UNIT 4: Three Phase Transformers

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Three Phase Transformers: Construction, Three phase transformer, phasor groups and their connections, open delta connection, three phase to 2 phase and their applications, Three winding transformers. Parallel operation of single phase and three phase transformers and load sharing.

OUTCOMES

1. **Three Phase Transformers: Construction**
   - Understand core types, insulation methods, cooling techniques, and mechanical design of three-phase transformers.
2. **Three Phase Transformer Phasor Groups and Their Connections**
   - Identify phasor groups, understand different connection types (Y-Y, Δ-Δ, Y-Δ, Δ-Y), phase shifts, and perform vector group testing.
3. **Open Delta Connection (V-connection)**
   - Comprehend the open delta configuration, its applications, limitations, and power rating calculations.
4. **Three Phase to Two Phase Conversion and Applications**
   - Learn the Scott-T connection method, its industrial applications, and design considerations for three-phase to two-phase conversion.
5. **Three Winding Transformers**
   - Understand the construction, design, applications, and equivalent circuit representation of three-winding transformers.
6. **Parallel Operation of Single Phase and Three Phase Transformers and Load Sharing**
   - Grasp conditions for parallel operation, principles of load sharing, techniques for load distribution, and methods for testing and troubleshooting.

❖ Three Phase Transformers: Construction

1. Understanding Transformer Core Types:

- **Core Type:**
  - **Construction**: Consists of three legs (one for each phase) with two yokes connecting them at the top and bottom. The primary and secondary windings are placed around each leg.
  - **Advantages**: Simpler design, easier to manufacture, and often used for lower voltage applications.
  - **Applications**: Common in smaller power transformers and distribution transformers.
- **Shell Type:**
  - **Construction**: Features a central core with two outer legs. The windings are placed around the central leg, and the magnetic path is through the outer legs and back through the central leg.
  - **Advantages**: Better magnetic shielding, reduced leakage flux, and better short-circuit strength.
  - **Applications**: Often used for high-voltage and high-capacity transformers.

2. Insulation Methods:

- **Materials**: Common insulating materials include paper, pressboard, and oil. Modern transformers also use synthetic materials like epoxy resin and polymer composites.
- **Techniques**:
  - **Layer Insulation**: Insulating materials are placed between winding layers to prevent electrical contact.
  - **End-turn Insulation**: Extra insulation is applied at the winding ends to handle higher electric stress.
  - **Oil Immersion**: Windings are immersed in insulating oil, which serves both as an insulator and a coolant.

3. Cooling Techniques:

- **Oil-Immersed Cooling**:
  - **ONAN (Oil Natural Air Natural)**: The simplest method where natural convection circulates the oil and air.
  - **ONAF (Oil Natural Air Forced)**: Fans are used to force air over the radiators, enhancing cooling.
  - **OFWF (Oil Forced Water Forced)**: Oil is pumped through a heat exchanger cooled by water.
- **Air-Cooled Cooling**:
  - **Dry-Type Transformers**: Utilize ambient air for cooling, with or without fans to enhance air circulation.
  - **Advantages**: Suitable for indoor use and areas where fire safety is a concern.
- **Radiators**:
  - **Function**: Extend the surface area for heat dissipation. Oil circulates through the radiators to release heat to the surrounding air.

4. Mechanical Design:

- **Core Clamping**: Ensures the core laminations are tightly clamped to reduce vibration and noise, and to prevent movement during operation.
- **Tank Design**: The transformer tank must be robust to contain the insulating oil and withstand internal pressures. Often equipped with conservators to manage oil expansion.
- **Bushing Design**: Insulated bushings are used to bring high-voltage connections through the transformer tank while maintaining insulation and preventing leaks.
- **Winding Support**: Windings are supported to withstand mechanical stresses due to short circuits and operational vibrations. Proper support also helps in maintaining the integrity of the insulation system.

❖ Three Phase Transformer Phasor Groups and Their Connections

1. Phasor Groups Identification:

- **Phasor Groups**: Transformers are categorized into different phasor groups based on their winding connections and the phase displacement between primary and secondary sides. Common groups include Dy11, Yd1, etc.
  - **Dy11**: Delta primary, star secondary, 30° lag phase shift.
  - **Yd1**: Star primary, delta secondary, 30° lead phase shift.
- **Significance**: Understanding these groups helps in ensuring compatibility when connecting transformers in parallel or within a network.

2. Connection Types:

- **Star-Star (Y-Y)**:
  - **Configuration**: Both primary and secondary windings are connected in a star.
  - **Advantages**: Neutral point availability, suitable for long-distance transmission.
  - **Disadvantages**: Can result in voltage imbalances if loads are not balanced.
- **Delta-Delta (Δ-Δ)**:
  - **Configuration**: Both primary and secondary windings are connected in a delta.
  - **Advantages**: No neutral needed, better handling of unbalanced loads, no phase shift.
  - **Disadvantages**: Higher cost due to more windings and insulation.
- **Star-Delta (Y-Δ)**:
  - **Configuration**: Primary winding in star, secondary in delta.
  - **Advantages**: No neutral point required on the secondary side, commonly used in distribution transformers.
  - **Disadvantages**: 30° phase shift must be considered in system design.
- **Delta-Star (Δ-Y)**:
  - **Configuration**: Primary winding in delta, secondary in star.

