SIMULATION ENABLES THE NEXT GENERATION OF POWER TRANSFORMERS AND SHUNT REACTORS

Transformers are the workhorses of the electrical grid, and now they are getting assistance from computer modeling in order to meet today's power demands.

By **DEXTER JOHNSON**

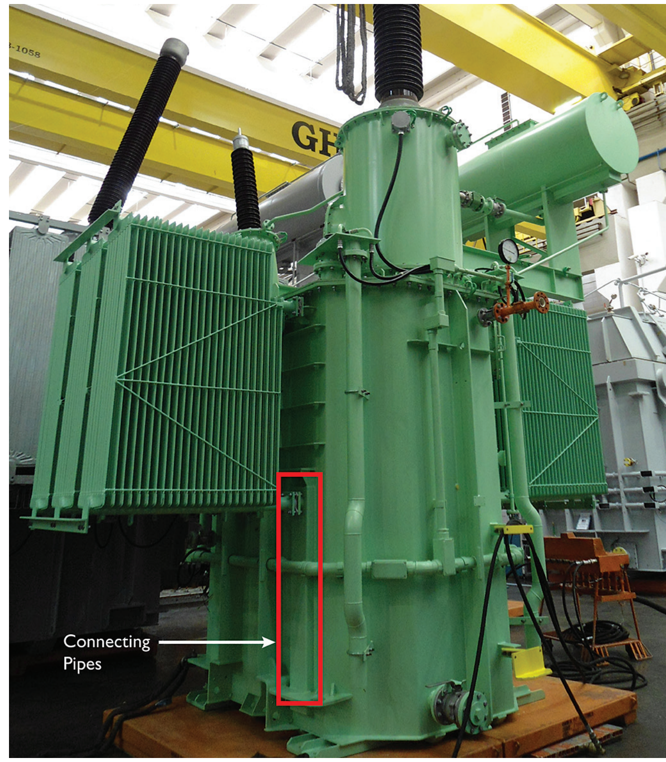

FIGURE 1: Shunt reactor. In the original design of the oil circuit the radiator is connected to the tank by pipes enclosed in rectangular boxes welded to the exterior of the reactor.

DESIGNERS AT SIEMENS BRAZIL, located in Jundiaí, São Paulo, are employing simulation to guarantee the safety of power transformer and shunt reactor operation. By performing these simulations in addition to using their internal tools, members of the design team at the company are now better able to control overheating despite the increasing power demands placed on this equipment.

Shunt reactors are used to absorb reactive power and increase the energy efficiency of transmission systems (see Figure 1). Power transformers are designed to efficiently transfer power from one voltage to another. Both devices are used in all stages of the electrical grid, from power generation to distribution to end users. The increasing demand for more power from constantly growing cities is translating into a need for larger devices. But sometimes conditions limit their size: Transportation and space to place the devices at the customer's plant are some examples of these limitations.

The need to produce more power without increasing the device size adds additional load and increases thermal losses, eventually leading to higher temperatures. While methods for the design of active parts (the cores and windings) of these devices are well-established, the design of their inactive components (structural parts) is still not straightforward and requires further investigation. If the equipment is not carefully designed, there is a risk of overheating, potentially leading to the degradation of the material properties of the transformer's insulating oil.

» OVERCOMING INDUCTIVE HEATING ISSUES

SIEMENS HAS EMPLOYED COMSOL® simulation software to address these design constraints and control the inductive heating of metal parts. Induction heating is the phenomenon of heating a conductive body subjected to a varying electromagnetic field, where eddy currents lead to the Joule heating of the material due to electrical resistance.

The modeling of inductive heating has helped designers at Siemens avoid "hotspots"—small regions with high induced current density and, consequently, high temperatures. With the geometric and material complexity of these transformers, it is very difficult to avoid these hotspots completely. The oil in immersed transformers is a powerful electrical insulator and also works as a coolant fluid. However, these hotspots can overheat the oil and bubbles of gas can be generated. These bubbles have a smaller dielectric strength than the insulating oil and may cause an electrical discharge in the oil, potentially damaging the transformer.

"With COMSOL, we can simulate this behavior and propose changes to transformer design to reduce inductive heating of structural parts," says Luiz Jovelli, Senior Product Developer at Siemens.

In their inductive heating work, Siemens used COMSOL Multiphysics® and the AC/DC Module. The first change that was made as a result of the simulation was to alter the design of the metal structure. For example, by changing the original clamping frame structure of the shunt reactor (see Figure 2, top), the design team was able to reduce induction heating and improve cooling with better oil circulation through that region. As a result, the temperatures of the hottest points were reduced by about 40°C. This change eliminated the need for installing copper shielding over the clamping frame, thus saving material costs (see Figure 2, bottom, and Figure 3).

