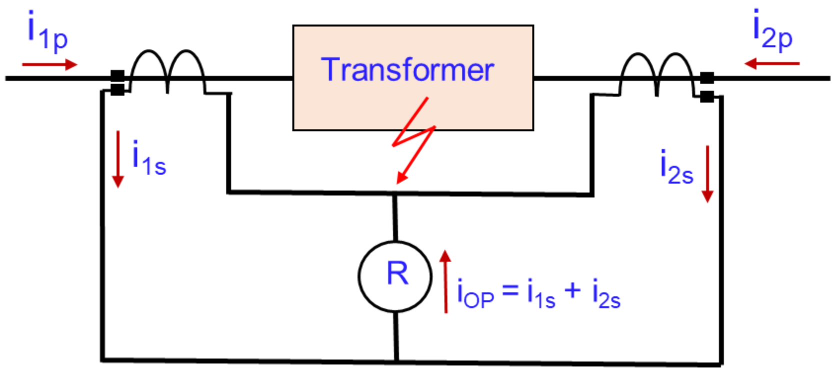
Demonstration of Laboratory Experiments on Numerical Relays

Experiment 03: Verification of Percentage biased Differential Relay Characteristic for Transformer Protection

Prof A K Pradhan
Department of Electrical Engineering
Indian Institute of Technology Kharagpur

Verification of Percentage biased Differential Relay Characteristic for Transformer Protection

- Objective
- Theory
- Circuit diagram – 3 phase transformer
- Relay Settings
- Observations and Verification



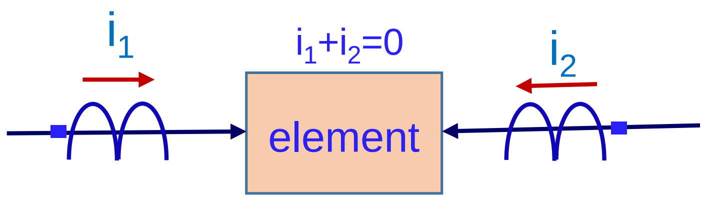
Internal Fault condition

Objective:

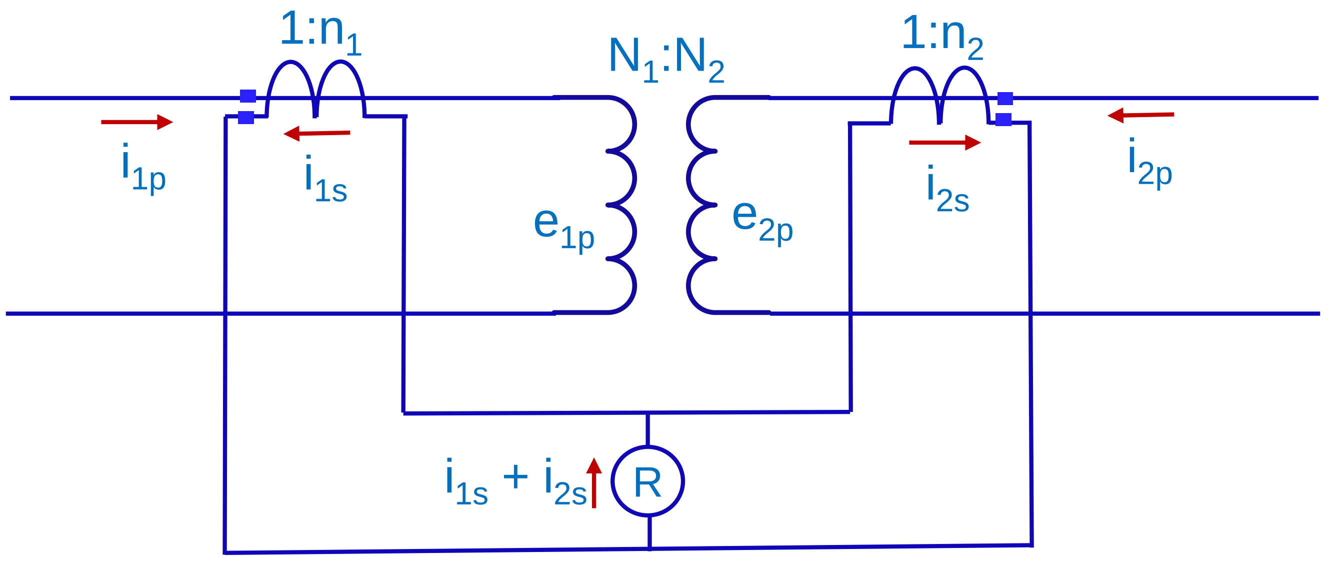
Verification of percentage biased differential relay characteristics protecting 3-PhaseTransformer

-Differential Relay- MICOM P634 (Schneider Electric) (87 T)

