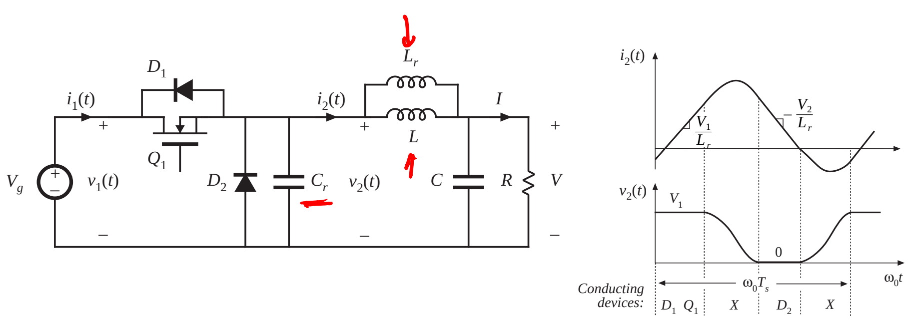
Chapter 20

Quasi-Resonant Converters

Doesn't use state plane analysis

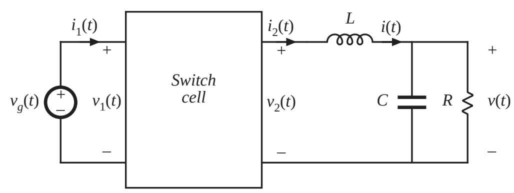
A quasi-square-wave ZVS buck

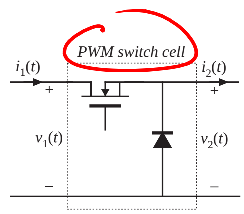


- Peak transistor voltage is equal to peak transistor voltage of PWM cell
- Peak transistor current is increased
- Zero-voltage switching in all semiconductor devices

The resonant switch concept

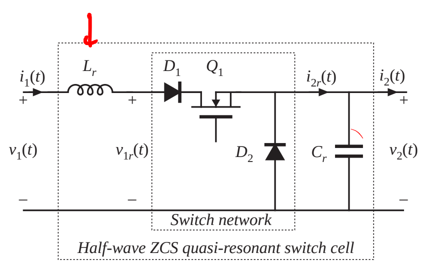
- A quite general idea:
- 1. PWM switch network is replaced by a resonant switch network
- 2. This leads to a quasi-resonant version of the original PWM converter

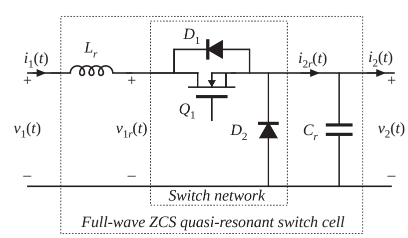




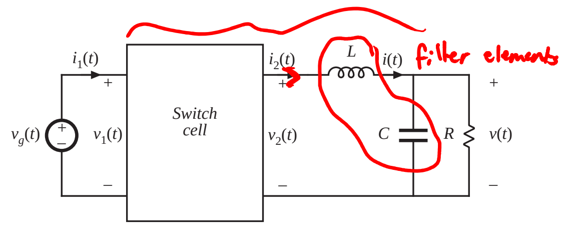
Example: realization of the switch cell in the buck converter

Two quasi-resonant switch cells





Insert either of the above switch cells into the buck converter, to obtain a ZCS quasi-resonant version of the buck converter. L_r and C_r are small in value, and their resonant frequency f_0 is greater than the switching frequency f_s.



20.1 The zero-current-switching quasi-resonant switch cell

Tank inductor L_r in series with transistor: transistor switches at zero crossings of inductor current waveform

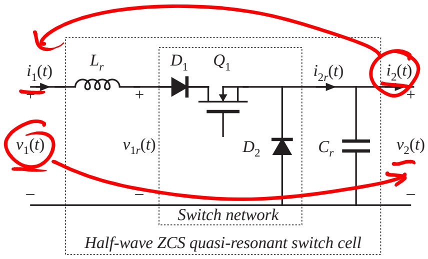
Tank capacitor C_r in parallel with diode D_2 : diode switches at zero crossings of capacitor voltage waveform

Two-quadrant switch is required:

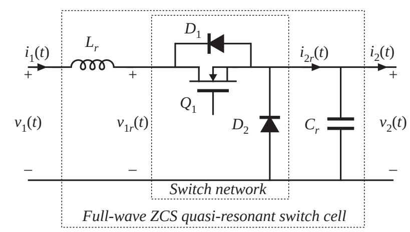
Half-wave: Q_1 and D_1 in series, transistor turns off at first zero crossing of current waveform

Full-wave: Q_1 and D_1 in parallel, transistor turns off at second zero crossing of current waveform

Performances of half-wave and full-wave cells differ significantly.



