SIDO converter with variable control time duty

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OUTLINE

• Background and Objective
• Conventional Buck-Buck SIDO converter and drawback of conventional control method
• Proposed control method
• Sawtooth wave generator circuit
• Simulation results
• Conclusions and Future works
• Background and Objective
  • Conventional Buck-Buck SIDO converter and drawback of conventional control method
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Background and Objective

Converts power-supply voltage for electronic device.

- AC-DC converter: AC input-DC output
- DC-DC converter: DC input-DC output
- AC-AC converter: AC input-AC output
- DC-AC converter: DC input-AC output

Voltage types:
- 220V AC
- 12V DC
- 1.5V DC
Numerous converters used in a single device.

Increases the area of electronic devices.
Background and Objective

Buck-Buck SIDO converter

DC-DC converter
DC input-DC output

SIDO means · · ·
Single Inductor Dual Output

Miniaturization
Dual Outputs
Single Inductor
High Performance

New control method

Background and Objective

Buck-Buck SIDO converter

DC-DC converter DC input-DC output

SIDO means · · ·
Single Inductor Dual Output

Miniaturization

High Performance
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Conventional Buck-Buck SIDO converter

Power Stage

Timing Chart

\[ V_{in} \]

\[ I_L \]

\[ S0 \]

\[ D \]

\[ S1 \]

\[ C1 \]

\[ R1 \]

\[ S2 \]

\[ C2 \]

\[ R2 \]

\[ V_{o1} \]

\[ I_{o1} \]

\[ V_{o2} \]

\[ I_{o2} \]

\[ T \]

\[ T_{o1} \]

\[ T_{o2} \]

\[ T1 \]

\[ T2 \]

\[ T3 \]

\[ T4 \]

\[ S1 \] ON

\[ S2 \] OFF

\[ S0 \] ON

\[ I_L \]

\[ I_{o1} \]

\[ I_{o2} \]
Conventional Buck-Buck SIDO converter

**Power Stage**
- S0, S1, S2: Switches
- C1, C2: Capacitors
- R1, R2: Resistors
- \( V_{in} \): Input voltage
- \( V_{o1}, V_{o2} \): Output voltages
- \( I_L, I_{o1}, I_{o2} \): Currents

**Determination of supply value**

**Determination of supply destination**

**Timing Chart**
- \( T, T_{o1}, T_{o2}, T_1, T_2, T_3, T_4 \): Time intervals
- S1, S2, S0: Switch states
- \( I_L, I_{o1}, I_{o2} \): Currents over time

**Conventional Buck-Buck SIDO converter**
- Timing chart for switch states and current flow.
Conventional Buck-Buck SIDO converter

Power Stage

Timing Chart

Load current is determined by this area
Conventional Buck-Buck SIDO converter

Control time ratio $T_{o1}:T_{o2}$ is fixed.
Drawback of conventional control method

It isn’t possible to work in large load current ratio.
Proposed method

Conventional

Control time ratio is **fixed**

Proposal

Control time ratio is **variable**

Operation range will become larger
• Background and Objective
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Proposed control method

Entire block diagram of the proposed circuit

Power stage

Control stage
Proposed control method

【Flow of the proposed control method】

I. Acquisition of error voltage $\Delta V_{o1}, \Delta V_{o2}$.

II. Generation of SEL signal responding to two output voltage error ratio.

III. Generation of sawtooth wave with matching the High/Low time width of SEL signal.

IV. Generation of PWM signal by comparing sawtooth with $\Delta V_{o1}, \Delta V_{o2}$. 
Proposed control method

Block diagram of control circuit

Flow of the proposed control method

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14年10月20日 月曜日
Proposed control method

Block diagram of control circuit

Relation between the value of and control time ratio

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Proposed control method

Block diagram of control circuit

Flow of the proposed control method

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III. Generation sawtooth wave with matching the High/Low time width of SEL signal.

IV. Generation of PWM signal by comparing sawtooth with \( \Delta V_{o1}, \Delta V_{o2} \).

In case of \( \Delta V_{o1} > \Delta V_{o2} \)

\[ V_{SEL} \]

\[ T_{o1} \quad T_{o2} \]

\[ \text{sawtooth1} \]

\[ \text{sawtooth2} \]

\[ t \]
Proposed control method

Block diagram of control circuit

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IV. Generation of PWM signal by comparing sawtooth with $\Delta V_{o1}, \Delta V_{o2}$.

In case of $\Delta V_{o1} > \Delta V_{o2}:

- $\Delta V_{o1}$
- sawtooth1
- $\Delta V_{o2}$
- sawtooth2

PWM1

PWM2

PWM

Time ($t$)
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Sawtooth wave generator circuit

Block diagram of control circuit

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More detail
Sawtooth wave generator circuit

Sawtooth wave generator used in proposal method

Searches the peak value of sawtooth.

Internal of sawtooth

Voltage controlled current source

Block diagram of control circuit

Sawtooth wave generator circuit is used in the proposal method. It searches the peak value of the sawtooth waveform.
Sawtooth wave generator circuit

Sawtooth wave generator used in proposal method

Timing chart

Sawtooth wave is generated.

