A Fast, Self-stabilizing, Boost DC-DC Converter - Sliding-mode Vs Hysteretic Controls

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Motivation

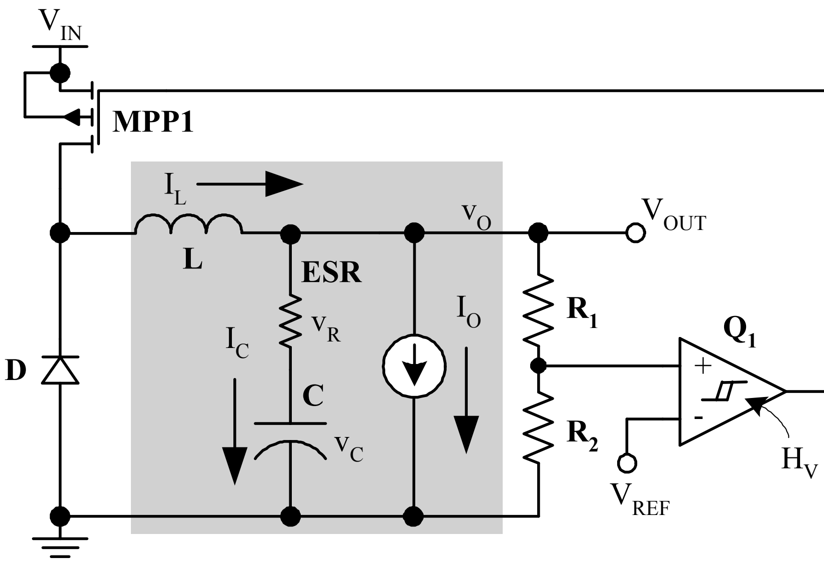
- Significant dependence of converter frequency response on passive components
- Tolerances in capacitor ESR, ESL values
- Variations in inductor, capacitor values per design

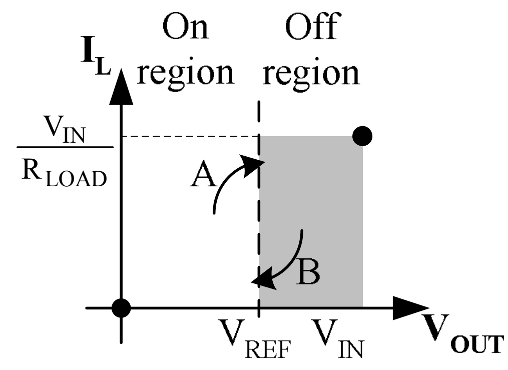
- IC solution for frequency compensation required because
  - Reduction in design time
  - Reduction in part count
  - Reduction in board size, cost
  - Ease of design

