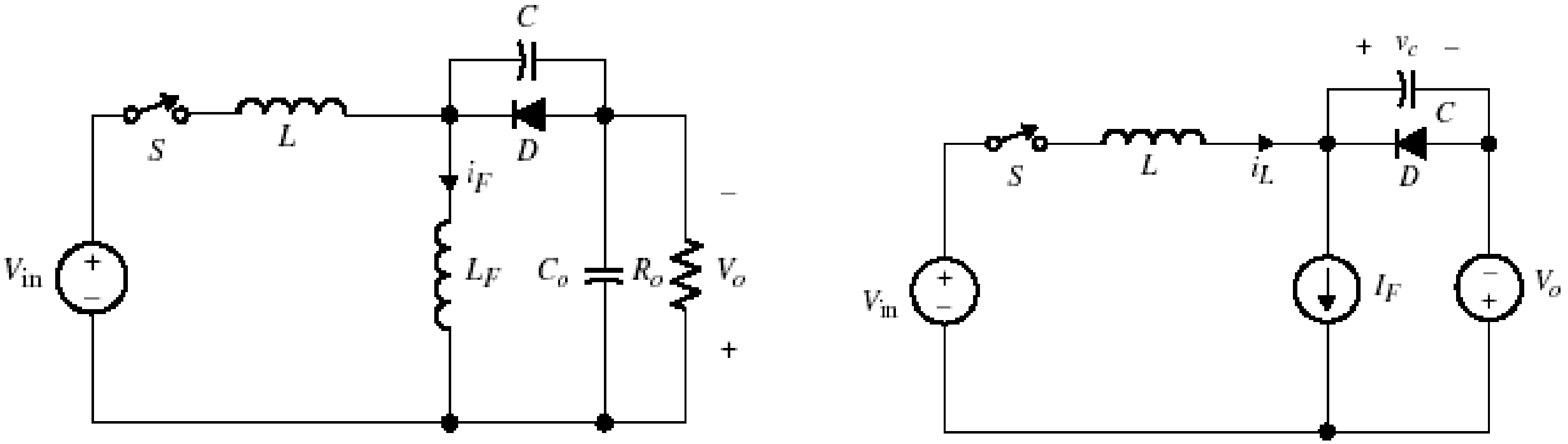
ZCS Buck-boost Converter

Quasi-resonant buck-boost converter by using the L-type switch as shown in Fig. 6.18(a), Fig. 6.18(b) shows the simplified equivalent circuit.



(a)

(b)

Fig 6.18 (a) ZCS buck-boost converter with L-type switch. (b) Simplified equivalent circuit.

ZCS Buck-Boost Converter-Steady-State Analysis

Mode I [$0 \le t < t_1$]:

Mode I starts at t = 0, the switch and the diode are both conducting. According to Kirchhoff's law, the voltage equation can be written as

$$L\frac{di_L(t)}{dt} = V_{in} + V_o \tag{6.50}$$

By integrating both sides of Eq. (6.50) with the initial condition of $i_L(0)=0$, is given by,

$$i_L(t) = \frac{V_{in}+V_o}{L}t$$

$i_L(t)$ (6.51)

and $v_c(t) = 0$

At t = t_1, the inductor current reaches I_F, forcing the output diode to stop conducting, so t_1 can be express as,

$$t_1 = \frac{LI_F}{V_{in}+V_o} \tag{6.52}$$

Steady-State Analysis (cont'd)

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

This is a resonant stage between L and C with the initial conditions given by

$$v_c(t_1) = 0$$

$$i_L(t_1) = I_F$$

Applying Kirchhoff's law, in Fig. 6.19(b), the inductor current and capacitor voltage equations may be given as

$$L\frac{di_l}{dt} = V_{in} + V_o - v_c \tag{6.53a}$$

$$C\frac{dv_c}{dt} = i_L - I_F \tag{6.53b}$$

Solving Eqs. (6.53) for t > t,

$$i_l(t) = I_F + \frac{V_{in} + V_o}{Z_o}\sin\omega_o(t - t_1) \tag{6.54}$$

$$v_c(t) = (V_{in} + V_o)\left[1 - \cos\omega_o(t - t_1)\right] \tag{6.55}$$

At $t = t_2$,the inductor current reaches zero, $i_L(t_2) = 0$,and the switch stops conducting. The time interval $(t_2 - t_1)$ is given by,

$$(t_2 - t_1) = \frac{1}{\omega_o}\sin^{-1}\left(-\frac{I_F Z_o}{V_{in} + V_o}\right) \tag{6.56}$$

