An Optimal Digital Control Algorithm for DC-DC Converters Under Input Voltage Changes

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I. The Principle of the Proposed Optimal Control Algorithm

- Predicts the duty cycle series based on the principle of capacitor charge balance
- Transient ends in two switching cycles

- Conditions to achieve the optimal transient performance
  - Transient ends in two switching cycles
  - Capacitor charge balance is achieved when transient ends
  - $i_L = i_{L\_end}$ at the end of transient
  - d set to new steady state value D_{new} at end of transient

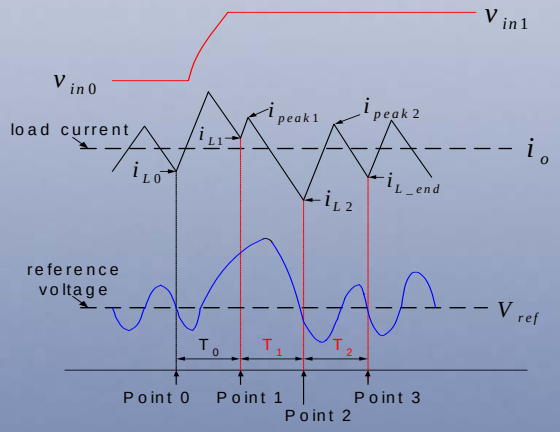


Fig. 1 Optimal Two-Switching Cycle Transient Response under Input Voltage Change

- Period T_0:
  - V_{in} steps, not sensed yet
  - d unchanged, i_L increases
  - Capacitor charges

- Point 1:
  - V_{in} change sensed
  - Optimal algorithm activates
  - Two-switching cycle duty cycle series is predicted

- Point 3:
  - i_L reaches new steady-state value, i_{L_end}
  - Charge delivered by capacitor is equal to charge delivered to capacitor
  - d *is set to* D_{new}
  - Transient ends
  - Conventional controller takes over

- **KEY POINT:**
  - Estimation of optimized duty cycle values d_1 for T_1 and d_2 for T_2
  - Estimation of new steady state duty cycle value D_{new} after point 3

- **Four key steps for optimal compensation algorithm:**

1. Calculate the sum of d_1 and d_2

$$d_1 + d_2 = \frac{(i_{L\_end} - i_{L1}) \cdot \frac{L}{T_s} + 2 \cdot v_o'}{v_{in1}} = k$$

2. Calculate capacitor discharge portion $A_{charge0}$

$$A_{charge0} = C \cdot (v_{C1} - v_{C0}) \approx C \cdot (v_{C1} - V_{ref}) = C \cdot (v_{o1} - i_{C1} \cdot ESR - V_{ref})$$
$$= C \cdot (v_{o1} - (i_{L1} - i_o) \cdot ESR - V_{ref})$$

3. Calculate duty cycle d_1 and d_2

$$d_1 = \frac{1}{2}\left[(1+k) - \sqrt{(1+k)^2 + \frac{4L}{v_{in1} \cdot T_s}(i_{L1} - 2i_o + i_{L\_end} - \frac{1}{2}k^2 v_{in1}\frac{T_s}{L} + \frac{A_{charge0}}{T_s})}\right]$$

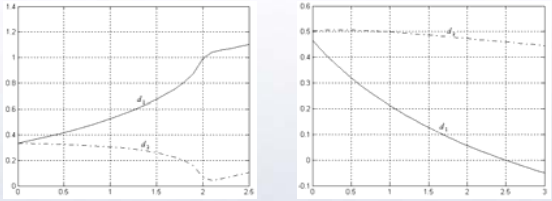
$$d_2 = k - d_1$$

4. Calculate new steady state value D_{new} and i_{Lnew}

$$D_{new} = \frac{v_o'}{v_{in1}}$$

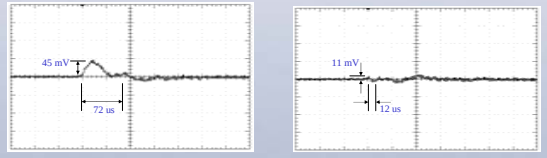
$$i_{Lnew} = i_{L\_end} + 0.3 \cdot v_o' \cdot \frac{T_s}{L}$$

II. Simulation and Experimental Results



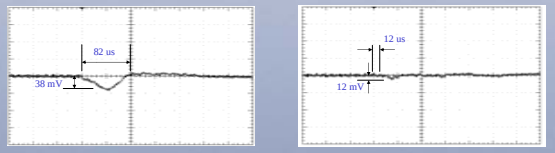
(a) $v_{in0} = 5V$, $v_{in1} = v_{in0} + \Delta v_{in}$ (b) $v_{in0} = 7.5V$, $v_{in1} = v_{in0} - \Delta v_{in}$

Fig. 2 The calculated duty cycle values under different input voltage step change (X axis: input voltage step change Δv_{in} (V); Y axis: duty cycle value) (solid line: d_1, dashed line: d_2)



(a) Current mode PID controller (b) Optimal compensation algorithm

Fig. 3 Output voltage response to an input voltage change from 5V to 7.5V at 5A load (X axis: 40us/div; Y axis: 50mv/div)



(a) Current mode PID controller (b) Optimal compensation algorithm

Fig. 4 Output voltage response to an input voltage change from 7.5V to 5V at 5A load (X axis: 40us/div; Y axis: 50mv/div)

III. Conclusion

- Capacitor charge balance is used to predict the optimized duty cycle series
- Transient ends in two switching cycles
- Achieves small overshoot/undershoot and short recovery time