SWITCHGEAR AND PROTECTION

CALCULATION OF SETTING FOR DIFFERENTIAL RELAYS PROTECTION

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Determine the settings for differential relays (Generator, Transformer and Bus-bar) for your system modeled for Assignment-I

Single-Line Diagram:

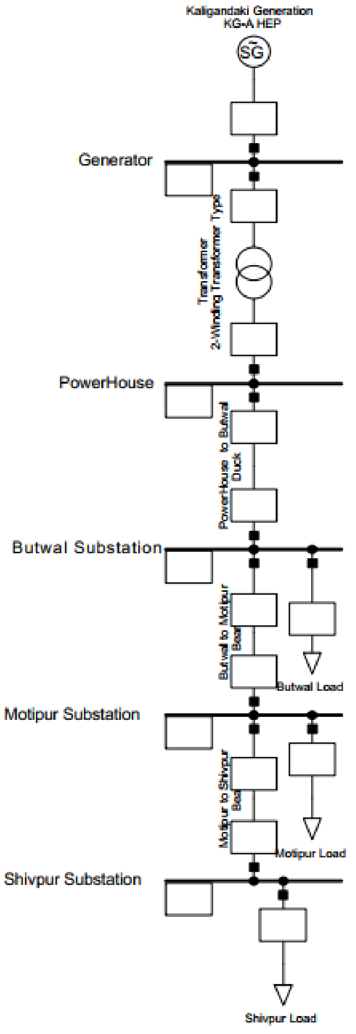


Figure 1: Radial network in Digsilent software

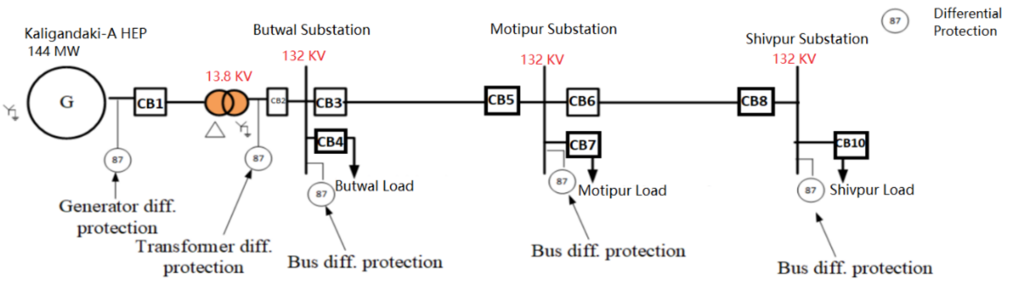


Figure 2: Single line diagram of selected network

BUSBAR DIFFERENTIAL PROTECTION

For any bus in the figure, we consider the following assumptions as constants:

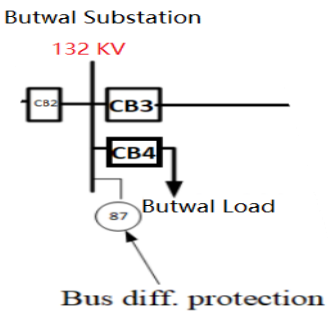
Rs = CT secondary resistance = 0.7 ohm

Pilot wire connecting CT secondary & Relay (Rwire) = 2 ohms

Relay load (1 A relay is used) = 1.0 ohm

CT magnetizing current up to 120 V = 0.28 mA/V (assumed linear)

1. Butwal Substation



In figure alongside,

Let, I_1 = RMS Current in Amp at left side of bus bar during peak load

I_2 = RMS Current in Amp at right side of bus bar during peak load

I_3 = RMS Current in Amp at Butwal load

From load flow analysis,

I_1=718A = 897.5A (Assuming 25% overloading)

I_2=160A= 200 A (Assuming 25% overloading)

I_3=558A= 697.5A (Assuming 25% overloading)

Since, $I_1 > I_2 > I_3$, we have to select the CT ratio of all CT's based on I_1.

