DC to Single-phase AC grid-connected inverter with Boost Type Active Buffer Circuit Operated in Discontinuous Current Mode

Jun-ichi Itoh*a), Tomokazu Sakuraba, Hoai Nam Le, Keisuke Kusaka

A circuit configuration for a single-phase inverter with a power decoupling capability operated in discontinuous current mode (DCM) is proposed in this paper. The inverter connected to a single-phase grid requires the power decoupling capability to compensate a power ripple with twice the grid frequency. Bulky capacitors are required as a DC-link capacitor in a conventional system. In contrast, the proposed active buffer, which operates without an additional inductor for a buffer circuit, uses ceramic capacitors instead of bulky electrolytic capacitors. In this paper, a control method for the power decoupling circuit operated in DCM is described. In addition, the validity of the proposed circuit is experimentally demonstrated by a 600-W prototype. As the experimental results, the input current ripple at twice the grid frequency is reduced by 96.8%.

Keywords : PV inverter, Power ripple compensation, Discontinuous current mode

1. Introduction

In recent years, single-phase grid connected converters have been studied actively as the power conversion systems (PCSs) for a PV system. Instantaneous power of the single-phase grid oscillates at twice the grid frequency whereas the output power is constant. As a result, a power ripple with twice the grid frequency occurs in the DC-link. In order to absorb this power ripple, bulky electrolytic capacitors are used in the conventional circuits. However, the electrolytic capacitor limits the lifetime of the PCSs.

As an alternative power decoupling method, an active power decoupling, which consists of small capacitors, switching devices and inductors has been proposed [1-2]. The PCS with long lifetime is expected by using film or ceramic capacitors. However, an additional circuit is necessary in order to control the buffer capacitor voltage. In particular, an additional inductor leads to low power density. Moreover, buck type active buffer circuits, whose the buffer capacitor voltage is lower than the DC-link voltage, are proposed [3-4]. In these circuit topologies, since the maximum voltage of the buffer capacitor is limited, the reduction of the buffer capacitance has limitations in order to satisfy the average stored energy of buffer capacitor $CV^2/2$.

This paper proposes a novel circuit topology, which requires no additional inductor for the power decoupling circuit in order to achieve higher power density. The proposed circuit uses discontinuous current mode (DCM) for the power decoupling control. In the proposed circuit, the capacitance of the buffer capacitor can be reduced by using the higher buffer capacitor voltage than DC-link voltage. The validity of the proposed circuit is experimentally demonstrated by a 600-W prototype.

2. Proposed Boost-Type Active-Buffer Circuit Operated in DCM

Fig. 1 shows a DC-AC converter integrating a power decoupling in the DC-DC converter stage. This circuit requires no additional inductor for the power decoupling circuit. When the boost converter operates in the continuous current mode (CCM), the discharge mode for the buffer capacitor cannot be realized because the current direction cannot be changed suddenly in CCM. Thus, in this paper, the charge and discharge modes are achieved by the discontinuous current mode (DCM). In particular, the zero-current period is utilized for the power decoupling operation.

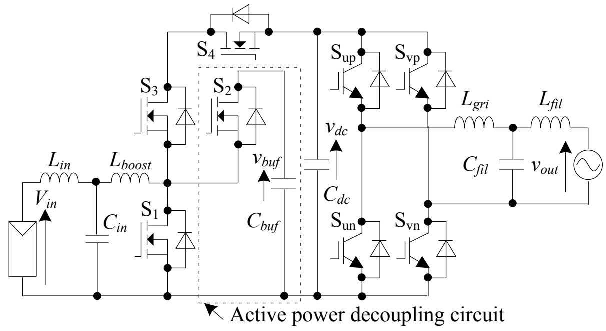


Fig. 1. Active power decoupling circuit operated in DCM.

