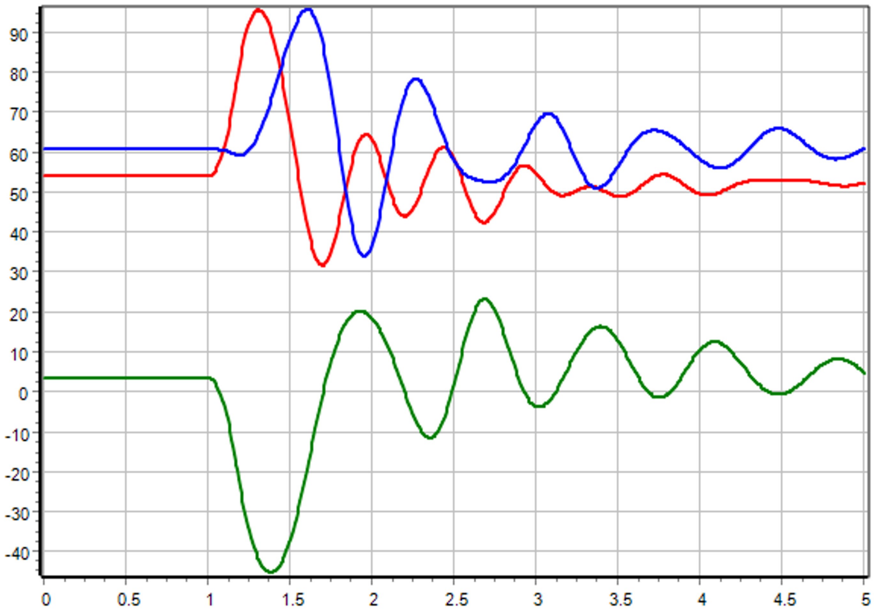
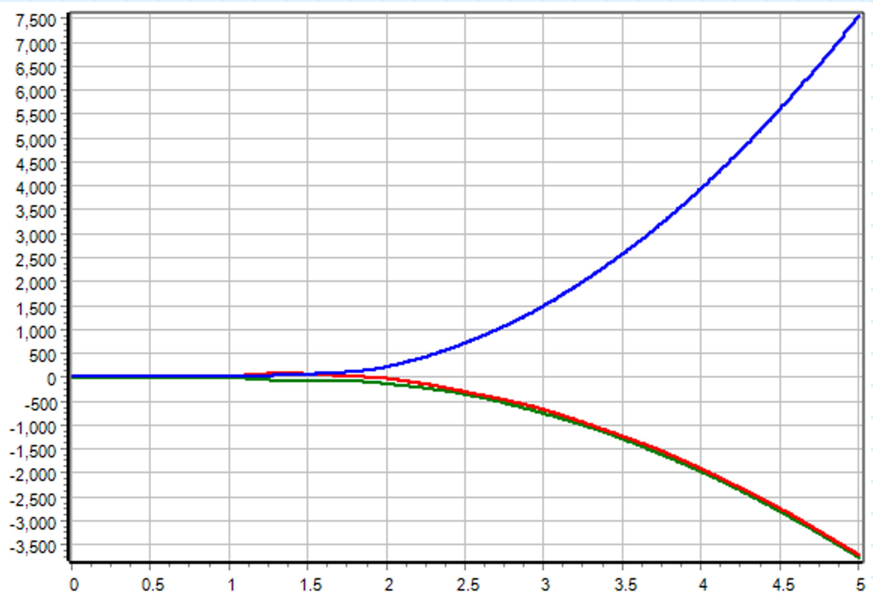
# Homework #5, Problem #1

