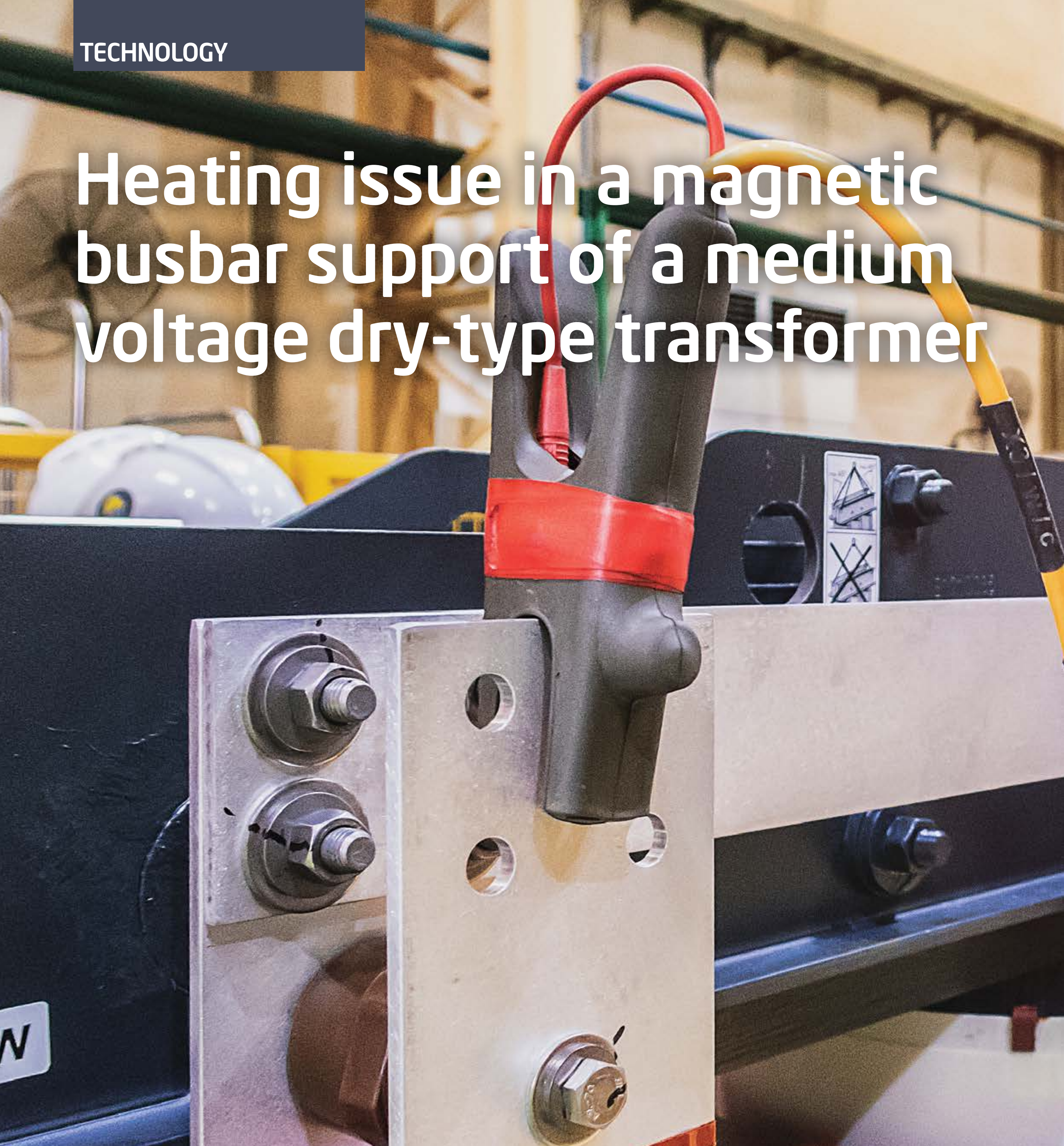
Heating issue in a magnetic busbar support of a medium voltage dry-type transformer



ABSTRACT

This article describes a thermal issue detected in a three-phase medium voltage dry-type transformer during the standard factory tests. High temperatures were detected in a busbar support during the load tests. This busbar support was designed and manufactured employing a magnetic material with high permeability and high electrical conductivity. Electromagnetic and thermal analyses at nominal frequency were performed to verify the induction of eddy currents in the busbar support. The stray losses and temperature in the magnetic busbar support were computed and compared with the temperature measured in the busbar support during the transformer load tests using infrared technology. The author and transformer manufacturer determined to change the material of the busbar supports to avoid future heating issues in substation dry-type transformers.

