Exam

Power System Analysis

5P645

Monday, April 14th 2014

14.00 – 17.00 h

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In this exam you are allowed to use one side of a self-made A4 sheet with formulas, definitions, etc. You have to hand in this sheet with <u>all</u> the writing paper you get. Only this exam containing the printed text of the problems you may keep for yourselves.

It is not allowed to consult the lecture notes and/or any text book or web resource.

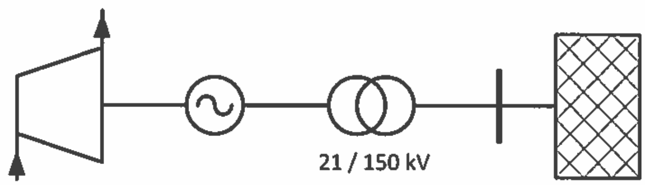
Only the program Matlab on your laptop or a pocket calculator may be used for your calculations.

Work neatly and write clearly! This ensures that you receive all the credits you deserve.

The four problems all have the same weight.

Answers may be given in Dutch or English.

PROBLEM 1.



A generator is driven by a steam turbine with a constant speed equal to the rated speed.

The following generator parameters are given:

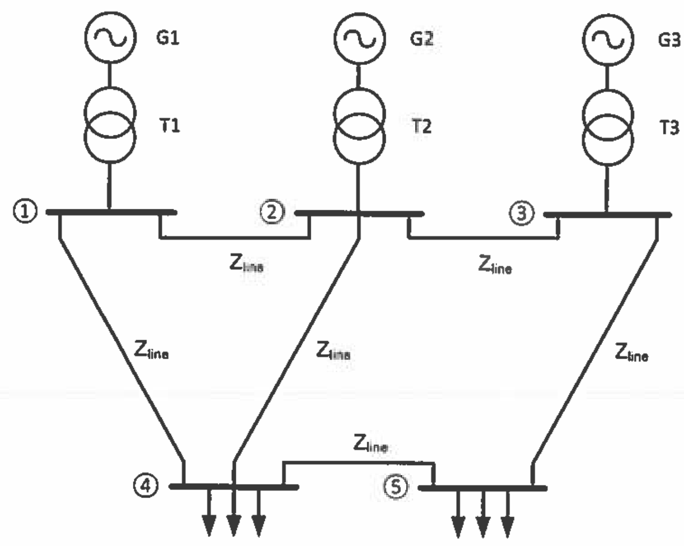
rated apparent power:	200 MVA
rated power factor (cos phi):	0,75
rated voltage (line-to-line):	21 kV
rated speed:	3000 rpm
synchronous reactance	220 %
transient reactance	22 %
sub-transient reactance	18 %

The generator is connected to a 150 kV network via a step up transformer of 21/150 kV.

1.1 If the voltage at the terminals of the generator is assumed constant and equal to the rated voltage, calculate the maximum reactive power that the generator can deliver. Take into account that the generator may not exceed the limits of its rated operating area (or capability region).

1.2 The generator delivers its rated active and reactive power while the terminal voltage is equal to the rated voltage. If a three phase balanced short circuit occurs at the generators terminals, what will be the rms value of the symmetrical sub-transient short circuit current?
What will be the peak value of this current?

PROBLEM 2.



In the figure above there are three generators that supply a 150 kV network via step up transformers. The three generators are identical. The same goes for the three transformers. The 150 kV lines are all identical, thus have the same impedance and the same length. The impedance of each line is $\underline{Z}_{line} = j5$ ohm.

For the generators it is known:

rated apparent power:	200 MVA
rated voltage:	21 kV
sub-transient impedance:	18 %

For the transformers it is known:

rated apparent power:	200 MVA
transformer ratio:	21/150 kV
short-circuit voltage:	12 %

We want to make some short circuit calculations for this electrical network.

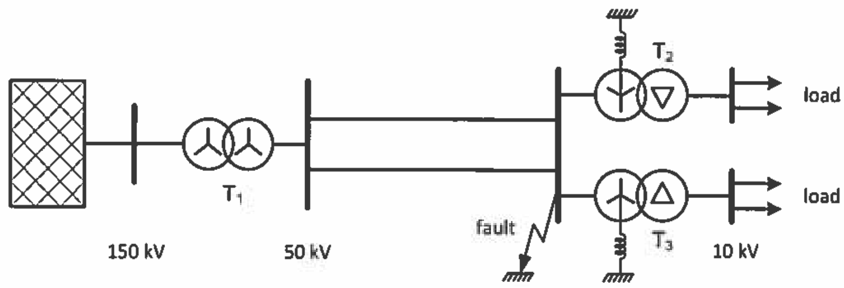
2.1 Determine the admittance matrix Y_{bus} necessary for the short circuit calculations.

2.2 Determine the short circuit power S_{sc} (including voltage factor 1,1) of bus 4. Note: It is not necessary to write the whole Z_{bus} in the solution, only the element(s) that are needed to calculate the short-circuit power S_{sc}.

Suppose the short circuit power of bus 4 is 2000 MVA. We want to connect a 150/10 kV station to bus 4. This station connects the 150 kV network at bus 4 to a 10 kV network by a transformer with a ratio of 150/10 kV and a rated apparent power of 50 MVA.

2.3 The short circuit power of the 10 kV station is not allowed to exceed 350 MVA (including a 1,1 factor). Calculate the necessary short circuit voltage of the 150/10 kV transformer.

PROBLEM 3.



In the figure above a 150 kV network connected to a 150/50 kV transformer T_1 is shown. This transformer is connected to two parallel 50 kV lines. The lines are connected to two 50/10 kV transformers T_2 and T_3.

The short circuit power of the 150 kV network is 2000 MVA (including factor 1,1).

For the 150/50 kV transformer it is known:

rated power:	60 MVA
transformer ratio:	150/50 kV
short-circuit voltage:	12 %

zero sequence to positive sequence impedance ratio: X_0/X_1=0,8

For the 50/10 kV transformers it is known:

rated power:	20 MVA
transformer ratio:	50/10 kV
short-circuit voltage:	10 %

zero sequence to positive sequence impedance ratio: X_0/X_1=0,8

The two parallel 50 kV lines have a positive sequence reactance of 5 ohms each and the zero sequence reactance is X_0 = 2,5 X_1, where is X_1 is the positive sequence reactance.

3.1 To limit the single line to ground fault current in the 50 kV network to 0,9 kA (including factor 1,1) the neutrals of the two 50/10 kV transformers are connected to earth by inductances. Calculate the necessary reactance X_L of these inductances so that the single line to ground current does not exceed 0,9 kA.

3.2 Calculate the rms values of the phase currents I_R, I_S and I_T that are delivered from the 150 kV network to the 150/50 kV transformer T_1 during the single phase to ground fault at the location shown in the figure above.

PROBLEM 4.

A two pole synchronous generator has a rating of 50 MVA and a power factor 0,8. The generator is running steadily at synchronous speed and delivers 40 MW active power to the network.
The maximum (transient) power the generator can deliver to the network is 80 MW.
The inertia moment J of the generator and turbine combined is 4863 kgm^2.

Suddenly the connection with the network is interrupted for 0,2 seconds. During this time the generator delivers no electrical power to the network.

4.1 Calculate the clearing angle δ_1. Note: this is not the critical clearing angle!

4.2 Through this interruption the rotor of the generator will swing. Assuming that we neglect the damping, then show by one or more graphics how we can calculate the minimum and maximum angles δ between which the rotor will swing.
Write also the two equations necessary to solve for these angles and give a rough estimate of the values of these angles. Note: It is not necessary to solve the equations accurately.