Numerical Differential Protection of 220/132KV, 250 MVA Auto Transformer using Siemens make differential relay 7UT612

Hashmat Hussain[1], Dr. Muhammad Naeem Arbab[2], Junaid Khalil[3]

[1]Senior Engineer NPCC NTDC Islamabad, Pakistan
[2]Professor, Deptt of Electrical Engg, UET Peshawar, Pakistan
[3]Senior Engineer Protection GSO Training Centre NTDC Tarbela, Pakistan

---

Abstract – *Differential protection of power transformer is the main protection of power transformer. First generation of Electromechanical differential relays were difficult to balance and had limited setting ranges while 3rd Generation microprocessor based Numerical Differential relays are multi functional, has user friendly HMI, more sensitive, reliable and have vast setting ranges & options. Setting calculation and balancing of differential relay for a power transformer is a difficult job for protection engineers. Methods used in field for elimination of zero sequence currents due to L-G external faults and unbalanced load current, balancing of differential relay during CT saturation and Magnetization Inrush current is discussed in this paper. Numerical Differential relay Siemens 7UT612 is discussed for through fault stability and harmonic restraint stability for a 250MVA 220/132KV YNaod1 Auto Transformer (T/F).*

***Key Words*: Numerical Differential Relay, CT saturation, Through Fault stability, Vector Group Of power Transformer, Zero Sequence current elimination, add-on stabilization, Back up protection, Magnetization Inrush current, overexcitation, harmonic restraint, slope setting, pickup setting, 250MVA 220/132 KV Auto Transformer.**

1. INTRODUCTION:

250 MVA, 220/132KV Auto T/F (Transformer) is an important piece of equipment costing more than 100 Million rupees. The protection of this transformer is to be designed carefully owing to its huge cost, long repair time and millions of consumers that are affected if it goes down. Main differential protection is the main protection of power T/F for its internal faults and it is instantaneous in its operation while Overcurrent is the backup protection to differential relay.

There are various external and internal faults of power transformers such as overloads, overexcitation and through faults while internal faults are classified into slow growing incipient faults and active faults [1].

The incipient faults are detected by Buchholz relay while active faults are detected by T/F main differential relay.

Differential relay balancing and setting calculation is very difficult job due to following reasons:

1. Power T/F phase shift between HV & LV Currents as per Vector group of Power T/F.
2. Different CT Ratios on HV & LV side of T/F.
3. Power T/F Magnetization Inrush current [2]
4. Zero sequence current elimination [3]
5. CT saturation on external faults [4].
6. Tap change operation.
7. CT Errors.
8. Through fault stability of differential relay.

1.1 Differential Circuit Balancing For Electromechanical relay (A Manual Method):

For electromechanical relays of First generation we need to do manual balancing of the Power T/F Main HV and LV CT currents (magnitude and phase angle balancing) through Matching CTs/Balancing CTs. For this purpose 250MVA 220/132 KV Auto T/F at principal tap is selected with HV CT ratio of 1200/1 and LV CT Ratio of 1600/1.

1.1.1 Phase Angle/Arrow Balancing:

STEP#1: a. Draw the current magnitude arrows on star side. In this case double headed arrow on C/Blue phase while single headed arrows on A/red & B/yellow phases in opposite direction.

b. Arrows on both side of transformer winding must be in confirmation with subtractive polarity method.

c. Draw the magnitude arrows CTs secondary wires on star side keeping in mind the subtractive polarity as shown in figure below.

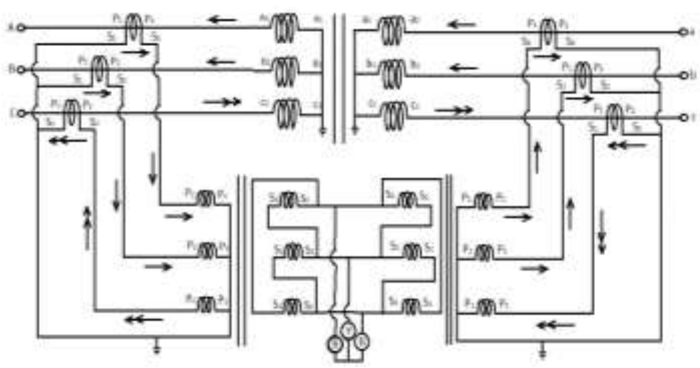

Figure No.1: phase balancing Of Main CT Currents (step1)

STEP#2: Draw the magnitude arrows on delta side of LV and HV MCTs keeping in mind the subtractive polarity of transformers, i.e. If current goes from P_1 to P_2 on primary side then on secondary side it must be from S_2 to S_1 as shown in figure below.

