A Study on the High Power Factor Control in a Boost Rectifier
Abstract

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A Study on the High Power Factor Control in a Boost Rectifier

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Abstract

The boost converter operating at the boundary of continuous conduction mode (CCM) and discontinuous conduction mode (DCM) in the inductor output current of the converter has been commonly and widely used as one of the power stable control devices.

This converter can achieve the power factor correction by minimizing the harmonic distortion in the input current of the circuit.

This paper examines an advanced boost converter based on the above proto-type converter to obtain more stable and constant DC power source.

In order to compose the converter, first of all, a filtering capacitor is added across the output of the bridge rectifier; this capacitor is to
filter the high-frequency switching noise so that the voltage reference for the control circuit is a clean sinusoidal wave, and a switching control circuit to decrease the harmonic distortion is connected.

Furthermore, optimum parameter values to minimize the harmonic distortion in the input current are derived from the analyses of switching characteristics, switching on-off time and switching frequency.

Based on the analyses, a simulation using the PSim was done and a 100[W] step-up converter was designed and fabricated. As a result, it has been found that the power factor of 14[%] was improved compared to the prototype boost converter.
1

주요 항목

1.1 주요 항목

1.2 주요 항목

1.3 주요 항목

1.4 주요 항목

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The current CCM and DCM schemes are based on the two-port (\( C \)) and the three-port (\( D \)) models. The two-port model is used to analyze the power transfer characteristics of the system. The three-port model is used to analyze the power transfer characteristics of the system with three ports. The analysis of the two-port model is given in [13].

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2

L-C

2.1

2.2

2.3
(a) L\[\text{L} \quad \text{L} \quad \text{L} \quad \text{L}\]

(b) L\[\text{L} \quad \text{L} \quad \text{L} \quad \text{L}\]

\[2.2 \quad \text{L} \quad \text{L} \quad \text{L} \quad \text{L} \quad \text{L} . \quad \text{L} \quad \text{L} \quad \text{L} \]

- 4 -
50 - 60[Hz]

\[ PF = \frac{\text{average power}}{\text{rms voltage} \cdot \text{rms current}} = \frac{\text{avg}[v(t) \cdot i(t)]}{V_{\text{rms}} \cdot I_{\text{rms}}} \] (2-1)

\[ V(t) \] RMS

\[ I_{\text{rms}} = \sqrt{I_{0}^{2} + \sum_{n=1}^{\infty} \frac{I_{n}^{2}}{2}} \] (2-3)

\[ PF = \frac{I_{1}}{\sqrt{2}} \left( \cos (\phi_{1} - \theta) \right) = D_{f} \cdot D_{\theta} \] (2-3)

\[ \phi_{1} \]

\[ \theta_{1} \]

\[ D_{f} \]

\[ D_{\theta} \]
\[ \cos \theta \]

\[ \text{THD} = \frac{\sqrt{\sum_{a=1}^{\infty} I_a^2}}{I_1} \]

\[ (2-4) \]

\[ D_f = \frac{1}{\sqrt{1 + (\text{THD})^2}} \]

\[ (2-5) \]
The THD ($D_f$) decreases as $D_f$ increases.

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2.1

2.3

2.4
\[ P_{in} = \frac{V_{in}^2}{R_e} \]  \hspace{1cm} (2-6)

\[ v_{in}(t) = \sqrt{2} V_{in} \sin wt \]  \hspace{1cm} (2-7)

\[ i_{in}(t) = \frac{v_{in}(t)}{R_e} \]  \hspace{1cm} (2-8)
\[ p_{in}(t) = \frac{(\sqrt{2} V_{in})^2}{R_e} \sin^2 wt \]

\[ = \frac{V_{in}^2}{R_e} (1 - \cos 2wt) \quad (2-9) \]

\[ R_e = \frac{v_{in}(t)}{i_{in}(t)} = \frac{V_{in}^2}{P_{in}} = \frac{V_{in}^2}{P_o} \quad (2-10) \]

2.5
\( C \) \( R \) \( 2.6 \)
2.2 电路分析

\[ L \frac{di_L}{dt} = \sqrt{2} V_{in} \sin wt \quad (2-11) \]

\[ L \frac{di_L}{dt} = \sqrt{2} V_{in} \sin wt - V_o \quad (2-12) \]
$\Delta i_{L(on)} = \frac{v_{in}(t)}{L}$  \hspace{1cm} (2-13)

