Multiphysics Simulation Drives Smart City Technology

Reimagining the utilitarian power box into a modular, modern installment requires a complete design reinvention to balance the physical phenomena at play.

by SARAH FIELDS

Contemporary power boxes (or feeder pillars, as they are known outside of the United States), are mounted in the street and control the electrical supply to dwellings within a neighborhood. As residents increasingly prioritize the aesthetic and continue to place a high value on urban living, there is a need for less conspicuous power boxes.

But as it turns out, there is a valid reason behind the bulky size of the power boxes. The size of the traditional design holds the hardware necessary to reduce the high power of the long-distance power line to a power suitable for distribution to homes and businesses. The worthy goal of reducing the size of the power boxes comes with the additional challenge of routing power with considerably less area while considering resistance and Lorentz forces, a not insignificant undertaking.

Ishant Jain, principal researcher in R&D at Raychem RPG, applied his years of simulation experience to the challenge of creating a smart city-ready and space-conscious power box. He along with his team at Raychem enlisted multiphysics simulation to tackle the engineering challenges that accompanied the creation of this radical new design.

➾ HOW POWER BOXES WORK

Thanks to this article, you are reminded of that obtrusive metal box near your sidewalk. But how exactly does a power box work?

The enclosure of a power box provides protection to an electrical distribution system. Its purpose is to distribute the current of a low-voltage supply line, suitable for electrical transport across short distances, into homes and businesses. Power boxes are used to both reduce physical losses of electricity as well as to more precisely distribute and account for the usage of that electricity.

"It is highly beneficial for power boxes to occupy less space," Jain says, "We could create a modular unit with all of the capabilities of the original model adapted for the needs of cities in the 21st century."

Jain and his team swiftly noted many aspects of the design of a classical power box to be improved. These upgrades included a reduction of the cost and of the electrical losses due to substandard connections as well as improvements in safety, size, installation ease, serviceability, and aesthetic.

Jain and his team were also motivated to create a futuristic power box that would be readily adopted by smart cities. This new power box would include smart features to allow for online monitoring of energy usage, as well as to monitor the health of the system and individual fuses.

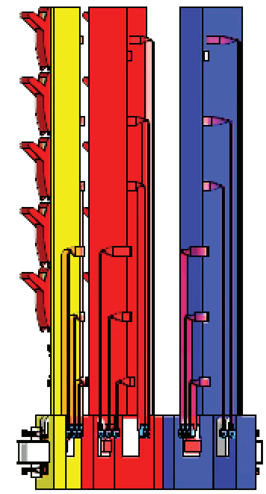

FIGURE 1. The innovative busbar system serves to distribute the same amount of power yet is contained within a smaller space than a conventional power box.

