Equivalent Circuit Model
Average vs RMS Currents

- Model uses average currents and voltages
- To correctly predict power loss in a resistor, use rms values
- Result is the same, provided ripple is small

MOSFET current waveforms, for various ripple magnitudes:

<table>
<thead>
<tr>
<th>Inductor current ripple</th>
<th>MOSFET rms current</th>
<th>Average power loss in $R_{on}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) $\Delta i = 0$</td>
<td>$I \sqrt{D}$</td>
<td>$D \bar{I} R_{on}$</td>
</tr>
<tr>
<td>(b) $\Delta i = 0.1 I$</td>
<td>$(1.00167)I \sqrt{D}$</td>
<td>$(1.0033)D \bar{I} R_{on}$</td>
</tr>
<tr>
<td>(c) $\Delta i = I$</td>
<td>$(1.155)I \sqrt{D}$</td>
<td>$(1.3333)D \bar{I} R_{on}$</td>
</tr>
</tbody>
</table>

Summary of Chapter 3

1. The dc transformer model represents the primary functions of any dc-dc converter: transformation of dc voltage and current levels, ideally with 100% efficiency, and control of the conversion ratio $M$ via the duty cycle $D$. This model can be easily manipulated and solved using familiar techniques of conventional circuit analysis.

2. The model can be refined to account for loss elements such as inductor winding resistance and semiconductor on-resistances and forward voltage drops. The refined model predicts the voltages, currents, and efficiency of practical nonideal converters.

3. In general, the dc equivalent circuit for a converter can be derived from the inductor volt-second balance and capacitor charge balance equations. Equivalent circuits are constructed whose loop and node equations coincide with the volt-second and charge balance equations. In converters having a pulsating input current, an additional equation is needed to model the converter input port; this equation may be obtained by averaging the converter input current.
Chapter 4: Switch Realization

4.1. Switch applications

Single-, two-, and four-quadrant switches. Synchronous rectifiers

4.2. A brief survey of power semiconductor devices

Power diodes, MOSFETs, BJTs, IGBTs, and thyristors

4.3. Switching loss


4.4. Summary of key points

Implementing with SPST Switches

Buck converter

\[ \text{with SPDT switch:} \]

\[ \text{with two SPST switches:} \]
SPST Operating Quadrants

- Single-quadrant switch
  - On-state current
  - Off-state voltage

- Current-bidirectional two-quadrant switch
  - On-state current
  - Off-state voltage

- Voltage-bidirectional two-quadrant switch
  - On-state current
  - Off-state voltage

- Four-quadrant switch
  - On-state current
  - Off-state voltage

The Diode

- Symbol
- Instantaneous $i$-$v$ characteristic
- A passive switch
- Single-quadrant switch:
  - Can conduct positive on-state current
  - Can block negative off-state voltage
- Provided that the intended on-state and off-state operating points lie on the diode $i$-$v$ characteristic, then switch can be realized using a diode
(Insulated Gate) Bipolar Junction Transistor

- An active switch, controlled by terminal C
- Single-quadrant switch:
  - can conduct positive on-state current
  - can block positive off-state voltage
- provided that the intended on-state and off-state operating points lie on the transistor $i$-$v$ characteristic, then switch can be realized using a BJT or IGBT

**MOSFET**

- An active switch, controlled by terminal C
- Normally operated as single-quadrant switch:
  - can conduct positive on-state current (can also conduct negative current in some circumstances)
  - can block positive off-state voltage
- provided that the intended on-state and off-state operating points lie on the MOSFET $i$-$v$ characteristic, then switch can be realized using a MOSFET
Buck Converter: Switch Realization

Current Bidirectional Two-Quadrant

- Usually an active switch, controlled by terminal C
- Normally operated as two-quadrant switch:
  - can conduct positive or negative on-state current
  - can block positive off-state voltage
- provided that the intended on-state and off-state operating points lie on the composite i-v characteristic, then switch can be realized as shown

Fundamentals of Power Electronics

Chapter 4: Switch realization
MOSFET Body Diode

Power MOSFET characteristics

Power MOSFET, and its integral body diode

Use of external diodes to prevent conduction of body diode

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Voltage-bidirectional Two-Quadrant

BJT / series diode realization

instantaneous $i$-$v$ characteristic

- Usually an active switch, controlled by terminal $C$
- Normally operated as two-quadrant switch:
  - can conduct positive on-state current
  - can block positive or negative off-state voltage
- provided that the intended on-state and off-state operating points lie on the composite $i$-$v$ characteristic, then switch can be realized as shown
- The SCR is such a device, without controlled turn-off

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Four-Quadrant Switches

Synchronous Rectifiers

Replacement of diode with a backwards-connected MOSFET, to obtain reduced conduction loss

ideal switch  conventional diode rectifier  MOSFET as synchronous rectifier  instantaneous i-v characteristic