Monday, October 25, 2021 11:56 AM

1) The critical clearing time is at 0.17s



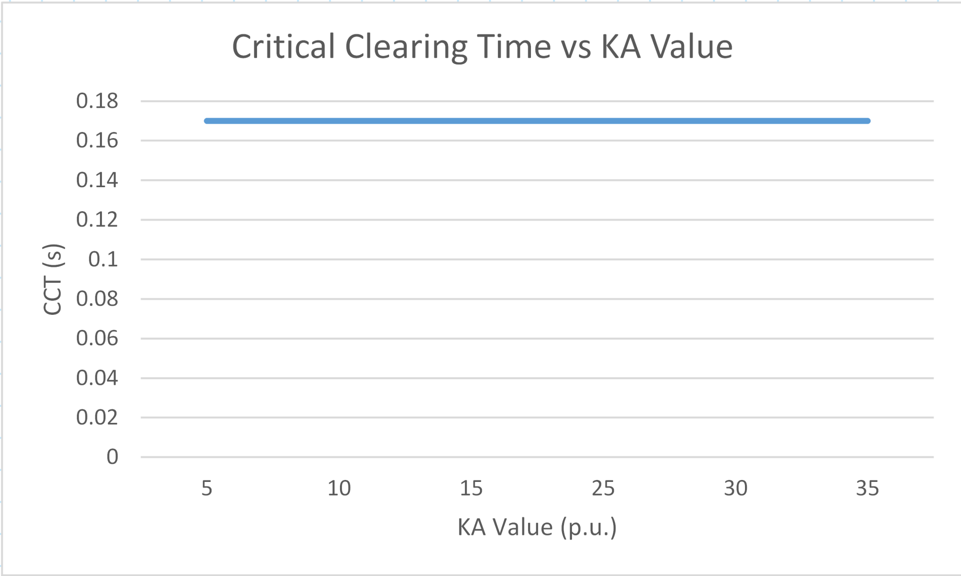

This is the rotor angle at t = 0.18s.



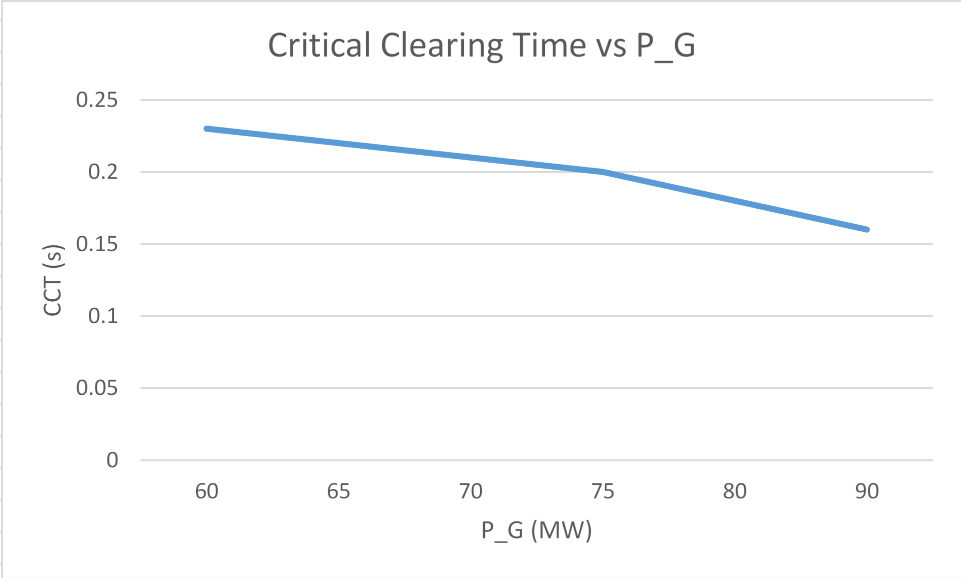
# Homework #5, Problem #2

Wednesday, November 3, 2021 11:48 AM

2) The sensitivity of the clearing time to the KA value is 0, where it does not change when the KA value is changed.




Averaging the changes of the clearing time to P_G, we get an approximate sensitivity of -0.0024



# Homework #5, Problem #3

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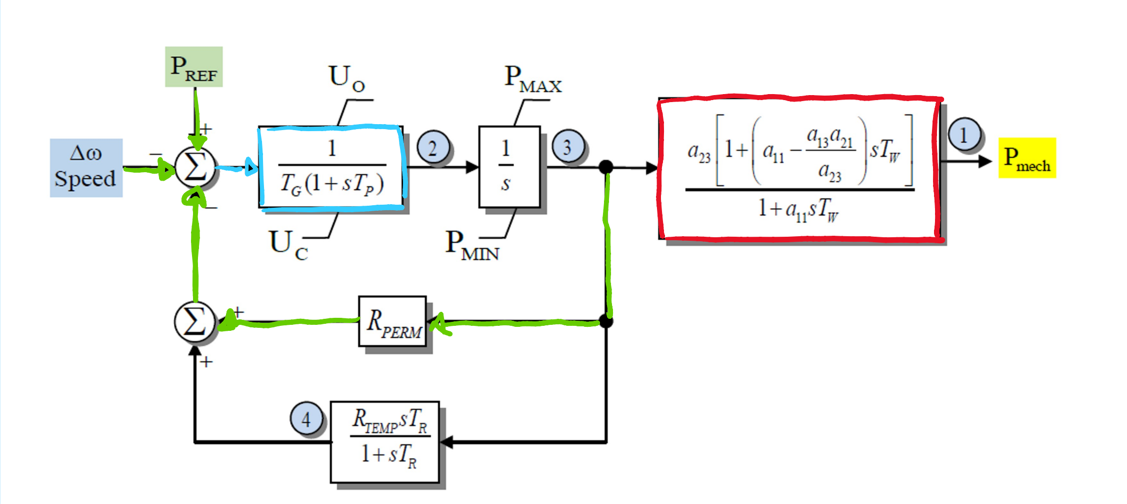