Because of the simulation work Jovelli and his colleagues have done with COMSOL, they have been able to suggest several improvements to the design of these devices. "Sometimes the cooling accessories of the equipment may be over dimensioned to fit some hotspots in the whole design," says Jovelli. "With COMSOL, we're able to control these spots." Jovelli noted that even a slight change can solve the problem and lead to a reduction in the costs associated with cooling accessories.

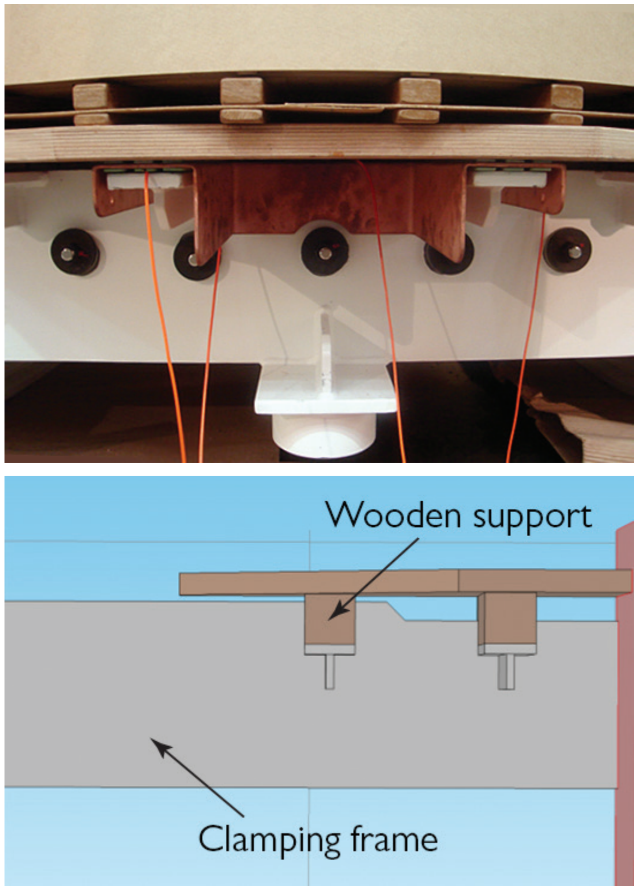

FIGURE 2: Top: Original clamping frame design with copper shielding. Bottom: Optimized clamping frame design using less materials.

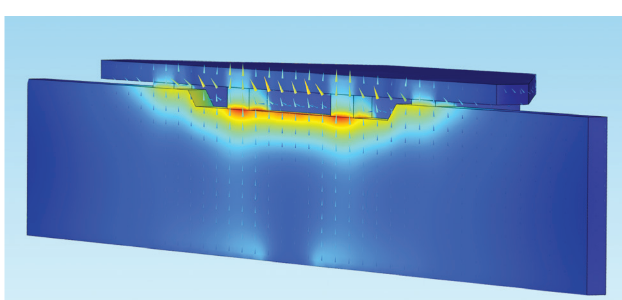

FIGURE 3: Optimized design of the clamping frame (back view). Temperature (surface plot) and oil flow fields (arrows) are shown.

"COMSOL is a powerful modeling and simulation software," says Jovelli. "We can improve the accuracy of our calculations by performing numerical experiments with it. It is also an ally against failure. Design checks can be quickly done to guarantee equipment quality for the entire service life."

» COOLING THE CORE MORE EFFICIENTLY

FROM A THERMAL point of view, a shunt reactor's core has higher heat loss relative to its winding than power transformers, i.e., the ratio of core loss to winding loss in a reactor is higher than in a transformer, and overheating may occur. Therefore, the design must guarantee the efficient cooling of the reactor's core (see Figure 4).

In this case, Siemens simulated the oil circulation and heat transfer in a shunt reactor to understand the oil's behavior and propose an optimized design. A small change in design improved the core cooling, is cleaner than previous designs, reduced man-hours of maintenance, as well as saved material.

Another change that was made involved the piping welded in the tank of the reactor (see Figure 1). Changing this design to the one shown in Figure 5 has reduced material and manufacturing costs and improved oil distribution at the bottom of the reactor tank.

