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

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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

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1-1 AC-DC Converter without PFC Circuit

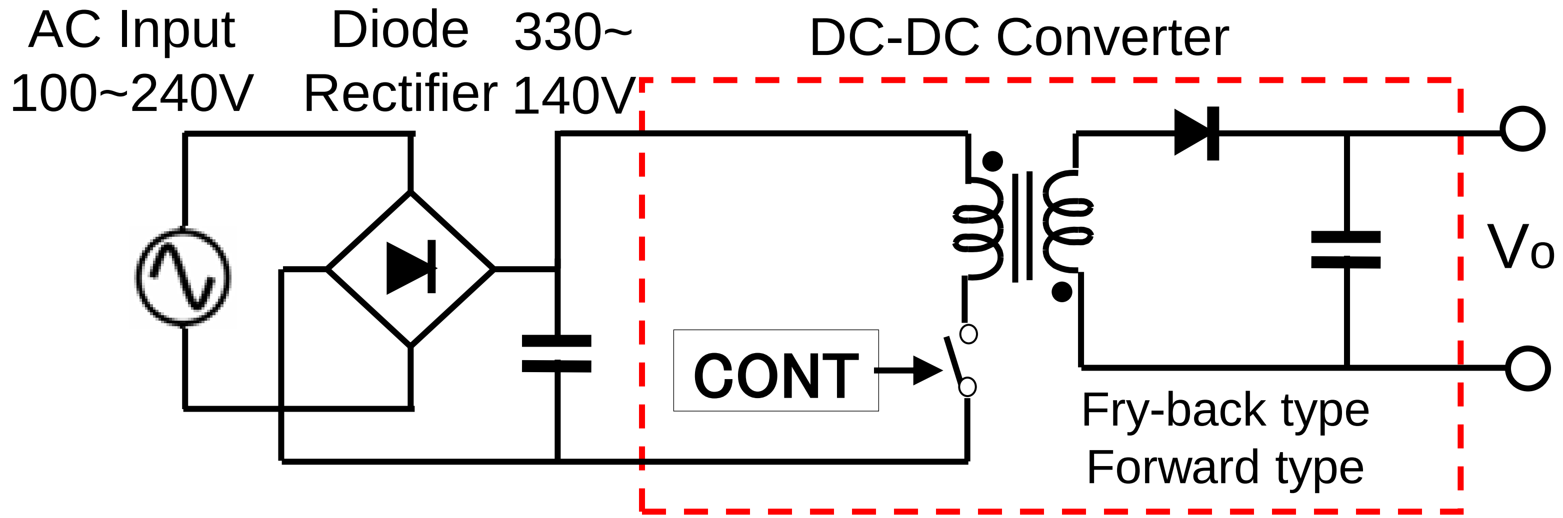
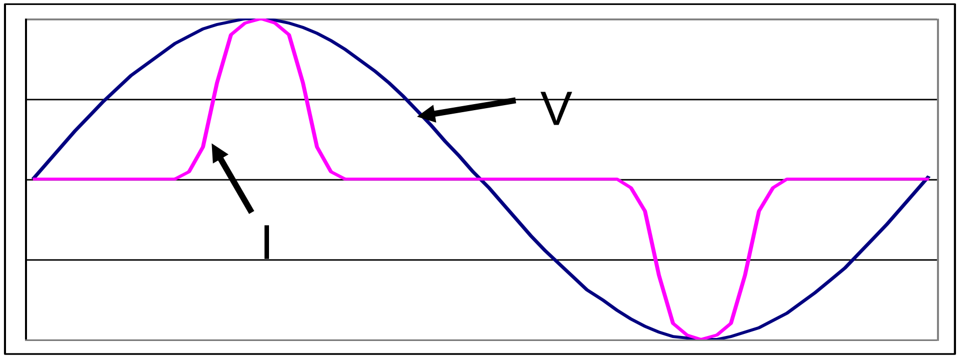


Fig.1-1 Construction of Conventional Converter 1



＊Condenser Input Type

＊Power Factor≒**0.5**

Fig.1-2 Waveform of Input Voltage & Input Current

1. Conventional AC-DC Converters

1-2 AC-DC Converter with PFC Circuit

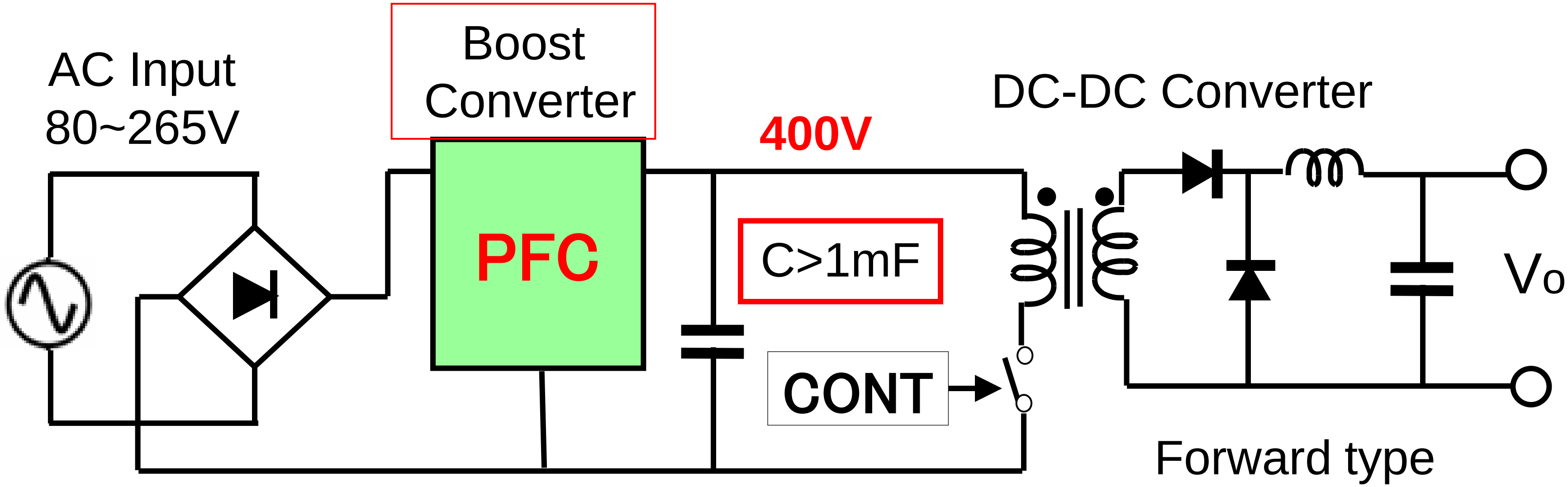
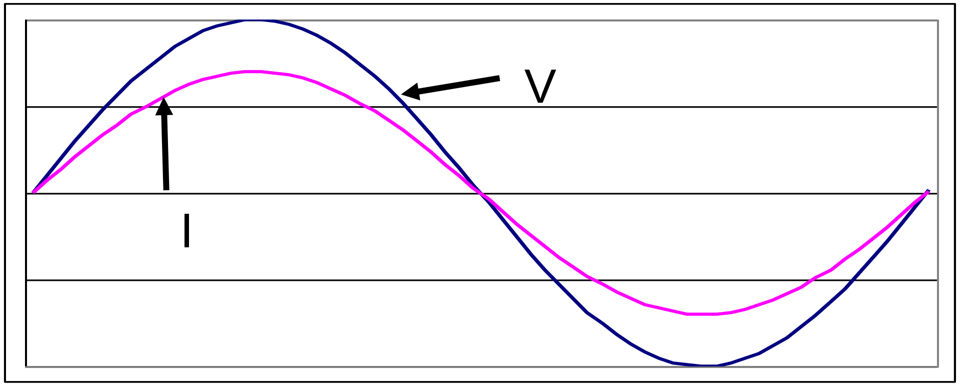


Fig.1-3 Construction of Conventional Converter 2



* Ii ∝ Vi
* Power Factor ＞ 0.9

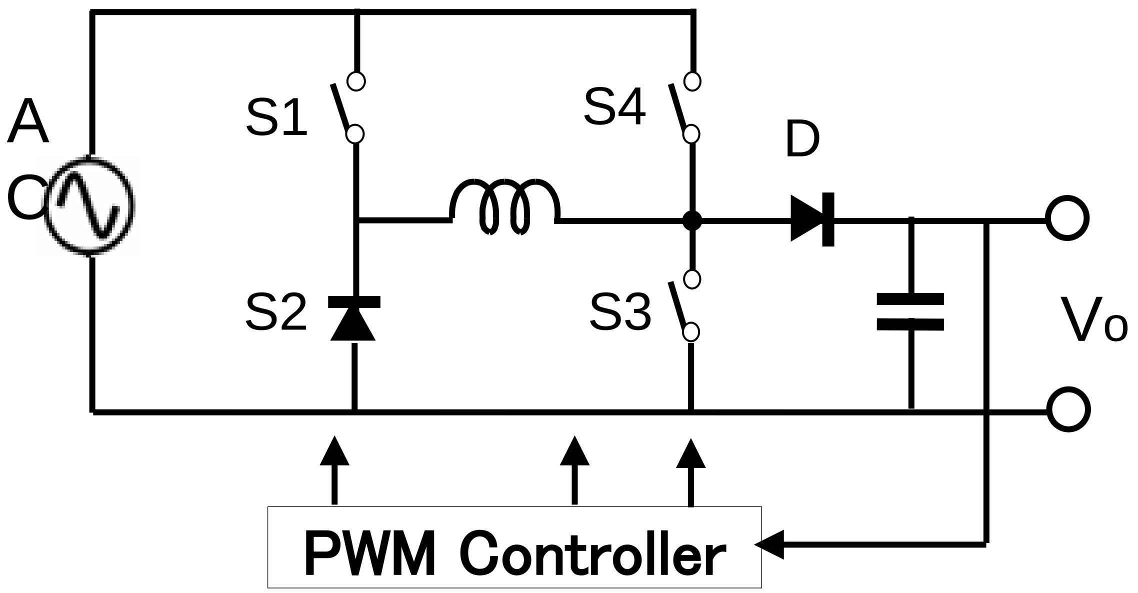
Fig.1-4 Waveform of Input Voltage & Input Current

OUTLINE

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 ： Vo ≒10～400V
- |Vi|>Vo：Buck Converter, |Vi|<Vo：Boost Converter



