Distortion-Free CV/CC AC Power Supply Having the Unity Input Power Factor by the Use of Variable Capacitance Devices

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Received: 21.06.2014 Accepted: 19.07.2014

Abstract- A new CV (Constant-Voltage) CC (Constant-Current) ac power regulator is proposed. Our original Variable Capacitance Device of linear reactance device is utilized in the power stage. This device makes almost no distortion. In this circuit, a sinusoidal output voltage and a high efficiency can be obtained. For the purpose of output voltage/current control and input power-factor correction, two Variable Capacitance Devices were adopted. Two dc-dc converters were used for high-speed driver of these devices. The unity input power factor can be obtained all over the constant-voltage region and the constant-current region. Input current of the proposed power supply becomes almost zero at no load and at short-circuit load.

Keywords- Variable Capacitance Device; ac power supply; no distortion; unity input power factor; dc-dc converter

1. Introduction

As constant-voltage ac power supply, ferroresonant circuits [1, 2] are well known. Ferroresonant circuits have advantage of the current limitation against short circuit and the absorption of noise flowing from ac line. However, waveform of output voltage is distorted, because the output voltage is controlled by nonlinear elements, e.g., saturable core or magnetic-saturation simulation circuit [3]. Therefore, an additional filter is needed for suppression of higher-harmonic voltages.

So, we proposed an entirely new type of ac voltage regulator [4]. This circuit makes no distortion of output voltage waveform, because only linear reactance devices are utilized in the power stage. To control output voltage, it is needed that inductance or capacitance can be varied. The inductance should be fixed so that the maximum load current may be limited at overloading. Here, our original Variable Capacitance Device [5] was employed as linear capacitor. A low-power boost-type switched-mode PWM (Pulse Width Modulation) dc-to-dc converter was used as high-speed low-output-impedance driver of this device. It is a remarkable advantage that this converter delivers almost no power in the steady state.

An additional Variable Capacitance Device made input power-factor correction possible except for light load [6]. Though the circuit proposed in [4] has an ability of overload protection, constant-current characteristics cannot be realized. So, we introduced a circuital technique to control the characteristics of load current limitation [7]. Moreover, power factor correction in the constant-current region was made possible [8].

In this paper, an advanced distortion-free constant-voltage constant-current ac power supply is proposed. This power supply is capable of perfect correction on input power factor. In addition, the input power factor correction circuit brings remarkable feature. The input current becomes almost zero at no load as well as at short-circuit load.

2. Power Stage

Fig. 1 shows a basic circuit of power stage in the proposed power supply. In this figure, V_i, I_i, I_o and V_o represent the input voltage, the input current, the output current and the output voltage, respectively. The power stage of distortion-free constant-voltage constant-current ac power supply is arranged by a distortion-free ac power supply and a power-factor correction circuit.

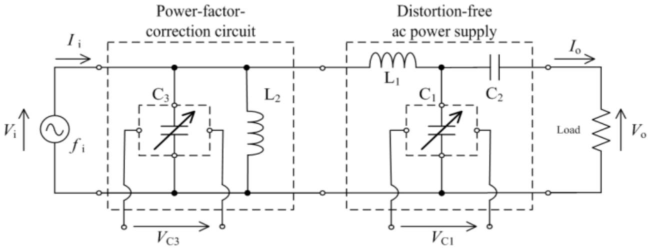
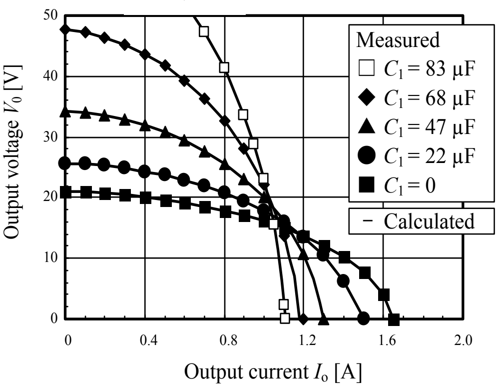


Figure 1. Power stage of the proposed distortion-free constant-voltage constant-current ac power supply using Variable Capacitance Devices.

