# The Improvement Effect of Input Current Waveform of Two New Main Switching Boost Rectifiers

Sung-Hyun Ha · Chang-Il Kim · Soo-Wook Kim · Jing-Rak Nam · Sang-Pil Mun*

## Abstract

This paper proposes a new sinusoidal rectifier which improves input factor and input current waveform without complicated switching modulation such as pulse width or a complicated feed back control. The proposed rectifier consists of a pair of capacitors connected in series, a full bridge diode rectifier, a pair of inductors, and a pair of switching devices connected in series. While the configuration of the sinusoidal rectifier is simple in itself, it effectively reduces the reactive power and harmonics involved (IEC555-2 SC77A90 Class C) in input line current. The excellent properties of the new sinusoidal rectifier are verified by theoretical analysis and experimental results.

Key Words : Input current waveform improvement, Sinusoidal rectifier, Control of distortion factor

## 1. Introduction

The capacitor input rectifier, which is used widely in home appliances contains too great an amount of high frequency in the input current and has poor power issues, which in turn have caused problems[1-5].

To resolve these issues, many studies have been conducted on the waveform correction circuit of the input current. For an effective improvement of input current waveform, either a feedback loop with current detection or a complicated control method is used, in general. However, this conventional method is complex and complicated [6-10].

This study aims to increase the improvement of the input current by adding elements to the conventional capacitor input rectifier or proposing a new two main switching boost rectifier that does not use complicated control methods such as PWM. This study will clearly demonstrate the relationship between boosting the ratio of the suggested circuit and the distortion factor of input current as well as the interpretation of high frequency in the input current. In this paper, problems such as a decrease in waveform improvement by the reduction of low-order harmonics in the input current when the duty ratio is operated at a certain level or by a low boosting ratio are detected and partial solutions are suggested. Furthermore, a comparative analysis

* Main author : Department of Electrical Engineering, Kyungnam University, KOREA
Tel : +82-55-249-2835, Fax : +82-55-249-2839
E-mail : mun2630@kyungnam.ac.kr
Date of submit : 2007. 10. 26
First assessment : 2007. 11. 9
Completion of assessment : 2007. 12. 11

was conducted after the application of the circuit to a conventional two-main switching boost rectifier using dual technology in the proposed two-main switching boost rectifier and general chopper circuit in order to find out an influence of the relation between boosting ratio and duty ratio on harmonics. The function and practical efficiency of the suggested circuit was then investigated.

## 2. Suggested two-main switching boost type

### 2.1 Circuit configuration and operating principle

Fig. 1 below demonstrates a conventional two-main switching boost rectifier. The conventional circuit is a dualized one-main switching boost type chopper circuit, consisting of two reactors ($L_1$, $L_2$), two switch elements ($S_1$, $S_2$), and two freewheeling diodes ($D_{F1}$, $D_{F2}$) to prevent reverse current. The switch elements use IGBT (FMG 2G50US60) and turn ON and OFF repeatedly[8-14].

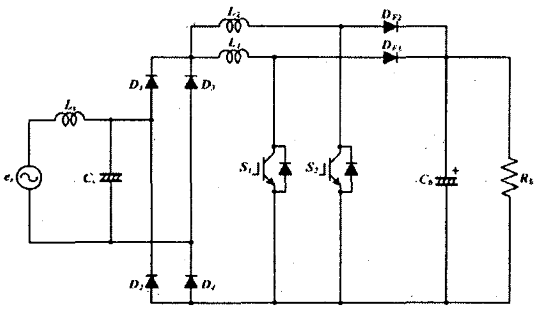


Fig. 1. Configuration of conventional two-main switching boost type rectifier

Fig. 2 shows the operating mode of a conventional circuit during a single switching cycle. The conventional rectifier repeats four (4) switching patterns during a positive half cycle of input current. Modes can be analyzed as follows:

○ Mode 1

As shown in Fig 2 (a) below, in Mode 1, if Switch $S_1$ turns on, the input current flow is 'lossless Capacitor $C_s$ → Diode $D_1$ → Reactor $L_1$→ $S_1$.' Energy is then stored in Reactor $L_1$.