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

➢ **Hysteretic control provides a way !**

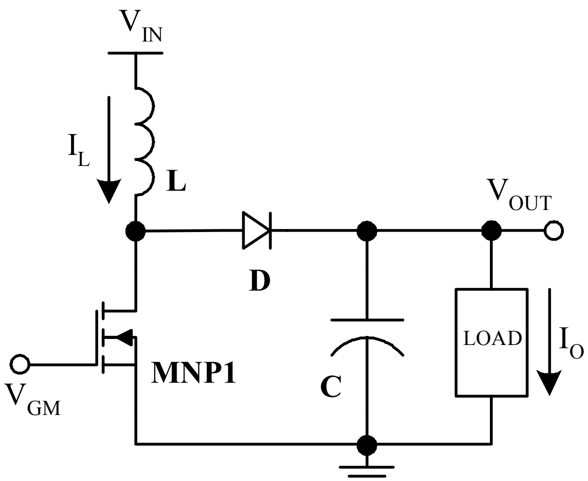
Hysteretic Buck Converter

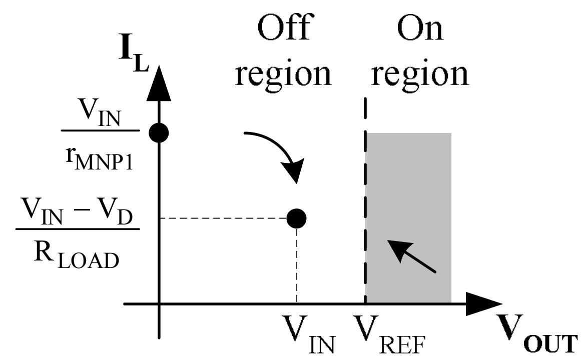




- Hysteretic control regulates output voltage ripple $\mathbf{v_O}$
- With switch MPP1 held on: $V_{OUT} = V_{IN}$
- With switch MPP1 held off: $V_{OUT} = 0$
- V_{REF} is between "ON" and "OFF" regions, forming "switching surface"
- *System state moves towards switching surface from either side*

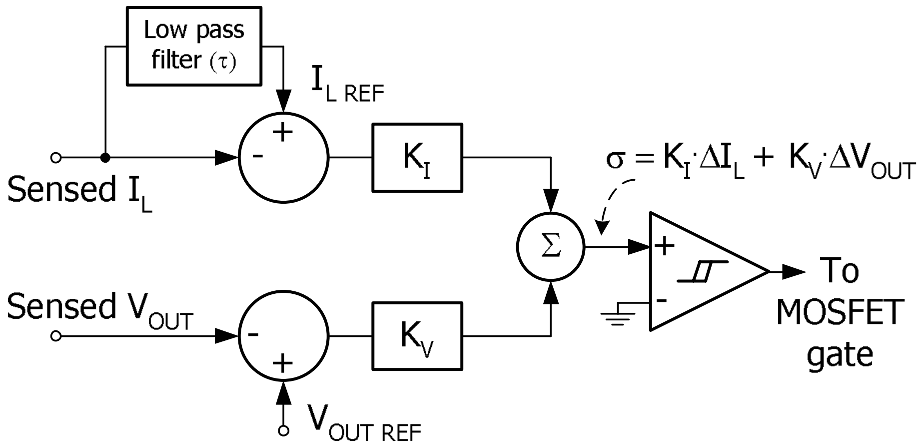
Issues with Hysteretic Control in Boost Converters

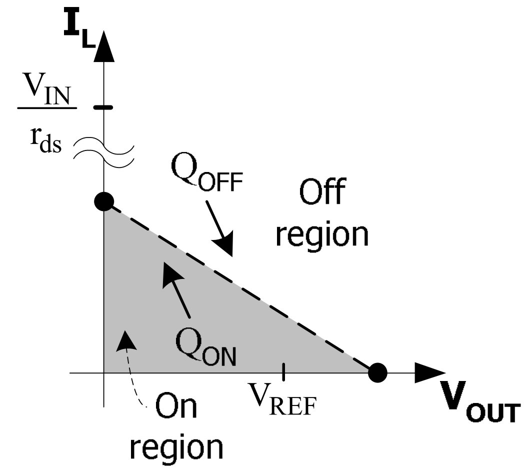




- With switch MNP1 held on: $V_{OUT} = 0$
- With switch MPP1 held off: $V_{OUT} = V_{IN}$
- V_{REF} is **not** between "ON" and "OFF" regions
- *System state does not move towards V_{REF} from either side*