$\Delta i_{L(off)} = \frac{v_{in}(t) - V_o}{L}$  \hspace{1cm} (2-14)
\[ I_{L(\text{peak})} = 2\sqrt{2}I_{\text{in}} = \frac{2\sqrt{2}P_o}{\eta V_{\text{in}}} \quad (2-15) \]

\[ P_o = \eta \cdot V_{\text{in}} \cdot I_{\text{in}} \]

\[ \eta = \frac{2.8}{2} \]

\[ I_{L(\text{peak})} = (2-16) \quad 2.8 \]

\[ I_{L(\text{peak})} = (2-16) \]

\[ I_{L(\text{peak})} = \frac{\sqrt{2} V_{\text{in}}}{L} t_{\text{on}} \quad (2-16) \]

\[ t_{\text{on}} = \frac{2LI_{\text{in}}}{V_{\text{in}}} = \frac{2LP_o}{\eta V_{\text{in}}^2} \quad (2-17) \]

\[ I_{L(\text{off})} = \frac{2\sqrt{2}LI_{\text{in}} \sin wt}{V_o - \sqrt{2} V_{\text{in}} \sin wt} \quad (2-18) \]

DCM\( \quad \)CCM\( \quad \)duty\( \quad \)ratio
\[ t_s = t_{on} + t_{off} \]

\[ f_s = \frac{V_{in}(V_o - \sqrt{2} V_{in} \sin wt)}{2L \sqrt{2} V_{in}} \]  \hspace{1cm} (2-19)

\[ f_{s(min)} = \frac{V_{in}(V_o - \sqrt{2} V_{in})}{2L V_o I_{in}} \]  \hspace{1cm} (2-20)

\[ P_o = \eta V_o I_o \]  \hspace{1cm} (2-15)

\[ \frac{1}{V_o I_{in}} = \frac{\eta V_{in}}{P_o V_o} \]  \hspace{1cm} (2-21)

\[ L = \frac{\eta V_{in}^2 (V_o - \sqrt{2} V_{in})}{2f_{s(min)} P_o V_o} \]  \hspace{1cm} (2-22)
2.2.2

\[ i_B(t) \]

\[ V_o \]

\[ \Delta v_o = \frac{\Delta Q}{C} = \frac{I_o \cdot t_{on}}{C} = \frac{V_o \cdot t_{on}}{RC} = \frac{V_o \cdot D}{RCf_s} \]  \hspace{1cm} (2-23)
\[ i_D(t) = \frac{P(t)}{V_o} = \frac{V^2_m}{R_e \cdot V_o}(1 - \cos 2wt) \quad (2-24) \]

\[ i_c(t) = \frac{C}{dV_o(t)} = -\frac{V^2_m}{R_e \cdot V_o} \cos 2wt \quad (2-25) \]

\[ \Delta V_o = \frac{V^2_m}{2w \cdot R_e \cdot V_o \cdot C} \sin 2wt \]

\[ = \frac{V_o}{2wRC} \sin 2wt \quad (2-26) \]
2.3

\[ D'(t) = 1 - D(t) \]

\[ D(t)R_{on} \]

\[ D'(t) : 1 \]

\[ v_{m(t)} \]

\[ + \]

\[ V_o \]

\[ - \]

\[ 2.10 \]

\[ i_{in}(t)D(t)R_{on} = v_{in}(t) - D'(t)v_o(t) \]  \hfill (2-27)

\[ i_{in}(t) = \frac{v_{in}(t)}{R} \]

\[ \frac{v_{in}(t)}{R} \]

\[ D(t)R_{on} = v_{in}(t) - D'(t)v_o(t) \]  \hfill (2-28)
\[
D(t) = \frac{v_o(t) - v_{in}(t)}{v_o(t) - v_{in}(t) \frac{R_{on}}{R_e}} \tag{2-29}
\]

\[
D'(t) = 1 - D(t) = \frac{v_o(t) - v_{in}(t)}{v_o(t) - v_{in}(t) \cdot \frac{R_{on}}{R_e}} \tag{2-30}
\]

\[
i_d(t) = D' i_{in}(t) = D'(t) \frac{v_{in}(t)}{R_e} \tag{2-32}
\]

\[
i_d(t) = \frac{v_{in}^2(t)}{R_e} \frac{1 - \frac{R_{on}}{R_e}}{v_o(t) - v_{in}(t) \frac{R_{on}}{R_e}} \tag{2-33}
\]
\[ v_{in}(t) = \sqrt{2} V_{in} \sin wt \quad \langle i_d(t) \rangle_{T_{ac}} \quad (2-33) \]