KEYWORDS:

dry-type transformer, busbar support, eddy current, stray loss, load loss, design review

During the design reviews, magnetic and non-magnetic materials utilized in transformers can be analyzed to be sure that they don't produce any negative effects

Stable temperatures between 140 and 171°C were detected in one of the mild steel busbars supports located between the three-phase busbars of the transformer

1. Introduction

Magnetic design reviews are essential after finishing any transformer design to avoid issues such as high stray losses and the presence of hot spots in structural elements. In previous Transformer Magazine editions, the author has demonstrated that the incorrect selection of magnetic materials and the incorrect application of stray loss reduction methodologies could produce failures and heating issues in transformers [1], [2]. During the design reviews, magnetic and non-magnetic materials utilized in transformers can be analyzed to be sure that they don't produce any negative effects, such as high-power losses and high temperatures, which could produce transformer failures [3], [4]. Magnetic materials should be selected based on their magnetic and electromagnetic characteristics, main function, and location in the transformer. For example, mild steels or low-carbon steels are magnetic materials used for structural elements and supports of transformers. Sometimes, high stray losses and hot spots can be generated in these magnetic structural elements, so they should be replaced by non-magnetic materials to mitigate the stray losses and limit local heating [5].

In dry-type transformers, the use of magnetic materials should be studied and analyzed during the different design steps. For example, in medium voltage (MV) dry-type transformers, the currents in the coils and the busbars are high, and they should produce considerable leakage and stray fields, which could produce high power losses and high temperatures in structural elements such as enclosures, frames, supports, and more [6]-[8].

In this article, a study of a heating issue presented in a busbar structural support of a 750 kVA MV dry-type transformer is presented. High temperatures were detected in busbar support on the low voltage (LV) side of the MV dry-type transformer. Electromagnetic analyses were performed to verify the induction of eddy currents in the busbar support, and thermal analyses were carried out to evaluate the final temperature distribution in the busbar support, which was later compared with the temperature measurements performed in the transformer factory.

Table 1. MV dry-type transformer characteristics

Characteristic	Value
# Phases	3
Power	750/1000 kVA
High voltage (HV)	13.8 kV
Low voltage (LV)	208 V - Wye 120 V - Delta
Frequency	60 Hz
Cooling type	Air/Fans

2. Thermal issue in a dry-type transformer

Load loss tests were performed for the 750 kVA three-phase MV dry-type transformer in the factory before shipping it to the customer. Table 1 shows the characteristics of the MV dry-type transformer tested in the factory laboratory. Figure 1 shows some photos of the low voltage (LV) side of the MV dry-type transformer during the factory tests. In Figure 1 one can see that the busbar support is located between the different three-phase busbars of the dry-type transformer. The busbar support was designed and manufactured of mild steel. Mild steel is a magnetic material with high electrical conductivity

