NATIONAL GRID MODELS UNDERGROUND CABLE ROUTES

The use of simulation to accurately predict the rating of underground electric cables within clear safety margins is enabling National Grid to maximize output, ensure reliability, and keep costs as low as possible.

By **JENNIFER HAND**

IF HOMEOWNERS PLUGGING IN new entertainment and kitchen devices were asked to describe their expectation of household electricity, the answers might well include the words "safe," "reliable," and "affordable."

Managing the electrical grid, ensuring that it matches demand throughout the day, and keeping voltage and frequency within acceptable limits are fundamental for safety, reliability, and affordability. In England and Wales, this responsibility lies with National Grid, which owns, constructs, maintains, and operates the high-voltage transmission network that provides electricity to homes and businesses. Figure 1 shows a photo of one of the high-voltage underground cable systems.

Challenges faced by National Grid include improving the thermal management of these enormous networks; optimizing routes for laying new cable and ensuring the accuracy of cable ratings, especially in cases where repairs of older sections have led to combinations of different materials in the same cable line. Meeting these needs requires a thorough understanding of the impact of surrounding soil, cable age, repairs, and how the proximity of other cables will affect a given section's performance.

RATING CHALLENGES

MOST TRANSMISSION and distribution networks use standards issued by the International Electrotechnical Commission (IEC) and supported by the International Council on Large Electric Systems (CIGRE), to work out the rating of a cable — the maximum load it can support while remaining within temperature limits and avoiding potential damage.

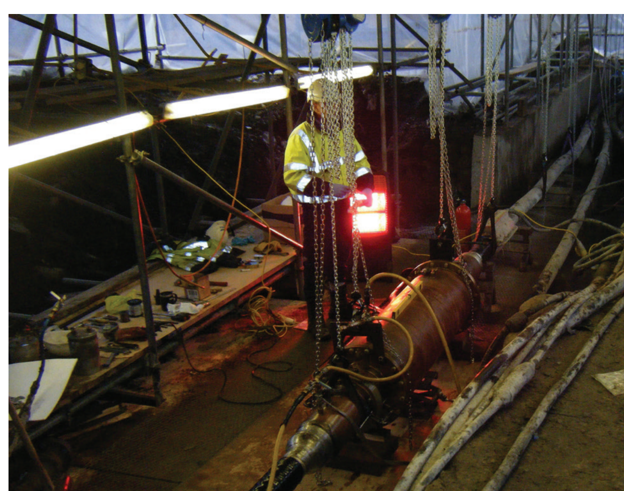

Figure 1. A section of a high-voltage cable system in a tunnel (top) and buried (bottom).

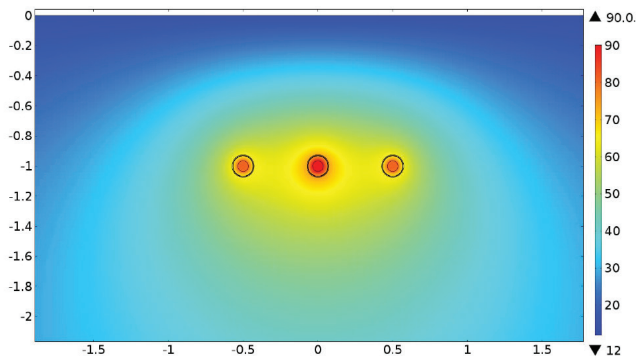

Figure 2. Simulation results in COMSOL® software of the thermal profile of cable laid directly in soil.

David Scott, network mapping engineer, looks after overhead and buried cable capabilities at National Grid's Asset Integrity Department. He explains, "The testing of high-voltage systems is not the easiest business. These cables are up to 165 feet [50 meters] underground and exist in the context of a larger system, not in isolation. The temperature of the earth around a cable may vary along its length, and the thermal load changes where other cables, such as those of distribution or rail power networks, cross or pass close by. It is difficult to validate test results. We are always looking for more accurate cable ratings."

The Tony Davies High Voltage Laboratory (TDHVL) at the University of Southampton, which collaborates with National Grid on innovation projects, has led the way in modeling different cable components and using simulation to better understand the changes in performance that occur as they undergo environmental changes and begin to age.

The research partnership between TDHVL and National Grid began with the creation of empirical models. Engineers at TDHVL work closely with National Grid and undertake finite element analysis (FEA) with the COMSOL Multiphysics® software. Focusing primarily on heat transfer, they first validated the ratings of particular types of cables, and then began to analyze cable ratings at specific "pinch points" in isolation and for different environments (see Figure 2).

For example, when soil is wet heat dissipates relatively quickly. Dry soil is more resistant due to the presence of small air pockets, which limits heat dissipation and affects the cable's thermal performance (Figure 3). The team accounts for soil dryness and cracking when modeling the trench in which a cable runs. "There are standards for soil and specialized backfill materials that we populate in the model. Soil does vary, so we tend to adopt a pessimistic assumption of how it will affect a cable," Scott explains.

» THERMAL AND ELECTRICAL PROFILING

FOR NATIONAL GRID the result of this modeling work is a new outlook, particularly for rating cables that lie close together and optimizing the configuration of new cable routes. Close proximity between cables can impede heat loss, lead to a rise in the temperature of both cables, and reduce their current-carrying capacity. However, sometimes assessments are overly cautious and can result in unnecessary costs in the form of extra cable being laid. "We have found that standards-based methods of assessing cable ratings are generally conservative," says Scott. "They have the potential to suggest overheating issues when two cables are actually over 330 feet (100 meters) apart and have very little bearing on each other."

