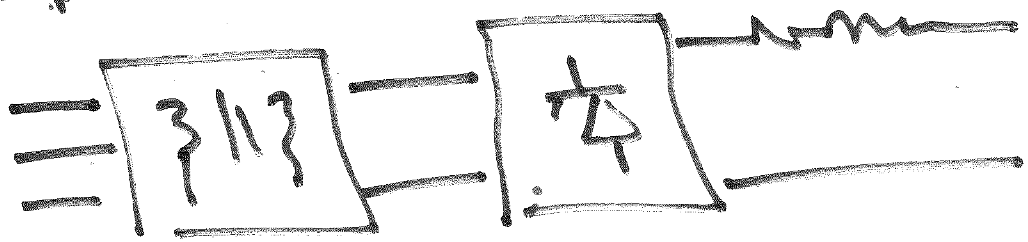
Selection of Turns Ratio

→ Suppose we wanted to achieve a certain output voltage



Specify $S_b = \sim 1.5\, P_{mx}$

$Z_p = 5\%$

$V_b =$ base, ln, pk voltage (caution) (normally l-l, rms)

$I_b =$ base, pk current (caution) (normally rms)

$S_b = \frac{3}{2} V_b I_b$

$Z_b = \frac{V_b}{I_b}$

$\omega_b (L_{lp} + L'_{ls}) = Z_p Z_b$

Selection of Turns Ratio

$$V_d = \frac{3\sqrt{3}}{\pi}\sqrt{2}\,E\cos\alpha - \frac{3}{\pi}L_c\omega_e I_d - r_{dc}I_d$$

Let $V_{d,min}$ be minimum acceptable voltage under maximum load

$$I_{d,max} = \frac{P_{mx}}{V_{d,min}}$$

$$E = \frac{1}{\sqrt{2}}V_{min}\left(\frac{N_s}{N_p}\right)$$

$$V_{d,min} = \frac{3\sqrt{3}}{\pi}V_{min}\left(\frac{N_s}{N_p}\right) - \frac{3}{\pi}\omega_e\frac{Z_b Z_p}{\omega_b}\left(\frac{N_s}{N_p}\right)^2\frac{P_{mx}}{V_{d,min}} - r_{dc}\frac{P_{mx}}{V_{d,min}}$$

Selection of Turns Ratio

$$\underbrace{\left[\frac{3}{\pi}\frac{\omega_e}{\omega_b}\frac{P_{mx}}{V_{d,min}}Z_b Z_p\right]}_{a}\left(\frac{N_s}{N_p}\right)^2+\underbrace{\left[-\frac{3\sqrt{3}}{\pi}V_{min}\right]}_{b}\left(\frac{N_s}{N_p}\right)+\underbrace{\left[r_{dc}\frac{P_{mx}}{V_{d,min}}+V_{d,min}\right]}_{c}=0$$

$$\frac{N_s}{N_p}=-\frac{c}{b}$$

$$\frac{N_s}{N_p}=\boxed{\frac{-b\pm\sqrt{b^2-4ac}}{2a}}$$

Selection of Turns Ratio

$$F(x) = \sqrt{1 - x} \qquad F(0) = 1$$

$$\frac{dF}{dx} = \frac{1}{2}(1-x)^{-\frac{1}{2}}(-1) \qquad \frac{dF}{dx}(0) = -\frac{1}{2}$$

$$F(x) = 1 - \frac{1}{2}x$$

$$\frac{N_s}{N_p} = \frac{-b - |b|\sqrt{1 - \frac{4ac}{b^2}}}{2a}$$

$$= \frac{-\cancel{b} - |b|\left(\cancel{1} - \frac{1}{2}\frac{4ac}{b^2}\right)}{2a} = \frac{|b|\,\cancel{2}\cancel{a}c}{\cancel{2}\cancel{a}\,b^2}$$

$$\approx \frac{c}{|b|}$$

ECE61016 Power Electronics Converters and Systems

Machine Rectifier Systems
Lecture Set 8

S.D. Sudhoff

Fall 2016

Reading: Reading: S.D. Sudhoff, K.A. Corzine, H.J. Hegner, D.E. Delisle, "Transient and Dynamic Average-Value Modeling of Synchronous Machine Fed Load-Commutated Converters," IEEE Trans. On Energy Conversion, Vol. 11, No. 3, September 1996