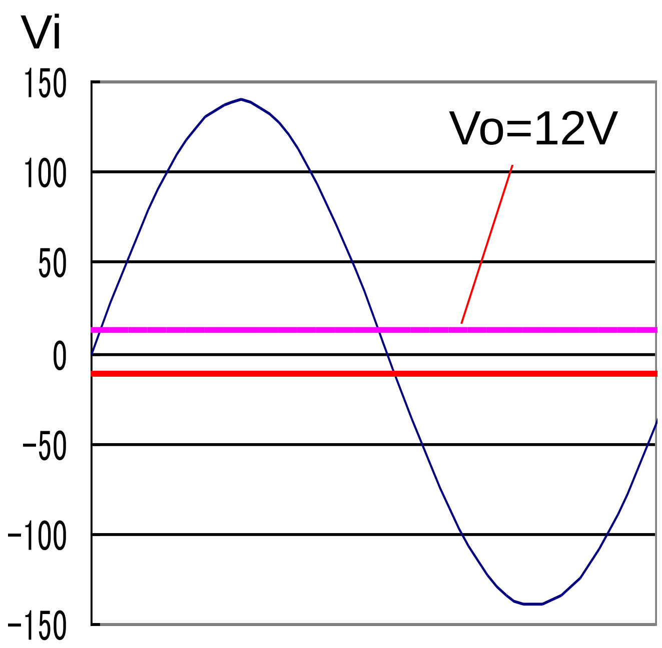


Fig.2-1 Block Diagram of Proposed Circuit without PFC

● Operation 1

1）Vi ＞ 0　　　　　［Switches］　（Current）

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

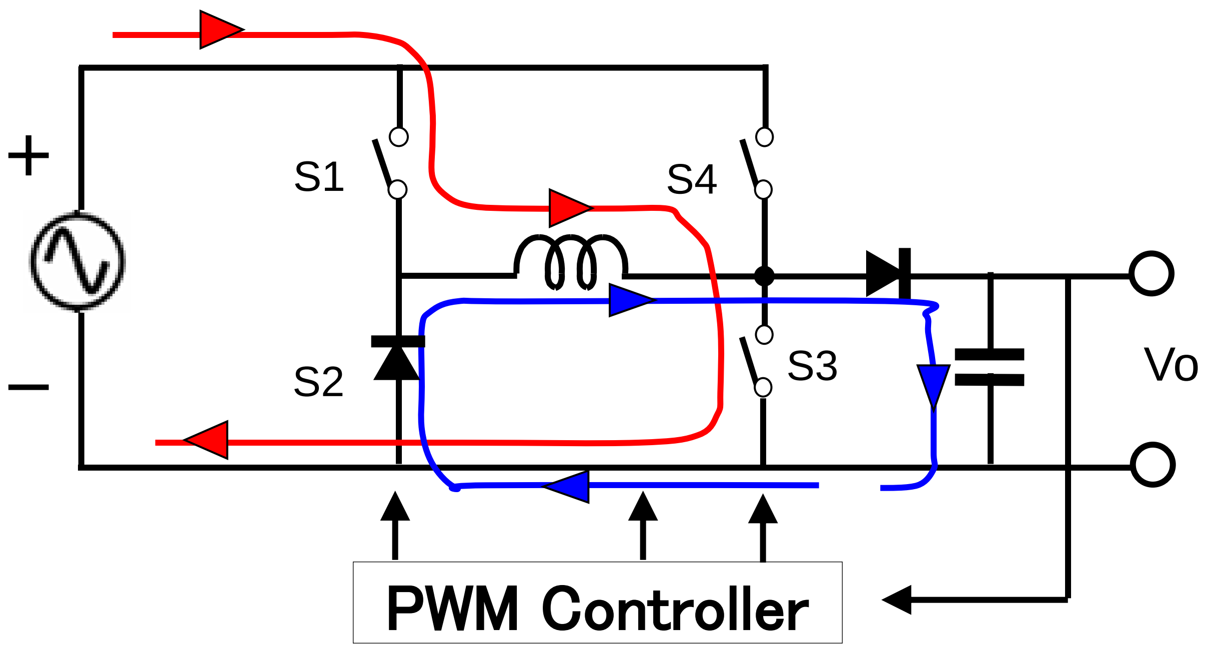


Fig. 2-2a Operation when Vi > 0

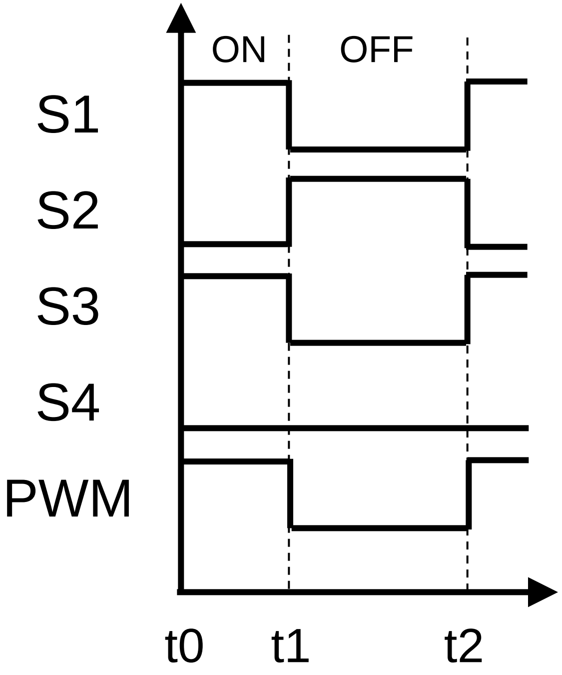


Fig. 2-2b Timing Chart

● Operation 2

2) Vi < 0 [Switches] (Current)

・when PWM=「H」⇒ S2, S4 : ON (RED line)

・when PWM=「L」⇒ S2 : ON (BLUE line)

⇒ S2 is exchange to Di.