Therefore, CT ratio = 900:1 = 900:1 (CT ratio is available)

In case of busbar, another CT of the same ratio and same saturation level is required at the left side of the bus bar and load side.

The system is solidly earthed and the switchgear capacity is 169.5 MVA at 132 kV. The maximum 'through fault' current that can be handled by the switchgear is:

$$\frac{169.5 * 10^6}{\sqrt{3} * 132 * 10^3} = 741.37A$$

$$\text{Vset} = \frac{741.37 * (\text{ Rs } + \text{ Rwire })}{CT \text{ ratio}} = \frac{741.37 * (2 + 0.7)}{900} = 2.224V$$

CT magnetizing current is given as 0.28 mA per volt.

Therefore, for a voltage of 2.224 V;

CT magnetizing current = (0.28 mA/V)*(2.224 V) = 0.000622

For minimum internal fault current of 900A, the pick-up value should be:

$$\text{I}_{\text{pu}} = \left(\frac{I_{\text{fint, min1,pri}}}{N_1}\right) - nI_o$$

$$\text{I}_{\text{pu}} = \frac{900}{900} - 0.000622*3 = 0.998\text{A}$$

Stabilizing Resistance + Relay load Resistance = $\frac{Vset}{Ipu} = \frac{2.224}{0.998} = 2.228$

Since, Relay Load resistance = 1 ohm
Therefore, Stabilizing Resistance (Rstab) =2.228-1 =1.228 ohm

Calculation of Supervisory Relay:

Supervisory relay is over voltage relay. So, we have to calculate the pickup voltage (Supervisory).
Neglecting magnetizing currents of the CTs, we get:

$V_{supervisiory} = \frac{I_{load,CT}}{N}(Rstab + Rocrelay) = \frac{25}{900} * 2.228 = 0.0618$ V

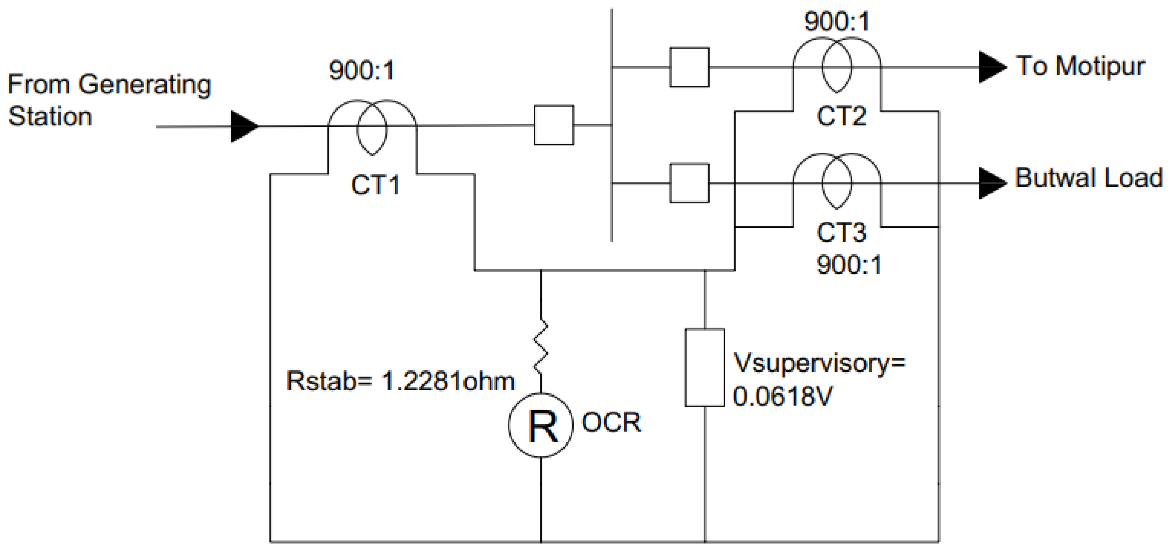
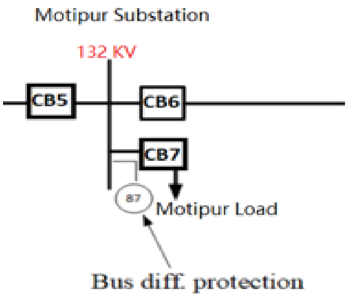