○ Mode 2

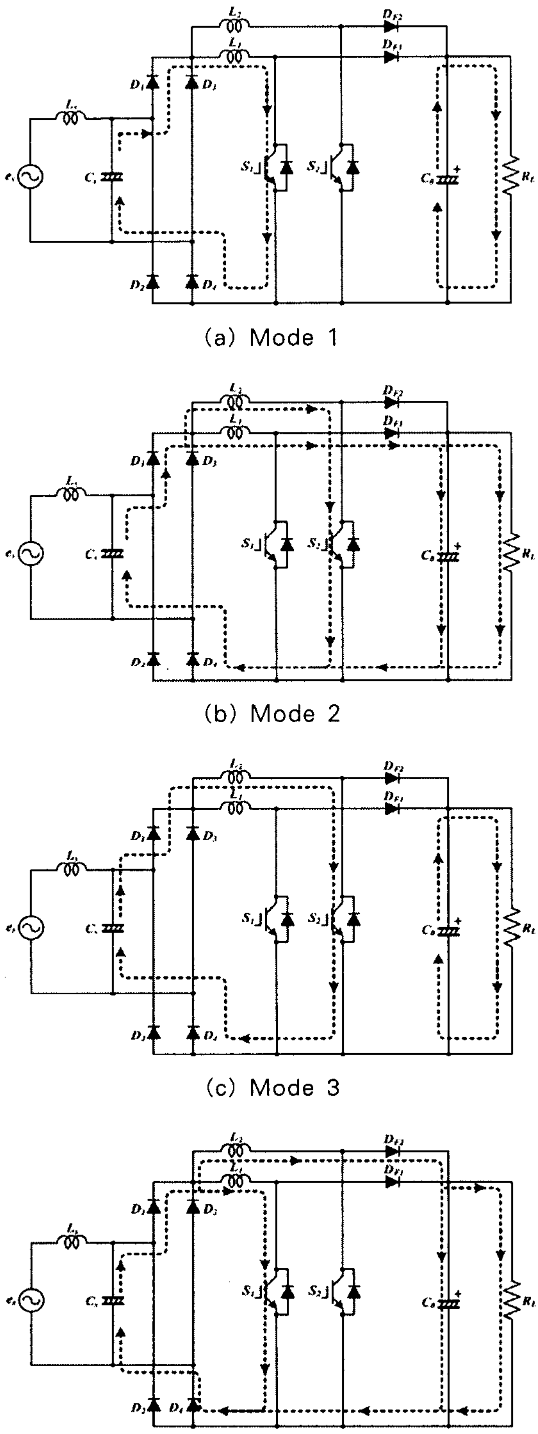
As shown in Fig 2 (b) below, in Mode 2, if Switch $S_1$ turns off, Switch $S_2$ turns on at the same time. The energy stored in Reactor $L_1$ is then released to smoothing Capacitor $C_0$ and load and the current flow is 'Capacitor $C_s$ → Diode $D_1$ → Reactor $L_1$→ $S_1$.' The energy is then stored in Reactor $L_2$. In Mode 2, therefore, when the energy stored in Reactor $L_1$ is released, it is also stored in Reactor $L_2$ at the same time.

○ Mode 3

In Mode 3, the energy stored in Reactor $L_1$ by Mode 2 is released. The energy is then stored in Reactor $L_2$ as shown in Fig. 2 (c) below.

○ Mode 4

In Mode 4, if Switch $S_2$ turns off, energy is released to smoothing Capacitor $C_0$ and load as shown in Fig. 2 (d). Then, the current flow is the same as that of Mode 1 and energy is stored in Reactor $L_1$. In Mode 4, therefore, when the energy stored in Reactor $L_2$ is released, it is also stored in Reactor $L_1$ at the same time. If the energy stored in Reactor $L_2$ is completely released, Mode 4 is ended and a mode in which the input current is a negative half cycle begins. While input current is in a negative half cycle, the rectifier diodes $D_2$ and $D_3$ turn on, on behalf of $D_1$ and $D_4$, respectively. Other rectifier operations are the same as Mode 1 thru Mode 4 described above.



(a) Mode 1

(b) Mode 2

(c) Mode 3

(d) Mode 4

**Fig. 2. Mode analysis of conventional circuit**

If it is assumed that the switching frequency is far higher than input frequency and input current is constant during the switching cycle, the current $i_{L1}$ of Reactor $L_1$ shall have the waveform as shown in Fig. 3 with Equation (1). Equation (2) states the maximum value $I_m$ of the current $i_{L1}$ in Reactor $L_1$. The Time $T_2$ taken for the energy stored in Reactor $L_1$ to reach '0' from the maximum value is stated in Equation (3). Here, Equation (3) is an equation with a substitution of $T_1+T_2$ to 0 and t in $i_{L1}$ by the 2nd equation of Equation (1).

$$i_{L_1} = \begin{cases} \frac{e_s}{X_{L_1}} t & (0 < t < T_1) \\ I_m - \frac{1}{X_{L_1}}(E_d - e_s)(t - T_1) & (T_1 < t < T_1 + T_2) \\ 0 & (T_1 + T_2 < t < T_{sw}) \end{cases} \tag{1}$$

$$I_m = \frac{e_s}{X_{L_1}} d_1 T_{sw} \tag{2}$$

$$T_2 = \frac{e_s}{(E_d - e_s)} d_1 T_{sw} \tag{3}$$

Here,

$i_{L1}$ : Reactor $L_1$

$I_m$ : Maximum value

$i_{L1}$ : Current

$e_s$ $E_s\sin(\omega t)$ $E_d$ : Input current (=), DC output voltage

$X_{L_1}$ $L_1$ : Reactor inductance

$T_1$ : Turn-on time of Switch $S_1$

$T_2$ $i_{L1}$ : Time taken to reach '0' from the maximum value

$T_{sw}$ $d_1$ $T_1$ $T_{sw}$ : Switching cycle, duty ratio (=/)

If the inductance value of $T_{sw}$ $i_{S_1}$ $e_s \geq 0$ in Reactor $L_1$ and $L_2$ is the same as L, the mean value of the input current on the switching cycle shall be expressed as Equation (4).

$$\left.\begin{aligned} i_{s_1} &= \frac{e_s}{L} d_1^2 T_{sw}\left(\frac{E_d}{E_d - e_s}\right) \\ &= \frac{e_s}{L} d_1^2 T_{sw}\left(\frac{E_d}{1 - e_s/E_d}\right) \\ &= \frac{e_s}{L} d_1^2 T_{sw}\left(1 + \frac{e_s}{E_d} + \left(\frac{e_s}{E_d}\right)^2 + \cdots\right) \end{aligned}\right\} \quad (4)$$

In Equation ($i_{s_1}$) (4), the mean value of the input current is divided into the terms 'proportioning' and 'non-proportioning' as regards input voltage. If $E_d \gg e_s$, the progression term of Equation (4) becomes lower and current that is proportional to a sine input voltage is observed.

