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Low Impedance Differential Protection Relay Settings for Transformer Differential Protection

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ABSTRACT:One of the most important and primary protection of transformer for internal faults is Transformer Differential Protection. Present trend is to use a Low Impedance Differential Protection Relay for Transformer Differential Protection. For the safety of transformer, it is imperative to set the Differential Protection Relay correctly. This paper describes the method to calculate settings of Low Impedance Differential Protection for a two winding transformer.

KEYWORDS: Transformer, Differential Protection, Slope, Relay, Low Impedance, Restraining Coil, Operating Coil, Restraining Current, Operating Current, Pickup Setting.

I.INTRODUCTION

Differential protection is one of the primary protections against phase to phase and phase to ground fault within transformer. Accurate setting of Transformer differential protection relay is of utmost importance to protect the transformer. Wrong setting of Transformer differential protection relay may lead to;

a) Severe damage to transformer for internal fault.
b) Inadvertent tripping of transformer for fault outside differential protection zone, resulting into loss of power to the healthy system.

This paper describes the criteria / steps to set Low impedance transformer differential protection relay. For better understanding, typical calculations are provided.

II.TRANSFORMER DIFFERENTIAL PROTECTION

There are two types of Transformer differential protection.

a) High impedance differential protection

Figure-1 shows a typical scheme for High impedance differential protection of a two winding transformer.

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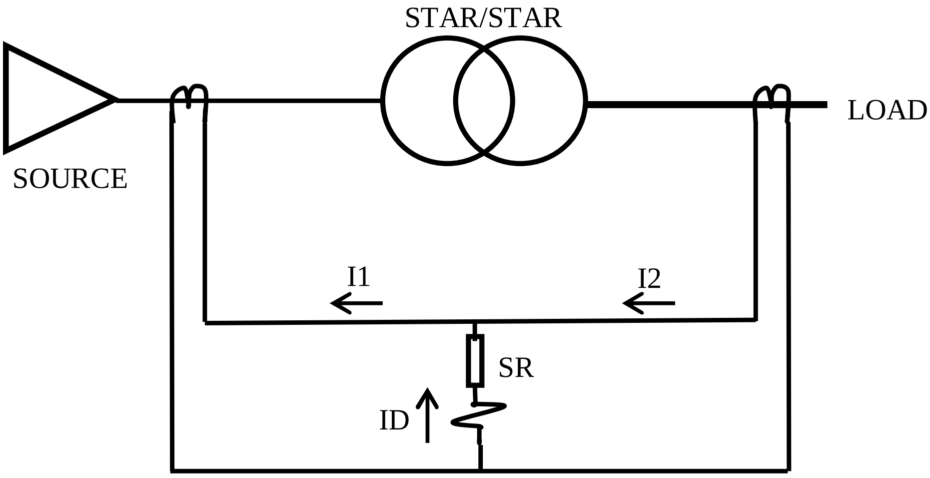

Figure-1

Differential Current ID = I1 – I2

If ID exceeds the set value, relay operates and gives trip command to transformer circuit breakers. In this scheme, Stabilizing Resistor (SR) is connected in series with the relay coil. The function of SR is to prevent spurious operation of relay due to different CT saturation levels of primary and secondary CTs, non-linearity of CTs during external through faults. The SR is set appropriately to avoid spurious operation of relay.

High impedance differential protection scheme for Transformer Differential protection has become obsolete now due to following reasons:

- For high impedance transformer differential protection, the scheme should have matching CT ratios as per transformer primary and secondary currents, same knee point voltage, same class of CTs with same magnetizing current.
- It may also require interposing CTs to match current and phase angle.

Instead, the modern digital protection relays offers Low impedance differential protection as described below in Item No. b.

b) Low impedance differential protection

Figure-2 shows a typical scheme for Low impedance differential protection of a two winding transformer. It is also known as Biased differential protection. This type of relay has a Restraining Coil and an Operating Coil.

In this type of protection, CTs with different ratios and specifications can be used. Current and phase angle matching is done by relay internally; hence interposing CTs are not required.

