# Course:
# ELEC ENG 3110 Electric Power Systems
# ELEC ENG 7074 Electric Power Systems PG

(Semester 2, 2021)

# Tutorial 5

(Due by 16:10 on Wednesday 27 October 2021)

Lecturer and coordinator: David Vowles
david.vowles@adelaide.edu.au

**5.1** **Frequency sensitive loads.** The total load connected to a power system is found to increase by D% due to a 1% increase in the frequency. For a particular operating condition the system load at the nominal system frequency, $f_0$, is $P_L(f_0) = P_{L_0}$.

(a) Derive the following equation for the system load, $P_L(f)$, as a function system frequency $f = f_0 + \Delta f$.

$$P_L(f) = P_{L_0}\left(1 + D\left(\frac{\Delta f}{f_0}\right)\right) \tag{1}$$

(b) Sketch a graph of the relationship you derived in (a) assuming that D > 0.

(c) The system is initially operating with a load of $P_{L1_0}$ at nominal frequency $f_0$. As above, the load increases by D% due to a 1% increase in frequency. An additional load is then connected to the system which consumes $\Delta P_{L_0}$ at the nominal frequency. Thus, the final load at nominal frequency is $P_{L2_0} = P_{L1_0} + \Delta P_{L_0}$. Assume that the frequency sensitivity of the initial and final values of the load are the same. Show that:

$$P_{L2}(f) = P_{L1}(f) + \Delta P_{L_0} \tag{2}$$

(d) Sketch a graph showing $P_{L1}(f)$ and $P_{L2}(f)$.

(e) For a particular system the load increases by 2% due to a 1% increase in frequency. The initial system load is 2000 MW at the nominal frequency of 50 Hz. An additional load of 50 MW (as measured at 50Hz) is connected to the system. The connection of this load causes a decrease in frequency of 0.2 Hz. What is the total system load taking into account the decrease in system frequency?

**T5.2** **Governor steady-state droop characteristic.** Consider a generating unit in which the generator has an MVA rating of 500 MVA and rated power factor of 0.8. The governor has a steady-state droop of 4% on the turbine power rating. The generator load reference is set such that the power output of the generator is 350 MW. The system nominal frequency is 50 Hz.

(a) What is the turbine power rating?

(b) Draw the governor steady-state characteristic.

(c) A disturbance occurs that causes an increase in the frequency of 0.2 Hz. What is the final steady-state power output from the generator due to the frequency change?

(d) A disturbance occurs that causes the power output from the unit to increase by 25 MW. What is the change in system frequency?

**T5.3** **Parallel operation of generating units.** Two generating units supply an isolated, 50 Hz power system. The system is initially operating at 50 Hz. The generating unit ratings, governor droop settings and initial power outputs are listed in the following table.

| Parameter | Generating Unit | |
|---|---|---|
| | 1 | 2 |
| Rating (MW) | 50 | 150 |
| Droop (% on unit power rating) | 3 | 5 |
| Initial output (MW) | 25 | 125 |

(a) Neglecting the frequency sensitivity of the loads find (i) the generator outputs and (ii) frequency after a load which consumes 10 MW at 50 Hz is connected to the system.

(b) Repeat the previous calculation but this time assume that the load increases by 1.5% due to a 1% increase in frequency.

**T5.4** **Automatic Generation Control.**

(a) What is the purpose of AGC?

(b) Neglect for the moment the operation of tertiary load / frequency control. Some generating units on the system are enabled for both primary speed-governing and some are enabled only to provide primary speed-governing. Following an increase in system load explain qualitatively how the power output from the two types of units changes over time.

(i) Consider a unit with primary control only. How does its final power output (after AGC has operated) compare with its initial power output (before the increase in load)?

(ii) Consider the units enabled with AGC. What is the aggregate power output from these units following the operation of AGC.

**T5.5** **Tertiary load/frequency control.**

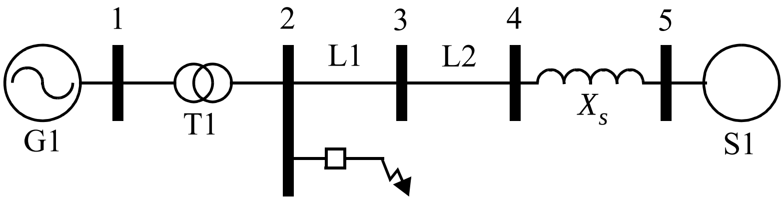
(a) What is the purpose of tertiary load / frequency control?

