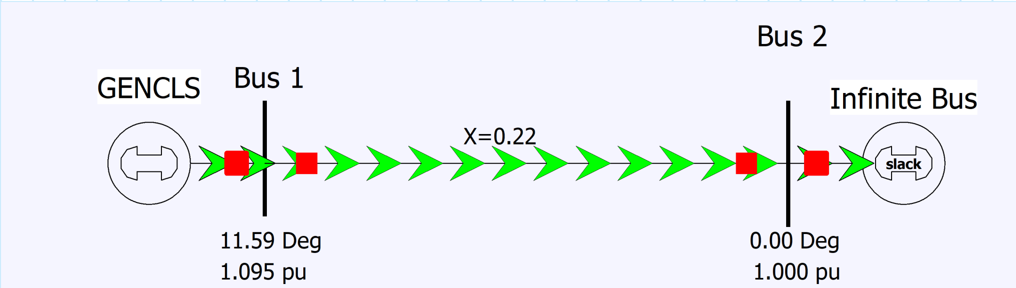
Homework #6, Problem #1

Tuesday, November 9, 2021 4:52 PM

Repeat the example from Lecture 15 with the implicit solution for the GENCLS supplying an infinite bus (slides 41 to 46), except rather than having a solid fault at the terminal of bus 1, assume 1) the balanced three-phase fault has per unit impedance of j0.1 (on the common 100 MVA base), 2) the fault occurs at t=0 (same as the example), and 3) that the fault is cleared at 0.06 seconds. Solve for the first 0.1 seconds using a 0.02 time step.



Now, the fault occurs at $t=0$, with impedance of j0.1

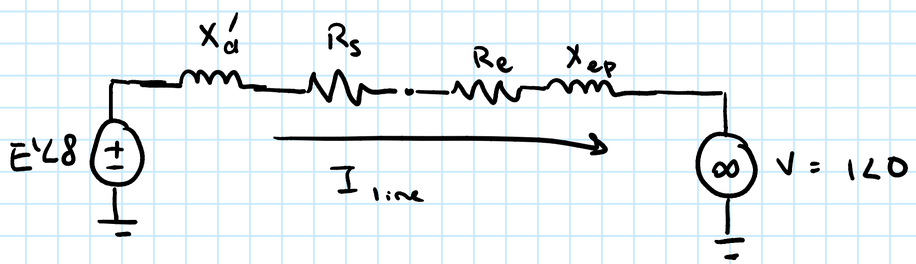
- For a classical model, the swing equations are:

$$\frac{d\delta}{dt} = \Delta\omega \cdot \omega_s \quad , \text{ where } \omega_s = 2\pi 60 \text{ rad/s}$$

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H}\left(P_M - P_E - D\Delta\omega\right) \quad , \text{ where } P_E = \frac{E' V_{inf}}{X_{th}} \sin\delta$$

- To initialize the system, we get:

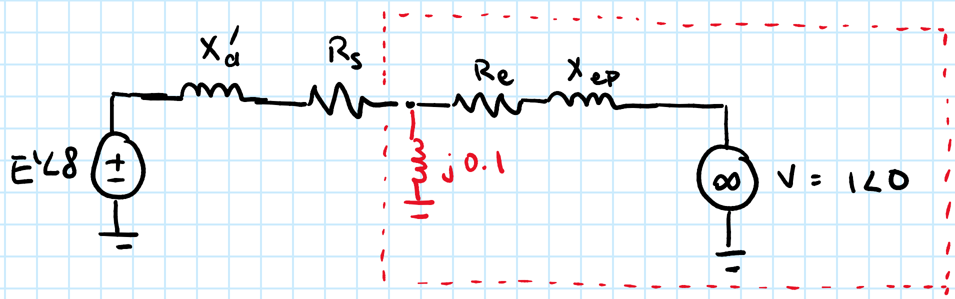
From SMIB Analysis with the classical model:



- The system is initialized such that the generator is supplying 1pu of real power at 0.95 pf lagging (same as prior examples) $\Rightarrow S = 1 + j0.3286$ pu

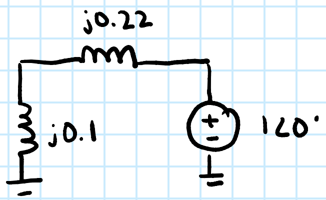
$\Rightarrow E'\angle\delta = 1.281\angle 23.946^\circ$ pu

• When the fault is applied, the system then becomes:



This section needs to be converted to a thevenin equivalent so we can re-apply the swing equations