The boundary between continuous and discontinuous triangle-wave current in Fig. 3, becomes $T_1=T_2$ through Equation (3) when the Duty Ratio $d_1$ is 0.5 and $E_d$ is $2e_s$ o under $T_2=T_{sw}/2$. If the boosting ratio is $E_d/E_s$ o, however, a sine wave input current cannot be obtained if the boosting ratio is more than 2 (the DC output voltage is more than twice the maximum value of the input current).

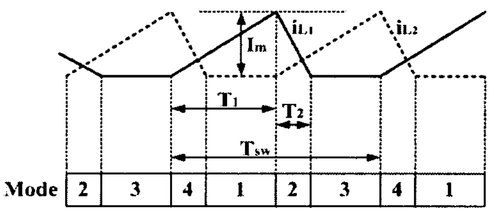



Fig. 3. Current waveforms of Reactors $L_1$ and $L_2$

Fig. 4 below demonstrates the individual operation waveform of a conventional circuit. In Fig. 4, energy is only stored without being released in the two Reactors $L_1$ and $L_2$. Therefore, discontinuous triangle-wave current flows through the two Reactors during a half switching cycle. If the input current is the same as the sum of the current on the two Reactors, a continuous sine-wave current in proportion to the input current is detected. The ripple frequency of the input current becomes twice that of the switching frequency and the ripple amplitude sufficiently decreases as compared to each reactor current (discontinuous current). Therefore, it is easier to analyze than the operation waveform in Fig. 4.

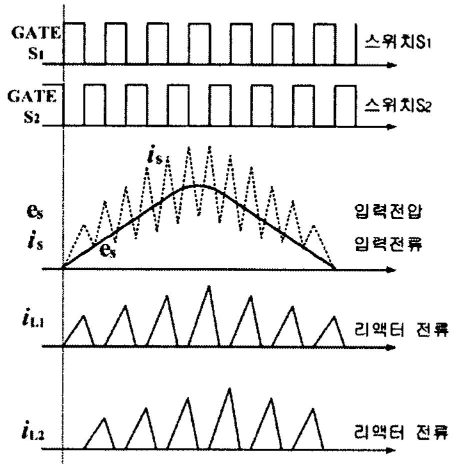



Fig. 4. Each segment of a conventional circuit operation waveform

Fig. 5 below demonstrates the new two-main switching boost rectifier that is suggested. This rectifier consists of two capacitors ($C_1$, $C_2$), two reactors ($L_1$, $L_2$), and two switches ($S_1$, $S_2$). In particular, the two switches ($S_1$, $S_2$) use IGBT, in which a freewheeling diode, equivalent to a conventional rectifier, repeats turning ON and OFF. The suggested rectifier requires neither the freewheeling diode ($D_{F1}$, $D_{F2}$) used in the conventional capacity input rectifier nor a complicated control such as a current detection sensor and PWM. Therefore, configuration of the entire system is simplified.

Fig. 6 demonstrates the operating mode during the switching cycle of the suggested rectifier. Four (4) switching patterns are repeated in the input current during a positive half cycle. The mode can be analyzed as follows:

○ Mode 1

As shown in Fig 6 (a) below, in Mode 1, if Switch $S_1$ turns on, the flow of input current is 'lossless Capacitor $C_s$ → Diode $D_1$ → Reactor $L_1$→ $S_1$.' Energy is then stored in Reactor $L_1$.

○ Mode 2

In Mode 2, if Switch $S_1$ turns off, Switch $S_2$ turns on at the same time. The energy stored in Reactor $L_1$ is then released to smoothing Capacitor $C_0$ and load as shown in Fig 2 (b) below while the current in the freewheeling diode stored in the switches ($S_2$, $S_2$) is determined by the sum of the current from Reactor $L_1$ and the current stored in Reactor $L_2$. In other words, if the current in Reactor $L_1$ is greater than the current in Reactor $L_2$, the freewheeling diode is transmitted. If Reactor $L_2$ is greater than the current in Reactor $L_1$, on the contrary, Switch $S_2$ is transmitted. In Mode 2, therefore, when the energy stored in Reactor $L_1$ is released, it is at the same time also stored in Reactor $L_2$.

○ Mode 3

In Mode 3, if the energy stored in Reactor $L_1$ by Mode 2 is released, the energy is stored in Reactor $L_2$ as shown in Fig. 6 (c) below.

○ Mode 4

In Mode 4, if Switch $S_2$ turns off, the energy stored in Reactor $L_2$ is released to smoothing Capacitor $C_0$ and load as shown in Fig. 6 (d). Then, the current on the freewheeling diode in Switches $S_1$ and $S_2$ 3 is determined as the sum of current from Reactor $L_1$ and current stored in Reactor $L_2$, as in Mode 2. In Mode 4, therefore, when the energy stored in Reactor $L_2$ is released, it is at the same time also stored in Reactor $L_1$. If the energy stored in Reactor $L_2$ is fully released, Mode 4 is at an end and the mode in which the input current is a negative half cycle begins.