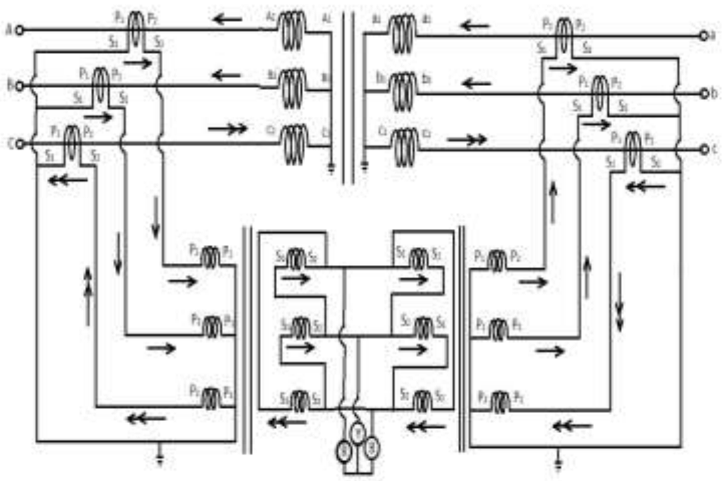

Fig No.2: phase balancing of main CT Currents (step 2)

STEP#3: Extend the delta side current in wires connected between windings and then by applying Kirchhoff's current rule to find the final magnitude of the current in delta side (both in LV & HV side MCTs) as shown in figure below.

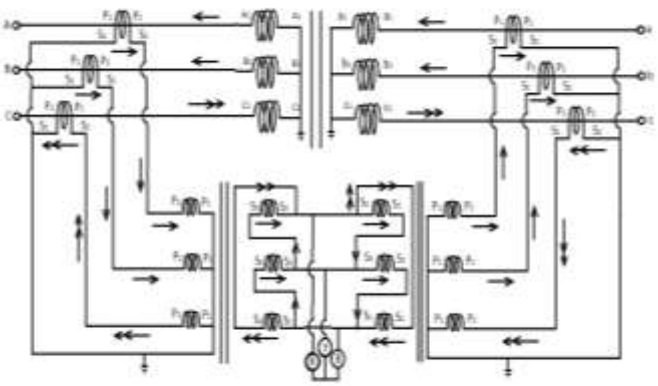

Figure No.3 phase balancing main CT Currents (step 3)

STEP#4: By applying Kirchhoff's current law check the sum of current magnitudes coming at the point of operating coil of each phase and going out of the that point. If the sum is equal then the relay is balanced otherwise not. Here in this specific case three magnitude of current are coming and going out at 'A/a' and 'C/c' phases whereas at 'B' phase current is already zero from both HV/MCT and LV MCT as shown in figure below. Hence the differential relay will be stabilized.

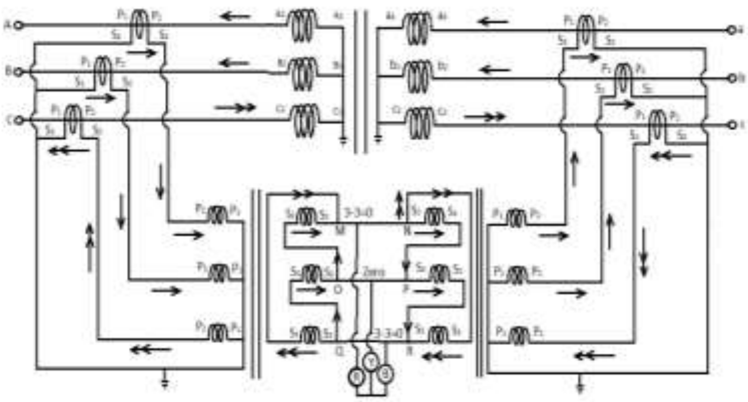

Figure No.4 Phase balancing of Main CT Currents (step 4)

