Six Basic DC/DC Converters

Presented by

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Power Converters

1. DC/DC
2. DC/AC
3. AC/DC
4. AC/AC
Non-Isolated DC-DC Converter: single-switch, dual-switch, and four-switch

- Single-switch: Buck, boost, buck-boost, Cuk, Zeta, and SEPIC;
- Dual-switch: Dual-switch buck-boost;
- Four-switch: Full-bridge converter.

Isolated DC-DC Converter: Single-Switch, Dual-Switch, and Four-Switch

- Single-switch: Forward, Flyback;
- Dual-switch: Forward, Flyback;
- Four-switch: Full-bridge converter.
Specifications:

- $V_{in} = 100$ V
- $V_o = 50$ V
- $I_o = 10$ A

Linear DC Converter

$V_Q = 100 - 50 = 50$ (V)

$P_Q = V_Q I_Q = 50 \times 10 = 500$ (W)

$\eta = \frac{V_o I_o}{V_{in} I_o} = \frac{V_o}{V_{in}}$

$= \frac{50}{100} = 50\%$

Too Low Efficiency!!!
Specifications:
- $V_{in} = 100$ V
- $V_o = 50$ V
- $I_o = 10$ A

$Q_{on}$: $P_{Q(on)} = V_{ces} I_o \approx 0$

$Q_{off}$: $P_{Q(off)} = V_{in} I_{ceo} \approx 0$

$\eta \approx 100\%$

High Efficiency!!!
Derivation of Buck Converter

freewheel diode

filter the high-frequency content

\[ V_{in} \quad Q \quad D \quad L_f \quad R_{Ld} \quad C_f \quad + \quad V_o \quad - \]
Operation Principle of Buck Converter: CCM

\[ \frac{V_o}{V_{in}} = D \]

\[ V_o / V_{in} = D \]
Operation Principle of Buck Converter: DCM

**Q ON**

**Q OFF**

- $V_{in}$
- $V_o$
- $L_f$
- $R_{Ld}$
- $C_f$

**Q OFF**

- $V_{in}$
- $V_o$
- $L_f$
- $R_{Ld}$
- $C_f$
Voltage Conversion Ratio

\[ \frac{V_o}{V_{in}} = \text{Const} \]

\[ I_o = I_{oG_{\text{max}}} \]

- \( D_y = 1.0 \)
- \( V_{in} = \text{Const} \)

CCM

DCM
Buck Converter with Bi-Direction Switches
Buck Converter with Bi-Direction Switches

$$V_{in} \rightarrow D_1 \rightarrow Q_1 \rightarrow Q_2 \rightarrow D_2 \rightarrow L_f \rightarrow R_{Ld} \rightarrow +V_o \rightarrow -$$

$$Q_1 \text{ OFF; } Q_2 \text{ ON.}$$

**Diagram:**

- $V_{in}$ input voltage
- $D_1$ diode
- $Q_1$, $Q_2$ power transistors
- $L_f$ inductor
- $R_{Ld}$ load resistance
- $C_f$ filter capacitor
- $+V_o$, $-V_o$ output voltages

**Waveforms:**

- $i_{L_f}$ inductor current
- $i_{Q_1}$ transistor $Q_1$ current
- $i_{D_2}$ diode $D_2$ current

**Timelines:**

- $Q_1$, $Q_2$, $Q_1$, $Q_1$ states
- $i_{L_f}$, $i_{Q_1}$, $i_{D_2}$ waveforms

**Key Points:**

- The converter operates in a bi-directional mode.
- The inductor current $i_{L_f}$ flows through the diode $D_1$ when $Q_1$ is ON.
- The transistor $Q_2$ is ON when $Q_1$ is OFF, allowing the flow of current through the diode $D_2$.
- The filter capacitor $C_f$ helps to smooth the output voltage $V_o$.

**Mathematical Expressions:**

- $i_{L_f}$ current through the inductor
- $i_{Q_1}$ current through $Q_1$
- $i_{D_2}$ current through $D_2$

**Analysis:**

- The converter can operate in continuous conduction mode (CCM) or discontinuous conduction mode (DCM).
- The switch timings and duty cycles determine the efficiency and output voltage.