Steady-State Analysis (cont'd)

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

Mode III starts at t = t_2 when the inductor current reaches zero. The switch and the diode are both *OFF*. The capacitor starts to discharge until it reaches zero, and the diode will start to conduct again at t = t_3. During this period, the inductor current is zero.

$$v_c = \frac{-1}{C}\int_{t_2}^{t} I_F dt = \frac{-I_F}{C}(t - t_2) + v_c(t_2)$$

The diode begins to conduct at the end of this mode, $t = t_3$, because the capacitor voltage is equal to zero

$$0 = \frac{-I_F}{C}(t_3 - t_2) + v_c(t_2)$$

where $v_c(t_2)$ may be obtained from Eq. (6.55) by evaluating it at t = t_2. The expression from Eq. (6.57) for the time between t_2 and t_3 is,

$$(t_3 - t_2) = \frac{C}{I_F} v_c(t_2)$$

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

Between t_3 and t_4, the switch remains *OFF*, but the diode is *ON*. At the end of the cycle, the switch is closed again when the current is zero. The cycle of the modes will repeat again at T_s.

ZCS Buck-Boost Converter-Equivalent Circuit Modes

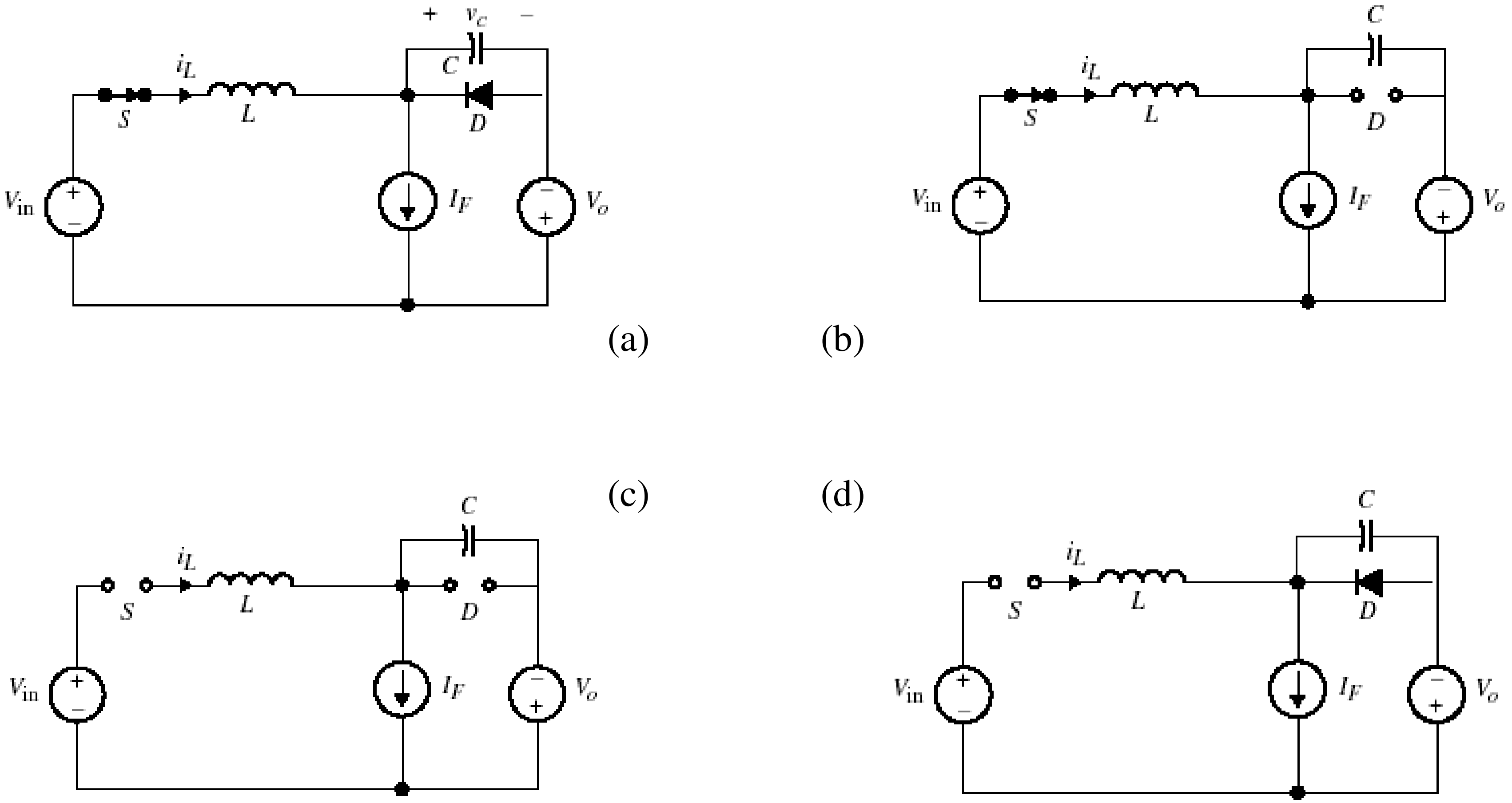


Fig 6.19 (a) Equivalent circuit for mode I. (b) Equivalent circuit for mode II. (c) Equivalent circuit for mode III. (d) Equivalent circuit for mode IV.

ZCS Buck-Boost Converter – Typical Steady-State Analysis

The steady state waveforms shown in Fig. 6.20 are the characteristic waveforms for the switch, v_c, and i_L.

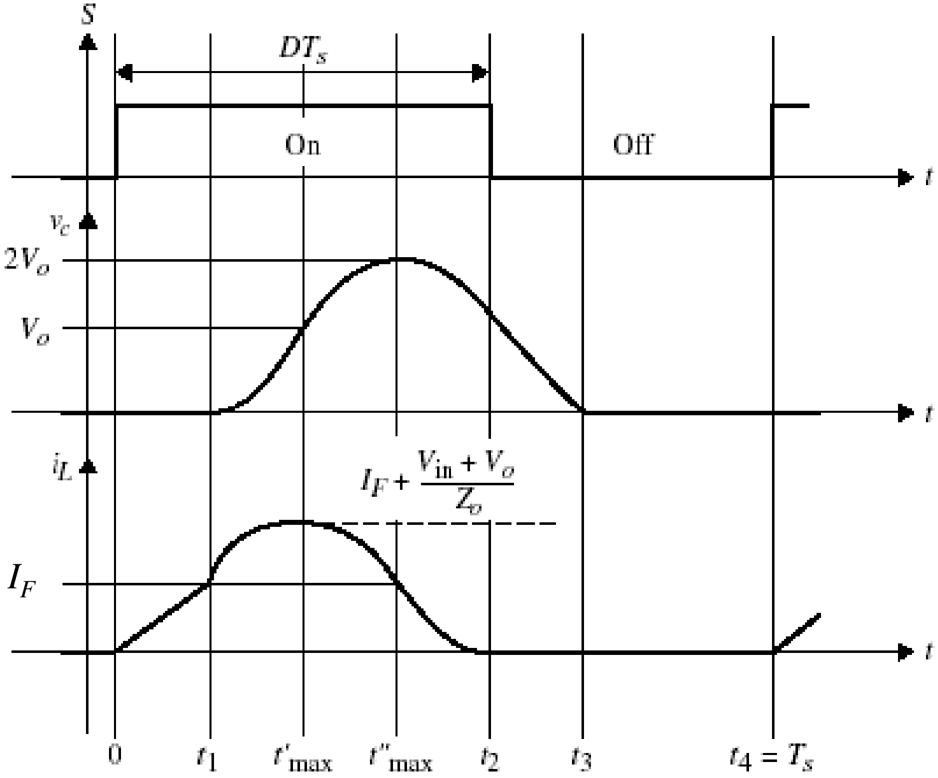


Fig 6.20 Steady-state waveforms for buck-boost converter with L-type switch.