$P_{mech} = 1$ pu.

Since we want the initial value of $P_{ref}$, lets look at steady state.

$$\Rightarrow \quad u \rightarrow \boxed{\frac{sK}{1+sT}} \rightarrow 0 \qquad\qquad 0 \rightarrow \boxed{\frac{K}{s}} \rightarrow y$$

derivative block $\qquad\qquad$ integrator block

$$u \rightarrow \boxed{\frac{K}{1+sT}} \rightarrow Ku$$

first order lag block

Looking at the block in red, we note that we distribute $a_{23}$ and get:

$$\frac{a_{23} + (a_{23}a_{11} - a_{13}a_{21})\, sT_w}{1 + a_{11} sT_w}$$

$$= \underbrace{\frac{a_{23}}{1 + a_{11} s T_W}}_{\text{first order lag block}} + \underbrace{\frac{(a_{23} a_{11} - a_{13} a_{21}) s T_W}{1 + a_{11} s T_W}}_{\text{derivative block}}$$

=> at (3), we have $\frac{P_{mech}}{a_{23}}$, where $a_{23} = K_{turb}$

=> (2) is the input to an integrator block = 0

=> Because the block in blue is a first order lag block, the input is also 0.

(4) is the output of a derivative block = 0

$$\Rightarrow -\Delta\omega + P_{ref} - R_{PERM}\left(\frac{P_{mech}}{K_{turb}}\right) = 0$$

$$\Rightarrow P_{ref} = R_{PERM}\left(\frac{P_{mech}}{K_{turb}}\right) + \Delta\omega$$

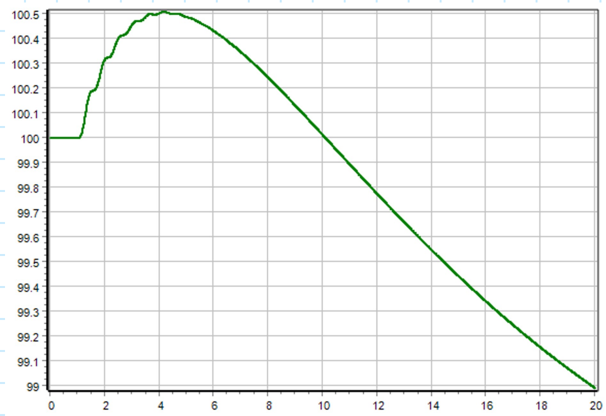
- Since we're looking at the inital value, $\Delta\omega = 0$

$$\Rightarrow P_{ref} = 0.05\left(\frac{1}{1}\right) \Rightarrow \boxed{P_{ref} = 0.05 \text{ pu}}$$

- We note that changing $R_{TEMP}$ has no impact on $P_{ref}$, given a fixed $P_{mech}$ at steady state.

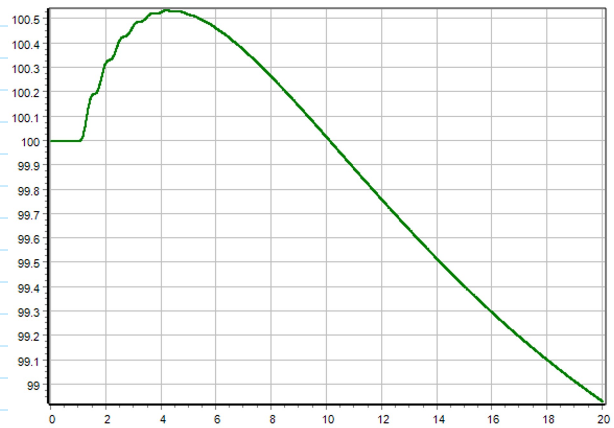
This can be observed in the fact that $P_{ref}$, as a function of $P_{mech}$, does not depend on $R_{TEMP}$. The same applies for the inverse.

