Unit Protection
Differential Relays

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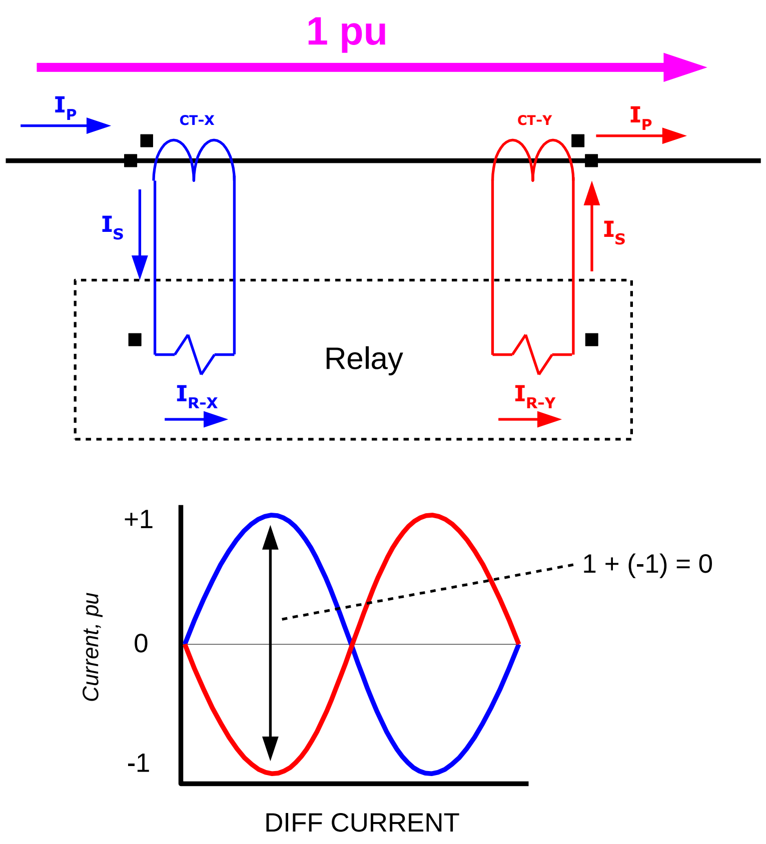
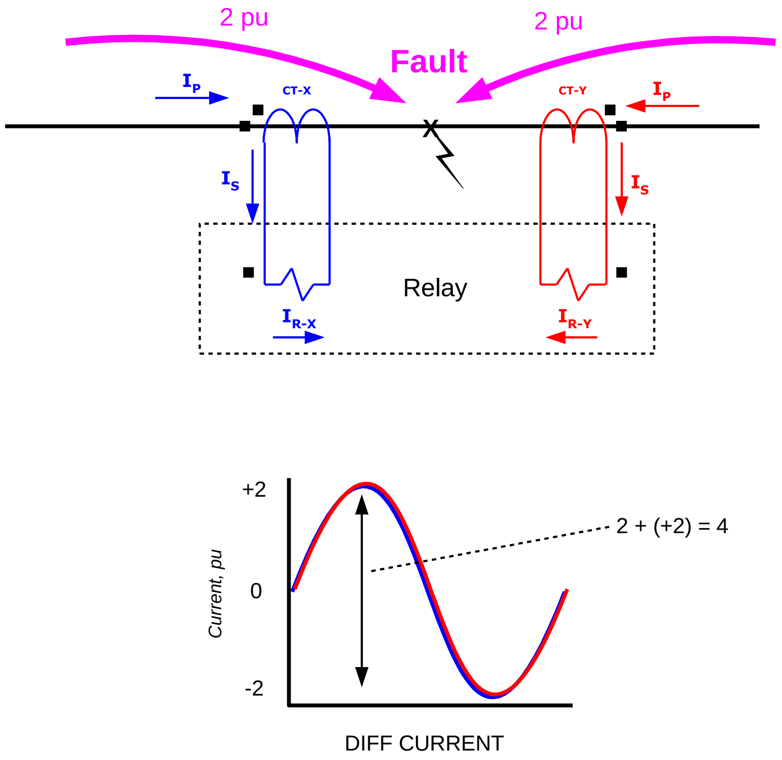
Differential Relays - BASICS

- Note on CT polarity dots
- Through-current: must not operate
- Internal fault: must operate
- The CT currents are matched Perfectly on waveforms, no saturation





Differential protection is a fast, selective method of protection against short circuits. It does not need coordination with other relays, however, it lakes to have backup protection.

Differential Relays - 87

How can we measure the differential current?

Simply by an overcurrent relay.

Our expectations are:

1- No operation for normal duty of the device

2- No operation for fault outside

3- Operate for a fault inside

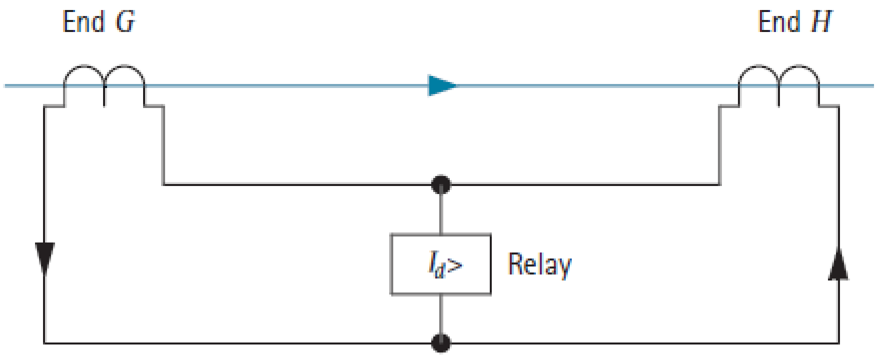
The problem is the mismatching of currents:

1- May occur during the normal operation of the device for instant when transformer tap changes

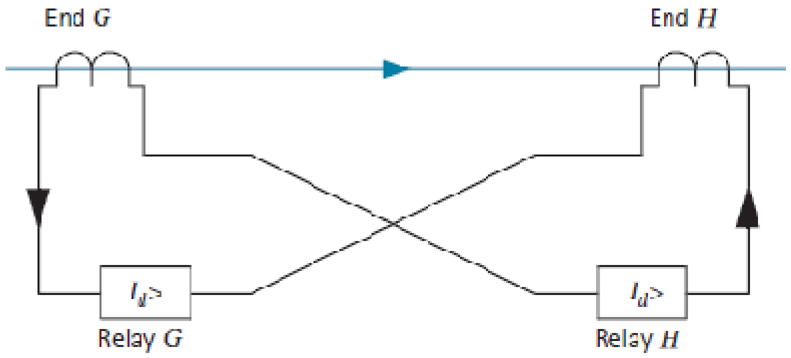
Can be overcome with proper setting of O/C relay

2- Occurs when carrying large outside through fault currents with dc components

This is the main cause of instability (malfunction) of the relay during external fault



Circulating Current System



Balanced Voltage System

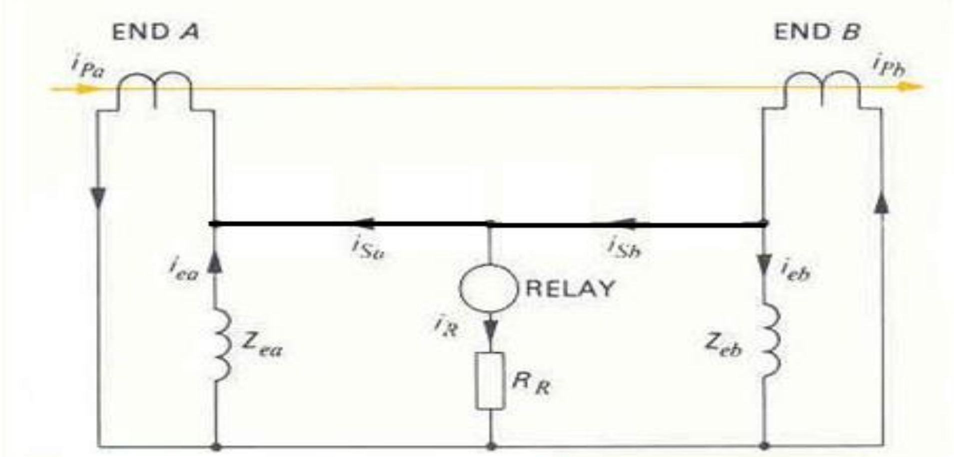
This system is included for historical reasons, mainly because of the number of such schemes still to be found in service - for new installations it has been almost completely superseded by circulating current schemes.

Differential Relays

Solution:

One technique applied to simple overcurrent differential schemes is to use sufficient time delay to ride through the period of CT saturation. Delayed tripping is generally unwanted, so other, more sophisticated techniques are available to provide secure operation for external faults with CT saturation and still provide fast operation for internal bus faults.

