

Research on Equivalent Modeling of Oil-Immersed Self-Cooling Transformer Radiator

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Abstract—The optimization of heat dissipation performance during transformer operation directly affects the reliability and service life of the equipment. Traditional heat dissipation calculation methods have certain limitations in terms of accuracy and resource consumption. To address this, this paper proposes an optimized heat sink equivalent method that reduces the number of cooling fins and adjusts the oil width while ensuring the same amount of heat dissipation. First, a mathematical model for heat sink equivalence is established, and the variation law of heat transfer coefficient is discussed. Then, based on the equivalent parameters, a finite element simulation model of transformer overall temperature field is constructed, and the effectiveness of equivalent method under multiple working conditions is verified. Finally, through a comparative analysis of experimental tests and simulation results, the accuracy of method and its potential for engineering applications are evaluated. The research results show that the error between simulation and experimental results is within 5%, verifying the feasibility and reliability of method, and providing solid theoretical support and practical evidence for the optimization design of transformer cooling systems.

Keywords—Equivalent method, Experimental tests, Heat sink, Temperature field

I. INTRODUCTION

THE HEAT generated by transformers during long-term operation needs to be dissipated promptly by the cooling system to prevent high temperatures from affecting the insulation materials and equipment lifespan[1],[2]. However, traditional heat dissipation calculation methods have limitations and are difficult to apply efficiently in complex structures or under multiple working conditions. Therefore, conducting research on heat sink equivalence, which simplifies the structural parameters of the heat sink for optimized calculations, holds significant theoretical value and engineering significance. This paper presents an optimization method based on equivalent heat dissipation theory, achieving the maintenance of heat dissipation performance by adjusting the structural parameters of the heat sink. The accuracy and feasibility of this method are verified through simulations of the overall temperature field of the transformer.

II. HEAT SINK EQUIVALENT

A. Theoretical Derivation

According to Newton's Law of Cooling,

$$Q = hA(T_0 - T_1) \quad (1)$$

Where, Q represents the heat dissipation of the heat sink; h represents the heat transfer coefficient of the outer surface of the fins; A represents the heat dissipation area of the fins; T_0 represents the temperature of the surface of the heat sink; and T_1 represents the surrounding ambient temperature.

The heat dissipation area of the fins is,

$$A = 2(X + 2d + L)HN \quad (2)$$

Where, X represents the oil flow width between the fins; N represents the number of fins in the heat sink; d represents the thickness of the fins; L represents the width of the fins; and H represents the height of the fins.

$$Q = 2(X + 2d + L)HNh(T_0 - T_1) \quad (3)$$

B. Equivalent Method

Fig. 1 shows the equivalence of a single heat sink for a 1000kVA oil-immersed transformer, where the number of fins is reduced from 10 to 8, 6, and 5. It is assumed that the heat transfer coefficient on the surface of the original fins is uniformly distributed, and calculated based on the literature[1] 4.96W/(m²·K), the equivalent heat transfer coefficient after reduction can be determined. As shown in Tab. 1.

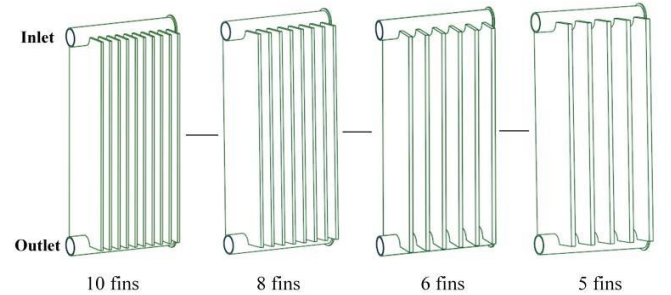


Fig. 1. Radiator equivalent model
Tab. 1 Heat Transfer Coefficient

Number of Heat Sink Fins	10	8	6	5
Heat Transfer Coefficient W/(m ² ·K)	4.96	5.54	6.2	8.18

III. SIMULATION VERIFICATION AND OVERALL TEMPERATURE FIELD ANALYSIS

A. Simulation Verification

Fig. 2 shows the increase in (a). average oil temperature and (b). outlet temperature with the rise in inlet oil temperature before and after equivalence. Fig. 3 illustrates (a). outlet hot-spot temperature and (b). error before and after equivalence. From (b), it can be observed that the error remains within $\pm 1.8\%$.

For the single heat sink of the 1000kVA transformer, with inlet oil temperature set to 70°C and other parameters unchanged, the simulation results, shown in Fig. 4, combined with Fig. 2 and Fig. 3, reveal that oil average temperature, outlet average temperature, and hot-spot temperature errors are small. Since the inlet oil temperature in typical transformers ranges from 70~80°C, this verifies the reliability of the method.