- **Advantages**: Provides a neutral point on the secondary side, suitable for stepping down voltage.
- **Disadvantages**: 30° phase shift, careful system design needed.

3. Phase Shift Understanding:

- **Phase Shift**: Transformers with different connections introduce phase shifts (e.g., 0°, ±30°) between primary and secondary sides. This affects how they can be connected in parallel and how they interact with the rest of the power system.
  - **Impact**: Phase shifts can lead to complications in synchronization and load sharing if not properly managed.

4. Vector Group Testing:

- **Purpose**: Ensures transformers are correctly connected and identifies the phasor group, which is critical for parallel operation.
- **Procedure**: Apply a three-phase voltage to the primary, measure the secondary voltages, and compare them to determine the phase relationship.

❖ Open Delta Connection (V-connection)

1. Open Delta Configuration:

- **Construction**: Uses two transformers instead of three, connected in a delta configuration.
- **Working Principle**: The open delta connection can provide three-phase power, albeit at a reduced capacity compared to a full delta configuration.

2. Applications and Limitations:

- **Applications**:
  - **Emergency Use**: When one transformer in a delta connection fails, the remaining two can continue to provide power.
  - **Cost Savings**: In situations where full capacity is not always needed, using an open delta can save on initial costs.
- **Limitations**:
  - **Reduced Capacity**: Only delivers 57.7% of the power capacity of a full delta connection.
  - **Unbalanced Load Handling**: Less effective at handling unbalanced loads compared to a full delta connection.

3. Calculation of Ratings:

- **Effective Power Rating**: The capacity of an open delta connection is approximately 86.6% of the rating of two transformers in full delta configuration.
- Formula: $P_{opendelta} = P_{fulldelta} \times \frac{2}{\sqrt{3}} \approx P_{fulldelta} \times 0.577$

- **Example**: If the full delta rating is 100 kVA, the open delta rating would be approximately 57.7 kVA.

❖ Three Phase to Two Phase Conversion and Their Applications

Scott-T Connection:

- **Method**: The Scott-T connection uses two transformers to convert three-phase power into two-phase power. One transformer (main transformer) is connected between two phases of the three-phase system, while the other transformer (teaser transformer) is connected between one of those phases and the neutral point.
- **Configuration**: The main transformer is typically connected to phases A and C, and the teaser transformer is connected between phase B and a tap point on the main transformer.
- **Purpose**: This method achieves a balanced two-phase output from a three-phase input.

Applications:

- **Industrial Use**: Conversion is often required for older two-phase equipment and specific types of motor drives that are designed for two-phase power.
- **Railway Electrification**: Some rail systems use two-phase power, and the Scott-T connection facilitates this from a three-phase supply.
- **Specialized Equipment**: Certain industrial processes and older machinery that were designed for two-phase operation continue to use this conversion.

Design Considerations:

- **Transformer Taps**: Accurate tap settings on the transformers are crucial to maintain phase balance and voltage levels.
- **Voltage Ratings**: Transformers must be designed to handle the input and output voltage ratings specific to the application.
- **Load Balance**: Proper design ensures that loads on the two-phase system are balanced to avoid overloading the transformers.

❖ Three Winding Transformers

Construction and Design:

- **Windings**: Three-winding transformers have three sets of windings – primary, secondary, and tertiary. The tertiary winding is usually connected in delta to provide stabilization.
- **Core**: The core structure is designed to accommodate the three windings, ensuring minimal flux leakage and efficient magnetic coupling.
- **Insulation**: Enhanced insulation is required due to the presence of three sets of windings and their interaction.

Applications:

- **Power Stations**: Used for voltage regulation and load distribution between different sections of the power grid.
- **Substations**: Facilitate connection between different voltage levels and improve system flexibility.
- **Industrial Applications**: Support multiple voltage requirements within industrial plants, allowing for efficient distribution and regulation of power.

Equivalent Circuit Representation:

- **Circuit Model**: Represents the transformer with equivalent impedances for each winding, along with mutual inductances.
- **Analysis**: Helps in understanding voltage regulation, power losses, and load sharing characteristics under various operating conditions.

❖ Parallel Operation of Single Phase and Three Phase Transformers and Load Sharing

Conditions for Parallel Operation:

- **Voltage Ratios**: Transformers must have identical voltage ratios to ensure proper voltage levels across all phases.
- **Impedance Matching**: The impedance of the transformers should be similar to ensure balanced load sharing.
- **Phase Sequence**: The phase sequence of all transformers must be the same to prevent phase mismatches.

Load Sharing Principles:

- **Impedance Ratio**: Load sharing is proportional to the impedance ratios of the transformers; lower impedance transformers will carry more load.
- **Current Distribution**: Proper load sharing ensures that each transformer carries its share of the load current based on its capacity.

Parallel Operation Techniques:

- **Voltage Matching**: Adjust tap changers to match the output voltages of the transformers.
- **Current Sharing**: Use of current sharing techniques such as load ratio control to distribute loads evenly.

Testing and Troubleshooting:

- **Compatibility Testing**: Verify that transformers meet the conditions for parallel operation by checking voltage ratios, impedance, and phase sequence.
- **Troubleshooting**: Identify and resolve issues such as circulating currents, unbalanced loads, and incorrect connections to ensure stable and efficient parallel operation.