Chapter 5. The Discontinuous Conduction Mode

5.1. Origin of the discontinuous conduction mode, and mode boundary

5.2. Analysis of the conversion ratio $M(D, K)$

5.3. Boost converter example

5.4. Summary of results and key points

$L$ too small or $I_0$ too small

$R_L$ too large or open circuit

$K_2 > 1$, $K > K_c$

for some $D$, 3 intervals
“What if inductor runs dry - $i_2 = 0$"?

Chapter 5. The Discontinuous Conduction Mode

Go back to go and recalculate $M(D, R_L)$.

Change is: DC gain depends on load.

5.1. Origin of the discontinuous conduction mode, and mode boundary

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Fundamentals of Power Electronics

Chapter 5: Discontinuous conduction mode
5.1. Origin of the discontinuous conduction mode, and mode boundary

Buck converter example, with single-quadrant switches

Continuous conduction mode (CCM)

Minimum diode current is \((I - \Delta i_d)\)

Dc component \(I = VR\)

Current ripple is

\[
\Delta i_L = \frac{V_d D T_s}{2L}
\]

Note that \(I\) depends on load, but \(\Delta i_L\) does not.

Fundamentals of Power Electronics
5.1. Origin of the discontinuous conduction mode, and mode boundary

Buck converter example, with single-quadrant switches

Minimum diode current is \((I - \Delta i_L)\)

DC component \(I = \frac{V}{R} = f(R_L)\)

Current ripple is

\[\Delta i_L = \frac{(V_g - V)}{2L} DT_t = \frac{V_g DD'T_s}{2L}\]

Note that \(I\) depends on load, but \(\Delta i_L\) does not.

**Open load:** DCM always happens

**Continuous conduction mode (CCM)**

**Trend**

**Load**

**Limbo time**

**Always occurs**

**Diode** \(i_D(t)\)

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Chapter 5: Discontinuous conduction mode
Reduction of load current

Increase $R$, until $I = \Delta i_L$.

Minimum diode current is $(I - \Delta i_L)$.

Dc component $I = V/R$.

Current ripple is $\frac{V_L}{2L} \frac{dI}{dt}$.

Note that $I$ depends on load, but $\Delta i_L$ does not.

Chapter 5: Discontinuous conduction mode
Further reduce load current for new $D_T$s not flat or dry.

**Get a third interval $D_T$**

Discontinuous conduction mode in Fig. 5.4 (

Chapter 5: Discontinuous conduction mode

Minimum diode current is \( I - \Delta I_L \)

Dc component \( I = V/R \)

Current ripple is

\[ \Delta I_L = \frac{(V_s - V)}{2L} \]

Note that \( I \) depends on load, but \( \Delta I_L \) does not. The load current continues to be positive and non-zero.
Mode boundary

\[ I > \Delta i_L \quad \text{for CCM} \]
\[ I < \Delta i_L \quad \text{for DCM} \]

Insert buck converter expressions for \( I \) and \( \Delta i_L \):

\[ \frac{DV_g}{R} < \frac{DD'V_g}{2L} \quad \text{CCM Eqs. still valid} \]

Simplify:

Key \( \frac{2L}{RT} < D' \)

This expression is of the form

\[ K < K_{\text{crit}}(D) \quad \text{for DCM} \]

where \( K = \frac{2L}{RT} \) and \( K_{\text{crit}}(D) = D' \)

- \( L \) too small
- \( R \) too big
- \( K \) too high

\( K \) depends on converter
Mode boundary

CCM: bipolar disorder

DCM: The third personality emerges fun begins

"K" Power of thinking

K & Kcritical way of thinking

K = f(R, L, fsw)

Kc = f(D)

Insert buck converter

expressions for I and Δi_L:

\[ \frac{DV_g}{R} < \frac{DD'T_sV_g}{2L} \]

Simplify:

\[ \frac{2L}{RT_s} < D' \]

This expression is of the form

\[ K < K_{crit}(D) \]

for DCM

where

\[ K = \frac{2L}{RT_s} \]

and

\[ K_{crit}(D) = D' \]

Choice of L, R, fsw

For Buck

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Chapter 5: Discontinuous conduction mode
$K$ and $K_{\text{crit}}$ vs. $D$

for Buck

**Fig 5.5**

for $K < 1$:

- $K < K_{\text{crit}}$: DCM
- $K > K_{\text{crit}}$: CCM

$K_{\text{crit}}(D) = 1 - D$

$K = 2L/RT_s$

**Fig 5.6**

for $K > 1$:

- $K > K_{\text{crit}}$: CCM

$K_{\text{crit}}(D) = 1 - D$

Always CCM

Choosing $K$ of circuit:

- $K = 2L/RT_s$

What happens here?

$\leq D \leq 1$

How to solve
Critical load resistance $R_{crit}$

Solve $K_{crit}$ equation for load resistance $R$:

$R < R_{crit}(D)$ for CCM
$R > R_{crit}(D)$ for DCM

where $R_{crit}(D) = \frac{2L}{D'T}$

Too high $R \rightarrow$ DCM

How to guarantee?

Simple way even for $R_L > R_{crit}$
Summary: mode boundary

Table 5.1

<table>
<thead>
<tr>
<th>Converter</th>
<th>$K_{crit}(D)$</th>
<th>$R_{crit}(D)$</th>
<th>$\max_{0 \leq D \leq 1} (K_{crit})$</th>
<th>$\min_{0 \leq D \leq 1} (R_{crit})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buck</td>
<td>$(1 - D)$</td>
<td>$\frac{2L}{(1 - D)T_s}$</td>
<td>$1$</td>
<td>$\frac{2}{T_s}$</td>
</tr>
<tr>
<td>Boost</td>
<td>$D(1 - D)^2$</td>
<td>$\frac{2L}{D(1 - D)^2 T_s}$</td>
<td>$\frac{4}{27}$</td>
<td>$\frac{27}{2T_s}$</td>
</tr>
<tr>
<td>Buck-boost</td>
<td>$(1 - D)^2$</td>
<td>$\frac{2L}{(1 - D)^2 T_s}$</td>
<td>$1$</td>
<td>$\frac{2}{T_s}$</td>
</tr>
</tbody>
</table>

For CCM

Intuitive

Parallel to $R_{Load}$ to insure?

Way of $K$ depends on circuit

Unique