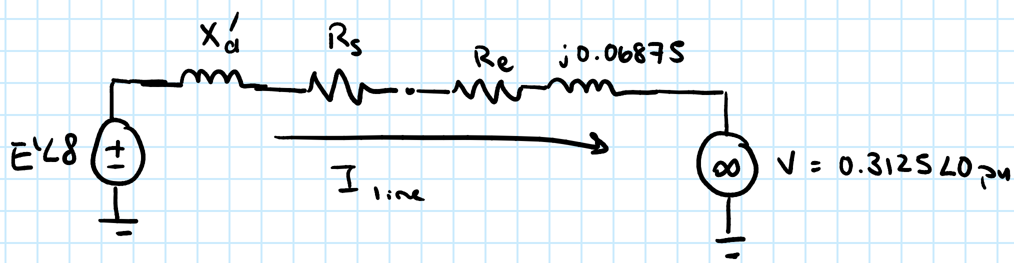
$\Rightarrow$



$$\Rightarrow Z_{th} = \frac{j0.22(j0.1)}{j0.22 + j0.1} = j0.06875 \text{ pu}$$

$$V_{th} = \frac{j0.1}{j0.1 + j0.22}(1\angle 0) = 0.3125\angle 0 \text{ pu}$$

$\Rightarrow$



$$\Rightarrow \frac{d\delta}{dt} = \Delta\omega \cdot \omega_s \quad (f_1)$$

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H}(1 - P_E), \text{ where } P_E = \frac{1.281(0.3125)}{0.36875}\sin\delta \quad (f_2)$$

$\Rightarrow$ In order to use the non-linear trapezoidal method with Newton's method, we need the Jacobian:

$$J(x) = \frac{\Delta t}{2}\begin{bmatrix} \partial f_1/\partial\delta & \partial f_1/\partial\Delta\omega \\ \partial f_2/\partial\delta & \partial f_2/\partial\Delta\omega \end{bmatrix} - I$$

$$= \frac{\Delta t}{2}\begin{bmatrix} 0 & \omega_s \\ \frac{-1}{2H}\frac{E'V_{th}}{X_{th}}\cos\delta & 0 \end{bmatrix} - I$$

- The idea behind this method is that each iteration, we use the trapezoidal method to generate the mismatch $h(x)$:

$$h(x(t+\Delta t)^{(k)}) = -x(t+\Delta t)^{(k)} + x(t) + \frac{\Delta t}{2}\left(f(x(t+\Delta t)^{(k)}) + f(x(t))\right)$$

along with the Jacobian (defined above), and they are used in conjunction with the Newton-Raphson method such that:

$$x(t+\Delta t)^{(k+1)} = x(t+\Delta t)^{(k)} - \left(\left[J(x(t+\Delta t)^{(k)})\right]^{-1} \times h(x(t+\Delta t)^{(k)})\right)$$

to refine the estimate for $x(t+\Delta t)$.

=> This can be done in code:

t	δ	$\Delta\omega$
0	0.418	0
0.02	0.425	0.0019
0.04	0.446	0.0037
0.06	0.479	0.0054
0.08	0.518	0.0048
0.1	0.551	0.0039

Homework #6, Problem #2

Wednesday, November 10, 2021 4:46 PM

In the Lecture 16 single cage induction motor example (introduced on slide 22) determine the operating slip if R_r is changed to 0.02 and X_r is changed to 0.03 with the load still consuming 100 MW of real power.

$H = 1 \quad R_s = 0.01 \quad X_s = 0.06 \quad X_m = 4.0 \quad R_r = 0.02 \quad X_r = 0.03$

We are looking for: $X = \begin{bmatrix} s \\ I_D \\ I_Q \\ E_D' \\ E_Q' \end{bmatrix}$

where: $f(x) = \begin{bmatrix} P_E - V_D I_D - V_Q I_Q \\ -V_D + E_D' + R_s I_D - X' I_Q \\ -V_Q + E_Q' + R_s I_Q + X' I_D \\ \omega_s s E_Q' - \frac{1}{T_0'}\left(E_D' + (X - X') I_Q\right) \\ -\omega_s s E_D' - \frac{1}{T_0'}\left(E_Q' - (X - X') I_D\right) \end{bmatrix}$

$$\Rightarrow J(x) = \begin{bmatrix} 0 & -V_D & -V_Q & 0 & 0 \\ 0 & R_s & -X' & 1 & 0 \\ 0 & X' & R_s & 0 & 1 \\ \omega_s E_Q' & 0 & X' - X/T_0' & -1/T_0' & \omega_s s \\ -\omega_s E_D' & X' - X/T_0' & 0 & -\omega_s s & -1/T_0' \end{bmatrix}$$