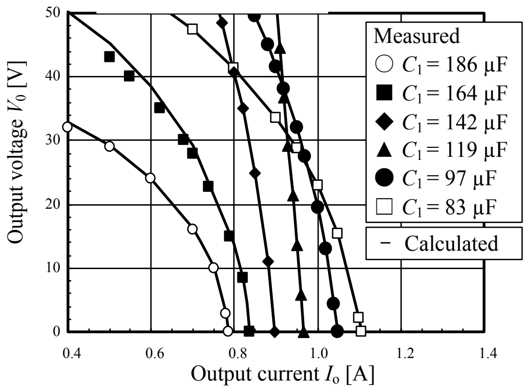
3. Distortion-Free AC Power Supply

Distortion-free ac power supply is constructed by the use of the inductor L_1, the capacitors C_1 and C_2. Here, the capacitance C_1 is variable. The load is assumed to be resistive. Characteristics of the distortion-free ac power supply are shown in Fig. 2 and Fig. 3. Fig. 2 is an example of output characteristics and Fig. 3 is that of input-output characteristics. For simplicity, measured values were obtained by using film capacitors as C_1. Equations for calculation have been given in [7]. The inductance of L_1, the loss resistance of L_1, the capacitance of C_2, and the operation frequency are L_1 = 58 mH, r_1 = 0.6 Ω, C_2 = 290 μF, and f_i = 60 Hz, respectively.

When I_o = 0 (no load) and C_1 = 0, it is obvious from Fig. 1 that the output voltage V_o is equal to the input voltage V_i. Output characteristics depend on the input voltage. For example, the output voltage at no load or the output current at short-circuit load is proportional to the input voltage.

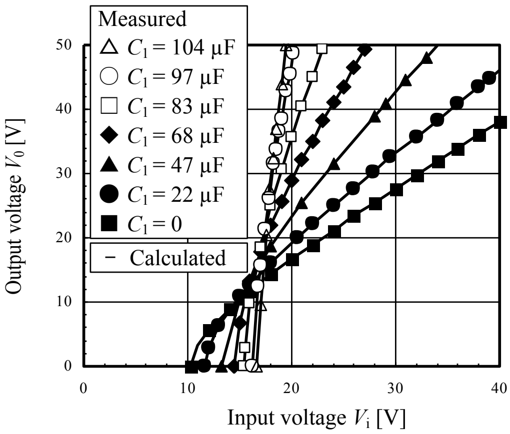


(a) $0 \leqq C_1 \leqq 83$ μF.

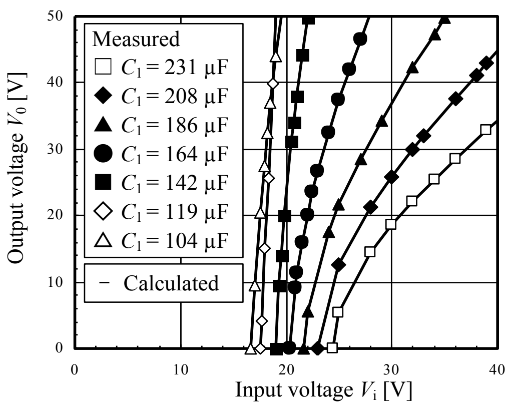


(b) $C_1 \geqq 83$ μF.

Figure 2. Output (V_o vs. I_o) characteristics of the distortion-free ac power supply, where V_i = 21 V.



(a) $0 \leqq C_1 \leqq 104$ μF.



(b) $C_1 \geqq 104$ μF.

Figure 3. Input-output (V_o vs. V_i) characteristics of the distortion-free ac power supply, where I_o = 0.81 A.