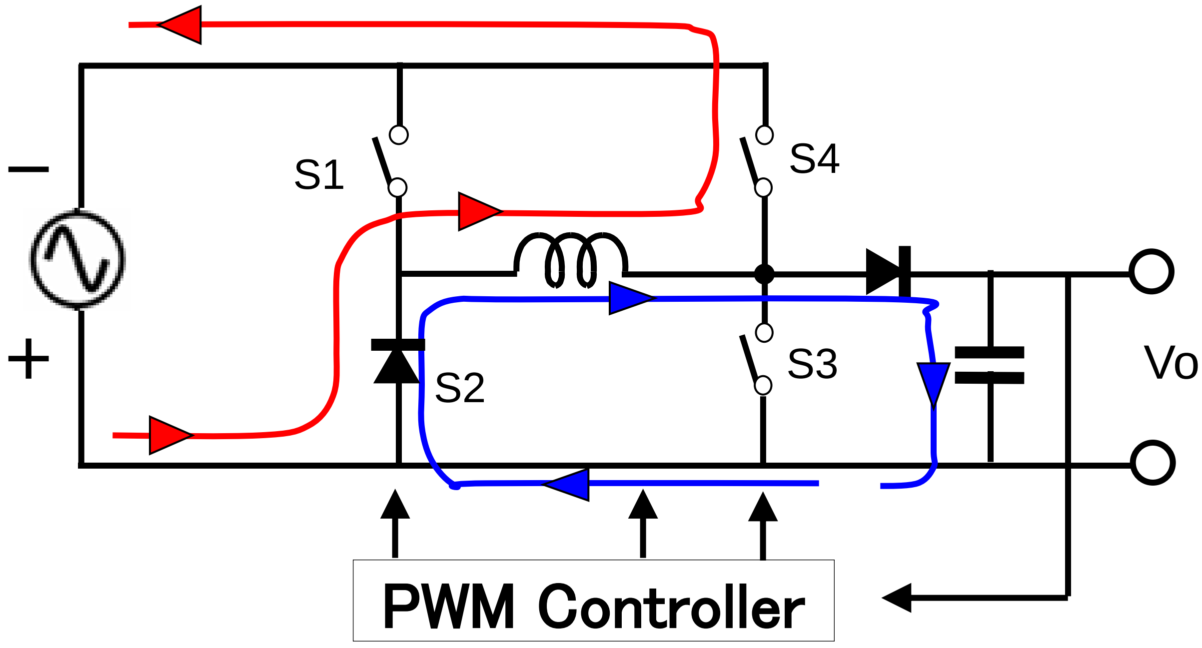


Fig. 2-3a Operation when Vi < 0

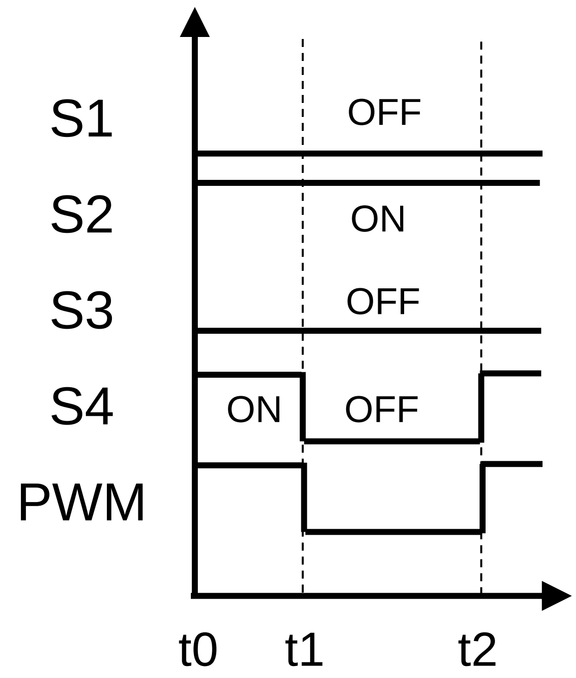


Fig. 2-3b Timing Chart

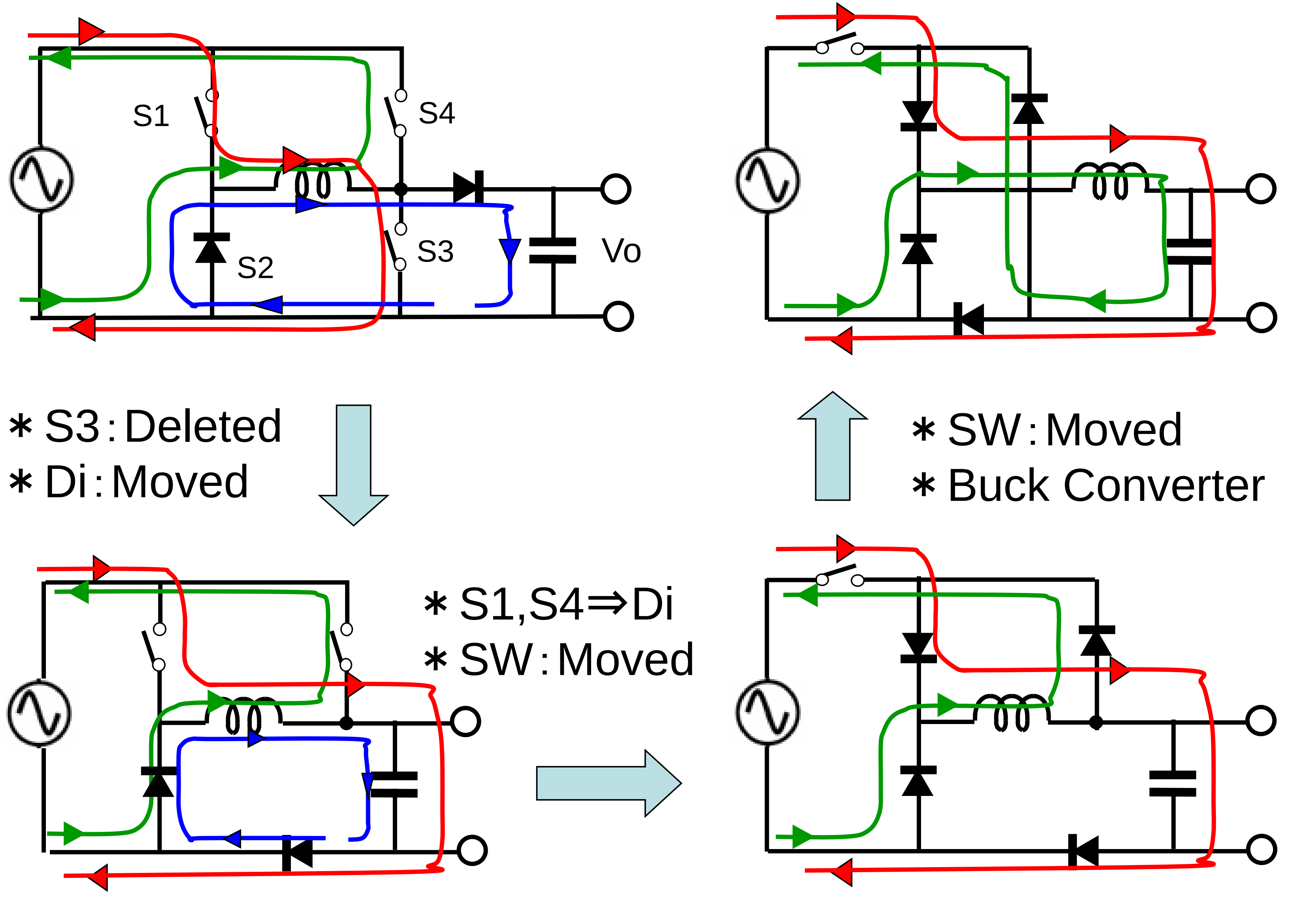
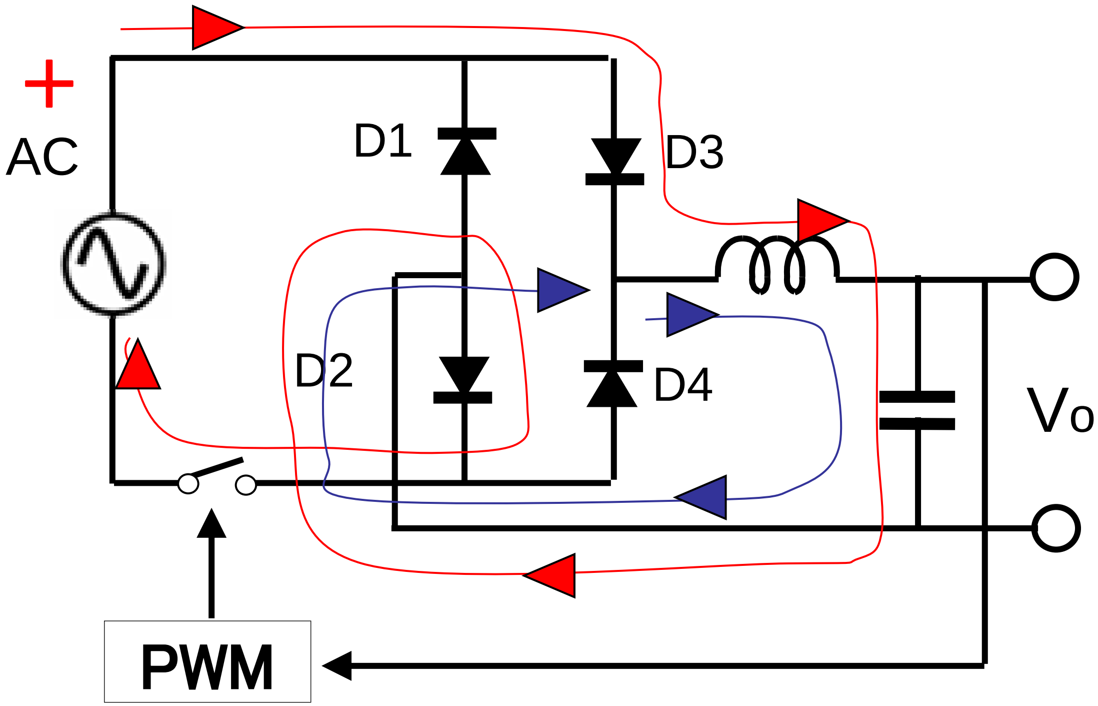
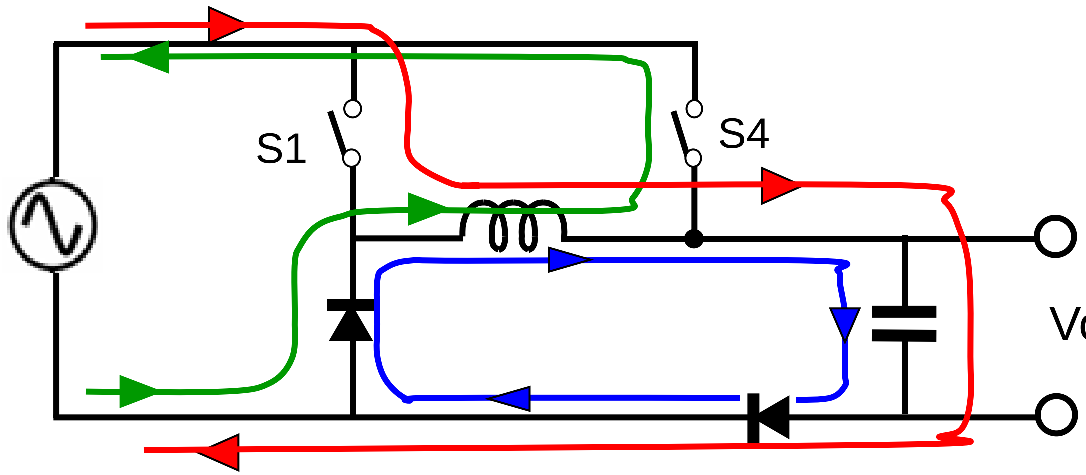


Fig. 2-3c Transformation from Buck-Boost to Buck Converter


+
AC
D1
D3
D2
D4
Vo
PWM


S1
S4
Vo

2-2 Di-Bridge Type Buck Converter

- Using Di-Bridge with Single SW
- Buck Converter when |Vi|＞Vo：Vo≒12～24V
  - ・when PWM = 「H」 ⇒ SW： ON (RED line)
  - ・ when PWM = 「L」 ⇒ SW：OFF (BLUE line)

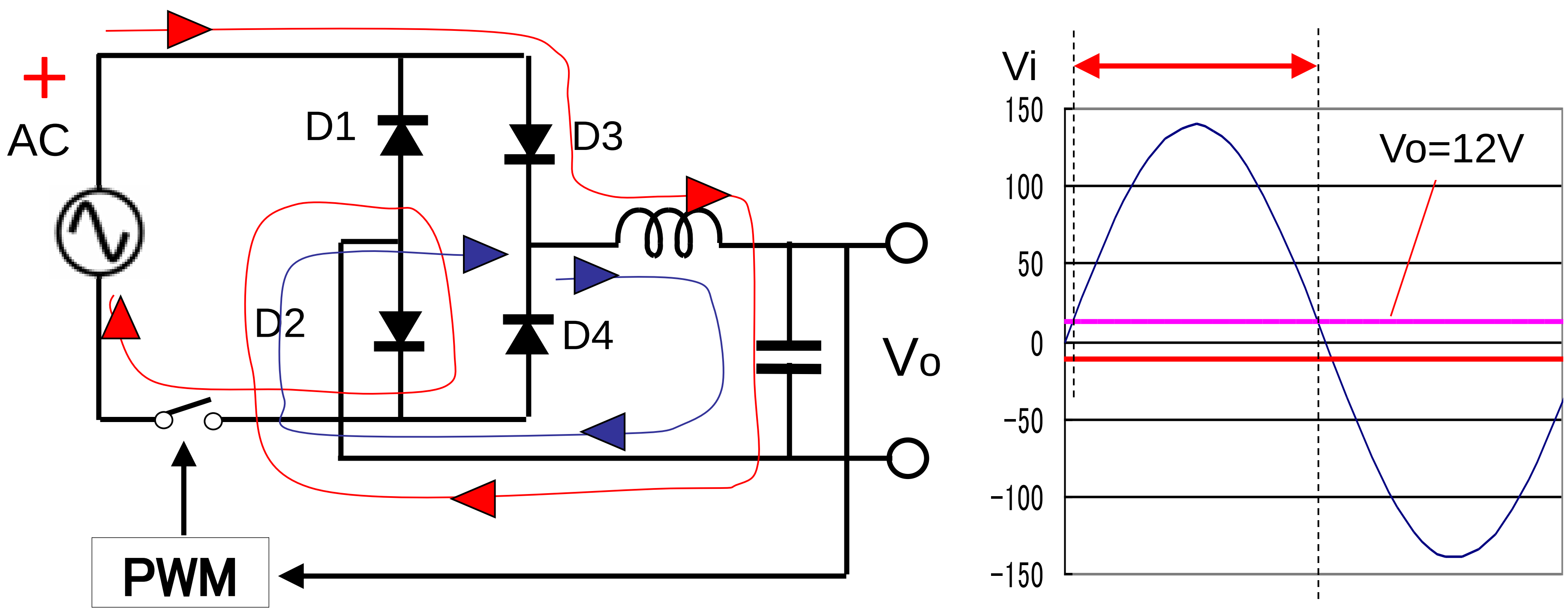


Fig.2-4 (a) Block Diagram & Operation (**Vi＞0**)

2-2 Di-Bridge Type Buck Converter

- ⊿θ: Phase not to work for Buck Converter
  - ⊿θ : 5.4% (when Vi=100 Vrms, Vo=12V)
  - ⊿θ : 2.1% (when Vi=260 Vrms, Vo=12V)

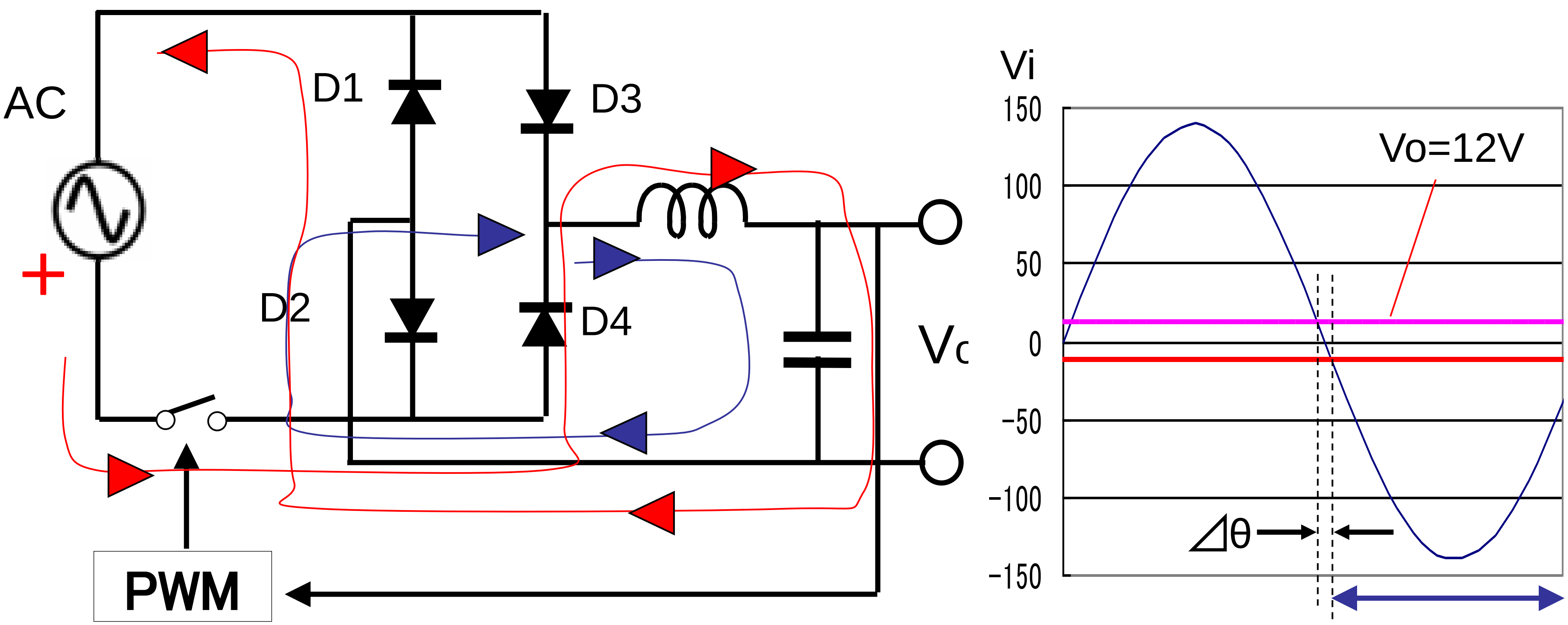


Fig.2-4 (b) Block Diagram & Operation (**Vi＜0**)