$X = X_s + X_m$

$X' = X_s + \frac{X_r X_m}{X_r + X_m}$

$T_0' = \frac{X_r + X_m}{\omega_s R_r}$

$V_D + j V_Q = 0.995 \angle 0^\circ$ pu

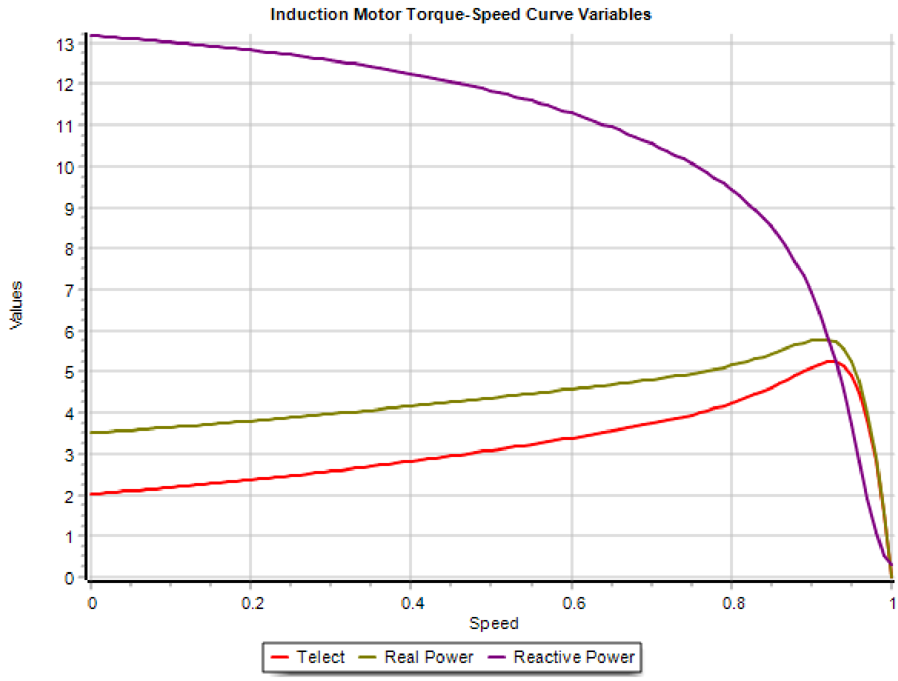
Assume: $V_D + j V_Q = 0.995 \angle 0^\circ$ pu

$P_E = 0.8$ pu (125 MVA base)

Thus, by Newton-Raphson: $x^{(v+1)} = x^{(v)} - J(x^{(v)})^{-1} f(x^{(v)})$

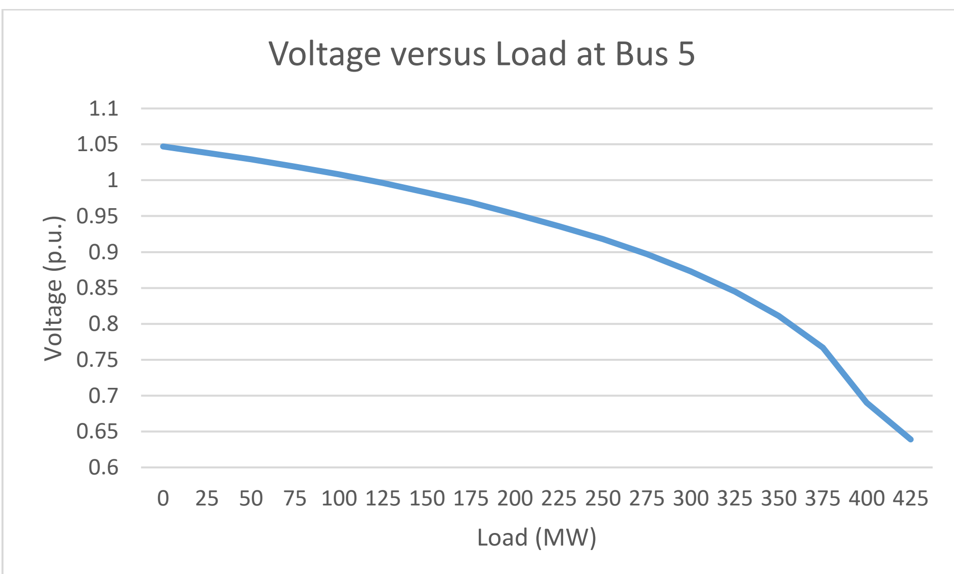
With our terminal voltage at $0.995 \angle 0^\circ$ pu, we get an initial slip of $\boxed{0.0169 \text{ pu.}}$ The code for this is attached to the back.

