



# **A Survey on Sequence Impedance Measurement of Three Phase Transformer under Asymmetrical Fault Conditions**

V.Malathi

Assistant Professor -II, Dept. of EEE, SCSVMV University, Kanchipuram, Tamil Nadu, India

**ABSTRACT:** The sequence impedance of the network describes the behaviour of the system under asymmetrical fault conditions. The performance of the system determines by calculating the impedance offered by the different element of the power system to the flow of the different phase sequence component of the current. Every power system component (static or rotating) has three values of impedance one for each symmetrical value of current. The sequence impedance of power system is of three types namely positive sequence impedance, negative sequence impedance and zero sequence impedance.

**KEYWORDS:** Negative sequence impedance and zero sequence impedance.

## **I. INTRODUCTION**

Usually power is generated and distributed in three phase system, and therefore it is obvious that we would need three phase transformers to step up and step down voltages. Although, it is practically possible to use three suitably interconnected 'single phase transformers' instead of one 'three phase transformer', the following advantages of three phase transformers encourage their use -

- One 'three phase transformer' occupies less space than a gang of three 'single phase transformers'.
- Single 'three phase' unit is more economical
- The overall bus-bar structure, switchgear and installation of 'three phase transformer' is simpler.

## **II. WORKING METHODOLOGY**

### **A. THEORETICAL DETAILS AND BLOCK DIAGRAM**

The sequence impedance of the network describes the behaviour of the system under asymmetrical fault conditions. The performance of the system determines by calculating the impedance offered by the different element of the power system to the flow of the different phase sequence component of the current. Every power system component (static or rotating) has three values of impedance one for each symmetrical value of current. The sequence impedance of power system is of three types namely,

1. Positive sequence impedance
2. Negative sequence impedance
3. Zero sequence impedance.

### **B. TRANSFORMERS**

Transformers. Transformer phase shift. Wye-delta connections and impact on zero sequence. Inductance and capacitance calculations for transmission lines. GMR, GMD, L, and C matrices, effect of ground conductivity. Underground cables.

# International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: [www.ijareeie.com](http://www.ijareeie.com)

Vol. 8, Issue 5, May 2019

## C. EQUIVALENT CIRCUITS

The standard transformer equivalent circuit used in power system simulation is shown below, where the R and X terms represent the series resistance and leakage reactance, and N1 and N2 represent the transformer turns. Note that the shunt terms are usually ignored in the model.

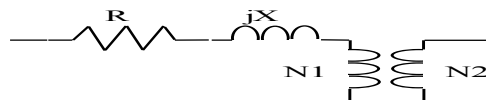


Figure 1. Power System Model for Transformer

Three-phase transformers can consist of either three separate single-phase transformers, or three windings on a three-legged, four-legged, or five-legged core. The high-voltage and low-voltage sides can be connected independently in either wye or delta.

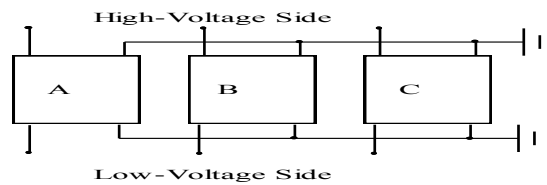


Figure 2. A Three-Phase Ground-Wye Grounded-Wye Transformer

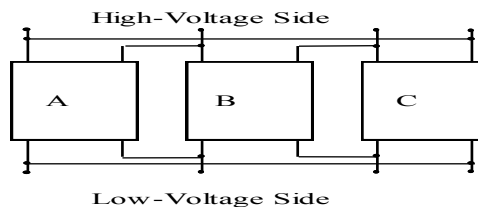


Figure 3. A Three-Phase Delta-Delta Transformer

The transformer impedances consist of winding resistances and leakage reactances. There are no mutual resistances, and the mutual leakage reactances between the separate phase a-b-c coils are negligible. Hence, in symmetrical components,  $S = R + jX$ , and  $M = 0$ , so that  $S + 2M = S - M = R + jX$ , so therefore the positive and negative sequence impedances of a transformer are  $Z_1 = Z_2 = R + jX$ . One must remember that no zero sequence currents can flow into a three-wire connection. Therefore, the zero sequence impedance of a transformer depends on the winding connections. In the case where one side of a transformer is connected grounded-wye, and the other side is delta, circulating zero sequence currents can be induced in the delta winding. In that case, the zero sequence impedance "looking into" the transformer is different on the two sides. The zero sequence equivalent circuits for three-phase transformers is given in Figure 4.