1- Using stabilizing resistor in circuit

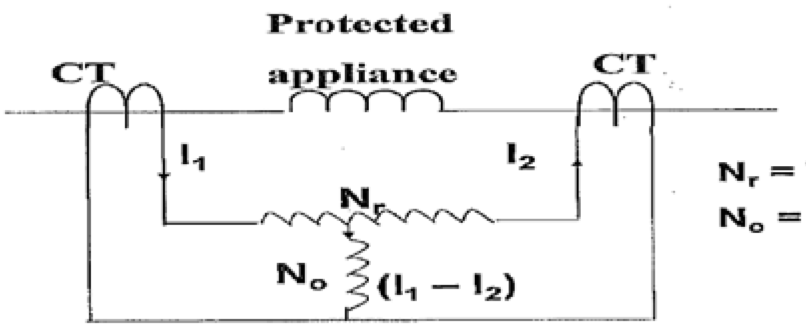


Cts magntizing branches and magntizing currents are also shown

2- Using Biased relays

This is the most Popular Scheme

Biased Differential Protection

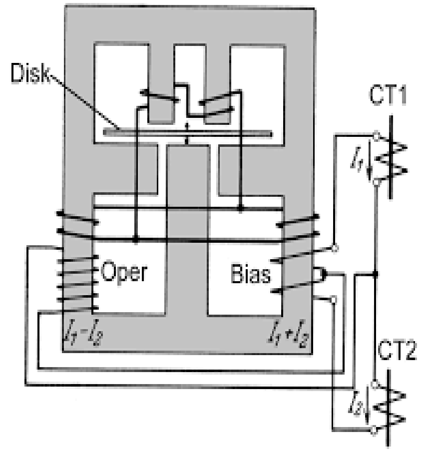


N_r = Total restrain coil turns

N_o = Operation coil turns

Relay operation force = $K(I_1 - I_2)N_o$

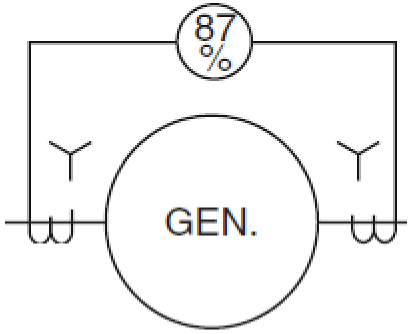
Relay restraining force = $K[(I_1 + I_2)/2]N_r$

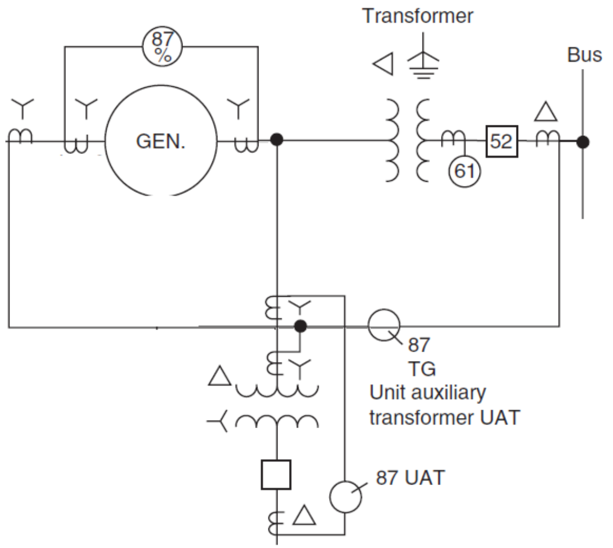


Differential Relays

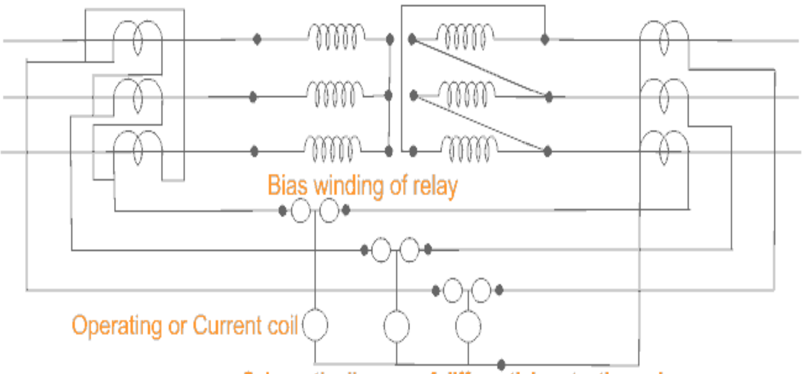
Where do they use? The followings are just some examples:

Generators-Motors

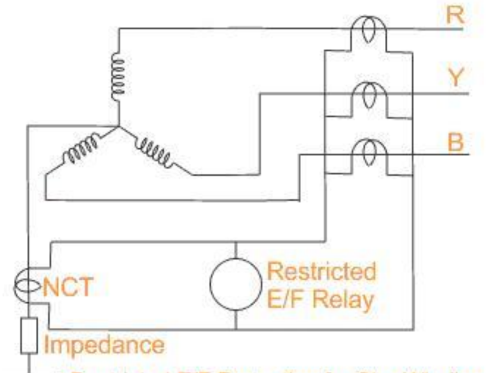




Transformers

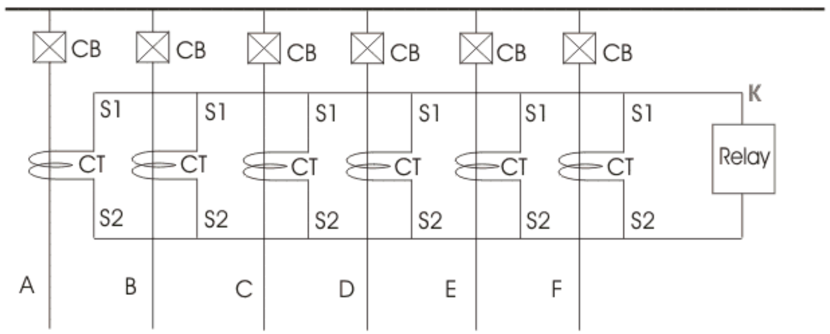


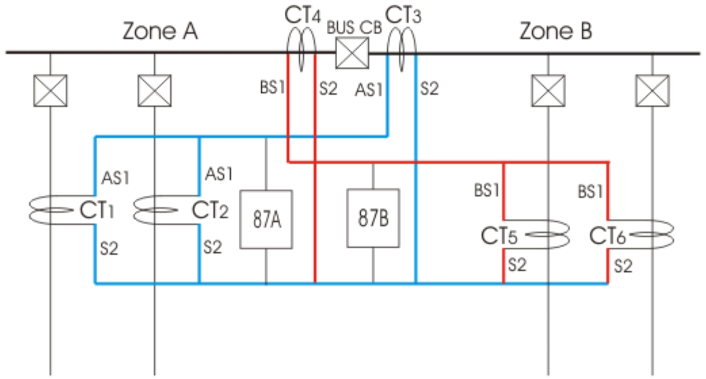
Schematic diagram of differential protection scheme



Restricted E/F Protection for Star Winding

Busbars





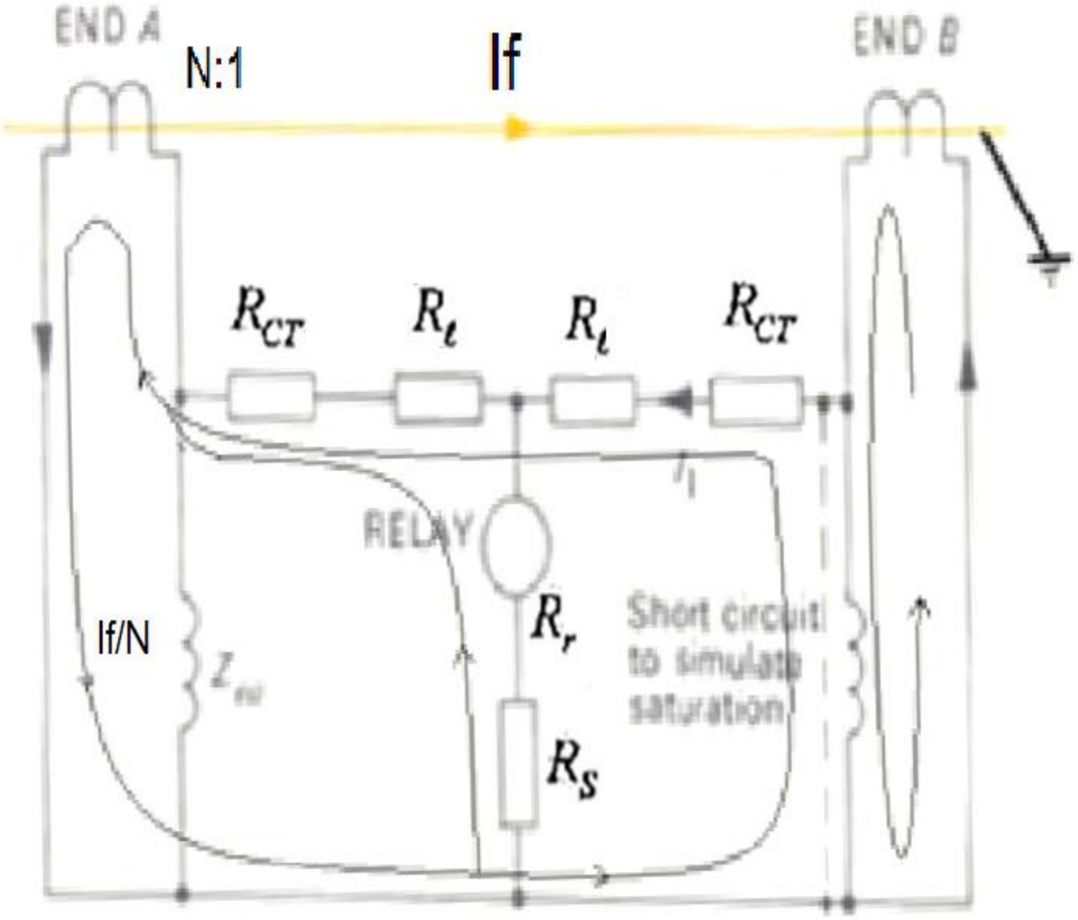
Differential Relays

1- Using stabilizing resistor:

a) Low Impedance Differential Protection :