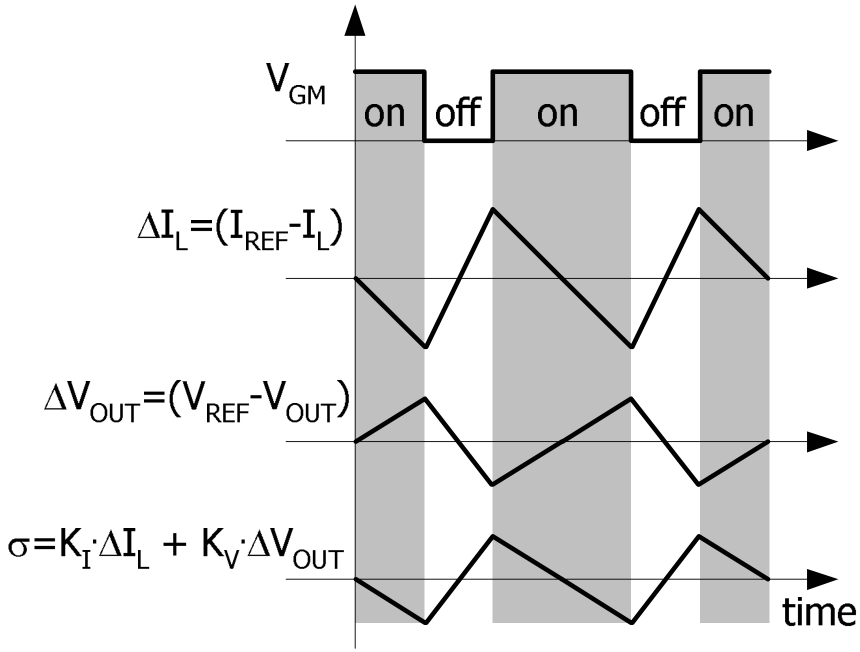
Solution 1: Sliding-mode Control





- Variable regulated is σ, which is a combination of I_L and V_{OUT}
- Variable $\sigma = K_I.(I_{REF} - I_L) + K_V.(V_{REF} - V_{OUT})$
- Control regulates $\sigma = 0$ using hysteretic controller
- At DC, $I_{REF} = I_L$, hence if $\sigma = 0$, then $V_{REF} = V_{OUT}$

Sliding-mode Control (contd.)



For stability:

$$\left(\frac{d\sigma}{dt}\right)_{ON} < 0$$

$$\left(\frac{d\sigma}{dt}\right)_{OFF} > 0$$

Hence,

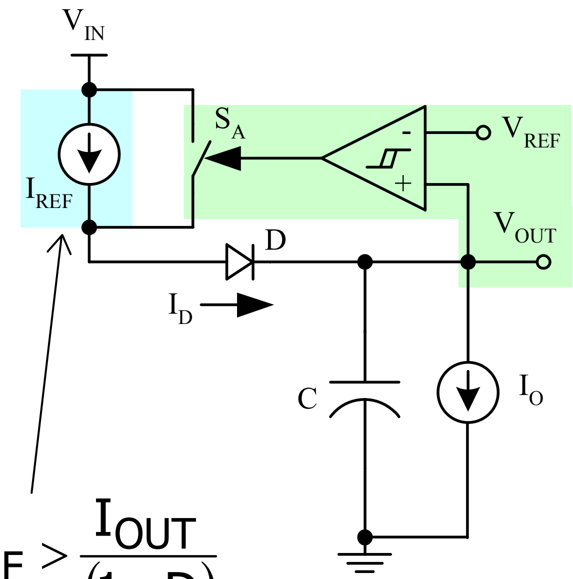
$$\left|K_I \Delta I_L\right| > \left|K_V \Delta V_{OUT}\right|$$

Hence, for boost converters: $\dfrac{K_I}{K_V} > \dfrac{L}{R_{LOAD} C (1-D)}$

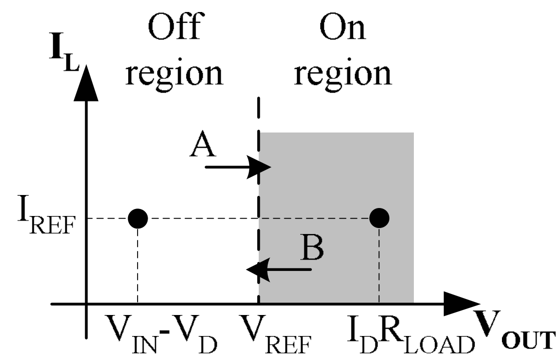
X For large L and small C, $K_I >> K_V$, giving slower, multiple cycle transient

