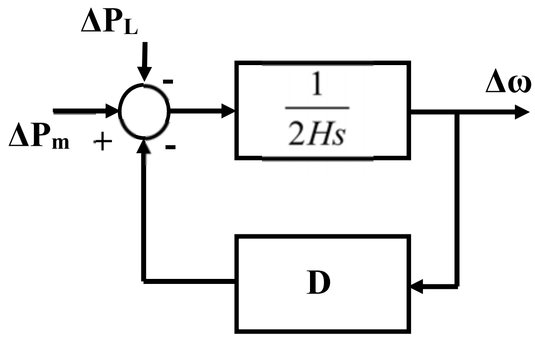
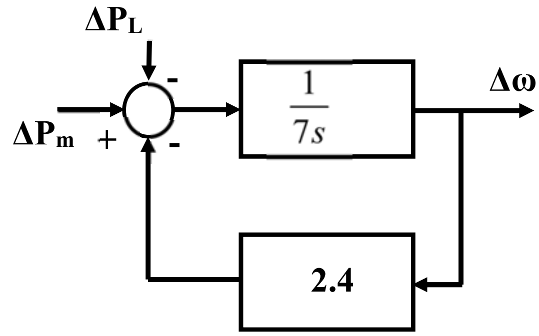
Part 4: Example 68.3

4.1 a)

Linearized model



⇨



Unit #1 on 10 MW base, H_1 = 2sec
Unit #2 on 5 MW base, H_2 = 3sec
On 10 MW base, H_1 = **2sec** (no change)
On 10 MW base, H_2 = 3 x 5/10 = **1.5sec**
Recall H = stored kinetic energy / machine MVA base,
=> stored K.E = H x MVA base
Hence, H_{old} x MVA_{old} = H_{new} x MVA_{new}
With 2 generators, $H = H_1 + H_2$ = **3.5sec**

Pump Load:
Given $P_{pump} \propto \omega^3$
$P_{pump} = P_0\omega^3$

$$\therefore \quad \frac{dP_{pump}}{d\omega} = 3P_0\omega^2$$

On 10 MW base, ω = 1pu, P_{pump} = 8MW = 0.8pu

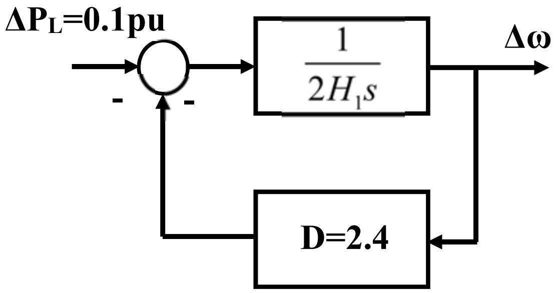
$$0.8 = P_0(1)^3 \quad \Rightarrow \quad P_0 = 0.8$$

$$\frac{dP_{pump}}{d\omega} = 3\times 0.8\omega^2 = 2.4 = D$$

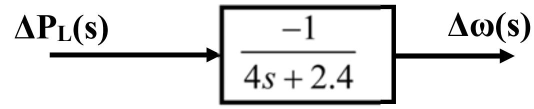
Note that resistive load is independent of speed (i.e. frequency).

4.1 b)

Following the tripping of the 5MW unit, only the 10MW unit is left connecting to the loads. The transfer function model is:



⇨

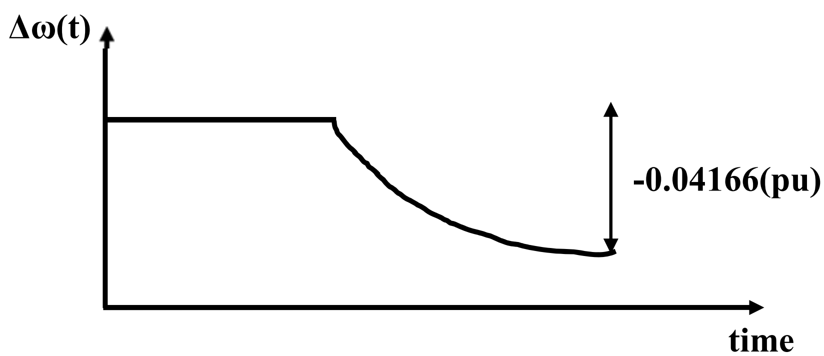


The 5MW generator was loaded to 1MW before it was disconnected. Therefore, the 1MW additional load has to be supplied by the remaining unit i.e. 10MW unit.

$$\Delta P_L = \frac{0.1}{s} pu$$

$$\begin{aligned}
\Delta\omega(s) &= -\frac{0.1}{s} \times \frac{1}{4s+2.4} \\
&= \frac{-0.1}{s(2.4)} + \frac{-0.1}{-0.6(4s+2.4)} \\
&= \frac{-0.04166}{s} + \frac{0.04166}{s+0.6}
\end{aligned}$$

$$LT^{-1} \quad \Delta\omega(t) = -0.04166 + 0.04166e^{-0.6t}$$



4.1 c)