Under external fault condition, the protection must remain stable and should not operate, even if one C.T. has completely saturated. A series resistor Rs can be inserted in series with the relay so that the current passing through the relay is less than its operating current under the maximum through fault current:

$$I_{Set} > \frac{\frac{I_F}{N}(R_{CT}+R_l)}{R_r+R_S+R_{CT}+R_l}$$

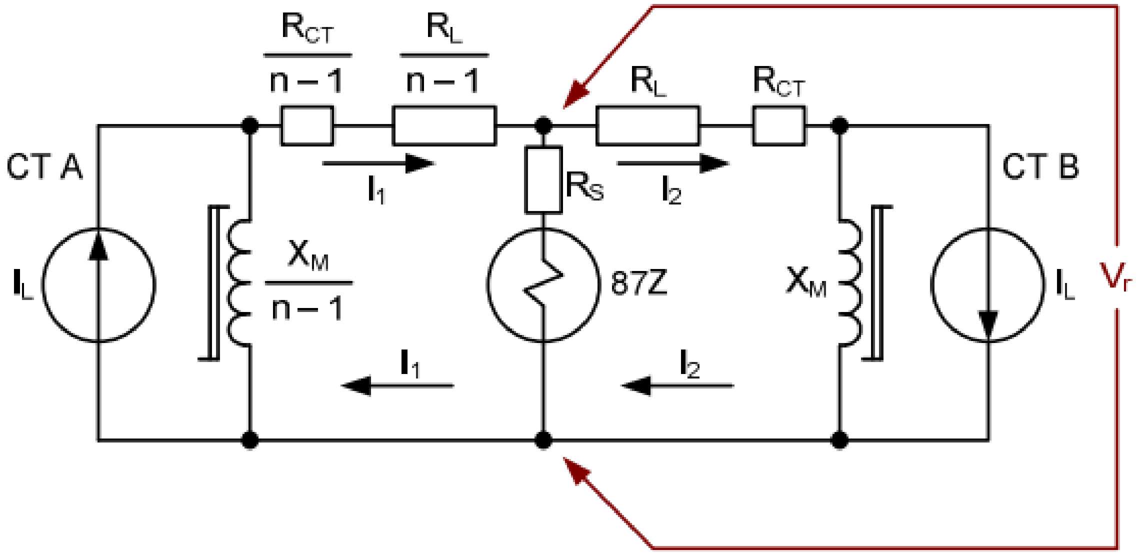


Differential Relays

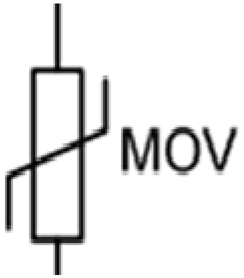
b) High Impedance Differential Protection :

The high-impedance input is created by an internal impedance, typically resistive, of 2000 ohms or higher. A sensitive current element in series with the high-impedance element is calibrated in volts based on the voltage drop across the internal impedance.

Metal Oxide Varistor (MOV) is used to prevent the danger of the over voltage that will be produced when fault is inside the protected area.



Normal current on a high impedance diffrential relay



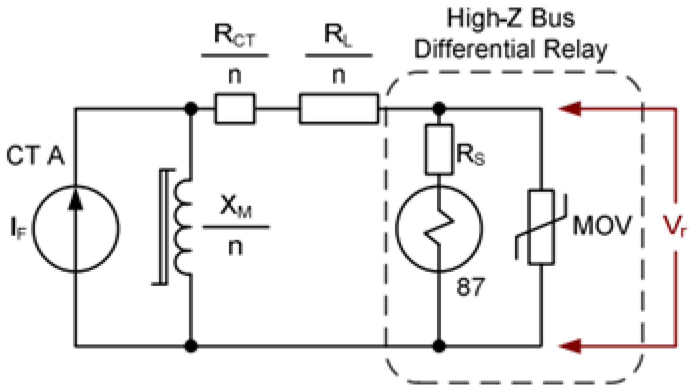
Differential Relays

High Impedance Differential Relay

High-impedance differential relays are typically used for bus protection.

Bus protection is an application that demands many sets of CT's be connected to the relays. It is also an application that demands the relay be able to operate with unequal CT performance, since external fault magnitudes can be quite large. The high impedance differential relay meets both requirements.

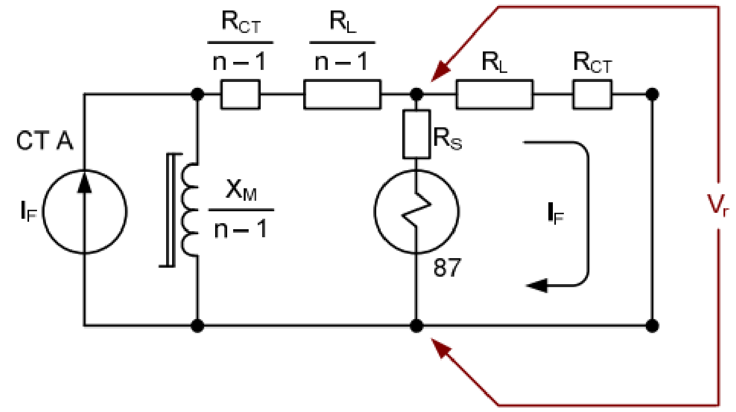
Also note that a voltage-limiting MOV connected across the high-impedance relay is shown in the figure. This is to keep the voltage less than a specified value (usually less than CT knee point voltage). MOV prevents the high voltage to be built up across the CT during internal fault and so preventing the relay and the CTs from damaging .



Equivalent circuit of *n* CTs driving current into the high-impedance bus differential relay during an internal bus fault

MOV prevents danger voltage to be builded up

Differential Relays

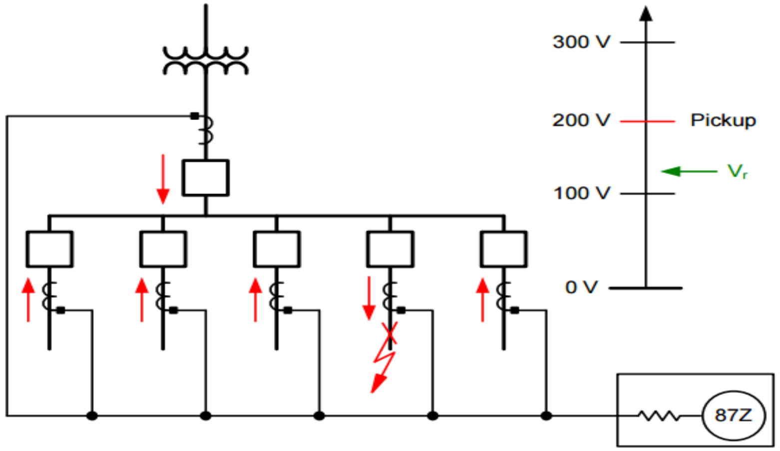


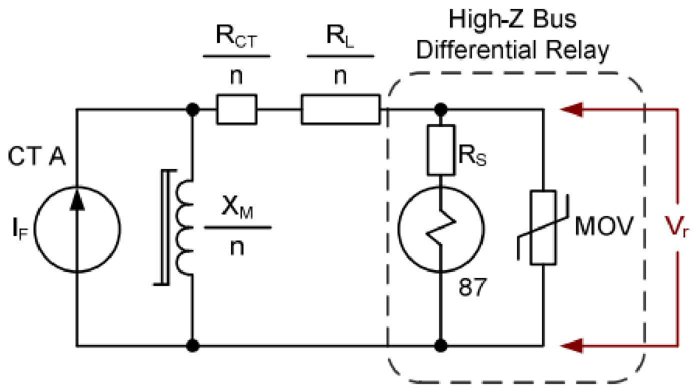
Equivalent two-CT circuit showing effects of complete saturation for through fault current

$$V_t = \frac{I_F}{N} \bullet (R_{CT} + R_l)$$

K=Safety Factor = 1.5

V_{pickup} = K.V_r

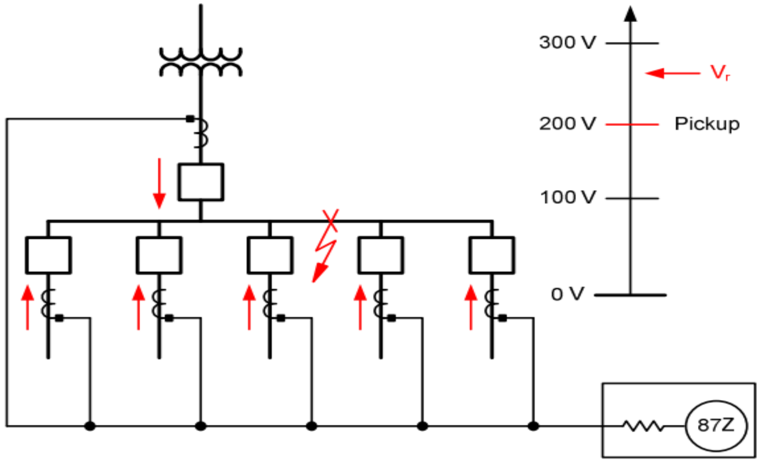




Equivalent circuit of *n* CTs driving current into the high-impedance bus differential relay during an internal bus fault