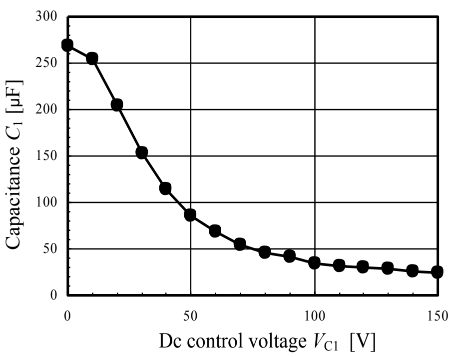
Therefore, when the input voltage V_i is selected to suitable value, we can see from Fig. 2(a) that a boost-type constant-voltage ac power supply can be constructed by the control of C_1. By utilizing the characteristics shown in Fig. 2(b), we can realize a constant-current ac power supply. Fig. 3 and other characteristics teach us the information on allowable value of V_i.

4. Power-Factor Correction Circuit

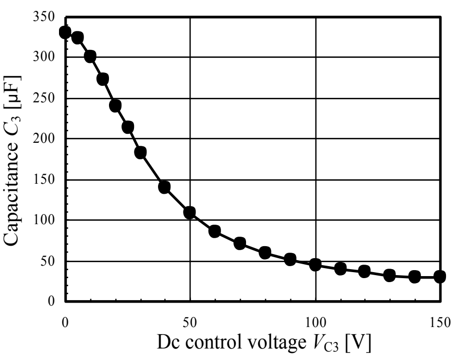
In Fig. 1, the capacitor C_3 and the inductor L_2 make an input-power-factor correction circuit. Here, the capacitance C_3 is variable. Input power factor of the distortion-free ac power supply is leading when the load is light at the constant-voltage region. Therefore, it is supposed that L_2 can make power-factor correction perfect. The inductance of L_2 and the loss resistance of L_2 are L_2 = 35 mH and r_2 = 0.2 Ω, respectively. These conditions are common through this paper. Experimental results will be presented in Chapter 8.

5. Variable Capacitance Device

As a passive device capable of varying its capacitance, variable capacitance diode is well-known. However, operating current is up to about 10 μA, because this device is a reverse-biased p-n junction diode. So, we proposed the Variable Capacitance Device for the purpose of dealing with a certain degree of power. Multilayered ceramic capacitors made of ferroelectric vary their capacitance with the dc bias voltage. The Variable Capacitance Device can be realized by utilizing these characteristics. Since well-balanced four capacitors are bridge-connected, ac leakage current flowing from the control voltage terminals is extremely small. Employment of low-output-impedance driver makes high-speed operation possible. The circuit symbol of the four-terminal Variable Capacitance Device is shown in Fig. 1.



(a) C_1.



(b) C_3.

Figure 4. Control characteristics of the Variable Capacitance Devices C_1 and C_3.

Measured characteristics of the capacitances C_1 and C_3 are presented at Fig. 4, where V_{C1} and V_{C3} are the dc control voltages.

6. Control Circuit

An example of the block diagram of the feedback control circuit is shown in Fig. 5. One control path from V_o and I_o to V_{C1} was introduced to keep the output voltage or the output current constant. Next, the other control path from V_i and I_i to V_{C3} was introduced to maintain the unity input power factor.

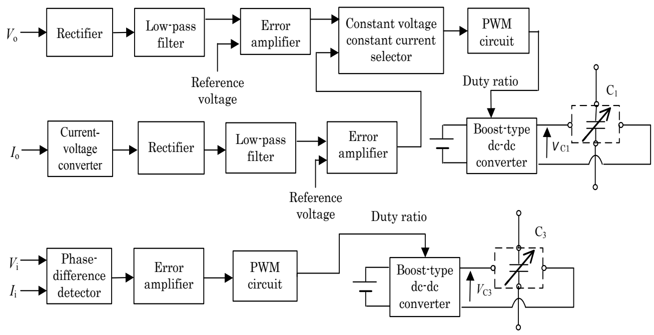


Figure 5. Control circuit of the proposed distortion-free constant-voltage constant-current ac power supply using Variable Capacitance Devices.

