

Some Basics of System Grounding

Grounding electrodes exist in a wide variety of forms, beginning with the most commonly recognized, the single driven rod. Progressively more elaborate structures are basically for the purpose of redundancy: two rods are better than one, whether coupled end-to-end or paralleled, and this principle can be implied *ad infinitum*. The result can be large grids or interconnected structures of complex design. This article will examine some of the fundamentals regarding substation, transmission line, and distribution grounding.

Substation Grounding

In the developmental phase of ground protection, it was commonly thought that separately grounding different functions, e.g., lightning protection and voltage stabilization, would provide better all-round performance. But this proved to be incorrect. Unnecessary expense was the lesser issue, while voltage gradients between isolated electrodes could defeat the purpose of lightning protection as well as acting as a source of various other unwanted currents entering the system. It was soon realized that interconnected grounds supplemented one another to afford maximum effectiveness, and so a substation will now have a single all-purpose ground bus or multiple interconnected buses if such a layout is more convenient.

Grounding is an important feature of substation design because of the high energy concentration, the necessity for switching to operate properly in order to maintain continuity of service, and the presence of costly equipment. But more important than any of these is personnel safety, as there is likely to be frequent maintenance and operations activity occurring within the station. The aim then is to achieve uniform potential of surfaces, a Faraday cage effect. This can be attained by distributed grounding and the attendant bonding, such as multiple interconnected rods or mesh, often covering a large area and extending beyond the fenced limits. Rods should be spaced farther apart than they are deep, so that their electrical fields do not coalesce and begin acting as one, thereby defeating the purpose. This is commonly achieved by driving a series of rods around the outer perimeter, supplemented by additional rods throughout the station area at points of connection to critical equipment. A suitable conductor must, of course, interconnect all these rods, and in so doing becomes an extension of, and possibly the major portion of, the ground bus. This conductor is typically buried several inches below the surface.

Difficult grounding areas (high soil resistivity) may be improved by various soil treatment measures. Salts, charcoal, or other chemicals were used initially. These could present problems of their own, such as corrosion and environmental issues, as well as the need to be maintained and renewed. Specialized commercial materials were then developed which can do away with these problems. In extreme conditions, deep wells have been sunk, with metal casing or deep-buried plates forming the electrode.

An arrangement of connected rods or similar structures constitutes a distributed ground, whereas a deep-driven single electrode is a point ground. An important difference between the two concerns the distribution of voltage gradients at the surface during fault conditions. Due to its concentrated area, a point ground can exhibit a steep voltage gradient near the single rod, which could be a dangerous step or touch potential. With much larger size, distributed grounds have more area with which to complete the circuit of fault current, resulting in much lesser gradients.

The resistance requirement on the grounding system depends on fault currents required for relaying, system voltage, impedance of equipment, and related factors. Potentials that would be hazardous to persons working in or around the station must not develop,

so that special precautions should be taken to equalize potentials between exposed structures and objects. All such structures must be solidly connected to the ground bus, with metal fences being included. Shallow-buried grids or meshes may extend several feet beyond the fence so as to prevent potentials from developing across the body of a person touching the fence during fault clearance. Locations requiring frequent designated duties should have added protection. Steel plates solidly connected to surrounding structures, switch handles, and so forth offer a protected area on which operating personnel can stand. The same purpose can be served by buried grids of light conductors a few inches below grade, and in some case, such a grid may cover the entire substation area.

There are also low-voltage circuits present, with commensurately lower insulation ratings. These include communication, control, metering, and relaying circuits that are connected to the ground bus for personnel protection, static dissipation, and protection against instrument transformer failure. Large potential differences must not occur along the ground bus so as to prevent breakdown of this insulation. Therefore, the ground bus must be of liberal size to accommodate good conductivity, and all bonding connections must be well made throughout. A related requirement is that conductors be large enough to avoid burning open from fault current. Copper conductors and brazed, clamped, or welded connections are advisable. Pieces of equipment that may receive heavy fault currents can be redundantly protected by two or more paths to ground. Each such conductor should be sized to carry the maximum calculated fault current based on all equipment being in service and taking into account all the equipment having grounded neutrals. Don't forget to consider current-limiting devices with bypass switches.