Theory: Principle of Transformer Differential Protection



KCL for differential protection principle



1-phase Transformer

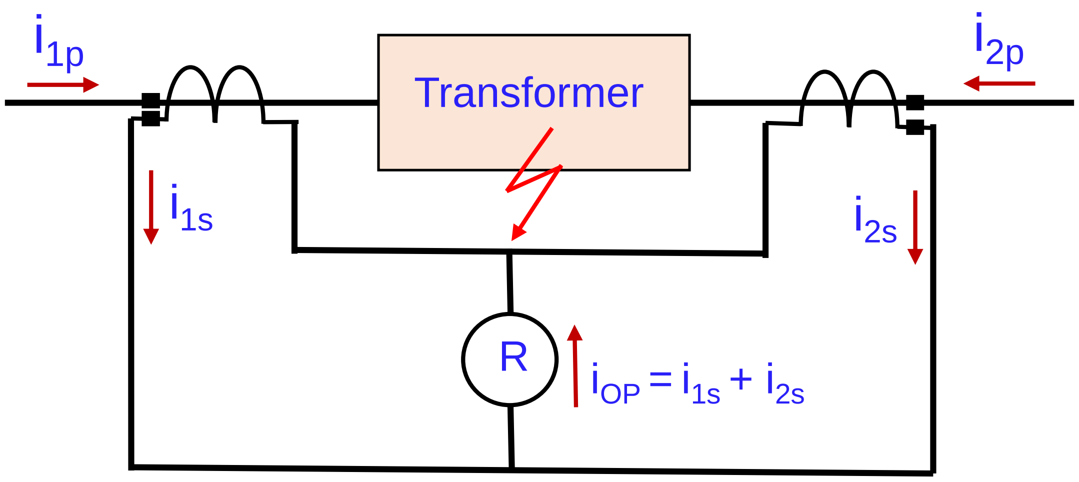
$$N_1 i_{1p} = N_2 i_{2p}$$

$$N_1 n_1 i_{1s} = N_2 n_2 i_{2s}$$

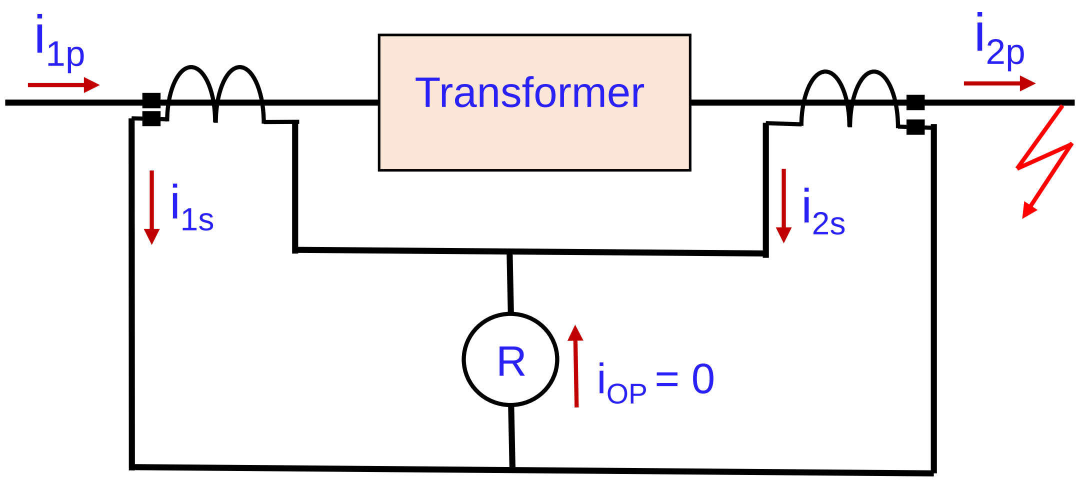
$$i_d = i_{1s} + i_{2s}$$

With proper selection of CT we can make $N_1 n_1 = N_2 n_2$

Differential Protection



Internal Fault condition



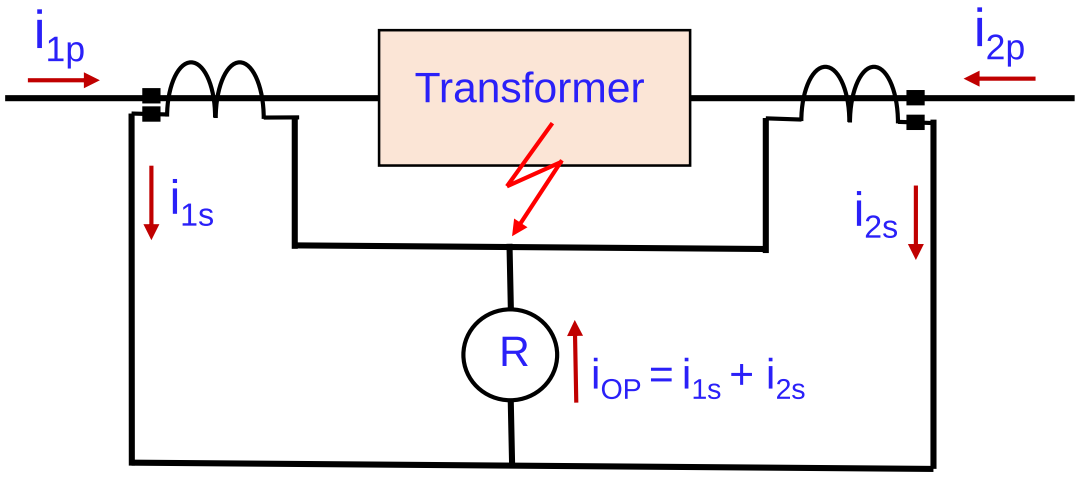
External Fault or Load condition

Now i_{2p} is reversed as compared to internal fault case; i_{2s} will also be reversed, thus $i_{OP} = i_{1s} + (-i_{2s}) = 0$

- Differential relay operates on the **sum of the currents** entering the protected element= the differential current.
- The differential current (CT secondary) is proportional to the fault current for internal faults, approaches zero for any other operating conditions.
- There is **another convention** as in the literature - CT with opposite polarity connection of the way we have connected here at one side(say secondary). In that case it becomes $i_{OP} = i_{1s} - i_{2s}$
- In our presentation we will consider the convention of $i_{OP} = i_{1s} + i_{2s}$ throughout as shown in the above diagram

