Final exam

R. Roche

ER57 – Fall 2019 – P227

First name: ______________________ **Last name:** ______________________

1 Instructions

- **This instructions sheet (*énoncé*) must be returned with your examination paper (*copie*).**
- The exam duration is 2 hours. You are assigned a specific seat: see the list at the entrance.
- **You are allowed to have a one-side, hand-written A4 sheet.**
- No other document or electronic device, except calculators, is allowed during the exam.
- The number of points assigned to each problem is specified over a total of 20.
- **Detailed calculations and explanations must be provided.**
- Problems can be solved in any order. Read *all* instructions first.
- All cheating attempts, including communicating with other students, will be penalized.

2 Quizz (5 points)

Answer the following questions. No point will be given for an answer without **detailed** explanations.

1. What are the main types of unbalanced faults? Describe their characteristics.
2. What is the role of a protection relay? What are the main differences between instantaneous and time overcurrent relay settings? Use a diagram.
3. What is the principle of differential protection? Which devices are typically protected with this type of device?
4. Explain how frequency and voltage control work on a synchronous generator using simple diagrams.
5. Provide 2 examples of smart grid technologies, with explanations on how they make the grid "smarter."

3 Balanced fault analysis (5 points)

The one-line diagram of a simple four bus power system is shown in Fig. 1. All impedances are expressed in per unit on a common MVA base. All resistances and shunt capacitances are neglected. The generators are initially operating on no load at their rated voltage. A balanced three-phase fault occurs at bus 2, with fault impedance $Z_f = j0.1$ p.u.

1. Determine the Y_{bus} matrix for this system.

2. Assume that the initial voltage at all buses is 1.0 p.u. and that the system is initially unloaded (so the generators initially output no power). Also assume that the Z_{bus} matrix is as follows:

$$Z_{\text{bus}} = j\begin{bmatrix} 0.24 & 0.14 & 0.2 & 0.2 \\ 0.14 & 0.2275 & 0.175 & 0.175 \\ 0.2 & 0.175 & 0.31 & 0.31 \\ 0.2 & 0.175 & 0.31 & 0.5 \end{bmatrix}$$

During the fault, determine the following quantities:

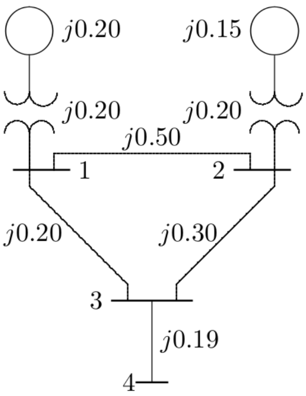

Figure 1: Impedance diagram of the studied system.

- The fault current, i.e., the current flowing from the system to the fault,
- The voltage magnitude at all buses,
- The current on all lines.

4 Frequency control (3 points)

A single area includes two generators (A and B):

- The generators are rated at 400 MVA (unit A) and 800 MVA (unit B).
- They have a speed regulation of 4% (A) and 5% (B) on their respective ratings.
- They are operating in parallel, sharing a load of 700 MW. Initially, unit A supplies 200 MW and unit B supplies 500 MW at 1.0 per unit (60 Hz) frequency.

The load suddenly increases by 140 MW. There is no frequency-dependent load, and there is no change in reference power setting, so $\Delta P_{\text{ref}} = 0$. Using a common base of 1000 MVA, determine the steady-state frequency deviation and the new power output of each unit in MW.

5 Frequency control (7 points)

An isolated power station has a frequency control system as shown in Fig. 2, with the following parameters:

- Turbine time constant $\tau_T = 0.5$ s,
- Governor time constant $\tau_G = 0.25$ s,
- Generator inertia constant $H = 8$ s,
- Governor speed regulation $= R$ per unit,
- The load varies by 1.6 percent for a 1 percent change in frequency, i.e., $D = 1.6$,
- The system frequency base is 60 Hz.

1. Assuming that $\Delta P_{\text{ref}} = 0$, show that the open loop (OLTF) and closed loop transfer functions (CLTF) of the system, with $(-\Delta P_L(s))$ as input and $\Delta\Omega(s)$ as output, are as follows:

$$OLTF(s) = \frac{1}{R\,(2Hs + D)(1 + \tau_g s)(1 + \tau_T s)}$$

$$CLTF(s) = \frac{(1 + \tau_g s)(1 + \tau_T s)}{(2Hs + D)(1 + \tau_g s)(1 + \tau_T s) + \frac{1}{R}}$$

   Detailed explanations and justifications with diagrams are expected.

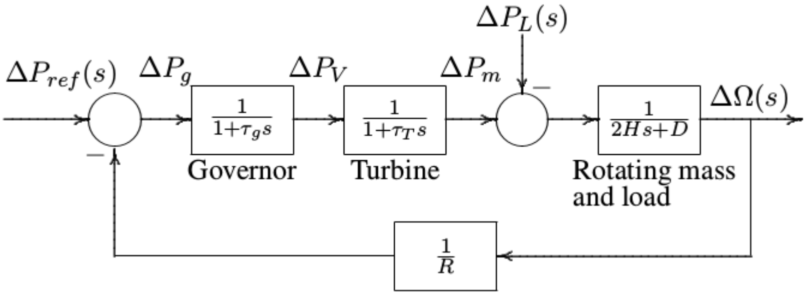

Figure 2: Frequency control system structure.

2. Show that the characteristic polynomial of this system is $2s^3+12.2s^2+17.2s+1.6+K$, with $K=\frac{1}{R}$.
3. Use the Routh-Hurwitz criterion to find the range of R for control system stability.
4. Assume now that $R=0.06$. Determine the steady-state response of the system for a step input of magnitude $\Delta P_L = 0.25$ p.u.
5. It can be shown that the control system in Fig. 2 is insufficient for adequate frequency control. How can the performance of a control system be measured? In other words, how can you determine whether a controller performs well or not? Then, how can performance be improved?

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