The previous issue, some fundamental considerations of substation grounding were described and reviewed. We shall continue with an examination of the bonding of metallic equipment to the ground grid. The focus will be on safety, as in the protection of workers from step and touch potentials. Some more sophisticated equipment requires additional considerations in order to function at maximum capability, but this review is directed toward personnel safety.

Substation construction replicates a giant Faraday cage, with all points at equipotential. If all equipment is properly grounded to the grid, it will prevent personnel from bridging between equipment and ground. Personnel must not be able to inadvertently create a circuit between an object not grounded to the grid and one that is. If an electrical fault should occur while personnel are working within the station, any gap in equipotential bonding would create a voltage gradient. A person making contact across that gap will have potentially lethal current flow through the body. In addition, the connections to the grid must be able to withstand the high-energy discharges resulting from lightning strokes and voltage surges. The Faraday structure may be in place at the beginning of an event, but if the bonds are not capable of withstanding high-energy transfer, they can open and present a dangerous situation.

Reinforcing bars (a/k/a rebar) and anchor bolts in concrete are all electrically tied together and connected to the grid. In the absence of this reinforcement, an interesting and dangerous situation can occur. Though it may not be widely recognized, concrete can carry electric current during fault conditions such as a lightning stroke. However, the heat resulting from current squared times resistance can be intense, vaporizing the moisture in the concrete and causing it to explode! Alternate paths through metallic structures like rebar and anchor bolts afford considerably less resistance, thereby providing a safe channel without the excessive heat generation. By tying these structures together, their effectiveness as an alternate channel is maximized, protecting the concrete, and far more important, protecting personnel.

Tying in the rebar and anchor bolts, by creating a much more pervasive equipotential structure, reduces stray dc (noise) flow and thereby further protects the steel from corrosion. It also enhances the size and scope of the total grounding electrode, lowering total resistivity. This type of grounding electrode has been proven effective and is known as a Ufer ground. The name derives from its inventor, an American engineer, George Ufer. It is emphatically not an acronym, such as “Underground Ferrous Electrode Razzmatazz” or whatever, as has been at times erroneously reported.

Structures that support switchgear and other equipment must be regarded as conductive and grounded to the substation grid. This is obvious in the case of steel structures like lattice steel, tubular steel and other framework. But we have already seen that concrete can be conductive, to include concrete poles. Even wood poles, which might otherwise be considered harmless, will typically have down-grounds that must be connected to the grid. Stranded copper cable can be attached by Cadweld® to every upright column and to the nearest or most convenient point on the grid. Tanks and other enclosures must be grounded. These will typically have a grounding pad as part of their design. This will serve as the attachment point for a grounding conductor from the grid.
The safety risk is higher around switchgear than in other parts of the substation. This is because switchgear can experience heavy usage, and during switching operations a breakage or malfunction can cause the grounded casework to contact a live part, thereby energizing the handle or toggle switch that the worker may be operating. To prevent electrocution (becoming part of a current path), the worker’s hands and feet must be kept at the same potential. To accomplish this, a grid under the worker’s feet is bonded to the switching mechanism, and in turn, a second bond is installed from steel casework to the switch handle. Sufficient operator protection can be afforded by bonding to the main grounding grid below the operator’s feet, but it is more common to install a steel grate on the surface, bonded to the switching mechanism and to the underground grid. This makes the bonding connections easier to inspect.

Numerous other equipment must be similarly bonded. Surge arresters exert heavy demands on the grounding connections because they are in a direct line with high-energy pulses from lightning and other faults. From the bottom of the arrester, a dedicated ground cable must be sized to provide a low-resistance path for high voltage and high current, and connections must be particularly tight in order to stand up against high stress. Cable trays are grounded and bonded to the grid in two or more places per run. This is to ensure that they maintain equipotential end-to-end and do not develop a voltage gradient due to an open or high resistance somewhere along the run. A bus bar runs the full length of instrument panels and control cabinets. This bus bar will serve as the reference ground for circuits monitored by the relays and is grounded to the grid.