Applying Overcurrent Principle for the Differential Current

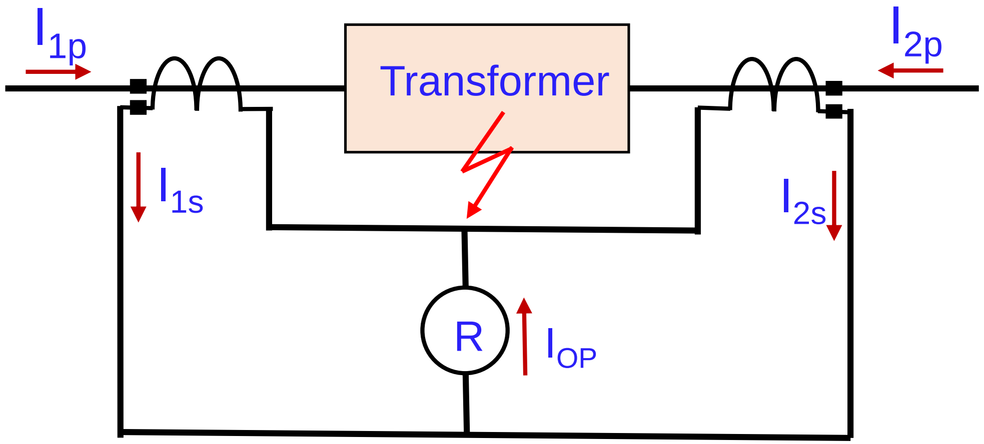
- When relay R with differential current uses Overcurrent principle for decision any spill current (magnetising current etc.) it will maloperate.
    - mismatch errors of CTs or CT-saturation error for external fault or
- To compensate all these errors, overcurrent relays should be set to operate above the anticipated maximum error value. Time delay to override inrush is also necessary.

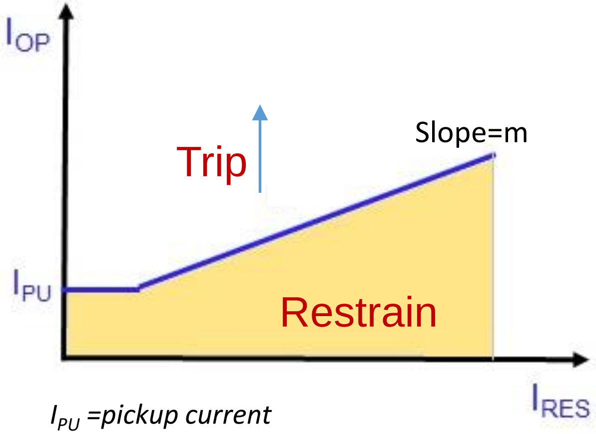


Internal Fault condition

Percentage Biased Differential Protection

- To overcome the drawbacks of applying overcurrent principle in differential relay, percentage biased differential relays are used.
- These relays offer sensitive differential protection at low currents and tolerate larger mismatches at high currents while still tripping for internal faults.





Trip condition:

$$I_{OP} > I_{PU}$$

$$I_{OP} > m\ I_{RES}$$

- I_{OP}: is the differential current, which is the phasor or instantaneous sum of the currents, flowing into the zone of protection. $I_{OP} = |I_{1s} + I_{2s}|$

- I_{RES}: A measure of the current flowing through the zone of protection. This provides the desirable feature of restraining the relay when high levels of current are flowing through the zone.

$$I_{RES} = k|I_{1s} - I_{2s}|$$

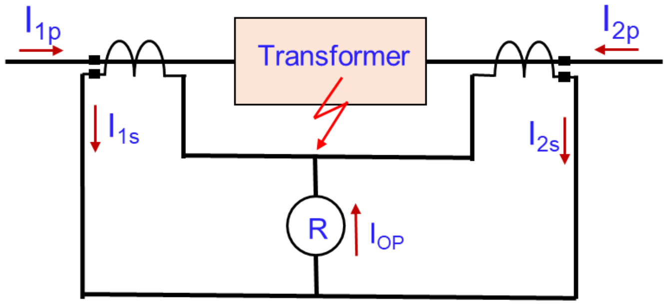
with k =0.5 or 1

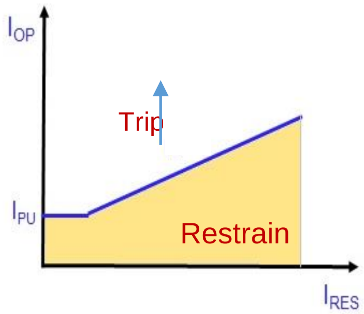
$$I_{RES} = k(|I_{1s}| + |I_{2s}|)$$

$$I_{RES} = Max(|I_{1s}|, |I_{2s}|)$$

- When high currents are present, it is more likely that a CT can saturate and cause false differential current.

- A characteristics require a higher percentage of differential current to operate at higher levels of through current.