1.1.2 Magnitude Balancing:

$$I_{HV} = \frac{250 \times 10^6}{220 \times 10^3 \times \sqrt{3}} = 656.08$$

$$HV\ CT\ ratio = \frac{1200}{1} = 1200$$

$$I_{LV} = \frac{250 \times 10^6}{132 \times 10^3 \times \sqrt{3}} = 1093.47\ A$$

$$LV\ CT\ ratio = \frac{1600}{1} = 1600$$

$$I_{HV(SEC)} = \frac{656.08}{1200} = 0.547A$$

$$I_{LV(SEC)} = \frac{1093.47}{1600} = 0.683A$$

HV Side MCT Calculations:

Primary Ampere Turns	Secondary Amperes Turns
P_1—P_2	S_1—S_2
0.547 x 1 = 0.547 AT	0.577 x 1 = 0.577 AT

Select the number of turns on both sides where Ampere turns are almost equal. Converting 1 A current from Star to delta side of MCT we get 0.577 A on secondary side of MCT.

Finding the Secondary side current with given turns ratio

$$I_{2(HV-MCT)} = \frac{N_1}{N_2} \times I_1$$

$$I_{2(HV-MCT)} = \frac{1}{1} \times 0.547 = 0.547\ A$$

Converting phase current into line current as relay is connected on delta side of HV MCT.

$I_{Line} = \sqrt{3}\ I_{Phase}$

$I_{HV\ MCT\ (sec)}$ = 1.732 x 0.547 = 0.95A

LV SIDE MCT CALCULATION

P_1—P_2 S_1—S_2

0.683 x 1 = 0.683 AT 0.577 x 1 = 0.577 AT

0.683 x 2 = 1.366 AT 0.577 x 2 = 1.154 AT

0.683 x 3 = 2.049 AT 0.577 x 3 = 1.731 AT

0.683 x 4 = 2.732 AT 0.577 x 4 = 2.308 AT

0.683 x 5 = 3.415 AT 0.577 x 5 = 2.885 AT

0.683 x 6 = 4.098 AT 0.577 x 6 = 3.462 AT

0.683 x 7 = 4.781 AT **0.577 x 7 = 4.039 AT**

Finding the Secondary side current with given turns ratio

$$I_{2(LV)} = \frac{N_1}{N_2} \times I_1$$

$$I_{2(LV)} = \frac{6}{7} \times 0.683 = 0.585A$$

Converting phase current into line current as relay is connected on delta side of LV MCT.

$I_{Line} = \sqrt{3}\, I_{Phase}$

$I_{LV\ MCT\ (sec)}$ = 1.732 x 0.585 = 1.014 A

Finding spill current into relay coil

$\mathbf{I_{(Spill)} = I_{2(LV\text{-}MCT)} - I_{2(HV\text{-}MCT)}}$

$I_{(Spill)}$ = 1.014 – 0.95= 0.064 A which is 6.4 % of I_N

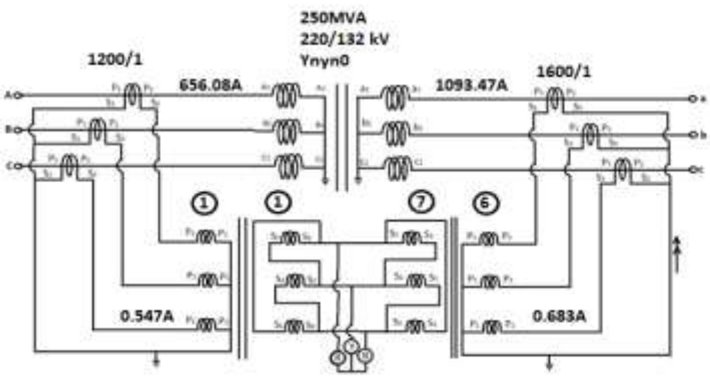

Figure No.5: Final Balanced Differential Circuit.

2. LIMITATION OF E/M DIFFERENTIAL RELAY

There are certain limitation in electromechanical relays regarding setting range and stability issue on through faults and magnetization inrush currents.

The pickup setting of differential relay operating coil is kept a bit higher due to tap changer +10% error and relay tap mismatch error. Due to these the spill current in relay operating coil increases. These all are added and therefore the pickup setting of Differential relay operating coil is kept 25% of I_N i.e. 1.25 A(I_N=5A for E/M Relays)[1],[5]. This means that some sensitivity is lost particularly for high impedance internal faults of Power T/F.

In some E/M Differential relays the pickup setting is fixed at 15% of Relay I_N and slope setting is variable. While in some E/M relays the slope is fixed at 50% while pickup setting is variable (20%, 30%, 40%, 50% of Relay I_N).