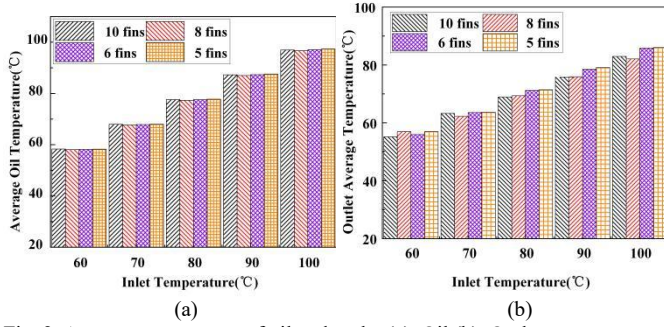


Fig. 2. Average temperature of oil and outlet (a). Oil (b). Outlet

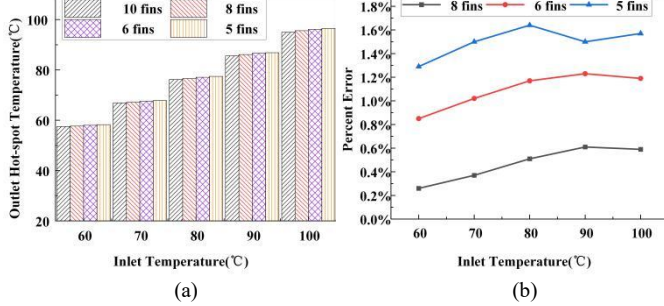


Fig. 3. Outlet hot-spot temperature and error (a). Outlet hot-spot (b). Error

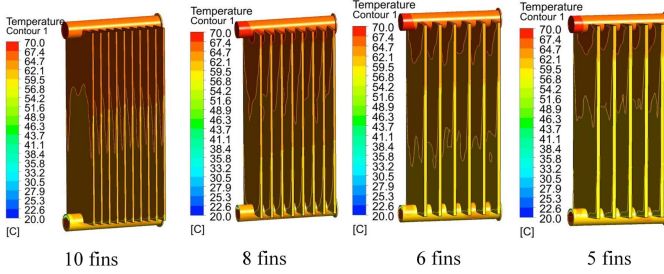


Fig. 4. Simulation of equivalent front and rear radiators when the inlet oil temperature is 70°C

B. Overall Temperature Field Analysis

Fig. 5 presents the temperature field simulation cloud images: (a). overall, (b). core, (c). low-voltage(LV) winding, and (d). high-voltage(HV) winding.

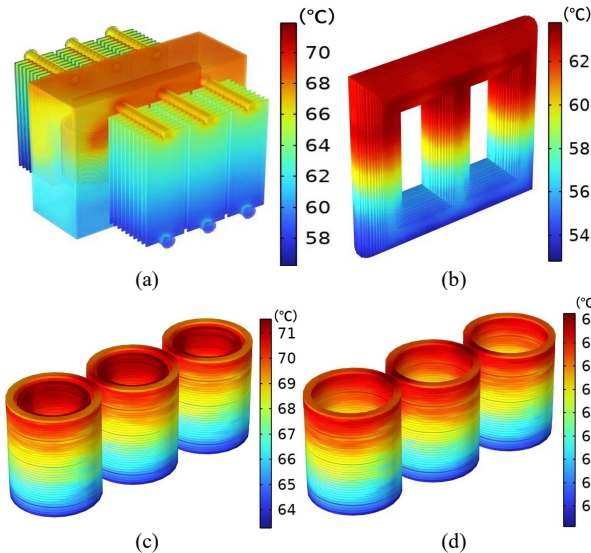


Fig. 5 Simulation contour plot (a) Overall (b) Core (c) LV Winding (d) HV Winding

With an ambient temperature of 15°C, the temperature distribution of windings exhibits a nonlinear upward trend along axial height. Hot-spots are concentrated at the upper ends, with the LV winding hot-spot temperature reaching 72.96°C and the HV winding hot-spot temperature reaching 69.15°C.

IV. EXPERIMENTAL

A. Experimental Platform

As shown in Fig. 6, the left side depicts the experimental prototype, while the right side shows the arrangement of fiber optic sensors and the fiber optic temperature sensor.

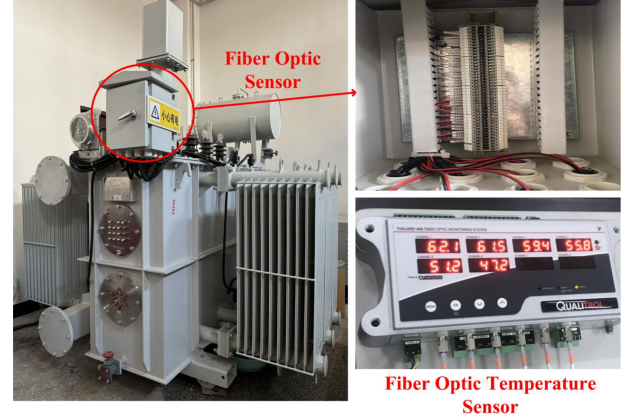


Fig. 6. Experimental prototype and testing instruments

B. Comparison of Experimental Results and Simulation

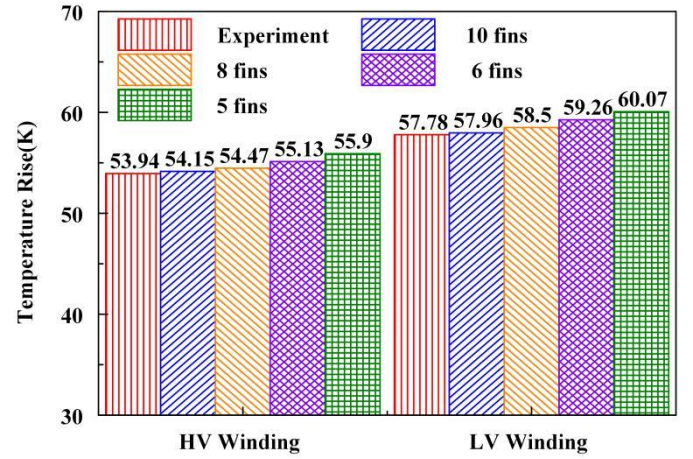


Fig. 7. Hot-spot temperature rise of HV and LV Windings

From the error analysis in Fig. 7, it can be concluded that the deviation between the experimental and simulation results is within 5%, verifying the reliability of the equivalent simulation model.

V. CONCLUSION

This paper presents an equivalent method for the cooling system, a 1000kVA oil-immersed transformer is used as example. The reliability of the method is validated through a combination of experimental and simulation results. The research findings provide new insights for the optimization design of transformer cooling systems.

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