Transmission-Line Grounding

There are some specialized exceptions, but transmission-line grounding is largely for purposes of lightning protection, in order to maintain service against flashovers and circuit trips. The most common protection is the shielding of conductors by overhead ground wires. These are simply elevated ground wires, paralleling the line conductors and supported at a higher level. The spacing is designed so that the ground wire takes the lightning stroke instead of the line conductor. A combination of field work and laboratory research has produced rules for the geometry of this configuration. In turn, such calculation may result in one ground wire or two, depending upon the situation. The wires are connected to earth at intervals, usually at each supporting structure.

Lightning striking the ground wire or tower will raise the potential at the tower top to possibly millions of volts. Protected by insulators, the conductors remain near zero. If inadequately grounded, a flashover from tower to line can occur, causing a surge current and tripping. But if well grounded, the tower's potential will be determined by ground resistance and surge current, and proper coordination will limit striking distance across insulators or through air. The role of the grounding electrode in this protection is complex, including contributions from surge impedances

of ground wire and tower, surge coupling between ground wire and conductors, and wave reflection in the tower and along the ground wire to adjacent towers. Practical formulas have been worked out so that performance can be reasonably well predicted based on a given set of conditions. In designing grounding protection for a given line, benefit can be weighed against cost, and using data on frequency and severity of lightning storms, outages can be limited to an acceptable degree.

Factors in this calculation include insulation, principally in the form of porcelain insulators, and span length. It is generally found less costly to decrease ground resistance than to increase line insulation. Tower footing itself, being in contact with soil, provides *some* amount of grounding, but this alone is generally not sufficient. Rods are driven to appropriate depths around the base of the tower. In order to keep their fields from acting as one, as was mentioned above, they are kept well away from underground sections of the legs.

In more demanding environments, where efficient use of driven rods is hampered, counterpoise may be used instead. This is a system of bare conductors buried at shallow depths and extending from the tower in two or more directions. Counterpoise differs significantly from more generic electrodes such as rods. It does more than just afford conductivity to earth. In flashover, time is a factor in addition to magnitude of surge. Upon lightning stroke, initially the wire behaves like a surge impedance on the order of 200 ohms. But this impedance rapidly decreases until it reaches the actual ohmic resistance to ground. The counterpoise then acts to rapidly transfer the surge from the top of the tower, where it can provoke an arc to the conductors, harmlessly to earth. The time required is related to the length of the counterpoise, and is shortened (i.e., protection improved) if the total length is expended in several wires radiating from the tower rather than a single stretch. Greater separation improves effectiveness up to four wires, but problems of ownership and land use may limit the extent of wires running at right angles to the line and make more wires at shorter lengths necessary. Another possible problem is the development of high voltage gradients at the surface around wire ends. These two issues, termination and right-of-way, are often solved by having a continuous counterpoise running down the center of the right of way, or two, one along each side. Wire diameter and material are not significant in counterpoise construction and can be decided on local considerations. Wood poles have some material advantages from the insulating properties of wood in comparison to steel; one foot of wood is roughly equivalent to one suspension-insulator unit, and butt-plate grounds are generally equivalent to one ground rod at the same depth.

A second form of lightning protection is the expulsion gap. This is a form of lightning arrester connected with an air gap so as to bridge the insulation to be protected. They limit surge potential to values lower than insulation flashover while providing a path to ground. By limiting surge potential, the gaps reduce the demand on the grounding electrode and can reduce the cost of that installation in difficult areas

that might otherwise require extensive and expensive electrodes. Tower footing, butt plates, or single rods are often sufficient. Gaps are installed in sets of one to four, with one terminal of each gap connected to the grounding conductor or the tower. The other terminal forms one electrode of an air gap to the line conductor, thereby augmenting the insulation with the resistance of air. Expulsion gaps can be installed at varying intervals, but the greater the separation, the more important the role of ground resistance. A special type of expulsion gap uses an elevated line conductor, as in a triangular shape with the other two, serving as a ground wire. A lightning stroke to this conductor passes through an air gap to the expulsion gap and on to the grounding conductor or tower. This configuration permits the use of only one gap per structure, but relies on minimal ground resistance the same as with ground-wire protection.

Distribution-System Grounding

Distribution grounding, because of the greatly increased proximity of the system to the general population, has greater safety demands, and operation focuses more on minimizing the effects of protective trips than on preventing them. Wide variance in the concentration of premises introduces a complicating factor, as is the regulation of current in neutrals. Distribution system grounding will be discussed in the next edition.

Source of information: W. R. Bullard, *System Grounding*, AIEE (now IEEE).



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.