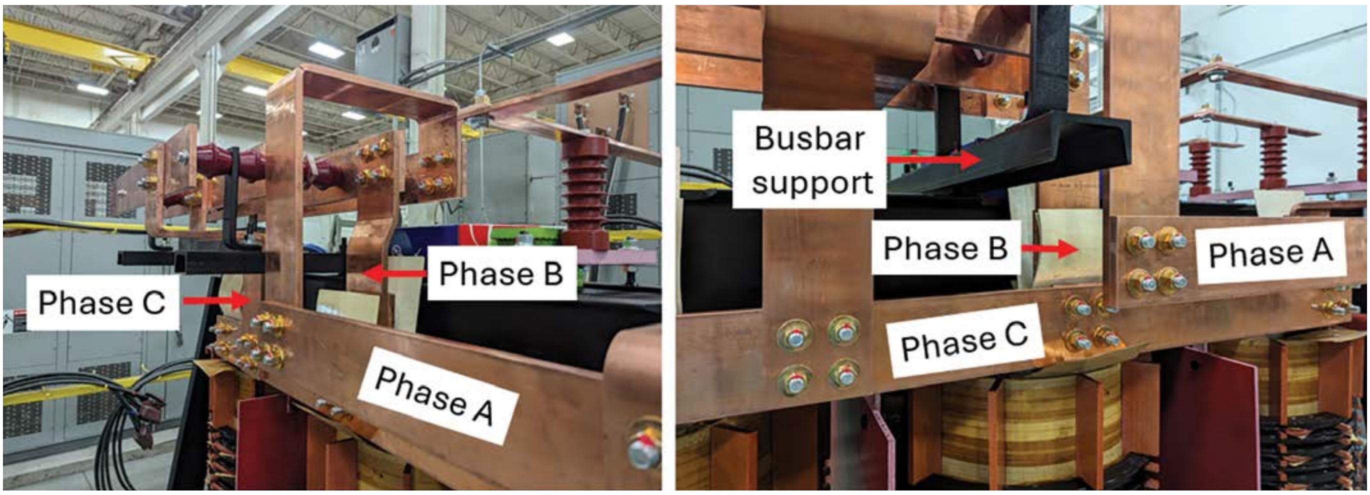


Figure 1. MV dry-type transformer during load tests in the factory

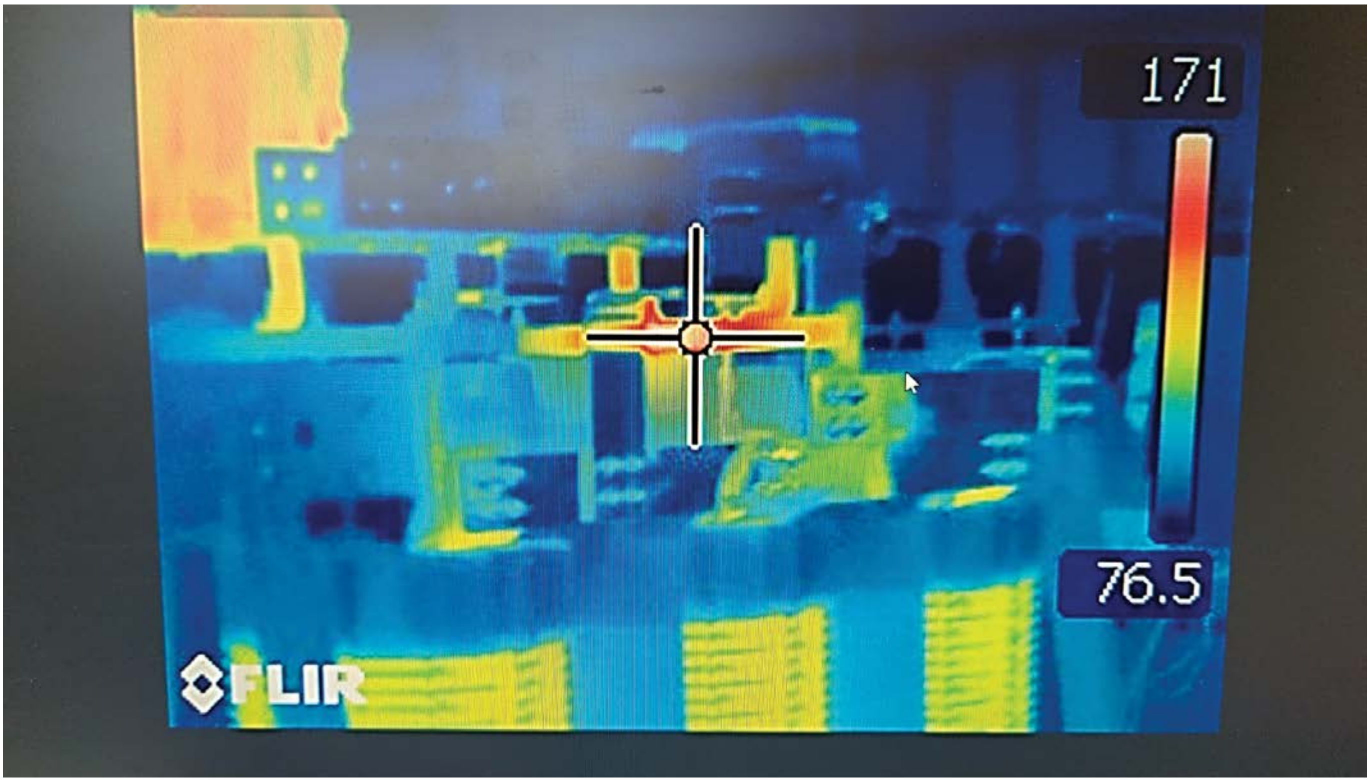


Figure 2. Infrared camera image of the temperature distribution in the magnetic busbar support

and magnetic permeability. This means that it is easy to induce eddy currents in this steel busbar support, especially with the presence of high stray fields produced by the busbar currents. During the load loss tests, currents of 5 kA at 60 Hz were circulating in the LV busbars of the dry-type transformer.

