SC Converter Topologies

M Seeman and S. Sanders, “Analysis and Optimization of Switched-Capacitor DC-DC Converters”

Dickson Converter
Dickson Converter Variants

Standard Dickson (SSL / FSL)

Hybrid Dickson
Add $L_f \Rightarrow$ can’t get current source type charging of all caps
1) just one inductor
2) Regulation possible

Switched Tank Converter
Unregulated for high $f$
Resonant charging of all caps.

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Dickson Subintervals

Ideal Analysis
- All caps have $\sim$ zero ripple

$V_o = 6V_0$ → This is a 6:1 implementation
$V_{c4} = 4V_0$
$V_{c2} = 2V_0$

$V_{c5} = 5V_0$
$V_{c3} = 3V_0$
$V_{c1} = V_0$

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Charge Vector Analysis: Notation

- \( M. \) Makowski and D. Maksimovic, “Performance Limits of Switched-Capacitor DC-DC Converters,” 1995

Charge Vector Analysis: Notation

- Finds \( M \) and \( R_0 \) for arbitrary switched cap converter
- Applies cap-charge balance to every capacitor in circuit

\[
\begin{align*}
\mathbf{a}_x^I &= \text{charge into capacitor } x \text{ during switching subinterval } I \\
\mathbf{a}_x^I &= \frac{\mathbf{b}_x^I}{\mathbf{b}_{\text{out}}} \rightarrow \text{normalized with respect to } \mathbf{b}_{\text{out}} = \mathbf{b}_{\text{out}} + \mathbf{b}_{\text{out}} + \ldots
\end{align*}
\]

\[
\mathbf{a}^I = \begin{bmatrix} a_{\text{in}}^I, a_{c_1}^I, a_{c_2}^I, \ldots, a_{c_n}^I, a_{\text{out}}^I \end{bmatrix}
\]

\[ n = \text{total } \# \text{ of caps in converter} \]

\[
\mathbf{V}^I = \begin{bmatrix} V_{c_1}, V_{c_2}, \ldots, V_{c_n}, V_{\text{out}} \end{bmatrix}
\]

\[ V_{c_i} \overset{\text{I}}{=} \text{Voltage on } c_i \text{ at the end of subinterval } I \]

assumed operation in SSL

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Charge Vector Analysis: Rules

- KVL and KCL apply always
- for all caps \( i_{c_i} \) \( V_{c_i} \) \( \neq \) \( \phi \) in steady-stat \( \quad \) (cap-charge balance)

\[
\frac{1}{n_0} \int_{t_0}^{t} i_{c_i} \, dt = \phi \quad \rightarrow \quad \mathbf{b}_{c_i}^I + \mathbf{b}_{c_i}^I + \ldots = \phi
\]

also, \( a_{c_i}^I + a_{c_i}^I + \ldots = \phi \)

a\( c_i \) for just two subintervals, \( a_{c_i}^I = -a_{c_i}^I \)

To find output resistance:

- turn off \( V_{c_i} \)
- apply test source at output

\[
R_0 = \frac{V_{\text{test}}}{I_{\text{test}}} = \frac{V}{I_{\text{test}}} - R_0
\]
2:1 Converter Charge Vector Analysis

\[ \mathbf{a}^x = \left[ b_1^x, b_2^x, b_3^x \right] / \text{gout} \]
\[ = \left[ -1, 1, 1 \right] / \text{gout} \]
\[ \mathbf{a}^z = \left[ \frac{-1}{\sqrt{2}}, \frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}} \right] \]
\[ \mathbf{a}^y = \left[ \frac{\phi}{\sqrt{2}}, -\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}} \right] \]
\[ \mathbf{a}^\pi = \left[ \frac{\phi}{\sqrt{2}}, -\frac{1}{\sqrt{2}}, \frac{1}{\sqrt{2}} \right] \]

\[ \text{gout} = \text{gout}^x + \text{gout}^y = 2 \]

\[ a_{\text{out}} = 1 \quad \text{(always, by normalization)} \]
\[ a_{\text{in}} = -\frac{1}{\sqrt{2}} \]

\[ L \quad \text{Ideal conversion ratio} \]
\[ m = \frac{V_0}{V_0} = -\frac{a_{\text{in}}}{a_{\text{out}}} = -\frac{1}{2} \]