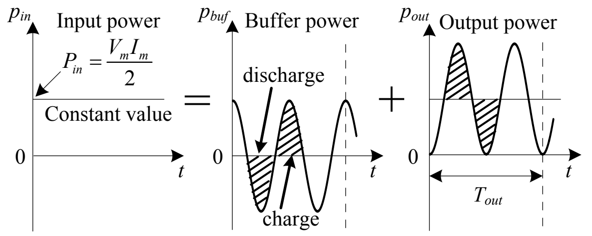


Fig. 2. Single-phase power pulsation compensation.

By using the zero-current period, the DC-link voltage and the buffer voltage are controlled by only one boost inductor.

3. Power decoupling and input control strategy

Fig. 2 shows the relationship among the input power p_{in}, the output power p_{out} and the compensation power p_{buf} in the active buffer. The output instantaneous power is given in (1) when the output current is the sinusoidal wave with unity power factor.

$$p_{out} = \frac{V_m I_m}{2}\left(1 - \cos 2\omega_{out} t\right) \quad \text{(1)},$$

where V_m is the peak voltage of the single-phase grid and ω_{out} is the angular frequency of a grid. From (1), the power ripple, whose frequency is twice the grid frequency, occurs in the DC link. In order to absorb the power ripple, the instantaneous power p_{buf} in the active buffer is controlled according to

$$p_{buf} = \frac{1}{2} V_m I_m \cos 2\omega_{out} t \quad \text{(2)}.$$

Fig. 3 shows the proposed control block diagram in the DC-DC converter stage. The proposed control block consists of the DC-link capacitor voltage, the buffer capacitor voltage and the boost inductor current controls. These current and voltage regulators are employed by PI controllers.

a) Correspondence to: Jun-ichi Itoh. E-mail: itoh@vos.nagaokaut.ac.jp
* Nagaoka University of Technology
1603-1, Kamitomioka-machi, Nagaoka, Niigata, Japan, 940-2188

3.1 DC-link capacitor voltage control In Fig. 3, the voltage command v_{dc}* for the DC-link is set to be higher than the maximum output voltage. Fluctuation of the DC-link voltage causes the increase of the output current THD. Thus, in order to control the constant value of the DC-link voltage, the inverter input current is feedforwarded to the output of a PI controller of the voltage regulator. The average current, which controls the DC-link voltage, is expressed by

$$i_{L\_ave\_dc} = \frac{i_{peak}}{2}(d_1 + d_2) = \frac{P}{V_m}\left[1 - \cos(2\omega_{out})\right] \quad (3),$$

where, P is the rated output power. Thus, the boost inductor current fluctuates at twice the grid frequency when the power decoupling control is not applied.

3.2 Buffer capacitor voltage control In order to absorb the power ripple by the buffer capacitor, the buffer capacitor voltage is controlled to oscillate at twice the grid frequency. However, when the voltage command with twice the grid frequency is input, the rapid response is required for the voltage control. Thus, by adding the inductor current command i^*_{buf} of the power ripple compensation to the output of a PI controller of the voltage regulator, the buffer capacitor voltage is oscillated at twice the grid frequency. When the power ripple is compensated completely by the power decoupling, the average current of the boost inductor is the constant value. Thus, from (3), the inductor current command for the power ripple compensation is given by

$$i^*_{buf} = \frac{P}{v_{buf}}\cos(2\omega_{out}t) \quad (4).$$

4. Experimental verifications

4.1 Operation waveforms Fig. 4(a) presents the operation waveforms without the power decoupling control when a small prototype of 600 W is operated. The boost inductor current oscillates at twice the grid frequency when the power decoupling is not applied. On the other hand, in Fig. 4(b), the buffer capacitor voltage with the power decoupling control is oscillated at twice the grid frequency. As a result, the single-phase power ripple is compensated by the active power decoupling, which is confirmed by the significant ripple reduction in the boost inductor current.