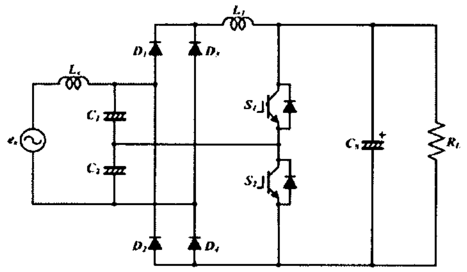


**Fig. 5. Configuration of the proposed new two main switching boost rectifier**

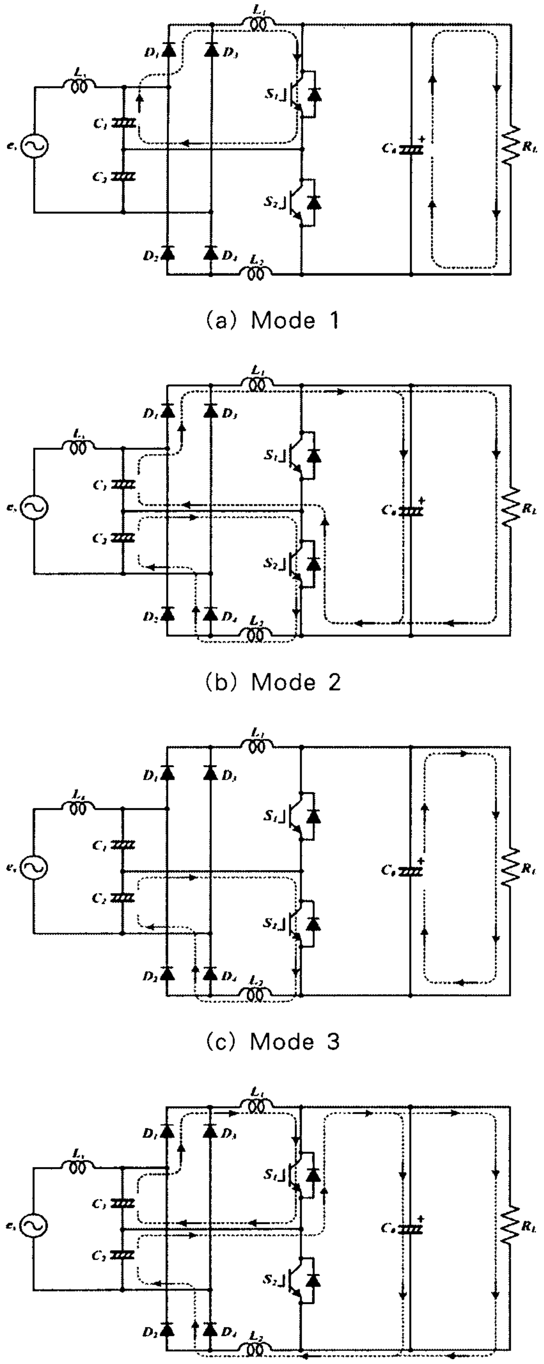
While the input current is in the negative half cycle, rectifier diodes $D_2$ and $D_3$ turn on, on behalf of $D_1$ and $D_4$, respectively. Other rectifier operations are the same as Mode 1 thru Mode 4 described above. Because the switching frequency is far higher than input frequency and input current is constant during the switching cycle, the current waveform on Reactors $L_1$ and $L_2$ have a triangle waveform just as a conventional rectifier does, which can be stated as follows:

$$i_{L_1} = \begin{cases} \frac{e_s}{2X_{L_1}} t & (0 < t < T_1) \\ I_m - \frac{1}{X_{L_1}}(B_d - \frac{e_s}{2})(t - T_1) & (T_1 < t < T_1 + T_t) \\ 0 & (T_1 + T_t < t < T_{sw}) \end{cases} \tag{5}$$

If the input current and mean value are calculated in Equation (5) with the same calculation method as for a conventional rectifier ( $i_{S_t}$), Equation (6) can be obtained as follows:

$$\left.\begin{aligned} i_{S_t} &= \frac{e_s}{4L} d_t^2 T_{sw} \left( \frac{2B_d}{2B_d - e_s} \right) \\ &= \frac{e_s}{4L} d_t^2 T_{sw} \left( \frac{1}{1 - e_s/2B_d} \right) \\ &= \frac{e_s}{4L} d_t^2 T_{sw} \left( 1 + \frac{e_s}{2B_d} + (\frac{e_s}{2B_d})^2 + \cdots \right) \end{aligned}\right\} \tag{6}$$

Here, $d_t$ $T_t$ $T_{sw}$ is duty ratio (=/).



(a) Mode 1

(b) Mode 2

(c) Mode 3

(d) Mode 4

**Fig. 6. Mode analysis of proposed circuit**

In Equation (6) ( $i_{S2}$), input current is divided into terms proportioning and non-proportioning as relates to input voltage. If $2E_d \gg e_s$, the progression term of Equation (6) becomes lower and current that is proportionate to sine input voltage is observed. The boundary between continuous and discontinuous triangle-wave current in Fig. 3 becomes $T_1=T_2$ by Equation (3) when Duty Ratio $d_2$ is 0.5 and $E_d$ is $e_s$ (boosting ratio $\alpha=1$) under $T_2=T_{sw}/2$. If the DC current voltage becomes higher than the maximum value of the input voltage, a sine wave input current is obtained.

Each operating waveform of the proposed circuit shall be same as the conventional circuit as shown in Fig. 4 while a discontinuous triangle-wave current flows through the two Reactors $L_1$ and $L_2$ during the half switching cycle. If a sum of the current on the two Reactors $L_1$ and $L_2$ is 1/2, a sine-wave continuous current proportionate to the input voltage is observed. Therefore, the ripple frequency of the input current becomes twice that of the switching frequency and the ripple amplitude becomes significantly weaker against each discontinuous reactor current.

## 2.2 Relationship between the boosting and duty ratios

In order for the duty ratio to main a certain operation, the boosting ratio should be set to 2 or below. The duty ratio should be set lower than the boosting ratio. The relationship between the boosting ratio and duty ratio in a conventional circuit is formed based on the following four conditions:

① If duty ratio ($d_1$) is 0.5

If the duty ratio ($d_1$) is 0.5, the boosting ratio becomes 2 or higher and current flows continuously on the reactor. Therefore, the output waveform is not improved.