Figure 3: Butwal Busbar Differential Protection

2. Motipur Substation



In figure alongside,
Let, I_1 = RMS Current in Amp at left side of bus bar during peak load
I_2 = RMS Current in Amp at right side of bus bar during peak load
I_3 = RMS Current in Amp at Motipur load

From load flow analysis,

I_1=160A = 200 A (Assuming 25% overloading)

I_2=118A= 147.5 A (Assuming 25% overloading)

I_3=42A= 52.5 A (Assuming 25% overloading)

Since, $I_1 > I_2 > I_3$, we have to select the CT ratio of all CT's based on I_1.

Therefore, CT ratio = 200:1 = 200:1 (CT ratio is available)

In case of busbar, another CT of the same ratio and same saturation level is required at the left side of the bus bar and load side.

The system is solidly earthed and the switchgear capacity is 169.5 MVA at 132 kV. The maximum 'through fault' current that can be handled by the switchgear is:

$$\frac{169.5 * 10^6}{\sqrt{3}*132*10^3} = 741.37\ A$$

$$\text{Vset} = \frac{741.37*(\text{Rs} + \text{Rwire})}{CT\ \text{ratio}} = \frac{741.37*(2+0.7)}{200} = 10.008V$$

CT magnetizing current is given as 0.28 mA per volt.
Therefore, for a voltage of 1.77 V;
CT magnetizing current = (0.28 mA/V)*(10.008 V) = 0.0028 A

For minimum internal fault current of 200A, the pick-up value should be:

$$I_{pu} = \left(\frac{I_{\text{fint, min1,pri}}}{N_1}\right) - nI_o$$

$$I_{pu} = \frac{200}{200} - 0.0028*3 = 0.99\ A$$

Stabilizing Resistance + Relay load Resistance = $\frac{Vset}{Ipu} = \frac{10.008}{0.99} = 10.1$

Since, Relay Load resistance = 1 ohm
Therefore, Stabilizing Resistance (Rstab) =10.1-1 =9.1 ohm

Calculation of Supervisory Relay:

Supervisory relay is over voltage relay. So, we have to calculate the pickup voltage (Supervisory).
Neglecting magnetizing currents of the CTs, we get:

$$V_{supervisiory} = \frac{I_{load,CT}}{N}(Rstab + Rocrelay) = \frac{25}{200} * 10.1 = 1.2625V$$

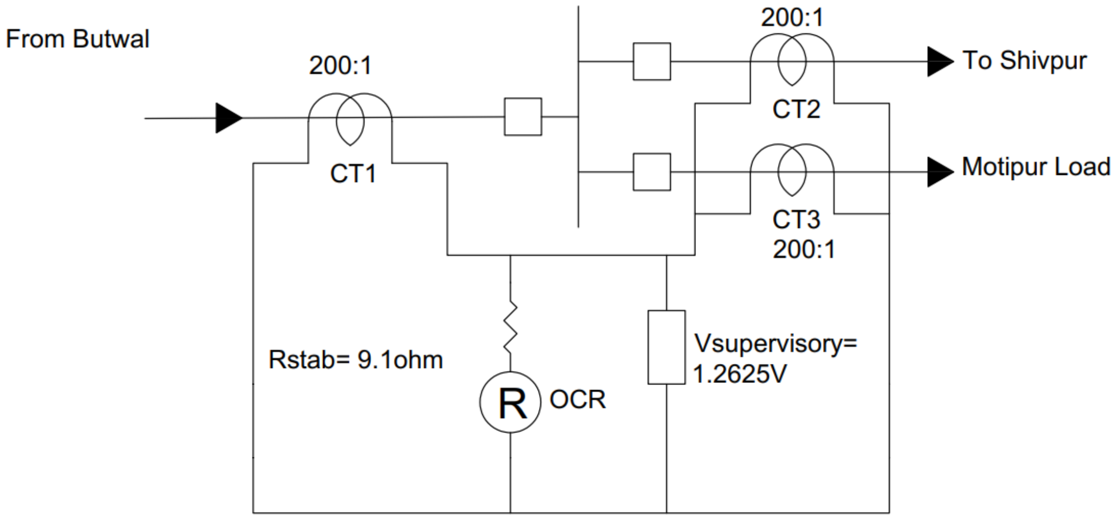
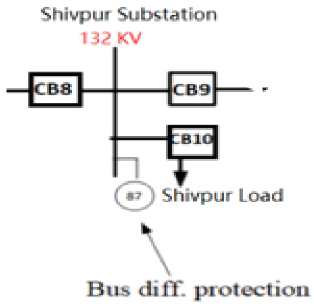