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

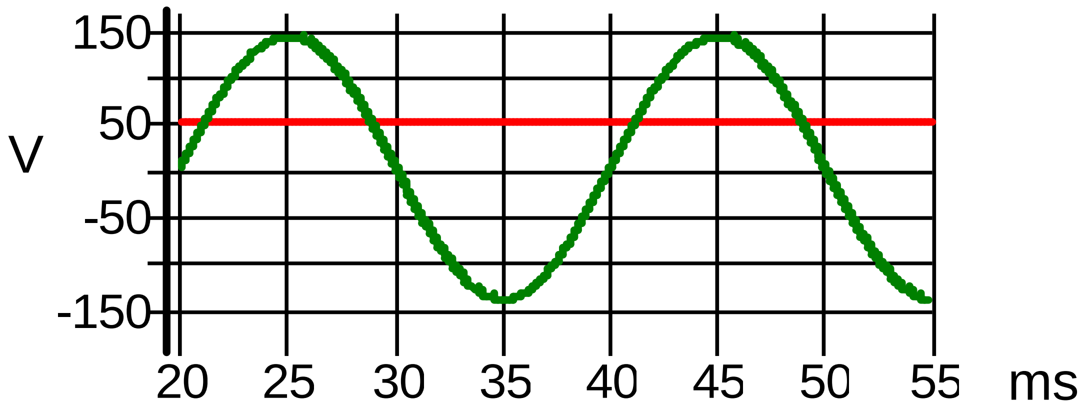


Fig.2-5 Waveform of Input & Output V

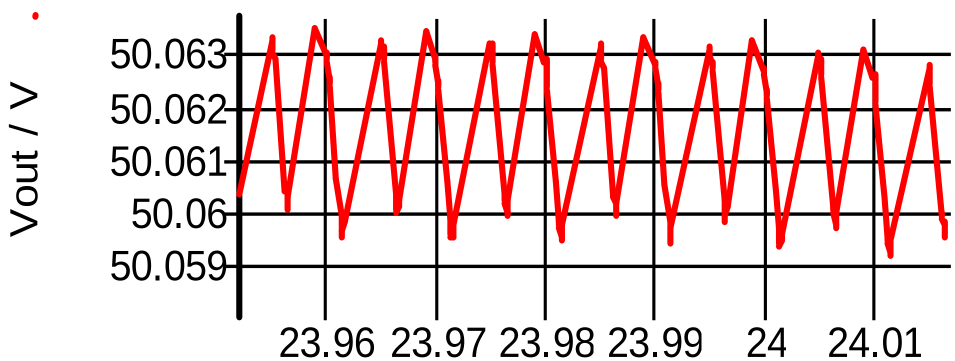


Fig. 2-6 Output Voltage Ripple

⊿Vo = 5 mVpp

⊿Vo／Vo = 0.01 %

(3) Transient Response

- Voltage Ripple

  $\Delta V_o = \pm 15\ \mathrm{mV}$

- Voltage Offset

  $\Delta V_{OS} = 5\ \mathrm{mV}$

∗ Conditions

$I_o = 1.0 / 0.5\ \mathrm{A}$

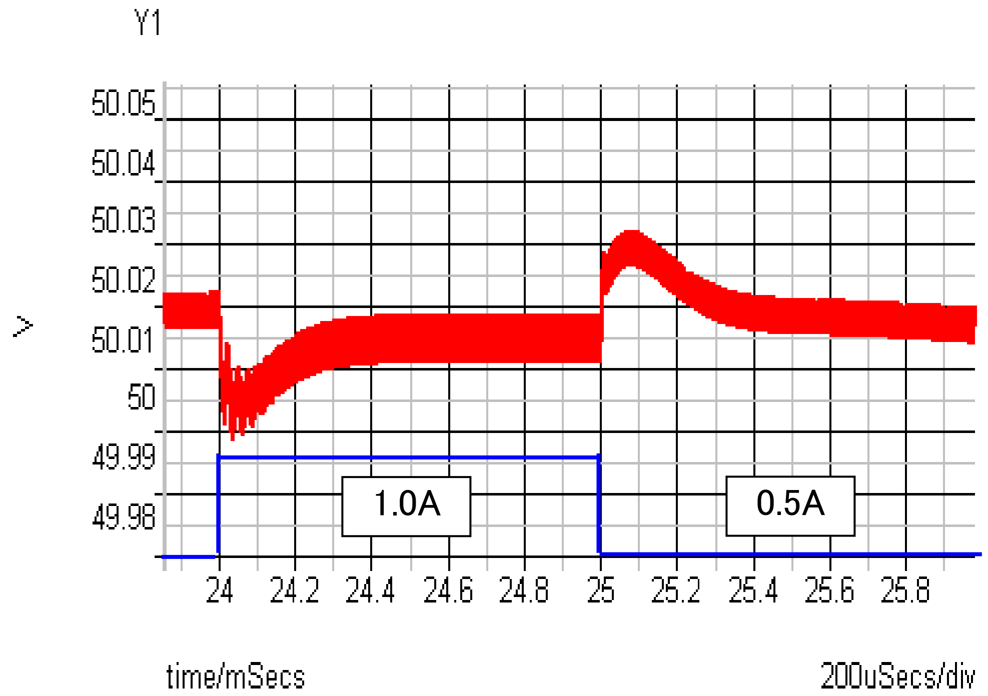


Fig. 2-7 Transient Response

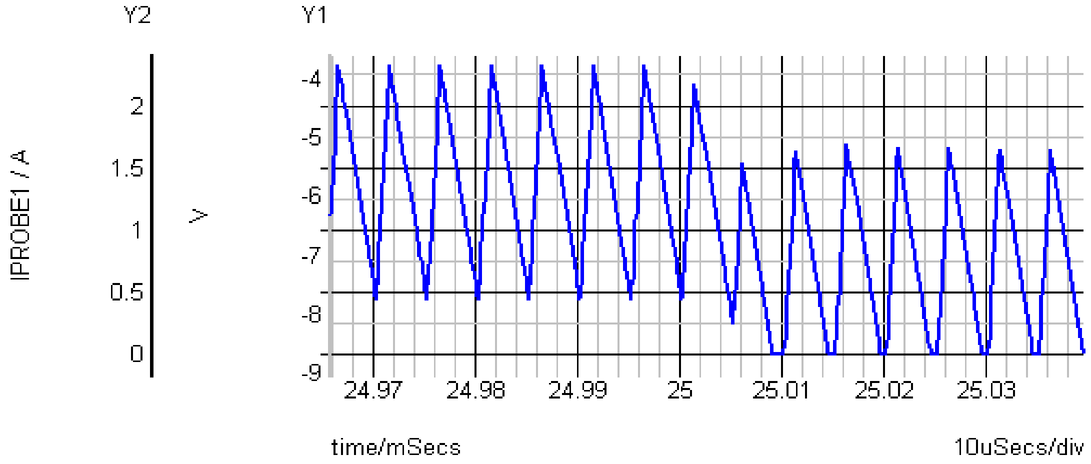


Fig. 2-8 Waveform of inductor current

(4) Simulation Circuit (H–Bridge Type)

- Conditions : Vi = AC100V、Vo=DC50V、Io=1.0/0.5 A
  L=220uH、C=220uF

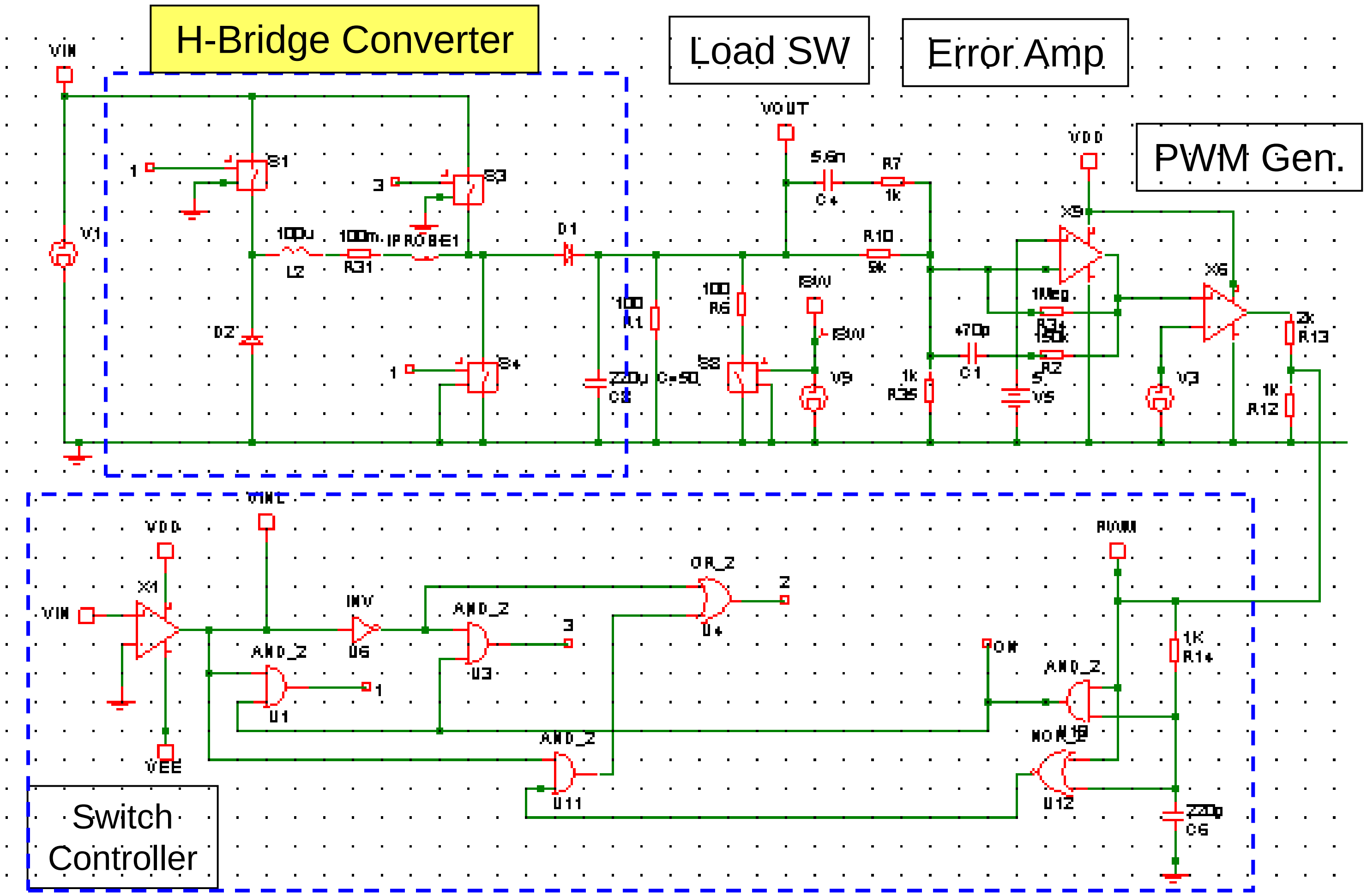


Fig.2-9 Simulation Circuit with H-Bridge

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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

