Zero-voltage and Zero-current Transition Converter

- Traditional converters operate with a sinusoidal current through the power switches, which results in high peak and rms currents for the power transistors and high voltage stresses on the rectifier diodes.

- When the line voltage or load current varies over a wide range, Quasi-Resonant Converters are modulated with a wide switching frequency range, making the circuit design difficult to optimize.

- As a compromise between the PWM and resonant techniques, various soft-switching PWM converter techniques proposed to aim at combining desirable features of both the conventional PWM and Quasi-Resonant techniques without a significant increase in the circulating energy.

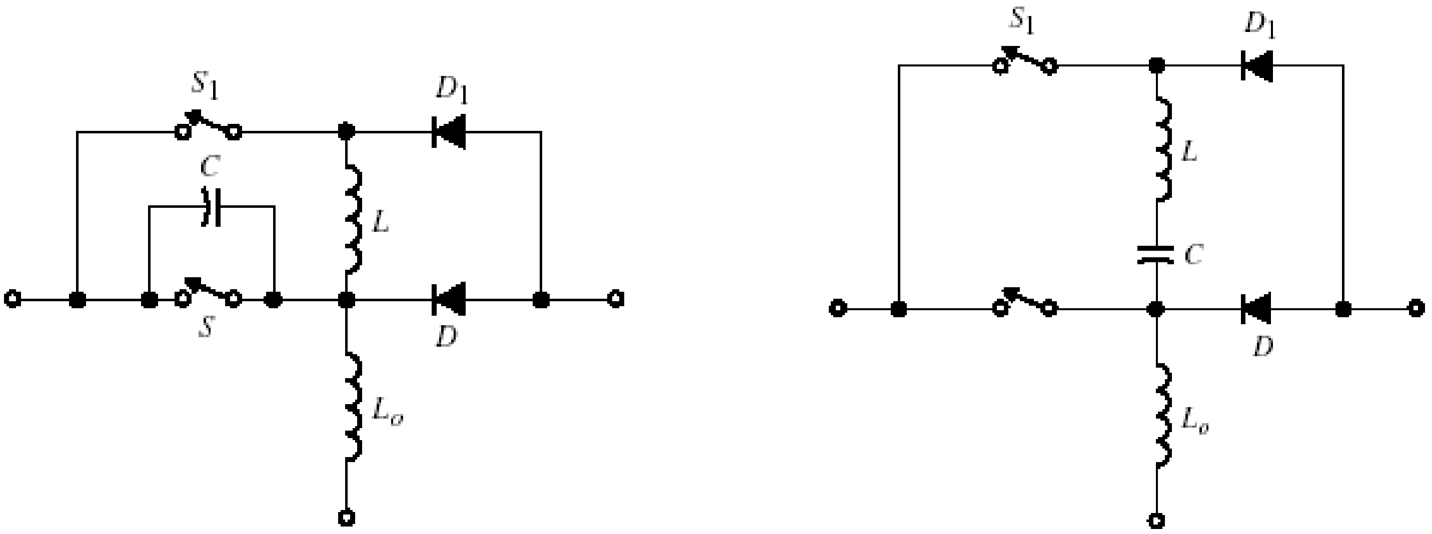
Switching Transition

- To overcome the limitations of the quasi-resonant converters, zero-voltage transition (ZVT) or zero-current transition (ZCT) is the solution. Instead of using a series resonant network across the power switch, a shunt resonant network is used across the power switch.
- The features of the ZCT PWM and ZVT PWM soft-switching converters are summarized as follows:
  - Zero-current/voltage turn-off/on for the power switch
  - Low voltage/current stresses of the power switch and rectifier diode
  - Minimal circulating energy
  - Constant-frequency operation
  - Soft switching for a wide line and load range
- One disadvantage is that the auxiliary switch does not operate with soft switching; it is hard-switching, but the switching loss is much lower than that of a PWM converter.

ZVT & ZCT Switch

The ZVT and ZCT converters differ from the conventional PWM converters by the introduction of a resonant branch.

