Non-Isolated Direct AC-DC Converter Design with BCM-PFC Circuit

Gunma University, Japan
Yasunori Kobori
OUTLINE

1. Conventional AC-DC Converters
2. Proposed AC-DC Converters w/o PFC Circuit
   2-1 H-Bridge Type Buck-Boost Converter
   2-2 Di-Bridge Type Buck Converter
   2-3 Simulation Results with Di-Bridge
3. Novel AC-DC Converters with BCM-PFC Circuit
   3-1 H-Bridge Type Buck-Boost Converter
   3-2 Di-Bridge Type Buck Converter
   3-3 Simulation Results with Di-Bridge
   3-4 Experimental Results with Di-Bridge
4. Conclusion

PFC: Power Factor Correction
BCM: Boundary Conduction Mode
OUTLINE

1. Conventional AC-DC Converters

2. Proposed AC-DC Converters w/o PFC Circuit
   2-1 H-Bridge Type Buck-Boost Converter
   2-2 Di-Bridge Type Buck Converter
   2-3 Simulation Results with Di-Bridge

3. Novel AC-DC Converters with BCM-PFC Circuit
   3-1 H-Bridge Type Buck-Boost Converter
   3-2 Di-Bridge Type Buck Converter
   3-3 Simulation Results with Di-Bridge
   3-4 Experimental Results with Di-Bridge

4. Conclusion
1. Conventional AC-DC Converters

1-1 AC-DC Converter without PFC Circuit

AC Input 100~240V
Diode Rectifier 330~140V
DC-DC Converter

**Fig.1-1 Construction of Conventional Converter 1**

*Condenser Input Type*
*Power Factor $\approx 0.5$*

**Fig.1-2 Waveform of Input Voltage & Input Current**
1. Conventional AC-DC Converters

1-2 AC-DC Converter with PFC Circuit

- AC Input 80~265V
- Boost Converter
- PFC
- DC-DC Converter
- Forward type
- 400V
- C > 1mF
- V<sub>i</sub> ∝ I<sub>i</sub>
- Power Factor > 0.9

Fig. 1-3 Construction of Conventional Converter 2

Fig. 1-4 Waveform of Input Voltage & Input Current
OUTLINE

1. Conventional AC-DC Converters

2. Proposed AC-DC Converters w/o PFC Circuit
   2-1 H-Bridge Type Buck-Boost Converter
   2-2 Di-Bridge Type Buck Converter
   2-3 Simulation Results with Di-Bridge

3. Novel AC-DC Converters with BCM-PFC Circuit
   3-1 H-Bridge Type Buck-Boost Converter
   3-2 Di-Bridge Type Buck Converter
   3-3 Simulation Results with Di-Bridge
   3-4 Experimental Results with Di-Bridge

4. Conclusion
2. Proposed AC-DC Converters w/o PFC

2-1 H-Bridge Type Buck-Boost Converter

- Using H-Bridge instead of Diode-Bridge
- Buck-Boost Converter: $V_o \approx 10 \sim 400\text{V}$
- $|V_i| > V_o$: Buck Converter, $|V_i| < V_o$: Boost Converter

Fig.2-1  Block Diagram of Proposed Circuit without PFC
● Operation 1

1) $V_i > 0$  

- when PWM=「H」 ⇒ S1, S3 : ON  (RED line)  
- when PWM=「L」 ⇒ S2 : ON  (BLUE line)

![PWM Controller Diagram](image)

Fig. 2-2a  Operation when $V_i > 0$  

Fig. 2-2b  Timing Chart
● Operation 2

2) $V_i < 0$

[Switches] (Current)

- when PWM=$H$ ⇒ S2, S4 : ON (RED line)
- when PWM=$L$ ⇒ S2 : ON (BLUE line)

⇒ S2 is exchange to Di.