Relay has variable bias settings. It has two independently settable slopes with a Break Point (BP).

Slope-1 setting range: 15% to 100% continuously variable
Slope-2 setting range: 50% to 200% continuously variable

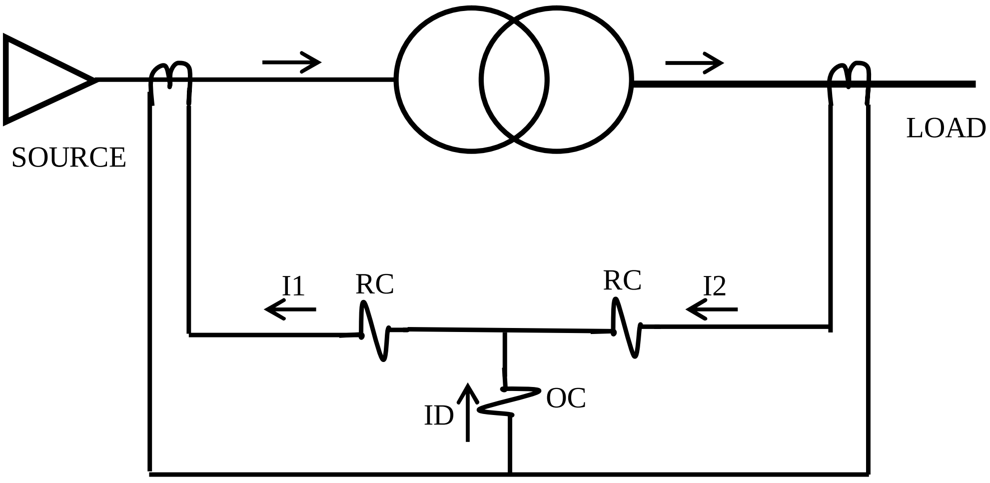

Figure-2

A typical dual slope characteristic is shown in Figure-3

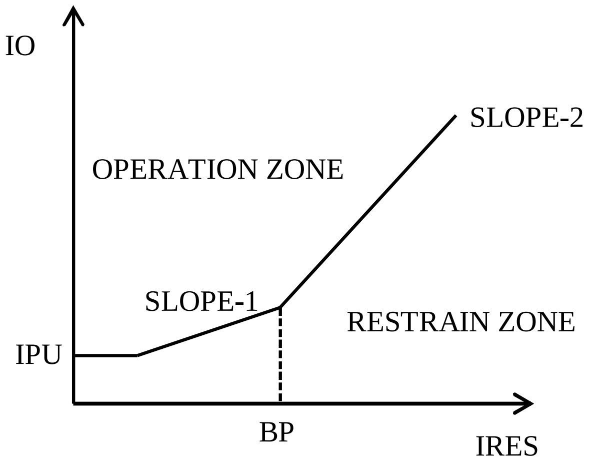

Figure-3

Restraining Current $I_{RES} = \frac{|I_1| + |I_2|}{2}$ or $\max(|I_1|, |I_2|)$ as per relay make, type and model.

Operating Current $I_D = I_1 - I_2$

For relay operation $I_D \geq k\ I_{RES}$, where k = Slope

III.TRANSFORMER LOW IMPEDANCE DIFFERENTIAL PROTECTION RELAY SETTING

Following example gives step by step relay setting calculation criteria for Transformer Low Impedance Differential Protection relay.

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Electrical system and transformer with differential protection scheme is indicated in Figure-4