Figure 6.48(a) shows the ZVT-PWM switching cell

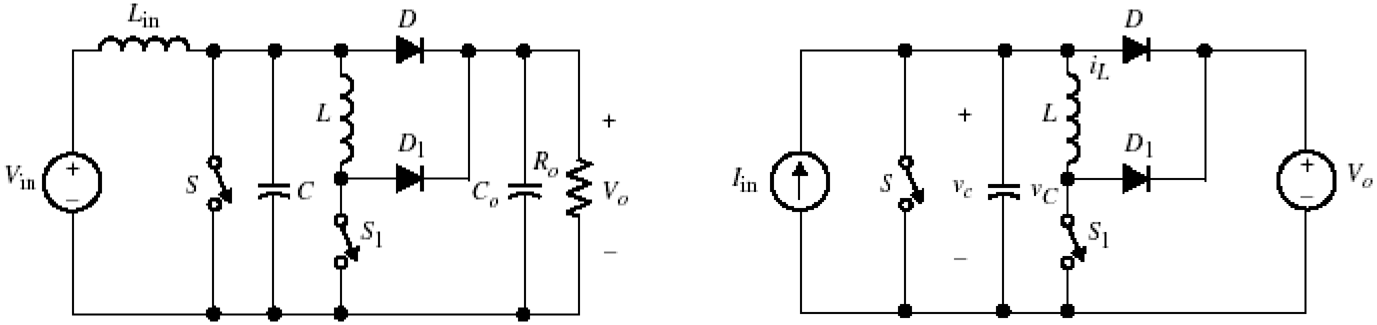


(a) (b)

Fig 6.48 (a) ZVT PWM switching cell. (b) ZCT PWM switching cell.

The Boost ZVT PWM Converter

- The boost ZVT PWM, shown in Fig. 6.49, by placing the ZVT PWM switching cell shown in Fig. 6.48(a) into the conventional boost converter.



(a) (b)

Fig 6.49 (a) Boost ZVT PWM. (b) Simplified equivalent circuit.

