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Tech Tips

Slope Method

The fall-of-potential method described in the previous column is the most general and most thorough way to perform a ground test. However, while this method has a sound theoretical base, it may suffer from physical limitations when applied to the practical world. One of the most common limitations is the frequent necessity, depending on size of the ground grid and other site considerations, to employ test leads that are too long. The theory supporting the fall-of-potential method is based on "ideal" test conditions, which include the separation of the electrical fields surrounding the test ground and the separation of the current probes from each other. If the test is being performed on a single-rod residential ground in a suburban neighborhood with plenty of yard space and not too many fences, the ideal test conditions can be accomplished without even pondering it. The graph of the readings obtained by walking the potential probe at regular intervals toward the current probe will reveal the extent of the two respective fields of influence. If it does not, there is no serious problem. The tester will just need to get some more lead wire, extend the current probe into the neighbor's yard, and repeat the procedure. The measurement and the proof of its validity are self-contained.

But, suppose the test technician is faced with one or both of two common situations — an enormous ground grid and little or no room. A large grid, such as the type that underlies a substation or encircles a transmission tower, will have a proportionately large electrical field in the soil. Getting the current test probe placed beyond this influence typically takes several multiples of the diagonal dimension. This can come out to several hundred feet and be prohibitive. Also, the environment might not even allow reasonable space since the site could be in a downtown area, surrounded by interstate highways, or contain a neighbor who is a psycho known to shoot trespassers! What then? Are you out of business? Not at all! Rest assured, many test technicians have encountered these and other daunting situations, and methods have been devised to complete the test so they could proceed with business as usual.

The most tried-and-true of these methods is known as the slope method. It was first described by Dr. G. F. Tagg in Paper #62975, Institution of Electrical Engineers (IEE) Proceedings, Volume 117, No. 11, November 1970. The method is based on calculus and the "rate of change of slope." The slope method simplifies the mathematical theory.

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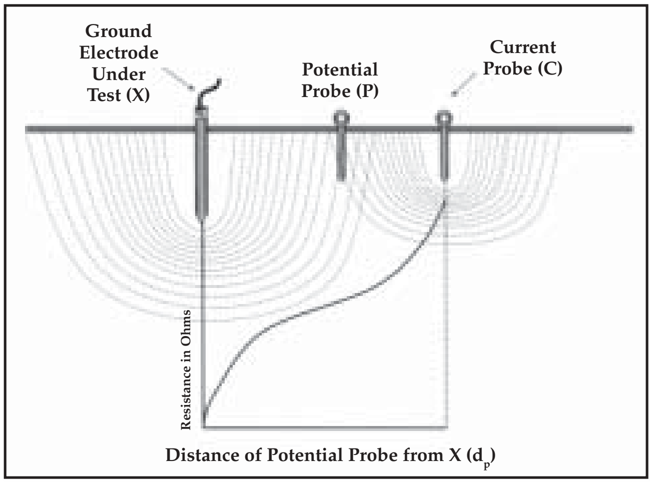
Picture this: A substation grid is to be tested in an industrial area encircled by railroad tracks, busy highways, and fenced properties. Perhaps even a river flows by cutting off a whole side. It appears to be a nightmare! The technician follows standard operating procedures and does a fall-of-potential test by staking out whatever limited room he or she can manage in the most open direction. But the current probe isn't far enough away. As the graph is plotted, the rising resistance curve associated with the grid runs directly into the curve from the test probe. The two "ends" of the fall-of-potential graph have been compressed together, thereby eliminating the plateau between which marks the desired measurement. The point at which the limit of resistance associated with the grid occurs may be somewhere in the graph, but no amount of eyeballing will distin-



guish where grid resistance stops and probe resistance begins. However, the slope method can make this distinction!

The critical data points will be measurements made with the potential probe placed at 0.2, 0.4, and 0.6 times the distance to the current probe. These points are called R_1, R_2, and R_3, respectively. These positions are chosen because readings taken too close to the grid will have errors since the current flow can not be approximated to that from a hemisphere, upon which the theory is based. Too great a distance will bring errors from the influence of the current spike. The latter is positioned somewhat arbitrarily, but it is best to obtain as much distance as the site will allow.

While these three readings are the ones that will be put through the mathematical exercise, the operator may find it useful to take additional readings and to construct a partial graph. Since the electrical center of the grid is not known, precise measurements and a neat graph, such as could be obtained from a single ground rod, are not possible. Rather, any graph will begin somewhere along the rising curve from the test electrode. Plotting a number of additional points may seem pointless, but, in fact, it serves as a safety net to eliminate localized abnormal highs and lows that could make the subsequent calculation unintelligible or even result in a negative value. This additional step helps to eliminate obviously "bad" readings from further consideration and can be of use in final analysis, as will be explained.

Next, the slope coefficient (μ), showing the rate of change of slope, can be calculated from the formula:

$$\mu = \frac{R_3 - R_2}{R_2 - R_1}$$

A relationship can be derived between the slope coefficient, the distance to the current probe (d_C), and the distance at which the potential probe would measure the true earth resistance (d_{PT}). A table can be commonly found in the literature, which gives the value of d_{PT}/d_C for various values of μ. From this table a simple equation yields the distance at which the potential probe should be placed using the known distance to the current probe. Supposing that the critical measurements are 2.1, 4.8, and 6.6 ohms, and the distance to the "C" probe is 100 feet, let's look at a sample calculation:

$$\frac{6.6 - 4.8}{4.8 - 2.1} = \frac{1.8}{2.7} = 0.667$$

Looking up the mu (μ) value of 0.667 from the standard table yields a slope coefficient (d_{PT}/d_C) of 0.6027. As the distance to the current probe (d_C) is known, we can solve for d_{PT}:

$$d_{PT}/d_C = 0.667 \quad d_{PT} = 0.667 \times 100 = 66.7 \text{ feet to P probe}$$

Therefore, if the potential probe were placed at this distance, the reading would indicate the measurement of ground resistance. Finding the measurement of ground resistance could be accomplished by physically moving the probe to that point or if a partial graph had been constructed, as was mentioned earlier, the reading could be taken from the graph. If the crew isn't especially fond of math they could take a sufficient number of data points back to the lab for a supervisor or engineer to analyze. Note that our example also coincided nicely with the well known "62 percent rule" for potential probe spacing, which will be discussed in a future column.

But the crew is not done yet. Recall that the method "may" find the point at which ground resistance ceases to increase. There are a number of problems even this specialized technique may not address. For example, what if the current probe is within the ground field? For large grids, this may well be so. An obvious indication is when the calculated mu value cannot be found on the table. If this happens, some more room must be found in order to move the current probe further.

Even when an intelligible calculation is achieved from this method, however, it is still risky to rely on a single test. In order to eliminate localized effects and uncharacteristic readings, it is better to proof the reading through additional tests taken in other directions and at greater probe distances. It may be found that the readings get lower with distance, but this is only because the shorter tests were performed too close. With increasing distances, readings will begin to come together. That agreement provides assurance the measurement is reliable.

Although the slope method requires extra work one will find that this method is an indispensable ally for the most difficult test sites.

In the next issue we will examine some additional methods for handling tight spaces.

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