Safety Grounding

Safety is the first and paramount consideration in virtually all electrical applications. Fortunately, properly certified consumer goods (to UL®, for example) and building wiring (if in conformance to the National Electrical Code®) make safety concerns second nature in everyday contact. Industry workers, on the other hand, have to face a different level of contact with potentially dangerous situations, so that a thorough safety review and understanding is indispensable to effective job performance.

In electrical testing, safety must be viewed with regard to both the tester and the test item (frequently referred to as the item under test or IUT). With regard to ground testing, the test instrument presents relatively little threat, but the tested item can pose a danger that must be eliminated through standard safe practice. At its inception nearly a century ago, and for many years after, ground testing was performed with the crudest of instrumentation, often no more than a current source and a voltmeter. Such instrumentation presented obvious safety considerations. Over the years, instrumentation has been refined with respect to both performance and safety, so that present day models have been brought well within accepted parameters. Prior to microprocessor technology, ground testers operated at line voltages, and this had to be taken into consideration by the operator. Improvements in measurement technology and sensitivity have made it possible to design present day instruments safely within accepted standards. These design parameters include limiting voltage below 50 volts, which is generally considered the limit of human safe tolerance, and keeping test current down to a few milliamperes (5 mA is typically regarded as shock level).

Some instruments specially designed for geophysical applications like oil prospecting, however, do still operate at considerable power in order to reach maximum depths. Furthermore, some premium testers offer higher current options for noise suppression or autorange to higher current at the lowest limits of measurement. These currents will be by no means lethal, but the operator should still be aware. The first order of the day, then, is to become familiar with the specifications of the instrument with which one will be working.

There remains the consideration of the test item. In electrical testing at large, typical safety concerns are live voltage and static voltage accumulated on the test item. In the case of ground testing, the test item includes both planet Earth, and more specifically the immediate soil environment, plus the electrical system of which the grounding electrode is a part. The earth is not likely to develop a static voltage from a ground test, but if testing in certain environments, such as around a utility substation, there may be voltage transients in the soil. These are produced by the utility as ground currents from unbalanced systems or system faults seek to return to the transformer. Earth transients are generally no more than a nuisance as they may be observed in destabilization of the test readings, but as they converge on the substation from which they emanated, earth transients intensify. This can culminate in the development of “step potential” between the feet of someone passing close to the substation. Utilities design substations so that lethal step voltages will not develop even at maximum fault current. So as a rule, step potential should be held below maximum safe levels, but some more sophisticated ground testers have a voltmeter function by which this can be checked.

So much for the surrounding earth. There remains the electrical system to be considered. Ground testing is sometimes performed on an isolated ground, in which case there isn’t much to worry about, but is also frequently done on electrodes that are connected into the electrical system. The first check should be with a clamp-on ammeter. This is
both a safety and performance check. Grounded systems can have surprisingly large currents going to ground. As a rule, low resistance precludes dangerous voltage, but this should not be taken for granted. Workers have been injured from contact with “live” grounds. Furthermore, the clamp-on ammeter can reveal unsuspected power quality problems.

A greater danger is from the occurrence of an “event” while testing is in progress. An event is a fault on the system or a lightning stroke. Remember, you do not have to see the lightning, or even be aware of a storm, for it to kill you! High voltage spikes and surges can travel for miles on utility lines into areas of clear weather where local personnel suspect nothing. If this happens and a ground test is in progress, the tested electrode will go “on line” to divert the fault current to earth. A connected ground tester, with probes inadvertently augmenting the ground grid, will become part of this process and so will the operator should he or she be in contact with the instrument. Fortunately, such dangers can be readily prevented by following industry-standard high-voltage safety practices like wearing protective gloves and footwear and conducting the test on an insulated mat. The instrument can be protected from damage and the operator’s protection made redundant by the use of isolation switches and fuse-protected leads. The C and P terminals are connected to the isolation switch first, with the switch appropriately rated to cope with maximum fault voltages. With the switch open, connection is made to the test leads and then in turn to the probes. When the probes have been positioned, the switch is closed and the test made. Remember that personnel must not contact the leads or probes, as in changing positions, unless the switch is open.

So far, the focus has been on the safe testing of installed grounds (electrodes). Permanent grounding electrodes protect the facility, which in turn protects personnel. But a discussion of grounding safety would be lacking without including a review of temporary safety grounds for individual protection. Much careless work is performed in this area, with electrical workers left ungrounded or poorly protected by inadequate substitutes like wire merely tied across phases. Workers on de-energized lines need the benefit of voltage equalization at the worksite and protection against induced voltages from adjacent energized lines. The use of personal protective grounds will equalize voltage differences across the worker to a safe level in the event that the line is accidentally energized as well as permit protective devices to disconnect within the specified interval and protect against induced voltages from parallel energized lines.

In order to work on a de-energized system, it might seem at first that all that is required is to ground all conductors so that all points would be at the same potential and there would be little voltage across a worker’s body. As an example, a lineman working on aerial distribution might have each conductor grounded by dropping cables down to a driven ground rod as illustrated in Figure 1. But to truly evaluate the degree of protection, the system must be examined in detail. The electrical equivalent is outlined in Figure 2, where the resistance of the jumper cable is $R_J$, resistance of the lineman is $R_M$, and the ground resistance of the local area is $R_G$. Note that during current flow, $R_J$ and $R_G$ are in series, and this resistance in turn is in parallel with $R_M$.

The combination of $R_J$ and $R_G$ will vary considerably in resistance from one site to another and cannot be standardized, or even necessarily anticipated. For purposes of example, this combined resistance can be assigned a representative value of 10 ohms, and the resistance of the worker’s body at 500 ohms. Imagine the system becoming accidentally energized at 1000 amperes of fault current. The voltage across the $R_J - R_G$ series will be 1000 amperes times 10 ohms, or 10,000 volts. The worker in parallel with this voltage could experience a current flow of 10,000 volts divided by 500 ohms, or 20 amperes. The limit of current that a human body can tolerate is variously debated, but regardless, is on the milliampere level. The worker would be in serious trouble in spite of the system being supposedly grounded and de-energized.

How might the protection be improved to lessen the impact on the worker? Lowering the ground resistance is an obvious measure, but this can be severely limited in terms of practicality where temporary grounds are concerned. All three grounding cables could be connected to a single driven rod, as shown in Figure 3. This would virtually eliminate phase-to-phase resistance but the worker is still in parallel and would not experience a significant voltage reduction across the body. The arrangement could be improved by jumpering directly from phase-to-phase, as shown in Figure 4. This configuration has the advantage of reducing the violent
and the jumper can be of a sufficient gauge to effectively divert fault current around the worker. A drastic reduction in voltage drop across the work area can be achieved and the worker effectively protected.\footnote{Example provided courtesy of AVO Training Institute, Dallas, TX; avotraining.com}

This example illustrates the difference between taking a cavalier approach to ground protection and taking a rigorous approach from a position of knowledge. Further safety discussion will be presented in the next issue. 

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electromagnetic agitation that can occur between long down leads and reduces resistance between phases to facilitate rapid fault clearance, but the single cable to a driven ground rod still leaves a high voltage across the worker.

A significant step would be to utilize the butt plate and grounding wire running down the length of the pole, as shown in Figure 5. This configuration is schematically represented in Figure 6 By reconfiguring to a common-point ground, the worker’s body is effectively shunted. If the butt plate is efficiently installed, it can establish a better ground contact than a temporary driven rod,