X Also, τ of low pass filter needs to be large slowing transient response

Solution 2: Novel Hysteretic Control

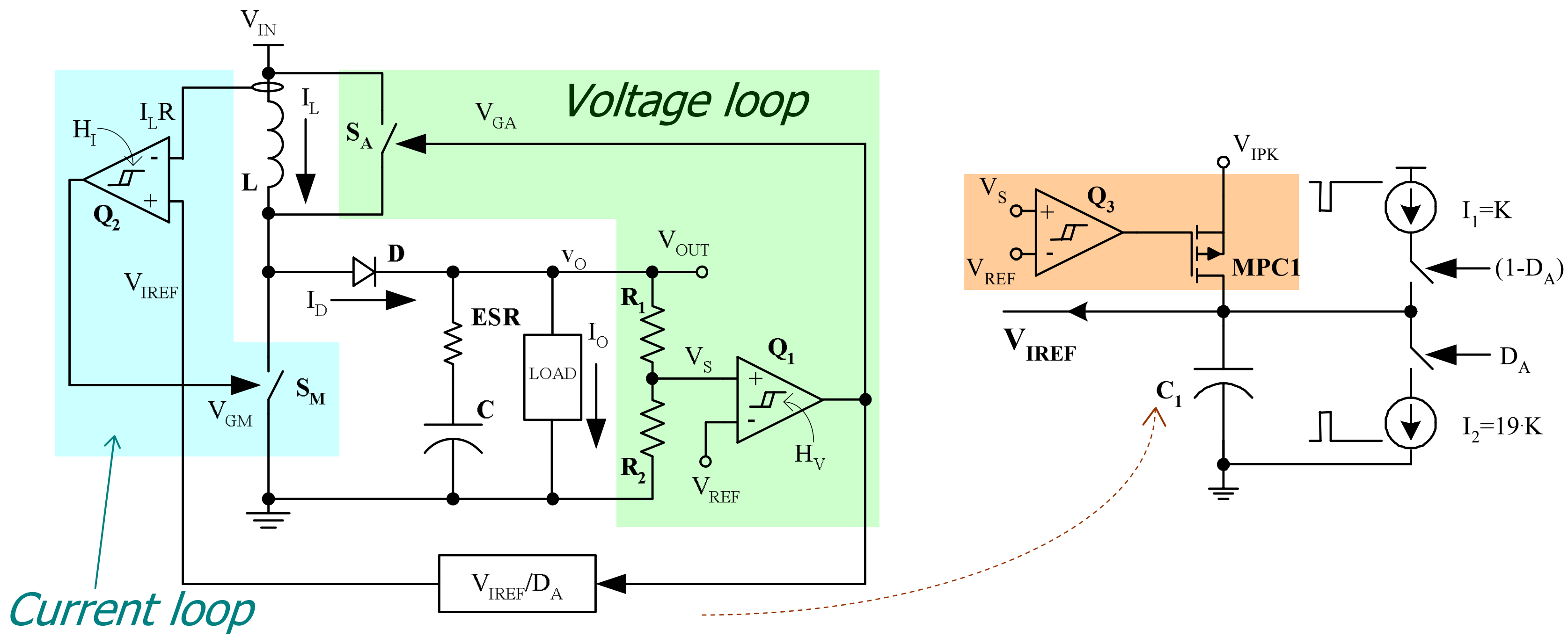


$$I_{REF} > \frac{I_{OUT}}{(1-D)}$$



- 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*

Novel Hysteretic Control (contd.)

