

A Study on EMI Noise Reduction in Boost-Type PFC Circuit

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Abstract. In this paper, we describe an improvement method of the Electro-Magnetic Interference (EMI) noise reduction for the Power Factor Correction (PFC) converter, which converts AC voltage of the power line to high DC voltage for the load circuit. There we propose EMI noise reduction with a spread spectrum technique and suppression of the freewheel diode recovery current using the Schottky Barrier Diode of SiC. Thanks to these suppressions, the operating clock frequency can be as high as 500kHz, which enables to use very small inductors and capacitors in the PFC.

1. Introduction

Commercial power supply circuits used in homes and factories provide AC voltage with high efficiency. Also consumer electronics appliances use DC voltage. The AC-DC converter connects commercial power circuit to consumer electronics appliances. Using capacitor input type power supply devices in AC-DC converter is efficient due to its simple circuit configuration. However, it has a problem of high-order harmonics generation due to input current waveform distortion, which may violate an international regulation of the EMI noise generation with high order harmonics.

A PFC circuit can alleviate this problem: it shapes the input voltage waveform to a sine wave and decreases high-order harmonics. Switching circuit has a problem of generating EMI noise generation, especially for high power and high frequency operation. Circuits around the switching circuit are affected by this EMI noise and may cause their malfunction. This is one of the problems of PFC power supply.

In this paper, its solutions are proposed: EMI noise reduction with spread spectrum and suppression of recovery currents generated in the diodes by using SiC-SBDs. We have published EMI reduction of the step-down DC-DC converter [3]. In this paper, we apply this technique to the PFC power supply. Their circuit operation was verified using the power circuit simulator SIMPLIS.

2. Conventional Power Factor Correction (PFC) Power Supply

2.1 Boost type PFC power supply

Figure 1 shows a boost-type PFC power supply. The input waves are changed to the rectifier waves through the diode bridge rectifier circuit. Thereafter, the rectified voltage (V_x) propagates to the output resistor R_o and the capacitor C when switches are off. Since the electric charge is stored in the capacitor C , the output voltage is almost constant. The current flows from the inductor to the MOS transistor during switching on. At this time, the inductor accumulates electromagnetic energy by the current and it can be supplied to the output side during switching off; the boost circuit operates in this manner. The

output voltage amplification ratio is determined by the ratio of the switching on-time (T_{on}) and off-time (T_{off}) as shown in Eq. (1):

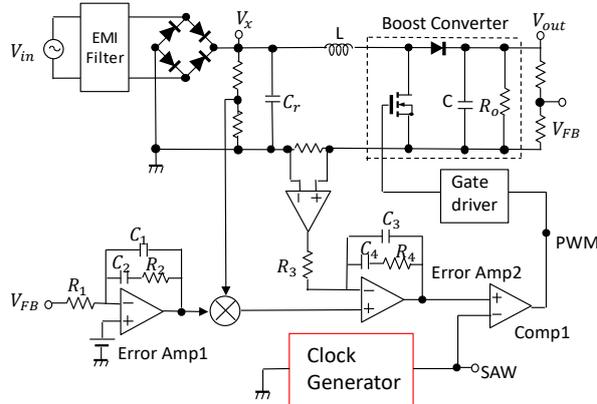


Table 1. Parameters in proposal circuit.

Parameter	Simulation Value
V_{in}	AC150 V@50 Hz
V_o	400 V
I_o	768 mA
L	2.2 mH
C	330 μ F
f_{clk}	100 kHz