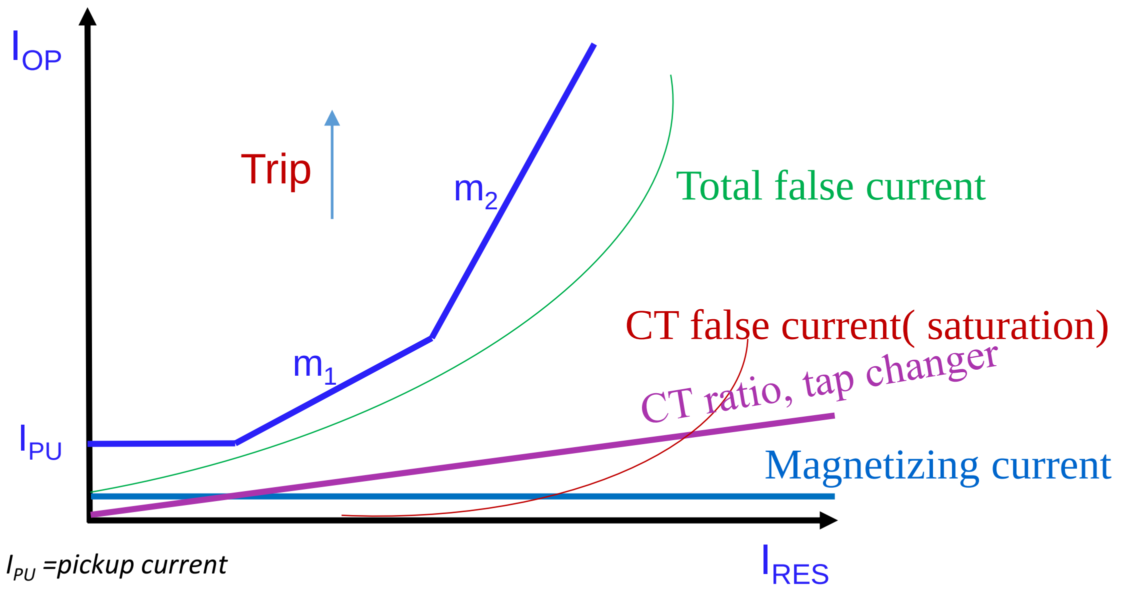




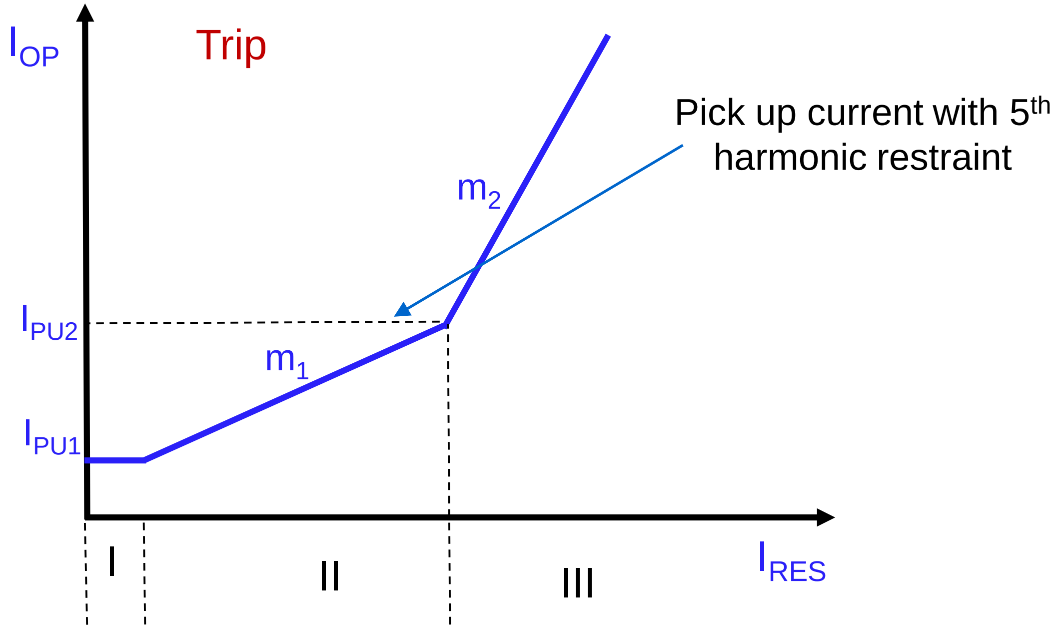
I_{PU} =pickup current

Percentage Biased Differential Relay

- The percentage difference can be fixed or variable, based on the relay design.
- There is also a minimum differential current threshold before tripping without regard to the restraint current.
- Details of minimum pickup, restraint current, and characteristic slope vary among manufacturers.
