Design Criteria on Substation Protection by using Instrument Transformers

Thinn Le Yee

Abstract *— The main purpose of the substation is to provide reliable and continuous electric power supply for consumers connected to the distributive network. When a fault in the distributive network occurs, it is necessary to interrupt the power supply until the fault is removed. For these reasons, distributive substation has to be provided with different protective systems, whose purpose is to recognize any significant fault emerging the substation, and to induce forced disconnection of power supply in a reasonable short time interval. In this paper, I will emphasize about the instrument transformers (current transformers and voltage transformers) as the protective relays for protection of Pyinmana-substation in Myanmar. The typical protection systems of two transformers – 60MVA, 230/33/11 kv and 100 MVA, 230/33/11 kv of Pyinmana-substation have been mentioned. Special attention has been paid to the differential protection and over current protection of these transformers, which has been used in this substation presently. Also, the 230 kv line protectie have been mentioned. Distance protection and over current protection have been paid attention in line protection. This protection system can satisfy the selectivity, sensitivity, stability, fastness and reliability of the substation.*

Keywords **— CTs, PTs, faults, transformer protection, line protection**

1. INTRODUCTION

The fundamental objective of system protection is to provide isolation of a problem area in the system quickly, such that as much as possible of the rest of the power system is left to continue service. Protective relays act only after an abnormal or intolerable condition has occurred. They require reasonably accurate reproduction of the normal, tolerable and intolerable conditions in the power system for correct sensing and operation. This information input from the power system is usually through current transformers (CTs) and voltage transformers (PTs or VTs). CTs and PTs provide insulation from the higher-system voltages and a reduction of the primary current and voltage quantities. Current transformers have ratio errors which for some types can be calculated and for other types must be determined by test. The normal rating of CT secondary has been standardized at 5A, with a second standard of 1A being used. Advantages of this lower rating may exist when unusually long secondary leads are required between the CTs and the relays, such as in high voltage (HV) installation. However, changing the current transformer rating does not necessarily reduce the energy required for relay operation. With a constant VA, lower current means higher voltage and more insulation between the primary and the secondary.

The measure of current transformer performance is its ability to reproduce accurately the primary current in secondary amperes both in wave shape and magnitude.

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2. DISCRIMINATION OF PYINMANA SUBSTATION 230/33/11kV

Distributive substations are points in a large electrical power transmission network where high-level voltage is transformed into medium-level voltage, suitable for some industrial consumers supply, and for further transformation and distribution to the low-voltage end consumers. The most important element in each distributive substation is a distributive power transformer. The structure of such distributive substations is usually very complex, including switchgear equipment, meters, protective and communication systems, which allows the control of the substation under different operating conditions.

A typical disposition of the substation 230/33/11 kV is shown on the one-line diagram in Figure 1. There are two distributive power transformers, 60MVA and 100MVA, in substations of this type, and they can operate either independently or in parallel which is more often. Each transformer has three windings, which are connected to the corresponding bus system. High voltage bus system (230kV) is fed through the incoming 230 kV transmission lines, which are from other five sub-stations. There are many load sending from this substation. The main purpose of the substation is to provide reliable and continuous electric power supply for consumers connected to the distributive network. When a fault in the distributive network occurs, it is necessary to interrupt the power supply until the fault is removed. For these reasons, distributive substation has to be provided with different protective systems, whose purpose is to recognize any significant fault emerging the substation, and to induce forced disconnection of power supply in a reasonable short time interval. In this paper, I will calculate and choose the CTs and PTs as the protective relays for protection substation. Special attention has been paid to the differential protection and over current protection of these transformers, which has been used in this substation presently. Also, the 230 kv line protection have been mentioned. Distance protection has been paid attention in line protection. This protection system can satisfy the selectivity, sensitivity, stability, fastness and reliability of the substation.