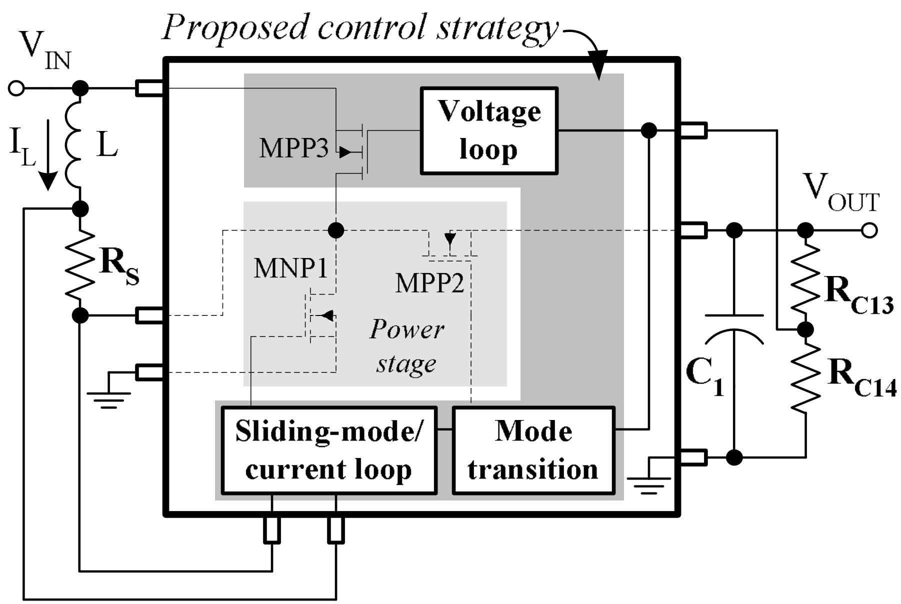


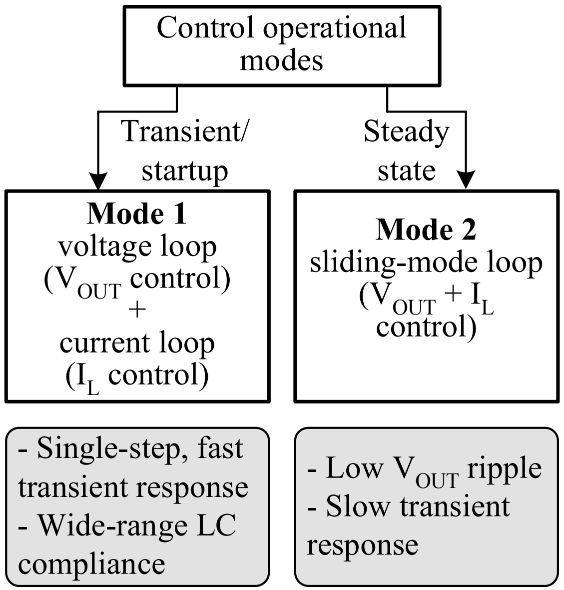
✓ Fast, single-step (slew-limited) transient response for all filter LC values

