Experimental Results for a Fast, Self-stabilizing, Hysteretic Boost DC-DC Converter

Neeraj Keskar
Advisor: Prof. Gabriel A. Rincón-Mora

Analog and Power IC Design Lab
School of Electrical and Computer Engineering
Georgia Institute of Technology
October 19, 2004

Motivation

- Significant dependence of converter frequency response on passive components
- Tolerances in capacitor ESR, ESL values
- Variations in inductor, capacitor values per design

- IC solution for frequency compensation required because
  - Reduction in design time
  - Reduction in part count
  - Reduction in board size, cost
  - Ease of design

- Need to have IC solution that will give frequency compensation independent of external components

➢ Hysteretic control provides a way!
Hysteretic Buck Converter

- Hysteretic control regulates output voltage ripple $v_o$
- With switch MPP1 held on: $V_{OUT} = V_{IN}$
- With switch MPP1 held off: $V_{OUT} = 0$
- $V_{REF}$ is between "ON" and "OFF" regions, forming "switching surface"
- System state moves towards switching surface from either side

Issues with Hysteretic Control in Boost Converters

- With switch MNP1 held on: $V_{OUT} = 0$
- With switch MPP1 held off: $V_{OUT} = V_{IN}$
- $V_{REF}$ is not between "ON" and "OFF" regions
- System state does not move towards $V_{REF}$ from either side
**Proposed Hysteretic Control**

- With switch $S_A$ held on: $V_{OUT} = 0$
- With switch $S_A$ held off: $V_{OUT} = I_D R_{LOAD} > V_{REF}$
- $V_{REF}$ is between "ON" and "OFF" regions
- System state moves towards $V_{REF}$ from either side

**Hysteretic Control in Boost Converters**

- If $V_{REF}$ too large, then power loss rises, efficiency decreases
- Hence, $I_1$ kept only 5% above $I_{MIN}$ duty-cycle-to-voltage demodulator
- $I_2 = 19I_1$, therefore $V_{REF}$ steady-state when $D_A = \frac{I_1}{I_1 + I_2} = \frac{I_1}{20I_1} = 5\%$
Hysteretic Control in Boost Converters: Transient Response

- $H_{VQ3}$ sets the hysteresis window for transient response
- If $V_{OUT}$ falls outside $H_{VQ3}$, switch MPC1 turned on
- $V_{REF}$ raised in single step to $V_{IPK}$ to support max designed $I_{OUT}$
- Then, $V_{OUT}$ rises in single cycle of switch $S_A$

Experimental Results: Steady-state

$V_{OUT} = 5 \text{ V}$, $I_{OUT} = 0.3 \text{ A}$, $V_{IN} = 3.5 \text{ V}$, $L = 6.8 \mu\text{H}$, $C = 76 \mu\text{F}$
Experimental Results: Load Transient Response

- \( \Delta V_{\text{OUT}} = 292 \text{ mV}, \Delta t = 400 \mu\text{s} \)
  - 0.1 A to 1 A load step
  - Fast, single cycle response for hysteretic boost converter

- \( \Delta V_{\text{OUT}} = 230 \text{ mV}, \Delta t = 50 \mu\text{s} \)

Experimental Results: LC Variation Limits

- \( C_{\text{MIN}} \) for proposed converter 9 times lower than that for leading conventional boost converter
**Experimental Results: Power Efficiency**

- Proposed solution has slightly lower high-load efficiency (by 2% @ 5 W) compared to leading boost converter.
- At medium and light loads (less than 2.5 W), proposed solution superior (2% improvement at 0.5 W).

---

**Summary**

- Need integrated DC-DC converter stable with wide variations in L, C.
- Hysteretic control in buck converters fastest, simple and w/o compensation.
- Novel dual-loop technique presented to implement hysteretic control in boost converters.
- Proposed method has superior performance over leading boost converter:
  - Lower $C_{\text{MIN}}$ required for stable operation (9 times lower).
  - Fast transient response (20% lower $\Delta V_{\text{OUT}}$) without using any compensation circuit.
- Efficiency degraded up to 2% @ 5 W, but improved by 2% at 0.5 W.
- Solution can be used towards an increased degree of integration in DC-DC converters – without an external frequency compensation circuit.