Electrical Grounding and Cathodic Protection Issues in Large Generating Stations

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The common bonding of underground ferrous structures to massive copper grounding grids creates problems for corrosion engineers and their attempts to provide cathodic protection to ferrous structures. This article discusses conflicts between the design and operation of copper and ferrous underground systems and presents alternatives. It describes the case of a large electrical generating station with a bare copper grounding grid, typical of late-1960s construction practices.

Most underground structures at generating stations have traditionally been electrically bonded together to reduce hazardous voltages associated with lightning and fault or induced currents in the earth. A common grounding system is more economical and reduces resistance to remote earth better than individual ground connections. The common ground tends to assure a low-resistance return path for power system earth-return currents and fault currents. It minimizes earth-potential gradients around individual earthing electrodes or elements, which limits step and touch voltages to safe levels at the surface of the earth. In addition, redundant electrical grounding circuits increase safety if one or more conductors are cut or otherwise damaged.

Electrically interconnecting many dissimilar metals in the soil can significantly increase corrosion rates on some underground structures.[1] When materials such as black iron (BI), cast iron (CI), and ductile iron (DI) are interconnected in the soil, they are very close together in the electromotive series of metals and each suffers very little additional corrosion by connection to the other metal.

Creating a dissimilar metal couple by connecting BI, CI, or DI to copper or brass forms a very significant corrosion cell. Copper is electropositive with respect to all ferrous metals. In addition, it does not polarize readily, as do ferrous metals. Therefore, accelerated corrosion occurs on ferrous structures whenever they are directly coupled to bare copper in the soil.

Cathodic protection (CP) is routinely used to overcome soil-instigated corrosion cells on underground piping found in power plants and other industrial facilities. In most instances, a dielectric coating is used on the underground piping and serves as a corrosion control barrier between the pipe surface and the local soil or water environment. These coatings are supplemented with CP to prevent corrosion at "holidays," or voids in the protective coating. The combination of dielectric coatings and CP generally produces a low-cost corrosion protection system with minimum current demands.

Most electrical engineers specify copper for grounding electrodes because it is the preferred material for electrical conductors. In addition, copper is erroneously believed to resist

FIGURE 1

Typical construction activity, not related to CP work. Such construction may damage buried CP components.

corrosion when buried in soil. When copper is directly buried in the soil and completely isolated from other construction materials, copper does corrode. In acidic soil conditions, the corrosion rate of isolated copper may be greater than that of iron or steel in the same environment. If, however, a copper grounding electrode is electrically interconnected with other engineering construction materials (e.g., BI, CI, DI, or steel [iron]), the copper will be cathodically protected at the expense of the ferrous metal to which it is connected. Therefore, copper is a poor choice in direct contact with the soil (i.e., not isolated). It accelerates corrosion on most other buried engineering metals to which it is connected. In addition, it does not polarize as readily as ferrous structures. Therefore, the CP current density (CD) required to polarize the copper to an adequate potential necessary to protect a ferrous structure may be 10 to 20 times as high—on a per-unit-area basis—as the level required to polarize ferrous structures. When one considers that the underground piping in most plant facilities is all coated pipe, it is not difficult to recognize that a bare copper grounding system places a very significant load on the CP system if the underground piping is to be polarized to an adequate CP potential.

Power plants usually bond all structures, including the electrical grounding grid, in common. This provides electrical safety by significantly reducing the chances for a dangerous difference in step or touch potential between the isolated structure and the grid. Directly connecting such a system to a bare copper grounding system may increase total CP current demand by several orders of magnitude. This effect creates a serious conflict between CP engineering design and electrical engineering safety design. Whenever an impressed current CP system is not functioning, a strong galvanic couple forms between the underground ferrous piping and the copper grounding grid. The couple accelerates the corrosion rate of all ferrous structures in direct soil contact.

Alternatives do exist.[2] Other construction materials that have been successfully used for grounding electrodes and/or grid conductors include bare iron or steel structural members, cast zinc anodes, zinc ribbon, galvanized iron pipe and groundrods, stainless steel ground rods, reinforcing steel encased in concrete, and insulated copper cables. If any of these materials are electrically coupled to an effective CP system for the buried plant piping, they will not corrode.