\[ I_o = \langle i_d \rangle_{T_{ac}} = \frac{2}{T_{ac}} \int_{0}^{T_{ac}/2} (\frac{2 V_{in}^2}{R_e}) \frac{(1 - \frac{R_{on}}{R_e}) \sin^2 wt}{(v_o(t) - \frac{\sqrt{2} V_{in} R_{on}}{R_e} \sin wt)} \, dt \quad (2-34) \]

\[ I_o = \frac{2}{T_{ac}} \frac{2 V_{in}^2}{V_o R_e} (1 - \frac{R_{on}}{R_e}) \int_{0}^{T_{ac}/2} \frac{\sin^2 wt}{1 - \alpha \sin wt} \, dt \quad (2-35) \]

\[ \alpha = (\frac{\sqrt{2} V_{in}}{V_o})(\frac{R_{on}}{R_e}) \]

\[ I_o = \frac{2 V_{in}^2}{V_o R_e} (1 - \frac{R_{on}}{R_e}) \frac{2}{\pi} \int_{0}^{\pi/2} \frac{\sin^2 \theta}{1 - \alpha \sin \theta} \, d\theta \quad (2-36) \]

\[ F(\alpha) = \frac{4}{\pi} \int_{0}^{\pi/2} \frac{\sin^2 \theta}{1 - \alpha \sin \theta} \, d\theta \quad F(\alpha) \quad (2-37) \]
\[ F(\alpha) = \frac{2}{\alpha^2 \pi} (-2\alpha - \pi + \frac{4 \sin^{-1} \alpha + 2 \cos^{-1} \alpha}{\sqrt{1 - \alpha^2}}) \] (2-37)

\[ F(\alpha) \equiv 1 + 0.862\alpha + 0.78\alpha^2 \] (2-38)

\[ P_{in} = <P_{in}(t)>_T = \frac{V_{in}^2}{R_e} \] (2-39)

\[ P_o = V_o I_o = V_o \left[ \frac{2 V_{in}^2}{V_o R_e} (1 - \frac{R_{on}}{R_e}) \frac{F(\alpha)}{2} \right] \] (2-40)

\[ \eta = \frac{P_o}{P_{in}} = \frac{1}{2} (1 - \frac{R_{on}}{R_e}) F(\alpha) \]

\[ = (1 - \frac{R_{on}}{R_e}) [1 + 0.862 \frac{V_{in}}{V_o} \frac{R_{on}}{R_e} + 0.78 (\frac{V_{in}}{V_o} \frac{R_{on}}{R_e})^2] \] (2-41)
\[
\frac{V_{in}}{V_o} = \frac{\sqrt{2} \times 220}{380} = 0.819 \quad 95\% \quad 2.11\]

\[
\frac{R_{on}}{R_e} \approx 0.15 \quad 69[\Omega] \quad 110[V] \quad 34.5[\Omega]
\]

\[
R_{on} \leq (0.15)R_e \quad R_{on} = 69[\Omega] \quad R_{on} = 34.5[\Omega]
\]

\[
R_{on}/R_e \approx 0.409 \quad R_{on}/R_e = 0.15 \quad R_{on}/R_e = 0.2
\]
3.1 

...
\[ t_{on} = \frac{L (I_k + I_p \sin wt)}{\sqrt{2} V_{in} \sin wt - wLI_p \cos wt} \quad (3-1) \]

\[ t_{off} = \frac{L (I_k + I_p \sin wt)}{V_o - \sqrt{2} V_{in} \sin wt} \quad (3-2) \]
$K = \frac{1}{t_1/t_i}$

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\[ I_q = \sqrt{\frac{1}{T_{ac}} \int_0^{T_{ac}} i_Q^2(t) dt} \]  
(3-3)

\[ I_q = \sqrt{\frac{1}{T_{ac}} t_s \sum_{n=1}^{T/s} \left( \frac{1}{t_s} \int_{(n-1)t_s}^{nt_s} i_Q^2(t) dt \right)} \]  
(3-4)

\[ T_{ac} \ll t_s \]  
(3-5)

\[ I_q \approx \sqrt{\frac{1}{T_{ac}} \lim_{t \to 0} \left[ \frac{1}{t_s} \int_{(n-1)t_s}^{nt_s} i_Q^2(t) dt \right]} \]

\[ = \sqrt{\frac{1}{T_{ac}} \int_0^{T_{ac}} \frac{1}{t_s} \int_t^{t + T_{ac}} i_Q^2(\tau) d\tau} \]

\[ = \sqrt{\langle i_Q^2(t) \rangle_{t, t + T_{ac}}} \]  
(3-6)

\[ \text{RMS} \]  
(3-3)

