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Research Article

Performing Analysis of Current Transformer in Short Circuit and Open Circuit Conditions Using ANSYS@Maxwell

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Abstract
Calculation of the design parameters of current transformers (CTs) is very complex due to their magnetic and thermal properties, complexity of their structure, different ferromagnetic properties of the materials and the nonlinearity of the B-H curve of the core material. The secondary output of these transformers is used for both measurement and protection circuits. Therefore, AT's accuracy must be very good and precise. In this study, the transformer is modeled as 2D using the Finite Element Method (FEM). ANSYS@Maxwell program, which realizes a solution based on finite element method, has been used in magnetic and thermal analysis of the current transformer. Analyzes of the transformer were carried out in 2D under open and short circuit conditions. From the results obtained from the analysis, the scattered electromagnetic flux distribution occurred in the core of the current transformer, which caused the secondary current of the CT to be erroneous. Therefore, it has been observed that unwanted operating conditions occur in the protection circuits..

Keywords: Electromagnetic field, Thermal analysis, Current transformer, Finite Element Method (FEM)

Akım Trafosunun Kısa Devre ve Açık Devre Koşullarında ANSYS@Maxwell ile Analizlerinin Gerçekleştirilmesi

Öz
Akım trafolarının (AT) tasarım parametrelerinin hesaplanması, manyetik ve termal özellikleri, yapılarının karmaşıklığı, materyallerin farklı ferromanyetik özellikleri ve nüve malzemesinin B-H eğrisinin doğrusal olmaması nedeniyle çok karmaşıktır. Bu trafoların sekonder çıkışı hem ölçü hem de koruma devreleri için kullanılmaktadır. Bu yüzden AT'nin doğruluk derecesi çok iyi ve hassas olmalıdır. Sonlu Elemanlar Yöntemi (SEY) kullanılarak bu çalışmada trafo 2D olarak modellenmiştir. Akım transformatörünün manyetik ve termal analizlerinde sonlu elemanlar yöntemine dayanarak çözüm gerçekleştiren ANSYS@Maxwell programı kullanılmıştır. Trafonun analizleri, açık ve kısa devre koşullarında 2D olarak gerçekleştirilmiştir. Analizlerden elde edilen sonuçlardan akım trafosunun nüvesinde dağınık elektromanyetik akı dağılımının meydana geldiği, bu durumun AT'nin sekonder akımının hatalı olmasına sebep olmuştur. Bu yüzden koruma devrelerinde istenmeyen çalışma koşullarının oluştuğu görülmüştür.

Anahtar Kelimeler: Elektromanyetik akı, Termal analiz, Akım transformatörleri, Sonlu Elemanlar Yöntemi (SEY).

1. Introduction

Modern protective systems require reliable reproduction of the primary short circuit current. In general, especially in high power plants, if the current transformer is selected according to the operating conditions, a significant part of the current causes the transformer to reach its saturation point (Hjalmars, M. 2012). In order for the

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*Corresponding Author: yildirimozupak@gmail.com measurement and protection systems to respond well and to ensure the reliability of the power systems, current transformers must be well analyzed and analyzed.

When primary current is applied to a current transformer, it is important to be able to determine the behavior of the AT within a certain accuracy range. This makes it easier to predict the behavior of the equipment used to protect electrical power systems.

Many analysis methods are available to determine the behavior of the current transformer. However, only a few of these methods are suitable for temporary regime analysis. Finite Element Method is one of the best and most suitable solution tools for this purpose (Kardag, R.2012, orosz, T. Kleızer, G. Iváncsy, T. Z. Tamus, Á. 2016). Due to technical limitations, the output currents must be increased as the output voltage of the generators cannot exceed 25 kV. These currents are measured by current transformers. The accuracy of these ATs is affected by the leakage flux produced by adjacent busbars, especially in gas plants where ATs are located close to each other (Myint, M. L. OO, Y. A. 2014, Hjalmars, M. 2012, Myint, M. L. Oo, Y. A. 2014). Different solutions have been proposed for this problem, such as using aluminum or copper shields or using shielded wraps (Chen, Y. Pillay, P. 2002, Madžarević, V. Kapetanović, I. Tešanović, Kasumović, M. M. 2011). In this paper, ANSYS@Maxwell software package was used for thermal and magnetic analysis of low voltage current transformer in transient regime.