# International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: [www.ijareeie.com](http://www.ijareeie.com)

Vol. 8, Issue 5, May 2019

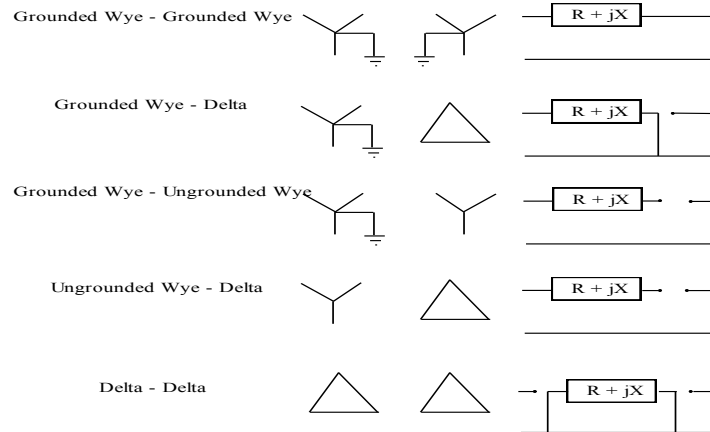


Figure 4. Zero Sequence Impedance Equivalent Circuits for Three-Phase Transformers

Transformer tap magnitudes can be adjusted to control voltage, and transformer phase shifts can be adjusted to control active power flow. The effect of these "off-nominal" adjustments can be incorporated into a pi-equivalent circuit model for a transformer.

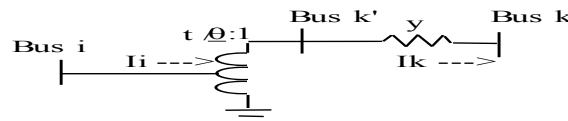


Figure 5. Off-Nominal Transformer Circuit Model

Assume that the transformer in Figure 5 has complex "off-nominal" tap  $t \angle \theta_t$  and series admittance  $y$ . The relationship between the voltage on opposite sides of the transformer tap is  $\tilde{V}_{k'} = \frac{\tilde{V}_i}{t \angle \theta_t}$ , and since the power on both sides of the ideal transformer must be the same, then  $\tilde{V}_i \tilde{I}_i^* = \tilde{V}_{k'} \tilde{I}_{k'}^*$ , implying that  $\tilde{I}_{k'} = \tilde{I}_i t \angle -\theta_t$ . Now, suppose that the transformer can be modelled by the following pi-equivalent circuit

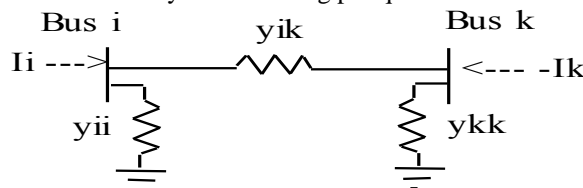


Figure 6. Pi Equivalent Circuit

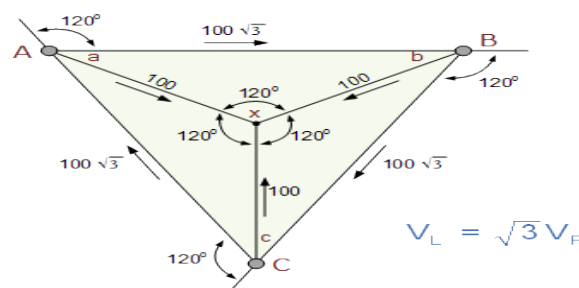


Figure 7. Three Phase Voltages And Currents

# International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: [www.ijareeie.com](http://www.ijareeie.com)

Vol. 8, Issue 5, May 2019

Where:  $V_L$  is the line-to-line voltage, and  $V_P$  is the phase-to-neutral voltage. A transformer can not act as a phase changing device and change single-phase into three-phase or three-phase into single phase. To make the transformer connections compatible with three-phase supplies we need to connect them together in a particular way to form a Three Phase Transformer Configuration. Consider the circuit below:

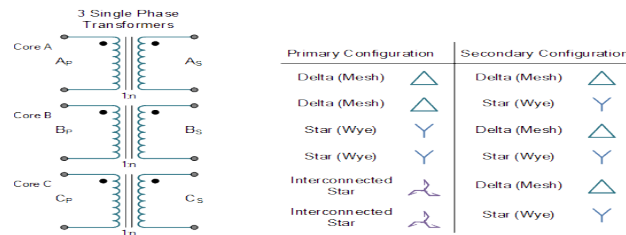


Figure 8. Three Phase Transformer Connections

## D. THREE PHASE TRANSFORMER STAR AND DELTA CONFIGURATIONS

But what do we mean by “star” (also known as Wye) and “delta” (also known as Mesh) when dealing with three-phase transformer connections. A three phase transformer has three sets of primary and secondary windings. Depending upon how these sets of windings are interconnected, determines whether the connection is a star or delta configuration. The three available voltages, which themselves are each displaced from the other by 120 electrical degrees, not only decided on the type of the electrical connections used on both the primary and secondary sides, but determine the flow of the transformers currents. With three single-phase transformers connected together, the magnetic flux’s in the three transformers differ in phase by 120 time-degrees. With a single the three-phase transformer there are three magnetic flux’s in the core differing in time-phase by 120 degrees. The standard method for marking three phase transformer windings is to label the three primary windings with capital (upper case) letters A, B and C, used to represent the three individual phases of RED, YELLOW and BLUE. The secondary windings are labelled with small (lower case) letters a, b and c. Each winding has two ends normally labelled 1 and 2 so that, for example, the second winding of the primary.

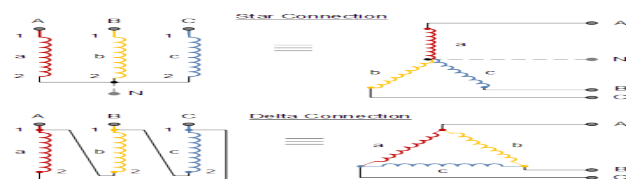


Figure 9. TRANSFORMER STAR AND DELTA CONFIGURATIONS

## III. TRANSFORMER WINDING IDENTIFICATION

### A. POSITIVE SEQUENCE IMPEDANCE

The impedance offered by the network to the flow of positive sequence current is called the positive sequence impedance. The positive sequence means all the electrical quantities are numerically equal and displaces each other by 120°.



Figure 10. Positive Sequence Impedance

# International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: [www.ijareeie.com](http://www.ijareeie.com)

Vol. 8, Issue 5, May 2019

## A. NEGATIVE SEQUENCE IMPEDANCE

The negative sequence impedance means the impedance offered by the network to the flows of negative sequence current.



Figure 11. Negative Sequence Impedance

## B. ZERO SEQUENCE IMPEDANCE

The impedance offered to zero sequence current is called the zero sequence impedance.

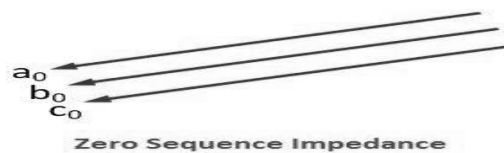


Figure 12. Zero Sequence Impedance

The impedance of the positive, negative and zero sequence components are given by the ratio of the phase sequence voltage to the phase sequence current of the system. There is no mutual impedance between various symmetrical components. The each sequence impedance considered separately, which simplifies the calculation of asymmetrical fault calculations.