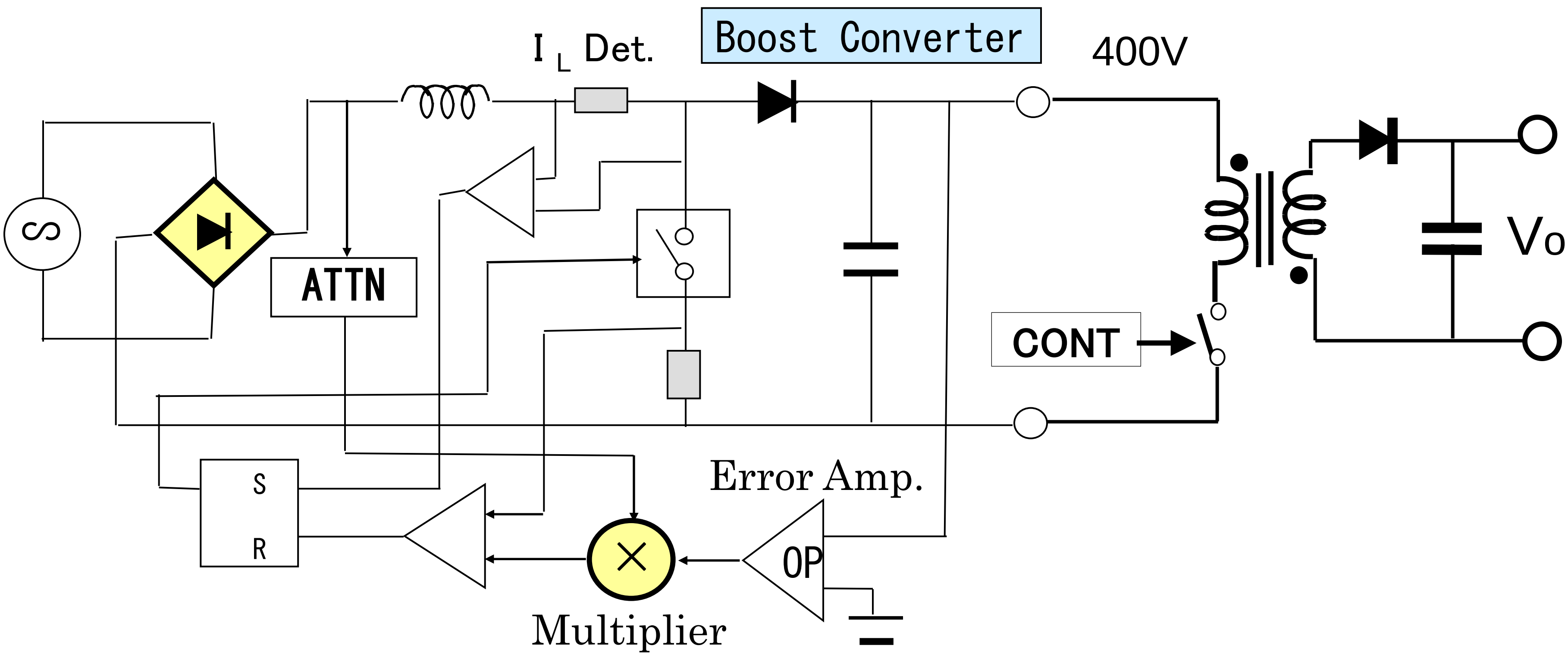

Fig. 3-1 Block Diagram of Conventional BCM PFC

3-1 Boundary Conduction Mode PFC

（1）Conventional Converter with BCM PFC

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

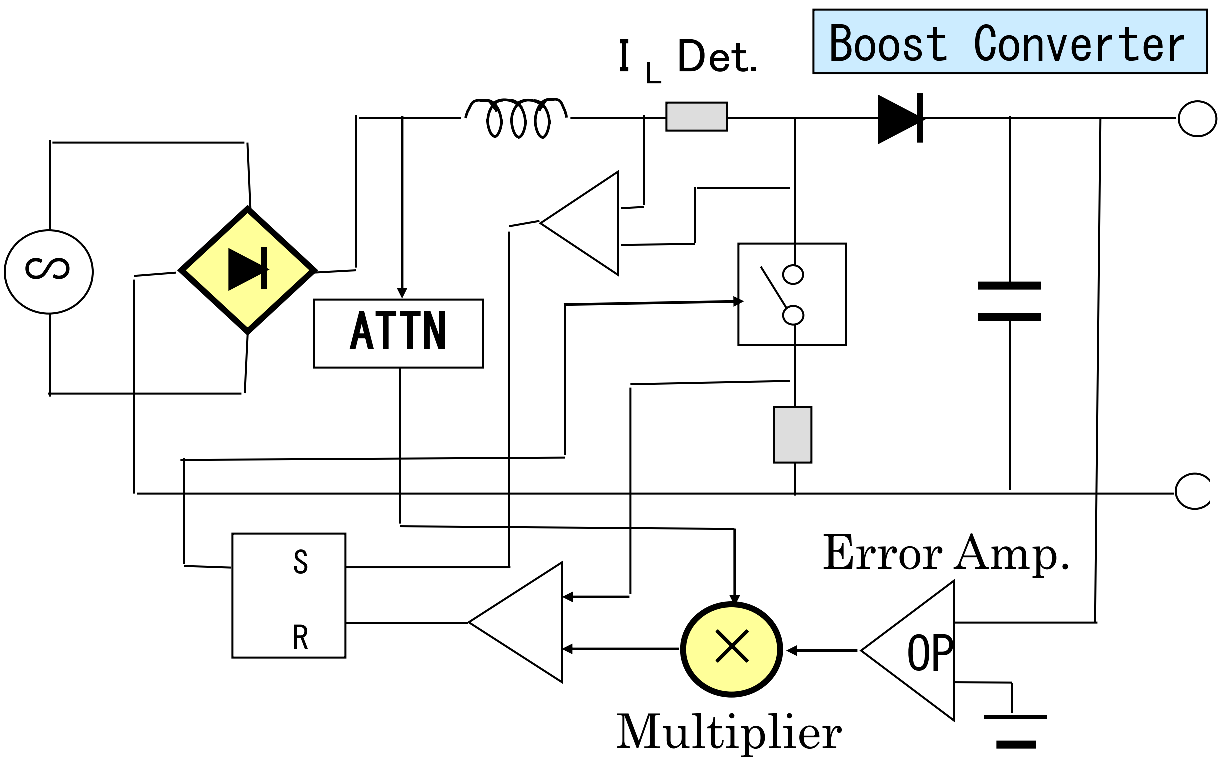

Fig. 3-1 Construction of Conventional BCM PFC

＊Current Condition

I min = 0 A

Ip ∝ Vi

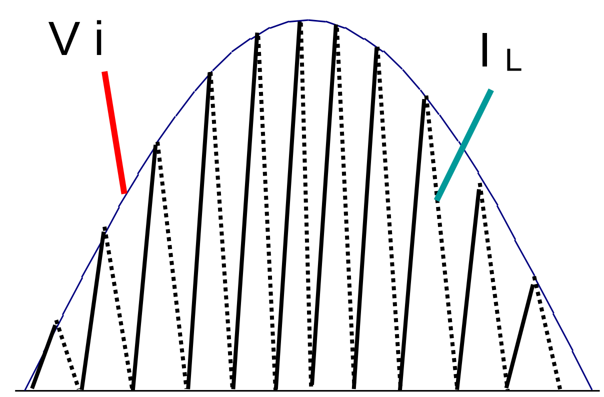

Fig.3-2 Inductor Current

(2) Proposed Buck-Boost Converter with H-Bridge

- Construction : H-Bridge + New Multiplier
- New Multiplier : using Voltage Controlled Current Source
- Conditions
  - ・Vo = 24 V, Io = 0.24A
  - ・L= 60 uH , C = 47mF
- Tr =Cr･Ve/ A∝Ve･E

  Kr=Vi／L

  Ip=Kr･Tr ∝ Vi

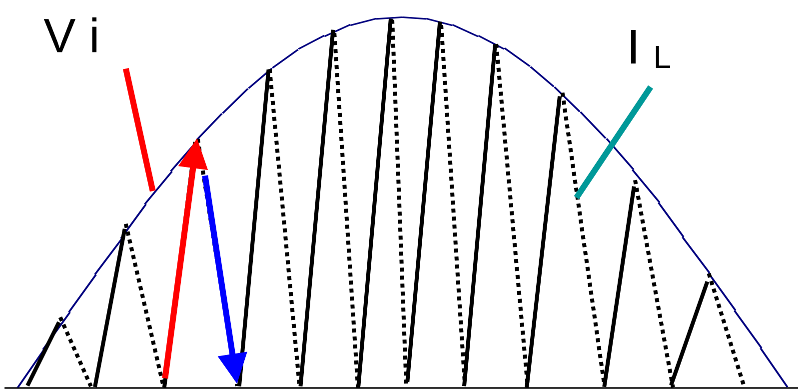

Fig.3-2 Inductor Current

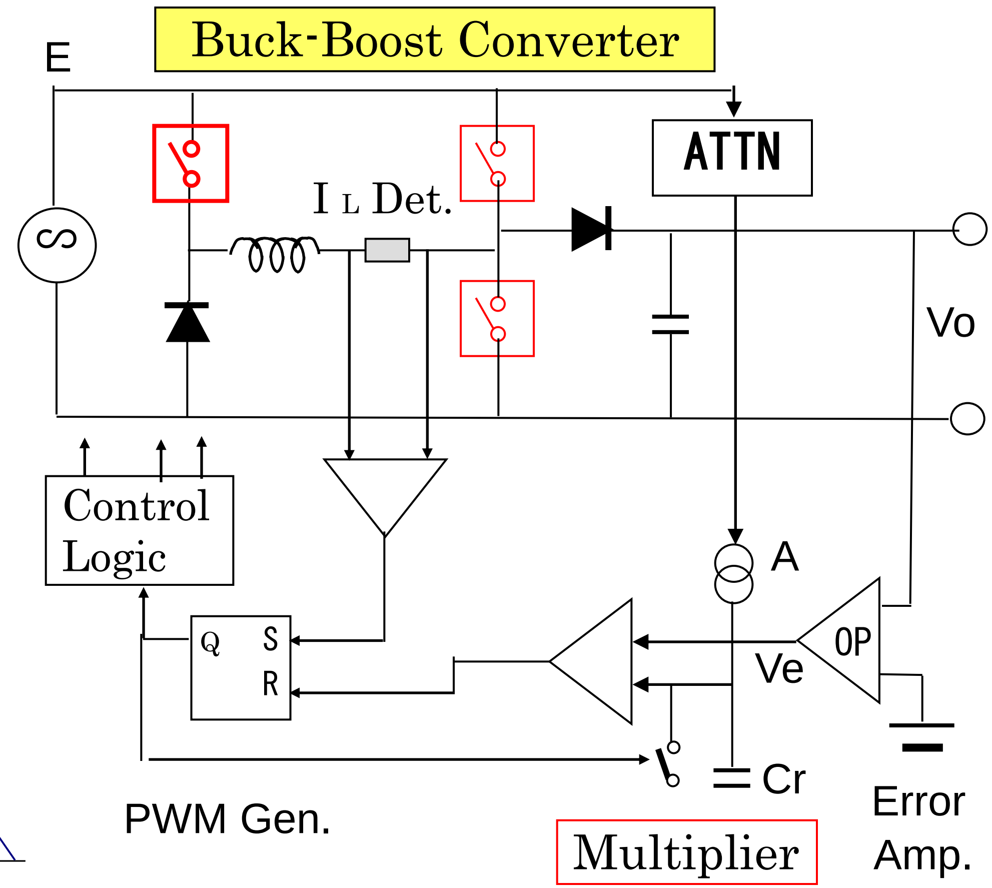

Fig. 3-3 Construction of New BCM PFC

(3) Proposed Buck Converter with D-Bridge BCM PFC

- Construction : Single SW + Di-Bridge + New Multiplier
- Conditions
  - ・Vo =12 V, Io=0.24A
  - ・L= 20 uH , C=100mF