➾ MINIMIZING ELECTROMOTIVE FORCES

The immediate challenge in adapting the geometry of an

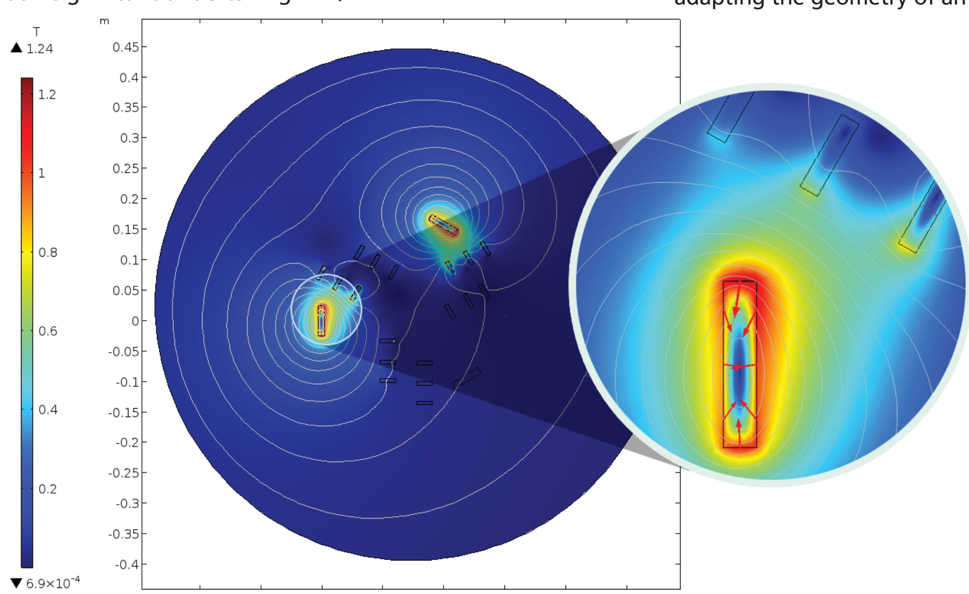

FIGURE 2. Three-phase power box, showing the magnetic flux density norm, surface plot, and the Maxwell surface stress tensor (N/m²), arrow plot.

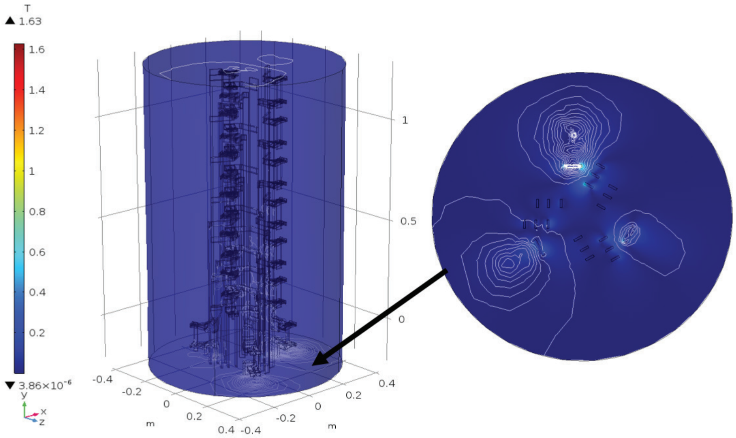

FIGURE 3. Magnetic flux density throughout the power box.

electrical distribution system to a radically small enclosure is the need to mitigate competing electromagnetic forces arising from the change in the design.

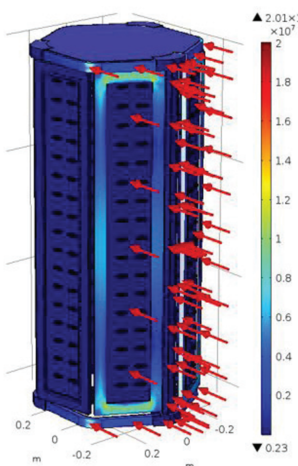

FIGURE 4. Induced von Mises stress at a wind flow velocity of 103 m/s.

Due to the dynamic nature of the physics and the complexity of the geometry, the need for multiphysics simulation in ensuring the stability of the design was immediately evident to the engineers.

To realize such a steep decrease in the size of the power box, the engineers needed to create a busbar system that would distribute the same amount of power yet fit within a smaller geometry (Figure 1).

Jain and his team created a 2D simulation to ensure that their design was suitable to reduce the cumulative impact of the electromagnetic forces (Figures 2 and 3). The 120° alignment of the panels serves to balance the forces acting on the busbars.

"The simulation gave us confidence that the design would work," Jain explains, "We could tell that the electromotive forces would be balanced by the 120° alignment."

⇨ ENSURING THERMAL AND STRUCTURAL INTEGRITY THROUGH SIMULATION

Another important consideration is the overall structural soundness of the power box. For this, Jain and team developed a structural simulation of the power box that would allow them to evaluate its durability. From a time-dependent study of winds of up to 103 m/s blowing against the structure, it was determined that the power box was structurally sound (Figure 4). The engineers also slowly increased the boundary load until the induced stress reached a critical value and determined that the design is safe up to a wind velocity of 570 m/s.