② If duty ratio ($d_1$) is 0.5 and boosting ratio ( $\alpha$) is 2 or below

If the duty ratio ($d_1$) is 0.5 and boosting ratio ( $\alpha$) is 2 or below, the time ($T_1$) of the switching factor when the DC output voltage is smaller than the input voltage ($d<2e_s$) will be shorter than the time $T_2$ taken for the reactor current to reach '0.' In other words, energy is stored before the reactor current becomes '0' due to the repeating operations of Mode 2 and Mode 4 only, as shown in Fig. 2 and reactor current flow. Therefore, the input current that becomes the sum of two reactor currents becomes an inrush current and improvement of the waveform is noted.

③ If duty ratio ($d_1$) is smaller than 0.5

If the duty ratio ($d_1$) is smaller than 0.5, the switch-ON time becomes shorter and the time taken for the reactor current to reach '0' becomes off time $T_2$. Therefore, the discontinuous waveform in the reactor current is improved.

④ If boosting ratio is less than 2

If the boosting ratio is less than 2, the reactor current becomes discontinuous and the waveform is improved. As a result, the boundary between the continuous and discontinuous reactor current during the switching cycle of the conventional cycle is observed at $T_{sw}= T_1-T_2=0$ in Fig. 3, which can be stated as follows:

$$T_{sw} - d_{1l} T_{sw} - \frac{e_s}{(E_d - e_s)} d_{1l} T_{sw} = 0 \tag{7}$$

Here,

$d_{1b}$ is the duty ratio of the continuous and discontinuous boundary of the reactor current during the switching cycle. For $d_{1b}$, Equation (7) can be restated as follows:

$$d_{1b} = \frac{\alpha - \sin(\omega t)}{\alpha} \qquad (\because \ \alpha = \frac{E_d}{E_s}) \tag{8}$$

Fig. 7 demonstrates a graph of the continuous and discontinuous boundary duty ratio $d_{1b}$ of the reactor current when the boosting ratio ( $\alpha$) is 1.8. In Fig. 7, $d_{1b}$ is the relation of Time t while the horizontal axis $\omega t$ is a half cycle of input voltage from 0 to $\pi$. If the duty ratio $d_1$ is larger than the $d_{1b}$, the reactor current flows continuously and waveform is not improved. In this study, therefore, the duty ratio $d_1$ is set to the minimum value or below to keep the circuit operating at a constant duty ratio. To determine the minimum value for $d_{1b}$, the sin( $\omega t$) of Equation (8) is set to 1 for $d_{1b}$ to reach the maximum permissible value of duty ratio $d_1$, which can be stated as follows:

$$d_1 \le \frac{\alpha - 1}{\alpha} \tag{9}$$

Here, the boosting ratio becomes the duty ratio at $\alpha \frac{E_d}{E_s}$ $\alpha \ge 2$ $d_1 \le 0.5$.

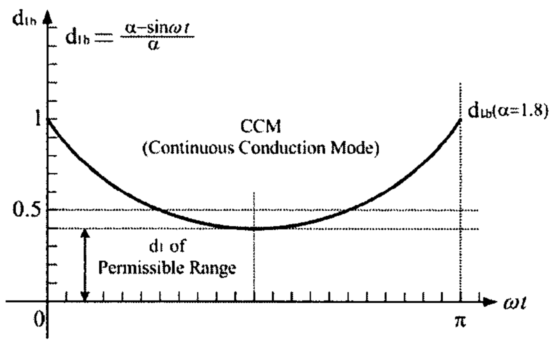



**Fig. 7. Permissible range of duty ratio $d_1$ (Where boosting ratio $\alpha$=1.8)**

As shown in Fig. 7, if the boosting ratio falls to 2 or below, the duty ratio $d_1$ is set in Equation (9). Conversely, if the boosting ratio is 2 or greater, the two conventional switches will not be ON while the duty ratio $d_1$ exceeds 0.5. Therefore, the maximum permissible value of duty ratio $d_1$ is limited to 0.5. Because the duty ratio is constant at 0.5 when the boosting ratio is 2 or above or 1 in the proposed circuit, an improved effect has been observed in waveform. The boundary between the continuous and discontinuous reactor current during switching cycles is observed at $T_{sw}-T_1-T_2=0$ in Fig. 3. Therefore, Equation 10 is formed. For $d_{2b}$ in Equation (0), Equation (11) can be restated as follows:

$$T_{sw} - d_{2b}T_{sw} - \frac{e_s}{2E_d - e_s} d_{2b}T_{sw} = 0 \qquad (10)$$

$$d_{2b} = \frac{2\alpha - \sin(\omega t)}{2\alpha} \qquad (11)$$

Here,

$d_{2b}$ is the duty ratio of the continuous and discontinuous boundary of the reactor current during switching cycles.

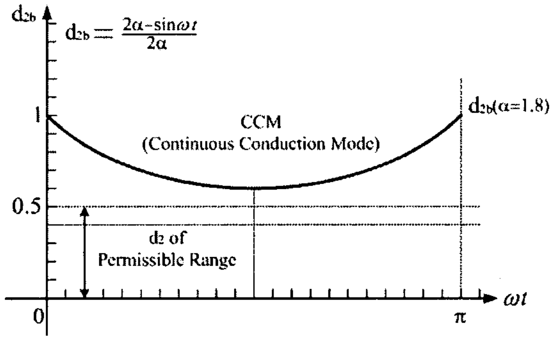



**Fig. 8. Permissible region of duty ratio $d_2$ (Where boosting ratio $\alpha$=1.8)**

Fig. 8 demonstrates a graph of $d_{2b}$ when the boosting ratio ($\alpha$) is 1.8. In Fig. 8, $d_{2b}$ is the relationship of Time t while the horizontal axis $\omega t$ is a half cycle of the input voltage from 0 to π. If the duty ratio $d_2$ is larger than $d_{2b}$, the reactor current flows continuously and the waveform is not improved. In this paper, therefore, the duty ratio $d_2$ is set to the minimum value or below to keep the circuit operating at a constant duty ratio. To determine the minimum value for $d_{1b}$, the sin ($\omega t$) of Equation (11) is set to 1 for $d_{2b}$ to reach the maximum permissible value of duty ratio $d_2$. Therefore, the maximum permissible value of duty ratio $d_2$ is limited to 0.5. Because the boosting ratio should be set to '1' to set the maximum value of $d_{2b}$ to 0.5, the boosting ratio is set to 1 or greater, keeping the duty ratio $d_2$ at 0.2 in this paper.