Half-wave ZCS quasi-resonant switch cell



Full-wave ZCS quasi-resonant switch cell

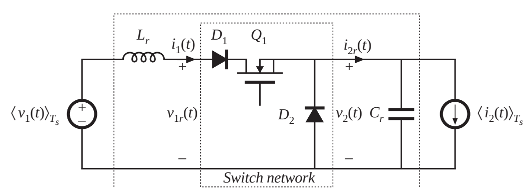
The switch conversion ratio μ

A generalization of the duty cycle $d(t)$

The switch conversion ratio μ is the ratio of the average terminal voltages of the switch network. It can be applied to non-PWM switch networks. For the CCM PWM case, $\mu = d$.

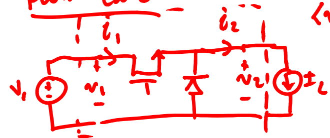
If $\boxed{V/V_g = M(d)}$ for a PWM CCM converter, then $\boxed{V/V_g = M(\mu)}$ for the same converter with a switch network having conversion ratio μ.

Generalized switch averaging, and μ, are defined and discussed in Section 10.3.



Half-wave ZCS quasi-resonant switch cell

PWM case:



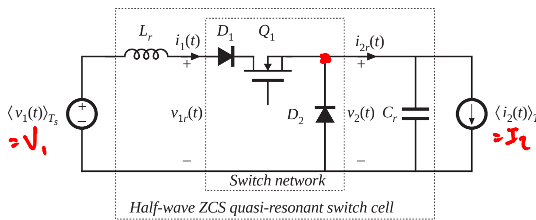
$$\langle v_2\rangle\big|_{T_s} = d\langle v_1\rangle$$

$$\langle i_1\rangle = d\langle i_2\rangle$$

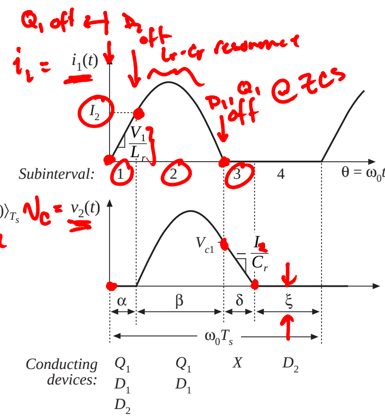
$$\mu = \frac{\langle v_2\rangle}{\langle v_1\rangle} = \frac{\langle i_1\rangle}{\langle i_2\rangle} = \underbrace{\frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{V}{V_g} = \frac{I_g}{I_1} = d}_{\text{PWM case}}$$

20.1.1 Waveforms of the half-wave ZCS quasi-resonant switch cell

The half-wave ZCS quasi-resonant switch cell, driven by the terminal quantities $\langle v_1(t)\rangle_{Ts}$ and $\langle i_2(t)\rangle_{Ts}$.



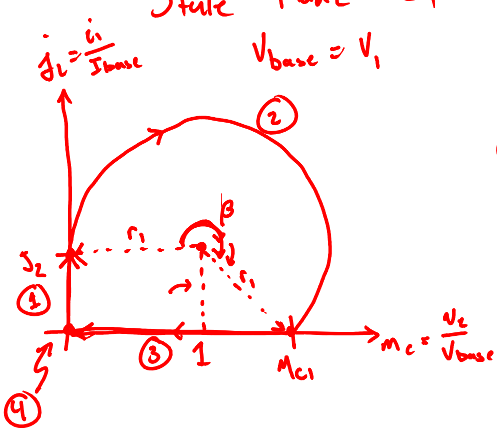
Waveforms:



Each switching period contains four subintervals

State Plane of ½-Wave ZCS

$V_{base} = V_1$



① $I_2 = \frac{V_1}{L_r} t_1 \Rightarrow \boxed{J_2 = \alpha}$

② $r_1 = 1$

$$\boxed{\begin{aligned} M_{c1} &= 1 + \sqrt{1 - J_2^2} \\ \beta &= \pi + \sin^{-1}\left(\frac{J_2}{1}\right) \end{aligned}}$$

③ $V_{c1} = \frac{I_2}{C_r} t_\delta$

$M_{c1} = J_2 \delta \rightarrow \boxed{\delta = \frac{M_{c1}}{J_2}}$

④ $t_4 \rightarrow \xi$

Boundary of zero current switching

$T_s = t_1 + t_2 + t_3 + t_4$

$\frac{2\pi}{F} = \alpha + \beta + \delta + \xi$

What is needed to obtain ZCS?