System Configuration

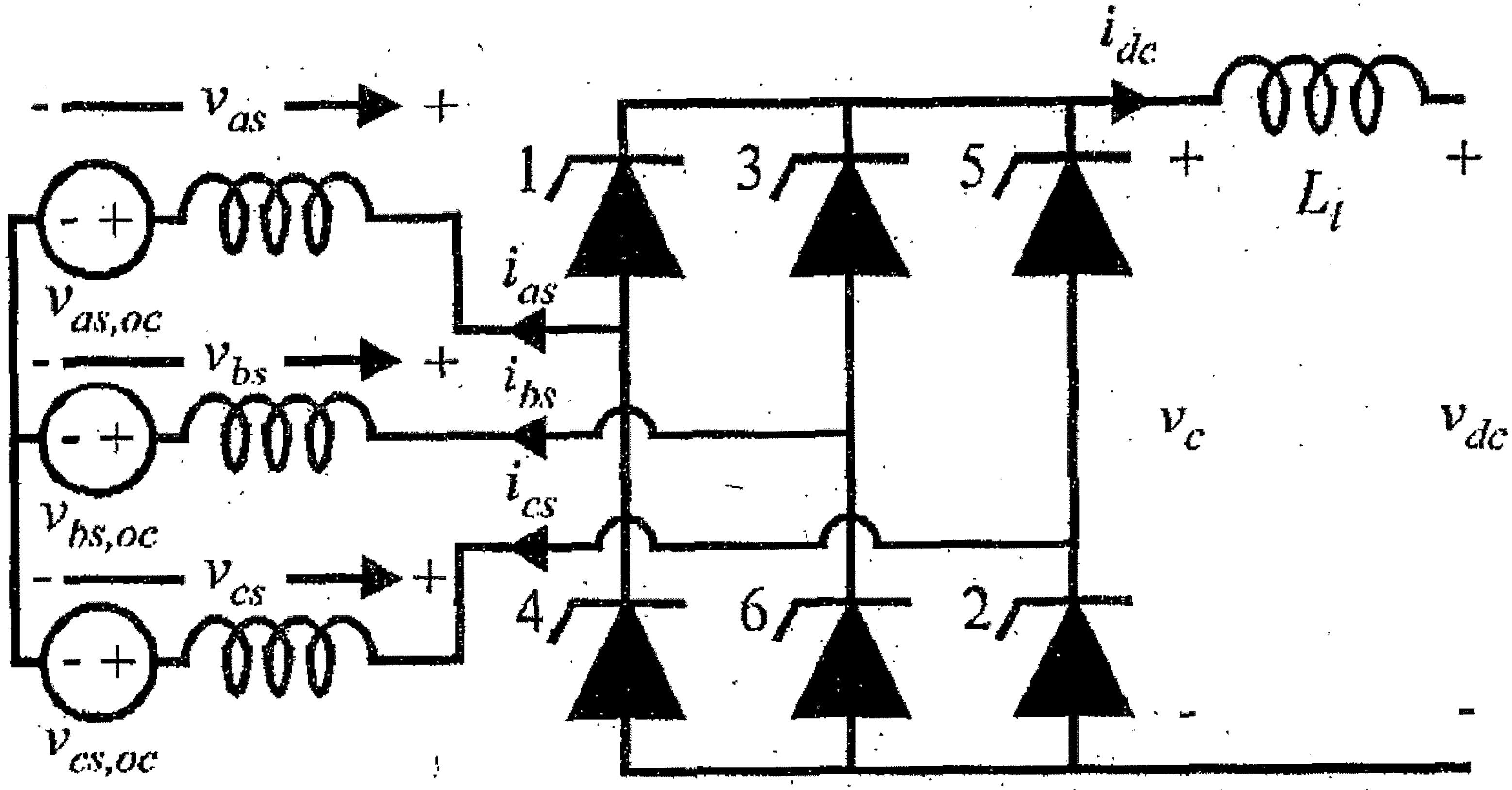


Fig. 1. Synchronous machine fed load-commutated converter.