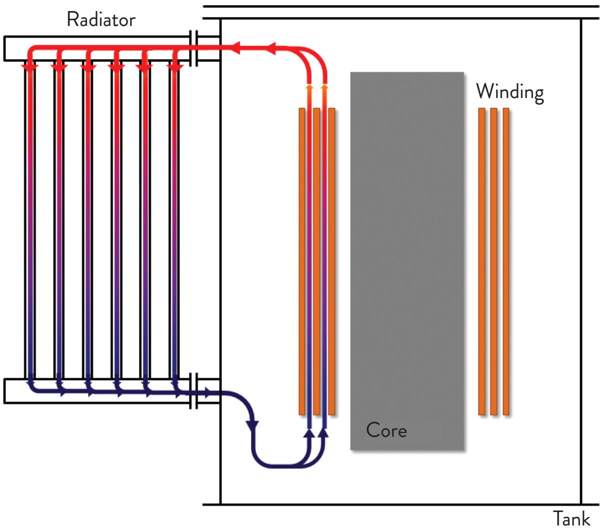

FIGURE 4: Schematic of the new oil circuit design used in shunt reactors and power transformers.

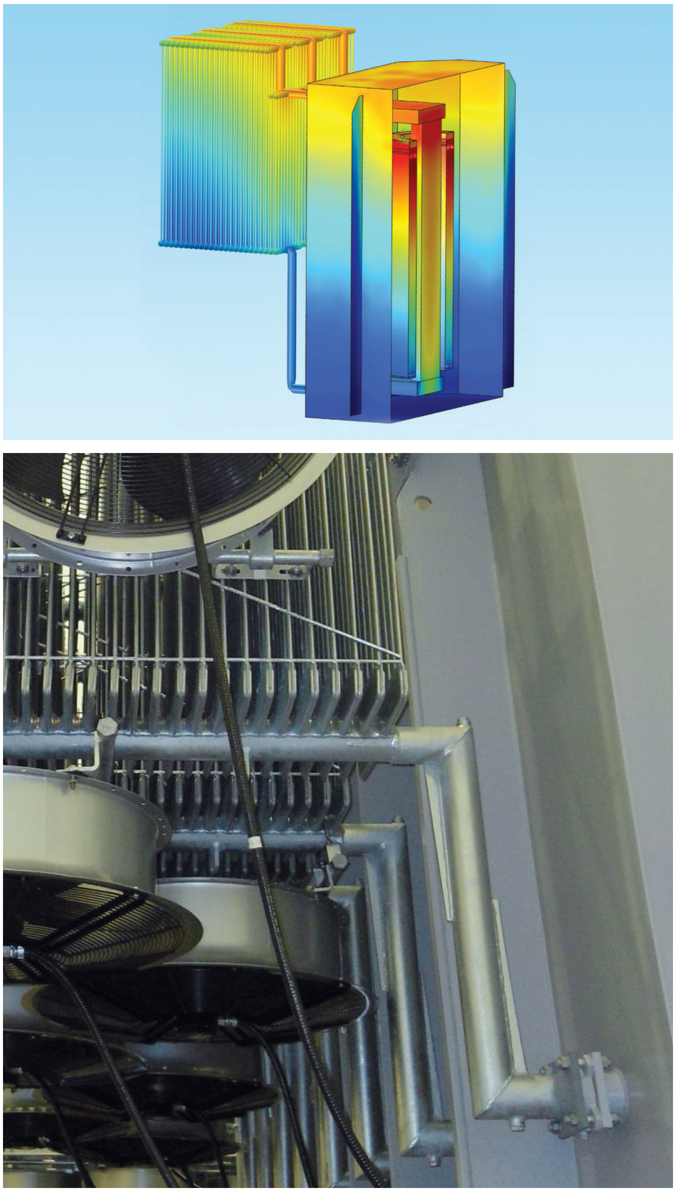

FIGURE 5: Top: The thermo–fluid dynamics simulation of the new design. Bottom: New collecting pipes design. In the new design, the pipes have been removed from their previous position circling exterior of the reactor. Instead, the pipes travel directly from the cooling fan and into the reactor itself.

» COUPLING 1-D, 2-D, AND 3-D MODELS INTO ONE FULL OIL CIRCUIT SIMULATION

JOVELLI AND HIS colleagues are also modeling the 3-D thermohydraulic behavior of free convection of oil inside a power transformer (see Figure 4). It is typically quite computationally demanding to perform computational fluid dynamics (CFD) simulations of transformers by representing all parts in 3-D.

COMSOL offers the ability to take a pipe or channel of a transformer and simulate it efficiently in 1-D. A particular strength of the software is that the pipe and channel models seamlessly combine with larger entities modeled in 2-D and 3-D.