- 28 -
\begin{align}
\langle i_2^2(t) \rangle_{t_s} &= \frac{1}{t_s} \int_{t_s}^{t_s + t_s} i_2^2(t) dt \\
&= D(t) \cdot i_\frac{2}{L}(t) \tag{3-6}
\end{align}

\begin{align}
D(t) &= 1 - \frac{\sqrt{2} V_{in}}{V_o} \sin wt \tag{3-7}
\end{align}

\begin{align}
I_2^2 &= \left[ \frac{I_{L(peek)} \sin wt}{\sqrt{3}} \right]^2 \tag{3-8}
\end{align}

\begin{align}
\langle i_2^2(t) \rangle_{t_s} &= \frac{I_{L(peek)}^2}{3} \left( 1 - \frac{\sqrt{2} V_{in}}{V_o} \sin wt \right) \sin^2 wt \tag{3-9}
\end{align}
\[ <I_q>_{ac} = \sqrt{\frac{1}{T_{ac}} \int_0^{T_{ac}} \left( 1 - \frac{\sqrt{2} V_{in}}{V_o} \sin wt \right) \sin 2wt dt} \]

\[ = \sqrt{\frac{2}{T_{ac}} \int_0^{T_{ac}/2} \left( \frac{I_{L(peak)}}{3} \right) \sin^2 wt - \frac{\sqrt{2} V_{in}}{V_o} \sin^3 wt dt} \]

\[ = \sqrt{\frac{1}{6} \cdot \frac{4\sqrt{2} V_{in}}{9\pi V_o} I_{L(peak)}} \]

\[ = \sqrt{\frac{1}{6} \cdot \frac{4\sqrt{2} V_{in}}{9\pi V_o} I_{L(peak)}} \]  \hspace{1cm} (3-10)

\[ <i^2_D>_{T_s} = (1 - D(t)) i^2_L(t) \]  \hspace{1cm} (3-11)

\[ <I_d>_{ac} = \sqrt{\frac{1}{T_{ac}} \int_0^{T_{ac}} <i^2_D>_{T_s} dt} \]

\[ = \sqrt{\frac{4\sqrt{2} V_{in}}{9\pi V_o} I_{L(peak)}} \]  \hspace{1cm} (3-12)
\[ I_L = \frac{1}{\sqrt{6}} I_{L(peak)} \]  \hspace{1cm} (3-13)

\[ I_L^2 = \left( \frac{I_K + I_P \sin wt}{\sqrt{3}} \right)^2 \]  \hspace{1cm} (3-14)

\[ I_Q = \sqrt{\left( \frac{I_K^2}{3} + \frac{I_K I_P}{3\pi} + \frac{I_P^2}{6} \right) - \frac{(2 I_K^2 + 2 \pi I_K I_P + 4 I_P^2)\sqrt{2 V_{in}}}{9\pi V_o}} \]  \hspace{1cm} (3-15)

\[ I_D = \sqrt{\left( \frac{6 I_K^2 + 3\pi I_K I_P + 4 I_P^2)}{9\pi V_o} \right)\sqrt{2 V_{in}}} \]  \hspace{1cm} (3-16)
\[ I_L = \sqrt{I_0^2 + I_D^2} \quad \text{or} \quad I_{in} \]

\[ I_L = \frac{2}{\sqrt{3}} I_{in} \quad (3-17) \]
3.2 \[ V_{in} \] and \[ f \] Table

<table>
<thead>
<tr>
<th>[ V_{in} ] [V]</th>
<th>[ f ] [Hz]</th>
<th>[ L ] [( \mu \text{H} )]</th>
<th>[ C ] [( \mu \text{F} )]</th>
<th>[ R ] [( \Omega )]</th>
<th>[ f_{c} ] [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>220</td>
<td>60</td>
<td>833</td>
<td>25.48</td>
<td>1445</td>
<td>50</td>
</tr>
</tbody>
</table>

3.3\[ f \] and \[ L \] Table

<table>
<thead>
<tr>
<th>( f_{c} ) [kHz]</th>
<th>[ L ] [( \mu \text{H} )]</th>
<th>[ L ] [( \mu \text{F} )]</th>
<th>( f_{c} ) [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>220</td>
<td>6</td>
<td>8.3</td>
<td>20</td>
</tr>
</tbody>
</table>

- 33 -
\[ i_L(t) \]

(a) \[ i_L(t) \]

(b) \[ i_L(t) \] (K=50)

\[ 3.4 \]
3.3 상호작용

이 단락은 아직 번역되지 않은 상태입니다. 3.5, 3.6 다음 틀에 대한 내용은 추후 번역할 계획입니다.
$V_o$ zero crossing pulse. IGBT Gate switching table. 