Operating Waveforms (2-3 Mode)

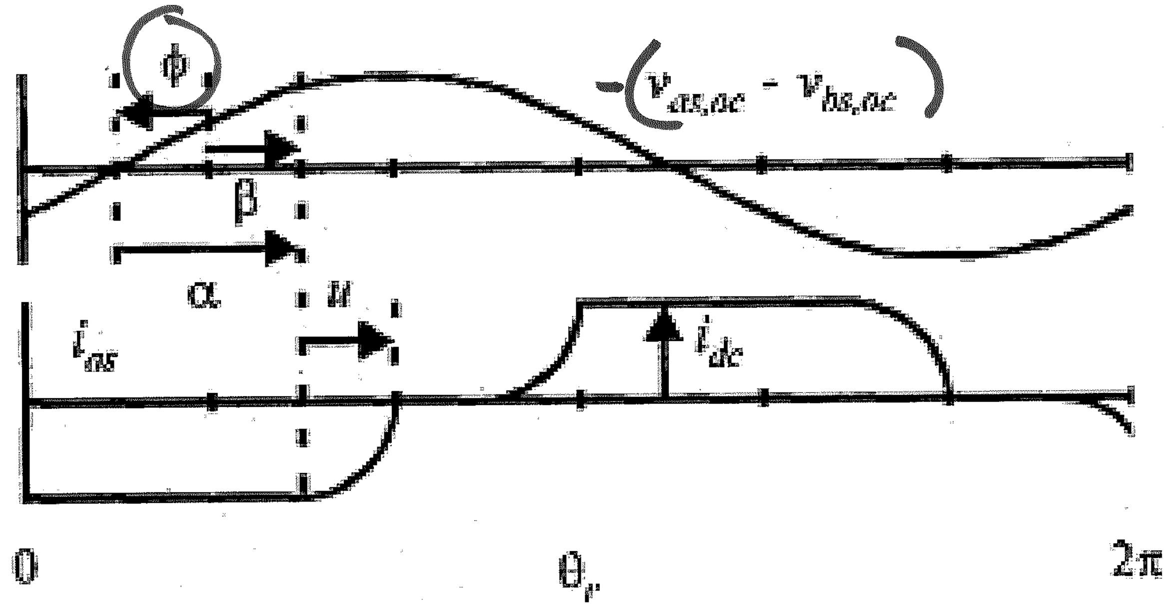


Fig. 2. Operation of synchronous machine fed load-commutated converter.

Value 3 turns ~~of~~ $\theta_s = \frac{\pi}{3} + \alpha$

α = firing angle relative to voltage

β is the firing angle relative to rotor position. Value 3 turns on at $\theta_r = \frac{\pi}{3} + \beta$