Fig. 1. Boost-type PFC power supply

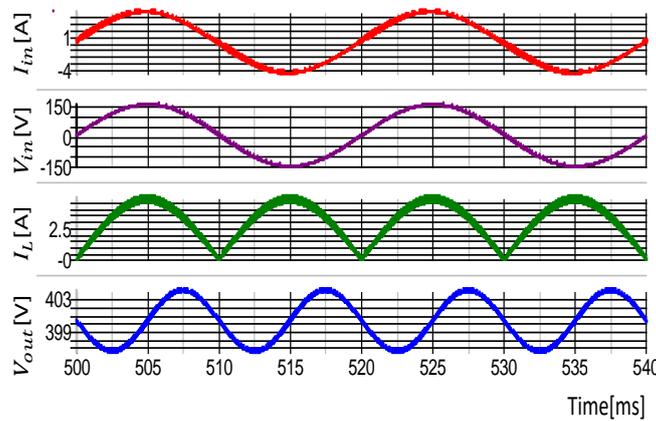


Fig. 2. Waveforms without frequency modulation

$$\frac{V_{out}}{V_{in}} = \frac{T_{on} + T_{off}}{T_{off}} > 1 \quad (1)$$

The feedback voltage (V_{FB}) which is proportional to the output voltage (V_o) is compared with the reference voltage (V_{ref}) and its output is amplified. Then the amplified output is multiplied by the rectified sine wave (V_x) and further the output is compared with the inductor current I_L , and then its output is compared with the sawtooth wave (SAW). This generated signal is used as a switching signal for PWM (Pulse Width Modulation).

It is desirable that the input current (I_{in}) is the same shape as the input voltage (V_{in}); this is well-known in case of the resistive loading. On the other hand, when their shapes are different, there is an energy loss for motor drive and capacitor input type circuit. This can be explained quantitatively by the power factor defined in Eq. (2).

$$PFC = \frac{\text{Effective power}}{\text{Apparent power}} = \frac{\int (\dot{V} * i) dt}{\bar{V} * \bar{I}} \quad (2)$$

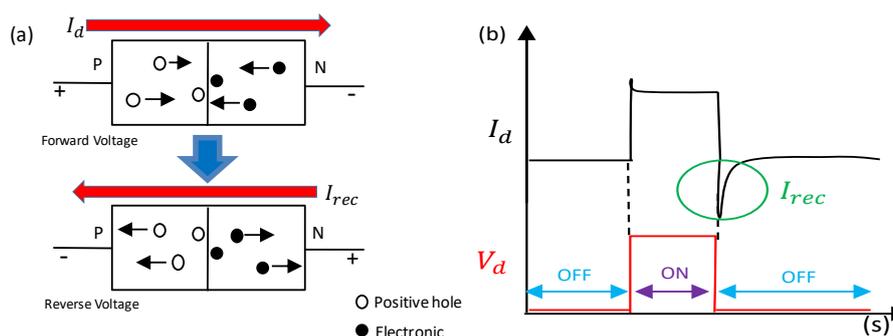


Fig. 3 Recovery current characteristics of a diode
(a) Explanation of recovery current. (b) Current waveform

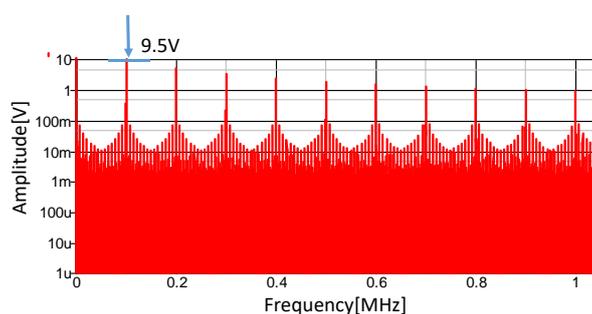


Fig. 4. Spectrum of PWM signal without modulation.

Using the PFC power supply, this problem can be solved; their shapes are brought closer to sine waves with the same phase as shown in Fig. 2. Table 1 shows the circuit parameters for the simulation. The shape of the inductor current (I_L) is formed by the wave generated by a full-wave rectifier of the diode bridge circuit. The output voltage has large ripple by 1% of the full scale of output voltage (4V) as shown in Fig. 2; however, this is not a big problem when the PFC power supply is directly used for motor driving or the DC-DC power supply is connected to the next stage.