## IV. SYSTEM SETUP

### A. THREE PHASE TRANSFORMER

Usually power is generated and distributed in three phase system, and therefore it is obvious that we would need three phase transformers to step up and step down voltages. Although, it is practically possible to use three suitably interconnected 'single phase transformers' instead of one 'three phase transformer', the following advantages of three phase transformers encourage their use –

### B. CONSTRUCTION OF THREE PHASE TRANSFORMER

Three phase transformers can be of core type or shell type (just like single phase transformers). The constructional details of core type as well as shell type three phase transformers are as follows.

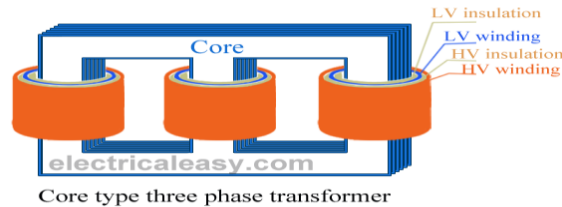
# International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: [www.ijareeie.com](http://www.ijareeie.com)

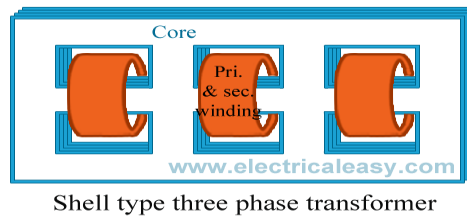
Vol. 8, Issue 5, May 2019

## 1. CORE TYPE CONSTRUCTION



The construction of a core type three phase transformer is as shown in the figure. The core consists of three legs or limbs. As usual, the core is made up of thin laminated sheets to reduce eddy current losses. Each limb has primary and secondary windings in cylindrical shape (former wound) arranged concentrically. The construction is well illustrated in the figure.

## 2. SHELL TYPE CONSTRUCTION



In a shell type three phase transformer, three phases are more independent than they are in core type. Each phase has its individual magnetic circuit. The construction of shell type three phase transformer is illustrated in the figure at right. The construction is similar to that of three single phase shell type transformers kept on the top of each other

## V. BLOCK DIAGRAM

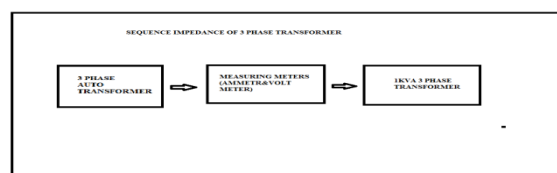


Figure 13. Block Diagram

## WORKING OF THREE PHASE TRANSFORMERS

Consider the below figure in which the primary of the transformer is connected in star fashion on the cores. For simplicity, only primary winding is shown in the figure which is connected across the three phase AC supply. The three cores are arranged at an angle of 120 degrees to each other. The empty leg of each core is combined in such that they form center leg as shown in figure.

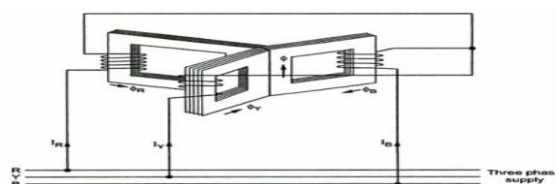


Figure 14. Primary winding in Star Connection

# International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: [www.ijareeie.com](http://www.ijareeie.com)

Vol. 8, Issue 5, May 2019

## THREE PHASE TRANSFORMER CONNECTIONS

As discussed above, either by a single three phase transformer or by three single phase transformers combination, three phase transformations can be carried out. The way of connecting the windings for three phase transformation is same whether the three windings of a three phase transformer or three windings of three single phase transformers are used. The primary and secondary windings are connected in different ways, such as in delta or star or combination of these two. The voltage and current ratings of the three phase transformer is depends on suitable connection. The most commonly used connections are

- Star-delta
- Delta-star
- Delta-delta & Star –star

### 1. STAR – DELTA CONNECTION

This type of connection is commonly used to step-down the voltages to a lower value in transmission end substations. Utility companies use this connection to reduce the voltage levels for distribution systems.