Fig. 2-3a  Operation when Vi < 0

Fig. 2-3b  Timing Chart
* S3: Deleted
* Di: Moved

* S1, S4 ⇒ Di
* SW: Moved

Fig. 2-3c Transformation from Buck-Boost to Buck Converter
2-2 Di-Bridge Type Buck Converter

- Using Di-Bridge with Single SW

- Buck Converter when $|V_i| > V_o$: $V_o \approx 12 \sim 24V$
  - when PWM = 「H」 ⇒ SW: ON (RED line)
  - when PWM = 「L」 ⇒ SW: OFF (BLUE line)

![Block Diagram & Operation](image)

Fig.2-4 (a) Block Diagram & Operation ( $V_i > 0$ )
2-2 Di-Bridge Type Buck Converter

- $\Delta \theta$: Phase not to work for Buck Converter
  - $\Delta \theta: 5.4\%$ (when $V_i=100$ Vrms, $V_o=12$V)
  - $\Delta \theta: 2.1\%$ (when $V_i=260$ Vrms, $V_o=12$V)

![Di-Bridge Type Buck Converter Diagram](image)

Fig.2-4 (b) Block Diagram & Operation ($V_i<0$)
2-2 Simulation Results (H-Bridge Type)

(1) Conditions ⇒

(2) Waveforms of Output

Conditions
1) Vi = 100 Vrms
2) Vo = 50V
3) Io = 0.5 A
4) Fck = 200kHz
5) L = 220 uH
6) C = 220 uF

\[ \Delta V_o = 5 \text{ mVpp} \]
\[ \frac{\Delta V_o}{V_o} = 0.01 \% \]
(3) Transient Response

- Voltage Ripple
  \[ \Delta V_o = \pm 15 \text{ mV} \]

- Voltage Offset
  \[ \Delta V_{OS} = 5 \text{ mV} \]

* Conditions
  \( I_o = 1.0 / 0.5 \text{ A} \)

Fig. 2-7  Transient Response

Fig. 2-8  Waveform of inductor current
(4) Simulation Circuit (H-Bridge Type)

- Conditions: \( V_i = \text{AC100V} \), \( V_o = \text{DC50V} \), \( I_o = 1.0/0.5 \text{ A} \), 
  \( L = 220 \mu\text{H} \), \( C = 220 \mu\text{F} \)

![Simulation Circuit with H-Bridge](image)

**Fig.2-9 Simulation Circuit with H-Bridge**
OUTLINE

1. Conventional AC-DC Converters
2. Proposed AC-DC Converters w/o PFC Circuit
   2-1 H-Bridge Type Buck-Boost Converter
   2-2 Di-Bridge Type Buck Converter
   2-3 Simulation Results with Di-Bridge
3. Novel AC-DC Converters with BCM-PFC Circuit
   3-1 H-Bridge Type Buck-Boost Converter
   3-2 Di-Bridge Type Buck Converter
   3-3 Simulation Results with Di-Bridge
   3-4 Experimental Results with Di-Bridge
4. Conclusion
3. Novel AC-DC Converters with BCM-PFC

3-1 Boundary Conduction Mode PFC

1) Conventional Converter with BCM PFC

- Construction: Diode-Bridge + Boost Converter
  Error Amp + Multiplier + 2 Comparators

Fig. 3-1 Block Diagram of Conventional BCM PFC
3-1 Boundary Conduction Mode PFC

(1) Conventional Converter with BCM PFC

● Construction: **Diode-Bridge + Boost Converter**
  Error Amp + Multiplier + 2 Comparators

![Diagram of Conventional BCM PFC](image)

* Current Condition

\[ I_{min} = 0 \text{ A} \]

\[ I_p \propto V_i \]

**Fig. 3-1 Construction of Conventional BCM PFC**

**Fig. 3-2 Inductor Current**
(2) Proposed **Buck-Boost** Converter with H-Bridge

- **Construction**: H-Bridge + New Multiplier
- **New Multiplier**: using Voltage Controlled Current Source
- **Conditions**
  - \( V_o = 24 \, \text{V}, \, I_o = 0.24 \, \text{A} \)
  - \( L = 60 \, \mu\text{H}, \, C = 47 \, \text{mF} \)
- **\( T_R = Cr \cdot V_e / A \propto V_e \cdot E \)**
- \( K_r = V_i / L \)
- \( I_p = K_r \cdot T_r \propto V_i \)