**Applications:**

- Used in power management systems, telecommunication equipment, and renewable energy systems.
Buck Converter with Bi-Direction Switches

\( D_1 \) Conduct; \( Q_1 \) ON; \( Q_2 \) OFF.
Buck Converter with Bi-Direction Switches

$Q_1$ ON; $Q_2$ OFF.
Buck Converter with Bi-Direction Switches
Buck Converter with Bi-Direction Switches

Power Flow
Voltage Conversion Ratio of Boost Converter

\[
\frac{V_o}{V_{in}} = D
\]

D is the duty cycle of \( Q_1 \)

\[
\frac{V_o}{V_{in}} = D
\]

D is the duty cycle of \( Q_1 \)

\[
\frac{V_{in}}{V_o} = 1 - D
\]

\[
\frac{V_o}{V_{in}} = \frac{1}{1 - D}
\]
Why Buck-Boost Converter?

\[ V_o < V_{in} \]

\[ V_o > V_{in} \]

\[ \frac{V_o}{V_{in}} = \frac{D_1}{1 - D_2} \]
Simplification of Buck-Boost Converter (1)
Simplification of Buck-Boost Converter (2)
How to get Cuk?

\[
\frac{V_o}{V_{in}} = \frac{D_1}{1 - D_2}
\]
Derivation of Cuk
Derivation of Zeta

Negative output voltage

Positive output voltage

\[ V_o = \frac{D}{1-D} V_{in} = \left(1 + \frac{D}{1-D}\right) D V_{in} \]

\[ = D \left( V_{in} + \frac{D}{1-D} V_{in} \right) \]
Derivation of SEPIC

Negative output voltage

Positive output voltage

\[ V_{ch} = \frac{D}{V_{in}} \]

\[ V_o = \frac{D}{1-D} V_{in} = \frac{1}{1-D} V_{in} - V_{in} \]
# Comparison of the Six Converters

<table>
<thead>
<tr>
<th>Converter</th>
<th>Topology</th>
<th>Voltage Conversion Ratio</th>
<th>Output Voltage Polarity</th>
<th>Input Current Ripple</th>
<th>Output Current Ripple</th>
<th>Configuration</th>
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</thead>
<tbody>
<tr>
<td>Buck</td>
<td><img src="image1" alt="Buck Topology" /></td>
<td>$\frac{V_o}{V_{in}} = D$</td>
<td>+</td>
<td>Large</td>
<td>Small</td>
<td>Simple</td>
</tr>
<tr>
<td>Boost</td>
<td><img src="image2" alt="Boost Topology" /></td>
<td>$\frac{V_o}{V_{in}} = \frac{1}{1-D}$</td>
<td>+</td>
<td>Small</td>
<td>Large</td>
<td>Simple</td>
</tr>
<tr>
<td>Buck-Boost</td>
<td><img src="image3" alt="Buck-Boost Topology" /></td>
<td>$\frac{V_o}{V_{in}} = \frac{D}{1-D}$</td>
<td>–</td>
<td>Large</td>
<td>Large</td>
<td>Simple</td>
</tr>
<tr>
<td>Cuk</td>
<td><img src="image4" alt="Cuk Topology" /></td>
<td>$\frac{V_o}{V_{in}} = \frac{D}{1-D}$</td>
<td>–</td>
<td>Small</td>
<td>Small</td>
<td>Complex</td>
</tr>
<tr>
<td>Zeta</td>
<td><img src="image5" alt="Zeta Topology" /></td>
<td>$\frac{V_o}{V_{in}} = \frac{D}{1-D}$</td>
<td>+</td>
<td>Large</td>
<td>Small</td>
<td>Complex</td>
</tr>
<tr>
<td>Sepic</td>
<td><img src="image6" alt="Sepic Topology" /></td>
<td>$\frac{V_o}{V_{in}} = \frac{D}{1-D}$</td>
<td>+</td>
<td>Small</td>
<td>Large</td>
<td>Complex</td>
</tr>
</tbody>
</table>
Thanks for your attention!

Questions? / Answer!