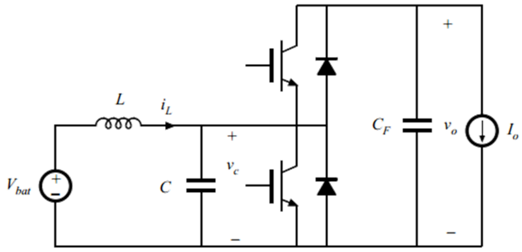
Example 3: ZVS-QSW Boost Converter



Bidirectional drivetrain boost converter in electric vehicles

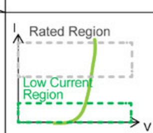
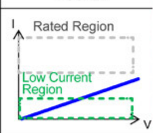
- P_o = 12.5 kW
- f_s = 100 kHz
- V_{bat} = 250 V
- V_o = 500 V
- F = 0.5

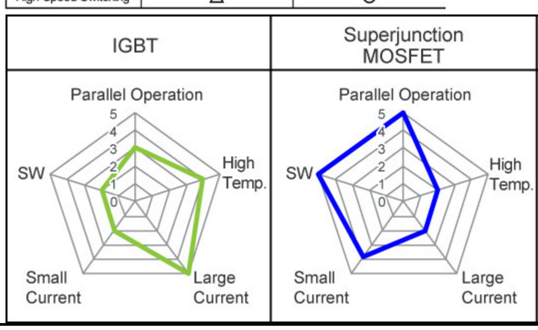
Goals:

- Find L_r, C_r to achieve ZVS for all operating points
- Sketch small-signal model for control design
- Solve $G_{vd}(s)$

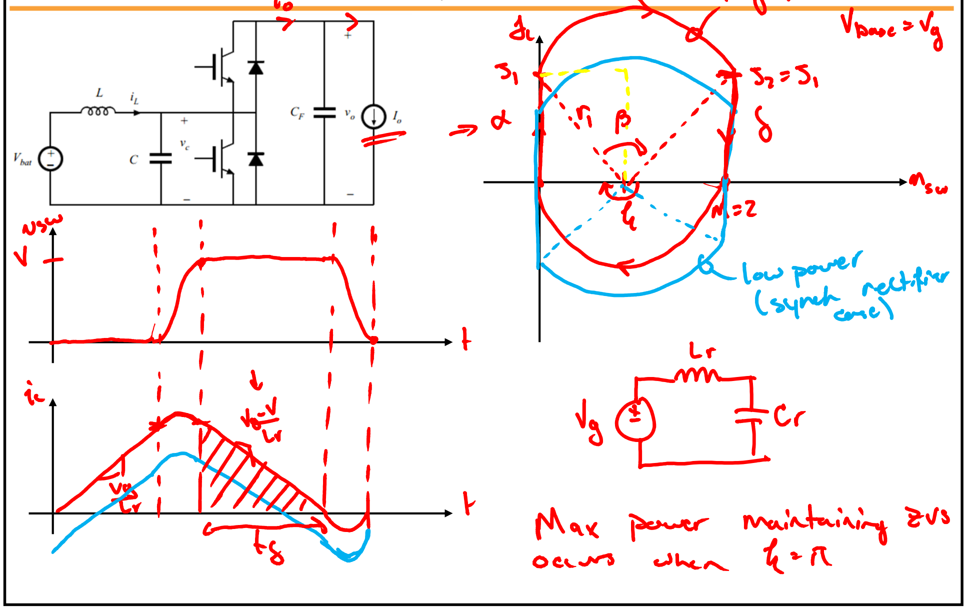
IGBT vs. MOSFET

Rohm, "New Hybrid MOS Combines the Best Characteristics of MOSFETs and IGBTs Improved energy savings"

	IGBT	Superjunction MOSFET
V-I Characteristics		
Low Current	×	○
High Current	○	×
High-Speed Switching	△	○



ZVS-QSW Boost



α: $I_1 = \frac{V_g}{L_r} t_\alpha \rightarrow \boxed{J_1 = \alpha}$

β: $2\tan^{-1}\left(\frac{1}{J_1}\right) = \boxed{2\tan^{-1}\left(\frac{1}{\alpha}\right)}$

By symmetry, I know $\delta = \alpha$, $J_2 = J_1$

$$\omega_0 \frac{1}{f_s} = (t_\alpha + t_\beta + t_\delta + t_\zeta)\,\omega_0$$

$$\frac{2\pi}{F} = \alpha + \beta + \delta + \zeta = 2\alpha + \tan^{-1}\left(\frac{1}{\alpha}\right) + \pi \quad (\text{at } P_{max}:\ \zeta \rightarrow \pi)$$

Apply $F = 0.5$

$$4\pi = 2\alpha + \tan^{-1}\left(\frac{1}{\alpha}\right) + \pi \rightarrow \boxed{\alpha = 4.5}$$

$J_1 = 4.5$

Average Iout

$$\langle i_{out} \rangle = \frac{1}{T_s}\left(t_\delta \cdot t_\delta \cdot \left|\frac{V_g - V}{L}\right|\right)\frac{1}{2} = \frac{1}{T_s}\cdot\frac{1}{2}\cdot\left(\frac{\alpha}{\omega_0}\right)^2 \cdot \frac{V_g}{L}$$

$$J = \frac{R_0}{V_g} f_s \cdot \frac{1}{2} \cdot \alpha^2 \cdot \frac{1}{\omega_0^2} \cdot \frac{V_g}{L} = \frac{R_0}{\omega_0 L} \cdot \frac{f_s}{\omega_0} \cdot \frac{\alpha^2}{2}$$

$$J = \frac{F}{2\pi}\frac{\alpha^2}{2} = \frac{4.5^2}{8\pi} = 0.8 \quad @\ P_{max}$$

$J_{max} = 0.8$

$@\ P_o = 12.5\,kW \rightarrow J_{max} = \frac{I_{max}}{I_{base}}$

$I_{max} = \frac{12.5\,kW}{500\,V} = 25\,A$

$J_{max} = \frac{25\,A}{250\,V} R_o \rightarrow R_o = 8\,\Omega = \sqrt{\frac{L_r}{C_r}}$

$F = 0.5 \rightarrow \frac{f_s}{f_o} = 0.5 \rightarrow f_o = 2 f_s = 200\,kHz$

$f_o = \frac{1}{2\pi\sqrt{L_r C_r}} = 200\,kHz$

$L_r = 6.4\,\mu H$

$C_r = 10\,nF$

$I_{Q,pk} = J_1 I_{base} = 140\,A$

$I_{L,pk} = \sqrt{1 + J_1^2} = 144\,A$