Indian Institute of Tecnnology Patna
Department of Electrical Engineering
EE549 - Power System Dynamics and Control
Spring - 2021
Mid Semester Exam- Online – Solution.
23 February 2021

There are 2 questions. They carry equal marks.

$(2 \times 10 = 20)$

---

1. A 5 kVA, 415 V, 1500 rpm, 3-phase synchronous machine has $X_d = X_q = 1.5$ and $X_{md} = 1.4$.

   (a) Find E_{fd} and I_{fd} when it supplies no load.

   (b) Find E_{fd} and I_{fd} when it supplies the rated load at unity power factor.

   Neglect armature resistance and magnetic saturation.

a) Under no-load, $I_d = I_q = 0.$

$$V_q = E_q = E_{fd} = V_t = \psi_d = X_{md} I_{fd}$$

(Refer to the slide 86) in M/c Modelling)

$$\therefore \; E_{fd} = 1.0 \text{ p.u}$$

$$I_{fd} = \frac{E_{fd}}{X_{md}} = \frac{1}{1.4} = 0.7143 \text{ p.u}$$

b) $I_t = 1.0$, $\cos\phi = 1.0$, $V_t = 1.0$ p.u

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

Since $R_s = 0$,

$$\bar{E}_q = 1.0\angle 0^\circ + 1\angle 0^\circ (j1.5)$$

$$\bar{E}_q = 1.8028\angle 56.31^\circ$$

$$\boxed{\delta = 56.31^\circ}$$

$$|E_q| = (X_q - X_d) I_d + X_{md} I_{fd}$$ (Refer to the slide 84) in M/c modelling.

Since $X_d = X_q = 1.5$,

$$|E_q| = X_{md} I_{fd} = E_{fd}$$

$$\therefore \; \boxed{E_{fd} = 1.8028} \qquad I_{fd} = \frac{1.8028}{1.4} \simeq \boxed{1.2877 \text{ p.u}}$$

2. The turbine/governor model is as follows:

$$T_{CH}\frac{dP_{CH}}{dt} = -T_M + P_{SV}$$

$$T_{SV}\frac{dP_{SV}}{dt} = -\frac{1}{R_D}\left(\frac{\omega}{\omega_{base}} - 1\right) + P_{ref} - P_{SV}.$$

Since there is no reheat system, $P_{CH} = T_M$.

$$T_{SV} = 0.2 \text{ sec},\ P_{ref} = 0.7 \text{ pu},\ R_D = 0.05 \text{ pu}$$

$$T_{CH} = 0.4 \text{ sec},\ \omega_{base} = 2\pi 60 \text{ rad/sec}$$

(a) Find the steady-state values of P_{SV} and T_M if $\omega = 376.9$ rad/s.

(b) Find the dynamic response of P_{SV} and T_M if ω changes at time zero to be 376.8 rad/s. (The change is small.)

a) At steady state,

$\omega = \omega_{base}$, $\quad \frac{dP_{ch}}{dt} = \frac{dP_{sv}}{dt} = 0$

$$\boxed{P_{sv_0} = T_{M_0} = P_{ref_0} = 0.7 \text{ p.u}}$$

b) Since the change is small, the turbine / governor model is

$$T_{ch}\frac{d\,\Delta P_{ch}}{dt} = -\Delta T_m + \Delta P_{sv} \quad \text{—①}$$

$$T_{sv}\frac{d\,\Delta P_{sv}}{dt} = -\frac{1}{R_D}\left(\frac{\Delta\omega}{\omega_{base}}\right) + \Delta P_{ref} - \Delta P_{sv} \quad \text{—②}$$

(Refer to Slide 37) in Turbine Modelling.

$\Delta P_{ref} = 0$; $\Delta\omega = 0.1$

Solving ②

$\Rightarrow \Delta P_{sv}(t) = 0.0133\,(1 - e^{-5t})$

Solving ①

$\Rightarrow \Delta T_m(t) = 0.0133\,(1 + e^{-5t}) - 0.0266\,e^{-2.5t}$

The dynamic response,

$$\boxed{P_{sv} = 0.7 + 0.0133\,(1 - e^{-5t})}$$

$$\boxed{T_m = 0.7 + 0.0133\,(1 + e^{-5t}) - 0.0266\,e^{-2.5t}}$$