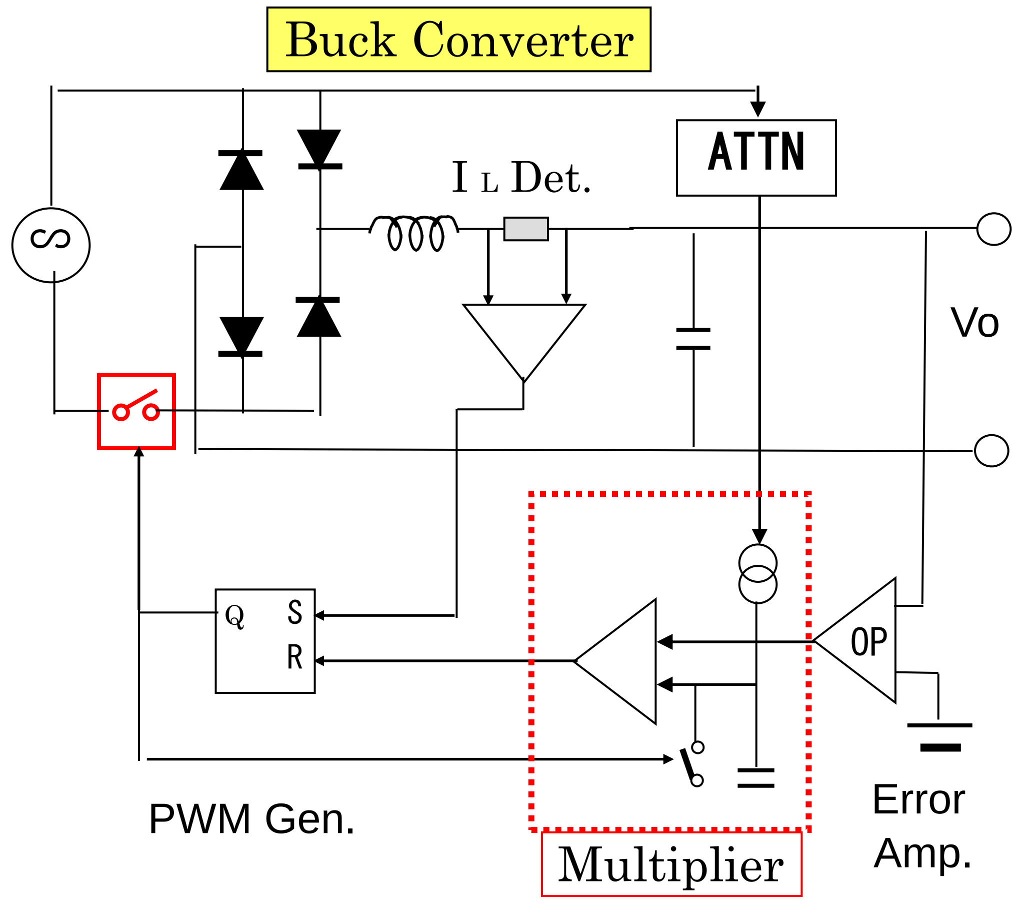

Fig. 3-3 Construction of New BCM PFC

3-2 Simulation Results (Buck-Boost with BCM PFC)

（1）Input Current (Low-Pass Filtered)

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

- Conditions
  - Vi = 100 Vrms, 50Hz
  - **Vo = 24 V**
  - Io = 0.24A, 1.0A
  - L=50uH,
  - C=47mF

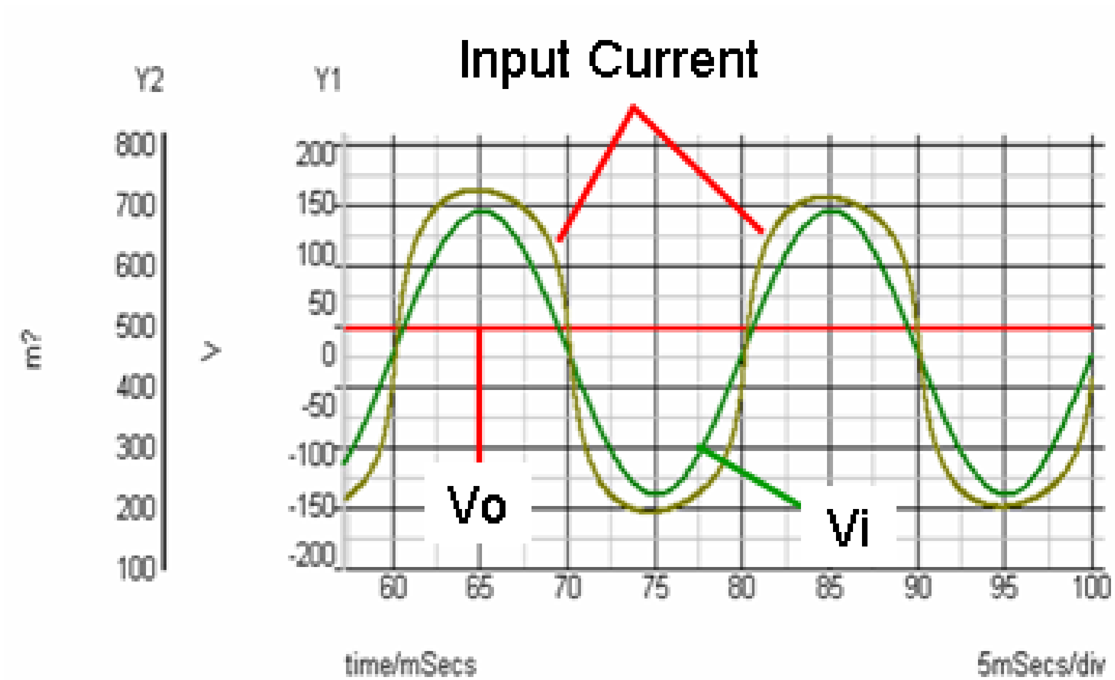

Fig.3-4 Input Voltage and Current

- 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)

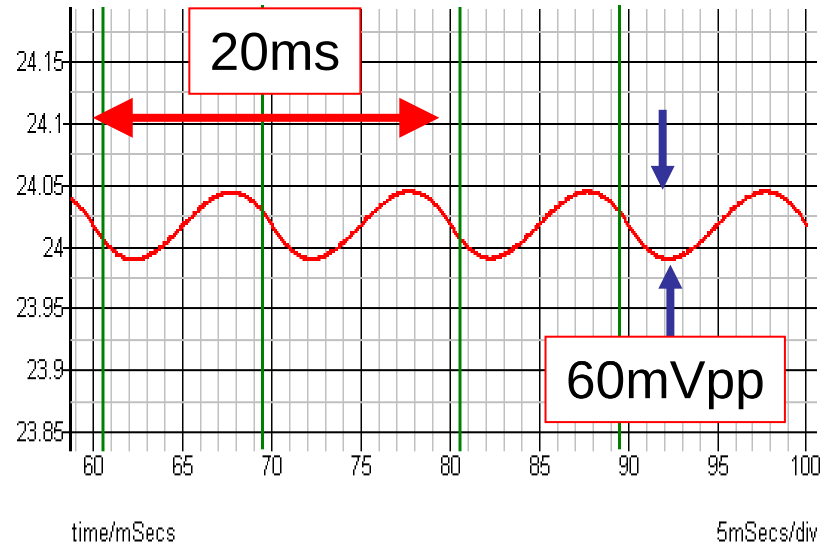

Fig.3-6 Output Voltage Ripple

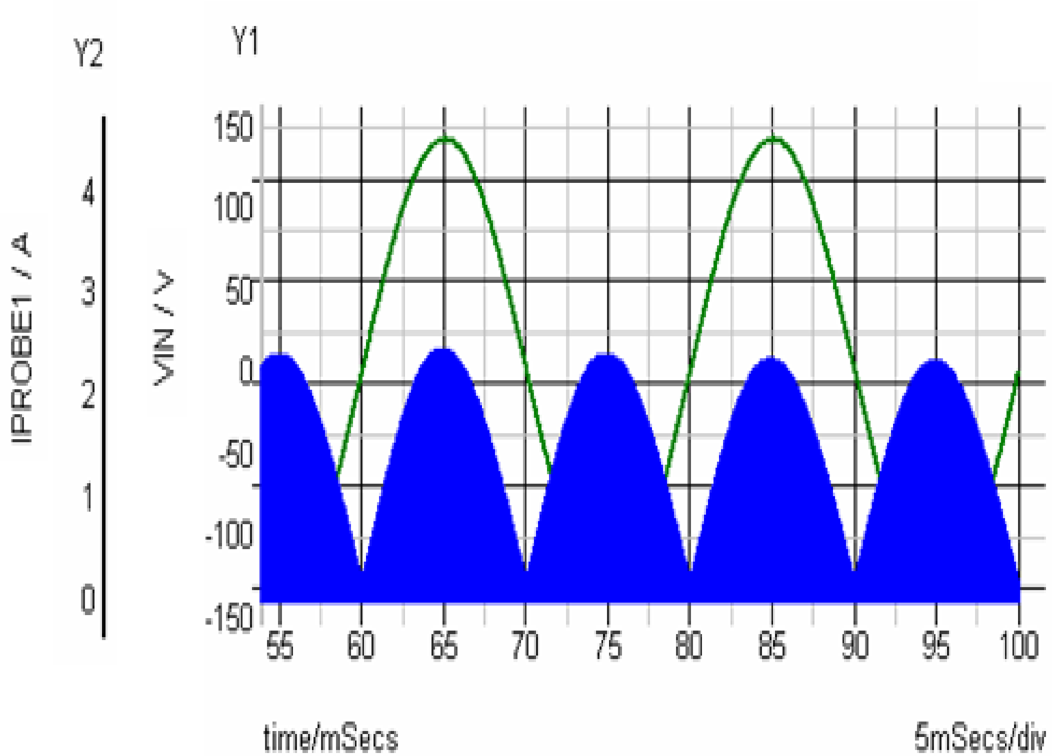

Fig.3-5 Inductor Current

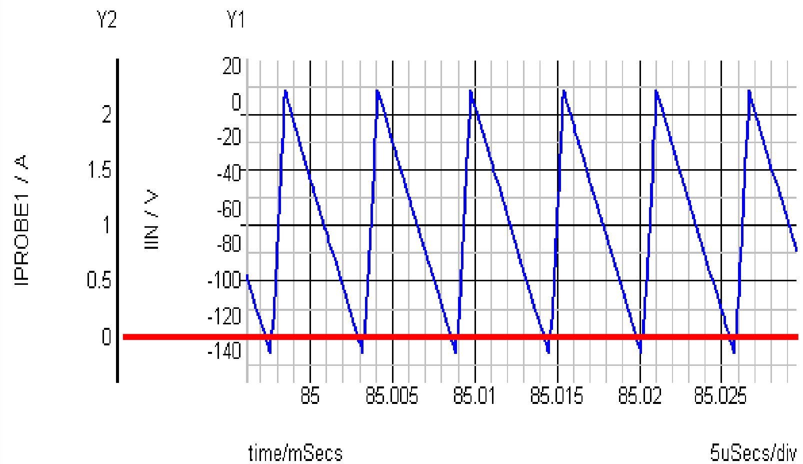

Fig.3-7 Inductor Current

(2) Output Ripple and Offset vs. Output Current

- Output Ripple: ⊿Vrip = 50mVpp · Io
- Voltage Offset: ⊿Vos ∝ −50mV · Io [∝ 1／Loop Gain]