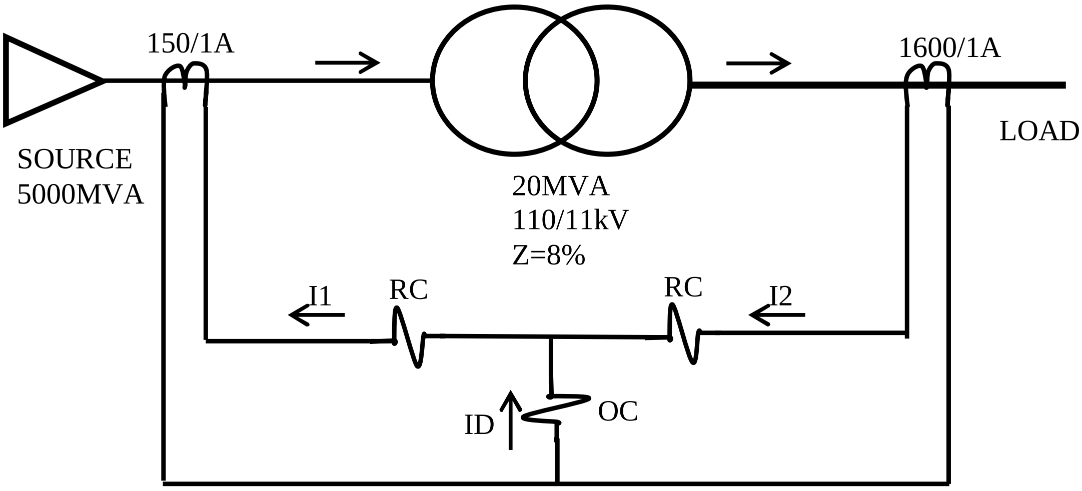

Figure-4

Dual Bias characteristic relay of GE Multilin, Model 745 is considered in the example.

Restraining Current $I_{RES}=\max(|I_1|, |I_2|)$ i.e. IRES = per phase maximum of the current after phase, ratio and zero sequence correction.

Operating Current $I_D = I_1 - I_2$

a) Normal case when load on transformer is 20MVA is shown in Figure-5

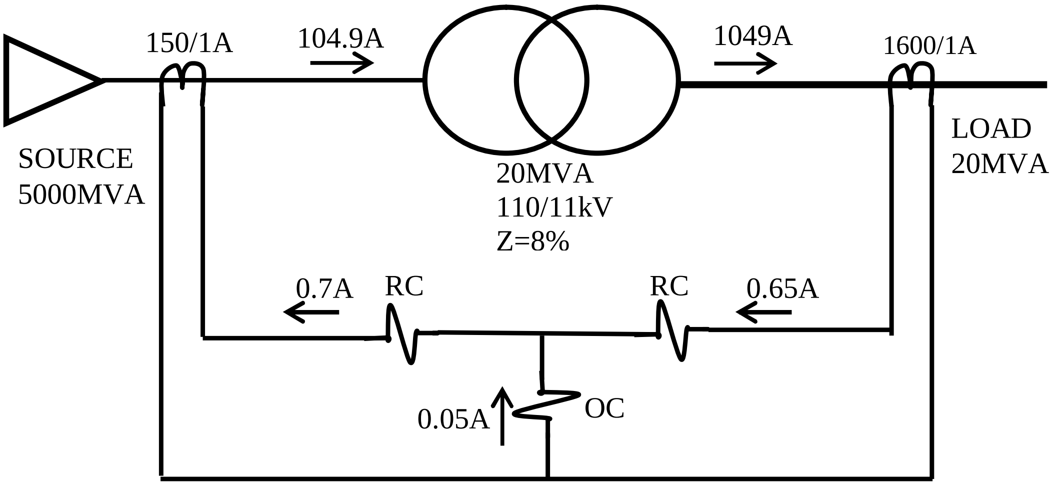

Figure-5

I1 = 0.7A, I2 = 0.65A and ID = 0.05A

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b) Fault conditions

Three phase fault at four different points is considered as indicated in Figure-6

