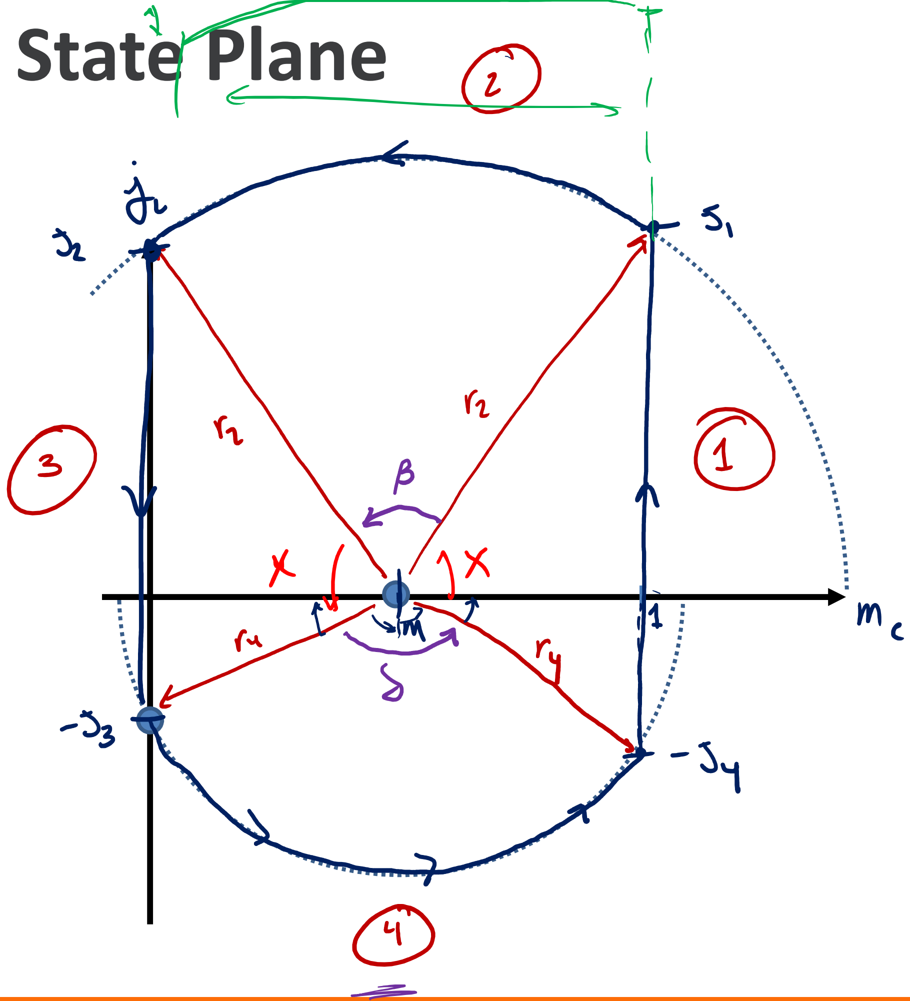
Sync-Buck Complete State Plane



usually easy to obtain if Buck converter has $I_{out} > \phi$

ZVS Conditions:

(2) $m - r_2 \leq \phi \rightarrow m - \sqrt{J_1^2 + (1-m)^2} \leq \phi$

if $m < 1/2$, $J_1 = \phi$ works

(4) $m + \sqrt{m^2 + J_3^2} \geq 1$

if $m > 1/2$, $J_3 = 0$ works

State Plane Solution: Intervals 1 & 2

(1) → Non-resonant subinterval : look at waveforms & relate I_1 & I_4

$$\left(\frac{1}{I_{base}}\right)\frac{V_g - V}{L} t_1 = I_1 + I_4 \left(\frac{1}{I_{base}}\right)$$

$$\frac{R_0}{L} = \frac{\sqrt{L/C}}{L} = \sqrt{\frac{1}{LC}} = \frac{1}{\sqrt{LC}} = \omega_0$$

$$(1-m)\frac{R_0}{L} t_1 = J_1 + J_4$$

$$\boxed{(1-m)\,\theta_1 = J_1 + J_4}$$

(2) → Resonant subinterval : 2 equations { relate radius @ beginning & end of period; solve angle of the circular segment

$$\left.\begin{aligned} r_2^2 &= J_1^2 + (1-m)^2 \\ r_2 &= J_2^2 + m^2 \end{aligned}\right\}$$

$$\boxed{J_1^2 + (1-m)^2 = J_2^2 + m^2}$$

$$\boxed{\beta = \pi - \tan^{-1}\left(\frac{J_1}{1-m}\right) - \tan^{-1}\left(\frac{J_2}{m}\right)}$$

State Plane Solution: Intervals 3 & 4

(3)

$$\frac{V}{L} t_3 = J_2 + J_3$$

$$m \, \theta_3 = J_2 + J_3$$

(4)

$$J_3^2 + m^2 = J_4^2 + (1-m)^2 = r_4^2$$

$$\delta = \pi - \tan^{-1}\left(\frac{J_3}{m}\right) - \tan^{-1}\left(\frac{J_4}{1-m}\right)$$

State Plane Solution: Averaging Step

$$I_{out} = \frac{1}{T_s}\int_0^{T_s} i_{out}(t)\,dt = \frac{1}{T_s}\int_0^{T_s} i_L(t)\,dt$$

$$= \frac{1}{T_s}\left[\int_0^{t_1} i_L(t)\,dt + \int_{t_1}^{t_1+t_2} i_L(t)\,dt + \int_{③} i_L(t)\,dt + \int_{④} i_L(t)\,dt\right]$$

$$= \frac{1}{T_s}\left[\frac{I_1 - I_4}{2}t_1 + q_{L2} + \frac{I_2 - I_3}{2}t_3 + q_{L4}\right]$$

$$q_{L2} = \int_{②} i_L\,dt = \int_{②} i_C\,dt = C_{sw}\,\Delta V_{sw}\Big|_{②} = -C_{sw}V_g$$

$$q_{L4} = \int_{④} i_L\,dt = \int_{④} i_C\,dt = C_{sw}V_g$$

$$\left(\frac{1}{I_{base}}\right) I_{out} = \frac{1}{T_s}\left[\frac{I_1 - I_4}{2}t_1 + \frac{I_2 - I_3}{2}t_3\right]\left(\frac{1}{I_{base}}\right)\left(\frac{\omega_0}{\omega_0}\right)$$

$$J_{out} = \frac{F}{2\pi}\left[\frac{J_1 - J_4}{2}\theta_1 + \frac{J_2 - J_3}{2}\theta_3\right]$$

Define $F = \frac{f_s}{f_0} = \frac{\omega_s}{\omega_0}$

Normalized Period

$t_1 + t_2 + t_3 + t_4 = T_s$

$$\theta_1 + \beta + \theta_3 + \delta = \frac{\omega_o}{f_s} = \frac{2\pi}{F}$$

total:

8 equations → unknowns: $J_1 \quad J_2 \quad J_3 \quad J_4$, $\theta_1 \quad \beta \quad \theta_3 \quad \delta$ } (8)

Design of hardware & op point

M, J_{out}, F L & C_{sw}