There is also stability issue regarding close external through faults as spill current increases along with restraining current but due to T/F Main CT saturation the spill current is increased to a value that relay may operate. There is no mechanism or intelligence in E/M Relays to detect CT saturation phenomena and consequently block the relay during external fault.

Regarding 2nd Harmonic restraint due to power T/F magnetizing inrush current the E/M differential relay has fixed factory setting value of 15% or 20% (I_{2f}/I_{0f}). This cannot be changed. While there is no 5th harmonic restraint.

3. SIEMENS MAKE 7UT612 NUMERICAL DIFFERENTIAL RELAY:

Numerical differential relays are 3rd generation Differential relays having 32 bit microprocessor, A/D Convertors , Digital Signal Processing, multiple Binary I/O, external PC Communication capabilities and easy HMI.

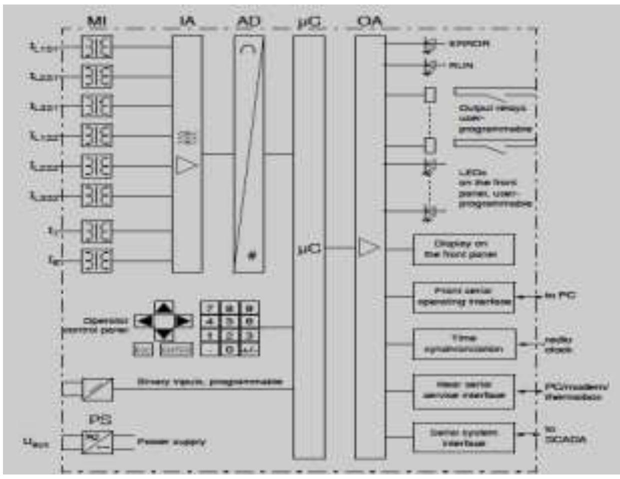

Figure No.6 Hardware structure of siemens 7UT612 Relay.

The numerical differential protection 7UT612 is a fast and selective short-circuit protection for transformers of all voltage levels, for rotating machines, for series and shunt reactors, or for short lines and mini-busbars with two feeders. It can also be used as a single-phase protection for busbars with up to seven feeders. The individual application can be configured, which ensures optimum matching to the protected object.

For use as transformer protection, the device is normally connected to the current transformer sets at the higher voltage side and the lower voltage side of the power transformer.

The device provides backup time overcurrent protection functions for all types of protected objects. The functions can be enabled for any side.

A thermal overload protection is available for any type of machine.

A version for 16 2/3 Hz two-phase application is available for traction supply (transformers or generators) which provides all functions suited for this application (differential protection, restricted earth fault protection, overcurrent protection and overload protection).

A circuit breaker failure protection checks the reaction of one circuit breaker after a trip command. It can be assigned to any of the sides of the protected object.

7UT612 Relay can be used as:

1. Differential Protection for Transformers.
2. Differential Protection for Generators and Motors.
3. Differential Protection for Mini-Bus bars and Short Lines.
4. Bus-Bar Protection.
5. Restricted Earth Fault Protection.
6. High-Impedance Unit Protection.
7. Tank Leakage Protection.
8. Time Overcurrent Protection for Phase Currents and Residual Current.
9. Time Overcurrent Protection for Earth Current.
10. Single-Phase Time Overcurrent Protection.
11. Unbalanced Load Protection.
12. Thermal Overload Protection.
13. Circuit Breaker Failure Protection.
14. External Direct Trip.
15. Processing of External Information.
16. User Defined Logic Functions (CFC).