However, during transient stability studies, we see that increasing $R_{TEMP}$ will decrease the overall change in power initially. This is observed by looking at the peaks.



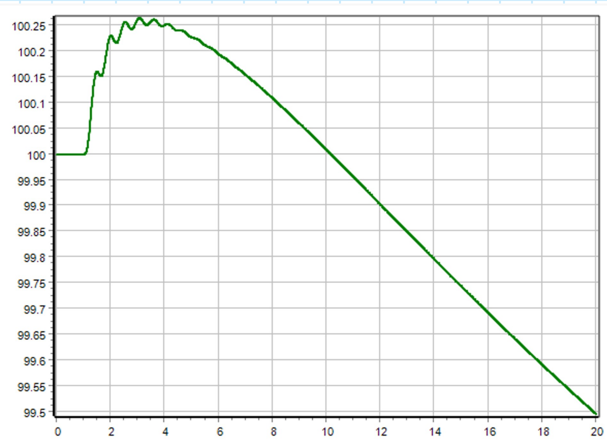

$R_{TEMP}$

0.05




$R_{TEMP}$

0.025




$R_{TEMP}$

0.5

# Homework #5, Problem #4

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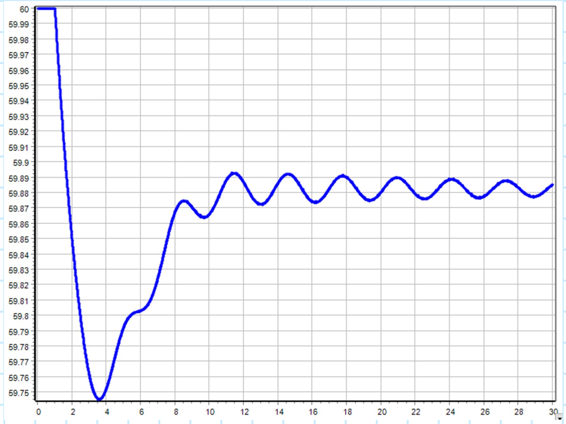
Using the Ziegler-Nichols method:

I) $K_I / K_D$ are set to 0.

II) $K_P$ is tuned such that we have marginal stability. This gives you a $K_u$ of roughly 17 p.u., and $T_u$ of roughly 3.117s



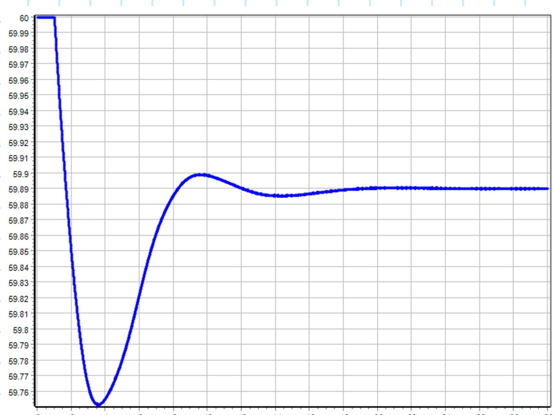
III) Thus for PID tuning:

$$K_P = 0.6\,K_u = 10.2 \text{ p.u.}$$

$$K_I = 2\,\frac{K_P}{T_u} = 6.545 \text{ p.u.}$$

$$K_D = \frac{K_P T_u}{8} = 3.974 \text{ p.u.}$$

This results in the behavior seen below:



# Homework #5, Problem #6

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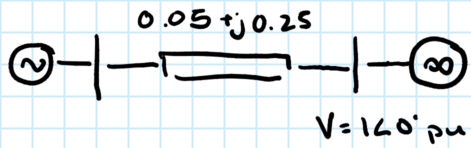
Prefault:



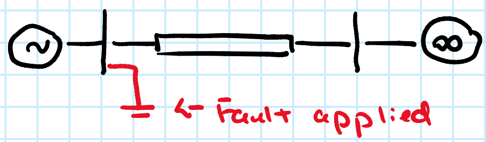

• This is used to initialize the system

**Constants**

$H = 5 \quad D = 1 \quad x_d' = 0.25$

$P_M = 100\text{ MW} \quad \Delta t = 0.01$

During Fault

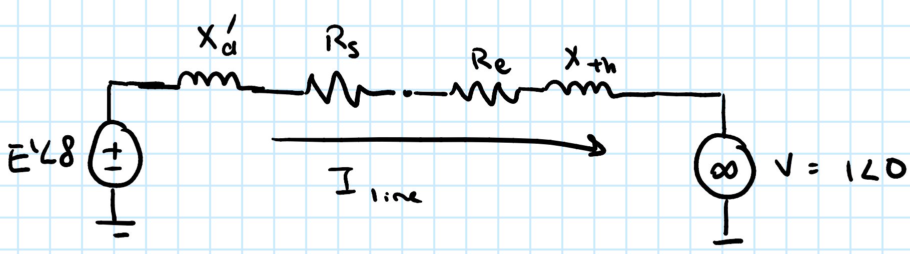



From the classical model, we get:

$$\frac{d\delta}{dt} = \Delta\omega_{pu} \cdot \omega_s, \text{ where } \omega_s = 2\pi 60$$

$$\frac{d\Delta\omega_{pu}}{dt} = \frac{1}{2H}\left(P_M - P_E - D(\Delta\omega_{pu})\right)$$

⇒ From SMIB Analysis with the classical model:




Given that power supplied is 1 pu:

$$\Rightarrow S = VI^* \Rightarrow I = \left(\frac{S}{V}\right)^* = \left(\frac{1}{1}\right)^* = 1\text{ pu}$$

$$\Rightarrow E'\angle\delta = V + \left[(R_s + jX_d') + (R_e + jX_{th})\right] I_{line}$$

$$= 1 + \left[(j0.25) + (0.05 + j0.25)\right]$$

$$= 1.05 + j0.5\text{ pu} = 1.163\angle 25.463^\circ$$

When the fault is applied, $P_E = 0$, which makes our system of equations:

$$\frac{d\delta}{dt} = \Delta\omega_{pu} \cdot \omega_s$$

$$\frac{d\Delta\omega_{pu}}{dt} = \frac{1}{2H}\left(P_m - D(\Delta\omega_{pu})\right)$$

=> For RK2:

$$X(t+\Delta t) = X(t) + \frac{(K_1 + K_2)}{2}$$

$$K_1 = \Delta t \; f(X(t))$$

$$K_2 = \Delta t \; f(X(t) + K_1)$$

where: $X(t) = \begin{bmatrix} \delta \\ \Delta\omega_{pu} \end{bmatrix}$ $f(X(t)) = \begin{bmatrix} \Delta\omega_{pu} \cdot \omega_s \\ \frac{1}{10}(1 - \Delta\omega_{pu}) \end{bmatrix}$

$$X(0) = \begin{bmatrix} 0.444 \\ 0 \end{bmatrix}$$

$$\Rightarrow K_1 = \Delta t \; f\left(\begin{bmatrix} 0.444 \\ 0 \end{bmatrix}\right) = (0.01)\begin{bmatrix} 0 \\ 1/10 \end{bmatrix} = \begin{bmatrix} 0 \\ 0.001 \end{bmatrix}$$

$$\Rightarrow K_2 = \Delta t \; f\left(\begin{bmatrix} 0.444 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0.001 \end{bmatrix}\right)$$

$$= \Delta t \; f\left(\begin{bmatrix} 0.444 \\ 0.001 \end{bmatrix}\right) = (0.01)\begin{bmatrix} 0.377 \\ 0.0999 \end{bmatrix} = \begin{bmatrix} 3.77\times10^{-3} \\ 9.99\times10^{-4} \end{bmatrix}$$

$$\Rightarrow X(0.1) = X(0) + \frac{1}{2}\left(\begin{bmatrix} 0 \\ 0.001 \end{bmatrix} + \begin{bmatrix} 3.77\times10^{-3} \\ 9.99\times10^{-4} \end{bmatrix}\right)$$

$$= \begin{bmatrix} 0.444 \\ 0 \end{bmatrix} + \begin{bmatrix} 0.00188 \\ 0.000995 \end{bmatrix} = \begin{bmatrix} 0.446 \\ 9.995 \times 10^{-4} \end{bmatrix}$$

$\Rightarrow$ Rotor Angle: $0.446\ \text{rad} = 25.55^\circ$

Generator Speed $= 1 + \Delta\omega_{pu} = 1.0009995_{pu}$

$\Rightarrow \quad f \approx 60.0599\ \text{Hz}$

$\omega \approx 377.368\ \text{rad/s}$