Figure 4:Motipur Busbar Differential Protection

3. Shivpur Sustation



In figure alongside,
Let, I_1 = RMS Current in Amp at left side of bus bar during peak load
I_2 = RMS Current in Amp at right side of bus bar during peak load
I_3 = RMS Current in Amp at Shivpur load

From load flow analysis,

I_1=118A = 147.5 A (Assuming 25% overloading)

I_2=118= 147.5 A (Assuming 25% overloading)

Since, $I_1 > I_2$, we have to select the CT ratio of all CT's based on I_1.

Therefore, CT ratio = 150:1 = 150:1 (CT ratio is available)

In case of busbar, another CT of the same ratio and same saturation level is required at the left side of the bus bar and load side.

The system is solidly earthed and the switchgear capacity is 169.5 MVA at 132 kV. The maximum 'through fault' current that can be handled by the switchgear is:

$$\frac{169.5 * 10^6}{\sqrt{3}^* 132^* 10^3} = 741.37A$$

$$\text{Vset} = \frac{169.5^*(\text{ Rs } + \text{ Rwire })}{CT \text{ ratio}} = \frac{169.5^*(2+0.7)}{150} = 3.051V$$

CT magnetizing current is given as 0.28 mA per volt.
Therefore, for a voltage of 3.051 V;
CT magnetizing current = (0.28 mA/V)*(3.051 V) = 0.000854 A

For minimum internal fault current of 200A, the pick-up value should be:

$$\text{I}_{\text{pu}} = \left(\frac{I_{\text{fint, min1,pri}}}{N_1}\right) - nI_o$$

$$\text{I}_{\text{pu}} = \frac{150}{150} - 0.000854*2 = 0.998 \text{ A}$$

$$\text{Stabilizing Resistance + Relay load Resistance} = \frac{Vset}{Ipu} = \frac{3.05}{0.998} = 3.056$$

Since, Relay Load resistance = 1 ohm
Therefore, Stabilizing Resistance (Rstab) =3.056-1 = 2.056 ohm

Calculation of Supervisory Relay:

Supervisory relay is over voltage relay. So, we have to calculate the pickup voltage (Supervisory).
Neglecting magnetizing currents of the CTs, we get:

$$\text{V}_{\text{supervisiory}} = \frac{\text{I}_{\text{load,CT}}}{\text{N}}(\text{Rstab} + \text{Rocrelay}) = \frac{25}{150} * 3.056 = 0.509 \text{ V}$$

