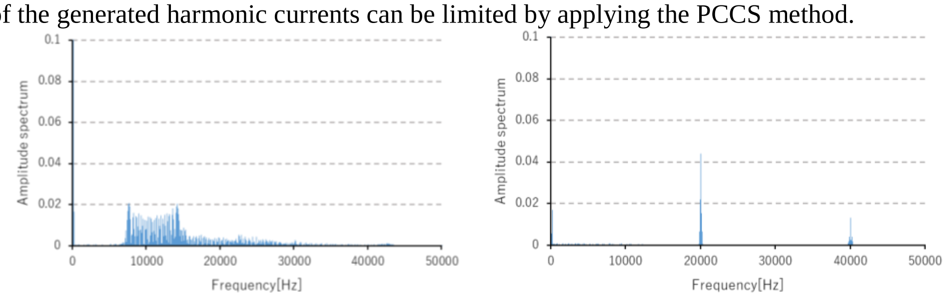


(a) Input power = 2kW (b) Input power = 4kW

Fig. 7. Waveforms of PCCS in steady state (proposed)

6 Spectrum

Harmonic analysis was performed for the current waveforms of the HCC and PCCS methods at an input power of 5 kW under the same conditions as in Table 1. Figure 8 shows the normalized harmonic currents; Figure (a) shows the spectrum of the HCC method and Figure (b) shows the spectrum of the PCCS method. These figures show that the HCC method generates harmonic components over a wide range, while the PCCS method generates harmonic components near the switching frequency. This result indicates that the frequency of the generated harmonic currents can be limited by applying the PCCS method.



(a) Spectrum of HCC (conventional) (b) Spectrum of PCCS (proposed)

Fig. 8. Normalized harmonic currents

7 Total harmonic distortion

Comparison of the total harmonic distortion THD was performed with the same maximum frequency of the conventional HCC method and the switching frequency of the proposed PCCS method. Figure 9 shows a comparison of the total harmonic distortion THD between the conventional and proposed methods at switching frequencies from 10 kHz to 50 kHz. The values in the graph are calculated from equation (7.1) shown below the figure. The figure shows that the total harmonic distortion of the PCCS method is always below that of the HCC method at switching frequencies between 10 kHz and 50 kHz. Therefore, the experimental results show that harmonic currents can be suppressed by applying the PCCS method.

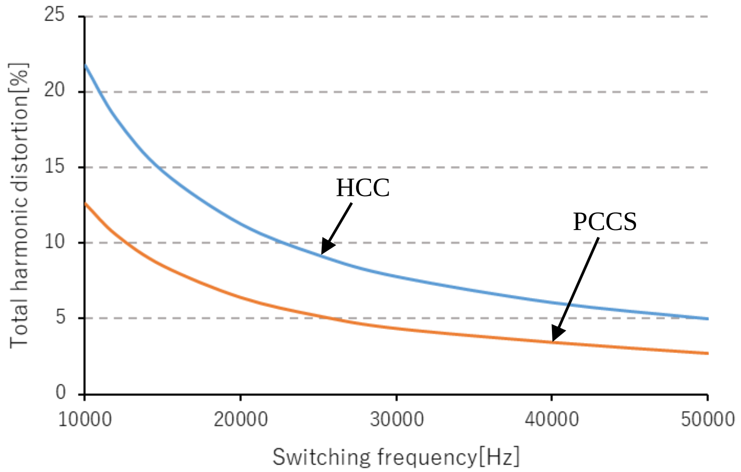


Fig. 9. Total harmonic distortion for PCCS and HCC methods

$$\mathrm{THD} = \frac{\sqrt{{I_2}^2 + {I_3}^2 + {I_4}^2 + {I_5}^2 + \cdots\cdots + {I_n}^2}}{I_1} \times 100[\%] \qquad (7.1)$$

I_1 : RMS value of fundamental current [A]
I_n : RMS value of the nth harmonic current of the grid current I_N [A]

8 Conclusions

This paper proposed the application of the PCCS method in power conditioner for PV Generation System using a half bridge inverter. The proposed half bridge inverter is characterized by its reduced number of components compared to conventional full-bridge inverters. Therefore, we performed a comparative simulation of the PCCS and HCC methods using a half bridge inverter and obtained the following results.

- The grid current I_N formed a sinusoidal waveform, confirming that reverse power flow was occurring.
- The PCCS method generated harmonic components near the switching frequency.

These simulation results show that the PCCS method is effective for half bridge inverters. Comparison of the total harmonic distortion THD shows that the PCCS method always has a distortion ratio about 43% lower than that of the HCC method for switching frequencies between 10 kHz and 50 kHz. This experimental result indicates that the proposed PCCS method suppresses harmonic currents better than the conventional HCC method.
In the future, the transient response of a half bridge inverter to which the PCCS method is applied will be investigated to demonstrate the effectiveness of the proposed method.

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