Sawtooth wave is generated.

voltage controlled current source
Sawtooth wave generator circuit

Sawtooth wave generator used in proposed method

By comparing $\Delta V_{o1}$, PWM1 is generated.

Relation between value of $\Delta V_{o1}$ and width of PWM

By comparing $\Delta V_{o1}$ sawtooth, PWM1 is generated.
Sawtooth wave generator circuit

Sawtooth wave generator used in proposal method

SET: $\Delta V_{o1-max} = \text{Peak value of sawtooth}$

Width of $PWM_{max} = \text{Width of } T_{o1}$.

Relation between value of $\Delta V_{o1}$ and width of $PWM$

$\Delta V_{o1-max}$

$V_{dd}$

$V_{ph}$

Peak Hold

$V_c$

PWM1

$sawtooth1$

$\Delta V_{o1}$

$T_{o1}$

$PWM_1$

$PWM_{max}$

$t$

$\Delta V_{o1}$とsawtooth1を比較しPWM1を生成する
Sawtooth wave generator used in proposal method

Sawtooth wave generator circuit

- $V_{dd}$
- $V_{ph}$
- $V_c$
- $\Delta V_{ol}$
- $PLM1$
- $SEL$
- $SW$
- $C$
- Timing chart

Increase of OFF time
Increase of peak value

$T_{o1}$

$I_o$ doesn’t increase.

PWMmax doesn’t increase.

$\Delta V_{o1max}$

$I_{o1max}$

$I_L$

$I_{o1max}$

$I_{o1max}$

$t$
Sawtooth wave generator circuit

Sawtooth wave generator used in proposal method

Control of current source

For any To1, peak value of sawtooth is constant

PWM1 max increases.

I_{o1max} increases.

Searched peak value of sawtooth

I_{o1max}

PWM1

sawtooth1

\Delta V_{o1max}

\Delta V_{o1}

V_{ph}

V_c

Peak Hold

sel

SW

C

control

voltage controlled current source
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Simulation Results

Schematic diagram of simulation circuit

Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>input voltage: $V_{in}$</td>
<td>10V</td>
</tr>
<tr>
<td>output voltage: $V_{o1}$</td>
<td>5.0V</td>
</tr>
<tr>
<td>output voltage: $V_{o2}$</td>
<td>4.0V</td>
</tr>
<tr>
<td>load current: $I_{o1}$</td>
<td>5.0A</td>
</tr>
<tr>
<td>load current: $I_{o2}$</td>
<td>0.5A</td>
</tr>
<tr>
<td>inductor: $L$</td>
<td>0.5µH</td>
</tr>
<tr>
<td>output capacitor: $C$</td>
<td>470µF</td>
</tr>
<tr>
<td>operating frequency: $f$</td>
<td>200kHz</td>
</tr>
</tbody>
</table>
Simulation Results

conventional method (control time ratio is fixed)

proposition method (control time ratio is variable)

I_{o1}=5.0[A] , I_{o2}=0.5[A]

Waveforms of SEL and I_{L}
Waveform of output voltage

\[ V[V] \]

\[ t[\text{ms}] \]

\[ V_{o1} \]

\[ V_{o2} \]

stable
Steady state output voltage ripple characteristics

$V_{o1}[V] \ 5$

16mV

$V_{o2}[V] \ 4$

3mV

0.1%

0.3%
Load step response characteristics

$I_{o1}=2.5\text{A}$

$I_{o1}=5.0\text{A}$

$I_{o1}=2.5\text{A}$

$V_{o1}[\text{V}]$ 5

$V_{o1}[\text{V}]$ 5

$V_{o2}[\text{V}]$ 4

$V_{o2}[\text{V}]$ 4

$t[\text{ms}]$

4.04

4.96

5.04

18mV

3mV

sufficiently small

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Load step response characteristics

$I_{o2}=0.25\text{A}$  $I_{o2}=0.5\text{A}$  $I_{o2}=0.25\text{A}$

$V_{o1}[\text{V}] 5$

$V_{o2}[\text{V}] 4$

$3\text{mV}$

sufficiently small
Peak value of sawtooth wave

$I_{o1} = 0.5\,[\text{A}]$, $I_{o2} = 0.5\,[\text{A}]$

$\quad I_{o1} = 5.0\,[\text{A}]$, $I_{o2} = 0.5\,[\text{A}]$

peak value is constant
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Conclusions and Future works

Conclusions

○ We have proposed a new control method that works in case of a large load current ratio, and confirmed the basic characteristics. By varying control time ratio of two converters, we have confirmed the operation of the proposed method in case of the load current ratio $I_{o1}:I_{o2}=5.0A:0.5A$ that is 10:1.

Future works

○ Operation in CCM (continuous current mode)
○ Operation with a much higher load current ratio
CCM動作での従来方式と提案方式の違い

従来方式

提案方式

Duty=0でも
多く電流が流れてしまう。
電圧が収束しない。