Case History—Steam Electric Station

A large, two-unit lignite-fired steam electric station was designed and constructed in East Texas in the mid- to late-1960s, and it began commercial operation in 1970. Underground utilities at the plant site include, at a minimum, the following components:

- Welded-steel-coated natural gas lines, compressed air lines, and service water lines.
- DI pipe, firewater, and potable water lines that may or may not be coated. (Pipe joints were jumper-bonded.)
- Bar grilles, traveling screens, and circulating water pumps in the clear wells at the intake structure.
- Driven sheet piling at the intake structure, with a total surface area exposed to soil or water of ~55,000 ft^2 (5,110 m^2).
- Dual 108-in. (2.74-m)-diameter prestressed concrete pipe circulating water lines.
- Various control lines, electrical conduit, and foundation rebar.
- An extensive bare-copper grounding grid containing ~10,000 ft (3,050 m) of 250-MCM (124 mm^2) and 4/0-AWG (105 mm^2) conductor with 50 driven-copper ground rods.

No intentional electrical isolation was provided between any of the underground structures. Some CP was provided for the underground plant at the time of initial construction. A few additional rectifiers and groundbeds were installed in the 1980s.

This plant site has been subjected to considerable construction activity since startup (Figure 1). Much of the construction activity has been associated with mandated environmental and pollution control requirements. Other construction has been associated with plant modernization.

The author began working with the plant's CP system in the mid 1990s after a number of water lines had been replaced because of corrosion failures. At that time, the CP system was in a general state of disrepair plantwide. The first course of action was to conduct a comprehensive CP survey. The existing rectifiers and/or anode-beds were then repaired over a 4-year period (Figure 2).

FIGURE 2

Repairs being made on a CP groundbed at the generating station.

Additional units have since been installed as maintenance funds have become available. For all new rectifier units in this facility, negative connections are made to the grounding grid or to building steel. When practical, negative connections are also made to nearby buried plant piping. Individual negative output shunts are provided whenever two or more negative outputs are employed.

During one of the comprehensive plantwide surveys, a remote reference electrode was established and the output of the largest rectifier was interrupted. "On" and "off" potentials were measured and recorded to both a remote and a close reference electrode. The remote readings clearly showed that there were several major electrical discontinuities in the plant grounding grid. This is a very common problem in old generating stations that have undergone extensive upgrades and new construction.

A revised plant grounding grid drawing was prepared calling for insulated bonding cables ranging from 4/0 AWG up to 500 MCM (248 mm^2) in order to provide an adequate degree of electrical continuity throughout the plant grid. The plant grid resistance-to-remote earth was <1 mil-Ω. Therefore, additional bare grounding elements were not required to ensure an adequately low grid resistance-to-remote-earth ratio.

At the time of the most recent survey, a total of 14 operational rectifier units and associated anode beds with a total rated current output capability of 810 A were protecting the buried piping within the plant. These rectifiers were putting out a total of 730.1 A. The plant covers a surface area of ~113 acres (46 ha). Therefore, the average CD per unit area at that time was ~6.46 A per acre. This is an average current output for the total area of the plant. Recognize that, in the congested areas of the plant with extensive copper grounding, the CD per unit area is likely at least an order of magnitude higher.

Conclusions

Earlier work discusses large-plant-area CP current demand in terms of average amperes per acre (0.4 ha) of plant area.[3] The conclusion is that, for the case of extensive bare copper grounding grids, the CP current requirement is almost an order of magnitude higher on a per-unit-area basis than is the case for a properly coordinated and integrated electrical grounding and CP design. This implies that these older designs are at best 10% efficient—from a CP standpoint.

It is also very important to assess adequate electrical continuity across the grid in older generating facilities to be certain that safe step and touch potentials will exist under fault conditions. This is especially important in facilities that have been subjected to considerable construction activity.

References

1. E.L. Kirkpatrick, "Effects of Electrical Grounding On Corrosion," CORROSION/79, paper no. 53 (Houston, TX: NACE, 1979).

2. "Alternatives to Copper Grounding in Sites Requiring Cathodic Protection," MP 25, 9 (1986): p. 17.

3. E.L. Kirkpatrick, "The Conflict Between Copper Grounding Systems and Cathodic Protection Systems," Paper presented at the Second EPRI Corrosion and Degradation Conference (Key West, FL: EPRI, 2000).

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