X Somewhat large steady-state output voltage ripple

X Lower high-load efficiency because of higher inductor current

Combined Control Strategy



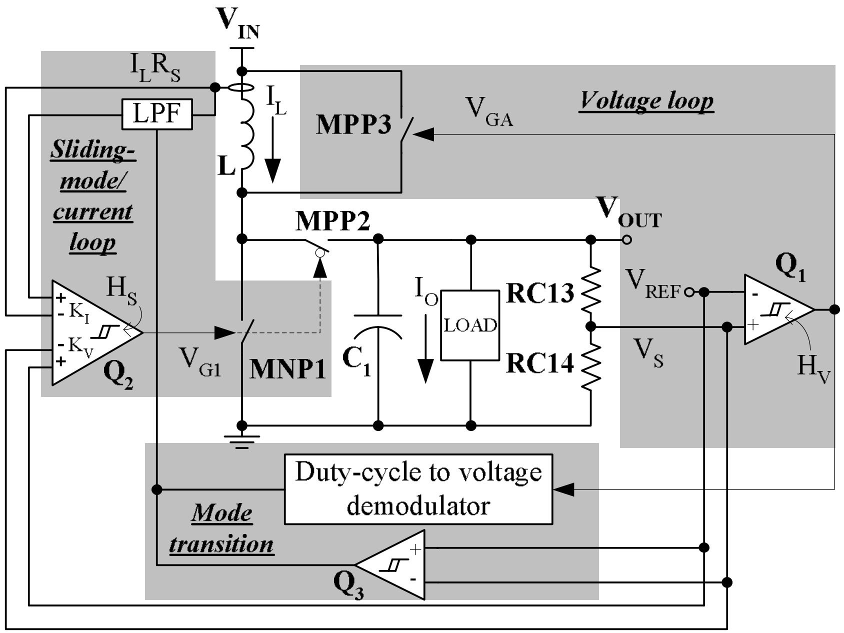


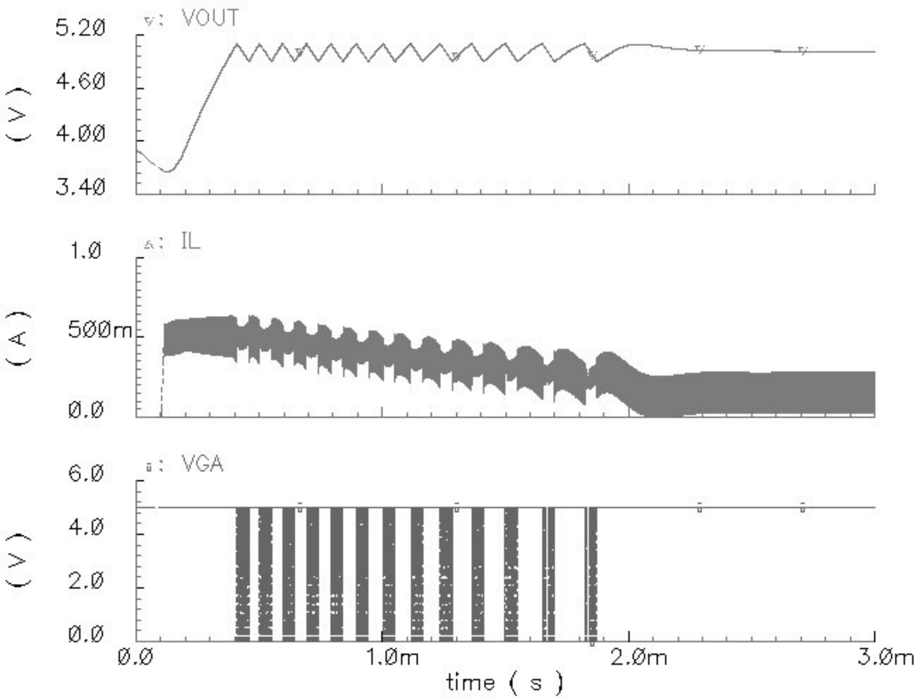
Combination of two previous strategies in multi-mode system

Mode 1 (Hysteretic control): Operated during transient for fast response

Mode 2 (sliding-mode control): Operated during steady-state for low ripple

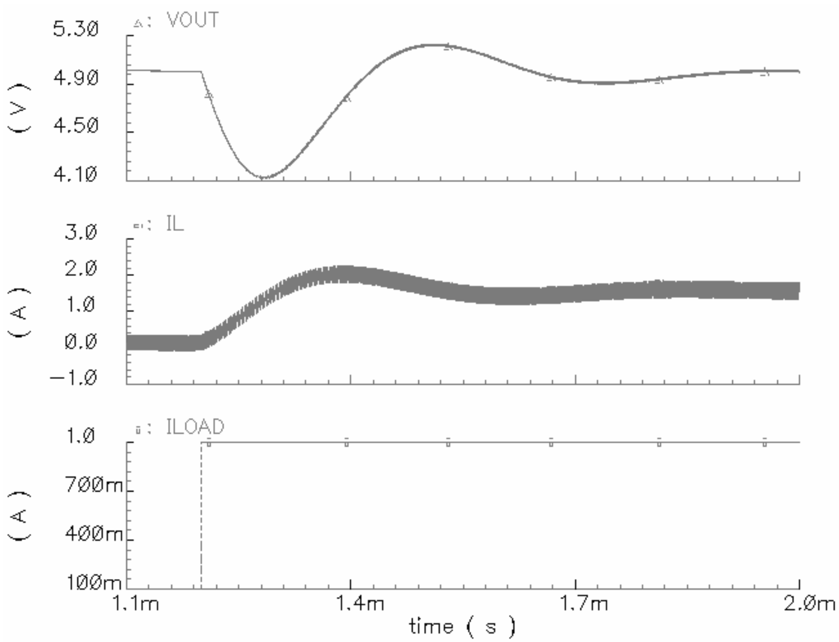
Combined Control Strategy (contd.)