In this study, a thermal model is proposed to obtain the temperature distribution in the transformer. The proposed model is formulated with ANSYS@Maxwell software, which performs field analysis and solves energy equations based on Finite Element Method (FEM). Electrical losses in the active parts (cores and yellows) are practically obtained by the manufacturer. These values are also calculated using the properties and dimensions of the transformer. These losses were characterized as heat generated in the thermal analysis procedure. The likely outcome expected from using the proposed model is to find the hottest region in the transformer by determining the temperature distribution of the main components of the transformer.

2. Modeling of Current Transformer

Using the parametric design part of ANSYS@Maxwell program, all parameters required for magnetic and thermal analysis, physical dimensions of the sample model and required nominal values are defined in the software environment. The nominal values of this model are given in Table 1 below.

Table 1. Design parameters of current transformer

Parameter	Value
Insulation level	0.7 – 3.2 kv
Temperature range	-20 – 55 °C
Rated primary current	8000 A
Rated seconder current	5 A
R_f	1.25
frequency	50 Hz

In Figure 1 and Figure 2 below, the geometric model of the current transformer and the magnetization curve of the core are presented, respectively.

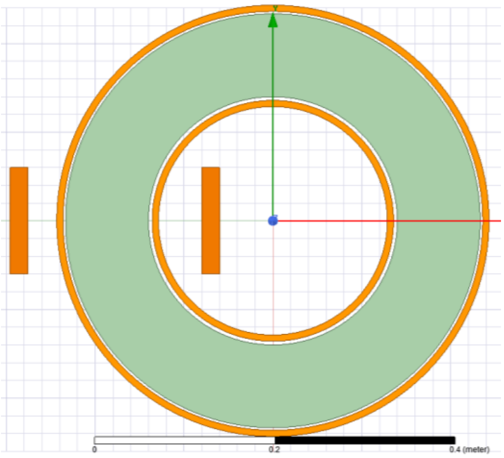

Figure 1. Geometric model of current transformer.

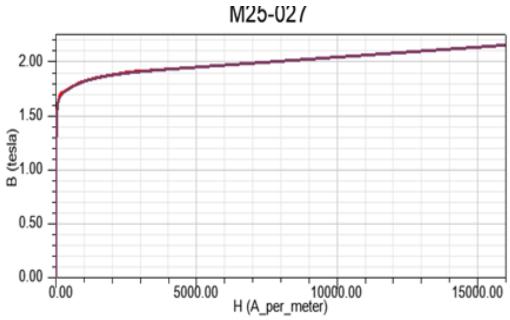

Figure 2: B-H curve of current transformer core material.

A) Magnetic Analysis

Magnetic analysis is carried out to determine the magnetic field distribution. The parameters required for this analysis are given below.

- Model geometry
- B Characteristic B-H curve of the magnetic material used in the core
- Primary and secondary flow rates
- Magnetic material properties of insulation, oil, dressing and core

For this analysis and simulation, firstly, the model geometry and all elements of the model are defined in the program. Then, the material properties of the core, the windings and other parts of the current transformer were added to the defined model and the design was verified. Finally, the core and all the windings are selected and meshed to perform analysis with FEM.

B) Thermal Analysis

Thanks to the combination of different areas for this analysis, the geometry of the model was transferred from the Maxwell environment to the Mechanical environment and then analysis and simulation were carried out to determine the temperature distribution. Thermal analysis can be performed in two ways;

- Direct combination
- Indirect combination

It is in the form.

In the first case, the two fields are combined directly and the results of the first field are applied as the charge or input of the second field. In the second case, both fields are analyzed separately. The results of the first field are stored in a file and used for load or input when necessary, during the second field analysis.

In this study, direct combination method was used. The results of the analysis in the Maxwell environment were used as a direct load for thermal analysis in the Mecanical environment.

3. Simulation and Analysis of the Model

In this part of the study, magnetic and thermal analyzes were performed to analyze the current transformer's losses, flux distribution, temperature distribution and magnetic field density.

A) Magnetic Analysis in an Open Circuit State

The flux density in the core was very high due to the saturation. The maximum value of flux density is determined as approximately 2.04 T at the core. The flux distribution and flux density of the 2D model for transient analysis in the open circuit state are presented in Figures 3 and 4 below.

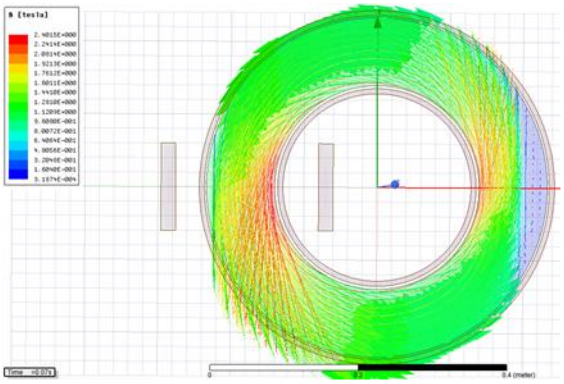

Figure 3. Vector distribution of 2D flux in case of open circuit.

