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COOLING SYSTEMS IN TRANSFORMERS.

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Abstract: This article provides an in-depth exploration of cooling systems in transformers. The article categorizes transformer cooling systems into air-cooled and oil-cooled types, further detailing subcategories like natural and forced cooling methods (e.g., ONAN, ONAF, OFAF, OFWF). Advanced cooling technologies such as directed oil cooling, gas cooling, water spray cooling, and heat pipe cooling are also discussed, highlighting their applications in specialized and high-capacity transformers.

Key words: Transformer cooling systems, Heat dissipation in transformers,Air-cooled transformers,Oil-cooled transformers, ONAN cooling system, ONAF cooling system, OFAF cooling system, OFWF cooling system, Directed oil cooling, Gas-insulated transformers (GIT), Water spray cooling, Heat pipe cooling technology, Transformer maintenance.

Transformers play a critical role in the transmission and distribution of electrical energy by adjusting voltage levels to meet the demands of various applications. As transformers operate, they generate heat due to electrical and magnetic losses. To ensure efficient performance and long-term reliability, managing this heat is essential. Overheating can lead to damage, decreased efficiency, and a shorter lifespan of transformers Cooling systems are therefore integral to transformer design, enabling the dissipation of heat and maintaining optimal operating conditions.

Importance of cooling in transformer

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Heat generated in transformers primarily arises from two sources:

1.Core Losses (Iron Losses): Caused by the alternating magnetic field in the core, resulting in hysteresis and eddy current losses.

2.Copper Losses (Winding Losses): Occur due to the resistance of the windings when current flows through them.

Excessive heat can degrade insulation materials, reduce efficiency, and potentially cause failures. Effective cooling systems ensure the following:

a)Enhanced Efficiency: Maintaining lower operating temperatures minimizes energy losses.

b)Improved Lifespan: Prevents damage to insulation and other components.

c)Safety: Reduces the risk of overheating and associated hazards.

Types of transformer cooling systems.

Cooling systems in transformers can be broadly categorized based on the cooling medium (air or oil) and the method of circulation (natural or forced). Below are the common types:

1.Air-Cooled systems.

An air-cooled system in transformers is a method used to cool the transformer's core and windings. This type of cooling system relies on air as the medium to carry away the heat generated during transformer operation. Here's an overview of how it works.

Basic Principle: Transformers generate heat due to the electrical losses (such as eddy current losses, hysteresis losses in the core, and I^2R losses in the windings). An air-cooled system uses ambient or forced air to dissipate this heat and maintain safe operational temperatures.

Types of Air-Cooled Systems:

a)Natural Air Cooling (AN): This relies on the natural convection of air around the transformer to carry away the heat. The heat dissipates from the transformer's

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surface to the surrounding air. This type is typically used in smaller transformers with low to moderate load.

- **Description:** Heat is dissipated through natural air circulation around the transformer.
- **Application:** Used in small, low-power transformers where heat generation is minimal.

b)Forced Air Cooling (AF): In this system, fans or blowers are used to force air over the transformer's surface to enhance the cooling effect. This method is often employed for larger transformers or those subjected to higher loads.

- **Description:** Fans are used to increase air circulation, improving heat dissipation.
- **Application:** Common in medium-sized transformers requiring additional cooling capacity.

2.Oil-Cooled Systems

Oil-cooled systems are widely used across industries to manage heat generated during the operation of mechanical or electronic components. These systems use oil as the primary cooling medium due to its thermal stability, insulating properties, and effectiveness in heat dissipation. Here's an in-depth look at oil-cooled systems, their components, applications, advantages, and challenges. Transformers often use oil as a cooling medium due to its excellent thermal conductivity and insulating properties.

How Oil-Cooled Systems Work?Oil-cooled systems function by transferring heat from heat-generating components to oil, which circulates through the system. The heated oil is then cooled, either through air cooling (using radiators or heat exchangers) or water cooling, and recirculated to maintain a consistent operating temperature.