A transient heat transfer analysis of the complete panel assembly was done to ensure the thermal integrity of the system in operation. The validated simulation allowed the team to calculate the temperature rise for conditions that could not be evaluated experimentally. The thermally optimized connectors make the final design safer and more efficient than its predecessors (Figure 5). The resulting design is also modular and scalable (Figure 6).

⇨ VERSATILE MODELING FOR BETTER DESIGN

Jain and his team were able to create a design (Figure 6) that is much smaller but can still dissipate the same level of power and current as traditional power boxes. The final power box design takes up the least amount of space of all power boxes on the market and is thermally sound and efficient.

"Using multiphysics simulation, we were able to ensure the integrity of the final contemporary design," Jain concludes,

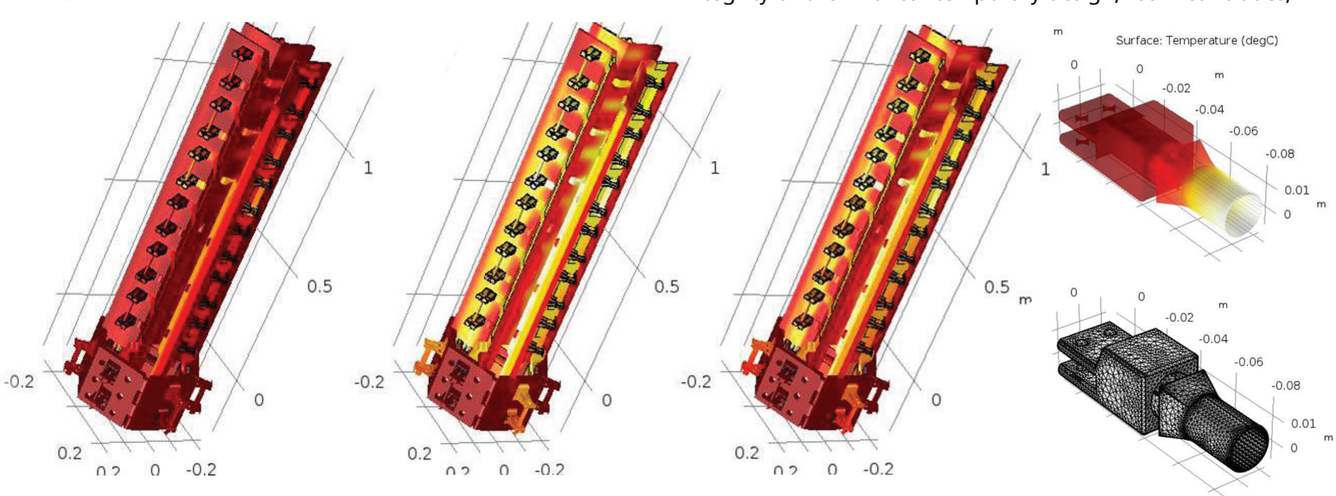

FIGURE 5. Simulation results from a transient analysis of the power box's thermal profile (left) the power box and connectors (right).

"We think that the benefit and impact will be far-reaching as it is adopted across the world."

The final design includes smart features such as a safety and theftproof system as well as the capability for remote monitoring of energy, fuse health, and the thermal profile. It includes fuse housings that are insulated and safe to work with while the system is operating as well as connectors with lower resistive losses.

