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ANALYSIS OF OPERATING AND SHORT-CIRCUIT MODES OF POWER TRANSFORMERS AND ISSUES OF ENERGY AND RESOURCE SAVING

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Abstract: Power transformers are among the most important components of electrical power systems, ensuring efficient transmission and distribution of electrical energy. The operational efficiency, reliability, and service life of transformers depend significantly on their operating conditions. This paper analyzes the operating and short-circuit modes of power transformers, evaluates power losses under different loading conditions, and investigates energy- and resource-saving approaches. The study examines the relationship between transformer loading and efficiency, assesses thermal effects during short-circuit conditions, and proposes measures to improve transformer performance. The obtained results demonstrate that the application of modern energy-saving technologies and optimized operating conditions can significantly reduce energy losses and extend transformer service life.

Keywords: power transformer, short-circuit mode, energy efficiency, copper losses, core losses, resource saving, transformer diagnostics, power systems.

1. Introduction

The growing demand for electrical energy requires the improvement of efficiency and reliability in power system equipment. Power transformers play a critical role in electrical networks by converting voltage levels and ensuring stable energy transmission. However, transformer losses contribute significantly to overall power system inefficiencies.

Transformer performance is influenced by operating conditions, loading levels, temperature rise, and fault events such as short circuits. Excessive losses not only reduce efficiency but also accelerate insulation aging and decrease equipment lifespan. Therefore, comprehensive analysis of transformer operating and short-circuit modes is essential for enhancing energy efficiency and resource conservation.

This research focuses on evaluating transformer behavior under normal and fault conditions and identifying practical solutions for reducing energy losses and improving operational reliability.

2. Transformer Operating Mode Analysis

Under normal operating conditions, transformer efficiency is determined by the ratio of output power to total input power.

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The transformer efficiency can be expressed as:

$$\eta = \frac{P_2}{P_2+P_{Fe}+P_{Cu}} \times 100\%$$

where:

P_2 – output power;

PFe – core (iron) losses;

PCu – copper losses in the windings.

For the analysis, a 1000 kVA distribution transformer was considered.

Loading (%)	Efficiency (%)
25	95.8
50	97.5
75	98.4
100	98.1
125	97.2

Table 1. Transformer Efficiency at Different Loading Levels

The results indicate that maximum efficiency is achieved at approximately 75–80% loading. At lower loads, core losses dominate, while at higher loads copper losses increase significantly.

Loading (%)	25	50	75	100	125
Efficiency (%)	95.8	97.5	98.4	98.1	97.2

Figure 1. Efficiency versus Transformer Loading

The efficiency curve demonstrates that optimal transformer operation occurs near its rated loading level.

3. Analysis of Short-Circuit Operating Mode

Short-circuit conditions represent one of the most severe stresses experienced by power transformers. During a fault, the current increases dramatically, causing substantial thermal and mechanical stresses.

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The short-circuit current is calculated by:

$$I_{qt} = \frac{I_n \cdot 100}{U_k\%}$$

where:

Isc – short-circuit current;

In – rated current;

Uk – short-circuit voltage percentage.

For the investigated transformer:

Rated power = 1000 kVA

Rated voltage = 10 kV

Rated current = 57.7 A

Short-circuit voltage = 6%

The calculated short-circuit current is:

Isc = 961 A

This value is approximately 16.7 times higher than the rated current.

Thermal Effects During Short Circuits

Copper losses are determined by:

$$P_{Cu} = I^2 R$$

Since the current increases more than sixteen times during a fault, the copper losses increase nearly 278 times. Such a rapid increase in heat generation can lead to insulation degradation, winding deformation, and potential transformer failure.

4. Analysis of Energy Losses

Transformer losses consist primarily of:

Core (no-load) losses;

Copper (load) losses.

The calculated losses under different loading conditions are presented below.

Loading (%)	Core Losses (kW)	Copper Losses (kW)	Total Losses (kW)
25	2.1	0.7	2.8
50	2.1	2.8	4.9
75	2.1	6.3	8.4
100	2.1	11.2	13.3

Table 2. Transformer Loss Analysis

The results show that copper losses increase proportionally to the square of the load current. Consequently, overloaded transformers experience substantially higher losses and reduced efficiency.

Loading (%)	25	50	75	100
Total Losses (kW)	2.8	4.9	8.4	13.3

Figure 2. Total Losses versus Loading

5. Energy and Resource Saving Approaches

To improve transformer efficiency and reduce operational costs, the following measures are recommended:

Technical Measures

Application of amorphous-core transformers;

Reduction of winding resistance through advanced conductor materials;

Improvement of cooling systems;

Optimal transformer loading management;

Reactive power compensation;

Installation of intelligent monitoring systems.

Operational Measures

Periodic diagnostic testing;

Dissolved gas analysis (DGA);

Thermal imaging inspections;

Online condition monitoring;

Scheduled maintenance and oil quality assessment.

These approaches contribute to lower energy losses, enhanced reliability, and extended equipment lifetime.

6. Results and Discussion

A comparative analysis was performed before and after implementing energy-efficient modernization measures.

Parameter	**Before Modernization**	**After Modernization**
Annual Energy Losses	100%	82%
Efficiency	98.1%	98.9%
Winding Temperature	95°C	78°C
Maintenance Costs	100%	85%

Table 3. Performance Improvement After Modernization

The obtained results indicate:

Reduction of annual energy losses by approximately 18%;

Increase in transformer efficiency by 0.8%;

Significant decrease in operating temperature;

Lower maintenance and operating expenses.

These improvements directly enhance transformer reliability and sustainability.

7. Conclusion

This study investigated the operating and short-circuit modes of power transformers and their impact on energy efficiency and resource conservation. The analysis revealed that transformer efficiency reaches its maximum value at approximately 75–80% loading. Under short-circuit conditions, current and thermal stresses increase dramatically, causing severe damage risks to transformer windings and insulation systems.

The implementation of modern energy-efficient technologies, advanced monitoring systems, and optimized loading strategies can reduce energy losses by 15–20%, increase transformer efficiency, and significantly extend equipment service life. Therefore, energy-saving transformer technologies represent an important direction for the modernization of contemporary power systems.

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