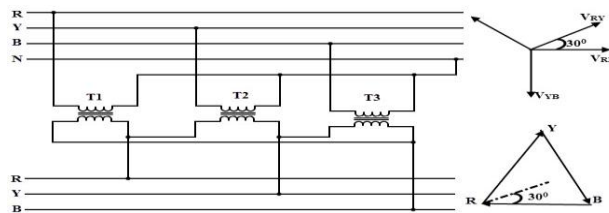


Figure 15. Star – Delta Connection

In this, the primary winding of the transformer is connected in star and secondary in delta connection.

- The neutral point on the primary or high voltage side can be grounded which is desirable in most of the cases.
- The line voltage ratio between secondary and primary is  $1/\sqrt{3}$  times the transformation ratio of each transformer.
- There exists 30 degrees phase difference between primary and secondary line voltages.
- Since the actual primary coil voltage is 58% of the primary line voltage, the insulation requirements for HV windings is reduced by using this winding.
- In this connection balanced three phase voltage are obtained at the secondary or LV side, even when the unbalanced currents are flowing the in the primary or HV side due to neutral wire. The neutral wire grounding also provides lightning surge protection.

### 2. DELTA – STAR CONNECTION

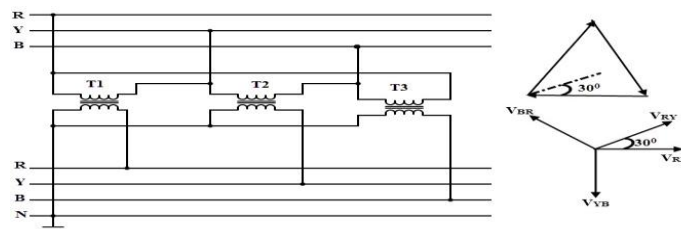


Figure 16. Delta – Star Connection

- This connection is used to step-up the voltage level and is commonly employed in sending end or starting of high tension transmission system.



# International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: [www.ijareeie.com](http://www.ijareeie.com)

Vol. 8, Issue 5, May 2019

- In this, the primary is connected in delta fashion and secondary in star fashion so that three phase 4 wire system at secondary is possible.
- The secondary voltage to the load is  $\sqrt{3}$  times the delta connected primary voltage. Also the load and secondary currents will be the same due to the same series circuit.
- This connection provides three single phase circuits at both lower and higher voltages and one three phase circuit at higher voltage so that single and three phase loads can be supplied.
- Dual voltages are obtained delta-star connection. Low single phase voltages are obtained by wiring between any phase and ground. Higher single phase voltages are obtained by wiring between any two phases. And by connecting all three phases to the load, three phase voltage is obtained.
- The insulation requirement on high voltage side is lowered due to the star (less number of turns per phase) connected secondary.
- Similar to star-delta, this connection causes to create a 30 degrees phase difference between primary and secondary line voltages.
- By using this connection, it is not possible to connect it parallel with delta-delta and star-star transformers due to the primary and secondary voltage phase difference.

### 3 DELTA-DELTA CONNECTION

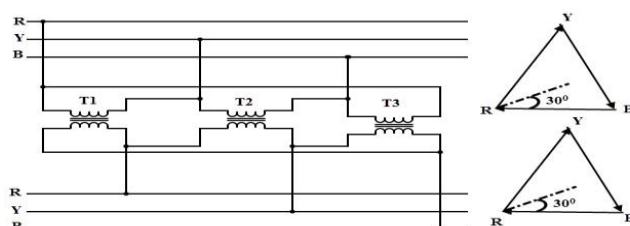


Figure 17. Delta – Delta Connection

- This type of connection is used when the supply source is delta connected and the secondary load needs single voltage with high current. This is generally employed for three phase power loads (like three phase motor).
- In this, both primary and secondary windings are connected in delta fashion.
- The voltage across the load is equal to the secondary voltage and voltage across the primary winding is equal to source voltage. In this, the current flow through the load will be 1.732 times the secondary current and the feeder current will equal to the 1.732 times current through the primary winding. Due to these high supply and load currents, it is recommended to place transformer much closer to both source and load circuits.
- In this, there exists no phase difference between the primary and secondary voltages.
- The three phase voltages remains constant even with unbalanced load, thus allows unbalanced loading.
- The main advantage of this connection is if the one transformer is defective or removed for service (open delta connection), then remaining two transformers continue to deliver three phase power at reduced load capacity.

