Optimum Design of Transformer for Wind-Turbine Generator Considering Temperature Behavior

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***Abstract*—Structural optimization technique based on the precise heat transfer analysis for transformers is presented in this paper. Mechanical and thermal stresses caused in operating condition are especially important in enclosed space such as wind turbine generator. To optimize the structure of transformer, firstly temperature behavior is precisely calculated through the computational fluid dynamics based on finite volume method. Eddy-current losses, which are required to thermal analysis, are computed by electromagnetic analysis. These results of thermal analysis are utilized as input condition of structural analysis. Finally, structural optimization is conducted for wicked point, mainly radiation fins and panel. All the models are computed by 3-D analysis. The analysis results are verified by comparison with experimental results.**

***Index Terms*—Transformers, structural engineering, thermal stresses, optimization.**

I. INTRODUCTION

Structural optimization is significantly important in transformer of wind turbine generator. Within the wind turbine generator transformers are frequently exposed to vibration. In enclosed space mechanical stresses of transformer are increased because of rising pressure within transformers under operating condition. Thus, it is essential that evaluations for mechanical stresses based on thermal behavior are precisely performed.

To optimize the structure of transformer, thermal characteristic based on the computational fluid dynamics (CFD) must be calculated firstly. In this paper, to obtain precise thermal behavior ohmic and eddy-current losses are acquired through electromagnetic analysis and 3-D heat transfer analysis is performed. Finally, structural analysis is performed with temperature behavior and optimization is conducted for wicked point.

The proposed technique is successfully applied to 3MVA transformer which is vegetable oil (FR3) based and natural convection cooling type. The comparison with experimental results for structural analysis will be dealt with in full paper.

II. LOSSES AND TEMPERATURE BEHAVIOR

A. Winding and Eddy-Current Losses

In this work the eddy current losses, which are mainly on the panel, fin, and the clamp, are obtained through an electromagnetic analysis. Winding and core losses are calculated by the Joule heating, I^2R. Fig. 1 shows configurations of 3MVA transformer. Because the transformer has symmetric geometries only quarter analysis model of the real transformer is used for eddy-current losses and CFD.

To calculate eddy-current losses 3-D quasi-static electromagnetic analysis is used with the finite element method. The eddy-current density at panel and clamp is shown in Fig. 1. The eddy-current losses are obtained by ratio of eddy-current density to the electrical conductivity, J_e/σ.

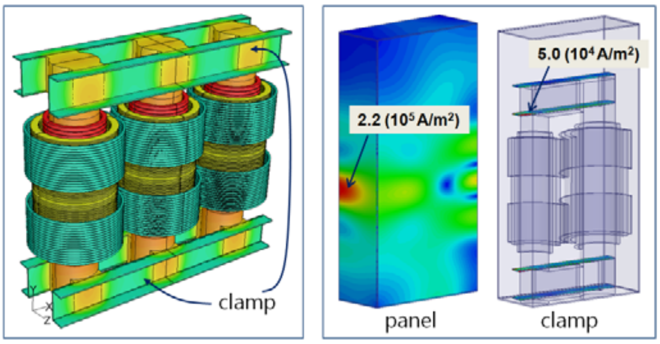


Fig. 1. 3MVA transformer and eddy-current density

B. Heat Transfer Analysis

To analyze natural convection flows in the transformer, Boussinesq approximation is used. Heat transfer coefficient for panel and fin are taken into account with empirical formula in order to consider heat exchange between panel and surrounding air [1]. Winding and eddy-current losses as above mentioned are inputted as heat source of the heat transfer analysis. Other required models (radiation model, conduction, turbulent model) are driven by computational fluid dynamics, in which commercial CFD Fluent is used. The ambient temperature is 300 K. Fig. 2 shows contours of temperature at panel, winding, and core. The hottest temperature of winding is 404 K, in which experimental value is 395 K, and the maximum temperature of panel is 357 K.

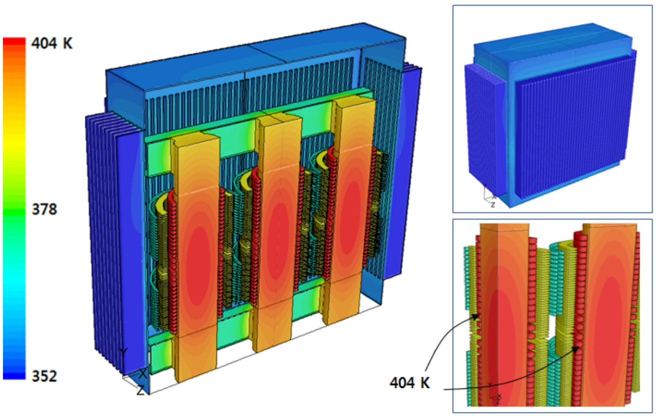


Fig. 2. The results of thermal analysis - Contours of temperature

III. OPTIMUM DESIGN

A. *Design variables and sampling*

The optimum design is performed to minimize the max. membrane stress [2]. Table I shows the design variables and its levels. The sensitive design variables are evaluated by the main effect of the max. membrane stress. Table II represents sampling, central composite design (CCD) and its analysis result. The structural and natural frequency analysis are performed by 3-D finite element method [3].