(b) On what basis are the load set-points of generators set under tertiary control?

(c) How does this form of control interact with the primary and secondary frequency controls.

**T5.6** **Balanced three phase faults – Problem 1**

Consider the following network.




| Bus | Rated Voltage (kV) |
|---|---|
| 1 | 16 |
| 2-5 | 275 |

| Item | Parameters |
|---|---|
| G1 | $X_d'' = 0.25$ pu on 500 MVA, 24 kV |
| T1 | $X_t = 0.15$ pu on 500 MVA, 24 / 275 kV |
| L1 | $X_l = 0.10$ pu on 100 MVA, 275 kV |
| L2 | $X_l = 0.04$ pu on 100 MVA, 275 kV |
| Xe | 0.02 pu on 100 MVA, 275 kV |
| S1 | Ideal source (no internal impedance) |

**Figure 1:** Problem 5.6 – Network for balanced three-phase fault-current calculation

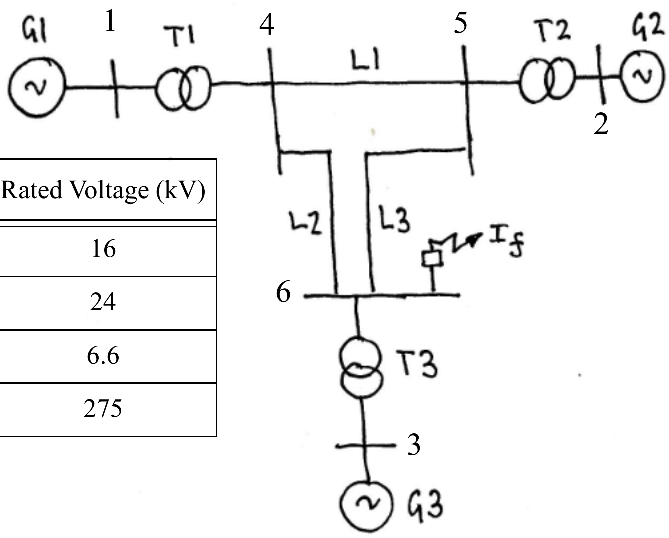
(a) Draw the network to be used to calculate the fault current $I_f$. Show on the network all impedances in per-unit on 100 MVA and the source voltages in per-unit. Number the buses. List the main assumptions that are made in constructing the fault-current calculation network.

(b) Calculate the fault current $I_f$ in per-unit and Amps.

(c) What is the contribution of each generator to the fault current?

(d) Calculate the voltage at node 4 in per-unit and kV.

**T5.7** **<u>Balanced three phase faults – Problem 3</u>**. For the network in Figure 2 calculate the fault current (pu and Amps) and the contribution of each generator to the fault current.




| Bus | Rated Voltage (kV) |
|---|---|
| 1 | 16 |
| 2 | 24 |
| 3 | 6.6 |
| 4, 5, 6 | 275 |

| Item | Parameters |
|---|---|
| G1 | $X_d'' = 0.22$ pu on 250 MVA, 16 kV |
| T1 | $X_t = 0.15$ pu on 280 MVA, 16 / 275 kV |
| G2 | $X_d'' = 0.2$ pu on 1000 MVA, 24 kV |
| T2 | $X_t = 0.12$ pu on 1200 MVA, 24 / 275 kV |
| G3 | $X_d'' = 0.25$ pu on 30 MVA, 6.6 kV |
| T3 | $X_t = 0.16$ pu on 30 MVA, 6.6 / 275 kV |
| L1 | 275 kV, 120 km line with $R = 0.04$ ohm / ph / km; $X_L = 0.319$ ohm / ph / km and $B_C = 3.651 \times 10^{-6}$ S / ph /km. |
| L2 | 275 kV, 80 km parameters the same as L1 |
| L3 | 275 kV, 200 km parameters the same as L1 |

**Figure 2:** Problem 5.7 – Network for balanced three-phase fault-current calculation.