The transformer manufacturer monitored the temperature of the MV dry-type transformer by employing an infrared camera. Stable temperatures between 140 and 171°C were detected in one of the mild steel busbars supports located between the three-phase busbars of the transformer, see Figure 2. After detecting the high temperatures in the magnetic busbar support, the author performed some electromagnetic and thermal analyses to investigate the origin of the busbar support heating.

Three-dimensional electromagnetic and thermal finite element analyses were performed to compute the stray losses and temperature in the mild steel busbar support under load loss test conditions

3. Electromagnetic and thermal analyses

Three-dimensional (3-D) electromagnetic and thermal finite element analyses were performed to compute the stray losses and temperature in the mild steel busbar support under load loss test conditions. Figure 3 (a) shows the simplified 3-D model of the LV side of the three-phase MV dry-type transformer, and Figure 3 (b) shows the busbar support model. The busbars are made of solid copper with a cross-section of 1300 mm^2, and the busbar support is made of mild steel which was modelled using its initial BH curve and an electrical conductivity of 6×10^6 S/m, see Figure 3 (c). Each phase busbar carries a peak current of ~5 kA at 60 Hz with its respective phase angles (Phase A: 0°, Phase B: 120°, Phase C: 240°), see Figure 4. Figure 4 shows the stray field distribution produced by the busbar three-phase currents. One can see that the stray field is produced by the three-phase busbar currents following Ampere's law (Maxwell's equation). This stray field penetrates the different regions of the magnetic busbar support, inducing eddy currents.

Figure 5 shows the magnetic flux density distribution in the magnetic busbar support produced by the stray field from the phase currents.

Figure 6 shows the eddy currents circulating in the busbar support, and Figure 7 shows the loss density distribution in the busbar support, where a maximum value of 3.5 kW/m^2 was computed for the verti-

Loss density distribution in the busbar support, where a maximum value of 3.5 kW/m^2 was computed for the vertical members of the busbar support

From the results obtained in the Multiphysics analyses and from the temperature measurements, the 3-D model of the dry-type transformer was validated with a difference of 0.1%

