From its inception nearly a century ago until the beginning of the last decade, the basis for ground testing remained largely unchanged. Testers steadily improved in such properties as efficiency of operation, accuracy, and reliability, but the principles of design remained rooted to the fall-of-potential procedure. The tester needed to have the capability to plot a soil profile in the vicinity of the test ground from which the operator could draw proper conclusions as to the electrode’s resistance and hence its effectiveness. Some testers offered more versatility than others, but no wholly new technology appeared until the emergence of the clamp-on ground tester, circa 1990. This technology revolutionized ground testing but not always to the good. The peril is that the method is too easy. To be properly applied, it must be properly understood. Yet its simplicity makes that very requirement consummately easy to ignore.

The clamp-on method arises from a critical modification to an established, though not recommended, procedure — the “dead earth” method. This method was intended to alleviate the labor-intensive problem of ground testing by the recommended fall-of-potential method, which requires the stringing of long leads and probes and the taking of multiple readings. The “dead earth” is simply a nonelectrical reference ground, such as the water pipe system or a metal post, by which a test circuit could be completed in a two-terminal configuration and a measurement taken of the entire loop resistance. The success of the method depends on the unverifiable assumption that nearly all of the measured resistance is contributed by the soil between the test ground and the reference, and the elements of the return path, being large and metallic, contribute nothing of significance. This assumption is risky for a number of reasons; therefore, the IEEE, in their ground-testing standard, accord it only limited sanction.

The clamp-on method takes advantage of noninvasive induction techniques that have been developed largely in the last two decades. It solves the inherent problem of “dead earth” by employing multiple returns in parallel by way of the many utility grounds that typically exist on the circuit feeding the test site. These could be the pole grounds on a distribution line or the concentric neutral of a buried cable. Collectively, following Ohm’s law of parallel resistances, the many returns add little to the measurement. An example is as follows:

Suppose the system has six parallel grounding electrodes, each at 10 ohms:

\[ R_{\text{loop}} = R_6 + (1/(1/R_1 + 1/R_2 + 1/R_3 + 1/R_4 + 1/R_5)) \]

where \( R_6 \) is the clamped (hence tested) electrode and the other five are the parallel returns. Doing the math for a 10 ohm resistance:

\[ R_{\text{loop}} = 10 \Omega + 2 \Omega = 12 \Omega \]

Now, suppose there are 60 equal returns:

\[ R_{\text{loop}} = 10 \Omega + 0.17 \Omega = 10.17 \Omega \]

Since the measurement desired is that of the clamped electrode (\( R_6 \)) and is 10 ohms, the first calculation leads to a significant error (20 percent), but with the addition of more electrodes, the error diminishes to an acceptable level (1.7 percent in the second example).

How does the tester accomplish this? Similar to a familiar clamp-on multimeter, the jaws are closed around the test item, such as a ground rod where it protrudes above the surface or a grounding conductor.
where accessible. Yet unlike a multimeter, the ground tester has two windings – a current transformer and voltage transformer. When energized, a current is induced onto the ground rod, travels through the electrode into the soil, and returns through the utility grounds and system neutral. This is bonded at the service entrance to the ground bus and, therefore, to the grounding conductor leading to the test item. Hence, a complete circuit is available for test current to flow. The transformer winding senses the voltage drop around the loop, and the tester calculates resistance according to the formula:

\[
\frac{V}{I} = R_x + \frac{1}{\sum_{k=1}^{n} \frac{1}{R_k}}
\]

where, usually \( R_x \gg \frac{1}{\sum_{k=1}^{n} \frac{1}{R_k}} \)

Usually the resistance of the test electrode \( (R_x) \) is much greater than \((>>()\) the rest of the measurement. As shall be shown, this assumption includes some risk, not unlike that described for the old dead earth method, though considerably less severe. The unit’s application to a parallel string of pole grounds is illustrated in Figure 1.

It has been shown how this new method was suggested by an old one, with technological innovations applied to address and solve the principle limitations (possible high resistance in return path and necessity to string test leads). A comparison to the basic method for all ground testing, fall-of-potential, is in order.

First, the clamp-on method is easy – at times too easy. Readings are obtained in seconds with a handheld instrument – just clamp and read. The operator need know nothing about ground testing, yet can still go out and collect data. There are instances where the clamp can be applied to the wrong part of the system, but as long as the test current can find a circuit, a reading will be obtained. The untrained operator does not know what was actually measured.