"In order to perform a realistic 3-D CFD simulation of an entire transformer oil circuit with this amount of detail, a large amount of computer resources are required," explains Jovelli. "Sometimes simplifications have to be made, and, depending on the objective, you don't get reliable results. With COMSOL Multiphysics, we can easily couple 1-D, 2-D, 2-D axisymmetric, and 3-D models for any physics and perform this simulation on a single workstation with desired reliability."

> *"By using COMSOL and its multiphysics coupling capabilities, we're the first Siemens Transformer unit in the world to make a real 3-D model of this equipment."*
>
> —LUIZ JOVELLI, SENIOR PRODUCT DEVELOPER, AND GLAUCO CANGANE, R&D MANAGER AT SIEMENS

Using the unique ability of COMSOL to map data from edges (1-D) to surfaces (2-D and 2-D axisymmetric) and volumes (3-D), Jovelli was able to model the windings of transformers using a 2-D axisymmetric model. Additionally, the tank and inlet and outlet pipes were modeled in 3-D, and the heat exchangers were modeled using 1-D elements. The silicon steel core is also a heat source and was modeled in 3-D. Since thin sheets of silicon steel make up the core of the transformer, their anisotropic thermal properties have also been taken into account.

» *THE MULTIPHYSICS APPROACH DELIVERS REALISTIC RESULTS*

FOR JOVELLI AND his colleagues, COMSOL makes it possible to perform more realistic simulations of equipment due to its multiphysics capabilities.

"The ability to couple physics allows us to accurately model real-world physics in a manner that is computationally efficient," say Jovelli and Glauco Cangane, R&D Manager at Siemens. "By using COMSOL and its multiphysics coupling capabilities, we're the first Siemens Transformer unit in the world to make a real 3-D model of this equipment. Maybe we're even the first transformer manufacturer to do it." ◎

MODELING TIPS: INDUCTION HEATING

BY VALERIO MARRA

THE ABILITY TO create multiphysics models is one of the more powerful capabilities of COMSOL Multiphysics®. Several predefined couplings are available where the settings and physics interfaces required for a chosen multiphysics effect are already included in the software. The user interested in modeling induction heating can select the Induction Heating multiphysics interface (Figure 1) that automatically adds a Magnetic Fields interface and a Heat Transfer in Solids interface. In addition, the necessary multiphysics couplings are defined where electromagnetic power dissipation is added as a heat source (Figure 2, Added physics section) and the electromagnetic material properties depend on the temperature. The next step is to select study types such as Stationary, Time Dependent, Frequency Domain, or a combination. Combined frequency-domain modeling for the Magnetic Fields interface and stationary modeling for the Heat Transfer in Solids interface is referred to as a Frequency-Stationary study and, similarly, Frequency-Transient modeling is also available (Figure 2, Added study section). The Magnetic Fields interface is used to compute magnetic field and induced current distributions in and around coils, conductors, and magnets. The Heat Transfer interfaces provide features for modeling phenomena such as phase change and heat transfer by conduction, convection, and radiation.

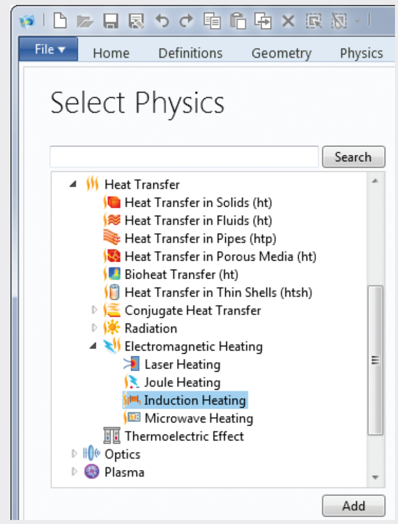

FIGURE 1: A multiphysics coupling is automatically created by selecting the predefined Induction Heating interface.

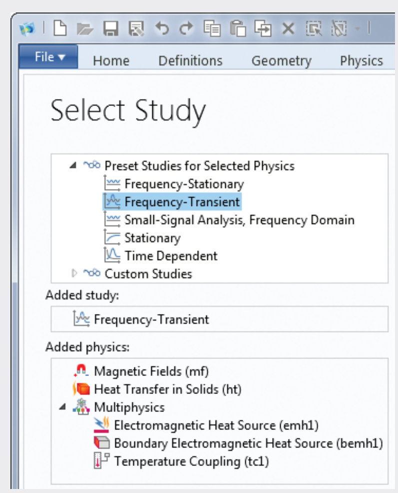

FIGURE 2: The Frequency-Transient study is used to compute temperature changes over time together with the electromagnetic field distribution in the frequency domain.