4.2 Evaluation for current ripple Fig. 5 shows the harmonics analysis result of the boost inductor current. When the power decoupling is applied, the second order harmonic component is reduced by 96.8% compared to that without power decoupling. Thus, the compensation of the single-phase power fluctuation is confirmed.

5. Conclusion

This paper proposed a new integrated DC-DC converter which uses discontinuous current mode for the power decoupling capability. The proposed circuit requires no additional inductor for the power decoupling circuit. This contributes to the high power density of the single-phase inverter. The experimental results demonstrate that the current ripple of the boost inductor with twice the output frequency of the inverter is reduced by 96.8% by the power decoupling control.

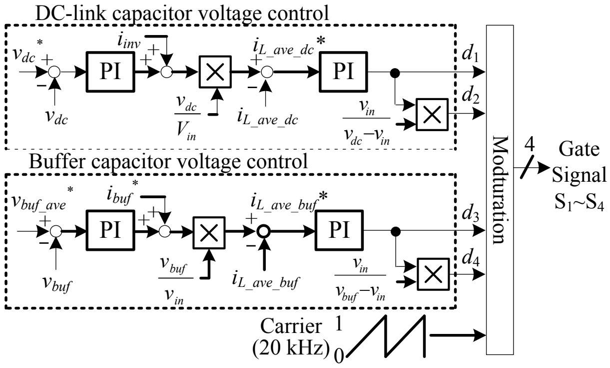
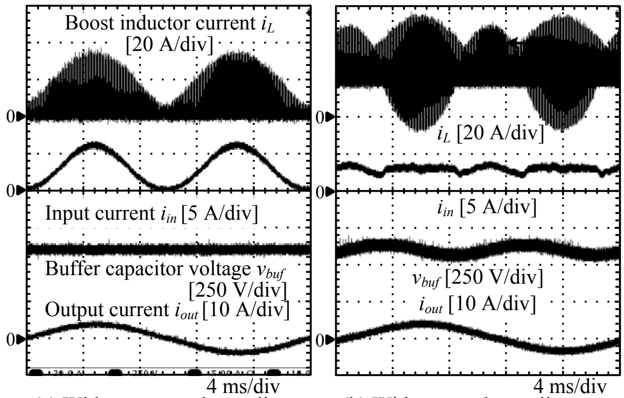


Fig. 3. Control block for DC link voltage and buffer voltage.

Table 1. Circuit parameters of the prototype.

Rated power	P	600 W
Input voltage	V_{in}	150 V
DC-link voltage	v_{dc}	300 V
Buffer average voltage	v_{buf_ave}	400 V
Switching frequency	f_{sw}	20 kHz
Capacitance	C_{buf}	55.6 μF
	C_{dc}	57.2 μF
Inductance	L_{boost}	56.6 μH (Critical condition:87.9 μH)
	L_{gri}	5.3 mH (%Z=2.5%)
Switching device	S_1~S_4	Rohm, SCH2080KE
	S_{up}~S_{wn}	Fuji electric, FGW30N60VD



(a) Without power decoupling (b) With power decoupling

Fig. 4. Experimental waveforms.
(Cutoff frequency of low pass filter:2kHz)

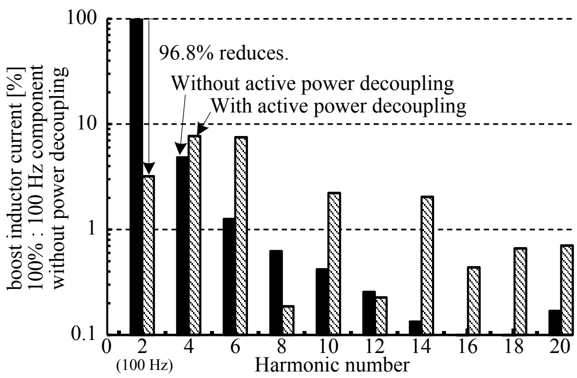


Fig. 5. Harmonics components on the boost inductor current.

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