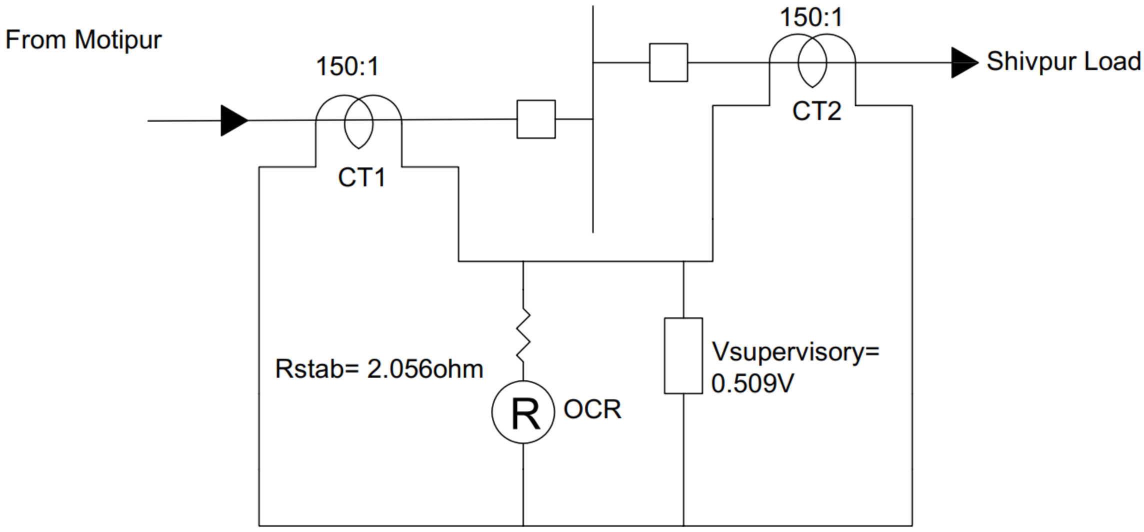


Figure 5: Shivpur Busbar Differential Protection

TRANSFORMER DIFFERENTIAL PROTECTION

Three unit of transformers of each 56.5 MVA, 13.8 kV/132 kV, 10% transformer impedance, and a delta-star transformer is operating in Kali Gandaki generation substation. For differential protection, we need two CT's each on each side. The ratio calculation and the CT connection configuration is shown in the following table:

Step		13.8 kV delta side	132 kV star side
1	Full-load line current, IFL (A)	$\frac{56.5^{*}10^{6}}{\sqrt{3}^{*}13.8^{*}10^{3}} = 2363.78$	$\frac{56.5^{*}10^{6}}{\sqrt{3} * 132^{*}10^{3}} = 247.12$
2	To allow for 25% overload, choosing (IFL * 1.25) as primary current(A)	2954.72 A	308.904 A
3	CT ratios (1 A relay)	3000:1 CT Ratio = 3000	350:1 Current Ratio = 400
4	CT secondary Current (A)	0.9849A	0.8825A
5	Pilot wire currents (A)	Since, 13.8 KV side is delta connected, CT secondaries are connected in the star. Current in the pilot wires: =0.9849A	Since,132 KV side is star connected, CT secondaries are connected in the delta. Current in the pilot wires: $\sqrt{3}$ *0.8825= 1.5285A
6	Turns ratio of the interposing CT (1.5285/0.9849) : 1 = 1.551: 1	Current in the pilot wires: =0.9849A	Current after interposing CT =1.5285/1.551 =0.9854A

A spill current = 0.9854-0.9849 = 0.0005A

Let's put I_{pu}(Pick-up Setting)= 5% of 1A= 0.5A

As spill current<I_{pu}, the system is stable.

For slope setting, calculating maximum through current fault

$I_f = \frac{E}{jx} = \frac{1}{0.15} = 6.67pu$

Now, Actual fault current

$I_{actual(fault)} = I_{pu} * I_{base} = 6.67*308.904 = 2060.38A$

Primary side fault current can be calculated as;