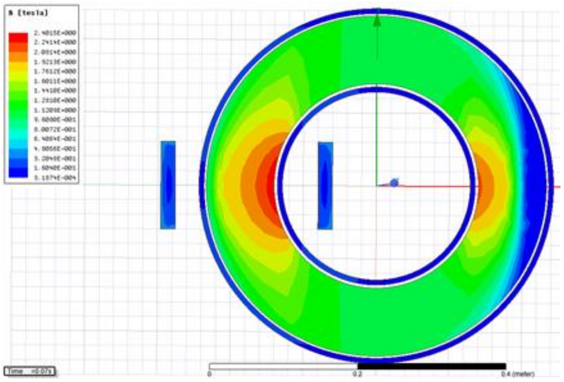

Figure 4. Flux density distribution in case of open circuit

The distribution of electromagnetic forces in the open circuit state analysis of the 2D model is given in Figure 5. Forces with a maximum of 1,398 N occurred around the primary winding.

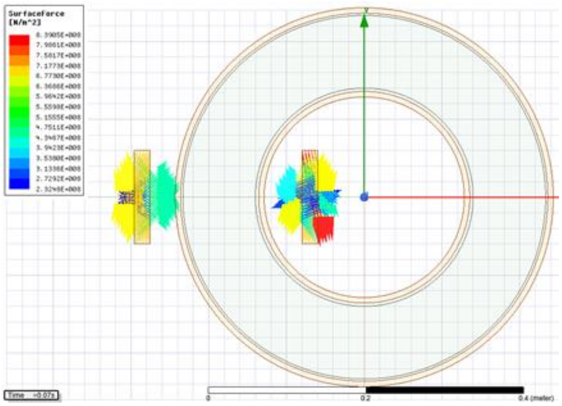

Figure 5. Electromagnetic force distribution in the open circuit situation

B) Magnetic Analysis in Short Circuit Status

For this case, the operation of the current transformer in a short circuit system was examined and the transformer analyzes were carried out. Under these conditions, the current transformer is not under normal conditions and can be affected by different voltages. These tensions should be analyzed correctly. The short circuit current is approximately 20 times the nominal value according to the short circuit level of the system. In Figure 6 and 7, the flow distribution and flux density of the model are presented in short circuit condition. The maximum flux density was found to be about 1.23 T.

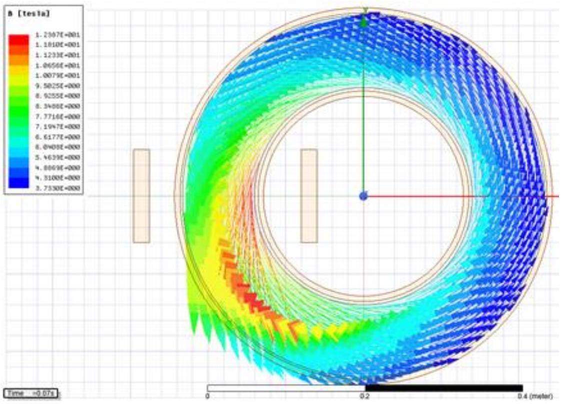

Figure 6. Vector distribution of 2D flux under short circuit conditions.

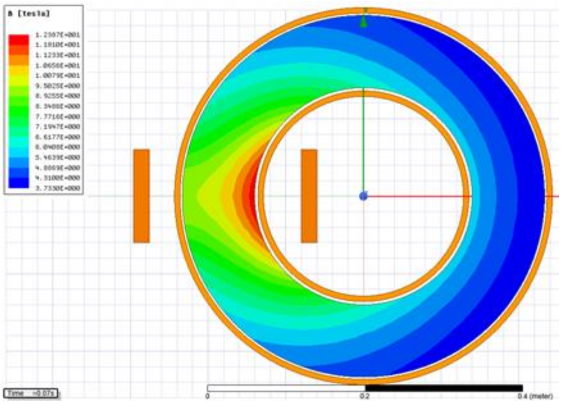

Figure 7. 2D flux density distribution in short circuit conditions

In Figure 8 below, the distribution of the electromagnetic forces of the model has reached a maximum of about 539.9 N around the primary winding. In these conditions, these forces are very high and can destroy the current transformer due to the generated electrodynamic and mechanical voltages.

