Dual active bridge (DAB) converter operated as DCX, \( M = V_{in} V_g = 1 \)

Operating waveform, neglecting resonant transistors

Phase-shift \( dT_s/2 \)

\[ 0 \leq d \leq 1 \]

\[ nI = n \langle i_{out} \rangle = Ip (1-d) \]

\[ \frac{2V_g}{L_e} \frac{dT_s}{2} = 2Ip \]

\[ Ip = \frac{V_g}{2L} dT_s \]

\[ nI = \frac{V_g}{2L} \frac{dT_s}{T_s} (1-d) \]

\[ J = \frac{\pi}{F} (1-d) \]

in normalized form

\[ J_p = \frac{\pi}{F} d \]
Converter would usually be designed to operate at low $f$ and with small phase shift $d$, $d \ll 1$.

$$\eta I = \frac{V_g}{2L f_s} d (1-d) \approx \frac{V_g}{2L f_s} d$$

$$\eta I \approx I_p$$

$$I \approx I_p = \frac{P}{F} d$$

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State-plane analysis of transitions

Focus on transition from $Q_2, Q_3, Q_6, Q_7$ conducting to $Q_4, Q_5, Q_6, Q_7$ conducting.

\[ \text{V}_{i1} \quad \text{t}_d \quad \text{t}_p \quad \text{t}_f \quad \text{t}_s \quad \text{t} \]

\[ \text{V}_{g} \quad \text{t} \]

\[ \text{V}_{6/8} \quad \text{t} \]

$Q_2, Q_3$ turn off

$Q_6, Q_7$ turn off

$Q_4, Q_5$ turn on at $\pi V$

$Q_8$ turn on at $\pi V$
Before

power delivery

Subinterval ① resonant transition of the primary-side bridge

\[ i_e(0) = -I_p \]

\[ v_{\phi}(0) = \emptyset \]

Subinterval ② L_e current ramp up from \(-I_1\) to \(+I_2\)

Subinterval ③ resonant transition of the secondary-side bridge

\[ v_{\phi} = +I_2 \]

\[ v_{\phi} = \emptyset \]

After

power delivery

\[ i_e = I_p \]
\[ j_1 = \sqrt{J_p^2 - 3} \]
\[ \alpha = \frac{\tan^{-1} J_p - \tan^{-1} \frac{j_1}{2}}{2} \]

Interval (2): \[ j_2 = -j_1 + 2 \beta \]

Interval (3): \[ R_6 = \frac{1}{n} \sqrt{\frac{L_e}{C_s}} \] may not be the same as \( R_0 \)

This is a multi-resonant converter

\[ m_6 = \frac{V_o/n}{V_o} \]

ZVS always met.

**Summary of basic design equations for \( d \ll 1 \)**

\[ J_{\text{max}} = J_{\text{pmax}} = \frac{\pi}{F} d_{\text{max}} \]
\[ d_{\text{max}} = 0.1 \] results in

\[ \frac{J_p}{J_{\text{max}}} \approx 1.1 \]

ZVS to \( J_{\text{min}} = J_{\text{pmin}} = \sqrt{3} \)

ZVS load range:

\[ \frac{J_{\text{pmax}}}{J_{\text{pmin}}} = \frac{\pi d_{\text{max}}}{\sqrt{3} F} \] \( \Rightarrow \) choose \( F \). Given \( C \)'s,

\( J_p \) and \( R_{\text{max}} \) are then determined.