7. Control Circuit Distortion-Free Constant-Voltage Constant-Current AC Power Supply Having The Unity Input Power Factor

Fig. 6 presents the output (V_o vs. I_o) characteristics of the constant-voltage constant-current ac power supply. Here, the points “N,” “F,” and “S” mean “No load,” “Full load,” and “Short-circuit load,” respectively. Next, Fig. 7 is an example of the input-output (V_o vs. V_i) characteristics in the constant-voltage region. The minimum value of C_1 was limited to 22 μF by the control circuit.

8. Input Power Factor and Input Current

Observed characteristics of input power factor cosθ and input current I_i vs. output current I_o at the constant voltage region are shown in Fig. 8(a). With respect to the constant current region, experimental results of cosθ and I_i vs. output voltage V_o characteristics are shown in Fig. 8(b). It is seen that input power factor is perfectly corrected.

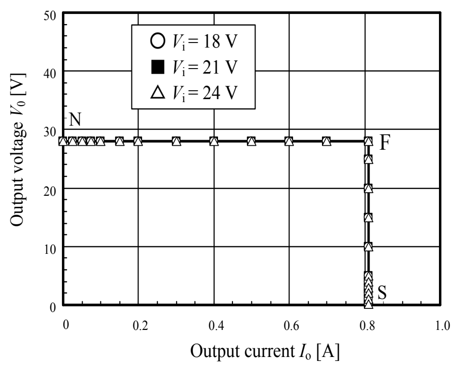


Figure 6. Measured output (V_o vs. I_o) characteristics of the distortion-free constant-voltage constant-current ac power supply.

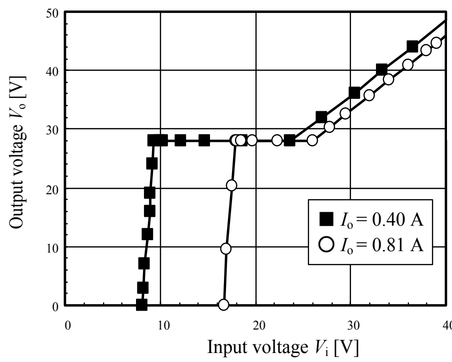
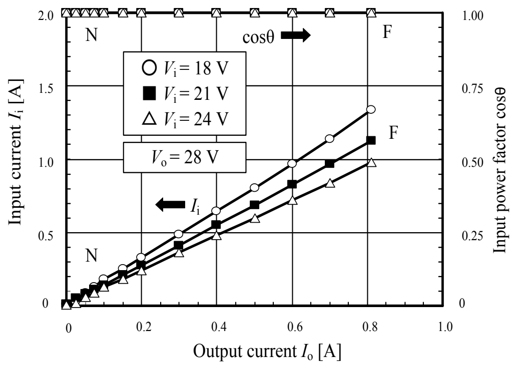
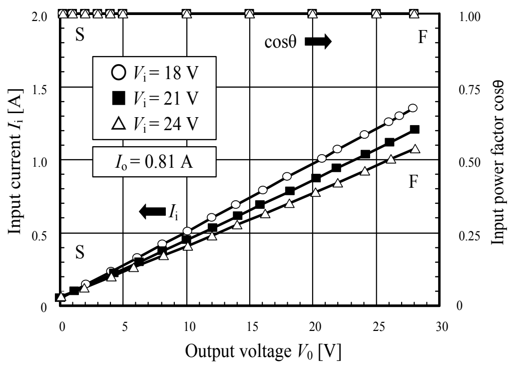


Figure 7. Measured input-output (V_o vs. V_i) characteristics of the distortion-free constant-voltage constant-current ac power supply.



(a) Constant-voltage region.



(b) Constant-current region.

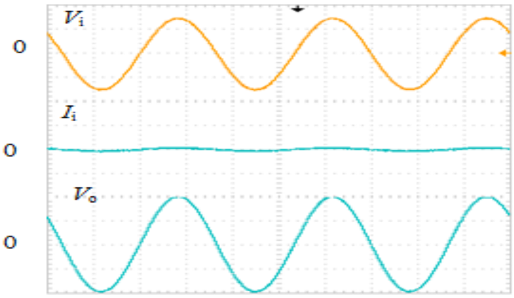
Figure 8. Measured characteristics of the input power factor cosθ and the input current I_i.