## 3. Results and Discussion

Fig. 9 demonstrates the relationship between boosting ratio and distortion factor. If the boosting ratio is 1, the distortion factor of the conventional circuit is approximately 50[%] while the improvement of waveform decreases. In Equation (4), the input voltage es had the maximum value when the maximum value $E_s$ of the DC output voltage $E_d$ and input current $e_s$ was identical. The progression term in Equation (4) becomes infinite and the low boosting ratio is activated. Therefore, the improvement of the waveform in a conventional circuit greatly decreases. Adequate input current was obtained with 11[%] of distortion because the proposed circuit established the boosting ratio to 1.1. For this reason, a better improvement of waveform was detected.

Fig. 10 demonstrates the ratio of harmonic third signals against basic current components included in the input current of both conventional and proposed circuits while Fig. 11 states the ratio of the $7^{th}$ harmonic signals under the same conditions.

In Fig. 10 and Fig. 11, a high level of the third and seventh harmonics is included in the input current when the boosting ratio decreases. Therefore, the improvement of the waveform decreases in the operation of a low boosting ratio.

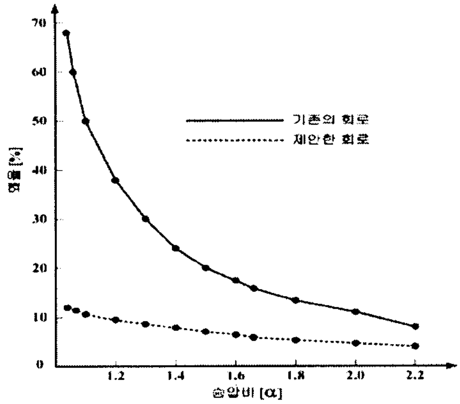



Fig. 9. The relationship between boosting ratio( $\alpha$) and distortion factor [%]

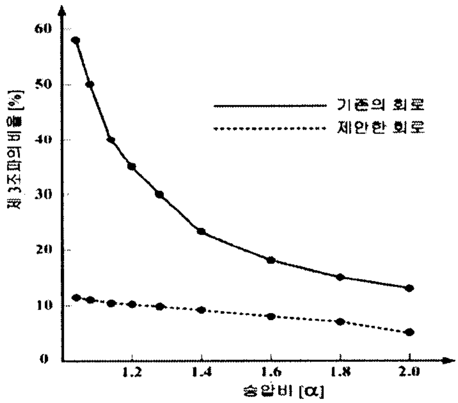



Fig. 10. The relationship between boosting ratio( $\alpha$) and 3rd harmonics

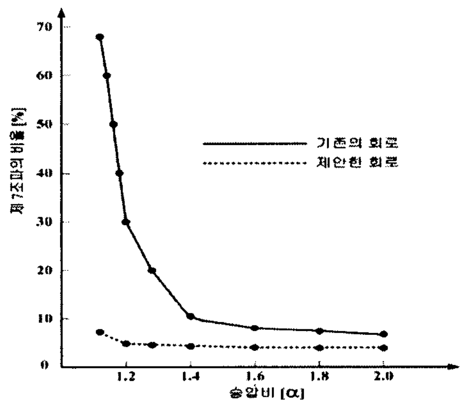



Fig. 11. The relationship between boosting ratio( $\alpha$) and 7th harmonics

In the proposed rectifier, as the boosting ratio decreased, the ratio of harmonic thirds increased. Therefore, the ratio reached approximately 12[%] when the boosting ratio was 1 and less than 1[%] for the $7^{th}$ harmonics. Therefore, improvement of the waveform was observed.

To investigate the improvement of waveform in both the proposed and conventional circuits, this paper has analyzed the waveform using a theoretical and frequency spectrum calculation of input current waveform based on the circuit parameters in Table 1. Filters Ls and $C_s$ connected to the input of a conventional rectifier eliminate switching ripple factors. Because Reactor Ls becomes a high impedance and Capacitor $C_s$ becomes a high impedance against input frequency and low harmonic frequencies (ex: $3^{rd}$, $5^{th}$), there is no influence on the system. For this reason, Filters $L_s$ and $C_s$ have been ignored.

To investigate low-order harmonics that have a substantial influence on the general improvement of waveform, this study conducted an analysis using the mean value from Equation (4) and Equation (6). Both the conventional and proposed circuits were set to be almost equivalent under $d_{12}/L_A = d_{22}/4L_B$, even though the actual current on the two circuits differed somewhat ($L_A$: Content of L in conventional circuit, $L_B$: content of L in proposed circuit). Because the distortion factor of input current is determined by the 2nd term in parenthesis in Equation (4) and Equation (6), there will be no influence on the distortion factor even though the content of the reactor in both the conventional and proposed circuits is different. Therefore, the frequency spectrum has been estimated without a Fourier transform along with the input current waveform after a single cycle of input current waveform was estimated by Equation (4) and Equation (6). The duty ratio $d_1$ of the conventional circuit was set to 0.2 (maximum permissible value in Equation (9)) while the duty ratio $d_2$ of the proposed circuit was set to 0.5 (boosting ratio ( $\alpha$) is 1.0 or greater).