Given that $P_{m1} \propto \omega$

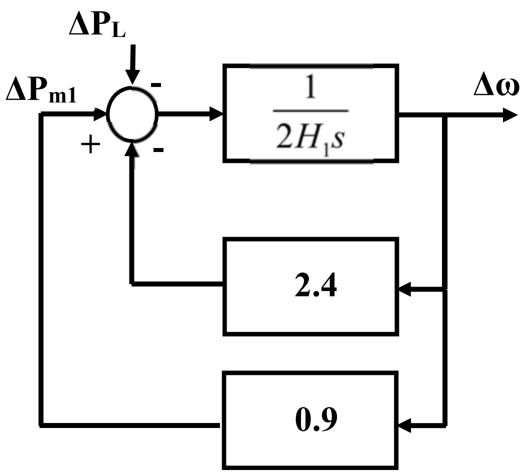
$$P_{m1} = P_{m0}\omega$$

when ω = 1pu, P_{m1} =0.9pu

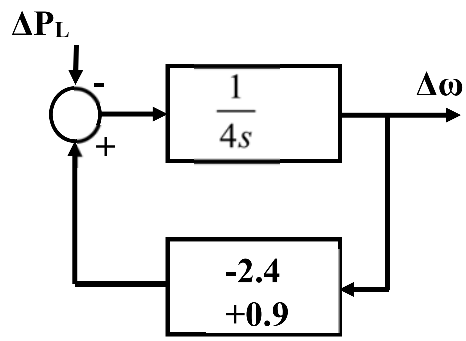
$$P_{m0} = 0.9$$

$$\frac{dP_{m1}}{d\omega} = P_{m0} = 0.9 = \frac{\Delta P_m}{\Delta\omega}$$

$\Delta P_L = \dfrac{0.1}{s}$, as before



➔



$$\Delta\omega(s) = -\frac{0.1}{s} \times \frac{1}{4s+1.5} = \frac{-0.1}{s(1.5)} + \frac{-0.1}{\left(\frac{-1.5}{4}\right)(4s+1.5)}$$

$$LT^{-1} \qquad \Delta\omega(t) = \frac{-0.1}{1.5}\left(1 - e^{-0.376t}\right)$$

4.2 a)

$$\frac{\Delta\omega(s)}{\Delta P_L(s)} = \frac{-\frac{1}{Ms}}{1+\frac{1}{RMs}\frac{(1-T_w s)}{\left(1+\frac{T_w}{2}s\right)}} = \frac{-R\left(1+\frac{T_w}{2}s\right)}{RMs\left(1+\frac{T_w}{2}s\right)+(1-T_w s)}$$

Characteristic Equation (C.E) is

$$RM\frac{T_w}{2}s^2 + (RM - T_w)s + 1 = 0$$

For stability, apply Routh Hurwitz criteria

$$RM\frac{T_w}{2} > 0 \quad \Rightarrow R > 0$$

$$RM - T_w > 0 \quad \Rightarrow R > \frac{T_w}{M}$$

Lowest $R = \frac{T_w}{M}$

4.2 b)

For critical damping, b^2-4ac = 0

(C.E) $as^2 + bs + c = 0$

i.e. $R^2M^2 - 2RMT_w + T_w^2 = 2RMT_w$

Solving R,

$$R = \frac{T_w}{M}\left(2 \pm \sqrt{3}\right)$$

But for stability, $R > \frac{T_w}{M}$

Hence, $R = \frac{T_w}{M}\left(2+\sqrt{3}\right)$

Substitute $T_w = 4$, $M = 10$

R = 1.49pu (for critical damping)

4.2 c)

Substitute $T_w = 4,\ M = 10,\ R = 1.49$ into $\dfrac{\Delta\omega(s)}{\Delta P_L(s)}$

We have, $\Delta\omega(s) = \dfrac{-1.49\left(1+2s\right)}{29.8\left(s+0.183\right)^2} \times \Delta P_L(s)$

When $\Delta P_L(s) = \dfrac{0.1}{s}$

$$\Delta\omega(s) = \frac{k_0}{s} + \frac{k_{11}}{\left(s+0.183\right)^2} + \frac{k_{12}}{\left(s+0.183\right)}$$

From LT table, standard pair

$$\frac{1+\alpha s}{s\left(s+\omega_1\right)^2} = \frac{\alpha_0}{s} + \frac{\alpha_1}{\left(s+\omega_1\right)^2} + \frac{\alpha_2}{\left(s+\omega_1\right)}$$

$$where \qquad \alpha_0 = \left.\frac{1+\alpha s}{\left(s+\omega_1\right)^2}\right|_{s=0} = \frac{1}{\omega_1^2}$$

$$\alpha_1 = \left.\frac{1+\alpha s}{s}\right|_{s=-\omega_1} = \frac{-\left(1-\alpha\omega_1\right)}{\omega_1}$$

$$\alpha_2 = \left.\frac{d}{ds}\frac{1+\alpha s}{s}\right|_{s=-\omega_1}$$

$$\therefore\ k_0 = \frac{-1.49\times 0.1}{29.8\times 0.183^2} = -0.149$$

$$k_{11} = \frac{-1.49\left(1+2(-0.183)\right)\times 0.1}{-29.8\times 0.183} = 0.0173$$

$$k_{12} = -\frac{d}{ds}\{\ \}_{s=-0.183} = \frac{-0.149}{29.8}\left(\frac{2s-\left(1+2s\right)}{s^2}\right)_{s=-0.183} = 0.149$$

$$LT^{-1} \quad \Delta\omega(t) = -0.149 + \left(0.0173t + 0.149\right)e^{-0.183t}$$