The switching cycle is divided into six modes

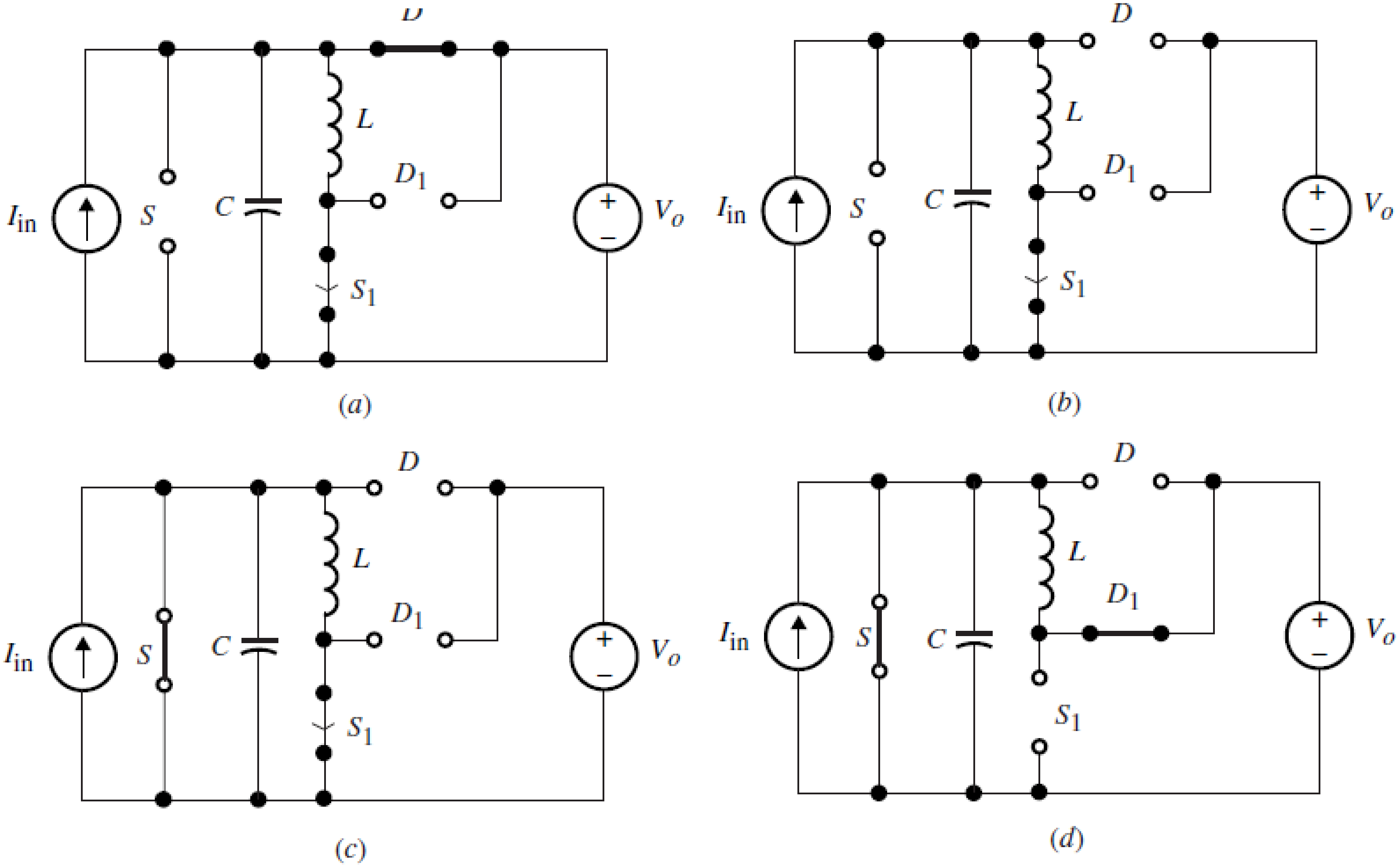


Figure 6.50 Equivalent circuits for the six modes of operation: (*a*) mode I, (*b*) mode II, (*c*) mode III, (*d*) mode IV, (*e*) mode V, and (*f*) mode VI.

