g. Sample of marking guide

1. Power System Protection and Control 1 (EE4040)

Question 1: Explain meaning of voltage transformer's specification (*1point*):

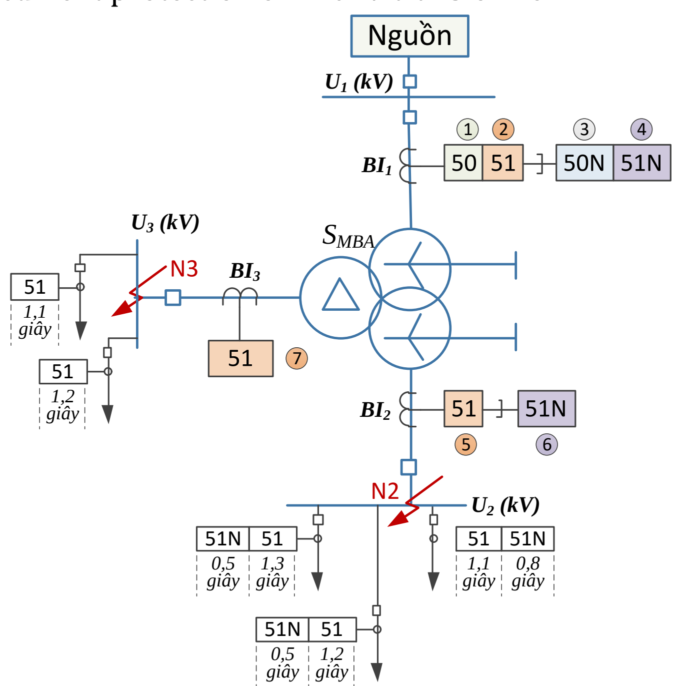
Voltage level (V)	Total core	Core 1	Core 2 &Core 3
$\frac{115000}{\sqrt{3}}:\frac{100}{\sqrt{3}}:\frac{100}{\sqrt{3}}:\frac{100}{\sqrt{3}}$	3	100VA; 0,2	200VA; 3P

Answer:

- This voltage transformer can be installed in 110kV network
- It has three cores with secondary voltage of 100V
- Core 1 has accuracy class of 0,2 and rated power of 100VA. This core is used for precise metering purpose only.
- Core 2 & Core 3: both have accuracy class of 3P with rated power of 200VA. Both cores are used for protective relaying purpose; not suitable to use for metering due to low accuracy.

Question 2: Calculate setting values for overcurrent protection of 110kV transformer:

<table>
<tr><td colspan="6">Transformer rated power: 32 MVA</td></tr>
<tr><td colspan="6">Voltage level U$U_1/U_2/U_3$ (kV): 110/23/35</td></tr>
<tr><td colspan="6">Permissible overload factor: 1,2</td></tr>
<tr><td colspan="6">Current measured by BI_1 when fault occurs at N3 (kA)</td></tr>
<tr><td colspan="3">$N^{(3)}$</td><td colspan="3">$N^{(2)}$</td></tr>
<tr><td colspan="3">1,47</td><td colspan="3">1,27</td></tr>
<tr><td colspan="6">Current measured by BI_1 when fault occurs at N2 (kA)</td></tr>
<tr><td>$N^{(3)}$</td><td>$N^{(2)}$</td><td>$N^{(1)}$</td><td>$N^{(1,1)}$</td><td>$3I_0$ của $N^{(1)}$</td><td>$3I_0$ của $N^{(1,1)}$</td></tr>
<tr><td>2,37</td><td>1,93</td><td>2,15</td><td>2,25</td><td>1,68</td><td>1,47</td></tr>
</table>



Require:

a. Determine current transformer ratios for BI1; BI2; BI3 (*0,5point*)

(Rated primary current of BI can be chosen as: 10 - 12,5 - 15 - 20 - 25 - 30 - 40 - 50 - 60 - 75A and its multiple of 10, 100, 1000 times).

b. Calculate pickup current and time delay for relay 2 & 3 (*1point*)

c. Evaluate minimum sensitivity of relay 2? Determine if this sensitivity of relay 2 meets regulation or not (*0,5 point*)?