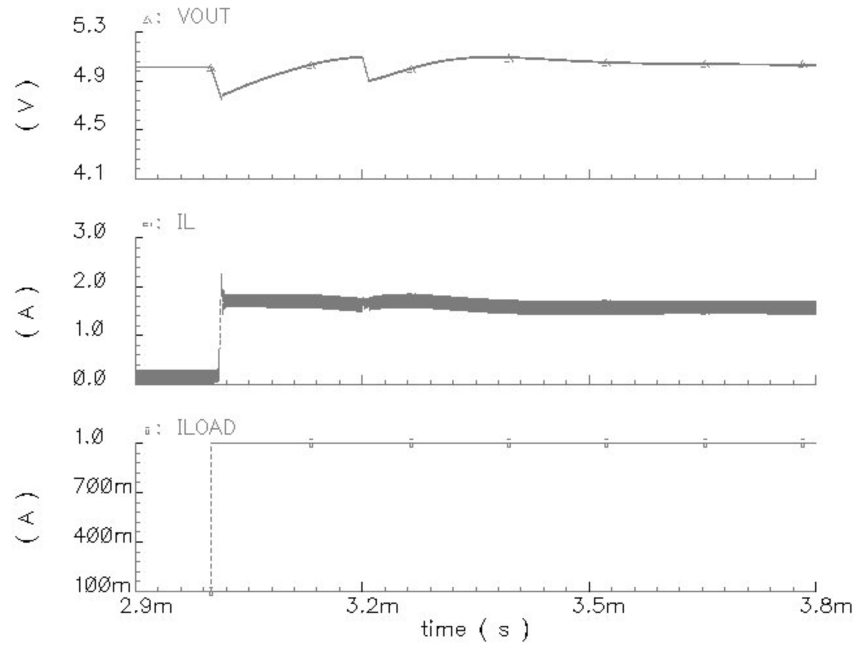


- Start-up under hysteretic mode with higher voltage ripple; inductor current higher than that at steady-state value with switch MPP3 switching
- Inductor current decreased by duty-cycle to voltage demodulator until steady state; switch MPP3 then stops switching

Comparison of Load Transient Response



Sliding-mode control



Proposed control

- Load step response: I_{LOAD} from 0.1 to 1 A, L = 5 μH, C = 47 μF
- Proposed technique gives a ΔV_{OUT} improvement of more than 650 mV, which is ~ 13% of V_{OUT}

GEDC

Conclusions

- A new multi-mode control strategy was introduced in boost DC-DC converters, combining speed advantages of hysteretic control and low steady-state ripple of sliding-mode control
- This strategy enables a de-coupling between the conflicting requirements of greater relative stability and fast transient response
- Wide variations in LC filter parameters can be accommodated without the use of any external frequency compensation circuit
- Fast, single-step (slew-limited) load transient response obtained in the proposed strategy for a wide range of LC filter parameters as against a compensation bandwidth limited response in conventional control
- An optimal boost DC-DC converter control strategy was introduced as most suitable for integration enabling a simple, user-friendly, and effective solution