Synchronous Machine Model

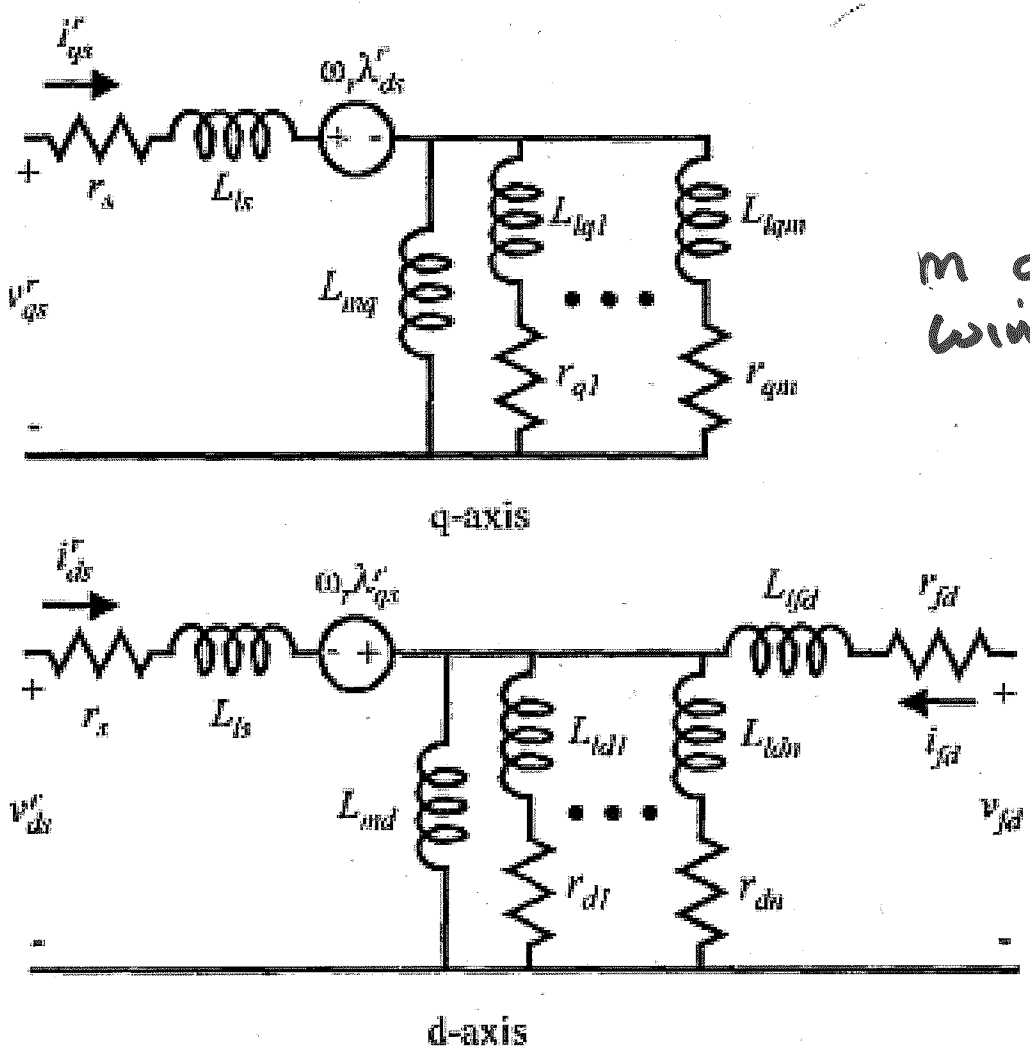


Fig. 3. Synchronous machine equivalent circuit.