$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$

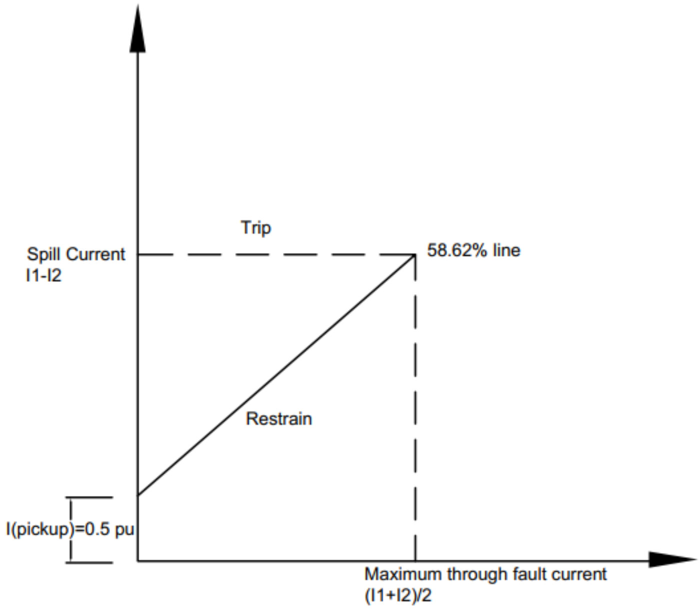
$I_{1\ (fault)} = \frac{V_2 \times I_2}{V_1} = \frac{132}{13.8} * 2060.38 = 19.707KA$

Current	Primary	Secondary
Fault Current	$\frac{19.707\ KA}{3000} = 6.569A$	$\frac{2.06KA}{350} = 5.88A$
Fault Current after Interposing	Current in the pilot wires = 6.569A	Current in the pilot wires $= \frac{5.88\ A}{1.551} = 3.7911A$

Bias Setting (%) = $[\frac{I_1 - I_2}{(I_1+I_2)/2} + 0.05] * 100\%$

$= [\frac{6.569-3.7911}{(6.569+3.7911)/2} + 0.05] * 100\%$

= 58.62%



Again, checking for maximum through fault condition,

$$I_{pickup}(I_1\text{-}I_2)_{\text{, from curve}} = \left[\frac{(I_1+I_2)}{2}\right] * \left(\frac{\text{Bias setting}}{100}\right) + I_{\text{pickup, from curve}}$$

$$=3.158A$$

Here, Actual spill current is 3.158A<$I_{\text{pickup, from curve}}$

So, differential relay will not operate(restrains).

Relay Settings

CT ratio:

Primary side: 3000:1

Secondary side: 350:1

$I_{\text{min(Pickup)}}$: 0.05A(5% of 1A)

