Utility substation ground grids ensure worker safety and improve power quality. Proper design and construction are indispensable, as is the establishment of a sufficiently low ground resistance. Workers as well as the public must be protected from step and touch potentials. These are the potentials that could develop across a person’s body as the result of contacting some part of the substation or its equipment, or merely the potential between the feet when walking in or near the substation, especially when the substation is experiencing a fault. Control relays need a solid ground reference in order to properly operate switchgear. There will be high current flow into the ground grid during a major fault. There is substantially less chance of anyone within the yard or near the fence getting between two different potentials when everything is bonded together.

Workers are protected from touch potentials if every piece of equipment, such as transformers and switchgear, is bonded to the ground grid. They are protected from step potentials by the design of the grid, such that one foot will not be at a different potential from the other. The public is protected in the near vicinity by the fence being bonded to the grid, and the grid extending underground beyond the fence.

Site selection should depend on the presence of optimal grounding soil, if at all possible. This can be determined by the use of a four-terminal ground tester and a dedicated procedure called the Wenner method. This is a procedure by which four probes are driven into the soil and a resistance measurement taken. The measurement, in ohms, is then applied to a simple mathematical formula that also takes into account the horizontal spacing of the probes. The calculation produces a measure of soil resistivity, which is commonly given in units of ohm-centimeters, though other units may be employed if more convenient. Other methods of obtaining resistivity measurements exist, but Wenner is the simplest and most widely employed for most applications.

Soil composition and structure vary widely in ohm-centimeters from a hundred to a million. This significantly impacts the ability to achieve an acceptable ground resistance and the design of the grid necessary to implement the requirement. In order to dissipate power surges, it is preferable that the soil have high conductivity; i.e., low resistivity. Clay soil works well, gravel poorly. Moisture in damp soil promotes conductivity, while contact of the grounding system with the water table supplies a more or less permanent source of moisture. High salt content is also desirable, as ions carry electric current. Even comparatively dry soils may provide surprisingly good grounds if ion content is high, such as ancient sea beds. Conversely, very moist soil that has poor salt content may prove unexpectedly difficult for the achievement of a good ground. Frozen soil is to be avoided, as the current path has been immobilized, just as it is in a frozen battery.

The data gathered by resistivity measurements serves three primary purposes: location, design, and installation of the grid. If it is possible to select an area of low resistivity (high conductivity), this will make design simpler and installation easier by reducing the amount of contact that must be made with the surrounding soil in order not to exceed the required resistance. Second, various formulae exist for simplifying and implementing the design of a substation grid, and these are typically packaged into software programs that are readily available from the grounding materials market. Obviously, a key datum for entry into such calculations is the on-site resistivity measurement. This value tells the software what to expect from the local soil conditions and what challenge must be met in order to achieve the required low level of resistance. Finally, by varying the configuration of the test probes when making the resistivity measurement, average resistivity to varying depths can be determined. This is a process known as vertical prospecting. It helps in making critical decisions such as whether to drive rods to water table, to expand the grid horizontally because of shallow bedrock, and so on.

Having selected a site and settled on a basic plan, the next consideration is the buried metallic grid that will underlie the substation. A typical grid can be made up on site from properly spaced and joined metal rods. The grid covers the entire area of the substation, extending beyond the fence. The individual elements are conductors, as they will be carrying current to ground when called on line. These are typi-
cally bare stranded copper or Copperweld, with minimum size for a distribution grid being #1/0. For a transmission substation, size is typically increased to #4/0 so as to accommodate the greater demand associated with transmission lines. In order to maximize the efficiency of the grid by maintaining equipotential, a firm electrical connection must be established at every crossover point. The conductors are arranged in a square pattern, with spacing dependent upon soil resistivity; the lower the resistivity, the less dense the rods need be, and hence spacing can be greater. Conductors can be spaced up to 15 feet apart in good soil; for transmission substations, spacing is tighter, typically 10 feet. Some additional structures and connections will typically be required in association with equipment and switchgear, and some special design may be required around access gates so that opening and closing does not affect the electrical integrity of the grid. Addition to or expansion of the facility requires careful integration of any new structures into the existing grid so as to maintain an equipotential plane. Never install a separate ground, as it will promote voltage gradients between the two.

A premanufactured grid may be made up from sections of mesh. Primarily, this saves the time and effort of making all the connections at each crossover point, plus less time is spent laying in individual lengths of conductor. Typically, a mesh is made up of two x two-foot squares, or two x four-foot rectangles of #6 copper or Copperweld, usually 20 feet wide. Any number of these units may be required in order to completely underlie the substation, and the separate mats must be carefully bonded together. In turn, ground rods are bonded to the mesh at selected points, dependent on the overall design. Ground rods augment the grid in such a way as to enable the achievement of the specified resistance. Substations, depending on their size, are generally specified with ground resistances of one or two ohms. In poorly conductive soils, this may be a challenge. The rods give the ability to greatly expand the configuration without taking up additional surface space. By adding rods, resistance goes down, with specific goals like contacting the water table significantly enhancing this capability. Ground rods are typically electroplated copper and are driven in at crossover points, adjacent to equipment, and around the perimeter. A typical rod length is eight feet, but to meet challenges, these can be coupled and doubled or made even longer (deeper). If rods are spaced too close together, their electrical fields coalesce and they begin to act like a single rod, defeating the purpose. Accordingly, eight-foot rods should not be placed less than 10 feet apart, with longer rods commensurately distanced from each other. Extremely difficult soil conditions may call for extreme measures, in which case, a bore hole may be drilled to accommodate the rod, rather than simply driving it into earth. The bore hole is then backfilled with chemically treated earth, conductive materials such as bentonite, or other specific materials on the market for this purpose. The function of the backfill is to create a constantly moist environment around the rod in contrast to difficult, dry or rocky conditions in the surrounding landscape.

Connections need to be able to withstand maximum fault current without opening, so that everything will remain bonded together when there is a rise in potential in the total network. This will protect personnel from getting between different potentials and thereby becoming a current path through the body (electrocution). Above ground, compression connectors, wedge-type connectors, and exothermic welds (Cadwelds®) are used. For below-grade connections, exothermic welds are preferred. Indoor substations may be above grade or at ground or basement level. The grid will usually be encased in the concrete floor, sometimes with additional grounding as by ¼-inch x 1 ½-inch copper or aluminum bars forming a closed loop around inside walls.

Outdoors, the grid is commonly buried 12 to 24 inches, with the surface augmented by three to six inches of crushed stone, asphalt, or concrete. An additional 18 inches of crushed stone is commonly spread on the surface to provide increased protection of personnel from step potentials. Crushed stone has generally about 100 times the resistance of concrete, and this additional protection is especially beneficial in preventing the development of potential when stepping onto remote ground around the edge of the grid. When the surface is concrete rather than crushed stone, an additional wire mesh may be embedded just below the surface. Prefabricated mesh is easily installed for this purpose and then bonded to the grounding grid. As concrete does not offer much resistance, the addition of the mesh significantly improves the equipotential quality of the surface. Similar enhanced protection by installed meshes can be important where switches are to be operated.

This outlines the general considerations for substation grounding. In the next edition, some further elaboration will be reviewed.

Information provided by NJATC® (National Joint Apprenticeship Training Committee), a partnership of the IBEW (International Brotherhood of Electrical Workers) and NEECA (National Electrical Contractors Association) in Substation Construction Guidelines.

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