Indian Institute of Technology Patna
Department of Electrical Engineering
EE549 - Power System Dynamics and Control
Spring - 2021
Quiz - I (Online) — Solution.
15 February 2021

There are 2 Questions. They carry equal marks.

$(2 \times 10 = 20)$

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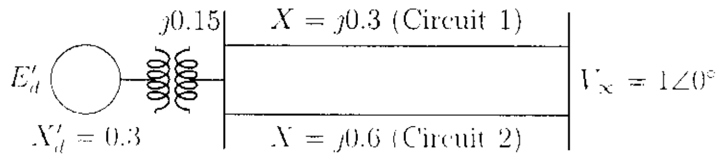
1. Consider a system where a synchronous machine is connected to an infinite bus. The network is purely reactive. The synchronous generator is delivering real power $P = 0.9$ p.u. and reactive power $Q = 0.3$ p.u. to the infinite bus of 1.0 p.u at steady state.

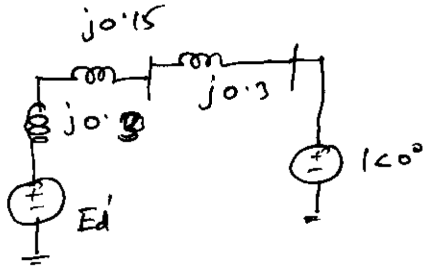


The synchronous generator is represented by the classical model with the following parameters.

$$X_d' = 0.3 \text{ p.u.}, \quad H = 5 \text{ sec}, \quad D = 0.1$$

Suppose the circuit 2 is lost which is a small disturbance. Determine the following if $\Delta\delta = 5^\circ$.

(a) the damped frequency of oscillation.
(b) the eigen values.
(c) the time response of rotor angle.
(d) the time response of rotor speed.
(e) the time constant.



$\bar{I} = \frac{0.9 - j0.3}{1\angle 0^\circ}$

$I = 0.9 - j0.3$

$E_d' = 1\angle0^\circ + \bar{I} \times j0.75$

$E_d' = 1.4\angle 28.86^\circ$

$\delta_{NW} = \sin^{-1}\left(\frac{0.9}{P_{max1}}\right)$

$= \sin^{-1}\left(\frac{0.9}{\frac{1.4\times 1}{0.75}}\right)$

$\delta_{NW} = 28.86^\circ$

$P_s = P_{max1}\cos\delta_{NW}$

$= \frac{1.4\times1}{0.75}\times\cos(28.86^\circ)$

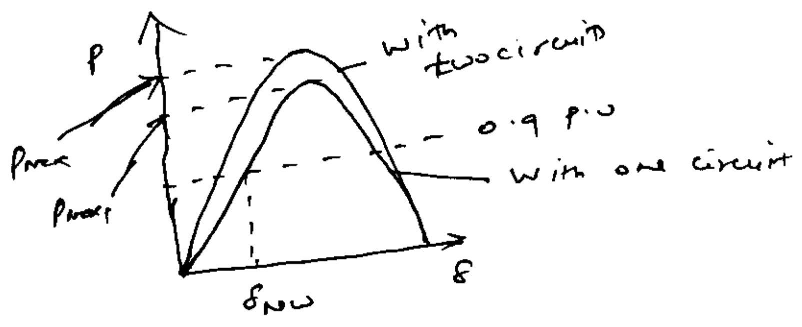
$= 1.6345$

$\omega_n = \sqrt{\frac{\omega_s}{2H}P_s}$

$\omega_n = 7.163$ rad/sec

$\zeta = \frac{D}{2}\sqrt{\frac{\omega_s}{2HP_s}}$

$\zeta = 0.22$



a) $\omega_d = \omega_n\sqrt{1-\zeta^2}$

$\omega_d = 6.9889$ rad/sec

b) $\lambda_1 = -\zeta\omega_n + j\omega_d$

$\lambda_2 = -\zeta\omega_n - j\omega_d$

$\boxed{\lambda_{1,2} = -1.57 \pm j6.9885}$

c) $\Delta\delta(t) = 5.1247\, e^{-1.57t}\sin(6.9885t + 77.33^\circ)$ degree

d) $\Delta\omega(t) = -0.6407\, e^{-1.57t}\sin(6.9885t)$ rad/sec

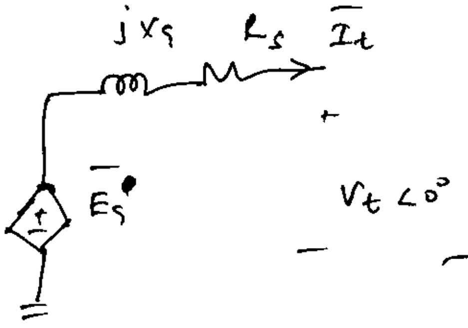
e) $\tau = \frac{1}{1.57}$

$\boxed{\tau = 0.6366 \text{ sec}}$

2. Consider a synchronous machine serving the rated load at 0.9 p.f. lagging and rated terminal voltage. It has $X_d = X_q = 1.5$, $X_{md} = 1.4$ and $R_s = 0.003$.

(a) Find the air gap torque T_e in p.u.

(b) Show that P_e and T_e are the same in p.u.



δ can also be found from the following.

$$\bar{E}_q = \bar{V}_t + \bar{I}_t (R_s + jX_q)$$

$$\bar{E}_q = \underline{2.14 \angle 39.15}$$

$$I_t = 1 \angle -\cos^{-1}(0.9)$$

$$V_t = 1 \angle 0^\circ$$

$$P_t = 0.9$$

$$\delta = \tan^{-1}\left(\frac{I_t X_q \cos\phi - I_t R_s \sin\phi}{V_t + I_t R_s \cos\phi + I_t X_q \sin\phi}\right)$$

$\delta = 39.1^\circ$ degree

$V_d = V_t \sin\delta = 0.631$

$V_q = V_t \cos\delta = 0.776$

$I_d = I_t \sin(\delta + \phi) = 0.906$

$I_q = I_t \cos(\delta + \phi) = 0.427$

$\psi_d = V_q + R_s I_q = 0.7773$

$\psi_q = -(V_d + R_s I_d) = -0.6337$

$T_e = \psi_d I_q - \psi_q I_d$

a) $\boxed{T_e = 0.9029}$

b) $P_e = P_t + I_t^2 R_s$

$= 0.9 + 1^2 \times 0.003$

$P_e = 0.903$

$\boxed{P_e = T_e}$ in p.u.