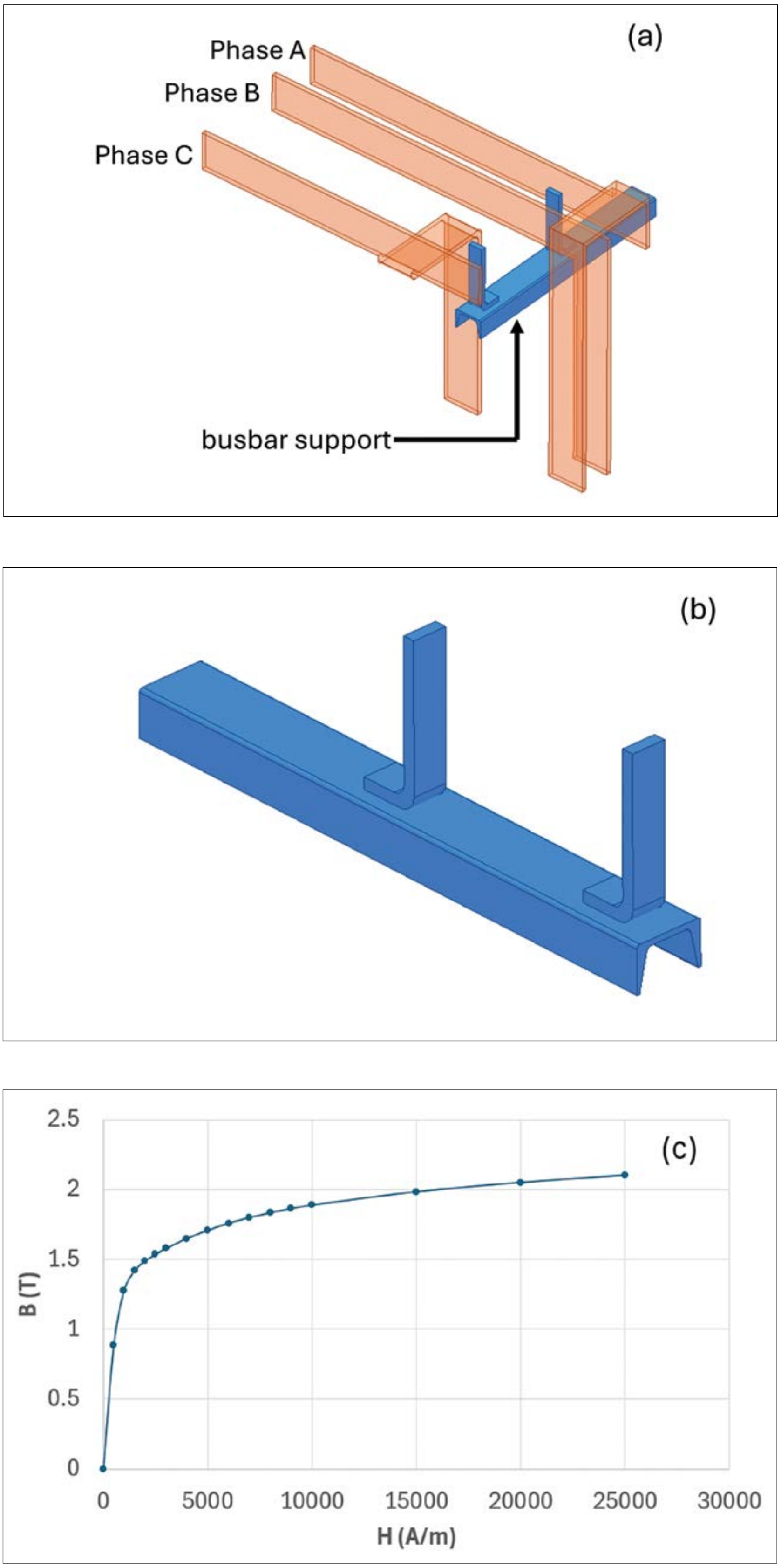


Figure 3. a) 3-D simplified transformer model, b) busbar support model, c) magnetization curve for mild steel

cal members of the busbar support. A total average loss of ~100 W was computed in the entire magnetic busbar support.

The stray losses computed in the magnetic busbar support were employed as heat sources for the static thermal analysis. Different convection coefficients between 5 and 10 W/m^2 °C were employed to simulate the complex free air convection between the busbar support regions and the surrounding air [1], [2].

Figure 8 shows the final temperature distribution computed in the magnetic busbar support. Temperatures between 140 and 171 °C were computed in the busbar support. A maximum temperature of 170.82 °C was computed on the horizontal support member region of the busbar support. From the results obtained in the Multiphysics analyses and from the temperature measurements (see Figure 2), the 3-D model of the dry-type transformer was validated with a difference of 0.1%.

One can note some differences between the maximum power loss location in Figure 7 and the maximum temperature location in Figure 8. This is because the final and stable temperature distribution in the different support regions depends on the complex cooling process between the surrounding air and the different support regions. The busbar support regions with high power losses are cooled faster compared with the support regions with low power losses. This free air-cooling process was simulated using the different convection coefficients utilized in the different regions of the magnetic busbar support.

The transformer manufacturer and author decided to change the material for all the busbar supports to avoid the induction of eddy currents and the presence of high temperatures. Materials like non-magnetic stainless steel and other plastic hard materials were analyzed for the busbar supports of the dry-type transformer considering electromagnetic and dielectric characteristics and hardness, durability, high corrosion resistance, and vibration conditions [9]-[12].

After this material change, the heating issue in the busbar supports was eliminated and some design rules were established for the structural busbar supports of dry-type transformers.

4. Conclusion

In this article, a heating issue found in a three-phase MV dry-type transformer is presented, analyzed, and discussed. High temperatures >150 °C were measured and detected in a magnetic busbar support of the MV dry-type transformer. 3-D Multiphysics analyses were performed to verify the induction of eddy currents in the magnetic busbar support and to verify the final temperature distribution. The final temperature distribution computed was compared with the temperature distribution measured in the busbar support for general validation of the 3D transformer model.

The author demonstrated that the high temperatures in the magnetic busbar support were caused by the induction of eddy currents produced by the three-phase busbar currents. The eddy currents generated an average stray loss of ~100 W, which produced high temperatures between 140 and 170 °C in the magnetic busbar support.