Rr >> Rct+Rl

$$V_t = \frac{I_F}{N} \bullet (R_r)$$



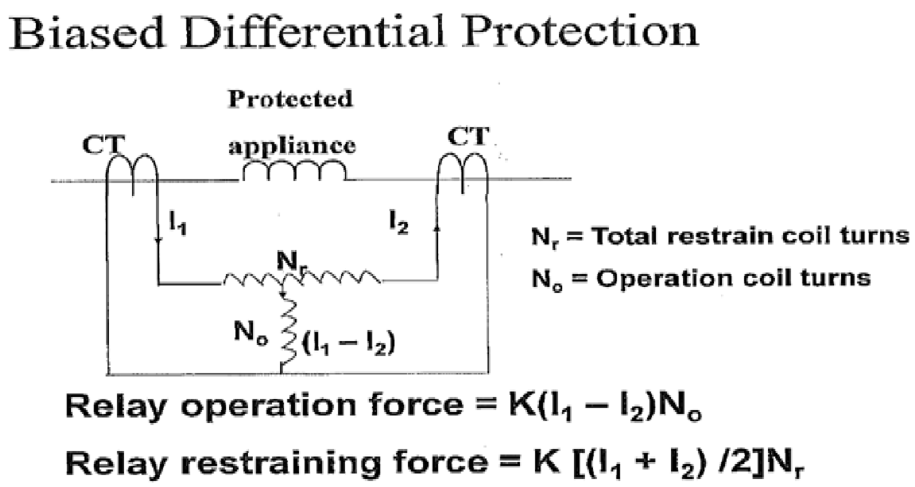
Differential Relays

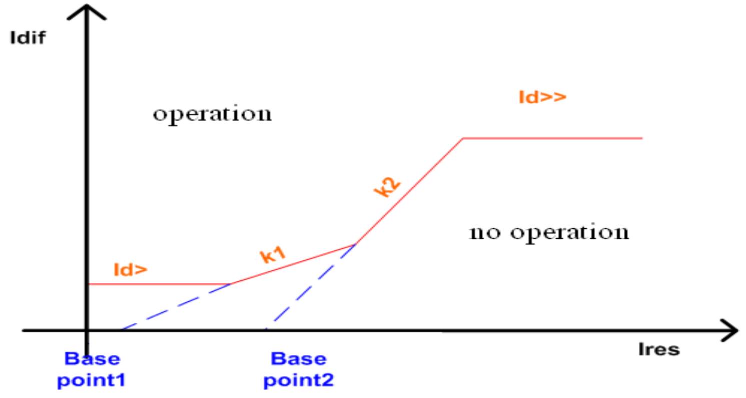
2- Using Biased relay:

This is designed to response to the differential current in the term of its fractional relation to the current flowing through the protected section. In this type of relay, there are restraining coils in addition to the operating coil of the relay. The restraining coils produce torque opposite to the operating torque. Under normal and through fault conditions, restraining torque is greater than operating torque. Thereby relay remains inactive. When internal fault occurs, the operating force exceeds the bias force and hence the relay is operated. This bias force can be adjusted by varying the number of turns on the restraining coils. As shown in the figure below, if I_1 is the secondary current of CT_1 and I_2 is the secondary current of CT_2 then current through the operating coil is $I_1 - I_2$ and current through the restraining coil is $(I_1 + I_2)/2$. In normal and through fault condition, torque produced by restraining coils due to current $(I_1 + I_2)/2$ is greater than torque produced by operating coil due to current $I_1 - I_2$ but in internal faulty condition these become opposite. And the bias setting is defined as the ratio of $(I_1 - I_2)$ to $(I_1 + I_2)/2$

It is clear from the above explanation, greater the current flowing through the restraining coils, higher the value of the current required for operating coil to be operated. The relay is called percentage relay because the operating current required to trip can be expressed as a percentage of through current.

$$\textit{Bias setting in percentage} = \frac{I_1 - I_2}{(I_1 + I_2)/2} \times 100\%$$





Differential Relays

- Setting:

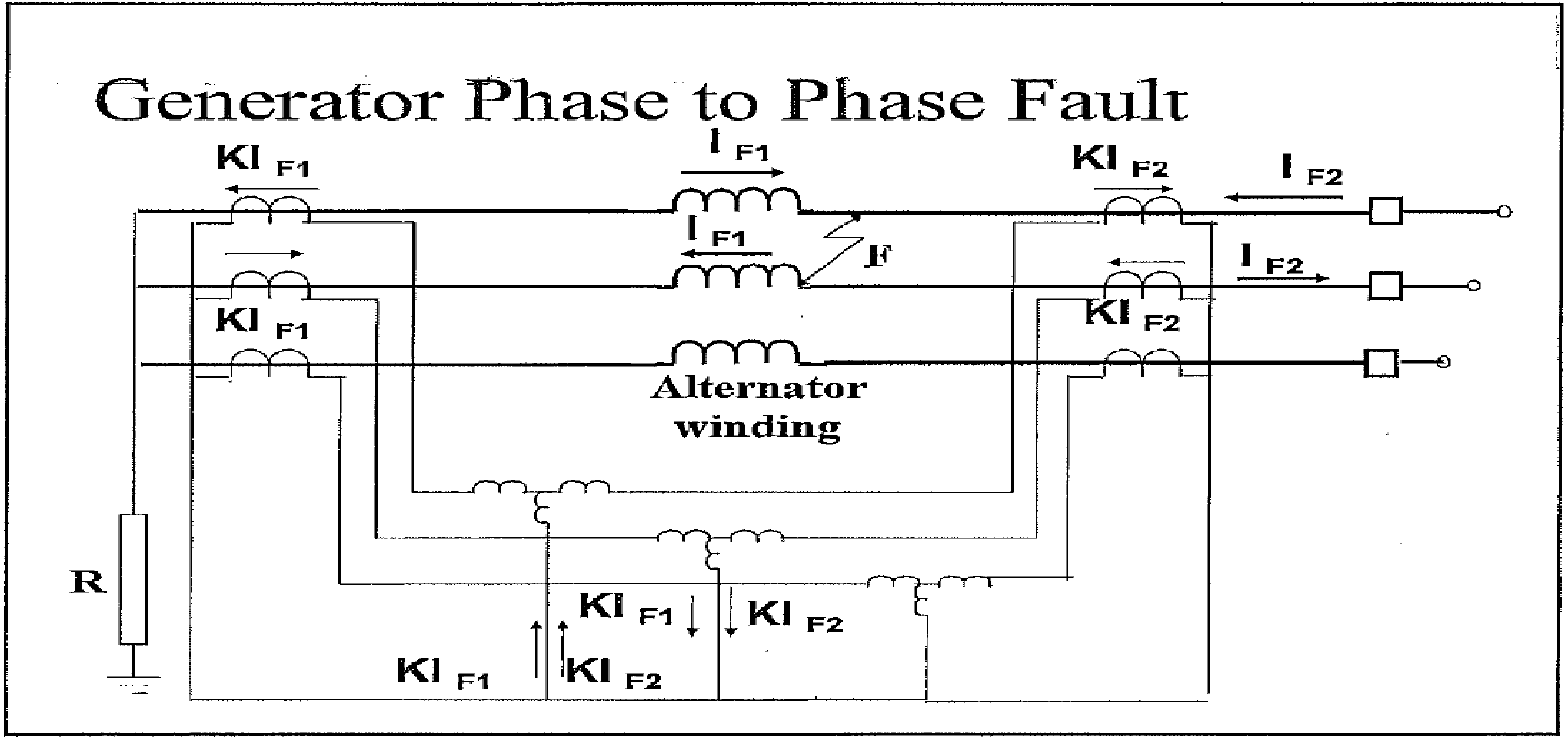
- Id> setting depends to the nominal current with considering: Transformer maximum tap change, cable capacitive current, Mismatching of CTs, No load magnetizing current

- Slope K1 together with its base point counts for current proportional false current due to CT errors about 20-25%

- Slope K2 together with its base point counts for CT saturation, setting is about 40-50%

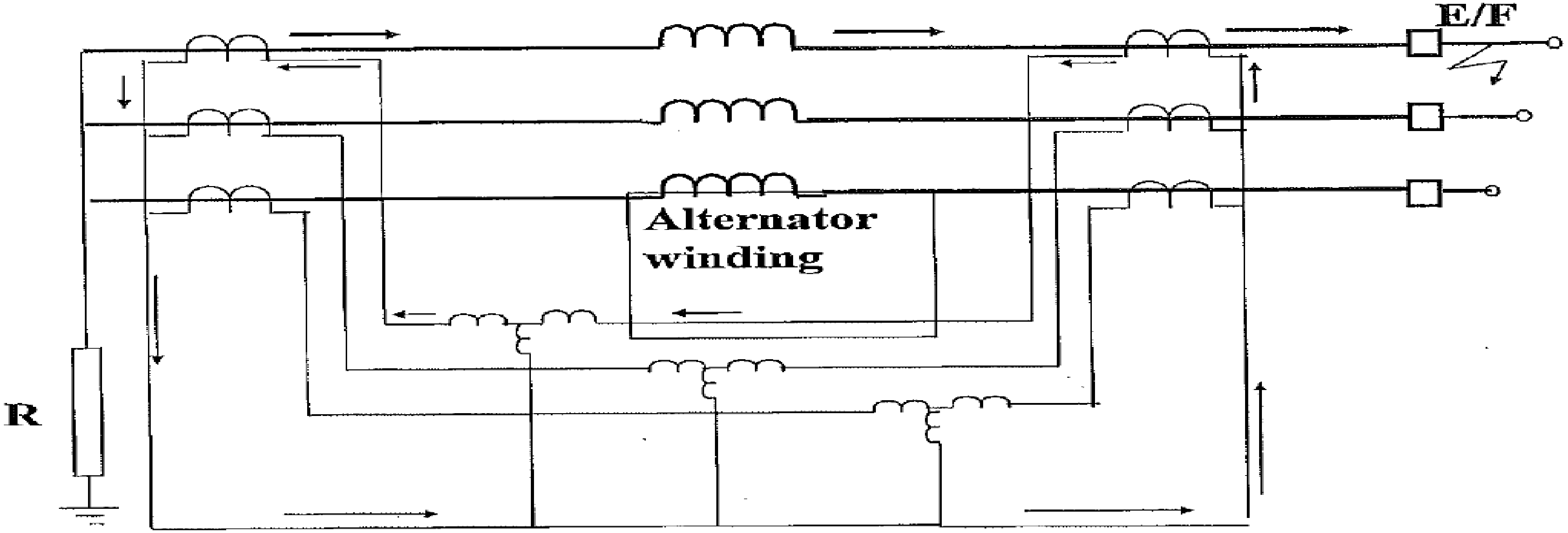
- Id>> works without restrain and designed for high internal fault currents on the primary side of the transformer with a high degree of CT saturation. It should be set to at least 20% above the max. through flowing fault current or the max. inrush currents, whichever is bigger.