Answer:

a. Determine current transformer ratios for BI1; BI2; BI3 (*0,5point*)

Rated current of transformer is calculated based on following formula:

$$I_{rated} = \frac{S_{rated}}{\sqrt{3} * U_{rated}}$$

Consider permissible overload factor ($K_{overload}$) then maximum current will be calculated as:

$$I_{max} = K_{overload} * \frac{S_{rated}}{\sqrt{3} * U_{rated}}$$

One should select rated primary current of BI to be equal or greater than I_{max} and be closet to standard value of manufacture. Secondary currents are all to be 1A.

Results:

Side	U_{rated}(kV)	S_{rated}(MVA)	I_{rated} (kA)	I_{max} (kA)	I_{BI} (A)	Ratio
1	110	32	0.168	0.20	200	**200/1**
2	23	32	0.803	0.964	1000	**1000/1**
3	35	32	0.528	0.633	750	**750/1**

b. Calculate pickup current and time delay for relay 2 & 3 (*1point*)

- Pickup current of time delay overcurrent 2 (ANSI 51):

$$I_{pickup} = K * I_{rated}$$

Minimum value of K can be chosen as 1.5 or higher.

Assume that K=1.6

$$I_{pickup\ Relay\ 2} = 1.6 * 0.168 = \mathbf{0.269\ (kA)}$$

Time delay of Relay 5:

$$t_{Relay\ 5} = \max(t_{lines\ 23kV}) + \Delta t = 1.3 + 0.5 = 1.8\ (sec)$$

(*one may select Δt=0.3÷0.6 sec*)

Time delay of Relay 2:

$$t_{Relay\ 2} = t_{Relay\ 5} + \Delta t = 1.8 + 0.5 = \mathbf{2.3\ (sec)}$$

Alternative: Or student may use more detailed formula:

$$I_{pickup} = \frac{K_{at} * K_{mm}}{K_{tv}} * I_{max}$$

- Pickup current of instantaneous earth fault overcurrent 3 (ANSI 50N):

$I_{pickup\ Relay\ 3} = K_{at} * 3I_{0max\ through\ BI1}$

Here safety factor K_{at} can be in range of 1,1÷1,3

Assume that K_{at}=1,1 hence:

$I_{pickup\ Relay\ 3} = 1.1 * 1.68 = \mathbf{1.85\ (kA)}$

Time delay of Relay 3: $t_{Relay\ 3} = \mathbf{0.05\ (sec)}$

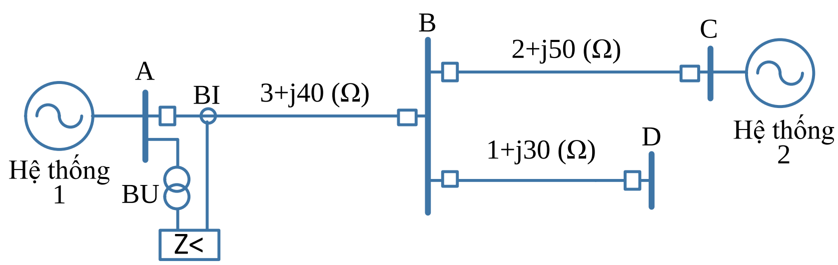
c. Evaluate minimum sensitivity of relay 2? Determine if this sensitivity of relay 2 meets regulation or not (*0,5 point*)?

Minimum sensitivity value of relay 2:

$$K_{n\,min} = \frac{I_{short\ circuit\ min\ through\ BI1}}{I_{pickup\ Relay\ 2}} = \frac{1.27}{0.269} = \mathbf{4.72} > 2$$

This minimum sensitivity value is greater than 2 then it safely meets regulation.

Question 3: Calculate setting values for distance protection in following scheme:



Network rated voltage: 115kV

a. Calculate setting values for 3 protection zones of distance protection (*1,5 point*)

Line AB impedance: $Z_{line\,AB} = 3 + j40 = 40(86^0)\ (\Omega)$

Line BC impedance: $Z_{line\,BC} = 2 + j50 = 50(88^0)\ (\Omega)$

Line BD impedance: $Z_{line\,BD} = 1 + j30 = 30(88^0)\ (\Omega)$

- Setting value for zone I:

$$Z_{pickup\ Zone\ I} = 0.85 * Z_{line\ AB} = 0.85 * 40(86^0) = \mathbf{34(86^0)}\ (\Omega)$$