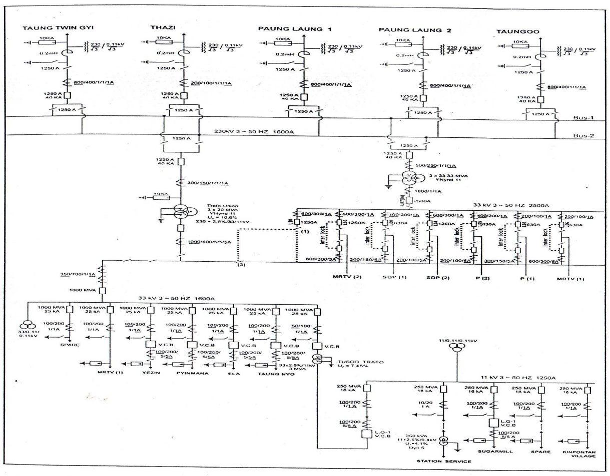


Fig. 1 One line diagram of Pyinmana-Substatoin

3. NATURE OF OVERCURRENT

Distribution system is essentially balanced three phase system and faults create an unbalanced circuit. Most faults are temporary fault which is one whose cause is transitory in nature. But some are permanent which is one in which damage is occurred either from the cause of the fault or from the fault arc.

For increased currents associated with system faults and overloading, the system must be provided adequate protection for all types of distribution apparatus and all segments of the system itself.

3.1 Types of Faults

The type of fault that can occur depends on the distribution system. Line to ground, line to line, and double line to ground faults are common to single, two and three phase systems. Three phase faults are characteristic only of three phase systems.

Line to ground faults result when one conductor falls to ground or contacts the neutral wire. Line to line faults result when conductors of a two phase or three phase system are short circuited. They can occur anywhere along a three phase wye or delta system, or along a two phase branch.

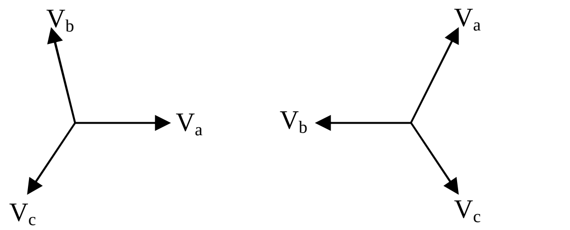
Double lines to ground faults result when two conductors fall and are connected through ground, or when two conductors contact the neutral of a three phase/ two phase grounded system.

Under normal operating conditions, a distribution circuit is essentially a balance three phase system.

The method traditionally used to solve problems of unbalanced three phase system is the analysis of symmetrical components.

The balanced systems of phasors used in three phase symmetrical component analysis are

1. Positive sequence components, consisting of three phasors of equal magnitude and 120 degree phase separation, and having the same phase sequence as the original phasors.
2. Negative sequence components, consisting of three phasors of equal magnitude and 120 degree phase separation, and having a phase sequence opposite to that of the original phasors.
3. Zero sequence components, consisting of three phasors of equal magnitude and 360 or 0 degree phase separation.



POSITIVE SEQUENCE NEGATIVE SEQUENCE

Fig.2 Balanced systems of phasors used in three phase symmetrical component analysis

The impedance information is necessary to conduct a fault analysis calculation. It includes system sequence impedance viewed from each of the fault points to be considered and value of fault impedance, Z associated with each type of fault.

4. TRANSFORMER PROTECTION

Typical protection system of two transformers 60MVA and 100 MVA are designed by CTs. Overcurrent protection and differential protections are mentioned.

4.1 Overcurrent protection

For 60 MVA, 230/33/11kVtransformer,

Full-load current is arrived by the following calculation.

$$\text{Transformer Full Load Current}=\frac{KVA_{3\phi}}{\sqrt{3}kV_{l-l}} \quad (1)$$

$$=\frac{60MVA}{\sqrt{3}\times 230kv}$$

$$=\frac{60{,}000}{\sqrt{3}\times 230}$$

$$= 150.6 \text{ A at } 230kv$$

Therefore, **150:1 primary CTs are selected**.