Three phase Differential Relays – How fault current flows



Three phase Differential Relays – How fault current flows

Generator External Fault

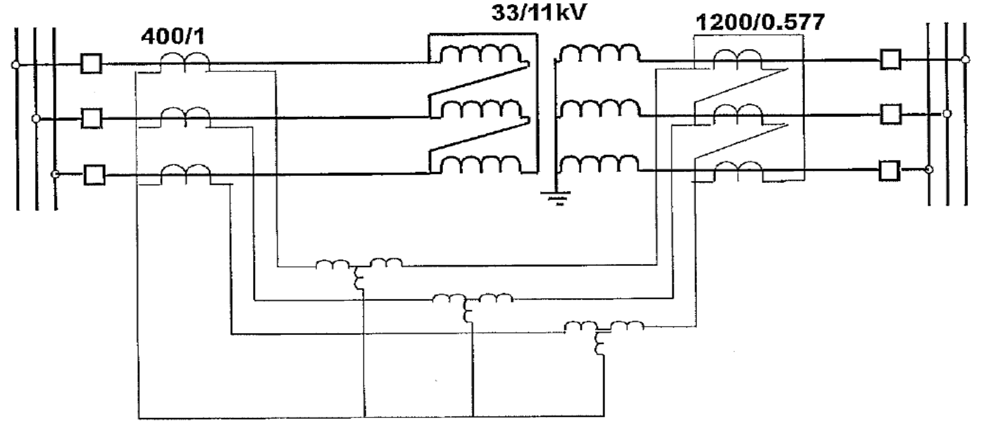


Differential Relays

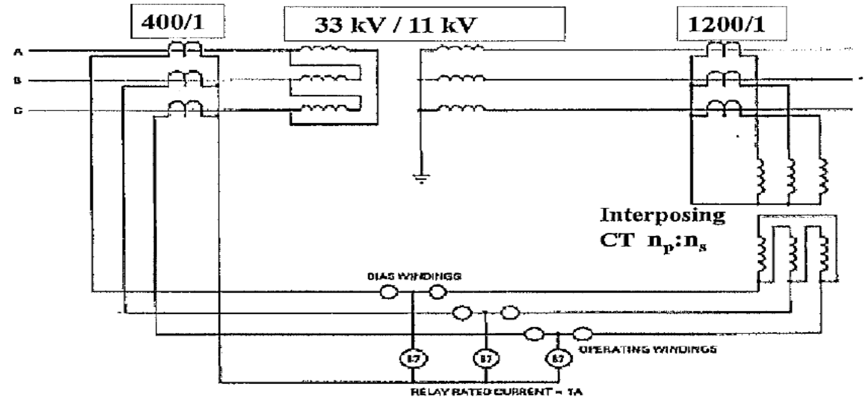
Phase Correction in Transformer Protection

- For different transformer vector group, phase correction must be implemented.
- Electromechanical and static relays use appropriate CT connections to ensure that the primary and secondary currents applied to the relay are in phase.
- For digital and numerical relays, it is common to use star connected line CT's on all windings of the transformer and compensate for the winding phase shift in software. The only data required is the transformer vector group designation. Phase compensation is then performed automatically.

Y side-CTs connected in Δ
Δ side-CTs connected in Y



Use of Interposing CT



Differential Relays

The formula for phase compensation in digital relays.
K is the transformer vector group

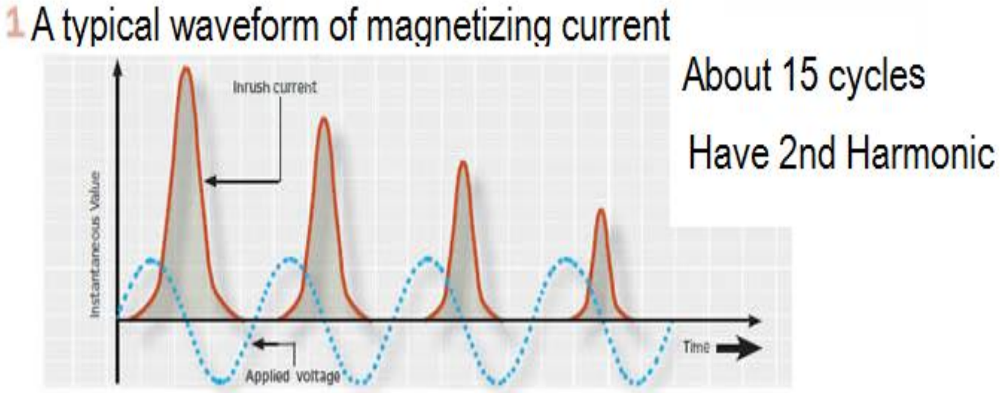
$$
\begin{pmatrix} I_a^* \\ I_b^* \\ I_c^* \end{pmatrix} = \frac{2}{3} \cdot \begin{pmatrix} \cos(k-30) & \cos[(k+4).30°] & \cos[(k-4).30°] \\ cos[(k-4).30°] & \cos(k.30°) & \cos[(k+4).30°] \\ cos[(k+4).30°] & cos[(k-4).30°] & cos(k.30°) \end{pmatrix} \cdot \begin{pmatrix} I_a \\ I_b \\ I_c \end{pmatrix}
$$

Differential Relays

Transformer inrush current

The phenomena of inrush current is fully described in Appendix VI

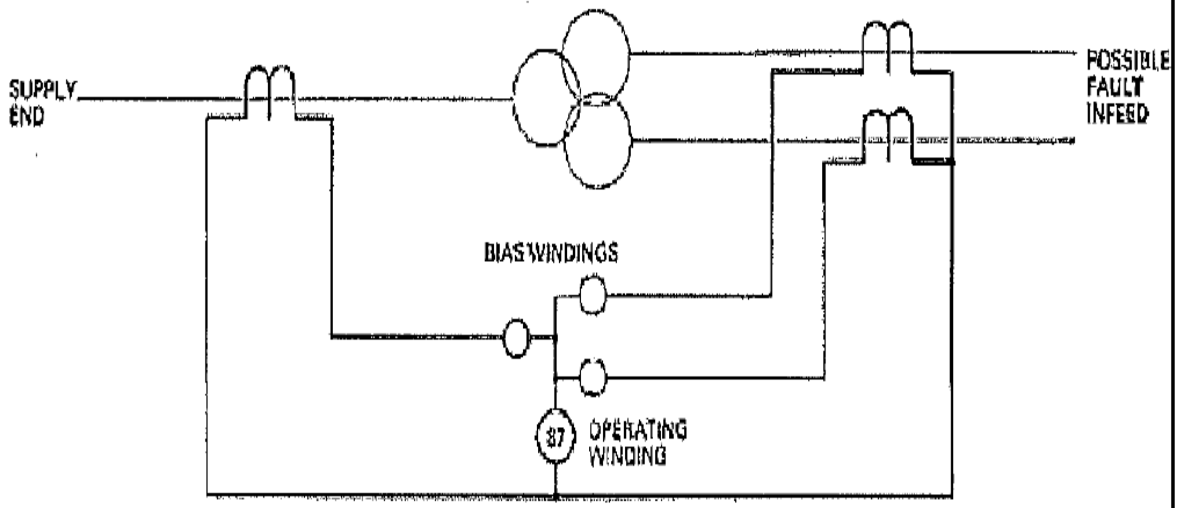
An inrush current with a high proportion of 2nd harmonics is generated when switching the transformer on, which can lead to false tripping of the differential protection. The preset value for the inrush restraint with 2nd harmonics of 15 % can be accepted unchanged. A lower value can be set for greater restraint in exceptional cases under unfavorable energizing conditions resulting from the design of the transformer.



The inrush restraint can be extended by the cross-block function. This means, that all three phases of the $I_{Diff}>$ stage are blocked when the harmonic component is exceeded in only one phase. A setting value of 3 periods, effective for the time of mutual blocking after exceeding the differential current threshold, is recommended (preset).