The transformer manufacturer and author decided to change the material for all the busbar supports to avoid the induction of eddy currents and the presence of high temperatures.

High temperatures in the magnetic busbar support can be caused by the induction of eddy currents produced by the three-phase busbar currents

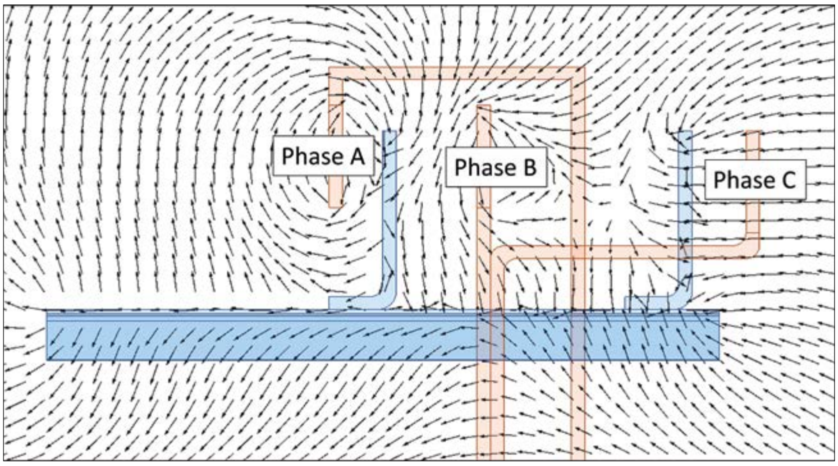


Figure 4. Three-phase busbar stray field distribution

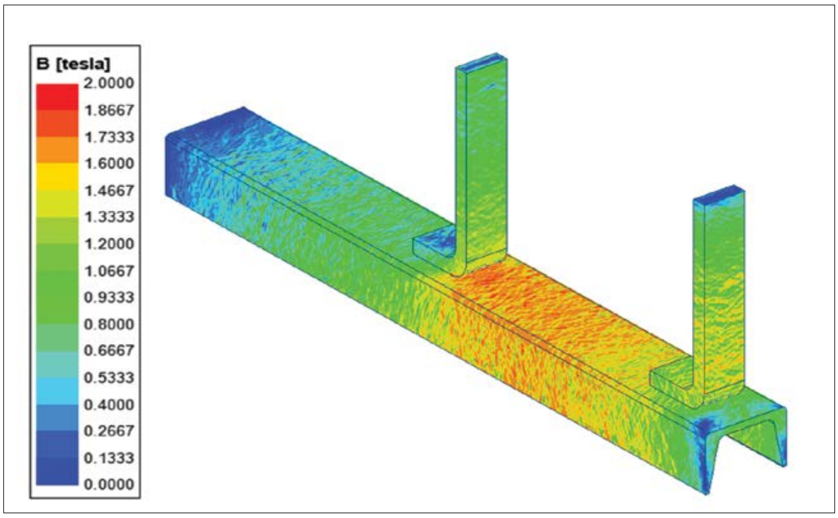


Figure 5. Magnetic flux density (in T) in the magnetic busbar support.

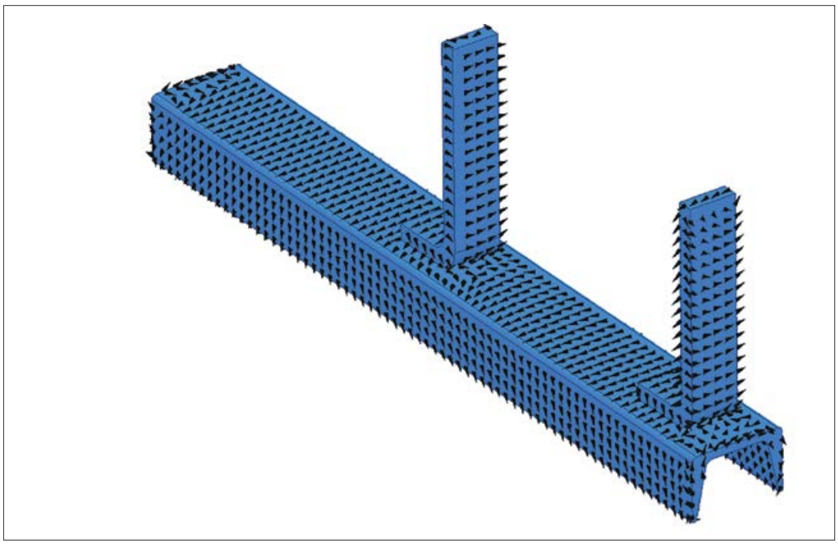


Figure 6. Current density distribution on the busbar support surface.