$$I_{\text{full-load}}=\frac{KVA_{3\phi}}{\sqrt{3}kV_{l-l}}=\frac{60MVA}{\sqrt{3}\times 33kv}=\frac{60{,}000}{\sqrt{3}\times 33}$$

$$= 1049.73\text{A at } 33kv$$

Therefore, **1000:5 (200:1) secondary CTs are selected.**

(ii) For 100 MVA,230/33/11kV transformer,

$$I_{full\text{-}load} = \frac{KVA_{3\phi}}{\sqrt{3}kV_{l-l}} = \frac{100MVA}{\sqrt{3}\times 230kv} = \frac{100{,}000}{\sqrt{3}\times 230}$$

= 251.021 A at 230kv

Therefore**, 250:1 primary CTs are selected**.

$$I_{full\text{-}load} = \frac{KVA_{3\phi}}{\sqrt{3}kV_{l-l}} = \frac{100MVA}{\sqrt{3}\times 33kv} = \frac{100{,}000}{\sqrt{3}\times 33}$$

= 1749.54 A at 33kv

Therefore, **1800:1 secondary CTs are selected.**

4.2 Differential Protection

Differential protection is applied on busses, generators, transformers, and large motors. Specialized relays exist for each of these applications, and their settings are described in the manufacturer’s literature. Differential relays require careful selection of current transformers. The full winding should be used when multiratio CTs are used in differential schemes, and other relays and meters should be fed from different CT circuits. Transformer differential protection requires CTs with limited mismatch.[9]

Generally, differential protection is applied to transformer banks of 10 MVA above. The key is the importance of the transformer in the system, differential may be desirable for smaller units to limit damage in critical interconnections.

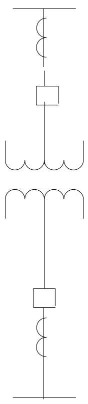


Fig.3 Typical connection of transformers in power system used for most applications. The CTs shown are for possible applications of differential protection.

4.2.1 Factor Affecting Differential Protection

1. Magnetizing inrush current.
2. Difference Voltage Level; hence, the current transformers are of different type, ratios and performance characteristics.
3. Phase Shifts in wye-delta- connected banks.
4. Transformer taps for voltage control.
5. Phase shift or voltage taps in regulating transformer.

4.2.2 Application and Connection of Transformer Differential Relays

The differential protective zone must always account for all circuits into or out of the zone. For two winding transformers with a single set of CTs associated with the windings, a two restraint relay is applicable. For multiwinding transformers, such as three winding banks, autotransformers with tertiary winding connected to external circuits, or where double breaker and CTs supply a single winding, a multiple restraint winding relay should be used. Differential relays are available with two, three, and four and up to six restraint windings, with a single-operating winding. The currents through the differential relay restraint windings should be in phase, and there should be a minimum difference current for load and external faults. The two steps for correctly connecting and setting transformer differential relays:

(i) Phasing: by using wye-delta units, to assure that the secondary currents to the differential relays are in phase.

(ii) Ratio adjustment: by selecting CT ratios or relay taps, or both, to minimize the difference current that will flow in the operating circuit.

4.2.3 Differential protection connections for three Winding Transformer

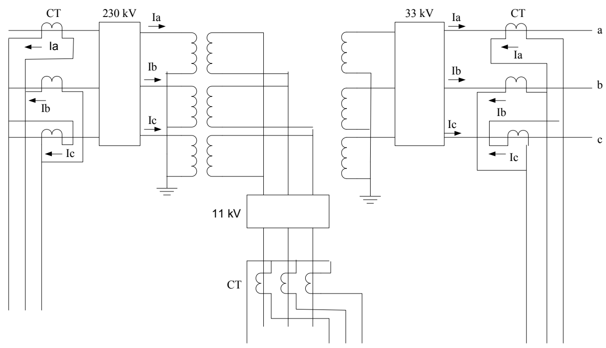


Fig.4 Connection of CTs with 3 winding transformer

In this part, differential relay connections for the protection of a three winding transformer bank have been mentioned. A set of CTs in each circuit, connected to a separate restraint winding. Thus, the protective zone is the area between these CTs.