3. The initial torque-speed curve is as follows:

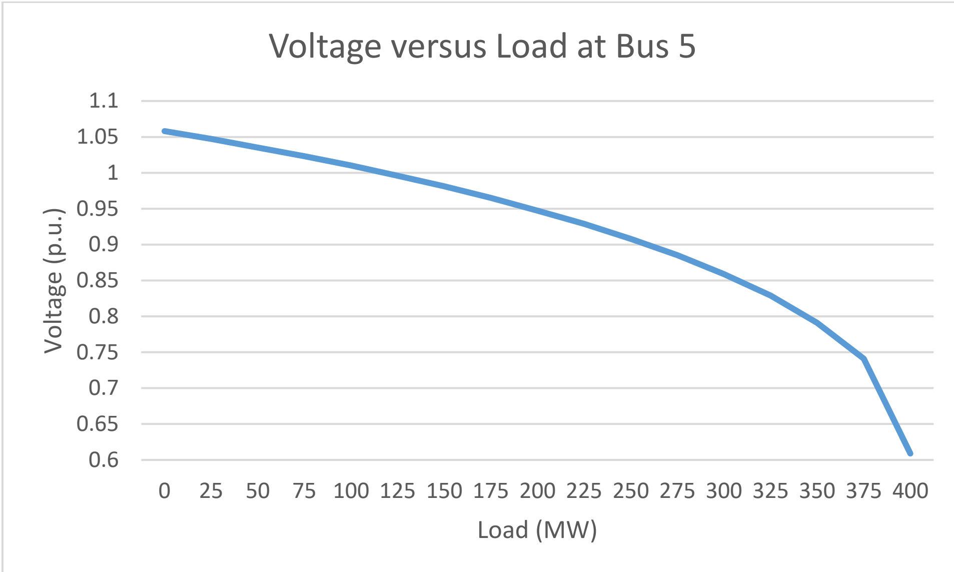


If you measure the change in Telect by doubling each of the parameters individually, the most impactful parameters are R_a, X_a, and X_r

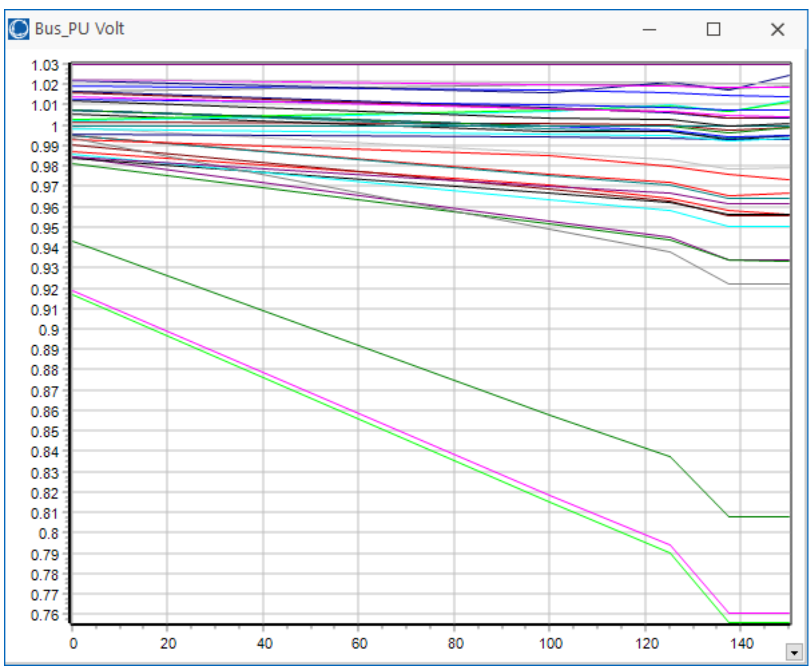
4. The voltage at bus 5 with respect to the load is:



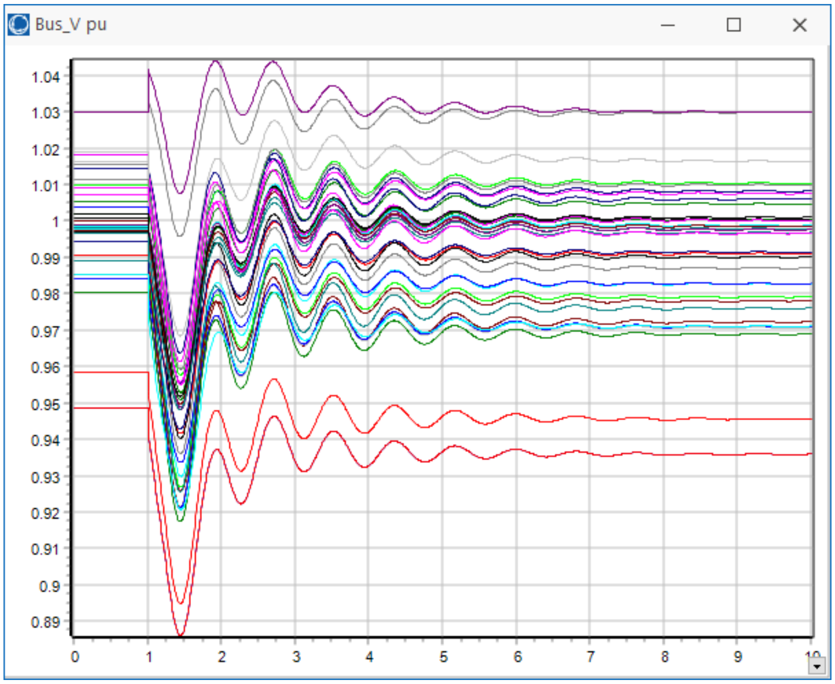
5. For participation factor-based analysis, the voltage at bus 5 with respect to the load is:



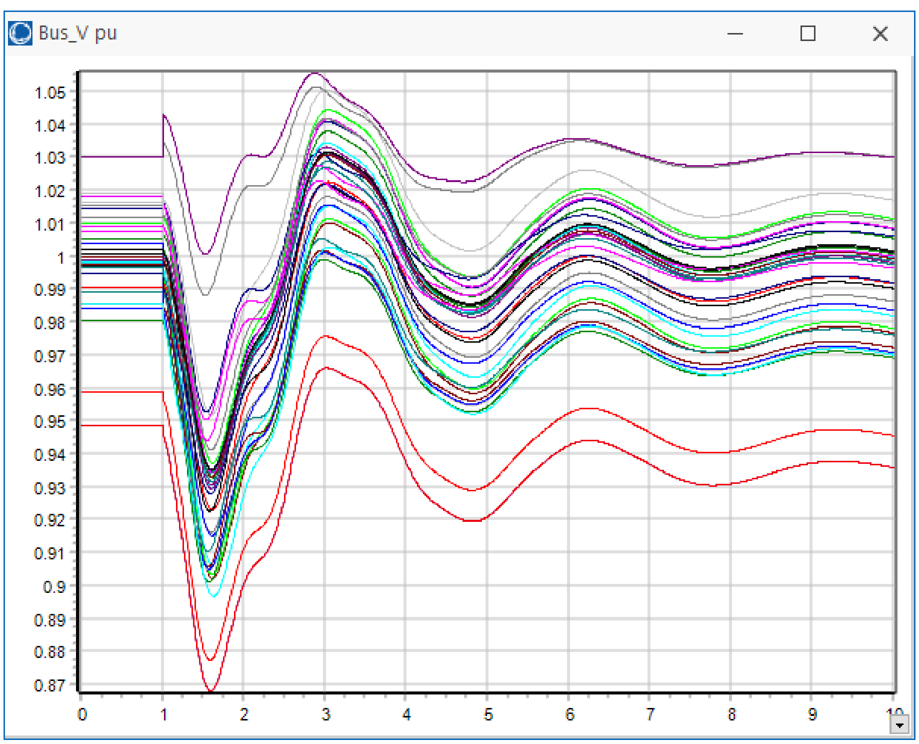
6. According to Contingency Analysis, the worst case contingency occurs when we take the OAK69 to WALNUT69 branch out of service. Resolving the power flow and applying PV curve analysis, we get the following plot:



7. We note that after running transient stability with the SLACK345-HOWDY345 line out of service, we see that the voltages oscillate but the oscillations damp out and our system returns to a new equilibrium point and has a solution.



If we drastically change the percentages, we see that the solution changes with it, and seems like an unstable solution.



If this represented an actual system and the contingency occurred, it would be very likely that load shedding would occur to compensate, or there would be mass line outage as a direct result of line overloads.