2.2 Problems of conventional PFC power supply

Currently there are two problems in the PFC power supply.

(1) Recovery current of diodes

This issue becomes serious as the clock frequency is increased. The benefits of the high frequency clock usage are high-speed transient response and small circuit size using small inductors and capacitors in the power supply circuit. On the other hand, the frequency of the recovery current generated in the diode increases, which degrades the efficiency. Figure 3 explains the recovery current in the diode. When the current switch is changed from on to off state in the diode, there are some carriers which do not conduct; this causes reverse current, or recovery current flow for moving back to the appropriate electric potential. Then the higher the clock frequency is, the larger the loss is.

(2) EMI noise generation

Most consumer electronics appliances use a fixed frequency clock, which causes an EMI noise generation problem. Figure 4 shows the output spectrum of the conventional boost type PFC, where the spectrum levels at 100 kHz is 9.5 V which is very high.

3. EMI reduction of proposed PFC power supply

3.1 Clock modulation PWM control method

We employ here the frequency modulation for a fixed clock in boost type PFC power supply for EMI reduction. The frequency modulation circuit is added to the clock signal generator in Fig. 1, as shown in Fig. 5, which realizes a linear frequency modulation using Voltage Controlled Oscillator (VCO). There the frequency modulation (Δf) proportional to the magnitude of the input voltage is provided. The frequency modulation is realized by the sum of the clock frequency (f_0) and the modulation frequency (Δf) as shown in Eq (3). The VCO input voltage utilizes the frequency modulation as Eq (4) and performs linear modulation.

$$f = f_0 + \Delta f \quad (3)$$

$$f(t) = k|V_{DC} + V_m(t)| \quad (\because k = 100\text{kHz/V}) \quad (4)$$

A schematic diagram using the triangular wave signal is shown in Fig. 5(b). The signal repeats the frequency increase and decrease in a back and forth manner centering on f_0 .

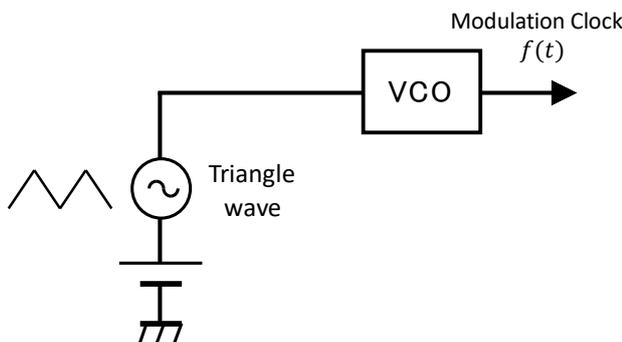


Fig. 5(a) Clock generator with modulation

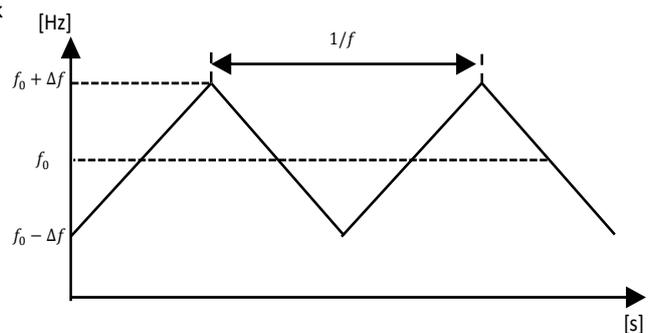


Fig. 5(b) Waveform of clock modulation.

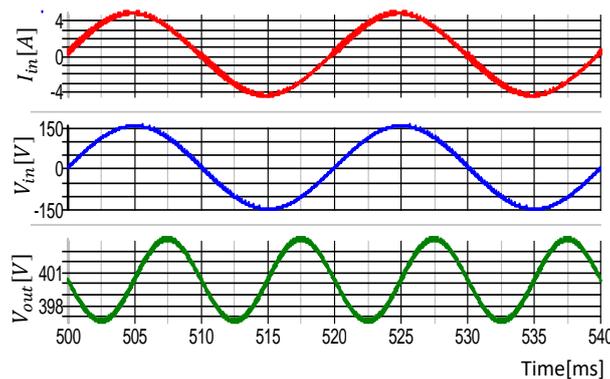


Fig. 6. Waveform with frequency modulation.