(i) For 60 MVA, 230/33/11kV transformer

$$I_H = \frac{60{,}000}{\sqrt{3}\times 230} = 150.6 \text{ A at 230 kV} \qquad (2)$$

$$I_L = \frac{60{,}000}{\sqrt{3}\times 33} = 1409.7 \text{ A at 33kV} \qquad (3)$$

Choosing 1000:5 CT ratio, the secondary currents are

$$I_L = \frac{1409.7}{200} = 5.24 \text{ A} \cong 5.0 \text{ A relay ampere}$$

To balance this current, the line currents produced from the delta connected CTs on 230kV side must also be 5.0 A. This will require that each of the secondary windings of the delta connected CTs have a current of

$$I_L = \frac{5.0}{\sqrt{3}} \cong 2.9 \text{ A in CT}$$

This current in the CT secondary ratio

$$\frac{150.61}{2.9} = 51.93$$

for CTs on the 230kV side. The available standard CT ratio is 150:1,

$I_H = \frac{150.61}{150} = 1.004$ A in CT secondary

and the line current from the delta connected CTs to the differential relays would be

$=1.004 \times \sqrt{3}$ =1.74 A in CTs to differential relays.

Clearly this current cannot balance to 5.0 A produced by 33kV side.

This saturation of mismatched currents when standard CT ratios are used is quite commonly encountered in designing the protection system for the wye-delta connected transformers. A convenient solution is provided by auxiliary CTs which provide a wide range of turn ratio. Using a set of three auxiliary CTs with turns ratios of $\frac{5.0}{1.74} = 2.87$ would produce a balance set of currents in the differential relay when the power transformer is carrying normal load.

(ii) For 100 MVA, 230/33/11kV transformer,

Choosing the CTs ratios of 250:1 and 1800:1on 230kV side and 33kV side respectively,

The turn ratio=2.81 would produce a balance set of currents in the differential relay when the power transformer is carrying normal load.

5. LINE PROTECTION

Line protection has mainly three types: transmission line protection, subtransmission line protection and distribution line protection. In this paper, transmission line from 5 substations to Pyinmana substation has been mentioned.

5.1 Distance Protection

Since impedance is an electrical measurement of distance along a transmission line, it is expedient to use a relay capable of measuring the impedance of a line up to a given point.

Many transmission and subtransmission lines are protected with distance relays. These relays sense local voltage and current and calculate the effective impedance at that point. When the protected line becomes faulted, the effective impedance becomes the impedance from that point to the fault.

Table .1 Parameter of transmission lines

from	to	Conductor type	Conductor size	Length (mile)	(km)
Taungoo	Pyin-mana	ACSR	2×605	61.02	98.2
Pyin-mana	Thazi	ACSR	795	83.15	133.82
Pyin-mana	Taung dwingyi	ACSR	2×605	59.03	95.0
Paung laung	Pyinmana(1)	ACSR	2×300 mm	8.11	13.05
Paung laung	Pyinmana(2)	ACSR	2×300 mm	11.68	18.8

There are total 5 lines supplies to *Pyinmana-Substation.*

By using the following equation, the impedances values of these lines between substations are

$$Z_p = R + 0.000988 f + j0.0029 f \log_{10} \frac{D_c}{d_c} \quad (4)$$

$$Z_m = 0.000988 f + j0.0029 f + \log_{10} \frac{D_c}{D} \quad (5)$$

$$Z_1 = Z_2 = Z_p - Z_m$$
$$Z_0 = Z_p + 2Z_m \quad (6)$$

$$Z_1 = Z_2 = R + j0.029 f \log_{10} \frac{D}{D_c} \quad (7)$$

$$Z_0 = R + j0.0296 f + j0.00869 f \log_{10} \frac{D_c}{\sqrt[3]{d_{D_c}^{\,2}}} \quad (8)$$

$$D_c = 216 \sqrt{\frac{\rho}{f}} \quad (\text{ohm/cm}^2) \quad (9)$$

$\rho =$ earth resistivity

The parameter calculated from line configuration, conductor size and earth resistivity (100Ω.m).