(*one may select Zone I with setting range of (0.8÷0.85) of Z_{line}*)

Time delay of Zone I:

$t_{Zone\ I} = \mathbf{0\ (sec)}$

- Setting value for zone II:

$$\begin{cases} Z_{pickup\ Zone\ II} \geq 1.2 * Z_{line\ AB} \\ Z_{pickup\ Zone\ II} \leq Z_{line\ AB} + 0.5 * Z_{shotest\ line\ from\ bus\ B} \end{cases}$$

Hence:

$Z_{pickup\ Zone\ II} = 1.2 * (3 + j40) = 3.6 + j48$

Checking restrain condition:

$Z_{line\,AB} + 0.5 * Z_{line\ BD} = 3.5 + j55 \rightarrow\ Z_{pickup\ Zone\ II} = (3.6 + j48) < (3.5 + j55)$

Final setting value for Zone II: $Z_{pickup\ Zone\ II} = (3.6 + j48)$=$\mathbf{48.13(86^0)}\ (\Omega)$

Time delay of Zone II:

$t_{Zone\ II} = \Delta t = \mathbf{0.5\ (sec)}$

- Setting value for zone III:

$Z_{pickup\ Zone\ III} = Z_{line\ AB} + +Z_{longest\ line\ from\ bus\ B} = Z_{line\ AB} + Z_{line\ BC} = 5 + j90$
$= \mathbf{90.14(87^0)}\ (\Omega)$

Time delay of Zone III:

$t_{Zone\ III} = 2\Delta t = \mathbf{1.0\ (sec)}$

In practice, time delay of Zone III may be set higher since it may need to coordinate with other protection function.

b. Assume that maximum line load is 300MVA with power factor cosφ=0.85. Determine maximum resistive reach value of protection zone (*1,5point*)

Rated line voltage is 115kV → minimum allowable operating voltage will be:

V_{min}=85%*115kV=97.75kV

(*one may select value of 90% instead of 85%*)

Minimum line load impedance will be:

$$Z_{line\ load} = \frac{V_{min}^2}{S_{load\ max}} = \frac{97.75^2}{300} = 31.85\ (\Omega)$$

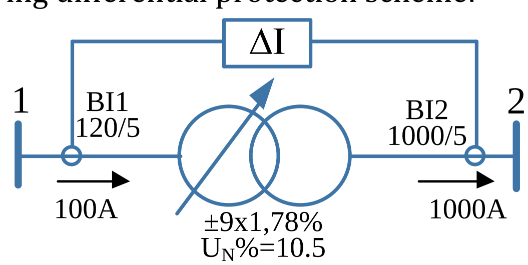
Power factor cosφ=0.85, hence resistive component of line load impedance will be:

$$R_{line\ load} = \cos\varphi * Z_{line\ load} = 27.1\ (\Omega)$$

Resistive reach setting of distance relay will be set with margin of 20%, then maximum resistive reach setting could be (*one may select different value of margin, but should not be less than 20% due to inherent errors of instrument transformers*):

$$R_{reach\ max} = 0.8 * 27.1 = \mathbf{21.68}\ (\Omega)$$

Question 4: Consider following differential protection scheme:



Given data:

- Rated current of side 1 is 100 (A) ; CT ratio (BI1)is 120/5
- Rated current of side 2 is 1000 (A) ; CT ratio (BI2)is 1000/5
- Maximum CT ratio erroris10%
- Tap changer regulationrange: ±9x1,78%
- Short-circuit voltage (percent) : U_N%=10,5

Require:

a. Evaluate maximum bias current during normal operation of transformer with permissible overload factor of 120% (*1 point*).

- Maximum secondary current at side 1: $120\% * 100A * \frac{5}{120} = 5A$
- Maximum secondary current at side 2: $120\% * 1000A * \frac{5}{1000} = 6A$
- Bias current due to different current transformer ratio: $I_{bias\ CT\ ratio}$=6A-5A=1A
- Bias current due to current transformer error and tap changer:

$$I_{bias\ CT\ error\ +\ tap\ change}=120\%*100*(10\%+9x1{,}78\%)*\frac{5}{120}=1.3A$$

- Total maximum bias current:

$$I_{bias\ total}=I_{bias\ CT\ ratio}+I_{bias\ CT\ error\ +\ tap\ change}=1A+1.3A=\mathbf{2.3A}$$

b. If differential relay is has ability to compensate for current transformer ratio at both side then what could be value of that bias current? (*1 point*)?