In addition, the power factor correction circuit makes the input current much smaller. Especially, the input current I_i becomes almost zero when the load is short circuited and open circuited.

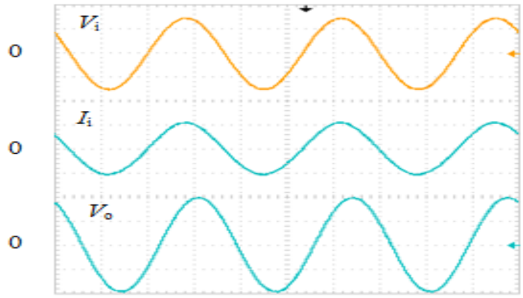
9. Waveforms

Fig. 9 and Fig. 10 show waveforms of the input voltage V_i, the input current I_i, and the output voltage V_o in the constant-voltage region. On the other hand, Fig. 11 and Fig. 12 are waveforms of V_i, I_i, and the output current I_o in the constant-current region. In Fig. 9 and Fig. 11, V_i was amplified sinusoidal voltage. The commercial ac voltage in our laboratory was used as V_i in Fig. 10 and Fig. 12.

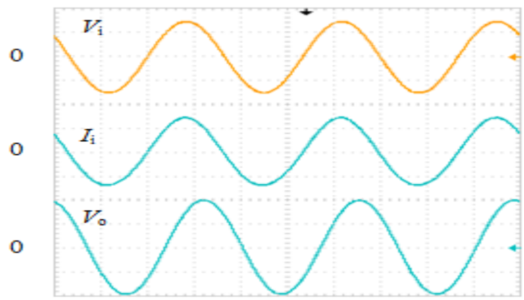
It is seen from Fig. 9 and Fig. 11 that the proposed power supply makes almost no distortion. Even if input voltage is distorted as Fig. 10 and Fig. 12, waveforms of output voltage or current become almost sinusoidal. In these figures, V_i is in phase with I_i.



(a) I_o = 0 (no load).

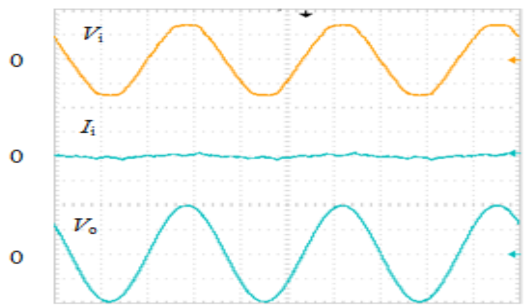


(b) I_o = 0.61 A.

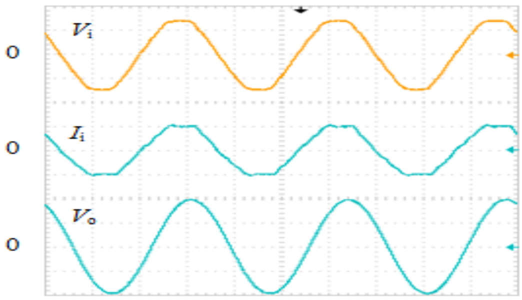


(c) I_o = 0.81 A (full load).

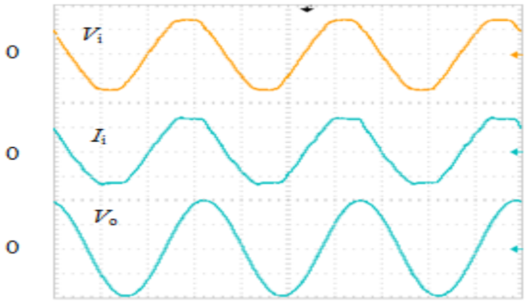
Figure 9. Observed waveforms of amplified sinusoidal input voltage V_i, I_i, and V_o in the constant-voltage region (V_o = 28 V), where V_i = 21 V; vertical: 20 V/div for V_i and V_o, 1 A/div for I_i, horizontal: 5 ms/div.