TABLE I
DESIGN VARIABLES AND ITS LEVELS

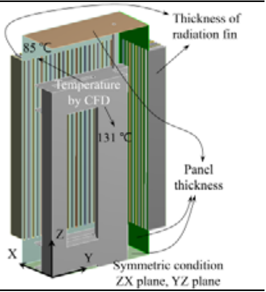
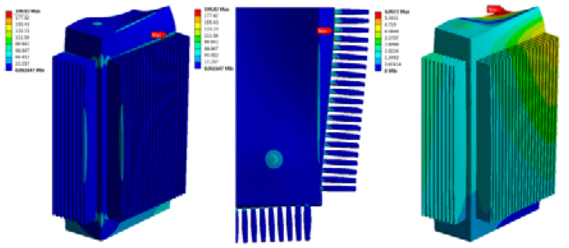
Level	Thickness of radiation fin (mm)	Panel Thickness (mm)	
1	0.7032	7.758.	
2	4.0968	16.242	

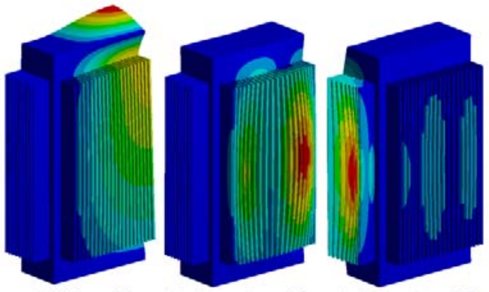
TABLE II
CENTRAL COMPOSITE DESIGN (CCD)

No.	Panel Thickness (mm)	Thickness of radiation fin (mm)	Maximum membrane stress (MPa)
1	15	3.6	163.21
2	12	0.7032	540.76
3	15	1.2	289.16
4	16.242	2.4	179.69
5	9	3.6	323.49
6	9	1.2	661.77
7	7.758	2.4	533.48
8	12	4.0968	206.75
9	12	2.4	291.68



Max. membrane stress (199.82 MPa) Max. displacement (6.07 mm)

Fig. 3. The membrane stress distribution of optimum B model



Initial model Optimum A model Optimum B model

Fig. 4. 1st natural frequency and mode shape of according to models

B. *Mechanical analysis and optimum design result*

Fig. 3 shows the membrane stress distribution and displacement result of optimum model B. The natural frequency and the surface results of max. membrane stress are shown in Fig 4 and Fig. 5 respectively. The more panel thickness and the less thickness of radiation fin, the membrane stress decreases. Also, the radiation characteristics of radiation part have been improved. Fig. 6 shows the region of the optimum solution and the optimum solutions by the optimizer. The optimum B model is better than optimum model A in consideration of radiation characteristics of radiation fin part. Table 3 represents the comparison of initial model with optimum models. The structural stability of the initial model is unstable and caused by excess of the used material's the yield strength about 240 MPa. Thus design modification should be considered. The optimum B model is outstanding for max. displacement and 1st natural frequency. The first natural frequency is the bigger the better because the frequency is increased, vibration displacement is decreased. The low-noise transformer will be expected to develop by avoiding the resonance. The detailed results will be dealt with in full paper.

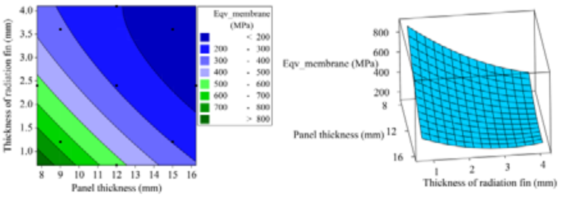


Fig. 5. The contour and surface results of max. membrane stress

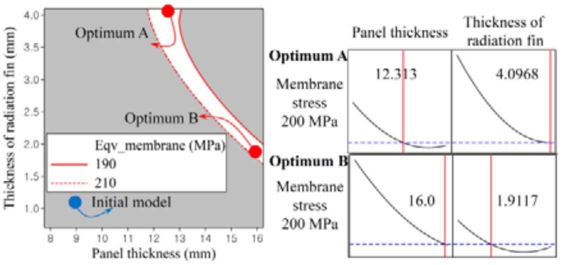


Fig. 6. The contour and optimizer

TABLE III
The comparison of original model with optimum models

Model	Max. membrane stress (MPa)	Max. displacement (mm)	1st natural frequency (Hz)
Initial	661.77	18.42	34.17
Optimum A	199.82	6.07	35.43
Optimum B	207.15	3.62	53.24

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