EEP3060

Power Engineering Lab

Determination of the Positive, Negative Zero Sequence Impedances of a Transformer

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I. Objective

To determine the positive, negative, and zero sequence impedances of a transformer, and to understand their significance in system opera on and fault analysis.

II. Apparatus

- 3-phase Transformer (3kVA)
- Ammeter (0 - 5A)
- Multimeter
- Connecting Wires
- 3-phase Power Supply (Auto Transformer/Variac)

III. Theory

Sequence impedances help analyze transformer behavior under unbalanced fault conditions, such as line-to-line or line-to-ground faults. They are essential for short-circuit analysis and protection coordination.

1. Positive Sequence Impedance (Z_1)

- Represents the impedance when balanced three-phase conditions are present.
- Defines transformer behavior under normal operating conditions when all phases are balanced.

2. Negative Sequence Impedance (Z_2)

- Represents the impedance under unbalanced conditions, especially during faults like line-to-line faults.
- Ideally similar to the positive sequence impedance in a perfect transformer.
- May differ slightly from Z_1 due to asymmetries such as:
  - Unbalanced winding resistances
  - Core saturation

3. Zero Sequence Impedance (Z_0)

- Comes into effect during unbalanced faults involving a line-to-ground fault.
- Zero sequence currents are in phase across all three phases.
- Strongly influenced by transformer winding configurations:
  - **Delta connections**: Typically exhibit very high Z_0 as they do not allow zero sequence currents to flow.
  - **Wye connections**: Allow zero sequence currents depending on grounding conditions.

IV. Experimental Procedure

a) Positive Sequence Impedance Measurement

Steps:

1. **Circuit Setup:**
   - Connect the ciruit as shown in Figure 1. (Circuit Diagram for Positive Sequence Impedance Measurement.)
2. **Applying Voltage:**
   - Gradually increase the voltage using the 3-phase Auto Transformer.
   - Adjust the voltage until the rated current of ≈ 4.2 flows through Ammeter A_2.
3. **Measurement:**
   - Measure the phase voltage (V_{ph}) between the R-phase & Neutral using a multimeter.
   - Record the current from Ammeter A_2.
   - Take three sets of readings at different current levels up to ≈ 4.2 A.
4. **Calculations:**
   - For each reading, calculate the positive sequence impedance using the following formula:

$$Z_1 = \frac{V_{ph}\,(\text{reading of multimeter})}{I\,(\text{reading of ammeter } A_2)} \tag{1}$$

   - Finally, calculate the average of the three Z_1 values to determine the final positive sequence impedance.

Ciruit Diagram

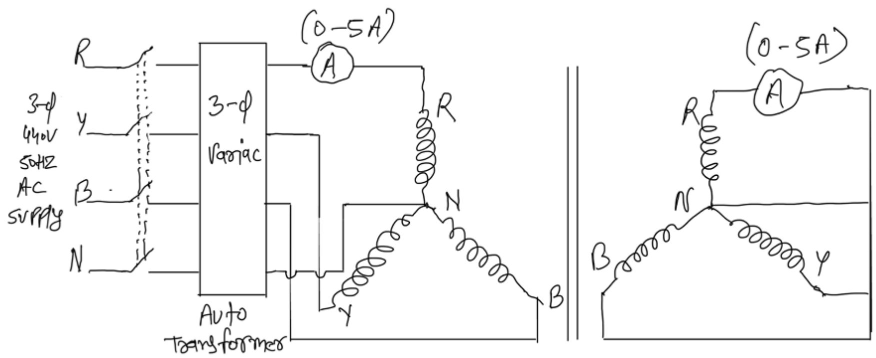

Figure 1: Circuit Diagram for Positive Sequence Impedance(Z_1) Measurement

Observation Table

$V_{ph}(V)$	$I(A)$	$Z_1(\Omega)$
12.70	2.20	5.72
17.09	3.00	5.70
23.72	4.20	5.65

Table 1: Observation Table for Positive Sequence Impedance

Calculations

1. For the first measurement:

$$Z_1 = \frac{V_{ph}}{I} = \frac{12.70}{2.20} = 5.72\,\Omega$$

2. For the second measurement:

$$Z_1 = \frac{V_{ph}}{I} = \frac{17.09}{3.00} = 5.70\,\Omega$$

3. For the third measurement:

$$Z_1 = \frac{V_{ph}}{I} = \frac{2.72}{4.20} = 5.65\,\Omega$$

Now, to calculate the average Z_1:

$$\text{Average } Z_1 = \frac{Z_1(1) + Z_1(2) + Z_1(3)}{3} = \frac{5.72 + 5.70 + 5.65}{3} = 5.69\,\Omega$$

b) Negative Sequence Impedance Measurement

Observations

- In an ideal transformer, the negative sequence impedance (Z_2) is generally equal to the positive sequence impedance (Z_1), due to the symmetrical nature of transformer windings.
- Thus, $Z_2 = Z_1$

c) Zero Sequence Impedance Measurement

i. Star Grounded - Star Grounded Connection

Steps:

1. **Circuit Setup:**
   - Connect the ciruit as shown in Figure 2. (Circuit Diagram for Zero Sequence Impedance Measurement of Star Grounded-Star Grounded Connection).
2. **Applying Voltage:**
   - Gradually increase the voltage using the 3-phase Auto Transformer.
   - Adjust the voltage until the rated current of ≈ 4.2 flows through Ammeter A_2.
3. **Measurement:**
   - Measure the phase voltage (V_{ph}) between the R-phase & Neutral using a multimeter.
   - Record the current from Ammeter A_2.
   - Take three sets of readings at different current levels up to ≈ 4.2 A.
4. **Calculations:**
   - For each reading, calculate the zero sequence impedance using the following formula:

$$Z_0 = \frac{V_{ph}\,(\text{reading of multimeter})}{I\,(\text{reading of ammeter } A_2)} \tag{2}$$

   - Finally, calculate the average of the three Z_0 values to determine the final zero sequence impedance.

Circuit Diagram:

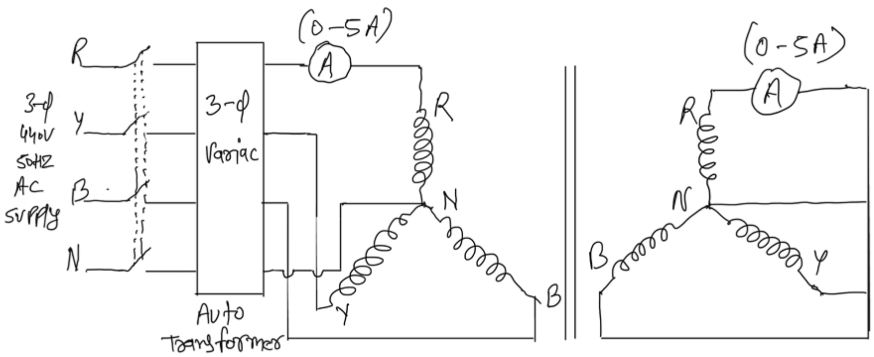

Figure 2: Circuit Diagram for Zero Sequence Impedance(Z_0) Measurement of Star Grounded-Star Grounded Connection

Observation Table:

$V_{ph}(V)$	$I(A)$	$Z_0(\Omega)$
16.03	2.72	5.89
20.50	3.48	5.89
24.05	4.16	5.78

Table 2: Observation Table for Zero Sequence Impedance

Calculations:

1. For the first measurement:

$$Z_0 = \frac{V_{ph}}{I} = \frac{16.03}{2.72} = 5.89\,\Omega$$

2. For the second measurement:

$$Z_0 = \frac{V_{ph}}{I} = \frac{20.50}{3.48} = 5.89\,\Omega$$

3. For the third measurement:

$$Z_0 = \frac{V_{ph}}{I} = \frac{24.05}{4.16} = 5.78\,\Omega$$

Now, to calculate the average Z_1:

$$\text{Average } Z_0 = \frac{Z_0(1) + Z_0(2) + Z_0(3)}{3} = \frac{5.89 + 5.89 + 5.78}{3} = 5.85\,\Omega$$

ii. Star Grounded-Star (Isolated Neutral) Connection

Steps:

1. **Circuit Setup:**
   - Connect the circuit as shown in Figure 3 (Circuit Diagram for Zero Sequence Impedance Measurement of Star Grounded-Star Connection)
   - In this configuration, the neutral on the secondary side is Isolated(not grounded).
2. **Observations:**
   - No current flows in Ammeter A_2 when voltage is applied to the primary winding.
   - Current will only be observed in Ammeter A_1 due to isolated neutral.

Circuit Diagram:

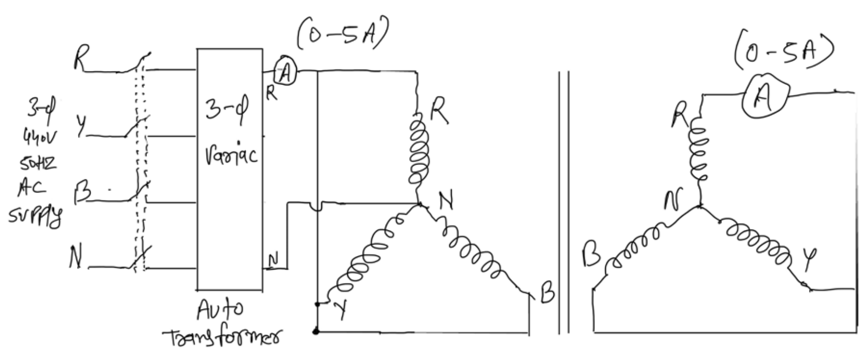

Figure 3: Circuit Diagram for Zero Sequence Impedance(Z_0) Measurement of Star Grounded-Star Connection

iii. Star Grounded-Delta Connection

Steps:

1. **Circuit Setup:**
   - Connect the circuit as shown in Figure 3 (Circuit Diagram for Zero Sequence Impedance Measurement of Star Grounded-Delta Connection)
   - In this configuration, the primary side is connected in Star with grounded neutral and the secondary side is connected in Delta.
2. **Observations:**
   - No current flows in Ammeter A_2 when voltage is applied to the primary winding.
   - Current will only be observed in Ammeter A_1 due to the delta connection, which blocks zero-sequence currents.

Circuit Diagram:

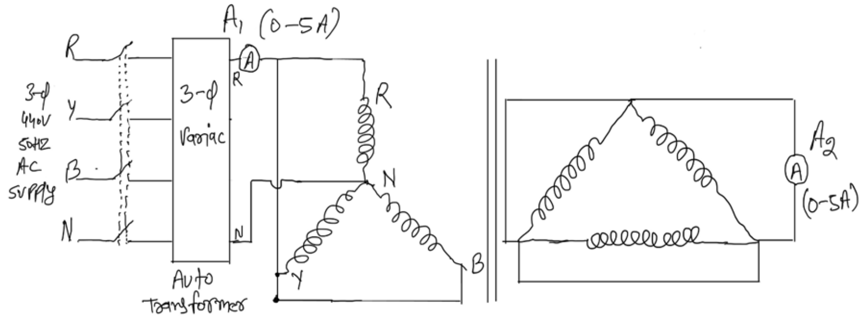

Figure 4: Circuit Diagram for Zero Sequence Impedance(Z_0) Measurement of Star Grounded-Delta Connection

V. Results & Conclusion

- In this lab, the sequence impedances of the transformer were successfully determined.
- The positive, negative, and zero sequence components were calculated and verified under different operating conditions.
- The results provide insight into transformer behaviour during fault conditions, which is crucial for protection system design.
- The Impedances are found as follows:
  - Positive Sequence Impedance: $Z_1 = 5.69$
  - Negative Sequence Impedance: $Z_2 = 5.69$
  - Zero Sequence Impedance: $Z_0 = 5.85$