Key components include:

Heat Source: Equipment or components generating heat, such as engines, transformers, or electronic circuits.

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Cooling Oil: Specialized oils with high thermal conductivity, low volatility, and stability under temperature variations.

Pump: Ensures the circulation of oil through the system.

Radiator or Heat Exchanger: Cools the heated oil.

Reservoir: Stores the oil and helps in its thermal expansion and contraction.

Advantages of Oil-Cooled Systems:

1. **Efficient Heat Dissipation**: Oil's high heat capacity allows it to absorb and dissipate large amounts of heat.
2. **Electrical Insulation**: Unlike water, oil acts as an insulator, reducing the risk of electrical short circuits.
3. **Durability**: Oil is less prone to corrosion, extending the life of cooling system components.
4. **Adaptability**: Effective in environments where traditional cooling methods, like air cooling, may not suffice.

a. Oil Natural Air Natural (ONAN)

- **Description:** Heat is transferred from the windings to the oil, which circulates naturally. The oil then transfers heat to the transformer tank, dissipated by natural air circulation.
- **Application:** Common in distribution transformers and low-capacity power transformers.

b. Oil Natural Air Forced (ONAF)

- **Description:** Similar to ONAN, but with fans to force air circulation, enhancing cooling efficiency.
- **Application:** Used in higher-capacity transformers where natural circulation is insufficient.

c. Oil Forced Air Forced (OFAF)

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- **Description:** Both oil and air are circulated using pumps and fans, providing highly efficient cooling.
- **Application:** Found in large power transformers with high heat dissipation requirements.

d. Oil Forced Water Forced (OFWF)

- **Description:** Heat is transferred from the oil to water via heat exchangers. Pumps circulate both oil and water.
- **Application:** Used in very large transformers, such as those in power generation plants.

3.Other Advanced Cooling Systems

a. Directed Oil Cooling

Directed oil cooling in transformers involves channeling the flow of insulating and cooling oil specifically to areas that generate the most heat, such as the windings and core. The system leverages:

Targeted Oil Flow: Cooling oil is directed through ducts or nozzles to high-temperature zones, ensuring efficient heat dissipation.

Active Circulation: Pumps circulate the oil under pressure to maintain a steady flow.

Heat Removal: The heated oil is transferred to cooling units, such as radiators or heat exchangers, where it is cooled before re-entering the system.

- **Description:** Oil flow is directed specifically to the hottest parts of the transformer, such as windings and core, for targeted cooling.
- **Application:** High-voltage and extra-high-voltage transformers.

b. Gas Cooling (GIT)

Gas cooling systems rely on the circulation of a gas medium through the transformer to absorb and dissipate heat. The process involves:

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Heat Absorption: The gas flows through the transformer, contacting hot components like windings and the core to absorb heat.

Heat Dissipation: The heated gas is directed to cooling units, where the heat is transferred to the ambient environment, typically through radiators or heat exchangers.

Recirculation: After cooling, the gas is recirculated back into the transformer for continuous heat management.

- **Description:** Involves the use of inert gases, such as SF6, for cooling and insulation.
- **Application:** Specialized applications where oil cooling is not feasible.

Selection of Cooling Systems.

The choice of a cooling system depends on several factors:

- **Transformer Size:** Larger transformers require more advanced cooling mechanisms.
- **Load Requirements:** Higher loads generate more heat, necessitating efficient cooling.
- **Environmental Conditions:** Ambient temperature and location influence the cooling design.
- **Cost and Maintenance:** Advanced systems like OFWF are costlier and require regular maintenance but are necessary for high-performance applications.

Conclusion

Cooling systems are vital for the efficient and safe operation of transformers. By understanding the different types of cooling methods and their applications, engineers can ensure optimal transformer performance and longevity. As technology advances, innovations in cooling techniques continue to enhance transformer efficiency, making them more reliable and adaptable to modern energy demands.

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