- Slope may not be a straight line but may curve up depending on the design of the percentage restraint system.
- This curve allows even larger percentage mismatches during large through-currents.



Setting for Dual slope Percentage Biased Differential Protection



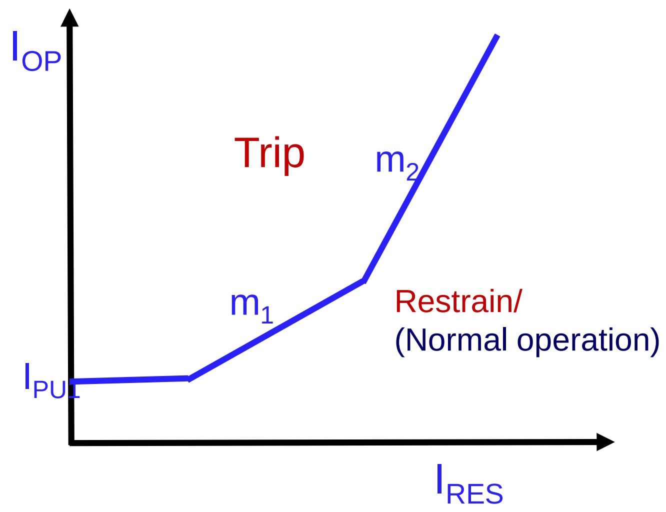
I_{PU} =pickup current

Preparing both side currents for comparison

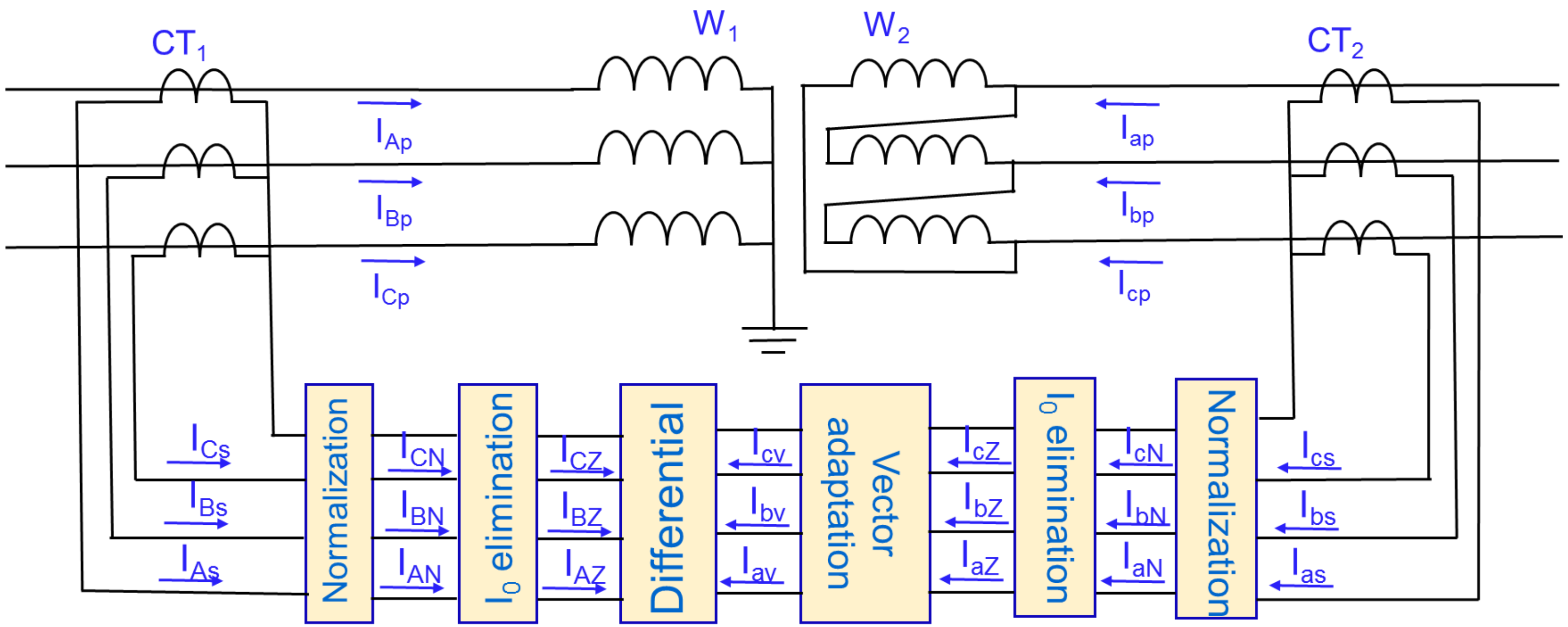
- Normalization of current
- Prior to the current comparison, two adaptations are required:

(i) on the earthed star-point winding side the zero-sequence component must be eliminated

(ii) vector group – the phase angle must be compensated



Steps in Differential Relay processing

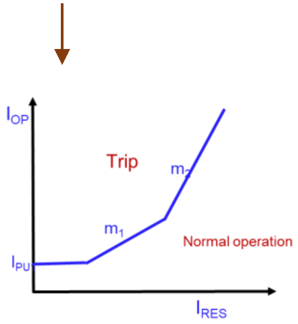


Step-1: Normalization

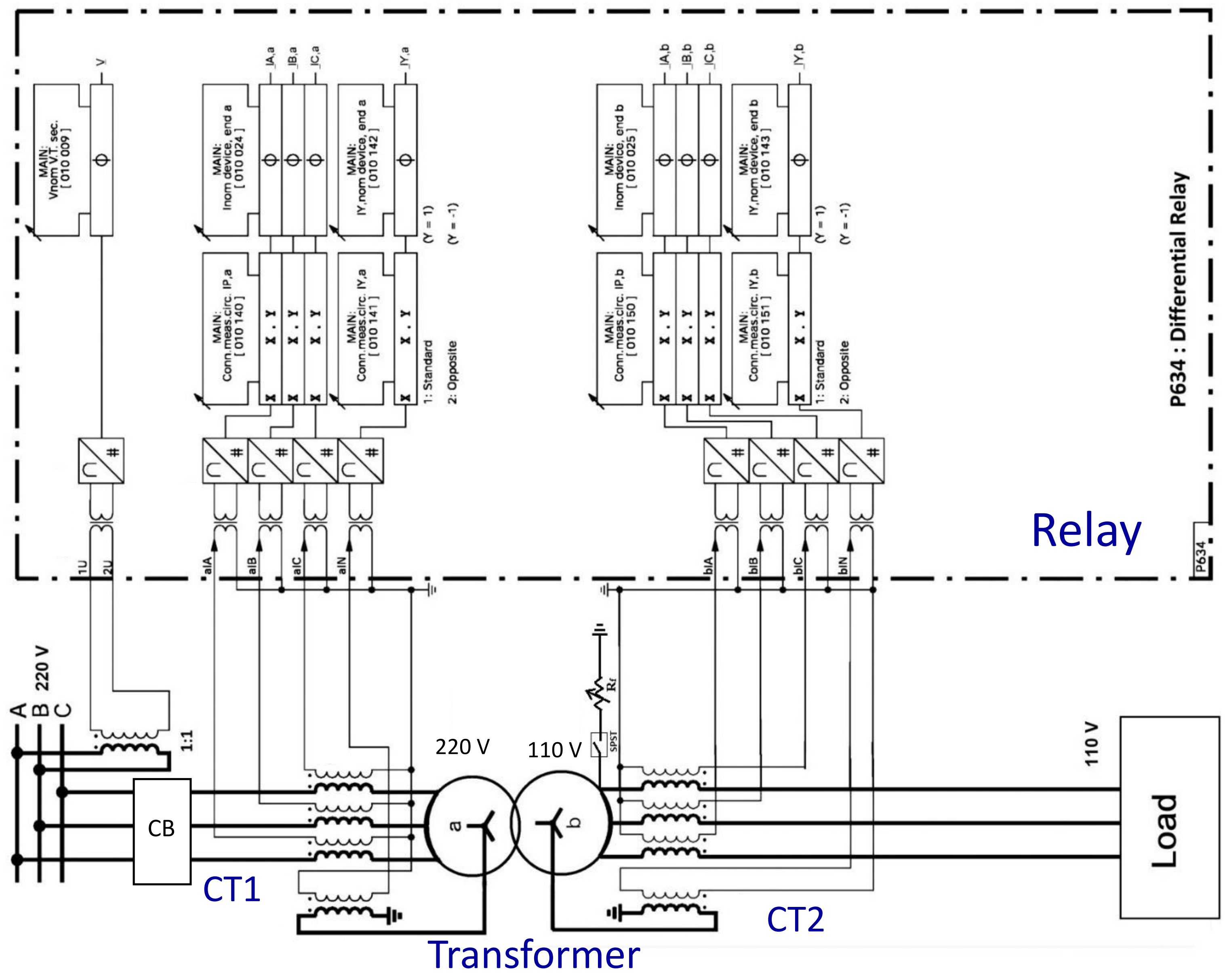
Step-2: I_0-elimination

Step-3: Vector group adaptation

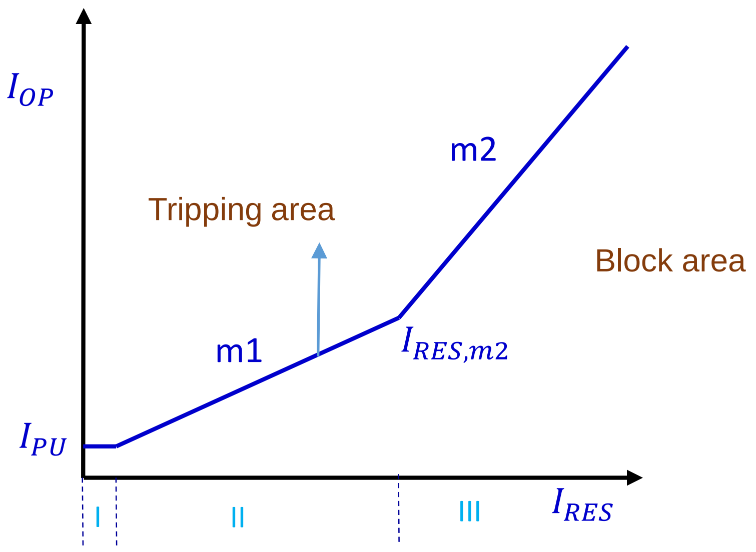
Step-4: Decision applying Differential Protection Principle



Circuit Diagram:



Setting for Dual slope Percentage Biased Differential Protection



$I_{PU} = 0.2$

$I_{RES,m2} = 1.5$

Trip condition:

$I_{OP} > I_{PU}$ for the range $0 \le I_{RES} \le 0.5 I_{PU}$

$I_{OP} > m_1 I_{RES}$ for the range $0.5 I_{PU} < I_{RES} \le I_{RES,m2}$

$I_{OP} > m_2 I_{RES}$ for the range $I_{RES} > I_{RES,m2}$

Reference:

https://rza.by/upload/iblock/bce/P634_EN_M_R-21-A__310_651.pdf Page no: 3-132

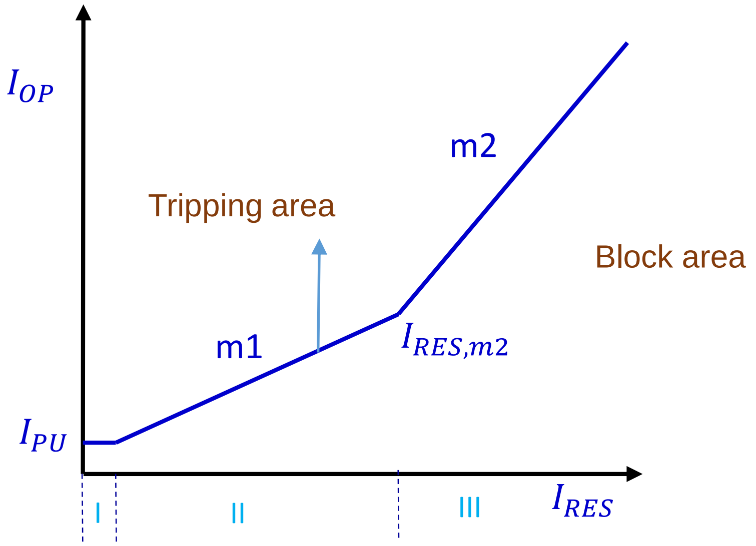
Settings

Settings	
Base Power	47.7 MVA
Base Voltage (HV)	220 kV
I (reference) HV	125 A
I (reference) LV	250 A
PT ratio (HV)	220kV/110V
PT ratio (LV)	110kV/110V
CT Ratio (HV)	2000/5
CT Ratio (LV)	1700/5
CT Ratio (HV) Neutral	2000/5
CT Ratio (LV) Neutral	1700/5

