Implementing with SPST Switches

Step 0: Implement all switches as SPST

Non-trivial step

Now possible to have

\[ X \text{ on } \rightarrow \text{Bar (short through \text{CAB})} \]

or

\[ X \text{ off } \rightarrow \text{Bar (dead time)} \]

Used in discontinuous conduction mode (DCM) – Chapter 5

Buck converter

with SPDT switch:

\[ V_x \quad \text{A on Bar} \]

\[ V_x \quad \text{A off Bar} \]

with two SPST switches:

\[ V_x \quad \text{A on Bar} \]

\[ V_x \quad \text{A off Bar} \]

SPST Operating Quadrants

Step 7: Determine polarities of \( V(\text{off}) \) \( i(\text{on}) \) in the circuit

Single-quadrant switch

Current-bidirectional two-quadrant switch

Voltage-bidirectional two-quadrant switch

Four-quadrant switch

\[ V_x \quad \text{on} \]

\[ V_x \quad \text{off} \]

\[ \text{Switch on-state voltage} \]

\[ \text{Switch off-state voltage} \]

\[ \text{Switch on-state voltage} \]

\[ \text{Switch off-state voltage} \]

\[ i_x \quad \text{on} \]

\[ i_x \quad \text{off} \]

\[ \text{Switch on-state current} \]

\[ \text{Switch off-state current} \]

- Use ch. 7/3 techniques

\[ \text{Noft, } i_{\text{on}} = f(V_x, R, D) \]

\[ V_{\text{on}} = 20 \]

\[ R_{\text{on}} = 12 \]

\[ V_{\text{off}} = 0 \]

\[ R_{\text{off}} = 1 \]
The Diode

- 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

Symbol: $\text{Ⅱ}$

instantaneous i-v characteristic

(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

Symbol: $\text{BJT}$

$\text{IGBT}$

instantaneous i-v characteristic
MOSFET

- Body shorted to source
- 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

\[ \begin{align*}
    i(t) &= i_c(t) \\
    v(t) &= v_c(t) \\
    s(t) &= s_c(t)
\end{align*} \]

From previous analysis:

1. \( i_A(t) = I_c > 0 \) (\( s = 1 = \frac{V_s}{R} \))
2. \( v_B(t) = -V_s < 0 \)

\[ \begin{align*}
    i_{on} &= \frac{V_s}{R} \\
    i_{off} &= 0
\end{align*} \]
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

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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Chapter 4: Switch realization
Voltage-bidirectional Two-Quadrant

- 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

Four-Quadrant Switches

- BJT / series diode realization
- instantaneous i-v characteristic

Fundamentals of Power Electronics

Chapter 4: Switch realization
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

4.2: Survey of Power Semiconductor Devices

- Power diodes
- Power MOSFETs
- Bipolar Junction Transistors (BJTs)
- Insulated Gate Bipolar Transistors (IGBTs)
- Thyristors (SCR, GTO, MCT)

- On resistance vs. breakdown voltage vs. switching times
- Minority carrier and majority carrier devices
Switching Nonidealities

[Diagram of electrical circuits and waveforms showing voltage and current changes over time.]