Traditional methods, by contrast, almost force the operator to learn something of the basics in order to position the probes according to accepted procedures and interpret the results in a prescribed manner. With traditional methods, the operator has complete control of the test setup and hence the determination of what is being tested. By placing the probes, the operator measures the resistance of the soil to a defined point. With the clamp-on, the tester determines what is being measured by the nature of the loop that the current describes. The operator must have adequate knowledge of the local wiring configuration. Otherwise, critical errors in interpretation can be made, as will be described more fully when faulty applications are discussed.

Note that, in a way, clamp-on and traditional testers function in opposite manner. Traditional testers drive test current to ground through all available electrodes – that is, all parts of a grid plus any parallel grounds such as the utility ground. Return is completed solely through the remote current probe, placed by the operator, and its attendant lead. By contrast, the clamp-on drives test current only through the element clamped, and return is by all available paths. These are “chosen,” so to speak, by the instrument, not the operator. This difference in operation has significant consequences, both good and bad. It is a good idea for the informed operator to understand them in order to utilize the test equipment effectively.

Because the clamp-on relies on finding a return path through permanent wiring, an “open” defeats its operation. The extreme example of this is a newly installed grounding electrode, not yet connected to the system. There is no return path of any sort, and a clamp-on cannot be used in commissioning tests of new grounds. Traditional three-point testers, where the operator deliberately establishes the return path through leads and probes, have no problem with commissioning tests. Where there are opens, there can be shorts, and clamp-on operation is no exception. At the opposite extreme, clamp-on test current can find low-resistance paths through metal in some types of wiring configurations and not be forced into the soil at all. With incorrect hookup, the tester will merely give a continuity reading of the grid. The experienced operator may recognize this through an uncommonly low reading, but the uninitiated will simply accept it as a test result. There have been many such instances in the field, and these values have entered permanent records as ground resistance tests. Again, because the operator is in complete control of the setup with a traditional tester, no such problem exists. The test current goes by way of the current probe, which the operator has placed in the soil.

At the same time, the clamp-on is performing an important bonding test of the grounding conductor to the electrode. An overrange indication would indicate an open in the return circuit, while an uncommonly high reading will alert the astute operator to a possible corroded or loose connection. A three-point tester will perform bonding tests also, but the leads have to be repositioned and a second measurement taken. With the clamp-on, both tests are simultaneous. By extension, it can be seen that clamp-on readings will always partially comprise some element besides the soil resistance. Clearly, that element would be the return path. Although this component can be minimized to an acceptable level by multiple returns, as was shown (Figure 2), it cannot be totally eliminated. A traditional tester, on the other hand, if four-terminal, can be configured as a true Kelvin bridge, or four-wire measurement. There will be no lead or contact resistance whatsoever.
Finally, but by no means of diminished significance, is the manner in which the test current goes to ground. With a traditional tester, the test current will divide according to Ohm’s law of parallel resistances through all paths to ground. If the operator is commissioning a new system, there will be only one — through the grounding electrode, as desired. If the electrode has been connected to the electrical system, the utility ground is paralleled and will be included in the measurement. The problem with this is twofold:

- The operator has no control over the utility ground, but can improve the on site electrode if necessary.
- Lightning protection calls for the shortest, straightest path into the soil, not a grounded neutral half a mile away.

Ideally, one would want the on-site ground to be fully adequate with the utility serving as redundant protection. Yet with a traditional tester, this cannot be determined in a single step. Either the utility has to be lifted (not a feasible step with welded connections) or the test current must be separately measured between the local and utility grounds, and some annoying arithmetic employed to calculate the separate contributions. The clamp-on method eliminates this problem by its reverse configuration: by placing the utility grounds collectively in series with the test ground, it is the latter that comprises nearly all of the measurement. The utility contributes only a negligible amount, as has been shown. In the practical sense, it is only the local ground that is being measured. Three-point testers, on the other hand, are configured with the local and utility grounds in parallel and the remote probe in series. The measurement, therefore, is a combination of the resistances of both grounds, the percentages of which require further exploration in order to be determined.

In summation, it can be seen that, while the traditional method can be used anywhere, the clamp-on method has certain limitations. Once these are understood, its efficiency in conserving man-hours makes it an indispensable part of a ground-testing program. Without such knowledge, the operator is blissfully “flying blind.” In Part II, we will examine these applications and the separation between the two methods in greater detail.

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