Automatic Correction of Current Imbalance for Multi Phase COT Ripple Based Control Converter

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Outline

1. Research Background
2. COT Ripple Based Control Converter
3. Characteristic of Multi-Phase Converter
4. Multi-Phase Configuration of COT Ripple Based Control Converter
5. Automatic Current Imbalance Correction
6. Simulation Verification
7. Conclusion
Research Background

AC 100V
Socket

AC-DC converter

DC 12V
DC-DC Converter

LED Display
Digital Camera
Smartphone
CPU for Server
Study of Power Supplies at Gunma University (1/2)

**EMI Reduction + Soft-Switching**
- C6-3
  - Soft-Switching ZVS, ZCS
  - Reported

**Low Noise**
- High Efficiency
- Multi-Phase
- Multi-Function
- SIMO
  - SIMO, IC
  - Reported

**Large Current**
- PWM Controlled Buck Converter
  - Reported
  - Fast Response
  - Ripple Control (Hysteretic Cont.)

**Down-Sizing Low Cost**
- Reported

**Multi-Phase + Ripple Cont.**
- C6-1

**EMI: Electro-Magnetic Interference**
**SIMO: Single-Inductor Multi-Output**

**ZVS: Zero Voltage Switching**
**ZCS: Zero Current Switching**
Study of Power Supplies at Gunma University (2/2)

- Multi-Phase + Soft-Switching
- Low Noise
- High Efficiency
- Fast Response
- Multi-Phase + Ripple Control
- Large Current
- PWM Controlled Buck Converter
- Soft-Switching ZVS, ZCS
- Ripple Control (Hysteretic Cont.)
- C6-4
- Down-Sizing Low Cost
- IC, SIMO
- Multi-Phase + Ripple Control
- EMI Reduction + Ripple Control
- EMI Reduction
- Ripple Control
- C6-5
- Soft-Switching ZVS, ZCS
- SIMO

- Multi-Phase + Soft-Switching
- Low Noise
- High Efficiency
- Fast Response
- Multi-Phase + Ripple Control
- Large Current
- PWM Controlled Buck Converter
- Soft-Switching ZVS, ZCS
- Ripple Control (Hysteretic Cont.)
- C6-4
- Down-Sizing Low Cost
- IC, SIMO

- Multi-Phase + Soft-Switching
- Low Noise
- High Efficiency
- Fast Response
- Multi-Phase + Ripple Control
- Large Current
- PWM Controlled Buck Converter
- Soft-Switching ZVS, ZCS
- Ripple Control (Hysteretic Cont.)
- C6-4
- Down-Sizing Low Cost
- IC, SIMO
Power Supply as Require Large Current

Power consumption of electronic information equipment

Increase

CPU for server: More than 100A

Power supply: Use Multi-Phase configuration

Problems with multi-phase converter:
Error of element value / Parasitic component

Inductor current of each channels: Imbalance occur

Control the current to be equal
Objective

COT ripple based control converter

COT: Constant On-Time

◆ For large load current
  Multi-Phase configuration

◆ Current imbalance correction
  Automatic current imbalance correction with feedback control

◆ Simulate proposed circuit
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COT Ripple Based Control Converter

After switch off output voltage drops to the reference

Switch on for a constant time

Constant On-Time

Output voltage < Reference: SW ON

Suppresses excessive increase in switching frequency

Set On-Time

COT Timer
Problems with Single-Phase Converter

- Large current
  - Increase allowable current of switching elements and coils
  - Increase gate capacitance
  - Can not high speed switching

- Single-Phase converter
  - High load current
Multi-Phase Configuration

- **Power stage**: Small current
- **Parallel connection of power stages**
- **Increase load current**
- **Decrease inductor current in each channel**
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Parallel connection of power stages

Ripple detection: 1\textsuperscript{st} phase only

Phase shifted pulse
1\textsuperscript{st} phase COT pulse

Detect amplitude of saw tooth wave & Divide

2\textsuperscript{nd} phase COT pulse
Current Imbalance by Element Variation

Element variation → Current imbalance occurs

Causes overcurrent, ripple increase and power loss
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Automatic Current Imbalance Correction (Dual-Phase)

Inductor current difference \( I_{L1} = I_{L2} \)  
Correct imbalance between two channels

Feedback

On-Time reference
Automatic Current Imbalance Correction (Limitedly)

Inductor current difference

$$3I_{L1} = I_{L2} + I_{L3} + I_{L4}$$

Corrects only imbalance between Main-Phase and Sub-Phase
Automatic Current Imbalance Correction Circuit (Completely)

Inductor current difference

\[ I_{L1} = I_{L2} = I_{L3} = I_{L4} \]

Feedback

On-Time reference

Fully corrects imbalance between all channels
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Simulation Conditions

Conditions: Quad-Phase configuration
2\textsuperscript{nd} phase COT timer capacitor $C_{t2}$ increase 10%

Increase $C_{t2}$ → Increase On-Time → Increase inductor current
Simulation Result (Without Correction)

2nd phase COT timer capacitor $C_{t2}$ increase 10%

1st phase inductor current: 1.25A
2nd phase inductor current: 2.13A
3rd phase inductor current: 1.33A
4th phase inductor current: 1.33A

2nd phase increase: 41%
Simulation Result (With Complete Correction)

2\textsuperscript{nd} phase COT timer capacitor $C_{t2}$ increase 10%

1\textsuperscript{st} phase inductor current: 1.51A
2\textsuperscript{nd} phase inductor current: 1.54A
3\textsuperscript{rd} phase inductor current: 1.50A
4\textsuperscript{th} phase inductor current: 1.50A

2\textsuperscript{nd} phase increase: 1%

Imbalance: 41\% $\Rightarrow$ 1\%
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Conclusion

◆ Considered Multi-Phase configuration for COT ripple based control converter

◆ Proposed automatic correction of current imbalance due to element variation

  Feedback the current difference to each COT pulse On-Time

◆ Simulation

  Improved current balance
  41% ➞ 1%
Thank you for your attention

謝謝
Q. 電流アンバランス補正には複数のループが存在するが、安定なのか。

A. 下図に示すように負荷電流をステップ変化させた場合は安定である。アンバランス発生要因の時間変化については今後検討する。