Analysis of electrical power and energy systems

Assignment 2

Power flow analysis with an auto-transformer, a phase-shifter and power generation limits

Consider the system of the first assignment, where the voltage base (3-phase) is 345 kV and the power base (3-phase) is 100 MVA.

- Bus-1 is a slack bus with $V_1 = 1.0$ pu and $\theta_1 = 0$.
- Bus-2 is a PV bus with $V_2 = 1.05$ pu and $P_2^0 = 2.0$ pu.
- Bus-3 is a PQ bus with injections of $P_3^0 = -5.0$ pu and $Q_3^0 = -1.0$ pu.

Lines electrical resistance and reactance are provided by $r = 0.037\ \Omega/\text{km}$ and $x = 0.376\ \Omega/\text{km}$. Shunt susceptances are ignored. Lines length are specified in Figure 1.

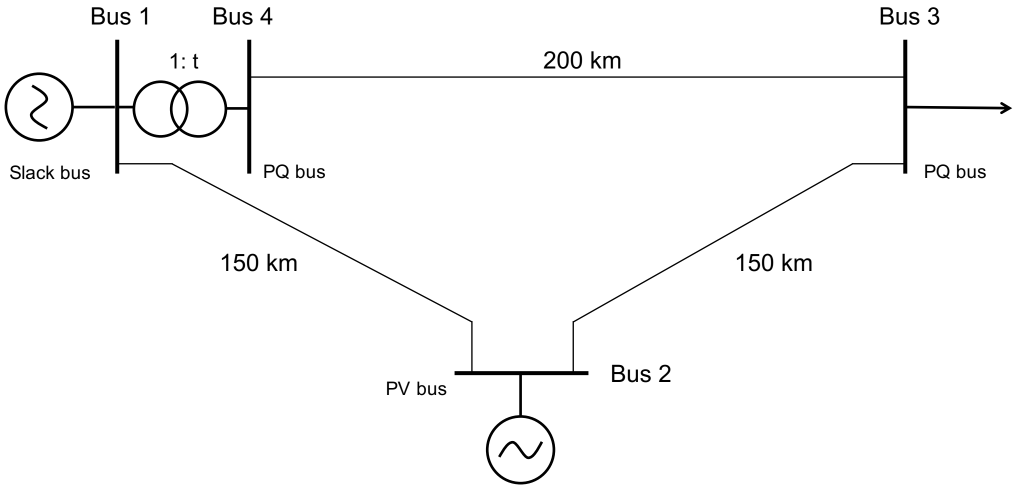

Figure 1: Four-bus power system with a transformer.

Implement with Python the Newton-Raphson method to calculate the power flow on all the lines of this network, progressively adding the following elements.

1. Add an auto-transformer in the system. For that, first add a 4th bus between bus 1 and bus 3 as shown in Figure 1, and then add an auto-tranformer between bus 1 and bus 4. Bus 4 is a PQ bus with no consumption ($P = 0$ and $Q = 0$). The auto-transformer has a leakage reactance of 0.02 pu, seen from the primary side (bus 1). The tap ratio is equal to 0.95. There is no phase shift.

2. Replace the auto-transformer with an ideal phase-shifter between buses 1 and 4. The phase-shifter has a leakage reactance of 0.02 pu, seen from the primary side (bus 1). The tap ratio is equal to 1 with a phase shift of $-15°$.

3. Keep the phase-shifter with a phase shift of $-15°$ and consider the following limits for the generating unit on bus 2: active power generation is between 0 and 300 MW and reactive power produced is between 0 and 200 Mvar.

This assignment will be solved and discussed during the practice session of the **9th of November**. Note that no file needs to be submitted, the assignments will not be marked.

Solutions

1. With a tap-ratio of 0.95, you should obtain the following solution: $\overline{V}_1 = 1\angle 0°$ pu, $\overline{V}_2 = 1.05\angle -2.97°$ pu, $\overline{V}_3 = 0.96\angle -10.64°$ pu, $\overline{V}_4 = 0.95\angle -2.36°$ pu
2. With a phase-shift of $-15°$, you should obtain the following solution: $\overline{V}_1 = 1\angle 0°$ pu, $\overline{V}_2 = 1.05\angle -6.70°$ pu, $\overline{V}_3 = 0.97\angle -18.13°$ pu, $\overline{V}_4 = 0.99\angle -15.76°$ pu
3. With a phase-shift of $-15°$ and generator limits, you should obtain the following solution: $\overline{V}_1 = 1\angle 0°$ pu, $\overline{V}_2 = 1.01\angle -6.48°$ pu, $\overline{V}_3 = 0.94\angle -18.56°$ pu, $\overline{V}_4 = 0.99\angle -15.87°$ pu