3.2 Simulation results

Figure 6 shows the waveforms using frequency modulation whose frequency was set to $f = 100 \text{ kHz} \pm 1 \text{ kHz}$. The output voltage has ripple under 1% for the full scale. Figure 7 shows the spectrum of PWM signal, and we see that the spectrum level at 100kHz point is lower by 9.7dB and other harmonics

are lower using frequency modulation; the frequency modulation technique in the boost-type PFC power supply is effective for EMI reduction.

The modulation frequency was set to $f = 100 \text{ kHz} \pm 0.5 \text{ kHz}$ in Fig. 7 (b).

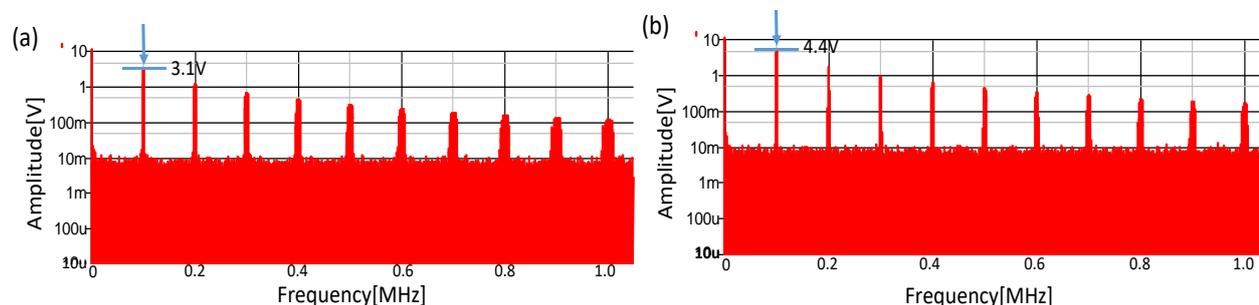


Fig. 7. Spectrum of PWM signal in frequency modulation;
(a) $\Delta f = \pm 1 \text{ kHz}$, (b) $\Delta f = \pm 0.5 \text{ kHz}$

The harmonics level becomes different when the modulation frequency is changed. The harmonic at 100kHz using frequency modulation to $\Delta f = \pm 0.5 \text{ kHz}$ is lower than that in the case of $\Delta f = 0 \text{ kHz}$ by 6dB, and higher than that in the case of $\Delta f = \pm 1.0 \text{ kHz}$ by 2dB. The harmonics energy is considered to be widely spread around the center frequency with the higher modulation.

The time-domain waveforms were checked and we see that the output voltage ripple increases only slightly, and the waveforms of the input and inductor currents have little distortion; harmonics in our PFC power supply is reduced. Next, the base clock frequency was changed from 100 kHz to 200 kHz, which allows to use a small inductor as shown in Table 2. Figure 8 shows the output voltage waveform at $f = 200 \text{ kHz} \pm 1.0 \text{ kHz}$, and we see that the output voltage does not have distinct noise.

4. Diode recovery current reduction

We consider that Schottky barrier diode (SBD) is suitable for the high-speed operation in the boost-type PFC circuit and the recovery current reduction in freewheel diodes. SBD has a short transient response time and is suitable for loss reduction due to recovery current. However, conventional Si SBD has the breakdown voltage of about 200V, whereas the PFC power supply demands about 400V breakdown voltage.

Recently, silicon carbide (SiC), a compound semiconductor of silicon (Si) and carbon (C). becomes popular, which has the band gap voltage of several times higher than Si. We consider that this is suitable for high frequency operation, high breakdown voltage and low on-resistance. The breakdown voltage is increased to about 600V for SiC-SBD.