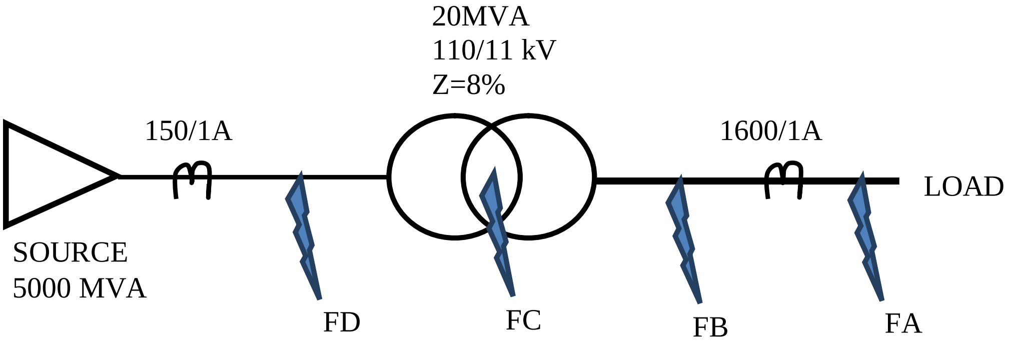

Figure-6

On 100MVA Base

XS = 100/5000 = 0.02 PU
XT = (100 x 0.08) / 20 = 0.4 PU

- Three phase fault on 11 kV side (at location FA and FB)

  Fault level = 100 / (XS + XT)
  Fault level = 238.1 MVA
  = 12.49 kA @ 11 kV
  = 1.249 kA @ 110 kV

- Three phase fault at 50% impedance of transformer (at location FC)

  In this case Transformer impedance = 0.5 x 8 = 4%. Hence XT = 0.2 PU
  Fault level = 100 / (XS + XT)
  Fault level = 454.54 MVA
  = 2.385 kA @ 110 kV

- Three phase fault on 110 kV side (at location FD)

  Fault level = 5000 MVA
  = 26.24 kA @ 110 kV

- External fault (Outside Differential protection zone) at FA

  Currents in the system for fault at FA is shown in Figure-7

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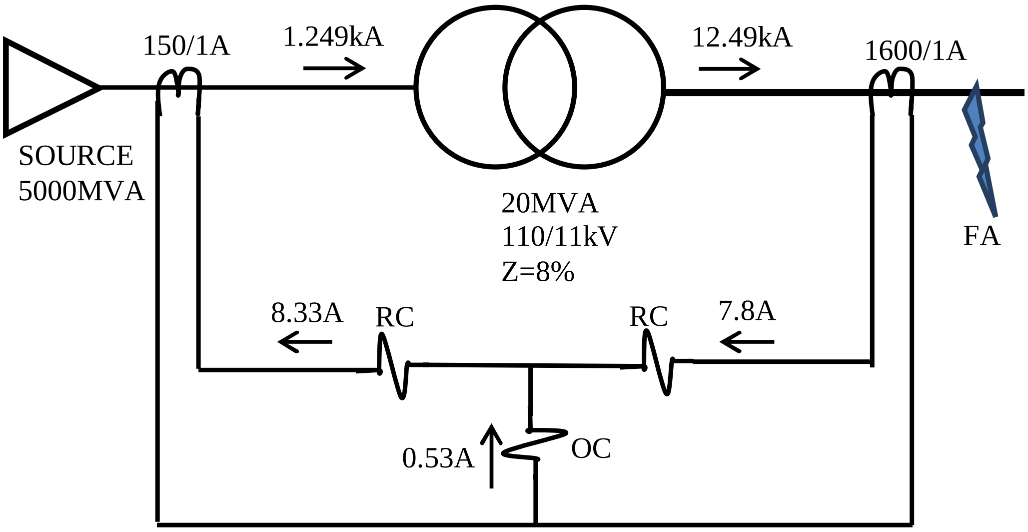