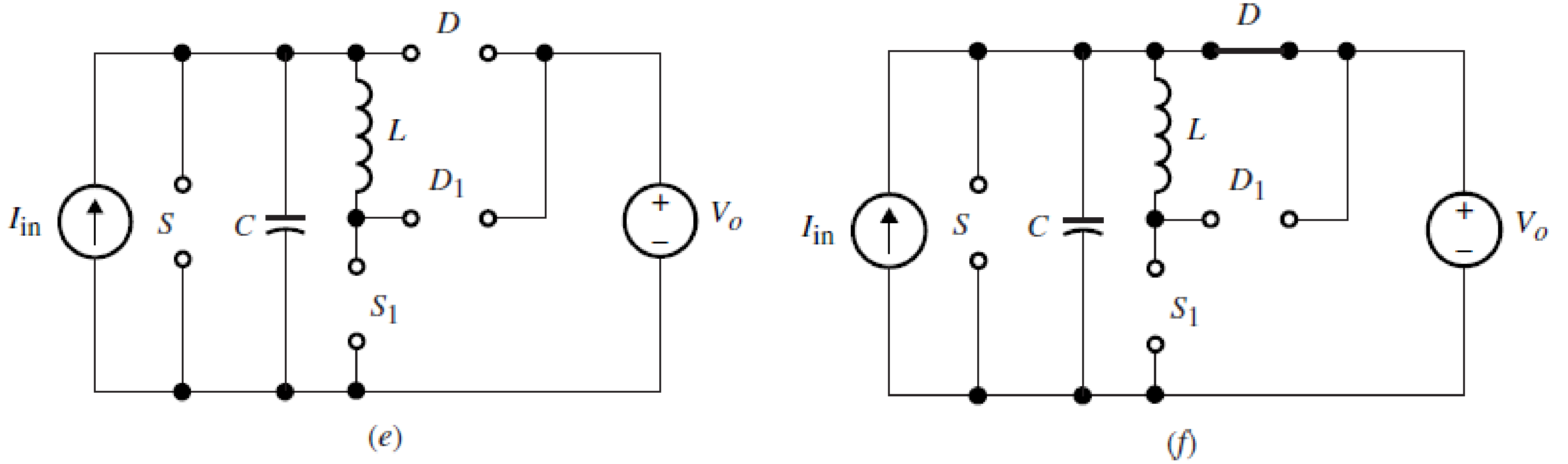


Figure 6.50 Equivalent circuits for the six modes of operation: (*a*) mode I, (*b*) mode II, (*c*) mode III, (*d*) mode IV, (*e*) mode V, and (*f*) mode VI.

Steady State Analysis

Mode I [$t_0 \le t < t_1$]

- Mode I starts at t = t_0 when the auxiliary switch S_1 is turned *ON*.

- Since the main switch, S, and the auxiliary switch S_1 were *OFF* prior to t = t_0 ,

- The capacitor voltage v_c ,is equal to the output voltage V_o and also equal to the inductor voltage as given by,

$$V_o = L\frac{di_l}{dt} = v_c$$

The inductor current i_l is given by,

$$i_l = \frac{V_o}{L}(t - t_0)$$

The above equation assumes zero initial condition for i_l

Steady State Analysis (cont'd)

As long as the inductor current is less than I_{in} ,the diode will stay conducting and the capacitor voltage remains at V_o .At time t_1, the inductor current becomes equal to I_{in} ,D stops conducting, and the circuit enters Mode II. From the above equation, we have,

$$I_{in} = \frac{V_o}{L}(t - t_0)$$

The time interval is given by

$$(t_1 - t_0) = \frac{L\, I_{in}}{V_o}$$

This is the inductor current charging state.

Mode II [$t_1 \leq t < t_2$]

Mode II starts at t_1 when D is *OFF*, resulting in a resonant stage between L and C .During the time between t_1 and t_2, the main switch, remains *OFF*, and S_1 is still *ON*, but S both diodes are *OFF*. The initial capacitor voltage is still V_o ,but the initial I_{in} has changed to .The first order differential equations that represent this mode are given by,

$$C\frac{dv_c}{dt} = I_{in} - i_L$$

$$v_c(t) = L\frac{di_L}{dt}$$

Steady State Analysis (cont'd)

Equation (6.109) is obtained from the above two equations.

$$\frac{d^2 i_L}{dt^2} - \frac{1}{LC} i_L = \frac{1}{LC} I_{in}$$

The solution for i_L and v_c is given by,

$$i_L = \frac{V_o}{Z} \sin \omega_o (t - t_1) + I_{in}$$

$$v_c = V_o (2 - \cos \omega_o (t - t_1))$$

The time interval between t_1 and t_2 is given by

$$(t_2 - t_1) = \frac{1}{\omega_o} \cos^{-1}(2)$$

The diode voltage starts to charge up due to the decreasing capacitor voltage.

$$v_d = V_o - v_c$$

Substituting for v_c, the diode voltage becomes,

$$v_d(t) = -V_o + V_o \cos \omega_o (t - t_1)$$

Steady State Analysis (cont'd)

Mode III $[t_2 \leq t < t_3]$:

Mode III starts when the capacitor discharge to zero. In this mode the main switch, S remains *OFF*, the auxiliary switch, S_1 is still *ON*, and both diodes are *OFF*.
The switch anti-parallel diode () start conducting in this mode.

$$v_c(t) = 0$$

Mode IV $[t_3 \leq t < t_4]$:

Mode IV starts at t = t_3 ,when the main switch, S is turned *ON* and the auxiliary switch, S_1 is turned *OFF*. At t_3 ,the initial capacitor voltage is zero, and the inductor starts linearly discharging from $i_L(t_2)$ to zero during t_3 to t_4 .The diode D remain *OFF* since its voltage is negative, but D_1 turns *ON* at t = t_3 to carry the inductor current.