(a) I_o = 0 (no load).

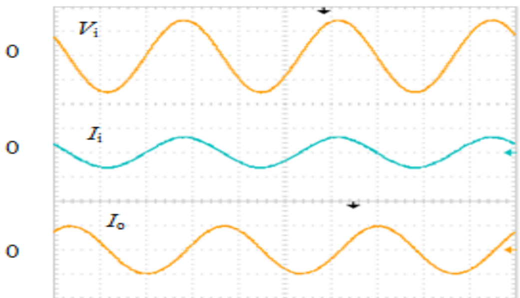


(b) I_o = 0.61 A.

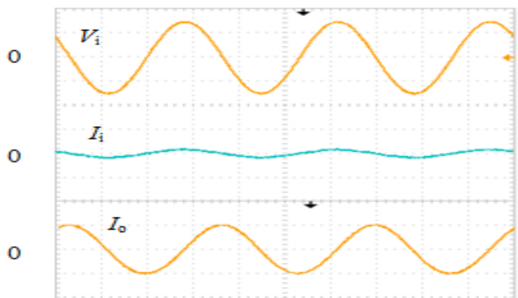


(c) I_o = 0.81 A (full load).

Figure 10. Observed waveforms of commercial ac input voltage V_i, I_i, and V_o in the constant-voltage region (V_o = 28 V), where V_i = 21 V; vertical: 20 V/div for V_i and V_o, 1 A/div for I_i, horizontal: 5 ms/div.

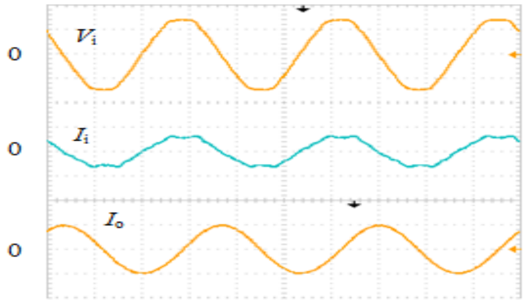


(a) V_o = 10 V.

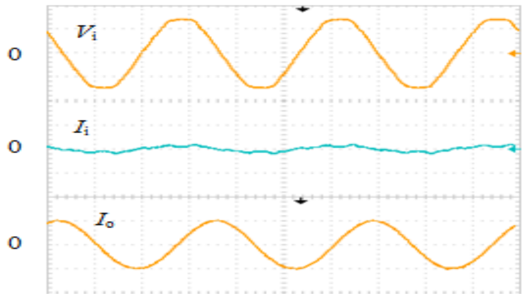


(b) V_o = 0 (short-circuit load).

Figure 11. Observed waveforms of amplified sinusoidal input voltage V_i, I_i, and I_o in the constant-current region (I_o = 0.81 A), where V_i = 21 V; vertical: 20 V/div for V_i, 1 A/div for I_i and I_o, horizontal: 5 ms/div.



(a) V_o = 10 V.



(b) V_o = 0 (short-circuit load).

Figure 12. Observed waveforms of commercial ac input voltage V_i, I_i, and I_o in the constant-current region (I_o = 0.81 A), where V_i = 21 V; vertical: 20 V/div for V_i, 1 A/div for I_i and I_o, horizontal: 5 ms/div.

10. Conclusion

The proposed circuit can realize a power-factor-corrected constant-voltage constant-current ac power supply. It has the following features. (1) The unity input power factor is obtained all over the constant-voltage region and the constant-current region. (2) The input current is nearly zero at short-circuit load. (3) The input current is nearly zero at open-circuit load. (4) Waveform of output becomes almost sinusoidal against distorted input voltage.

Two inductors L_1 and L_2 can be assembled into one transformer. By introducing a transformer, voltage compensation against boost-type characteristics is simultaneously solved including isolation.

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