If relay has ability to compensate for different current transformer ratio at both side then $I_{bias\ CT\ ratio}$ will be omitted from total maximum bias current; therefore maximum bias current now only be: $I_{bias\ total}=I_{bias\ CT\ error\ +\ tap\ change}$ =**1.3A**

c. Determine minimum low-set value of differential relay characteristic (in per unit of $I_{secondaryCT}$=5A)? (*1point*);

Assume that relay has ability to compensate for different current transformer ratio then maximum bias current during normal operation is $I_{bias\ total}$=1.3 A as proven in section (b). Low set pickup value of differential relay would not less than:

1.3A/5A=0.26 (pu)

Hence one may select setting value of **0.26** or higher but do not greater than 0.5 due to limit in setting range of most of nowadays relays.

d. If high-set value of differential relay characteristic is 10 (in per unit of transformer rating current) then what could be minimum short-circuit voltage value of transformer? (*1point*)

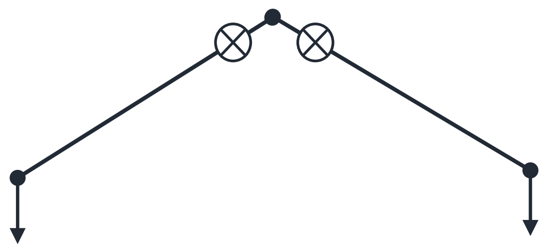
Minimum high set value is set as 120% of 1/(U_N%)
(*one may select value of 100% instead of 120% due to conservative assumption in calculating high set value*)
As high set value is 10 then:

$$U_{N\%} = \frac{1}{10/120\%} * 100 = 12\ (\%)$$

2. Power Delivery System EE3420

<u>Item 1:</u>

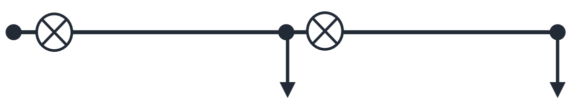
- Distribution network configurations
  - Radial system:



    - High reliability
    - Simple operation
    - High investment

Application: For critical and essential loads, centralized load, LV system (for simple operation)

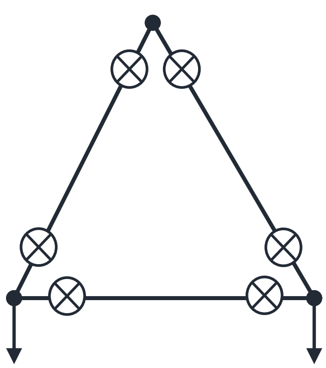
  - Radial-lateral feeder



    - Low reliability
    - More complicated operation
    - Reduced investment

Application:For normal load, distributed loads

  - Loop

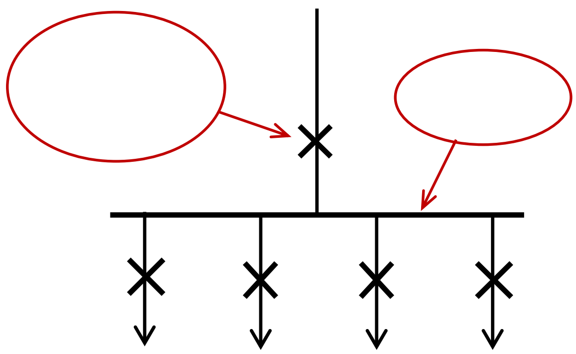


- Very high reliability
- Most complicated operation
- High investment

Application:For critical and essential loads, HV system, MV system with open-ring operation

- Bus schemes at substations

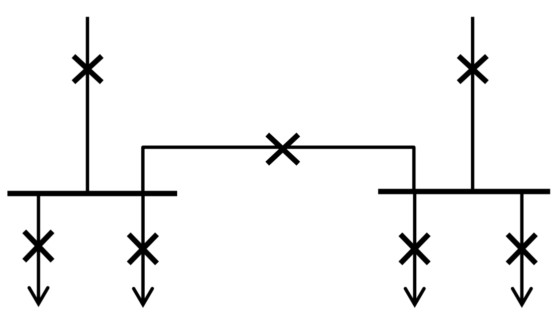
- Single bus



- Needing less switching devices ⇒ Lowest cost.
- Simple bus protection
- Low reliability:

Application:For normal load. Used in low voltage system (Distribution boards) for simple protection.