m damper windings

n damper windings

we will be using the rotor reference frame

Desired Model Structure

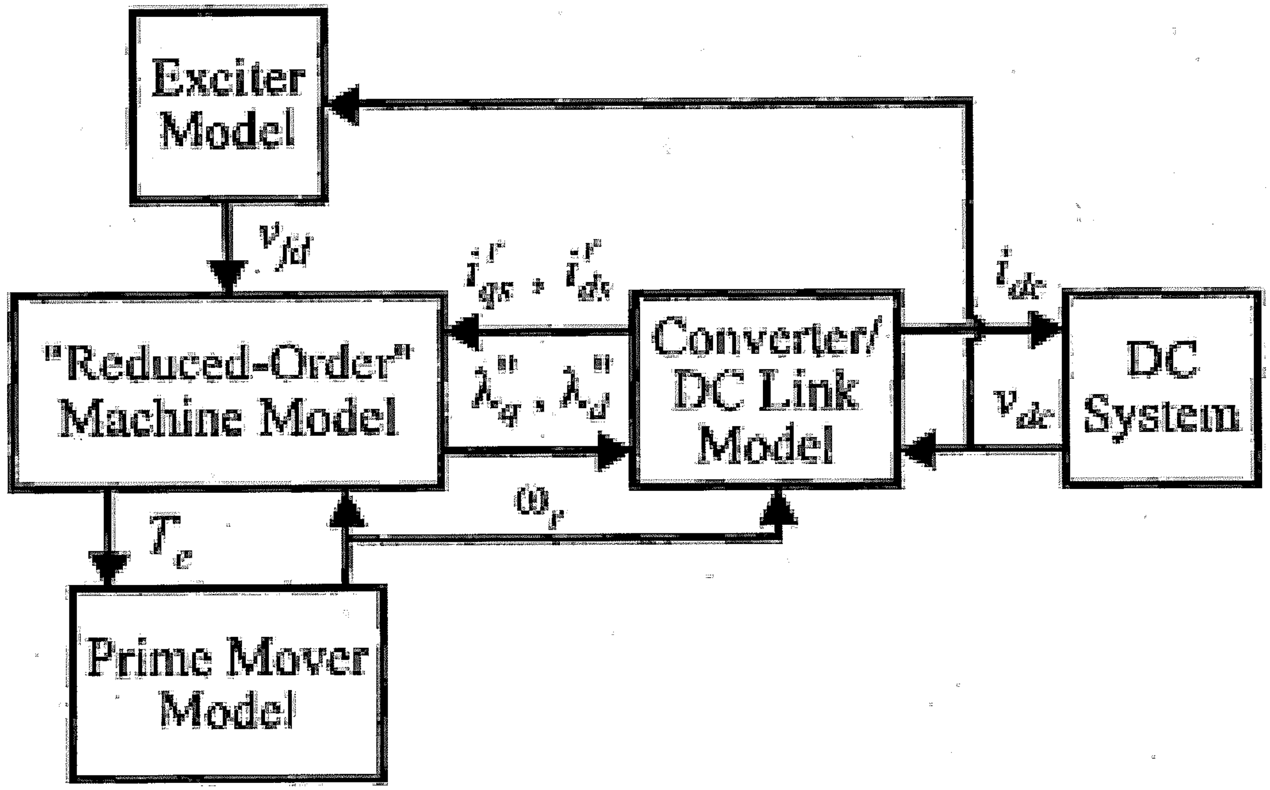


Fig. 4. Simulation structure.

Reduced-Order Machine Model

$$v_{qs} = r_s i_{qs} + \omega_r \lambda_{ds} + \cancel{p\lambda_{qs}}$$ neglect

$$v_{ds} = r_s i_{ds} - \omega_r \lambda_{qs} + \cancel{p\lambda_{ds}}$$ neglect

$$v_{qi} = r_{qi} i_{qi} + p\lambda_{qi} \qquad i \in [1 \ldots m]$$

$$v_{dj} = r_{dj} i_{dj} + p\lambda_{dj} \qquad j \in [1 \ldots n]$$

$$v_{fd} = r_{fd} i_{fd} + p\lambda_{fd}$$

Inputs to ROM: i_{qs} & i_{ds}, v_{fd}

Outputs: T_e, Rotor states

Need: derivative of the rotor flux linkages

Reduced-Order Machine Model

$$\lambda_{qs} = L_{ls} i_{qs} + L_{mq} i_{mq}$$

$$\lambda_{ds} = L_{ls} i_{ds} + L_{md} i_{md}$$

$$\lambda_{qi} = L_{lqi} i_{qi} + L_{mq} i_{mq}$$

$$\lambda_{dj} = L_{ldj} i_{dj} + L_{md} i_{md}$$

$$\lambda_{fd} = L_{lfd} i_{fd} + L_{md} i_{md}$$

$$i_{mq} = i_{qs} + \sum_i i_{qi}$$

$$i_{md} = i_{ds} + \sum_j i_{dj} + i_{fd}$$

Reduced-Order Machine Model

$$i_{qi} = \frac{\lambda_{qi} - L_{mq}\, i_{mq}}{L_{\ell qi}}$$

$$i_{mq} = i_{qs} + \sum_i \left(\frac{\lambda_{qi} - L_{mq}\, i_{mq}}{L_{\ell qi}} \right)$$

$$i_{mq} \left[1 + L_{mq} \sum_i \frac{1}{L_{\ell qi}} \right] = i_{qs} + \sum_i \frac{\lambda_{qi}}{L_{\ell qi}}$$

$$i_{mq} = \frac{i_{qs} + \sum_i \frac{\lambda_{qi}}{L_{\ell qi}}}{1 + L_{mq} \sum_i \frac{1}{L_{\ell qi}}}$$

Summary of Reduced-Order Model

$$i_{mq} = \frac{i_{qs}^{r} + \sum_{i=1}^{m} \frac{\lambda_{qi}}{L_{lqi}}}{1 + L_{mq} \sum_{i=1}^{m} \frac{1}{L_{lqi}}} \quad 1$$

$$i_{md} = \frac{i_{ds}^{r} + \sum_{i=1}^{n} \frac{\lambda_{di}}{L_{ldi}} + \frac{\lambda_{fd}}{L_{lfd}}}{1 + L_{md}\left(\frac{1}{L_{lfd}} + \sum_{i=1}^{n} \frac{1}{L_{ldi}}\right)} \quad 1$$

$$i_{qi} = \frac{\lambda_{qi} - L_{mq} i_{mq}}{L_{lqi}} \quad 1 \le i \le m \quad 2$$