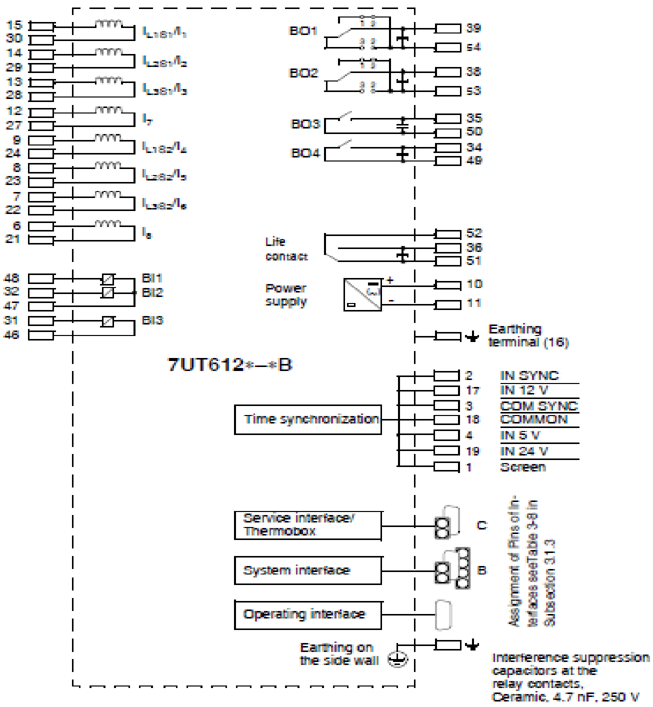

Figure 7: Connection diagram of 7UT612 Relay

3.1 DIFFERENTIAL PROTECTION OF TWO WINDING T/F BY 7UT612 RELAY:

When a fault occurs in the zone limited by the transformers, a current I1 + I2 which is proportional to the fault currents i1 + i2 flowing in from both sides is fed to the measuring element. As a result, the simple circuit shown in above figure ensures a reliable tripping of the protection if the fault current flowing into the protected zone during a fault is high enough for the measuring element **M** to respond.

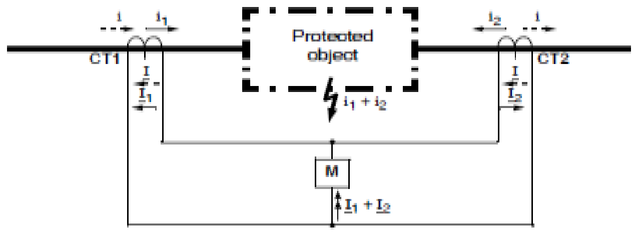

Fig No.8: basic diagram to explain differential protection.

3.2 CURRENT RESTRAINT & ADD-ON STABILIZATION ON THROUGH FAULT CT SATURATION:

The following definitions apply:

A tripping effect or differential current

IDiff = |I1 + I2|

and a stabilization or restraining current

IRest = |I1| + |I2|

IDiff is calculated from the fundamental wave of the measured currents and produces the tripping effect quantity, IRest counteracts this effect.

To clarify the situation, three important operating conditions should be examined

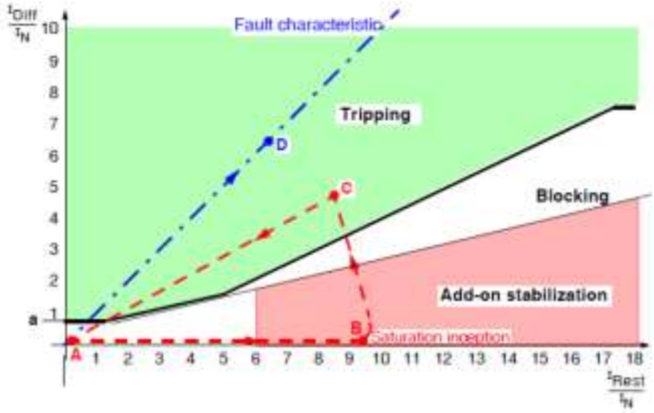

Figure No.9 Tripping Characteristics of 7UT612 Relay.

During an external fault which produces a high through-flowing fault current causing current transformer saturation, a considerable differential current can be simulated, especially when the degree of saturation is different at the two sides. If the quantities IDiff/IRest result in an operating point which lies in the trip area of the operating characteristic, trip signal would be the consequence if there were no special measures.

7UT612 provides a saturation indicator which detects such phenomena and initiates add-on stabilization measures. The saturation indicator considers the dynamic behavior of the differential and restraint quantity.

The dashed line in figure shows an example of the shape of the instantaneous quantities during a through-fault current with current transformer saturation at one side.

3.3 HARMONIC RESTRAINT DURING T/F INRUSH AND OVEREXCITATION CONDITION:

When switching unloaded transformers or shunt reactors on a live busbar, high magnetizing (inrush) currents may occur. These inrush currents produce differential quantities as they seem like single-end fed fault currents. Also during paralleling of transformers, or an overexcitation of a power transformer, differential quantities may occur due to magnetizing currents cause by increased voltage and/or decreased frequency [6].

The inrush current can amount to a multiple of the rated current and is characterized by a considerable 2nd harmonic content (double rated frequency)[6] which is practically absent in the case of a short-circuit. If the second harmonic content exceeds a selectable threshold, trip is blocked.