Calculation result for impedances

Base MVA=100MVA, $Z_{base} = 529\Omega$

from	To	Positive sequence		
		R(Ω)	X(Ω)	Y_c(Ω)
Taungoo	Pyinmana	5.254	31.15	348.18
Pyinmana	Thazi	11.06	56.63	358.57
Pyinmana	Taungdwingyi	5.08	30.13	336.83
Paunglaung	Pyinmana(1)	0.75	3.97	48.12
Paunglaung	Pyinmana(2)	1.09	5.72	69.30
from	**To**	**Zero sequence**		
		R(Ω)	X(Ω)	Y_c(Ω)
Taungoo	Pyinmana	19.7	115.39	247.08
Pyinmana	Thazi	30.87	172.02	248.07
Pyinmana	Taungdwingyi	19.14	111.90	212.26
Paunglaung	Pyinmana(1)	2.69	15.71	26.56
Paunglaung	Pyinmana(2)	3.87	22.63	38.25

(i) From Taungoo S/S to Pyinmana S/S,

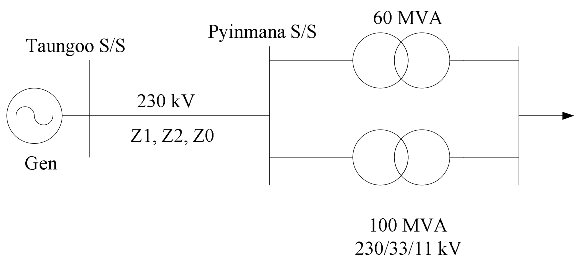


Fig.5 One line diagram of Taungoo S/S to Pyinmana S/S

Check setting range of relay

Relay is calibrated in secondary ohms and is arranged to measure the positive sequence line impedance. The primary protection zone will be 80% of line. Second zone will reach 50% into the next line section.
In this part, the next line section has nor been considered. So, we consider only the primary protection zone.

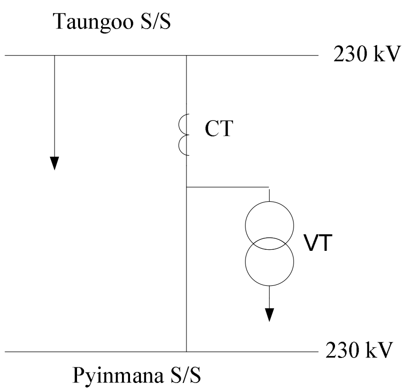


Fig. 6. The diagram of Taungoo Subsutation and Pyinmana Substation with CT and VT

Z_1=5.254+j31.15= $31.2\angle 85.86°$

Z_0=19.79+j115.39

CT ratio = 800:1

VT ratio =33000:110

Setting range of relay using CT and VT ratios,

80% of Z_1 = 0.8 x 31.2 = 24.96

$$= 24.96 \times \frac{C.Tratio}{V.Tratio}$$

$$= 24.96 \times \frac{800 \times 110}{33,000}$$

= 66.56 ohm secondary

Calculation results for relay secondary ohm using CT and VT ratio

from	to	CT ratio	VT ratio	Relay secondary ohm
Taun goo	Pyin-mana	800:1	33000:110	66.56
Pyin-mana	Thazi	200:1	33000:110	30.77
Pyin-mana	Taung dwingyi	800:1	33000:110	65.2
Paunglaung	Pyinman a(1)	800:1	33000:110	8061
Paunglaung	Pyinman a(2)	800:1	33000:110	12.4

6. OTHER RECOMMATIONS

In line protection, the parallel effects of impedence from each line were not considered.The result will be changed when parallel effects of impedances are calculated.

7. CONCLUSION

Recently, protective relays have become available and are popular in many applications. These relays offer flexibility, self-checking, and ease of installation .This paper describes instrument transformers (CT, VT) for substation protection. Settings calculations for these relays are straightforward and are outlined in the relay's applications manual. In order to make these calculations, knowledge of peak load current, minimum and maximum fault currents, and the CT and VT ratings is required.

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