Table 2 shows theoretical and experimental results of the frequency spectrum on the input current of the conventional and proposed circuits.

Fig. 12 below demonstrates the experimental waveform of the reactor current in the conventional circuit where $d_1$=0.5, $\alpha$=1.8. In the said figure, it was verified that the current on the reactor is continuous but the waveform was not improved. Under the low boosting ratio in which the duty ratio $d_1$ is set in accordance with the boosting ratio and the boosting ratio ( $\alpha$) is set to 1.25 using Equation (9), the waveform was somewhat improved. Fig. 13 shows the experimental waveform of input current in the conventional rectifier while Fig. 14 shows the experimental results of frequency spectrum (distortion factor: 33.1[%]).

Because the boosting ratio falls in the conventional circuit as shown in Fig. 13 and Fig. 14, the improvement of waveform falls with a high level of low-order harmonics in input current. A high level of harmonics has been observed in input current by frequency spectrum and the ratio is shown in Table 2.

Fig. 15 below demonstrates the experimental waveform of the reactor current in the proposed circuit where $d_2$=0.5, $\alpha$=1.8. As shown in the said figure, it was verified that the current on the

**Table 1. Circuit parameter used in experiment**

| | | |
|---|---|---|
| Input voltage ($e_s$) | | 100[V]/50[Hz] |
| Switching frequency ($f_s$) | | 10[kHz] |
| Boosting ratio ( $\alpha$) | | 1.25(Vdc=177[V]) |
| Reactor | $L_s$ | 1.5[mH] |
| | $L_1$, $L_2$ | 1.5[mH] |
| Capacitor | $C_s$ | 0.5[$\mu$F] |
| | $C_1$, $C_2$ | 1.0[$\mu$F] |
| Freewheeling diode | $D_1$ | 0.2 |
| | $D_2$ | 0.15 |
| Smoothing capacitor | | 2200[$\mu$F] |
| Load resistance ($R_L$) | | 300[Ω] |

**Table 2. Result of frequency spectrum for input current**

| Low harmonic signals Distortion | Conventional two-main switching boost type rectifier | | Proposed two-main switching boost type rectifier | |
|---|---|---|---|---|
| | Theoretical result | Experimental result | Theoretical result | Experimental result |
| Power factor (3[%]) | 31.9[%] | 32.0[%] | 10.4[%] | 13.0[%] |
| 10[%] | 7.1[%] | 7.5[%] | 0.7[%] | 1.1[%] |
| 7[%] | 2.2[%] | 2.6[%] | 0.5[%] | 0.6[%] |
| Distortion factor (DF) | 32.7[%] | 33.1[%] | 0.4[%] | 12.9[%] |

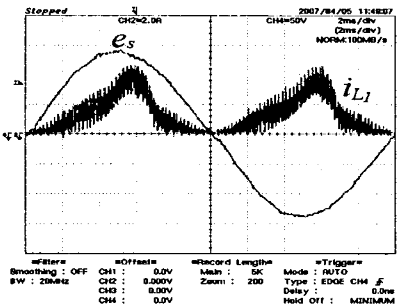



**Fig. 12. Experimental waveform of input voltage and reactor current in conventional circuit**

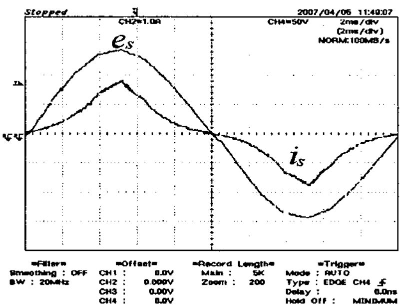



**Fig. 13. Experimental waveform of input voltage and current in conventional circuit**

reactor is discontinuous and its waveform was improved in proportion to the input voltage.

Fig. 16 shows the experimental waveform of the input current in the proposed rectifier while Fig. 17 shows the experimental result of the frequency spectrum in the input current of the proposed rectifier (distortion factor: 12.9[%]).

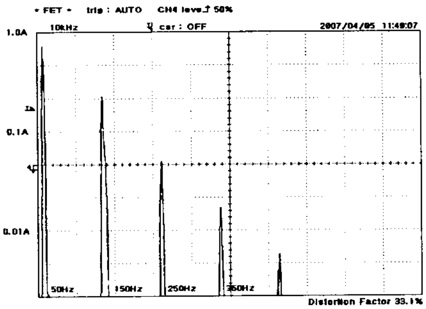



Fig.14. Frequency spectrum analysis of input current in conventional circuit

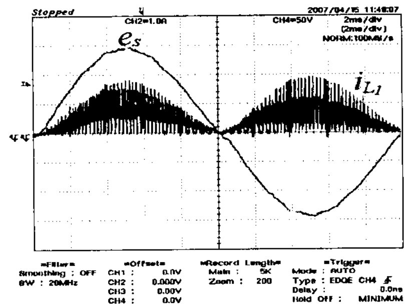



Fig. 15. Experimental waveform of input voltage and reactor current in proposed circuit