Relay Settings

$$I_{ref,HV} = \frac{S_{ref}}{\sqrt{3}V_{nom,HV}}$$

$$I_{ref,LV} = \frac{S_{ref}}{\sqrt{3}V_{nom,LV}}$$



For each phase

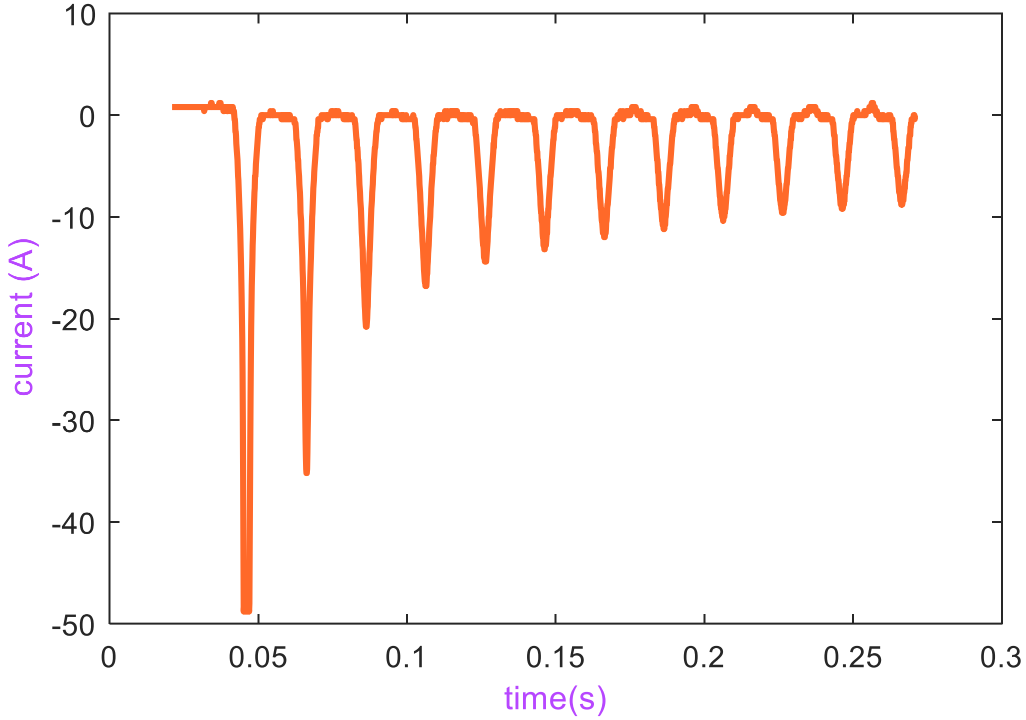
$$I_{OP} = |I_{HV} + I_{LV}|$$

$$I_{RES} = 0.5|I_{HV} - I_{LV}|$$

$$I_{ref,HV} = \frac{S_{ref}}{\sqrt{3}V_{nom,HV}} = \frac{47.7 \times 10^6}{\sqrt{3} \times 220 \times 10^3} = 125A$$

$$I_{ref,LV} = \frac{S_{ref}}{\sqrt{3}V_{nom,LV}} = \frac{47.7 \times 10^6}{\sqrt{3} \times 110 \times 10^3} = 250A$$

Inrush waveform in one phase

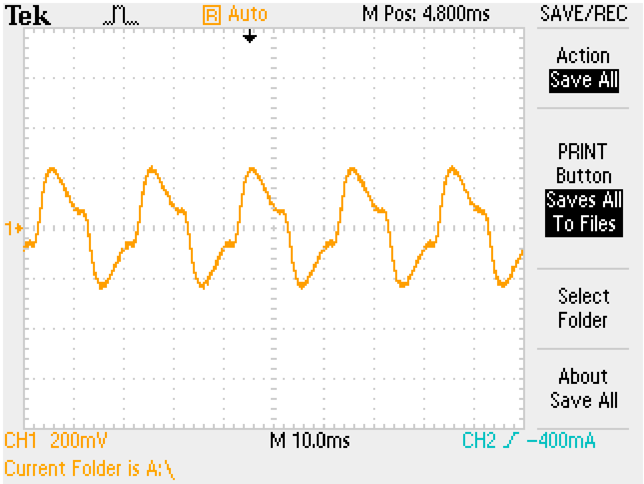


FFT analysis

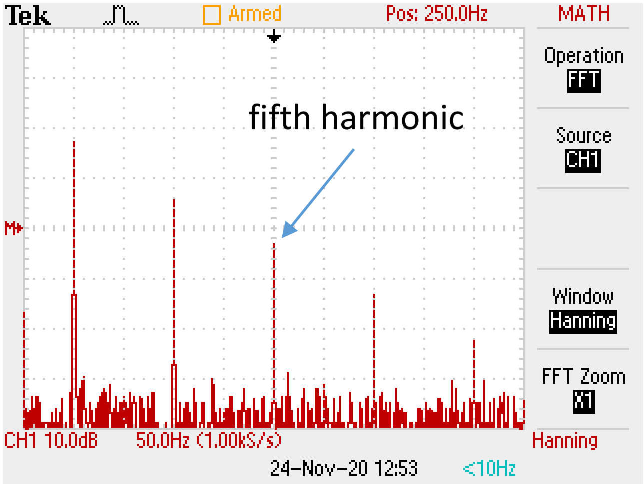
Harmonic order	% of fundamental
2^{nd}	75%
4^{th}	28%
5^{th}	18%

switching on the bank of three 1 kVA transformer 220 V/110V, 50 Hz

Overfluxing –shows high fifth harmonic



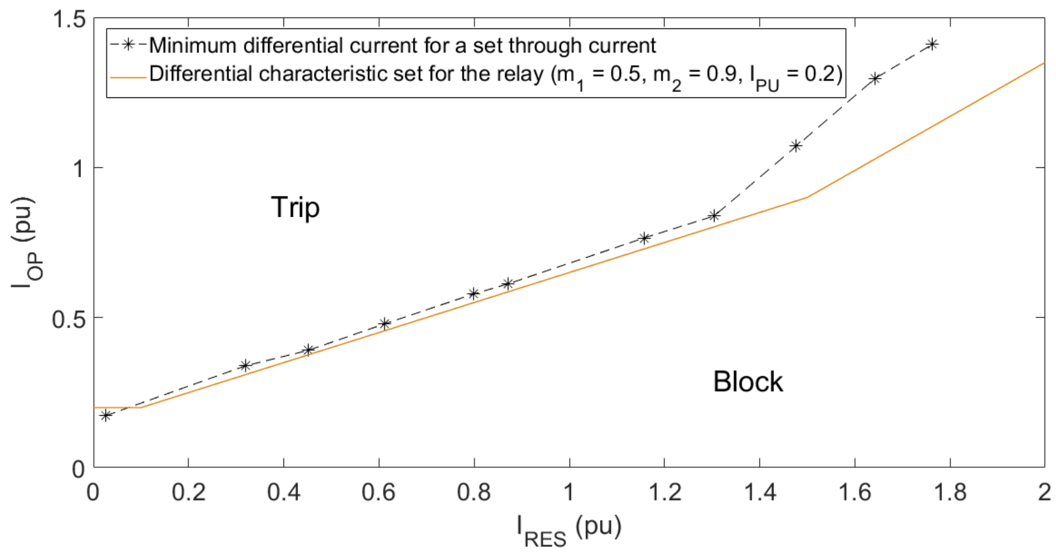
Current signal in one phase



FFT of the signal

Test Case 1:

Settings: m1=0.5, m2=0.9, I_{PU} = 0.2



Measurements Transformer		Observed Relay data	
Load current (A)	Fault current (A)	Restraining current (pu)	Differential current (pu)
0.2	1.213	0.026	0.173
2.4	1.568	0.319	0.339
3.4	1.877	0.452	0.391
4.5	2.03	0.612	0.479
5.8	2.389	0.798	0.578
6.5	2.419	0.871	0.612
8.4	3.126	1.157	0.765
9.5	3.442	1.304	0.838
10.8	4.823	1.477	1.071
12	6.416	1.643	1.297
12.8	7.351	1.763	1.41