ZCS Buck-Boost Converter

Voltage Gain

- Conservation of energy per switching cycle will be used as before to obtain the voltage gain,

$$M = V_o / V_{in}$$

- The buck-boost-ZCS converter gain is given by

$$\frac{M}{1+M} = \frac{f_{ns}}{2\pi}\left\{\frac{M}{2Q} + \alpha + \frac{Q}{M}[1-\cos(\alpha)]\right\} \qquad (6.59)$$

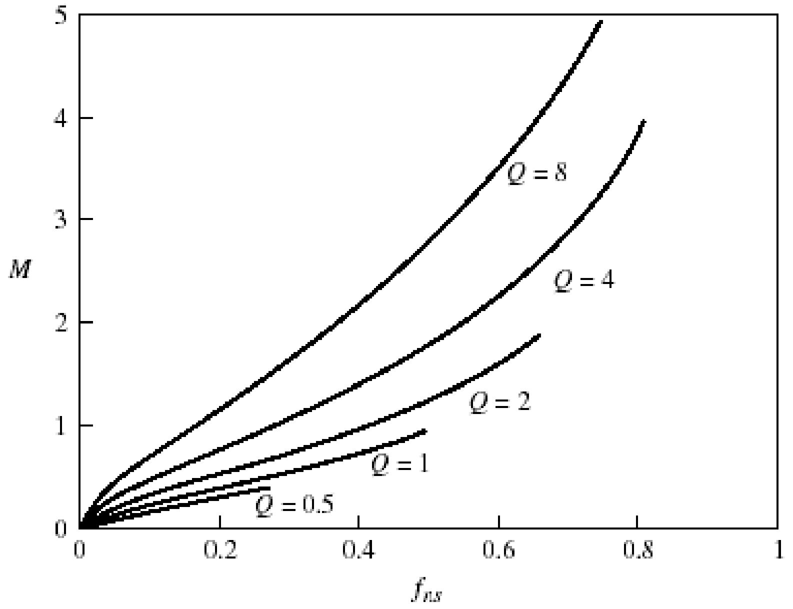


Fig 6.21 Characteristic curve for ***M*** vs. f_{ns} for the ZCS buck-boost converter.

Example 6.4

Consider a buck-boost QRC-ZCS converter with the following specifications: V_{in}=40V, P_o=80W at I_o=4A, f_s=250kHz, L_o=0.1mH, and C_o=6 µF. Design values for L and C and determine the output ripple voltage.

Solution:

The output voltage and load resistance are given by

$$V_o = \frac{80}{4} = 20V \qquad R_o = \frac{20}{4} = 5\Omega$$

The voltage gain is given by

$$\frac{V_o}{V_{in}} = \frac{20}{40} = 0.5$$

With M = 0.5, and f_{ns}= 0.17, we select , $Q = 3$ to yield, $f_o = \frac{250}{0.17} = 1470.6kHz$

From Q, and Z_0,

$$Q = \frac{R_o}{Z_o} = \frac{5}{Z_o} \qquad Z_o = \frac{3}{5} = 0.6\Omega \qquad \sqrt{L/C} = 0.6$$

and

$$\sqrt{1/LC} = 2\pi f_o = 2\pi \times 1470.6 \times 10^3 \qquad \frac{1}{C} = 0.6 \times 2\pi \times 1470.6 \times 10^3$$

From the above equation C and L are given by,

$$C = 180.4nF \qquad L = 3^2 \times C = 1.6\mu H$$

The duty cycle D is approximately 33% since the voltage gain for the buck-boost is 0.5. Hence, the voltage ripple is,

$$\frac{\Delta V_o}{V_o} = \frac{D}{RC_o f} = \frac{0.5}{5 \times 6 \times 10^{-6} \times 250 \times 10^3} = 6.67\%$$