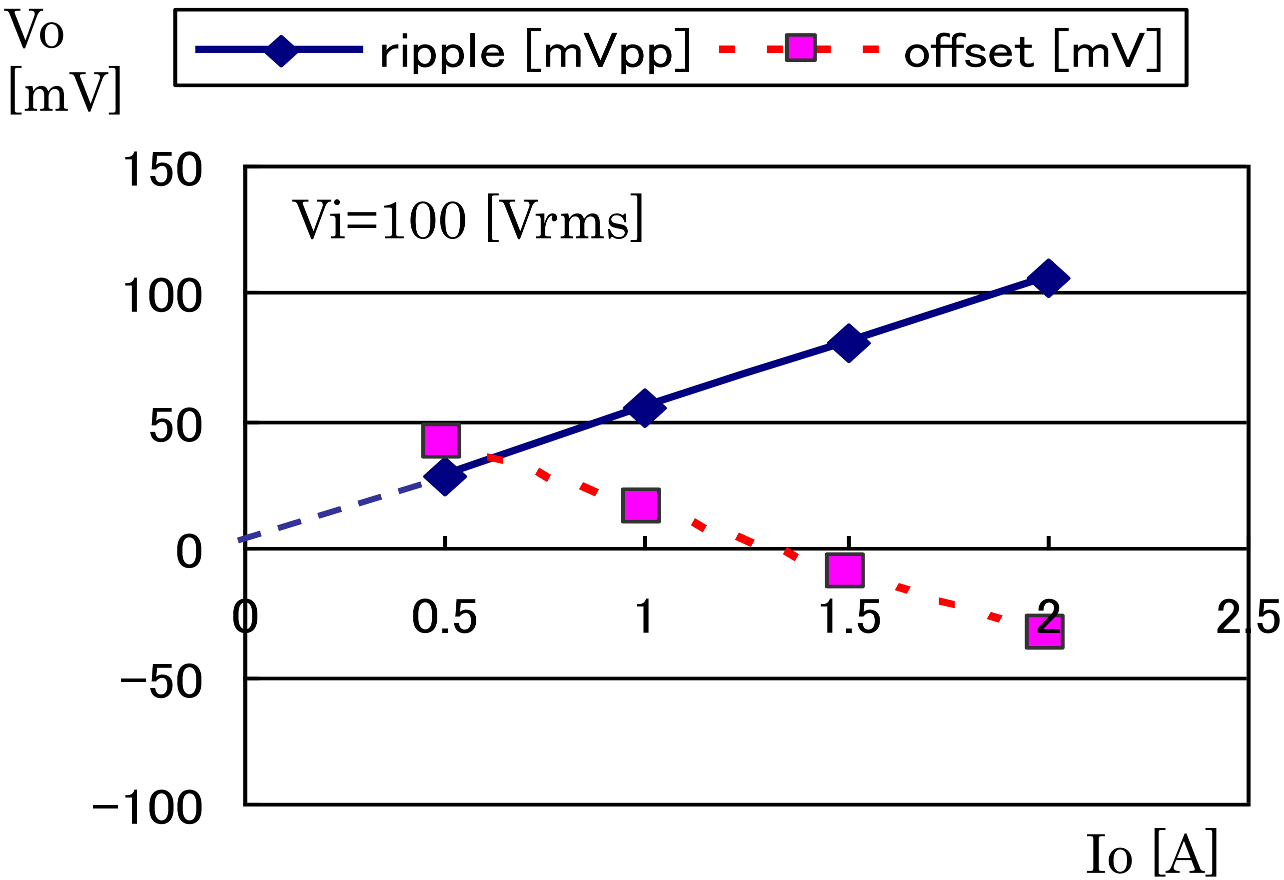

Fig.3-8 Output Ripple & Offset vs. Output Current

（3）Output Ripple and Offset vs. Input Voltage

- Output Ripple ＝ Constant (@ Vi=100Vrms, Io=1.0A)
- Voltage Offset ∝ 1／Vi （≒60－4000/Vi mV）