Differential and restraining current as in the relay:

$$I_{ref,HV} = \frac{S_{ref}}{\sqrt{3}V_{nom,HV}} = \frac{47.7 \times 10^6}{\sqrt{3} \times 220 \times 10^3} = 125A$$

$$I_{ref,LV} = \frac{S_{ref}}{\sqrt{3}V_{nom,LV}} = \frac{47.7 \times 10^6}{\sqrt{3} \times 110 \times 10^3} = 250A$$

Measurement for one instant during internal fault

HV side phase-a current

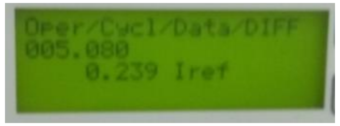
005.021	MAIN	Current IA,a prim.	60 A

LV side phase-a current

005.022	MAIN	Current IA,b prim.	60 A

Operating current:

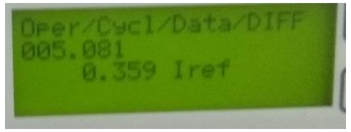
$$I_{OP} = \left(\frac{60}{125}\right)_{HV} - \left(\frac{60}{250}\right)_{LV} = 0.24\ A$$



As seen in the relay screen

Restraining current:

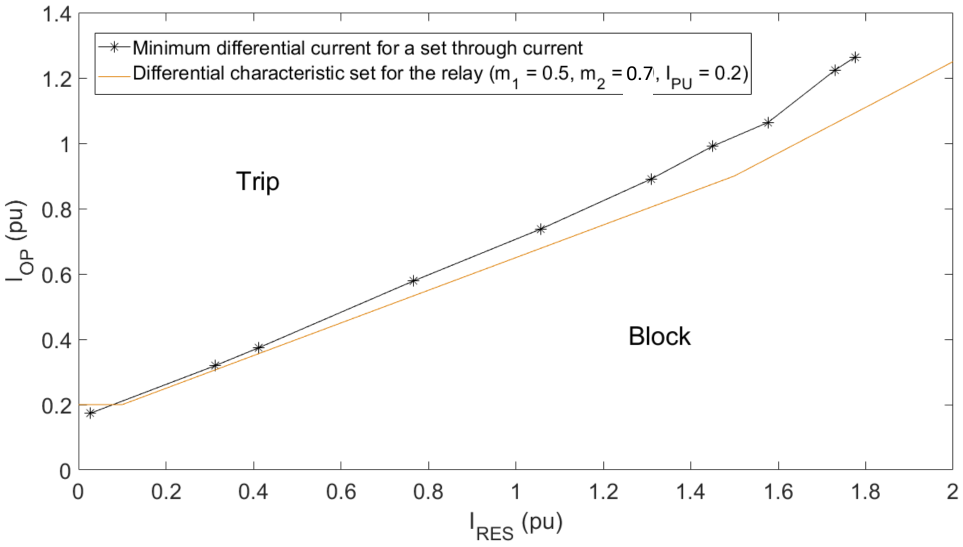
$$I_{RES} = 0.5\left[\left(\frac{60}{125}\right)_{HV} + \left(\frac{60}{250}\right)_{LV}\right] = 0.36\ A$$



As seen in the relay screen

Test Case 2:

Settings: m1=0.5, m2=0.7, I_{PU} = 0.2



Measurements Transformer		Observed Relay data	
Load current (A)	Fault current (A)	Restraining current (pu)	Differential current (pu)
0.2	1.18	0.026	0.173
2.3	1.58	0.312	0.319
2.9	1.82	0.412	0.374
5.5	2.59	0.765	0.578
8.3	3.37	1.058	0.738
9.4	3.68	1.31	0.891
10.4	4.38	1.45	0.991
11.3	5.19	1.577	1.064
12.3	5.87	1.73	1.224
12.8	6.05	1.776	1.264

Demonstration is available on:

https://www.youtube.com/watch?v=8E7B_IQXiyE&feature=emb_logo

Report Submission Guidelines: **Handwritten**

1. Plot the percentage biased differential characteristics for the two data sets provided in two graph sheets. (Write your roll number and name at the top of the sheets)
2. Plot the reference characteristic for the mentioned setting for each graph plotted.
3. Write on your assessment for each experimental data set compared to reference graph.
4. Write your suggestions how the performance of the relay can be improved further.
5. A transformer differential relay observes the presence of 2nd, 3rd, 4th and 5th harmonic components as (9%, 0.02%, 4% and 41%) respectively of the fundamental component in the differential current. Such a situation indicates which of the following situation?

   a) High loading   b) Inrush   c) Overexcitation   d) CT saturation

6. For the three data sets provided in the table write the fault situation (internal/ external) in the column provided with justification.

Transformer rating: 37.5 MVA, 220 kV/11 kV. **Relay setting**: I_{pu} = 0.2, m_1 = 0.5, and m2 = 0.9

	I_1 (A)	I_2 (A)	Fault (internal/ external)	Justification
Case 1	$76.84\angle -17.92°$	$420.02\angle 145.5°$		
Case 2	$48.30\angle -20.66°$	$955.78\angle 160.1°$		
Case 3	$49.51\angle -17.99°$	$426.12\angle 148.5°$		

6. A Simulink model is attached where a 37.5 MVA, 220 kV/ 11 kV transformer is protected by percentage bias differential protection. Create phase-A-to-ground faults at F1, F2 and F3 with a fault resistance of (last digit of roll number) Ω. Write your analysis for the fault situations.

(Note: Those who have '0' as the last digit of roll number should take the fault resistance as 0.01 Ω)

Fault Resistance	Current (in Per Unit)	F_1	F_2	F_3
R_f (in Ω)	I_1			
	I_2			
	$I_{operating}$			
	$I_{restraining}$			
	Remarks			