Figure-7

IRES = 8.33A (maximum of I1 and I2), ID = 0.53A

- 11 kV fault inside Differential protection zone at FB

Currents in the system for fault at FB is shown in Figure-8

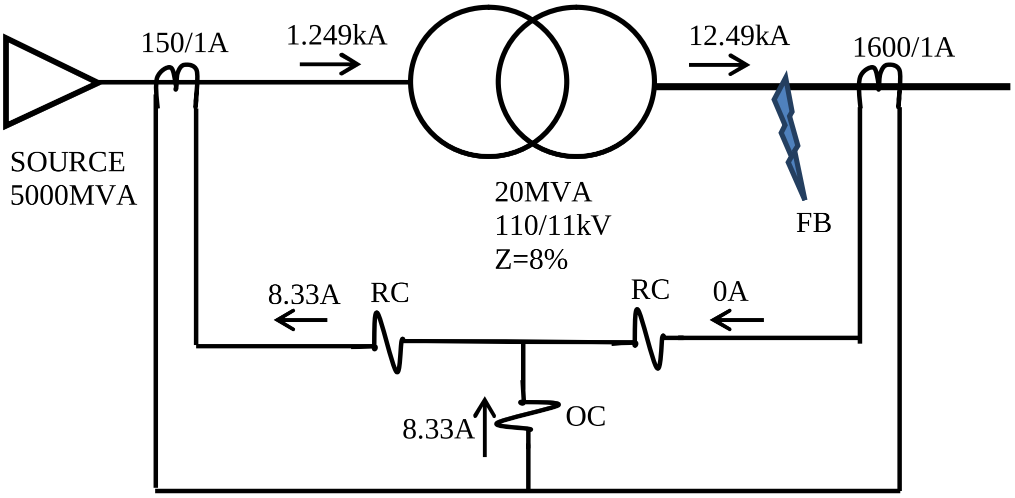

Figure-8

IRES = 8.33A, ID = 8.33A

- Fault at 50% impedance of transformer, at FC

Currents in the system for fault at FC is shown in Figure-9

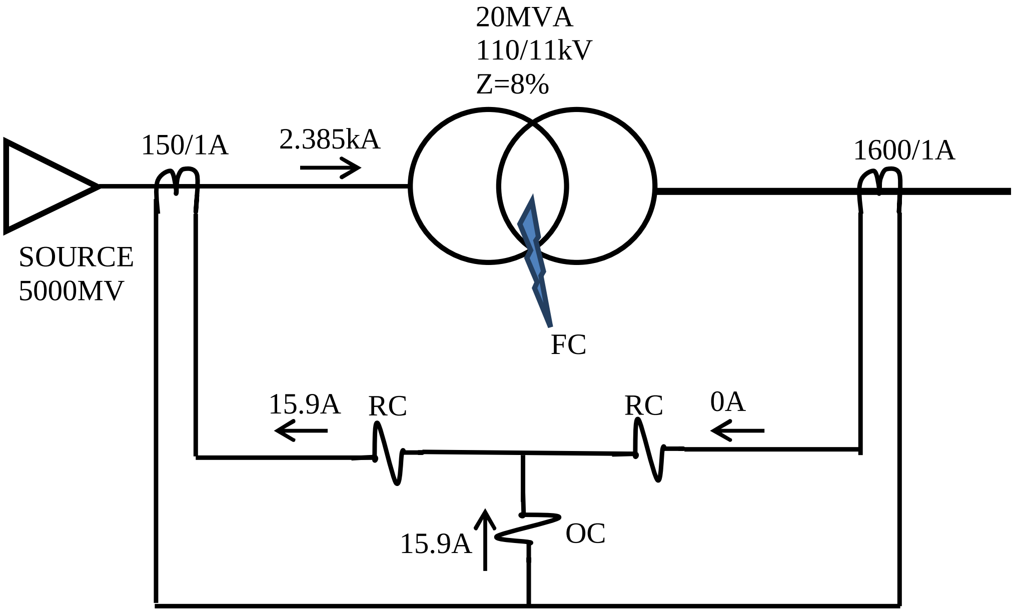

Figure-9

IRES = 15.9A, ID = 15.9A

- 110 kV fault inside Differential protection zone at FD

Currents in the system for fault at FD is shown in Figure-10

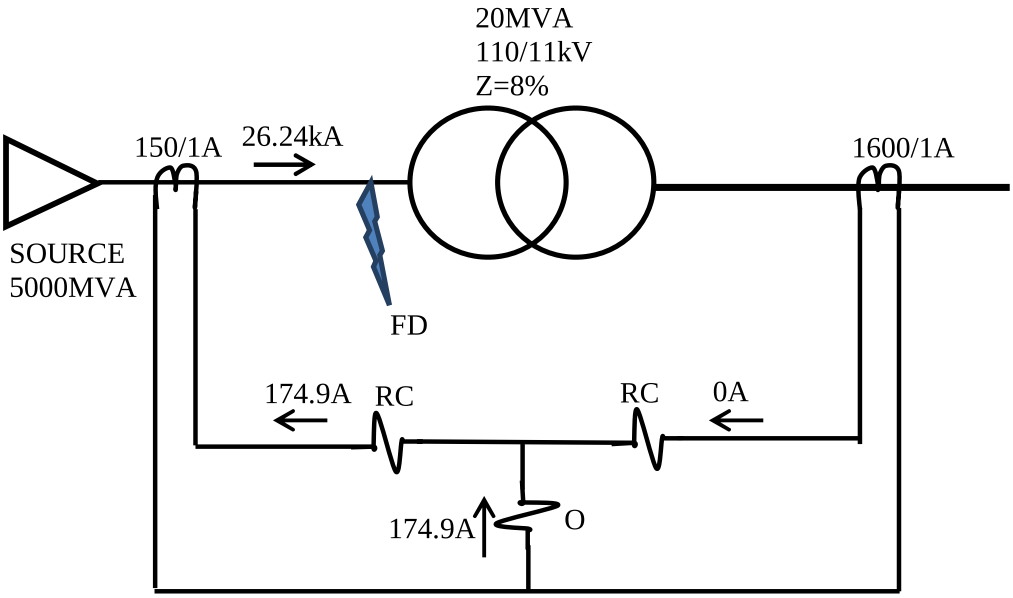

Figure-10

IRES = 174.9A, ID = 174.9A

Table-1 indicates Fault summary

Fault Location	Restraining Current IRES	Operating Current ID
External Fault FA	8.33A	0.53A
11kV Internal Fault FB	8.33A	8.33A
Transformer Internal Fault FC	15.9A	15.9A
Internal Fault at 110 kV FD	174.9A	174.9A

- Setting of I Pick up (IPU):

  Setting Range: 0.05 to 1.00 x CT in steps of 0.01

  During Normal load condition, ID = 0.05A (Refer Figure-5)

  Add 0.1A for CT characteristics mismatch and CT Ratio mismatch

  Add 0.1A for transformer tap changer range

  Hence set IPickup = 0.3A (0.3 x CT) (Note in this example CT is 1A secondary)

- Setting of Slope-1:

  Setting Range: 15% to 100% in steps of 1%

  For IRES $\leq$ 15.9A, in case of internal fault at FC, set lower bias Slope-1 = 30% to ensure sensitivity for internal fault, as for relay operation;