His team uses the relevant COMSOL model

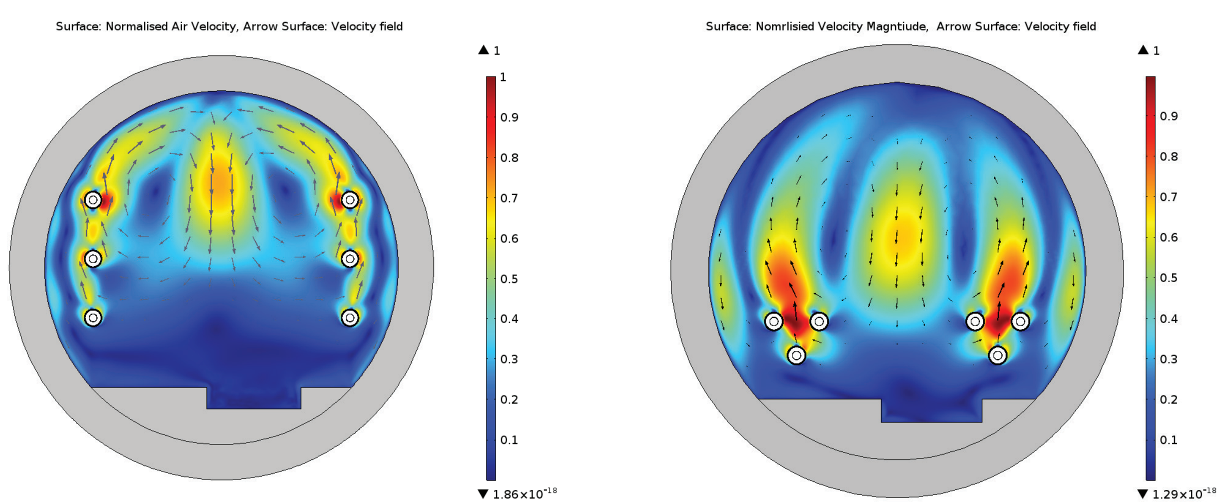

Figure 3. Simulation results of a normalized airflow profile within a cross section of a long horizontal tunnel.

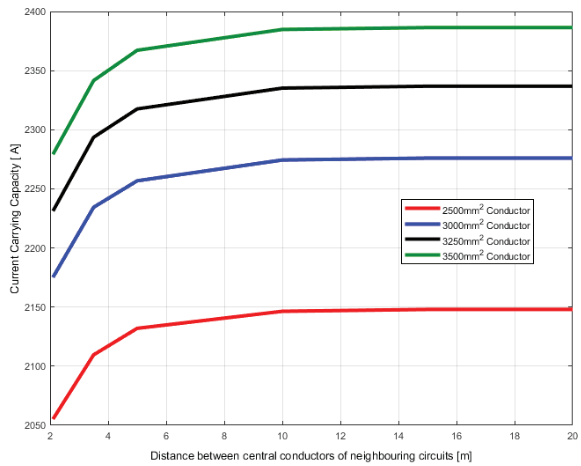

Figure 4. COMSOL® model showing the current-carrying capacity of four identical circuits as the separation between them is varied.

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> **—DAVID SCOTT, NETWORK MAPPING ENGINEER, UK NATIONAL GRID**

Figure 5. Photos of field joints being used to connect separate sections of cables together.

to ascertain whether a new cable can be laid on top of an existing route and still adhere to safety and performance standards, as well as the optimal position (Figure 4). "With modeling, we can now, for example, give precise feedback on the design of the new system and how it impacts the existing network," says Scott.

"Previously we might have had to ask for specific mitigation, mostly by asking the relevant third party to separate their cables further or bury them more deeply. Deeply buried cables do not perform particularly well, and a widely spread cable is expensive in terms of land required — and in confined urban areas may not be possible. With FEA we gain a clearer understanding of the real situation, the true cable rating, and what is possible."

Another challenge is the availability of spares for maintaining older systems and repairs that result in mixed materials (see Figure 5). "Many older cables include a lead outer sheath, whereas new cables tend to be aluminum. If we need to do repairs we prefer to replace only the damaged section because of the obvious cost implications. However, many cable systems are designed to minimize induced currents, thus maximizing capacity. By mixing materials in any given repair, this element of the cable design may be compromised. Existing industrial standards do not consider the case of mixed conductors in parallel. COMSOL allows us to calculate cable circuit losses and understand what countermeasures are required when specific materials are combined."

»» *RELIABLE RESULTS UNDERPIN DECISION-MAKING*

THE REAL VALUE OF SIMULATION becomes clear when Scott discloses the cost of a new transmission cable. "A ballpark figure is 20 million pounds [26 million USD] per kilometer of buried 400-kV cable. Where work that necessitates the installation of a cable is triggered, lean asset design and the maximization of cable capacity are the top priorities for minimizing costs. The knowledge we gain from simulation means we can safely opt for much less deep and convoluted options." This knowledge is of particular benefit when working in tightly constrained parts of a power transmission system such as in central London, where there is often little scope to extend the footprint of a substation horizontally.

There is no shortage of ideas for how to use modeling in the future to inform decision making regarding the life cycle, compatibility, and connectivity of high-voltage equipment, including aboveground cables.

"If we model wind and air temperature around overhead lines and add in the system load for a given time, we'll have a powerful method for identifying potential issues early, such as where pollution may have congealed on the surface of the line," Scott explains. There is also the potential to search for issues with compression fittings, perhaps as a result of fatigue cycling or mechanical damage, and predict potential failure modes for such fittings.

Scott adds: "It is easy to focus on the physical problem without getting caught up in mathematical complexities. We can use the work of TDHVL and adjust key parameters to explore design options while remaining confident in the results. If we ensure accurate input, the simulation has proven extremely reliable and helps us to make good decisions about cable laying and repairs." ◎