Metallic conduit housing control cables also must be grounded to the grid. It is grounded at one end only, usually that closest to the control house. Only one ground is employed in order not to establish a continuous loop through the grid and back to the conduit through a second bond. The presence of such a loop facilitates the induction of a counter EMF on the metallic conduit. This unwanted current flow steals energy from the system, which in turn is dissipated as unwanted and potentially destructive heat. Conduit grounding affects not only worker safety but also the proper functioning of control systems and so must not be applied randomly but in careful accordance with drawing specifications.

Workers themselves need redundant ground protection, such as when handling “hotsticks” or other tools that come in contact with potentially live equipment. Such tools have grounding clamps that can be attached to the system ground so as to complete a safe current path around, instead of through, the worker. However, it is not recommended to make casual connection to any nearby point on grounded steel. Such connections can be blown free during a fault, and the worker left unprotected. Instead, the best practice is to install multiple ground electrode connections at critical positions. Half-inch stainless steel bolts are a good choice, or similar configuration that can be easily clamped. These are connected directly to the substation grounding grid. The connection must be firm and secure, capable of carrying the high fault currents typical of substations. Leave nothing to chance; redundant protection is key to worker safety.

Finally, there is the substation fence to consider. Step and touch potentials are to be held low for the duration of a fault, so that personnel both inside and outside the fence are protected. The fence, grid and gate are bonded together in an equipotential unit. Standards that describe the requirements and various acceptable alternatives are provided by the National Electrical Safety Code® (NESC®), IEEE® and ANSI®. The buried grid should extend beyond the fence perimeter about three feet. This is a requirement if the fence is within the grid area. This affords protection to a person walking close by, and possibly contacting, the fence. There may be some risk if one foot is over the grid and the other off the grid, as ground currents returning to the source during a fault create voltage gradients. But this risk can be minimized by a surface layer of high-resistivity crushed rock spread along the fault line. If the fence is outside the grid area, a counterpoise (buried wire) can be installed around both the inside and outside perimeters and bonded to the substation grid. Instead of a metallic fence, a wall of nonconductive material may be constructed in order to secure the site. The wall does not need to be grounded, but the grid should not extend all the way to the wall so as to prevent persons just outside the wall from experiencing step potentials.

Every fence post is grounded and bonded to the grid. Connections can be implemented by thermoweld, compression, or fired-wedge connectors. Each strand of barbed wire atop the fence is also bonded, typically to the ground wire that is grounding the post. This wire also serves as the connection for the bonding of the wire mesh of the fence itself. Copper “C” connectors are good for achieving mesh and barbed-wire connections. Though not easy to ensure, the success of mesh bonding depends on all links making solid metal-to-metal contact with each other. A tight-mesh fence, therefore, is more effective than a loose mesh. There are also the cable-ties that secure the grounding conductor to the fence. White or clear tend to disintegrate from the ultraviolet rays of the sun within a year; black cable-ties last about five years.

The gate should also not create a break in the continuity of the fence grounding when opened. The gateposts on both sides are to be grounded to the grid in order to assure this electrical continuity. The gate demands an additional protection when it opens outward. It would be easy to overlook the hazard of a person inadvertently stepping off of the ground protection while stepping back to open an outward-swinging gate. To prevent this, the grid must be extended in the vicinity of the gate to a distance three feet beyond the full radius of the swing. Inward-opening gates, of course, present no additional requirements. The gate itself must be bonded to the gatepost. This can be done with a flexible jumper. Welding cable is a good choice because it
is flexible and, by definition, has a high current-carrying capacity.

In a subsequent edition, we will conclude the review of substation grounding. But next, we will examine the use of tracing equipment for subgrade grounding conductor and grid deterioration and some related examples.

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

Jeffrey R. Jowett is Senior Applications Engineer for Megger in Valley Forge, Pennsylvania, serving the manufacturing lines of Biddle, Megger, and Multi-Amp for electrical test and measurement instrumentation. He holds a BS in Biology and Chemistry from Ursinus College. He was employed for 22 years with James G. Biddle Co. which became Biddle Instruments and is now Megger.