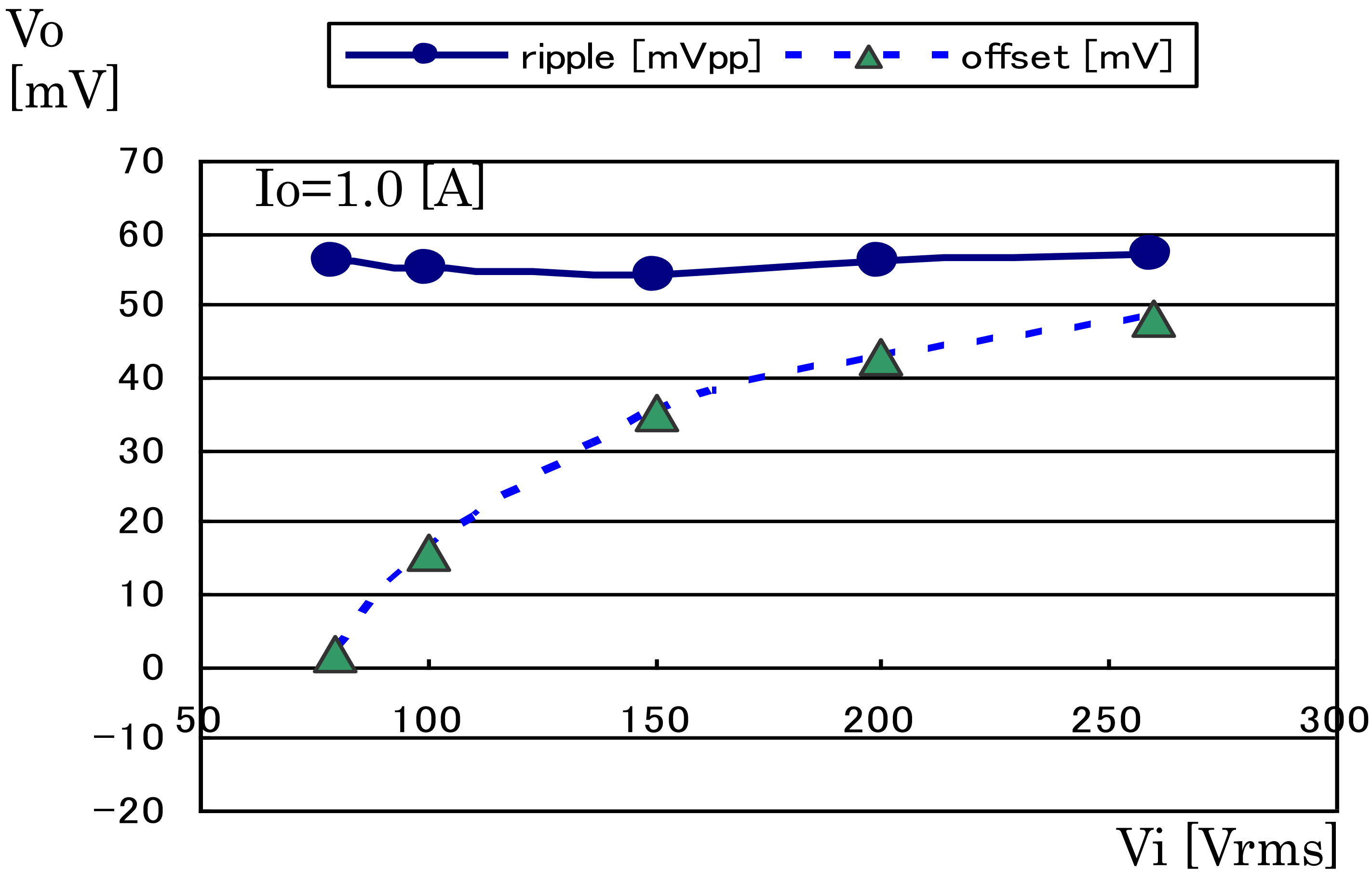

Fig.3-9 Output Ripple & Offset vs. Input Voltage

(4) Simulation Circuit 1 : H-Bridge Converter

- Conditions : Vo=12V、Io=1.0A、L= 50uH、C = 47mF

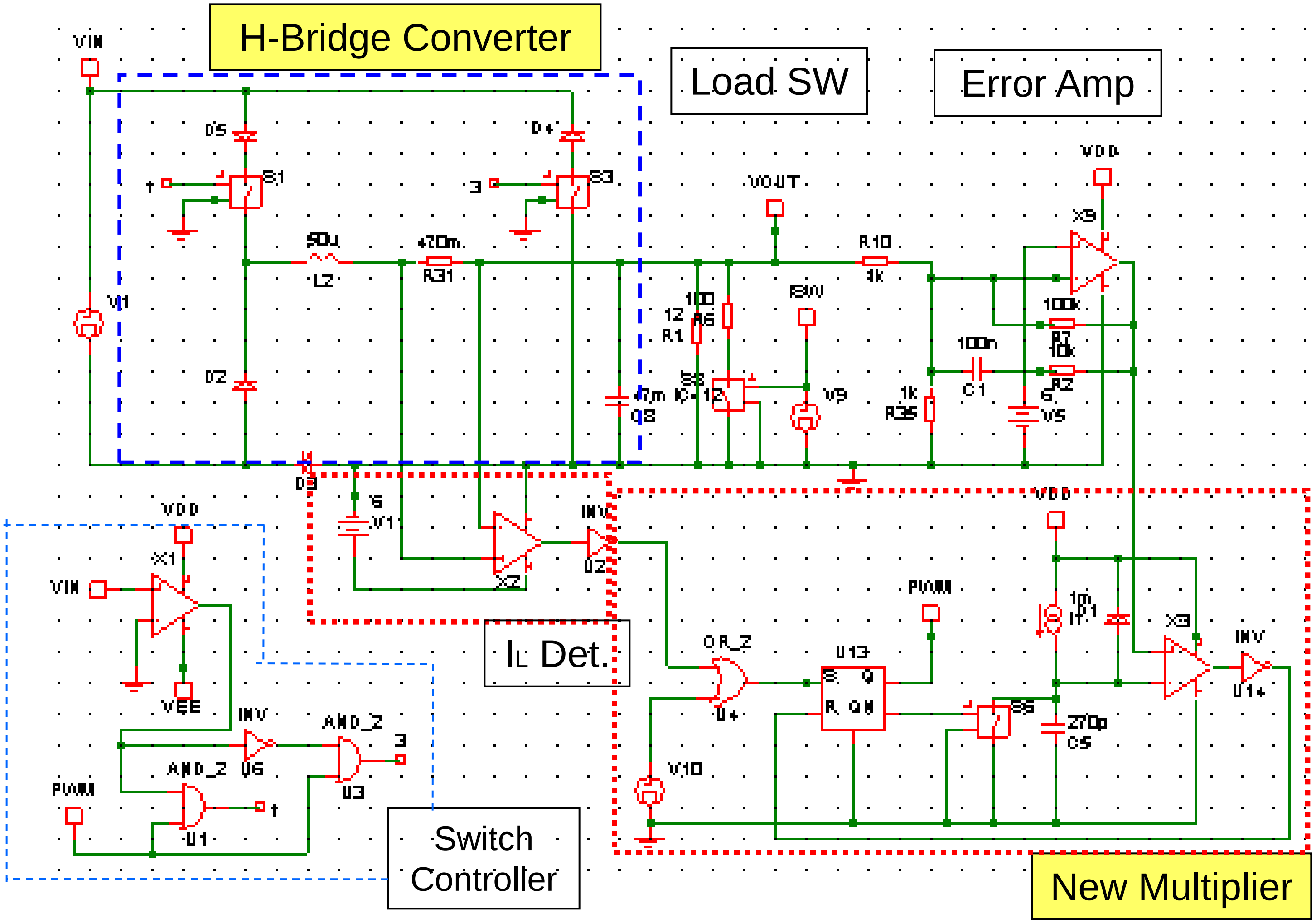

Fig.3-10 Simulation Circuit with **H-Bridge BCM-PFC** Circuit

(5) Simulation Circuit 2：Di–Bridge Converter

● Conditions : Vo=12V、Io=1.0A、L= 20uH、C = 100mF

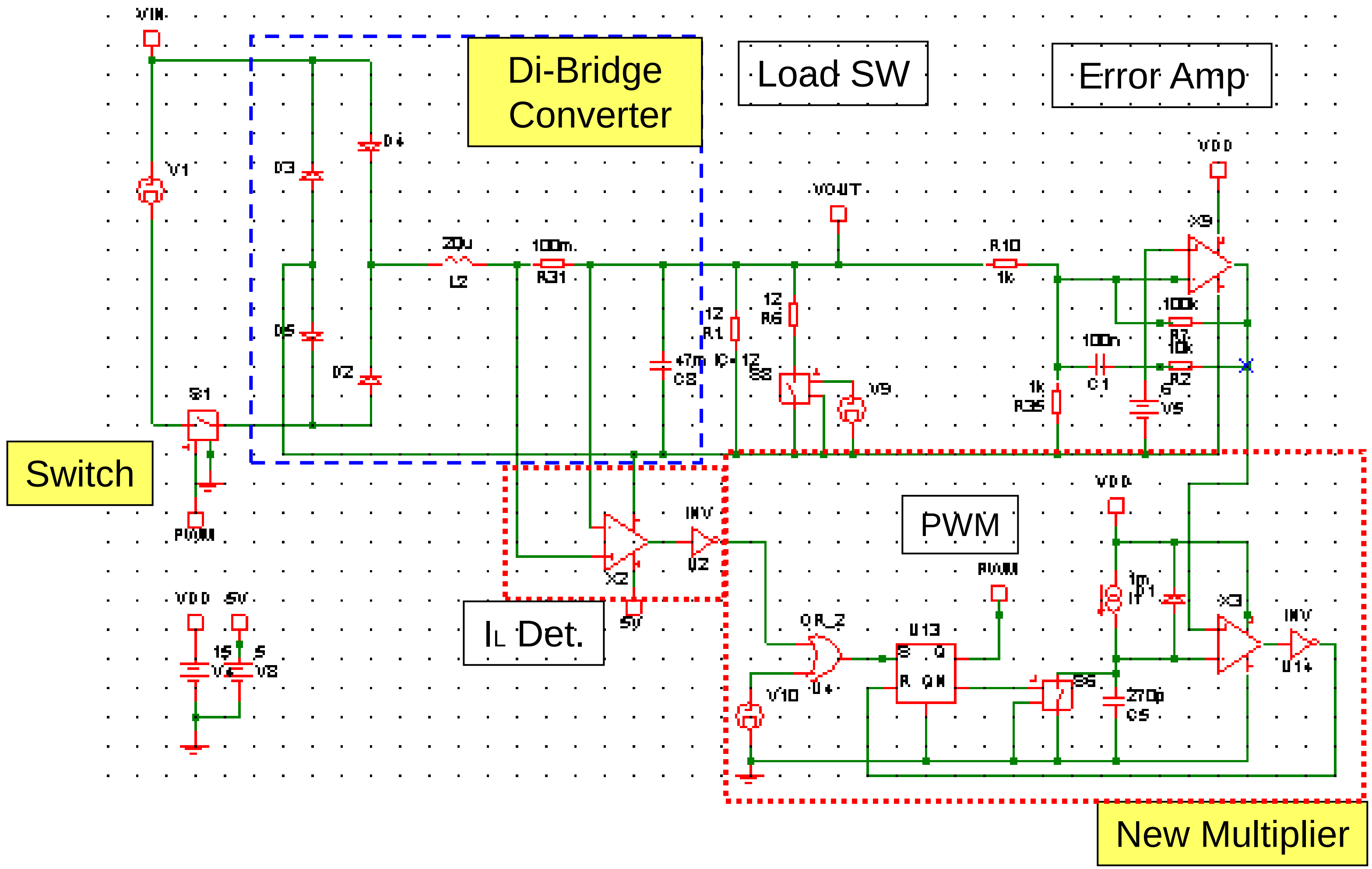

Fig.3-11 Simulation Circuit with **Di-Bridge BCM-PFC** Circuit

3-3 Experimental Results (Buck Converter with BCM PFC)

（1）Input Current Waveform

- Condition：Vo=12 V, Vi=50Vrms (50Hz), Io=0.2A
  L=200mH, C=2000uF , Fpwm=50kHz

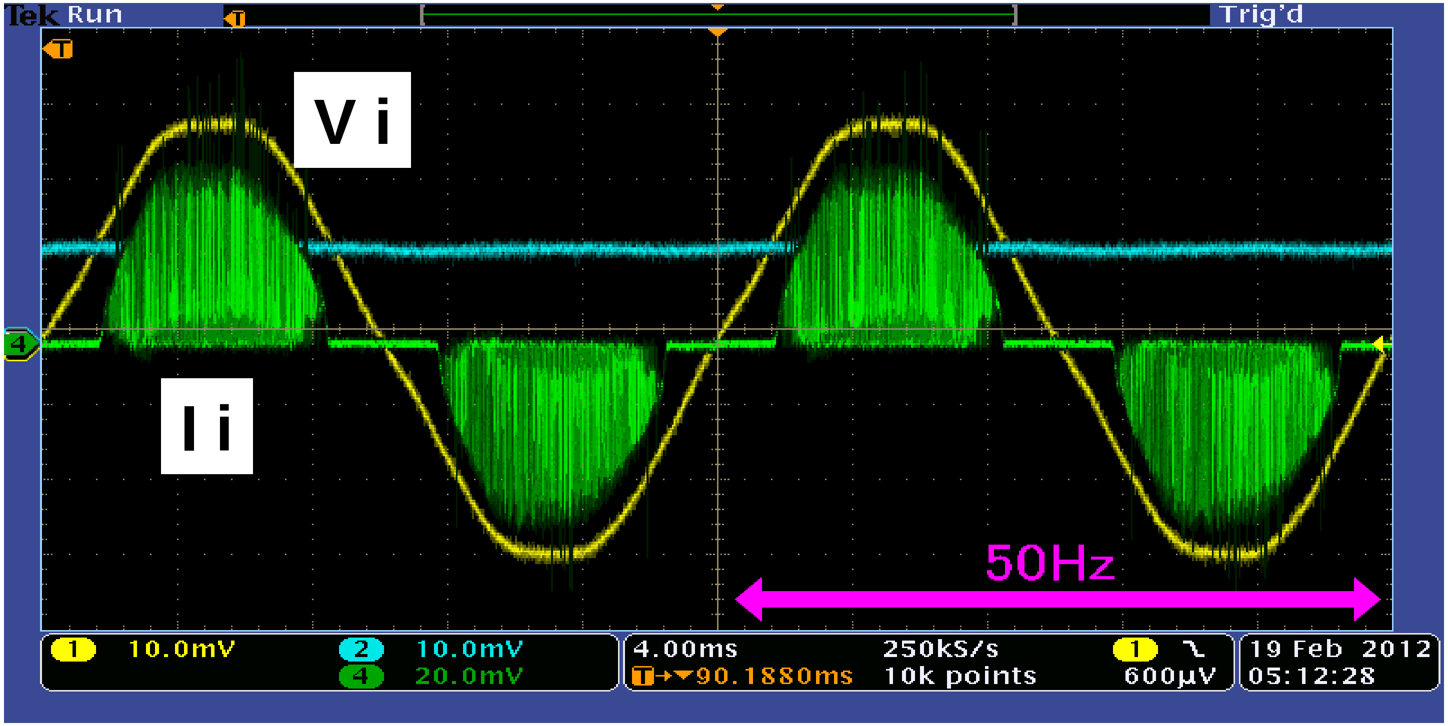

Fig.3-12 Input Voltage and Current

3-3 Experimental Result (Buck Converter with BCM PFC)

（1）Output Voltage Ripple (Output of Amplifier)

- Output Voltage Ripple = 20 mV_{pp} (Amp. Gain = 40 dB)
- Frip =2･Fin (Frip =100Hz)

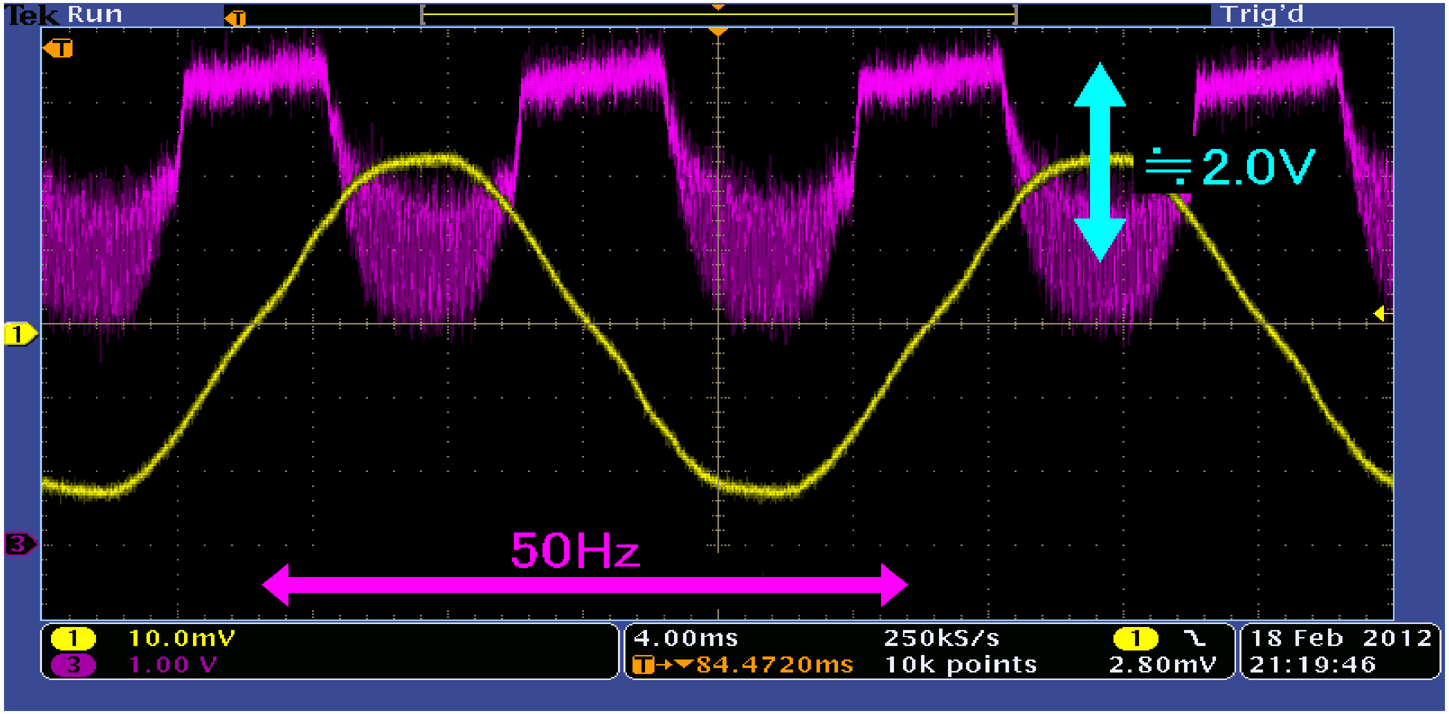

Fig.3-13 Output Voltage Ripple after Amplified

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!