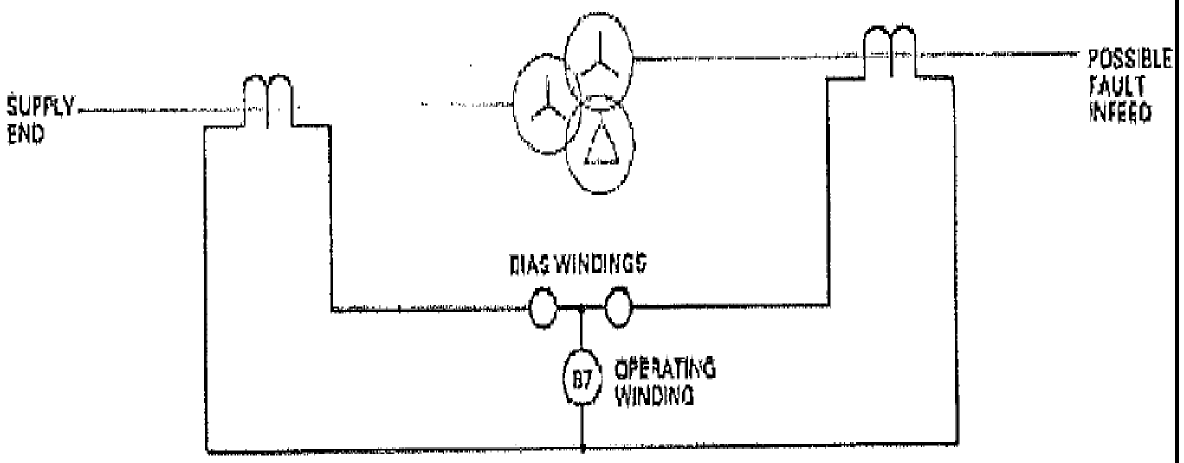
Differential Relays

Biased differential protection for three–winding transformer



Three winding transformer (three power sources)

Biased differential protection for three–winding transformer



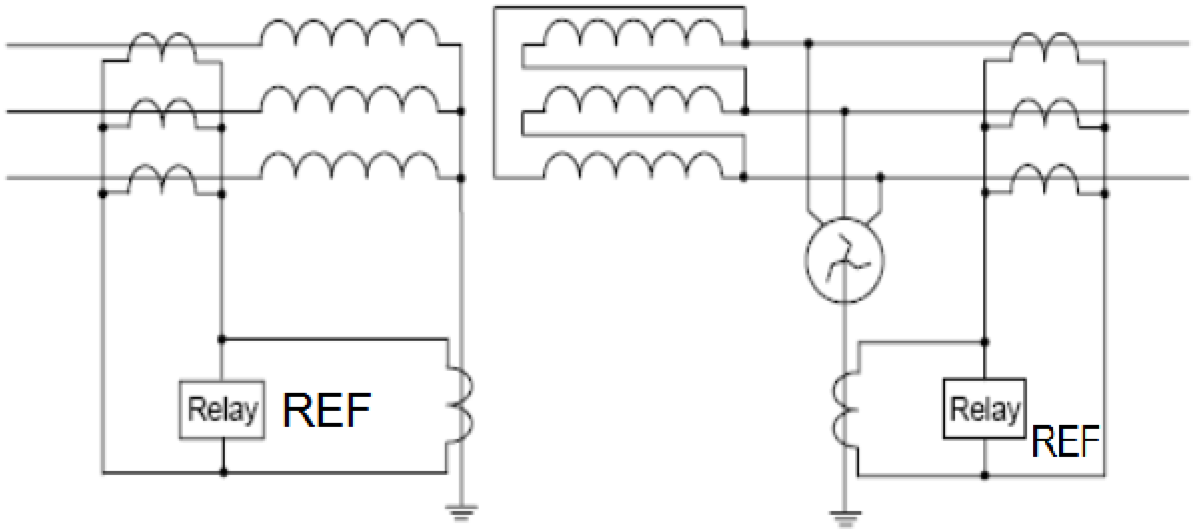
Three-winding transformer with unloaded delta tertiary

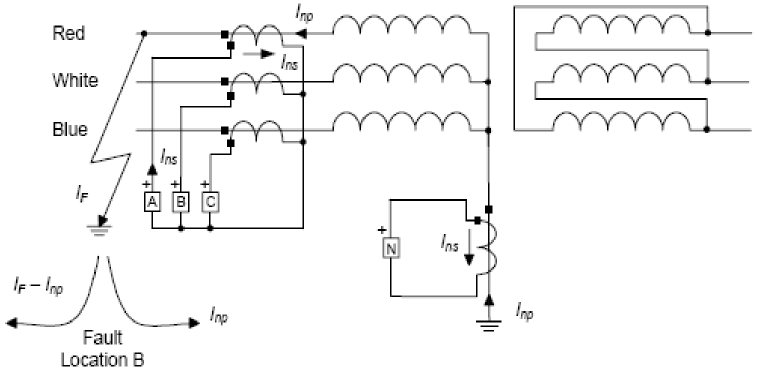
Differential Relays

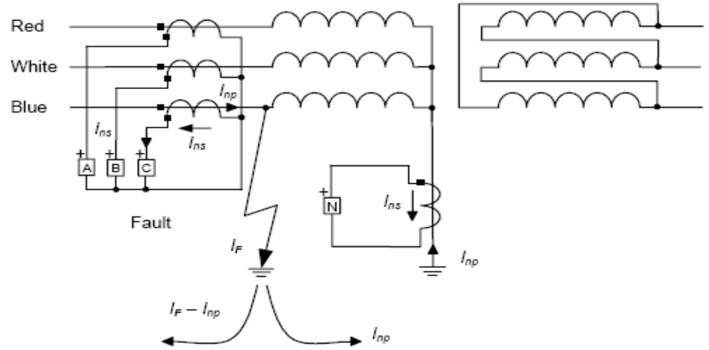
Transformer earth fault protection: Restricted Earth Fault (REF) 64

The same philosophy as differential protection will be used in REF.

Here we compare the 3I0 going through the earth with that residual current of the line:

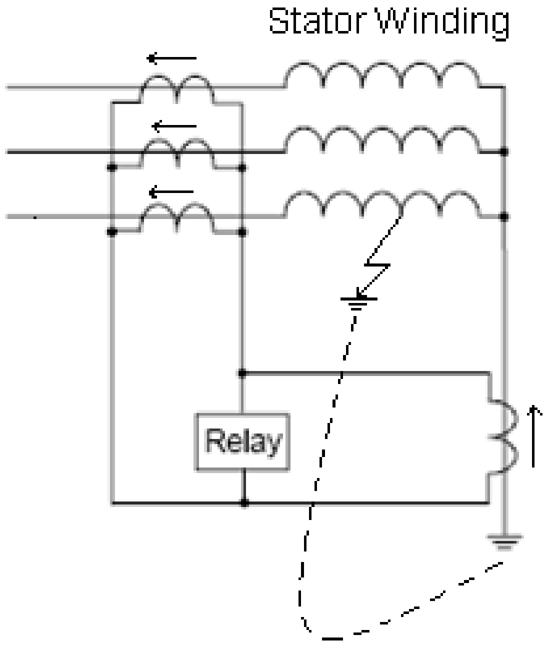


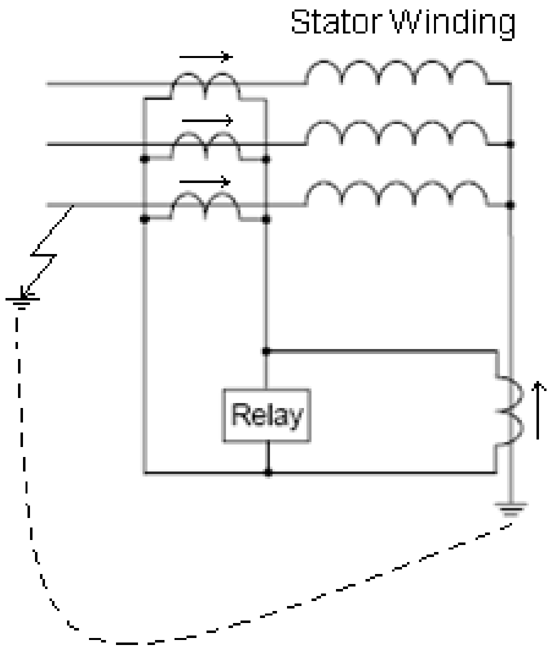




Differential Relays

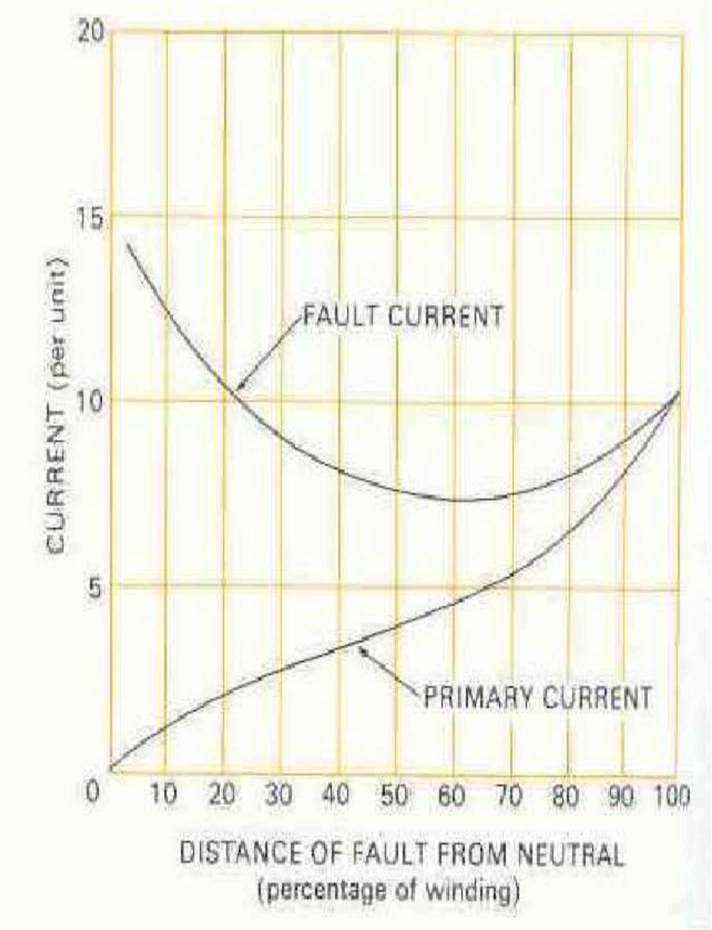
Generator REF protection

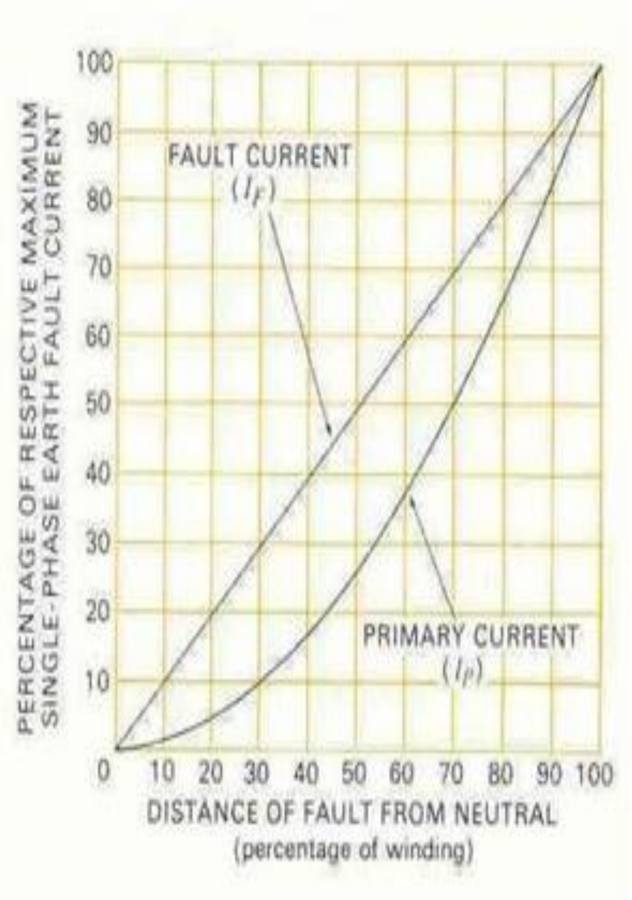


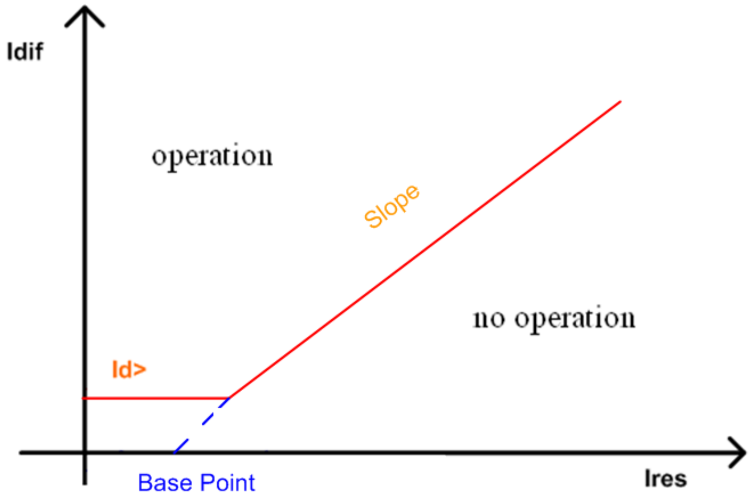


Differential Relays

Solidly earthed and resistor grounded single phase fault current: REF protection







Differential Relays

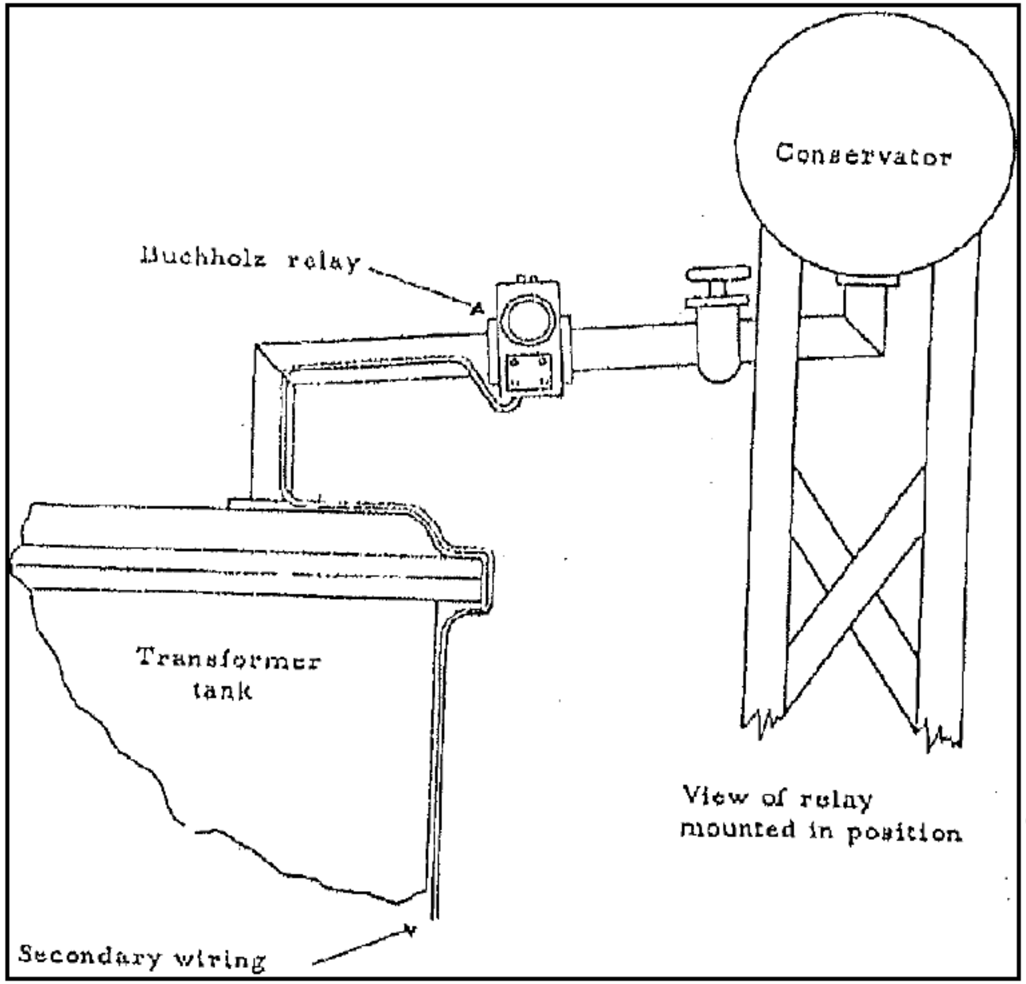
Other areas of concern

- Over-current
- Gas detection
  - Faults give rise to generation of gas
    - Slow for minor faults
    - Violent for heavy faults
- Overheating
  - Oil
  - Winding