Suffice to say, in developing a power box that is a fraction of the size of the industry standard, with its reimagined and efficient busbar system, Jain and his team succeeded in reinventing the power box, using multiphysics simulation at every step. ❖

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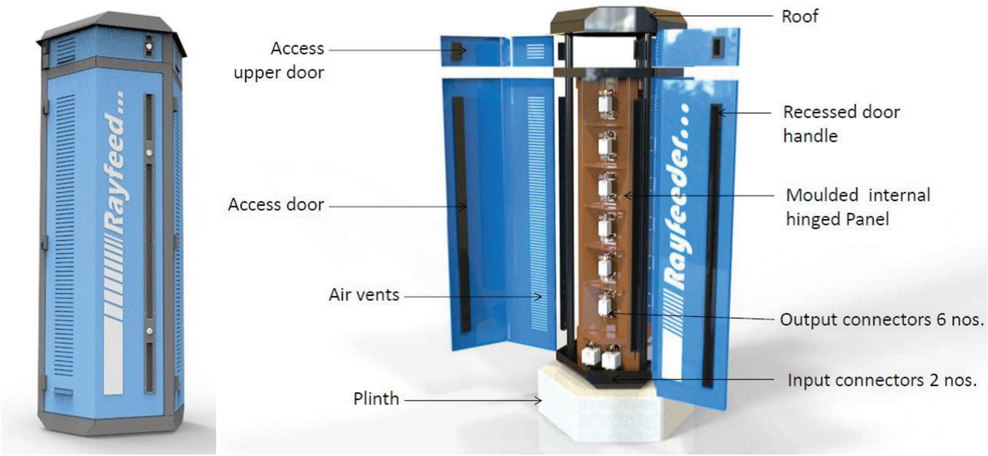

FIGURE 6. Engineers at Raychem developed an innovative, smart city-ready power box design.

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>
> — ISHANT JAIN, PRINCIPAL RESEARCHER IN R&D AT RAYCHEM RPG

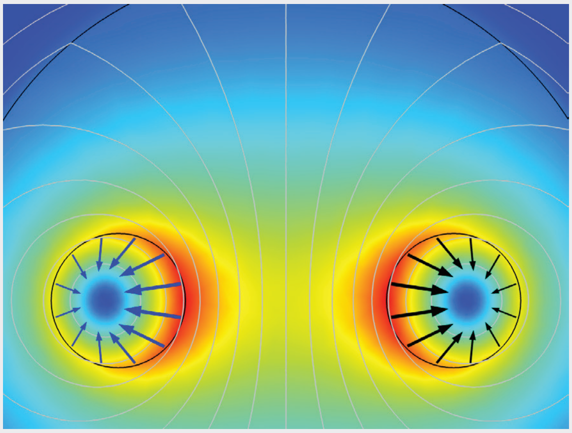
LORENTZ FORCE CALCULATIONS IN COMSOL

by Durk de Vries

The electromagnetic forces that the busbars in the power box are subjected to are known as Lorentz forces. Lorentz forces arise when a current is passing through a magnetic field (as opposed to electrostatic forces or forces between magnets). Just how powerful a Lorentz force can be is illustrated by some railgun designs: With a high-enough current, busbar systems can be ripped apart. Another issue occurs with constantly varying loads (fatigue problems).

In the COMSOL® software, Lorentz forces can be evaluated in various ways. One way is by using the Maxwell surface stress tensor. The projection of this tensor is available on the exterior boundaries of the busbar as an electromagnetic pressure. In the *Magnetic Fields* physics interface in the AC/DC Module, the *Force Calculation* domain feature integrates this pressure and derives lumped quantities, such as the total force and torque on the busbar. Alternatively, the pressure can be used locally, like in a structural mechanics model.

Another way to determine the Lorentz forces is to evaluate the cross product between the current density, J, and the magnetic flux density, B. The vector field resulting from this computation has been predefined as the Lorentz force contribution. Integrating it over the volume will give the total force on the busbar. Generally speaking, the volume integral results in a much more accurate figure than the surface stress tensor boundary integral, but the boundary integral approach is more versatile. Both methods are demonstrated in the Electromagnetic Forces on Parallel Current-Carrying Wires, tutorial model available online in the COMSOL Application Gallery.



Electromagnetic forces on parallel current-carrying wires.