DEPARTMENT OF ELECTRONIC & ELECTRICAL ENGINEERING

EE467/EE967

Power System Design, Operation & Protection

Academic year 2024/25

INDIVIDUAL ASSIGNMENT

Notes

1. Please complete the assignment outlined below. The deadline for submission of the assignment is **Friday, 21 March 2025, 5pm.**

2. The assignment should be submitted electronically through myplace as one pdf (preferably) or Word document. Include your name in the filename of your submission (e.g. JSmith_EE467_assignment.pdf)

3. Your assignment should be no longer than 3000 words (6-9 pages), excluding the title page. Text size should be no smaller than 10 points and no larger than 12 points.

4. A report should have a front title page with student details. This page is excluded from the page count. A word document template is provided for those who want to use it, but it is not compulsory, and any consistently formatted submission is acceptable.

5. There is no need to repeat all the information (or detailed task description) given in this document. However, the report should have the same structure and clearly named section headings.

6. Always state your assumptions, explain your reasoning clearly and provide full answers when asked. In numerical tasks, used formulas and example workings should be included. The result tables could be an effective way of summarising repeated calculations (where appropriate).

7. Structure, length, explanations, formatting consistency and presentation quality of your report will also be marked and will contribute 10% of your mark for this assignment.

8. This assignment counts for 15% towards the final mark for this class.

Assignment topic

Part 1. Transformer differential protection operation (45%)

Consider a 275kV/33kV transformer TR1, which supplies Substation A as illustrated in Figure 1.

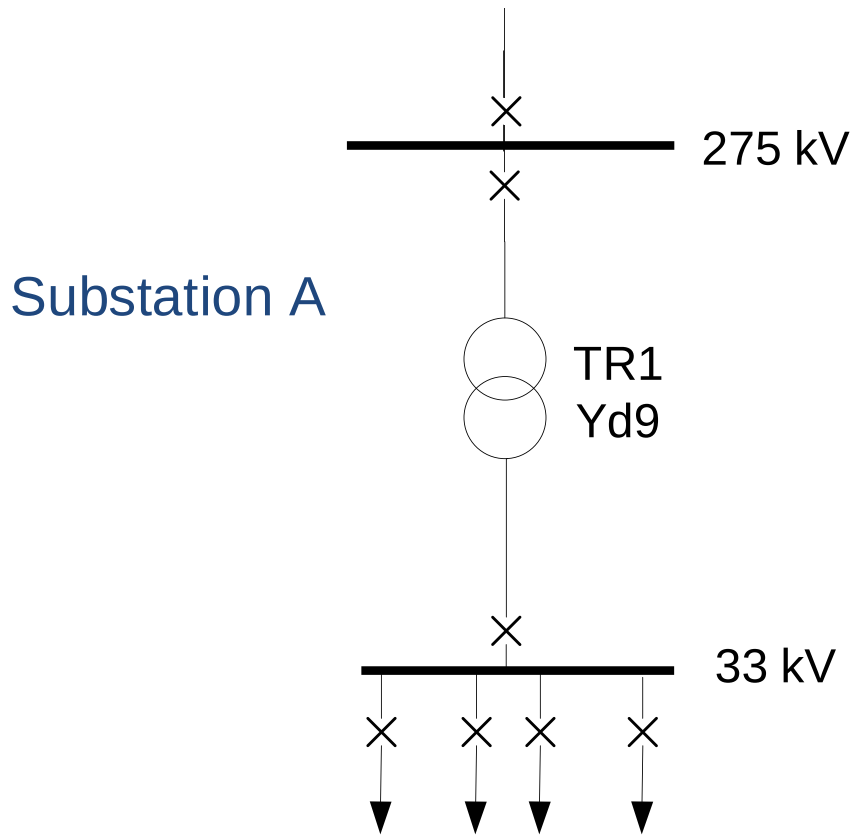

Figure 1. Simplified diagram of Substation A

The transformer parameters are as follows:

S_n = 60 MVA, V_H = 275 kV, V_L = 33 kV, Connection group **Yd9**
On-load tap changer on HV side can be adjusted within $\pm 15\%$ of nominal voltage.

Transformer is protected by a 3-phase differential biased protection with the operational characteristic as presented in Figure 2 which is also described by the tripping logic (1).

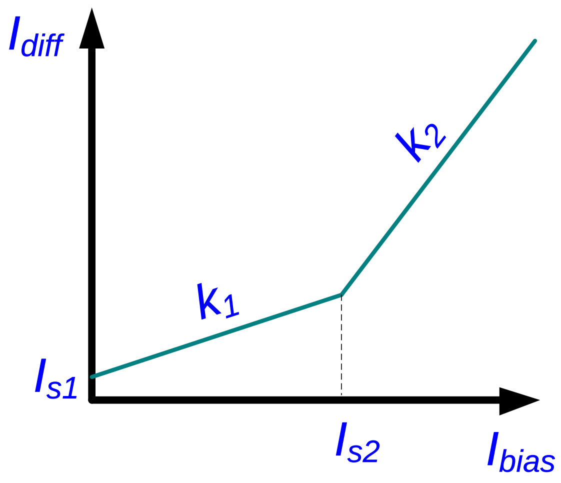

Figure 2. Differential relay operational characteristic

$$\textbf{Trip} = \left(I_{diff} > I_{s1} + k_1 I_{bias}\right) \wedge \left(I_{diff} > I_{s1} + (k_1 - k_2) I_{s2} + k_2 I_{bias}\right) \tag{1}$$