  ID $\geq$ k IRES

  ID $\geq$ (0.3 x 15.9) $\geq$ 4.77A. Actual ID = 15.9A. Hence, relay will operate.

- Setting of Brake Point (BP) or Knee Point:

  Setting Range: 1.0 to 20.0 x CT in steps of 0.1

  Select BP setting little lower than FA Restraining current.

  Hence, set BP = 8A

- Setting of Slope-2:

  Setting Range: 50% to 200% in steps of 1%

  For IRES = 8.33A, in case of external fault at FA, set bias Slope-2 higher than Slope-1. This will ensure stability of differential protection for external fault as with higher bias slope setting, ID2 > ID1 (Refer Figure-11).

Hence, Set Slope-2 = 60%. So for relay operation, required ID ≥ (0.6 x 8.33) ≥ 4.998A.

Actual ID = 0.53A. Hence, relay will not operate for external fault.

With above setting of 60%,

a) For internal fault at FB (11 kV internal fault), IRES=8.33A and ID=8.33A. Hence relay will operate as ID >kIRES, even with higher slope value of k=0.6, and thus the sensitivity is easily achieved.
b) For internal fault at FC (Transformer winding fault), IRES=15.9A and ID=15.9A. Hence relay will operate as ID >kIRES, even with higher slope value of k=0.6, and thus the sensitivity is easily achieved.
c) For internal fault on source side (Fault FD), IRES=174.9A and ID=174.9A. Hence relay will operate as ID >kIRES, even with higher slope value of k=0.6, and thus the sensitivity is easily achieved.