Differential Relays

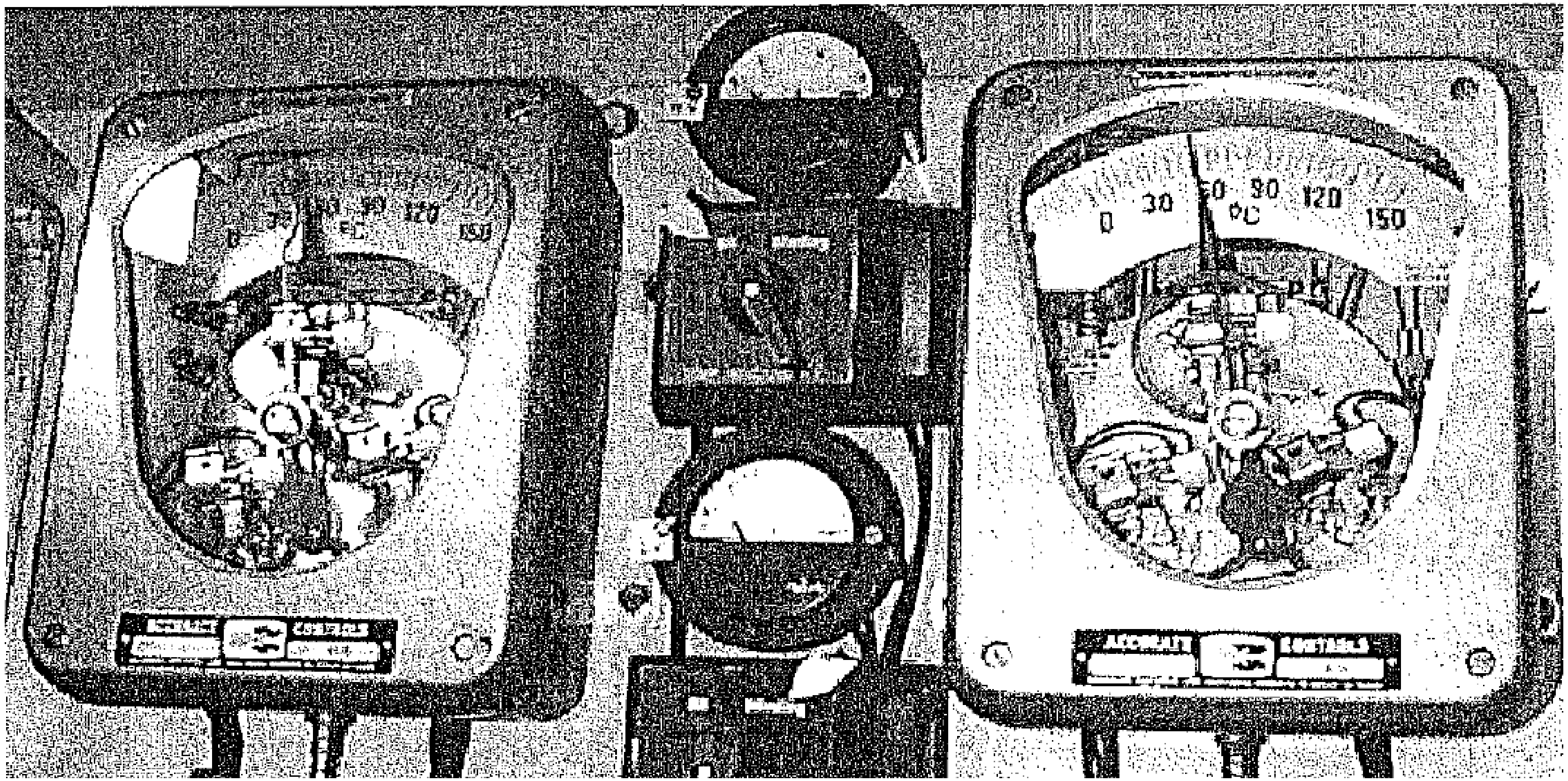
Bochholz Relay

Very slow to act on fault, just backup for overloading



Differential Relays

Oil Temp / Winding Temp Indicator



Differential Relays Example

Low Impedance Differential Relay

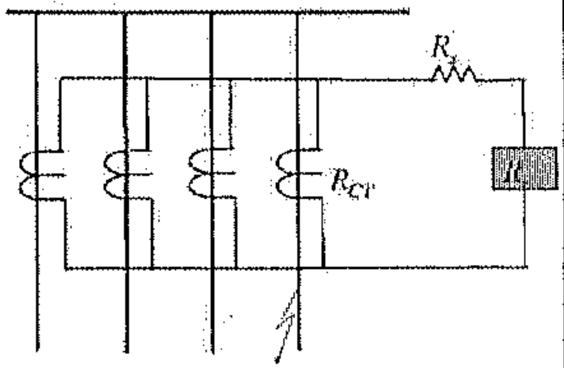
Low-Impedance Differential Protection Example

- A 11 kV busbar with four outgoing circuits is protected by a low impedance differential protection system on each phase. The CT used has a ratio of 400/1 and a d.c. winding resistance of 0.5 Ω. The current setting of the relay used is 1A and consume 1VA under rated current. The maximum fault current for a busbar fault is 6000 A.
- Calculate the value of the series resistor that can be inserted in series with the relay in order to prevent mal-operation under the maximum through fault current.

When there is no series resistor,

$$I_r = \frac{\frac{I_F}{N}(R_{CT})}{R_r + R_{CT}} = \frac{6000}{400} \times \frac{0.5}{1+0.5} = 5\,A,$$

Relay will operate



When there is a series resistor, let the max current th rough relay is 0.5 A when one CT saturates on external fault

$$I_r = \frac{\frac{I_F}{N}(R_{CT})}{R_r + R_{CT} + R_S}$$

$$= \frac{6000}{400} \times \frac{0.5}{1.5 + R_S} = 0.5\,A,$$

$R_S = 13.5\ \Omega$ to prevent relay operate on through fault

Differential Relays Example

High Impedance Differential Relay

Example

Given $R_{CT}=2\Omega$, $R_l=0.46\Omega$,

Maximum fault level of the 132 kV plant =6000 MVA

Knee point of CT=380V, CT ratio=600/1

Magnetizing current of CT at 120V=0.015A

MOV current at setting=0.02A

Stabilizing shunt resistor=200Ω

Choose the setting of the relay and calculate the primary fault setting

Max through fault current

$$I_F=\frac{6000\times10^6}{\sqrt{3}\times132\times10^3}=26243\text{A}$$

$$V_{Set}\geq\frac{26243}{600}\times(2+0.46)=108\text{V}$$

Vset = 1.5 * 108 = 162 V

162 < MOV voltage < 380 V

$$\text{Primary fault setting}=600\times\left[0.015\times2+0.02+\frac{162}{200}\right] = 516\text{ A}$$

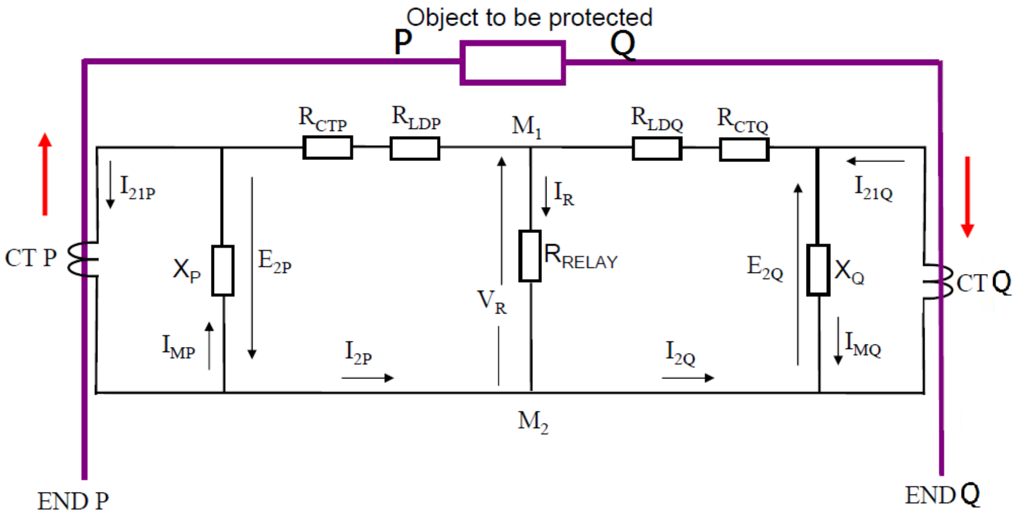
This means that if the internal fault current is bigger than 516A the relay will operate

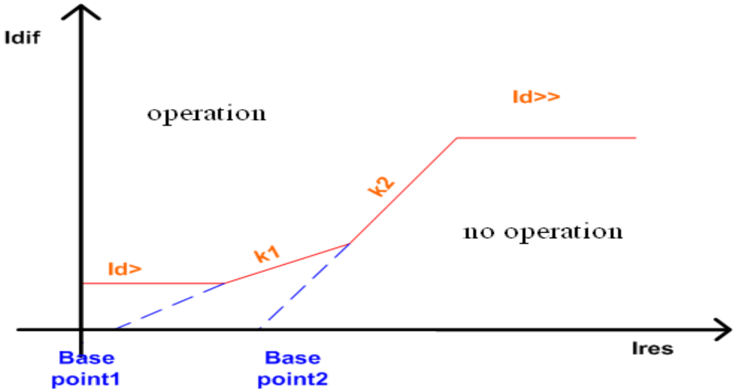
Differential Relays Example

Biased differential Relay model and example:

Example

Transformer = 420MVA, 530kV/23kV, 17.4%
Tap changer = 21 taps, nominal tap = tap 9
HV voltage at maximum tap = 450.5kV indeed 450.5kV/23 kV
(The tap specified means: we have 0-1-2----9------21 tap number positions then 530-450.5=79.5*100/530=15% therefore each tap is 15%/12=1.25% maximum tap is 15% and minimum tap is 1.25*9=11.25%)
CTRHV = 1500/1, CTRLV = 19000/1
At nominal tap:
I FLLV = 420*1000/(1.73*23) = 10543A primary or /19000 =0.555 A in secondary
$Ct_{correction}$ = 19000*23/1500*530=0.55
We will set this value or digital relays calculate that from network specifications that are entered.





Differential Relays Example

I FLHV = 420*1000/(1.73*530) = 457.5 primary or /1500*0.55 =0.555 A in secondary
I FLHVinmaxtap = 420*1000/(1.73*450.5) = 539A primary or /1500*0.55 =0.655A in secondary
I FLHVinmintap = 420*1000/[1.73*(530+0.1125*530)] = 411.26A primary or /1500*0.55 =0.495A in secondary

a) *Idif:*

Id > 0.555-0. 655= -0.1
Id>0.555-0.495=0.06

Therefore id>0.1 or 10% Let put a 2% margin the it is 12%.

Type A, $I_{TOT} = \frac{|I_1|+|I_2|}{2}$ KBCH, MICOM P54x, SEL

Type B, $I_{TOT} = |I_1|+|I_2|$ SIEMENS 7SD

Type C, $I_{TOT} = \frac{|I_1 - I_2|}{2}$ SEPAM 80 Series – motor diff

Type D, $I_{TOT} = \max(|I_1|,|I_2|)$ SEPAM 80 Series – trfr diff

b) Slope 1: Assume type A relay (ITOT = Ires):
K1= Idif/Ires = 0.1/0.5*(0.555+0.655)=0.17 or 17% then a 20% setting is good.

C) Turning Point 2, ITP2 Slope 1 dictates the relay restraint characteristic over the load current range of the transformer.
Thus it is meant to be effective up to the maximum possible loading of the transformer.
For large power transformers this could be up to200% of rated current.
For smaller transformers allowable maximum loading could be anything from 100% to 200% of rated load typically 150%.
For most cases a turning point of 2 (corresponding to twice rated load) suffices.

Again assume type A: Ires at PT2 = 2*IFLres = (0.655+0.555)*2 = 2.42 A

Differential Relays Example

d) *Slope 2:* The second bias slope is intended to ensure additional restraint with severe through fault currents that could lead to CT saturation.

Assuming that the CT saturation will occur for the through fault current then: ILV = 0

For Type A:

Idif = 20(IHV)

*Ires= 20*0.5*(IHV)*

K2= 1/0.5 =200%

e) *Id>> will set like Instantaneous for over current relays. We need to have fault current for fault at the primary side of transformer. Then Id>> will be calculated*