Where: $I_{diff} = |I_1 + I_2|$, $I_{bias} = \frac{|I_1| + |I_2|}{2}$

Available setting values:

$I_{s1} = (0.05, 0.06, 0.07, \dots, 1.99, 2.00)$ A
$I_{s2} = (0.5, 0.51, 0.52, \dots, 4.99, 5.00)$ A
$k_1, k_2 = (0.1, 0.2, 0.3, \dots, 1.9, 2.0)$

i) Differential protection design and settings

Perform the following tasks:

1. Draw the phasor diagram and the connection diagram of the transformer windings and the CTs according to the given transformer connection group, which is Yd9.
2. Select and the appropriate CT ratios from the available values shown below.
3. Establish the settings I_{s1} and I_{s2} for the biased differential protection considering the following guidelines:
   - o I_{s1} should be at least 4 times the maximum steady state spill current at full transformer load, and
   - o I_{s2} should be approximately 1.1 times the transformer rated current (referred to the secondary side of the CTs),
   - o $k_1 = 0.1$, $k_2 = 0.5$.

Available CT ratios: 50:1, 100:1, 150:1, 200:1, 250:1, 300:1, 400:1, 500:1, 600:1, 750:1, 1000:1, 1250:1, 1500:1, 2000:1

ii) Differential protection operation

Consider two independent fault cases (each can be either internal or external to the transformer) resulting in the primary line currents flowing on the HV and LV side of the transformer as depicted in Table 1. Note that the current phasors are given according to the current direction convention as marked in Figure 3.

Table 1. Transformer primary line currents captured during two different faults

Fault	Currents on HV side (275 kV)	Currents on LV side (33 kV)
Case 1	$I_A = (532.54\angle -26.26°)$ A	$I_a = (550.77\angle -94.26°)$ A
	$I_B = (248.97\angle 167.84°)$ A	$I_b = (3{,}899.04\angle 149.84°)$ A
	$I_C = (297.33\angle 141.96°)$ A	$I_c = (3{,}691.80\angle -22.45°)$ A
Case 2	$I_A = (117.36\angle 16.24°)$ A	$I_a = (2{,}201.56\angle 39.43°)$ A
	$I_B = (170.33\angle -123.79°)$ A	$I_b = (646.90\angle 150.17°)$ A
	$I_C = (110.21\angle 99.37°)$ A	$I_c = (2{,}063.19\angle -123.52°)$ A

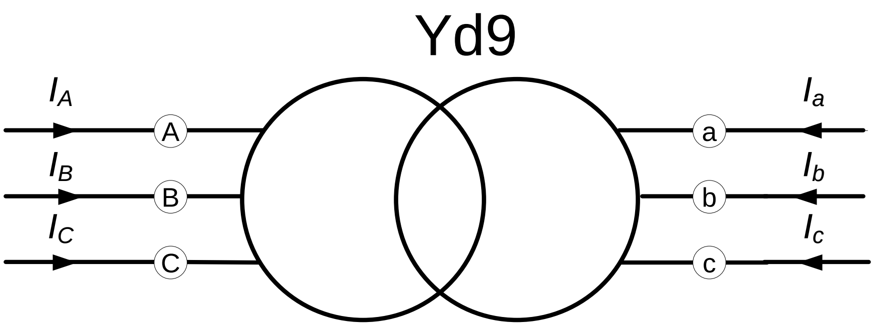

Figure 3. Transformer line currents

Considering the protection settings established in i), and operational characteristic presented in Figure 2, determine in both cases if the differential protection will operate in response to the fault, and thus, determine for each fault if it is internal or external to the transformer.

<u>Additional practical hints:</u>

- When establishing maximum value of the spill current consider all possible positions of the transformer tap changer.
- Correct connection diagram of the CTs in point i) is essential for achieving proper calculation of the secondary line currents flowing into the three differential relays.
- The type of fault is not known, therefore, it is necessary to check the operation of the differential relay in all three phases.

Part 2. System stability and control (45%)

i) Power system stability classification and analysis

Complete Table 2 shown below, adding as much details as possible. Please **create your OWN table** so that you can elaborate on your response as necessary.

Table 2. Power system stability classification.

Stability Type	Definition	Purpose of analysis	Time period of interest	Method of analysis
Steady-State				
Transient				
Dynamic (Small-Signal)				
Voltage				
Frequency				

ii) Steady-state power limit

A synchronous generator with synchronous reactance of 1 p.u. is connected to a transformer of 0.1 p.u. reactance. The transformer feeds a line of reactance 0.1 p.u. which terminates in another transformer (0.125 p.u. reactance). At the LV side of this second transformer, a synchronous motor is connected. The motor is of the round-rotor type and of 1 p.u. reactance. Calculate the steady-state power limit. All per unit reactances are expressed on a 100 MVA base and resistance may be neglected. The internal voltage of the generator is 1.1 p.u. and of the motor 1 p.u.

iii) Critical clearing time

A synchronous generator with inertia constant of H = 4.5 s operates at 50 Hz and delivers 1 p.u. power to an infinite bus through a network in which resistance may be neglected. A fault occurs which reduces the maximum transferrable power to 0.4 p.u., whereas before the fault this power was 1.8 p.u., and after the clearance of the fault it is 1.3 p.u. Using the Equal Area Criterion determine the critical clearing time.

Structure, length, explanations, formatting, and presentation quality (10%)