Bias Setting: 60%

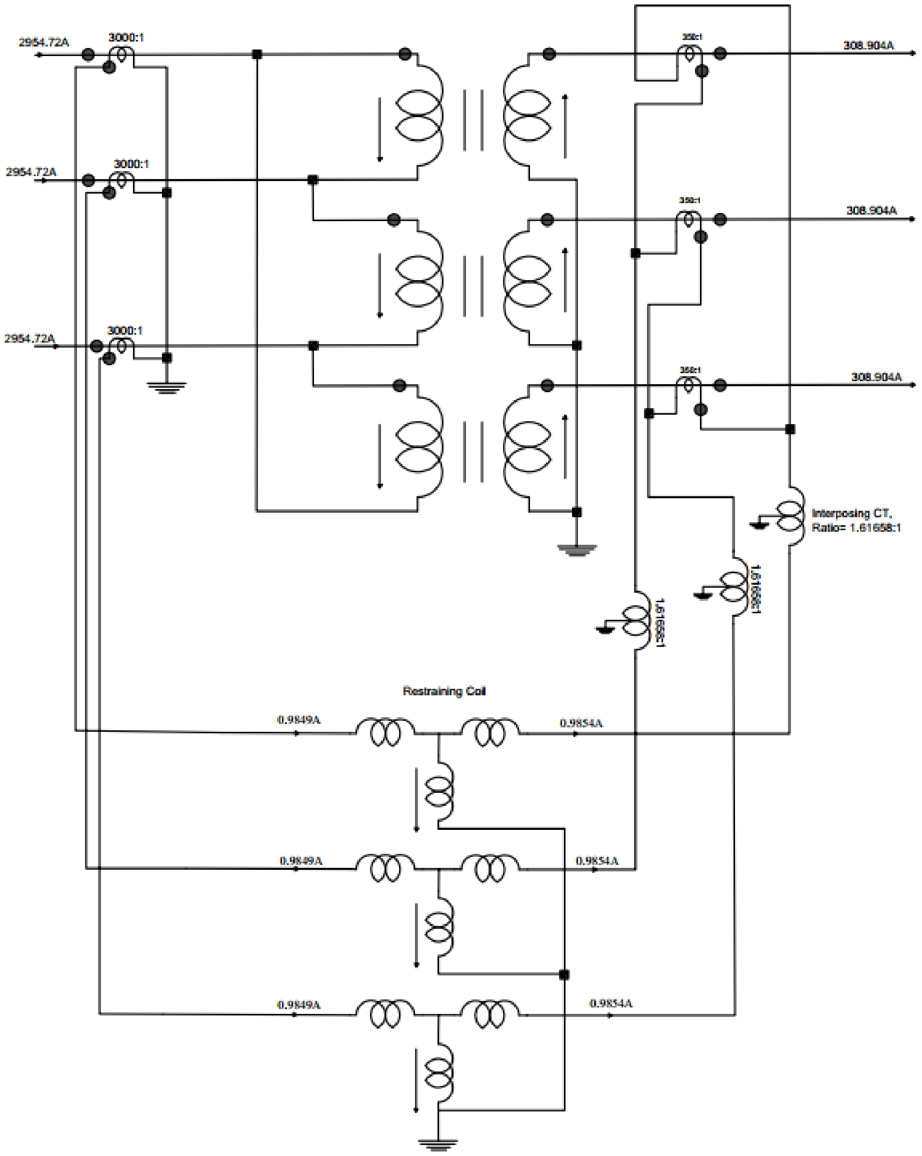


Figure 6: Transformer Differential Protection

GENERATOR PROTECTION

Three units of generator of each capacity of 56.5 MVA is operating in in Kaligandaki generation substation producing a total power of 170 MVA.

Rated capacity of each generator (P) = 56.5 MVA

Rated current of generator (I_L) = $\frac{P}{\sqrt{3}\times V} = \frac{56.5\times10^6}{\sqrt{3}\times13.8\times10^3}$ = 2363.78A

Earth fault current (I_f) = $\frac{1<0}{j0.3}$ = 3.33 pu

Actual Earth fault current ($I_{f,actual}$) = I_f*I_{base} = 3.33*2363.78 = 7871.38A

Limiting the earth fault current to rated current, calculating the value of resistance;

$I_l = \frac{\frac{(13.8*1000)}{\sqrt{3}}}{(j0.3+Rn)}$ (Assuming, Rn>>>Xd)

Rn = $\frac{(13.8*10^3)}{\sqrt{3}*2363.78}$ = 3.37 ohm

Maximum value of resistance allowed for grounding

$R_{max} = \frac{10^6}{6\pi fc} = \frac{10^6}{6\pi*50*0.25}$ = 4246 ohm

Since, the rated current of generator is 2363.78A. We use CT of 2500:1 on both sides of stator.

The plug setting is 10% of 1A = 0.1

During fault condition, current reading at secondary winding of CT is;