The input voltage is equal to the inductor voltage, and the output voltage is equal to the negative of inductor voltage, v_L

$$v_L = L\frac{di_L}{dt} = -V_o$$

The inductor current for t > t_2, is given by,

$$i_L(t) = -\frac{V_o}{L}(t - t_2) + i_L(t_2)$$

Steady State Analysis (cont'd)

Mode V [$t_4 \leq t < t_5$]:

In this mode, at t = t_4 both switches are *OFF*, and also both diodes are *OFF*. The inductor current is zero, and the input current is only going through the capacitor,

$$I_{in} = C\,\frac{dv_c}{dt}$$

The capacitor voltage can be expressed as,

$$v_c(t) = \frac{1}{C} I_{in}(t - t_4)$$

The capacitor is charging up from zero and will reache the output voltage at t = t_5
The time interval is,

$$(t_5 - t_4) = \frac{V_o C}{I_{in}}$$

then it enters mode VI at this point.

Mode VI [$t_5 \leq t < t_6$]

When the capacitor reaches the output voltage, D starts conducting, but in this mode, both switches are still *OFF*. The diode current will equal the input current immediately. At t = , the capacitor voltage is equal to the output voltage until the auxiliary switch is turned *ON* again, then the cycle will repeat from mode I. The waveforms for the six modes of operation are shown in Fig.6.51.

Steady State Waveforms

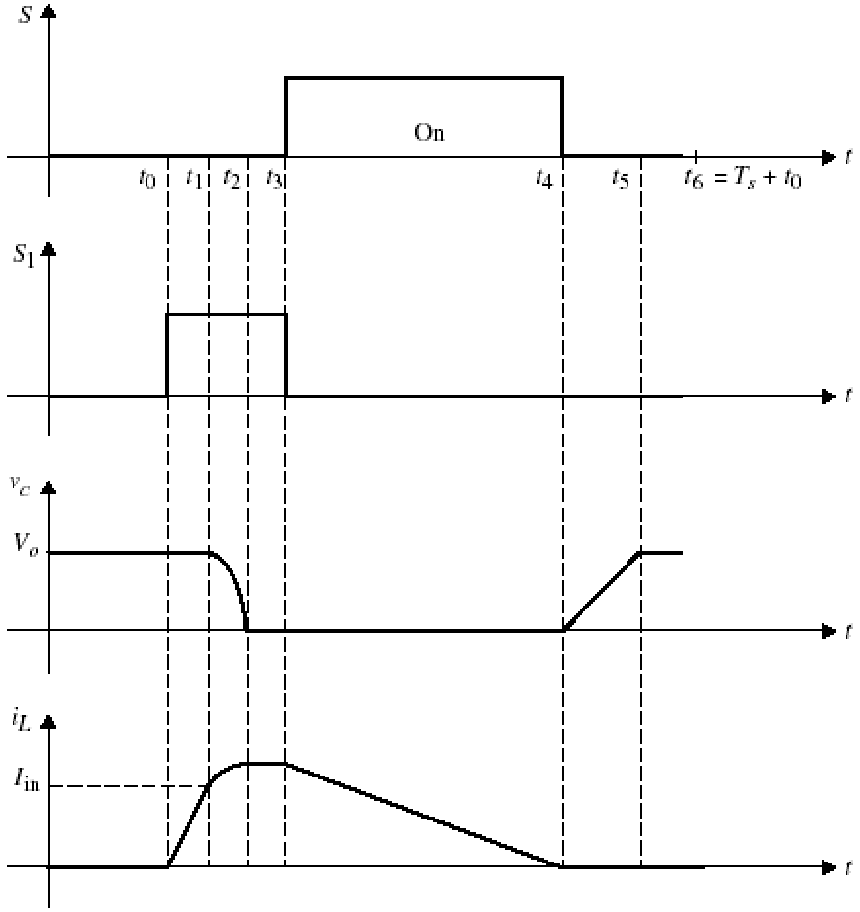


Fig 6.51 Steady-state waveforms for the ZVT boost converter of Fig 6.49(b).