- Single bus with bus sectionalizer

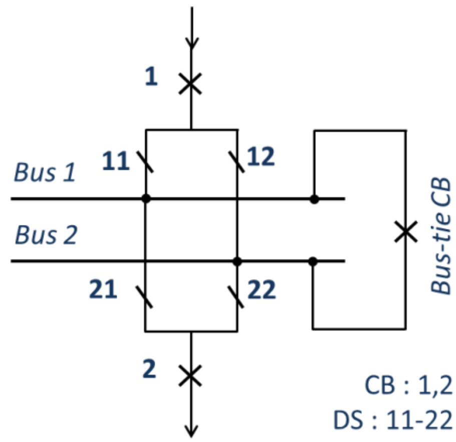


- Add one more supply (2 supplies)

  ⇒ No power outage in case of one supply failure.
- N.O. bus sectionalizer

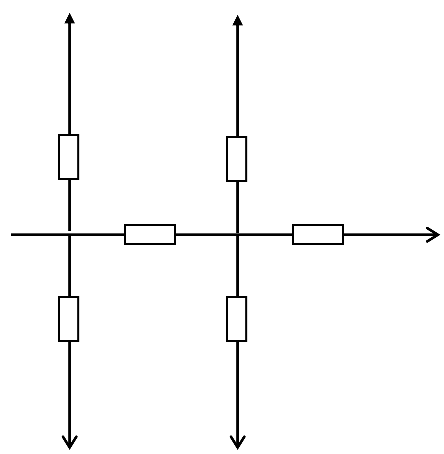
⇒ Only half number of loads suffer outage in one bus-section failure.

- Applicable for essential and critical loads in medium or low voltage systems.
- Automatic Transfer Switch (ATS) used for LV distribution board.



<u>Item 2</u>

Solution:



$Q_{03} = Q_4 + Q_5 + Q_6 = 700kVAr$
$Q = Q_{03} + Q_1 + Q_2 = 1800kVAr$

$R_{eq1} = r_4//r_5//r_6 = 0,02\Omega$
$r_{03} = R_{eq1} + r_3 = 0,06\Omega$

$R_{eq} = r_{03}//r_1//r_2 = 0,015\Omega$

$Q_{c1} = Q_1 -$ ———— $= 600 -$ ———— $=$ <u>200kVAr</u>

$Q_{c2} = Q_2 -$ ———— $= 500 -$ ———— $=$ <u>300kVAr</u>

$Q_{c3} = Q_c - Q_{c1} - Q_{c2} = 1000 - 200 - 300 = 500kVAr$

$Q_{c4} = Q_4 -$ ——— $= 400 -$ ——— $=$ <u>300kVAr</u>

$Q_{c5} = Q_5 -$ ——— $= 250 -$ ——— $=$ <u>200kVAr</u>

$Q_{c6} = Q_6 -$ ——— $= 50 -$ ——— $=$ <u>0kVAr</u>

<u>Item 3.</u>

Solution:

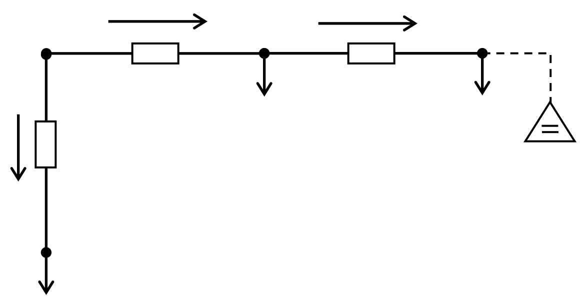
a) Question 1:

- Equivalent circuit:

$Z_{01} = r_o.l_{01} + j\ x_o.l_{01} = 0.46\times2.5 + j\ 0.38\times2.5 = 1.15 + j0.95\Omega$

$Z_{03} = r_o.l_{03} + j\ x_o.l_{03} = 0.46\times1.5 + j\ 0.38\times1.5 = 0.69 + j0.57\Omega$