① enough time

② Large enough r_1

From ref text

(20.21)

② $J_2 < 1 \rightarrow \boxed{I_2 < \frac{V_1}{R_0}}$

① $\xi \geq 0 \rightarrow \frac{2\pi}{F} \geq \alpha + \beta + \delta$ (20.31)

$$\boxed{\frac{2\pi}{F} \geq J_2 + \pi + \sin^{-1}(J_2) + \frac{1+\sqrt{1-J_2^2}}{J_2}}$$

20.1.2 The average terminal Waveforms

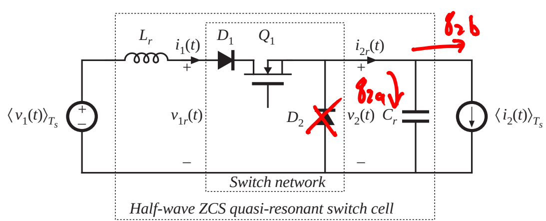
Averaged switch modeling: we need to determine the average values of $i_1(t)$ and $v_2(t)$.

$\langle i_1 \rangle = \frac{1}{T_s}\left[q_1 + q_2\right]$

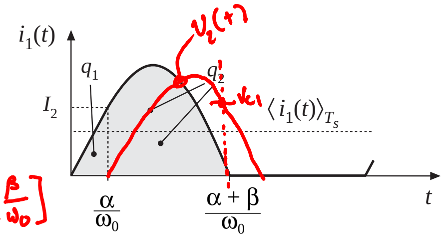
$q_1 = \frac{1}{2}\frac{\alpha}{\omega_0} I_2$

$q_2 = \underbrace{C_r V_{c1}}_{q_{2a}} + \underbrace{I_2 t_2}_{q_{2b}}$

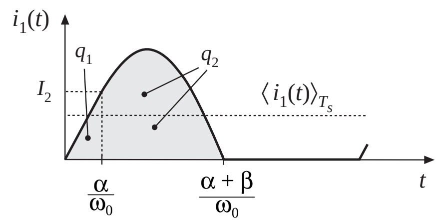
$\langle i_1 \rangle = \frac{1}{T_s}\left[\frac{1}{2}\frac{\alpha}{\omega_0} I_2 + C_r V_{c1} + I_2 \frac{\beta}{\omega_0}\right]$

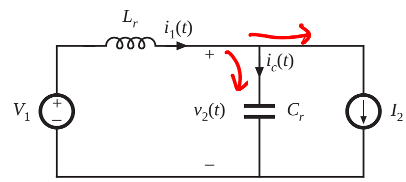


Half-wave ZCS quasi-resonant switch cell



Charge arguments: computation of q_2





Circuit during subinterval 2

Switch conversion ratio μ

$$\langle i_1\rangle = \frac{1}{T_s}\left[\frac{1}{2}\frac{\alpha}{\omega_0}I_2 + C_r V_{c1} + \frac{\beta}{\omega_0}I_2\right]$$

$$\mu = \frac{\langle i_1\rangle}{I_2} = \frac{1}{T_s}\left[\frac{1}{2}\frac{\alpha}{\omega_0} + \frac{C_r V_{c1}}{I_2}\left(\frac{V_{base}}{V_{base}}\right) + \frac{\beta}{\omega_0}\right]$$

$$\mu = \frac{F}{2\pi}\left[\frac{\alpha}{2} + \beta + \frac{M_{c1}}{J_2}\right]$$

$$\mu = F\,\underbrace{\frac{1}{2\pi}\left[\frac{J_2}{2} + \pi + \sin^{-1}(J_2) + \frac{\sqrt{1-J_2^2}+1}{J_2}\right]}_{P_{1/2}(J_2)}$$

$$\mu = F\,P_{1/2}(J_2)$$

from book (20.43)