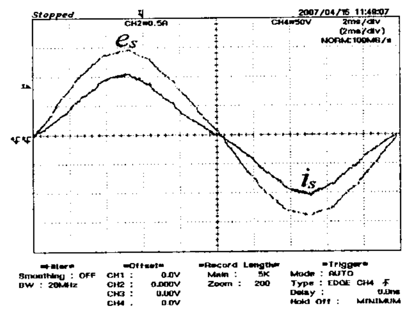



Fig. 16. Experimental waveform of input voltage and current in proposed circuit

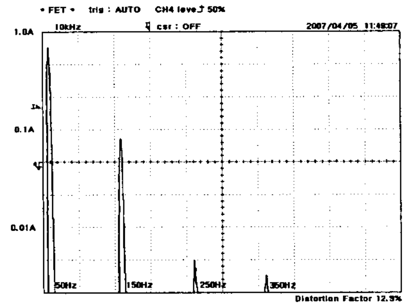



Fig. 17. Frequency spectrum analysis of input current in proposed circuit

As shown in Fig. 16, the waveform of the input current in the proposed circuit is improved (adequate sine wave). Because the input current is waveform included in two reactor currents, the switching ripple is almost eliminated just as the filter has been connected to the input. In the frequency spectrum shown in Fig. 17, the 3rd harmonics turned out to be 13.0[%] (the 5th harmonics: 1.1[%], the 7th harmonics: 0.6[%]) with a 12.9[%] distortion factor. Therefore, the experimental results turned out to be similar to the theoretical results.

## 4. Conclusion

Because a conventional two-main switching boost rectifier has a high level of low-order harmonics in the input current, its improvement of waveform has been low. To solve this problem, many complicated methods of control have been used to keep the duty ratio constant. Because complex control methods such as feedback and PWM are not available in a low boosting ratio range, however, related problems such as size, weight, cost, and restrictions on harmonics range have been left unresolved.

To resolve these issues, this paper has proposed a new two-main switching boost rectifier. Adequate input current was obtained by keeping the duty ratio constant without complicated conventional control methods and the improvement of the waveform was increased. With a decrease of distortion (low-order harmonics) up to 12.9[%], the scope of restriction on harmonics was set to 13.0[%] ($3^{rd}$ harmonics), 1.1[%] ($5^{th}$ harmonics), and 0.6[%] ($7^{th}$ harmonics), respectively. Because complicated methods of control are avoided, the circuit configuration is simple and practical. In particular, the said effect turned out to be highly efficient in the low boosting ratio range (boosting ratio ( $\alpha$) = 1.25). The feasibility of these facts has been proven both theoretically and experimentally.

## References


〔1〕 M.C Chanen, K. AL-Haddad and G. Roy, "Unity Power Factor Scheme Using Cascade converters", IEEE Trans. Ind. NO 3. pp 936-940. May. 1993.

〔2〕 Fang Zheng Peng et al, "A new approach to harmonic compensation inpower system-A combined system of shunt passive and series active filters", IEEE Trans, Ind. Appl., Nov./Dec., 1990.

〔3〕 H.M.EL-Bolok, "A microprocessor-based firing circuit for Thyristors working under three-phase variable-frequency Supply", IEEE Trans, Ind. Appl., 1990.

〔4〕 B.I.Baliga, "Switching lots of watts at high speed", IEEE spectrum, Vol.18, pp. 42-48, Dec., 1981.

〔5〕 M.Inoue, "Harmonic propagation on power system",Takaoka Review, Vol.32-1, No 105, 1985.

〔6〕 D.D.Shipp, "Harmonic Analysis and Suppression for Electrical System Supplying Static Power Converters and Other Nonlinear Loads", IEEE Trans, Ind. Appl, No 5, Sept./Oct., 1979.

〔7〕 Kuniomi Oguchi et al, "A Multilevel-Voltage Source Rectifier with a Three-Phase Diode Bridge Circuit as a Main Power Circuit", IEEE-IAS. Ann. conf., pp. 695-702, 1992.

〔8〕 高橋勳, 池下亙, "單相整流回路の入力電流波形改善",電學論B, Vol.105, pp.174-180, 1998.

〔9〕 資源エネルギー廳公益事業部, "家電・汎用品高調波制御對策ガイドラン", 2000.

〔10〕 松井景樹, 坪井和男,"中間タシプ付きリアクトルを用いて高調波を低する單相整流回路", 電學論D, Vol.109, pp.905-1001, 2001.

〔11〕 松井景樹, 坪井和男, "低次高調波を低減する單相整流電源回路の検討", 電氣學會全國大會, pp.579, 2001.

〔12〕 山本勇,松井景樹, "2分割電流流入方式による高力率單相整流回路", 電學論D, Vol.121, No.2, 2001.

〔13〕 Hee Jun Kim, "Switched-Mode Power Supply", Sungandang.Inc, 2001.

〔14〕 Robert L. Boylestad, "INTRODUCTORY CIRCUIT ANALYSIS-9th Edition", Prentice Hall, 2000.


## Biography


### Sung-Hyun Ha

BS degree (2003) and MS degree (2006) in Electrical Engineering, Kyungnam Univ.

### Chang-Il Kim

BS degree (1993), MS degree (1995), and Ph.D. (2002) in Electrical Engineering, Changwon National Univ., a professor of Dept. of Electricity, Gyeongnam Provincial Namhae College.

### Soo-Wook Kim

BS degree (1992) and MS degree (1997) in Electrical Engineering, Pukyong National Univ., an associate professor of Dept. of Electric Measurement & Control, Korea Polytechnic College (Busan Campus)

### Jing-Rak Nam

BS degree (1990) and MS degree (1994) in Electrical Engineering, Pukyong National Univ., Ph.D. in Electrical Engineering, Changwon National Univ. (2004), a professor of Dept. of Electronics & Electrical Engineering, Tongmyong Univ.

### Sang-Pil Mun

BS degree (1997) in Electrical Engineering, Pukyong National Univ., MS degree (1999) and Ph.D. (2003) in Electrical Engineering, Kyungnam Univ.