$$i_{di} = \frac{\lambda_{di} - L_{md} i_{md}}{L_{ldi}} \quad 1 \le i \le n$$

$$i_{fd} = \frac{\lambda_{fd} - L_{md} i_{md}}{L_{lfd}}$$

2

$$p\lambda_{qi} = -r_{qi} i_{qi} \quad 1 \le i \le m \quad 3$$

$$p\lambda_{di} = -r_{di} i_{di} \quad 1 \le i \le n$$

$$p\lambda_{fd} = v_{fd} - r_{fd} i_{fd}$$

3

$$T_e = \frac{3}{2}\frac{P}{2}\left(\underbrace{\lambda_{md}}_{L_{md} i_{md}} i_{mq} - \underbrace{\lambda_{mq}}_{L_{mq} i_{mq}} i_{md}\right)$$

Subtransient Machine Model

$$v_{qs} = r_s i_{qs} + \omega_r \lambda_{ds} + p\lambda_{qs}$$

$$v_{ds} = r_s i_{ds} - \omega_r \lambda_{qs} + p\lambda_{ds}$$

$$\lambda_{qs} = L_{ls} i_{qs} + L_{mq} i_{mq}$$

$$\lambda_{ds} = L_{ls} i_{ds} + L_{md} i_{md}$$

Recall

$$i_{mq} = \frac{i_{qs} + \sum_i \frac{\lambda_{qi}}{L_{lqi}}}{1 + L_{mq} \sum_i \frac{1}{L_{lqi}}}$$

$$i_{md} = \frac{i_{ds} + \frac{i_{fd}}{L_{lfd}} + \sum_j \frac{\lambda_{dj}}{L_{ldj}}}{1 + L_{md}\left[\frac{1}{L_{lfd}} + \sum_j \frac{1}{L_{ldj}}\right]}$$

Subtransient Machine Model

$$\lambda_{qs} = \underbrace{\left[L_{\ell s} + \frac{L_{mq}}{1 + L_{mq} \sum_i \frac{1}{L_{\ell qi}}} \right]}_{L_q''} i_{qs} + \underbrace{\left[\frac{L_{mq} \sum_i \frac{\lambda_{qi}}{L_{\ell qi}}}{1 + L_{mq} \sum_i \frac{1}{L_{\ell qi}}} \right]}_{\lambda_q''}$$

$$\lambda_{ds} = \underbrace{\left[L_{\ell s} + \frac{L_{md}}{1 + L_{md} \left[\sum_j \frac{1}{L_{\ell dj}} + \frac{1}{L_{\ell fd}} \right]} \right]}_{L_d''} i_{ds} + \underbrace{\left[\frac{L_{md} \left[\frac{\lambda_{fd}}{L_{\ell fd}} + \sum_j \frac{\lambda_{dj}}{L_{\ell dj}} \right]}{1 + L_{md} \left[\frac{1}{L_{\ell fd}} + \sum_j \frac{1}{L_{\ell dj}} \right]} \right]}_{\lambda_d''}$$

Subtransient Machine Model

$$\left.\begin{aligned} \lambda_{qs} &= L''_q\, i_{qs} + \lambda''_q \\ \lambda_{ds} &= L''_d\, i_{ds} + \lambda''_d \end{aligned}\right) \text{ exact}$$

$$v_{qs} = \cancel{r_s i_{qs}} + \omega_r (L''_d i_{ds} + \lambda''_d) + p(L''_q i_{qs} + \cancel{\lambda''_q})$$

$$v_{ds} = \cancel{r_s i_{ds}} - \omega_r (L''_q i_{qs} + \lambda''_q) + p(L''_d i_{ds} + \cancel{\lambda''_d})$$

$$v_{qs} = \omega_r L''_d i_{ds} + L''_q p i_{qs} + \overbrace{\omega_r \lambda''_d}^{e''_q}$$

$$v_{ds} = -\omega_r L''_q i_{qs} + L''_d p i_{ds} \underbrace{- \omega_r \lambda''_q}_{+ e''_d}$$

$0 = ri + p\lambda$

$v_{fd} = r_{fd} i_{fd} + p\lambda_{fd}$

$v_{qs} = \omega_r \lambda_{ds} + p\lambda_{qs}$

$v_{ds} = -\omega_r \lambda_{qs} + p\lambda_{ds}$