Besides the second harmonic, another harmonic can be selected to cause blocking.

A choice can be made between the third and fifth harmonic.

Overexcitation of the transformer iron is characterized by the presence of odd harmonics in the current. Thus, the third or fifth harmonic is suitable to detect such phenomena. But, as the third harmonic is often eliminated in power transformers (e.g. by the delta winding), the use of the fifth is more common [6].

The differential quantities are examined as to their harmonic content. Numerical filters are used to perform a Fourier analysis of the differential currents. As soon as the harmonic contents exceed the set values, a restraint of the respective phase evaluation is introduced. The filter algorithms are optimized with regard to their transient behavior such that additional measures for stabilization during dynamic conditions are not necessary.

Since the harmonic restraint operates individually per phase, the protection is fully operative even when e.g. the transformer is switched onto a single-phase fault, whereby inrush currents may possibly be present in one of the healthy phases. However, it is also possible to set the protection such that not only the phase with inrush current exhibiting harmonic content in excess of the permissible value is restrained but also the other phases of the differential stage are blocked (so called “cross block function”).

This cross block can be limited to a selectable duration.

4. SETTINGS OF 7UT612 RELAY FOR 250MVA 220/132KV AUTO T/F YNaod1:

After putting the basic T/F info such as vector group, MVA Capacity, rated HV and LV Voltages, Main HV and LV CTs rated primary and secondary currents and most importantly direction of Star point of Wye connected main CTs the following important settings are considered for captioned Auto T/F after enabling Differential protection and disabling all other protection schemes.

1. Pickup setting = 0.25 $I_{diff}/I_{N0.}$
2. Pickup for high set trip = 8.0 I_{diff}/I_{N0}
3. Slope No.1 = 25% , Base Point = 0.00 I/I_{N0}
4. Slope No.2 = 60%, base point = 2.00 $I/I_{N0.}$
5. Maximum permissible starting time = 5 sec.
6. Pick up for add-on stabilization = 4.00 I/ I_{N0}
7. Duration of add-on stabilization = 15 cycles.
8. Time for cross blocking add-on stabilization = 15 cycles

9. Nth harmonic = 5th harmonic
10. 2nd harmonic restraint setting = 15%
11. Time for cross blocking 2nd harmonic = 3 cycles.
12. 5th harmonic restraint setting = 35%
13. Time for cross blocking nth harmonic = 0 cycles
14. Limit for nth (5th) harmonic restraint = 0.5 I/I_{N0}

5. CONCLUSIONS:

Due to multiple protection schemes in single numerical relay, exclusion of matching CTs, Add-On stabilization due to External fault CT saturation phenomena, 5th harmonic restraint, vast setting range for differential protection and easy HMI 7UT612 Numerical Differential relay is replacing electromechanical differential relays in field on almost all power T/Fs whether big or small except for distribution T/Fs where it is not feasible to install differential protection due to added cost.

Only one shortcoming exist for 7UT612 which is restriction of use on two winding T/F only while for 3 winding power T/Fs Siemens has developed 7UT613 [7].

REFERENCES

1. **P.M Anderson** "Power System Protection" IEEE Press 1999

2. **Ming Ji**, **Yuanlong Liu** "A new inrush current identification algorithm based on transformer core saturation" 2017 IEEE Power & Energy Society General Meeting, 16-20 July 2017.

3. **Xu Guangfu ; Guo Jinxue ; Zhang Chunhe ; Yu Qunbing** "The influence of low resistance grounding system in delta side of transformer on differential protection and its solutions." CICED 2010 Proceedings, 2010.

4. **Michael Stanbury and Zarko Djekic,** "The Impact of Current Transformer Saturation on Transformer Differential Protection." IEEE Transactions on Power Delivery, December 2014.

5. **Michael J Thompson**, "Percentage Restrained Differential, Percentage of What?" Schweitzer Engineering Laboratories, Inc., https://selinc.com/literature/technical-papers/. Presented at WPRC 2010, Texas A&M Relay Conference 2011.

6. **Ken Behrendt, Normann Fischer, and Casper Labuschagne,** "Considerations for Using Harmonic Blocking and Harmonic Restraint Techniques on Transformer Differential Relays." Schweitzer Engineering Laboratories,Inc., https://selinc.com/literature/technical-papers/. Presented at WPRC 2006, MIPSYCON 2007.

7. Siemens 7UT613 Manual.