### 4. STAR – STAR CONNECTION

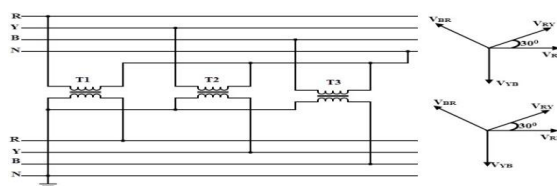


Figure 18. Star – Star Connection





ISSN (Print) : 2320 – 3765  
ISSN (Online): 2278 – 8875

# International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

*(A High Impact Factor, Monthly, Peer Reviewed Journal)*

Website: [www.ijareeie.com](http://www.ijareeie.com)

**Vol. 8, Issue 5, May 2019**

- In this, both primary and secondary windings are connected in star fashion and also there exist no phase difference between the primary and secondary voltages.
- In this, current flowing through both primary and secondary windings are equal to the currents of the lines to which they are connected (supply source and load). And voltages between line phases on either end equal to 1.732 times respective winding voltages.
- Due to neutral availability, it is well suited for three phase four wire system.
- This type connection satisfactorily works if the load is balanced. But if the load is unbalanced, the neutral point shift causes unequal phase voltages.
- Large third harmonic voltages would appear in both primary and secondary windings without the neutral tie. This may lead to the insulation failures.
- This connection considerably generates interference with communication lines and hence with this connection configuration, telephone lines cannot be run in parallel.
- Due to these disadvantages, the star-star connection is rarely used and not employed in practice.

## VI. CONCLUSION

- The impedance of the positive, negative and zero sequence components are given by the ratio of the phase sequence voltage to the phase sequence current of the system.
- There is no mutual impedance between various symmetrical components. The each sequence impedance considered separately, which simplifies the calculation of asymmetrical fault calculations.

## REFERENCES

- [1] Electric Power Transformer Engineering - edited by James H. Harlow, Page no.15.3
- [2] Symmetrical Components for Power Systems Engineering - By J. Lewis Blackburn, Page No. 227
- [3] Short-circuit Currents - By Jürgen Schlabbach, J. Schlabbach Page No. 19
- [4] Transformer Engineering: Design and Practice - By S.V. Kulkarni, S.A. Khaparde, Page No.74
- [5] Allis-Chalmers Manufacturing Company, 1941, Page No.6
- [6] Principles of Power Engineering Analysis- By Robert C. Degeneff, M. Harry Hesse, Page No. 189
- [7] Electrical Power System Analysis - By S. Sivanagaraju, B. V. Rami Reddy,Page No. 137
- [8] Electrical Power Engineering by Hensley William Kabisama McGraw-Hill Companies, 01-Jan-1993, Page No.245
- [9] [https://web.ecs.baylor.edu/faculty/grady/\\_07A\\_ELC4340\\_Spring13\\_Transformers.doc](https://web.ecs.baylor.edu/faculty/grady/_07A_ELC4340_Spring13_Transformers.doc)
- [10] John Horak, "A Derivation of Symmetrical Component Theory and Symmetrical Component Networks," Georgia Tech Protective Relaying Conference, April 2005. Available at [www.basler.com](http://www.basler.com).
- [11]. T.K Nagsarkar and M.S Sukhija, "Power System Analysis", New York Oxford University Press, pp.14-25, 2005
- [12] Hadi Saadat. Power System Analysis. Milwaukee Scholl of Engineering. WBC McGraw-Hill.