The Art and Science of Substation Design

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Gary Pence, Darin K. Penner and Steven M. Carringer

GIS, underground construction and custom landscaping innovations enable utility to integrate a substation into a sensitive location.

Knoxville, Tennessee, U.S., has undertaken a project to redevelop an area on the grounds that hosted the 1982 World's Fair. This project's anchor is the construction of a new convention center on a site that hosts the city's Network Substation, which feeds downtown Knoxville. To make way for the convention center, this 66-kV substation had to relocate. Moreover, the developer wanted the new substation and its lines to be virtually invisible to maintain the high profile of the center and the surrounding World's Fair Park.

To achieve this goal, Burns & McDonnell, Kansas City, Missouri, U.S., teamed with a local architect and a landscape architect to maintain consistency between the design of the convention center buildings and the area. The collaboration proposed an indoor gas-insulated substation, set below grade and surrounded by an attractive fence and wall, as well as extensive landscaping. The team would install incoming lines at 66 kV and four 13.8-kV busses feeding the downtown network underground.

The new substation required a short building schedule - 12 months maximum for design, procurement and construction, including all landscaping. For this reason, the developer (Public Building Authority of Knoxville) and the owner (Knoxville Utilities Board) chose a design/build approach for the contract. This approach allowed them to energize the substation in February 2000, just nine months after contract signing. A joint venture between Burns & McDonnell and the New River Electrical Corp. finished demolition of the old station and work on the screening fence, wall and landscaping by June 2000.

Finding the Site Step one in this fast-track project was to find a site for the new substation. The companies selected a site near the Network Substation that had the advantage of being close to the existing primary and secondary circuits. However, the site also had its disadvantages. It had a triangular shape (about 240 ft by 340 ft [73 m by 104 m]) and sloping terrain. The site served as a parking lot during the 1982 World's Fair and as a dumping site for demolition debris from the fair's construction. These conditions and other unexpected issues required extra work, time and money.

Preparing the Site Exploratory drillings of the site's ground located potential sinkholes. Bedrock existed at 50 ft (15 m) - too far down to be economically practical for drilled-shaft foundations for the equipment. The level of the substation had to be sunk to an average level of 20 ft (6 m) below grade to make the equipment invisible below the 10- to 12-ft (3- to 4-m) retaining walls. The contractor dug down an additional 6 ft (2 m) and out to a distance of 14 ft (4 m) beyond the

retaining wall footings. He then added a layer of rock, installed a polyurethane mat (a Geomat) and several layers of compacted soil, which allowed the whole site to act as a large spread footing. This way, if one part should collapse into a sinkhole at the bedrock level, the site would remain as one unit and hold together. In effect, a small depression might appear at the substation grade level instead of the equipment falling into a hole.

Crews poured footings for the retaining wall, which were 17 ft (5 m) wide on the Henley Street side of the station, on top of the Geomat. They then brought back the extra 6 ft (2 m) of excavation to the desired grade in compacted 6- to 8-inch (15- to 20-cm) lifts of structural fill. The wall height on the Henley Street side spans 28 ft (9 m) from the top of the footers to the top of the wall, of which only 12 ft (4 m) shows because of the site's slope. The design called for a finished height above grade of at least 10 ft (3 m).

Supply to the New Station Electrical 66-kV supply lines into and out of the new substation required conversion to underground from the two existing overhead 66-kV lines near the site. One underground supply comes from an existing overhead line across the street at a new steel riser pole. The other supply comes from an overhead line one block away, using a modified existing steel pole as the riser pole. The underground cables are ethylene propylene rubber (EPR) insulated and installed in duct banks. These cables feed the substation in a loop-through arrangement.

Outgoing lines that feed the downtown Knoxville network also lie underground. Crews installed these 15-kV EPR-insulated cables in a new duct bank that ties into the existing underground duct system serving the network. The old substation supplied the network via lead-covered cables. At the time of the cut-over to the new station, the crews de-energized the circuits, cut the old cables and spliced the new EPR-insulated cables to the lead-covered cables using existing manholes as splicing points. Once they re-energized the circuits, they pulled the old lead-covered cables extending from the old substation to the manholes out of the duct bank.

Substation Equipment Crews placed the substation equipment on either spread footings or slab on grade. Separate buildings, erected on site, housed the 66-kV GIS equipment and the 15-kV switchgear. The substation equipment comprises three 66-/13.8-kV, 30-/40-/50-MVA transformers; 21 15-kV circuit breakers in a separate enclosed building; 66-kV GIS switching equipment in a separate enclosed building; and a capacitor bank inside a metal outdoor enclosure.

The buildings are metal, and the GIS building has a removable roof for easy access to the equipment during assembly and maintenance. The GIS building measures 28 ft by 50 ft (9 m by 15 m). Crews set one-half of the building in place first. Then they placed the equipment on rollers so they could move it around and set it in place easily. Finally, they erected the second half of the building and set the roof in place to enclose everything. When the roof required removal several times during construction, an aerial bucket or derrick easily performed the task. The switchgear building measured slightly larger at 28 ft by 56 ft (9 m by 17 m).

Manufacturers built the GIS equipment in Germany and transported it to the United States by ship and truck on five skids. The factory pre-assembled large sections, but further assembly and testing were required on site.

Final Finish A combination of rose-colored rough-cut marble and brick in a varying abstract pattern finishes the walls surrounding the substation. The landscape architect coordinated the plants around the station with those to be placed around the convention center. The contract's extensive landscaping includes 8-inch (20-cm) diameter magnolia trees.

The project, including demolition of the old substation, was completed on time in June 2000. Final work on the grounds continued into the late spring, giving plenty of time for plants to become established over the summer. Now, convention attendees can enjoy the surroundings of the redeveloped area totally unencumbered by the source of electric power that keeps the center cool in summer, warm in winter and well supplied for all of its electrical needs. As an added benefit, downtown Knoxville has gained reliable electrical service from a new substation.

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