$Z_{32} = r_o.l_{32} + j\ x_o.l_{32} = 0.46\times1.5 + j\ 0.38\times1.5 = 0.69 + j0.57\Omega$



$\dot{S}_1 = P_1 + jQ_1 = 4000\times0.6 + j4000\times0.8 = 2400 + j3200$ kVA

$\dot{S}_2 = P_2 + jQ_2 = 2000\times0.8 + j2000\times0.6 = 1600 + j1200$ kVA

$\dot{S}_3 = P_3 + jQ_3 = 2500\times0.6 + j2500\times0.8 = 1500 + j2000$ kVA

Maximum loss hours:

$\tau = (0.124 + T_{max}\times10^{-4})^2\times8760 = (0.124 + 5000\times10^{-4})^2\times8760 = 3410h$

Load flow calculation:

$\dot{S}_{32} = \dot{S}_2 = 1600 + j1200$ (kVA), $\dot{S}_{03} = \dot{S}_3 + \dot{S}_{32} = \dot{S}_3 + \dot{S}_2 = 3100 + j3200$ (kVA),

$\dot{S}_{01} = \dot{S}_1 = 2400 + j3200$ (kVA),

Branch power losses:

$$\Delta P_{01} = \frac{S_{01}^2}{U_n^2} \times R_{01} = \frac{S_1^2}{U_n^2} \times R_{01} = \frac{4000^2}{35^2} \times 1.15 \times 10^{-3} = 15.02kW$$

$\Delta A_{01} = \Delta P_{01}.\tau = 15.02 \times 3410 =$ <u>51218kWh per year</u>

$$\Delta P_{32} = \frac{S_{32}^2}{U_n^2} \times R_{32} = \frac{S_2^2}{U_n^2} \times R_{32} = \frac{2000^2}{35^2} \times 0.69 \times 10^{-3} = 2.25kW$$

$\Delta A_{32} = \Delta P_{32}.\tau = 2.25 \times 3410 =$ <u>7672.5kWh per year</u>

$$\Delta P_{03} = \frac{S_{03}^2}{U_n^2} \times R_{03} = \frac{3100^2 + 3200^2}{35^2} \times 0.69 \times 10^{-3} = 11.18kW$$

$\Delta A_{03} = \Delta P_{03}.\tau = 11.18 \times 3410 =$ <u>38123.8kWh per year</u>

$\Delta A = \Delta A_{01} + \Delta A_{03} + \Delta A_{32} = 51218+38123.8+7672.5=$ <u>97014.3kWh per year</u>

b) Question 2:

Before switching on the capacitor at node 2:

$$\Delta U_{03} = \frac{(P_{03}.R_{03} + Q_{03}.X_{03})}{U_n} = \frac{3100 \times 0.69 + 3200 \times 0.57}{35} \times 10^{-3} = 0.113kV$$

$$U_3 = U_0 - \Delta U_{03} = 36.5 - 0.113 = 36.387kV$$

$$\Delta U_{32} = \frac{(P_{32}.R_{32} + Q_{32}.X_{32})}{U_n} = \frac{1600 \times 0.69 + 1200 \times 0.57}{35} \times 10^{-3} = 0.051kV$$

$$U_2 = U_3 - \Delta U_{32} = 36.387 - 0.051 = 36.336kV$$

After switching on the capacitor at node 2:

$\dot{S}'_{23} = \dot{S}_2 - Q_c$ = 1600 + j(1200-500) = 1600 + j700 (kVA),

$\dot{S}'_{03} = \dot{S}_3 + \dot{S}'_{23}$ =3100 + j2700 (kVA)

$$\Delta U'_{03} = \frac{(P'_{03}.R_{03} + Q'_{03}.X_{03})}{U_n} = \frac{3100 \times 0.69 + 2700 \times 0.57}{35} \times 10^{-3} = 0.107kV$$

$$U'_3 = U_0 - \Delta U'_{03} = 36.5 - 0.107 = 36.393kV$$

$$\Delta U'_{32} = \frac{(P'_{32}.R_{32} + Q'_{32}.X_{32})}{U_n} = \frac{1600 \times 0.69 + 700 \times 0.57}{35} \times 10^{-3} = 0.043kV$$

$U'_2 = U'_3 - \Delta U'_{32} = 36.393 - 0.043 = 36.35kV \Rightarrow$ Node 2 voltage is increased.