The recovery current simulation results for conventional PN diode and SiC-SBD are shown in Fig. 9, where the switching frequency is 500kHz. We see that in the case of PN diode (Fig. 9 (a)), the peak value of the recovery current is -40 A, whereas in the case of SiC-SBD (Fig. 9 (b)), it is -16A. From this result, the peak value using SiC-SBD is less than half using PN diode. Also, loss comparison with PN diode and SiC-SBD was obtained with simulations; the loss peak value for PN diode is 208W while that of SiC-SBD is about 100W. Loss is reduced by using SiC-SBD by 40% of the PN diode usage case, which improves efficiency substantially when the switching frequency increases.

Table2. Parameter values in the proposed circuit.

Parameter	Simulation Value
L	1.0 mH
C	330 μ F
f_{clk}	200 kHz

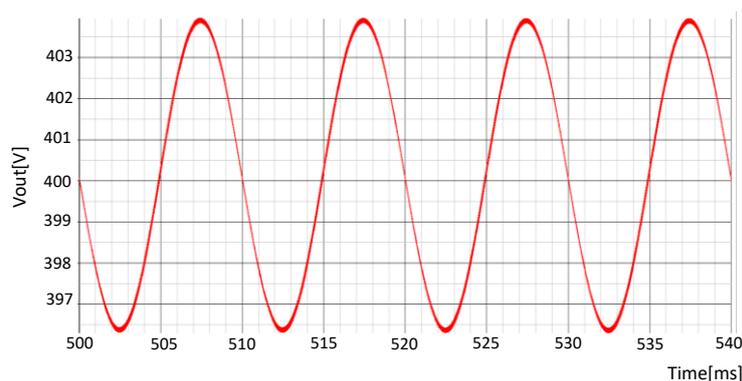


Fig. 8. The waveform of output voltage ($\Delta f = \pm 1$ kHz)

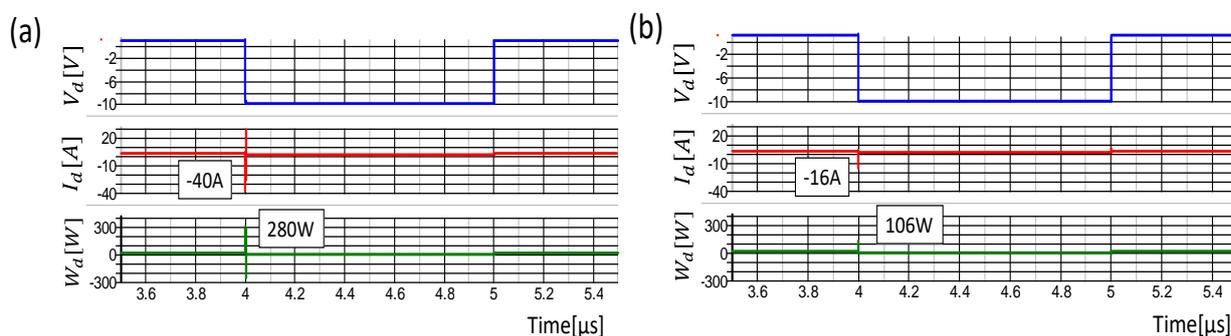


Fig. 9. Waveform of voltage and current in diode
(a) with PN Junction Diode, (b) with SiC-SBD

5. Conclusion

We have proposed an EMI reduction technique using spread spectrum and diode recovery current reduction using SiC SBD in the boost-type PFC power supply, and these were verified with circuit simulations. We have found that the frequency modulation for spread spectrum clock is suitable for EMI reduction and the output spectrum level reduces by 9.7dB using modulation frequency ± 1 kHz. Also our simulation results show that the higher modulation frequency is, the lower EMI spectrum levels are. We have also found that the diode recovery current can be substantially reduced by using SiC-SBD compared to using PN diodes; this is important for maintaining high efficiency with high-frequency clock operation.

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