$I_1 = \frac{7871.38}{2500}$ = 3.14A

During rated operation,

$I_2 = \frac{2363.78}{2500}$ = 0.94A

Now,

$$I1 - I2 = \frac{m}{2} * (I1 + I2) + Ipu$$

$$3.14 - 0.94 = \frac{m}{2} * (3.14 + 0.94) + 0.1$$

Slope(m) = 97%

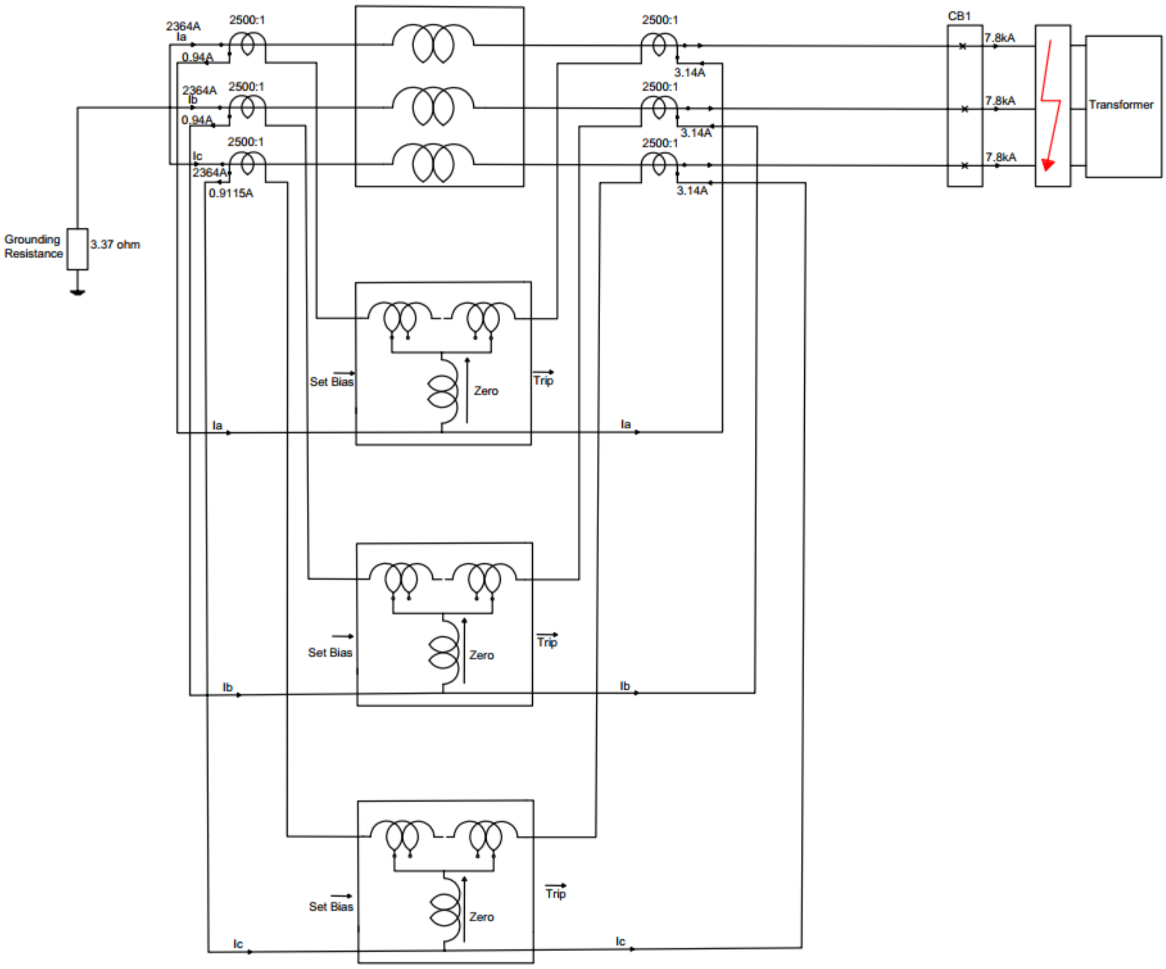


Figure 7: Generator Protection

Results

S.N	Substation Name	Result
1	Kaligandaki-A Generator Bus	CT ratio = 2500:1 Pickup = 10% of 1A Bias setting = 97% Grounding resistance = 3.37Ω
2	Kaligandaki-A Transformer	LV side CT ratio = 3000:1A HV side CT ratio = 350:1A Interposing CT = 1.551 :1 A Pickup = 5% of 1A Bias setting = 60%
3	Butwal Load Bus (132kV)	CT ratio = 400:1A Pickup = 0.876 A Stabilising resistance = 167.5 Ω Voltage of supervisory relay = 10.53V
4	Motipur Load bus (66kV)	CT ratio = 300:1A Pickup= 0.8346 A Stabilising resistance = 234.8 Ω Voltage of supervisory relay = 90.65V
5	Shivpur Load bus (132kV)	CT ratio = 200:1A Pickup = 0. A Stabilising resistance = 352.7 Ω Voltage of supervisory relay = 44.21 V