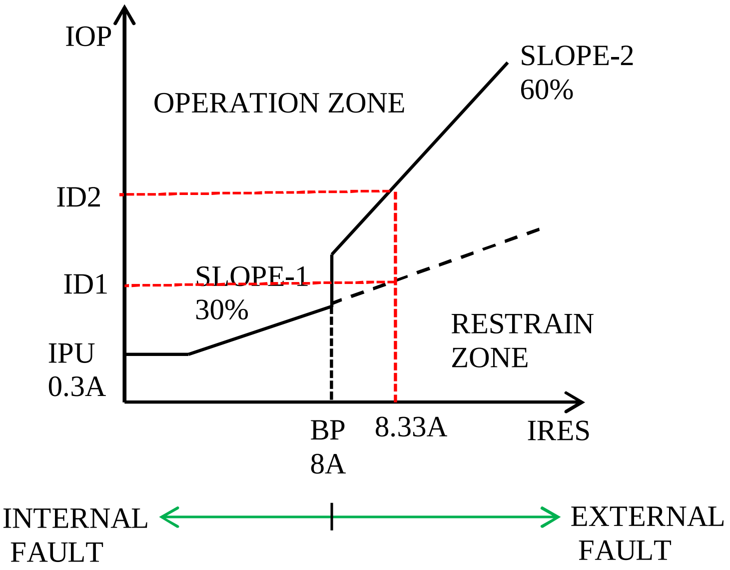

Figure-11

- Setting of 2nd Harmonic Inhibit:

  Setting Range: 0.1%f0 to 65%f0 in steps of 0.1

  2nd harmonic inhibit is used to distinguish between Inrush current and Internal fault current of transformer. During both these conditions, current is seen only on one side of differential protection circuit and it presents a large differential current to the differential element of relay.

  Transformer inrush current is rich in 2nd harmonic. Typical inrush current is 20% of fundamental current. It is presumed that fault current does not have 2nd harmonic content. To avoid relay operation during energization of transformer (which will have high inrush current), set 2nd Harmonic inhibit to 18%. So if 2nd Harmonic content of sensing current exceed 18%, the relay is restrained from operation.

  2nd Harmonic Inhibit setting = 18%f0

- Setting of 5th Harmonic Inhibit:

  Setting Range: 0.1%f0 to 65%f0 in steps of 0.1

  5th harmonic inhibit feature allows inhibiting the percent differential during intentional overexcitation of the system. This setting is primarily provided for Generator Transformers, which can experience overexcitation conditions. For distribution transformers or transformer under discussion this protection shall be disabled.

  5th Harmonic Inhibit setting: Disable

- Setting of Instantaneous Differential Current:

  Setting Range: 3 to 20xCT in steps of 0.01

  This element is for protection under high magnitude internal faults. This element shall be set above maximum inrush current. Transformer inrush current is 8 to 12 times the normal current. Set this element to 14 (14 x CT)

  Note: In some relays this Instantaneous Differential element also has a polarity detector to detect polarity of the current in addition to the differential current. This unit will not operate for a unidirectional inrush which can be even 8 to 12PU. The bi-directional inrush current can be typically 6 to 7 PU. So set this Instantaneous Differential Unit to 7 x CT (7 PU) so that it does not operate for a bi-directional inrush current. For a through fault condition, the relay operation is restrained due to high restrained current. However, for an internal fault condition, the fault current, which is bi-directional; will exceed 7 PU and unit will operate within one cycle and issue a trip command.

IV.CONCLUSION

The above example provides a brief guideline on the setting of low impedance transformer differential protection using GE make 745 Transformer Protection System relay. The basic principles for low impedance differential protection settings remain the same however the relay algorithm for calculation and setting may vary as per relay manufacturer.

DISCLAIMER

Setting values and setting calculations used in this paper are based on GE make 745 Transformer Protection System relay. Network parameter values are based on an example operating conditions and are for education purpose only. User is advised to use his/her discretion before using the same. For relay of other make, type and model; user is advised to refer respective relay manual for working out relay settings.
This paper has explained only the current, slope and harmonic inhibit settings. Other settings are outside the scope of this paper.

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