---

**Fig. 3-2** Inductor Current

**Fig. 3-3** Construction of New BCM PFC
(3) Proposed Buck Converter with D-Bridge BCM PFC

- **Construction**: Single SW + Di-Bridge + New Multiplier

- **Conditions**
  - $V_o = 12$ V, $I_o = 0.24$ A
  - $L = 20$ uH, $C = 100$ mF

Fig. 3-3  Construction of New BCM PFC
3-2 Simulation Results (Buck-Boost with BCM PFC)

(1) Input Current (Low-Pass Filtered)

- Output Voltage Ripple = 25 mV_{pp} (I_o=0.24A)
- DC Offset = 20mV (<0.1 %)
- Power Factor \(\equiv 0.97\)

- Conditions
  - \(V_i = 100 \text{ Vrms, 50Hz}\)
  - \(V_o = 24 \text{ V}\)
  - \(I_o = 0.24\text{A, 1.0A}\)
  - \(L=50\mu\text{H,}\)
  - \(C=47\text{mF}\)

Fig.3-4 Input Voltage and Current
● Inductor Current (Fig.3-5)
  I peak = 2.2A,
  Envelope is SIN wave

● Output Voltage Ripple (100Hz)
  25 mVpp (@ Io=0.24A)
  60 mVpp (@Io=1.0A)
(2) Output Ripple and Offset vs. Output Current

- Output Ripple: $\triangle V_{\text{rip}} = 50\text{mVpp} \cdot I_o$
- Voltage Offset: $\triangle V_{\text{os}} \propto -50\text{mV} \cdot I_o \left[ \propto \frac{1}{\text{Loop Gain}} \right]$
(3) Output Ripple and Offset vs. Input Voltage

- Output Ripple = Constant (@ Vi=100Vrms, Io=1.0A)
- Voltage Offset $\propto \frac{1}{V_i} \left( \approx 60 - 4000/V_i \right)$ mV

![Fig.3-9 Output Ripple & Offset vs. Input Voltage](image_url)
(4) Simulation Circuit 1: **H-Bridge Converter**

- Conditions: $V_o=12\,\text{V}$, $I_o=1.0\,\text{A}$, $L=50\,\mu\text{H}$, $C=47\,\text{mF}$

**Fig.3-10 Simulation Circuit with H-Bridge BCM-PFC Circuit**
(5) Simulation Circuit 2: **Di-Bridge Converter**

- **Conditions**: \( V_o = 12V \), \( I_o = 1.0A \), \( L = 20\mu H \), \( C = 100mF \)

---

**Fig.3-11 Simulation Circuit with Di-Bridge BCM-PFC Circuit**
3-3 Experimental Results (Buck Converter with BCM PFC)

(1) Input Current Waveform

- Condition: $V_o=12\, \text{V}$, $V_i=50\, \text{Vrms (50Hz)}$, $I_o=0.2\, \text{A}$
  - $L=200\, \text{mH}$, $C=2000\, \text{uF}$, $F_{\text{pwm}}=50\, \text{kHz}$

![Input Voltage and Current](image)

Fig.3-12 Input Voltage and Current
3-3 Experimental Result (Buck Converter with BCM PFC)

(1) Output Voltage Ripple (Output of Amplifier)

- Output Voltage Ripple = 20 mVpp (Amp. Gain = 40 dB)
- \( F_{rpp} = 2 \cdot F_{in} \) (\( F_{rpp} = 100 \text{Hz} \))

![Fig.3-13 Output Voltage Ripple after Amplified](image)
4. Conclusion

1. Proposed Non-Isolated Direct AC-DC converter with BCM-PFC Circuit
   (1) Two types of Converter:
       H-Bridge Buck-Boost Converter: Vo=10~200V
       Di-Bridge Buck Converter with Single SW
   (2) New Multiplier with Voltage Controlled I Source

2. Output Voltage Ripple with Di-Bridge BCM-PFC is
   60 mVpp @ Vo=12V, Io=1A, Vi=100V, C=100mF

3. Power Factor is about 0.97.

PFC: Power Factor Correction
BCM: Boundary Conduction Mode
Thank you

for your attention!