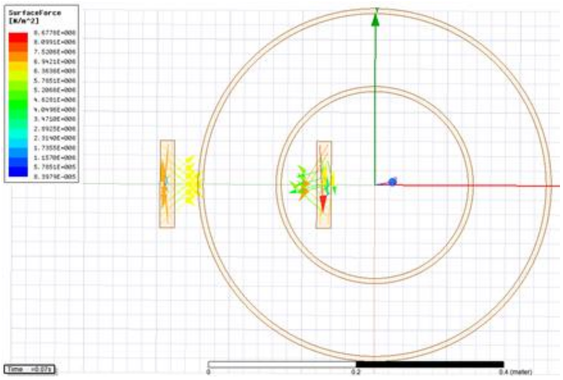

Figure 8. Electromagnetic force distribution in the event of a short circuit

C) Thermal Analysis

The thermal distribution of the designed model in the short circuit state of the thermal analysis performed in ANSYS @ Mecanical environment is presented in Figure 9. It was observed that the temperature increase around the primary winding was faster. The temperature of the primary winding was approximately 160.1 °C and the temperature of the secondary winding was approximately 59.5 °C. In fact, the heat generation of the secondary winding is lower than that of the primary winding.

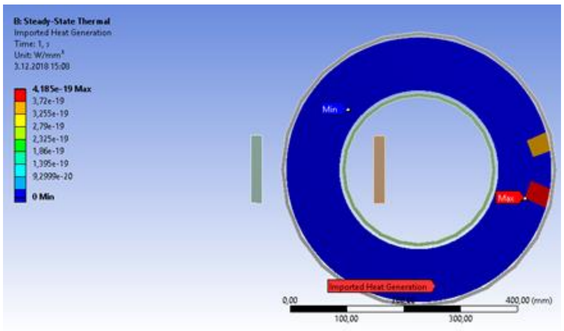

Figure 9. Thermal distribution in the normal state

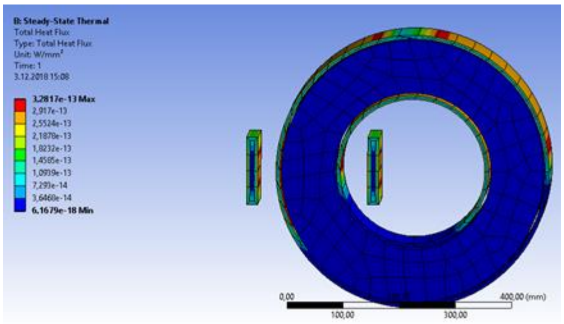

Figure 10. Thermal distribution in the case of a short circuit

The following shows the thermal flux production in the short circuit state and the distribution of flux in the model in Figure 11. Maximum heat production is due to the primary winding of the current transformer.

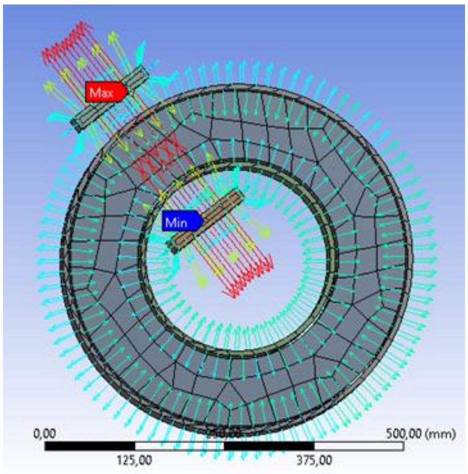

Figure 11. Thermal flow distribution in the event of a short circuit

4. Conclusion

In this study, magnetic and thermal analysis of current transformer was performed in 2D with Finite Element Method (FEM). For analysis and simulation, ANSYS@Maxwell and ANSYS@Mecanical, which can perform multiple physics analyzes together, were combined and used. Magnetic and thermal examinations of the designed model in different operating conditions were carried out.

Under normal conditions, primary and secondary windings of the AT carry nominal currents. Maximum flux density, maximum field strength and maximum electromagnetic force were 1.23 T, 7893 A / m and 1.348 N, respectively. In the case of AT secondary open circuit, the maximum flux density and maximum electromagnetic force were 2.04 T and 1.398 N, respectively. In the case of an open circuit, the flux density was much higher than in the normal state and the core was saturated.

In the case of a short circuit, large electromagnetic forces occur at a current approximately 20 times the normal current. These large electromagnetic forces can generate larger electrodynamic voltages and can seriously damage this current transformer. Using the combined magnetic and mechanical field, weak and strong points of AT were determined in terms of mechanical strength.

Acknowledgment

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