Analysis of electrical power and energy systems

Practical session 5

19 October 2020

1 Synchronous generators in power systems[1]

1. In the per-phase equivalent circuit of Figure 1, assume $R_s = 0$ and $X_s = 1.2$ pu. The terminal voltage $\overline{V}_a = 1\angle 0$ pu and $\overline{I}_a = 1\angle -\pi/6$ pu.
   (a) Calculate $\overline{E}_{af}$.
   (b) Show that the 3-phase active power produced at the stator is equivalent to the 3-phase active power transferred between two voltage sources ($\overline{E}_{af}$ and $\overline{V}_\infty$) where $\overline{V}_\infty = 1\angle 0$ pu is an ideal voltage source.
   (c) If E_{af} is kept constant, calculate the maximum power this machine can supply in theory and in practice.

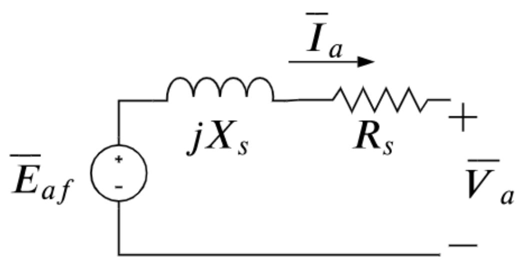

Figure 1: Per-phase equivalent circuit.

2. In a synchronous generator, assume $R_s = 0$ and $X_s = 1.2$ pu. The terminal voltage $\overline{V}_a = 1\angle 0$ pu. It is supplying 1 pu active power. Calculate $\overline{I}_a$ in such a way the active power remains constant while the reactive power Q is as follows: (a) $Q = 0$, (b) $Q = 0.5$ pu and (c) $Q = -0.5$ pu. For each configuration, show that $E_{af} \sin \delta$ is kept constant.

3. In a synchronous generator, assume $R_s = 0$. The steady-state, transient and subtransient reactances are respectively given by (a) $X_s = 1.2$ pu, (b) $X'_s = 0.33$ pu and (c) $X''_s = 0.23$ pu. The terminal voltage $\overline{V}_a = 1\angle 0$ pu and the current $\overline{I}_a = 1\angle -\pi/6$ pu. Calculate $\overline{E}_{af}$ in each configuration of the machine. Compare the results.

2 Solutions

1. (a) $\overline{E}_{af} = 1.91$ pu $\angle 0.58$ rad
   (b) $P = 2.598$ pu
   (c) $P_{max,th} = 4.770$ pu, $P_{max,pr} = 3.066$ pu

2. $E_{af} \sin \delta = 0.4$

[1]Exercises 9.5, 9.6, 9.7, and 9.9 of Ned Mohan's book "Electric power systems, a first course"

(a) $\overline{I}_a = 0.333 \text{ pu } \angle 0 \text{ rad}$

(b) $\overline{I}_a = 0.373 \text{ pu } \angle -0.464 \text{ rad}$

(c) $\overline{I}_a = 0.373 \text{ pu } \angle 0.464 \text{ rad}$

3. (a) $\overline{E}_{af} = 1.91 \text{ pu } \angle 0.58 \text{ rad}$

   (b) $\overline{E'}_{af} = 1.2 \text{ pu } \angle 0.24 \text{ rad}$

   (c) $\overline{E''}_{af} = 1.13 \text{ pu } \angle 0.18 \text{ rad}$