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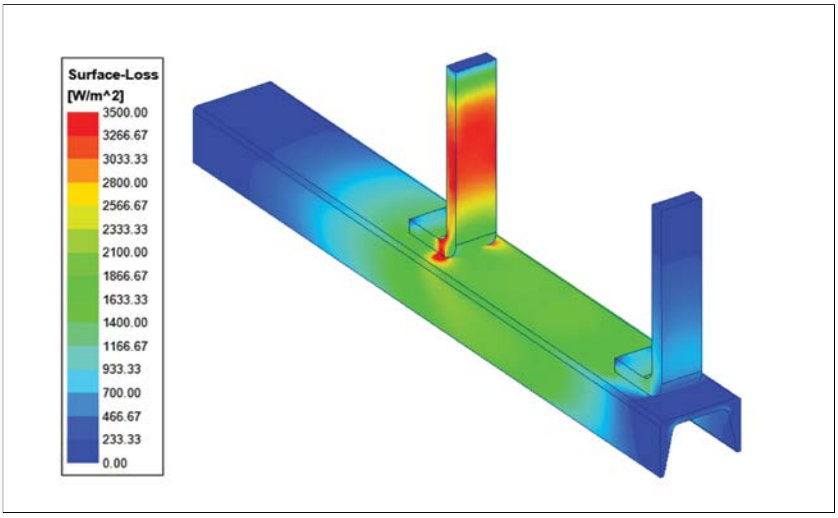

Figure 7. Loss density distribution (in W/m²) in the busbar support.

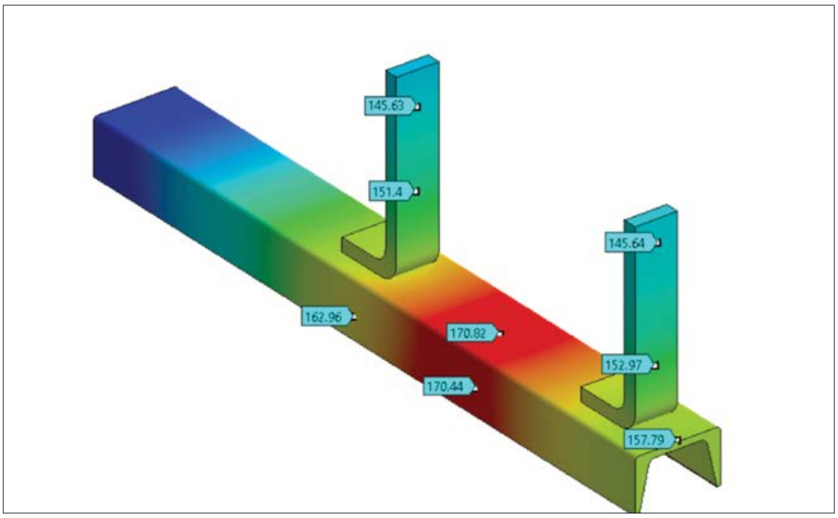

Figure 8. Distribution of temperature computed in the busbar support.

Author

Salvador Magdaleno-Adame received a B.Sc. degree in electrical engineering from the Universidad Michoacana de San Nicolas de Hidalgo in 2008 and an M.Sc. degree in electrical engineering from the Instituto Tecnologico de Morelia in 2013. From 2008 until 2010, he worked at Industrias IEM S.A. de C.V. as an R&D engineer for power transformers, where he conducted research and design reviews on shell-type and core-type power transformers, and he also worked on the development of HV shunt reactors. He has occupied several magnetic and electromagnetic engineering positions in companies in the United States, working in diverse magnetic and electromagnetic technologies, including transformers, permanent magnet motors, actuators, loudspeakers, permanent magnet technologies, magnetic materials applications, etc. He has authored over 60 papers for journals and conferences, and he has over 20 years of experience in finite element electromagnetic analysis of electromagnetic devices. He owns a consultancy business called **"Salvador Consultant – www.salvadorconsultant.com"** to support the magnetic and electromagnetic industry in the United States.

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