K=50·$\frac{\text{K}}{\text{sec}}$ IGBT converter controller Intel 80C196KC, IGBT 2MBIP0L-060. AD Converter 10bit 80C196KC. 

10bit 80C196KC. 

$6\text{[KHz]}$ switching table. $20\text{[KHz]}$ switching table. $7\text{[MHz]}$ switching table. $50\text{[KHz]}$ switching table. 

K=50. 

80C196KC. 

$K=50$·$\frac{\text{K}}{\text{sec}}$ IGBT gate switching table. 

$50\text{[KHz]}$ AD converter. $50\text{[KHz]}$ AD converting. 

$PI$·$\frac{\text{K}}{\text{sec}}$ switching table. 

$K=50$·$\frac{\text{K}}{\text{sec}}$ switching table. 

- 37 -
<table>
<thead>
<tr>
<th>$t_{on}$</th>
<th>$t_{on}$</th>
<th>$t_{off}$</th>
<th>$t_{off}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>47.9</td>
<td>2.1</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>38.0</td>
<td>4.0</td>
<td>27</td>
</tr>
<tr>
<td>4</td>
<td>35.1</td>
<td>6.0</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>33.7</td>
<td>8.3</td>
<td>29</td>
</tr>
<tr>
<td>6</td>
<td>32.9</td>
<td>10.8</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>32.4</td>
<td>13.6</td>
<td>31</td>
</tr>
<tr>
<td>8</td>
<td>32.0</td>
<td>16.8</td>
<td>32</td>
</tr>
<tr>
<td>9</td>
<td>31.7</td>
<td>20.3</td>
<td>33</td>
</tr>
<tr>
<td>10</td>
<td>31.5</td>
<td>24.3</td>
<td>34</td>
</tr>
<tr>
<td>11</td>
<td>31.3</td>
<td>28.7</td>
<td>35</td>
</tr>
<tr>
<td>12</td>
<td>31.2</td>
<td>33.7</td>
<td>36</td>
</tr>
<tr>
<td>13</td>
<td>31.1</td>
<td>39.3</td>
<td>37</td>
</tr>
<tr>
<td>14</td>
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<td>38</td>
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<td>15</td>
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<td>52.5</td>
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<tr>
<td>16</td>
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<td>60.2</td>
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<td>17</td>
<td>30.8</td>
<td>68.7</td>
<td>41</td>
</tr>
<tr>
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<td>30.7</td>
<td>77.8</td>
<td>42</td>
</tr>
<tr>
<td>19</td>
<td>30.7</td>
<td>87.6</td>
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<tr>
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<td>30.6</td>
<td>97.6</td>
<td>44</td>
</tr>
<tr>
<td>21</td>
<td>30.6</td>
<td>107.6</td>
<td>45</td>
</tr>
<tr>
<td>22</td>
<td>30.6</td>
<td>117.1</td>
<td>46</td>
</tr>
<tr>
<td>23</td>
<td>30.5</td>
<td>125.4</td>
<td>47</td>
</tr>
<tr>
<td>24</td>
<td>30.5</td>
<td>132.0</td>
<td>48</td>
</tr>
<tr>
<td>25</td>
<td>30.5</td>
<td>136.2</td>
<td>49</td>
</tr>
</tbody>
</table>

K=50 switching table
4

4.1 L-C回路のL- C回路の
4.2 L- C回路のL- C回路の
4.3 L- C回路のL- C回路の
4.4 L- C回路のL- C回路の

FFT

7

L- C回路の(L- C回路の

60.5(%), L- C回路の

10.3(%)

L- C回路の(L- C回路の

100 81.6 48.1 17.4 5.2 9.4 6.3 97.24

100 48 26.1 18.8 7.2 11.3 16.9 60.5

100 7.8 3.36 2.0 1.29 1.2 2.5 10.3
Ch1 : 100[V/div], Ch2 : 250m[A/div]

4.1 L-C 파형

4.2 L-C 파형, FFT
Ch 1 : 100[V/ div], Ch 2 : 250m[A/ div]

4.3

FFT

4.4
Ch1 : 100[V/div], Ch2 : 250m[A/div]

4.5

FFT

4.6
(5)

1. CCM, DCM, and CDM simulation results were analyzed. The
2. percentage of 10.3% was obtained, which is 50% of the
3. initial value. The percentage of 14% was obtained after
4. 44 -
[2] ÓëÈñÁØ, ½ºÀ§Ä¡¸ðµåÆÄ¿ö¼­ÇöóÀÌ, pp.49-111, 1993
Applications, Vol. 31, No. 5, 1995


