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FEATURE: AEMC® INSTRUMENTS

Fall-of-Potential vs. Clamp-On Ground Resistance Testing

Fall-of-Potential vs. Clamp-On Ground Resistance Testing

By John Olobri, Director of Sales and Marketing, AEMC® Instruments

How do these test methods differ? Why choose the Clamp-On method? Is the Clamp-On method as accurate as the Fall-of-Potential method? I was told that I had to use the Fall-of-Potential method. Why can't I use the Clamp-On method?

These are questions that come up on a regular basis by technicians out in the field trying to get a job done correctly and efficiently. This article will attempt to explain, in basic terms, the functions, differences, advantages and disadvantages of each testing method. We will also discuss the latest advancements in Clamp-On test instruments.

Let's start with the Fall-of-Potential method. This test method has been in use since the very early 1900s. A Fall-of-Potential ground resistance test requires an instrument, three or four spools of wire (depending on the test to be conducted) and an equal quantity of auxiliary test rods. The principal operation is simple; a known test current at a controlled frequency, usually 128 Hz (to avoid interference with the fundamental power frequencies of 50 or 60 Hz), developed in the instrument is injected into the earth at a point downstream from the grounding electrode or system to be tested. This is accomplished through the use of one of the auxiliary grounding rods and one of the spools of wire. This rod is referred to as the injector. Various manufacturers have different labels for this. It is referred as the Z rod or the C2 rod. The most recent international standard label for this rod is H. The test current injected at this point wants to get back to its source and does so through the connection to the ground test instrument connection at the rod or grounding system under test. This point again labeled differently by manufacturers of ground test instruments as X or Xv or C_1 and P_1 and now the international standard is E and Es. Finally a voltage drop (Fall-of-Potential) is measured along the path between the injector and the point of test by inserting a second auxiliary rod and wire at various points. This auxiliary rod is labeled Y or P_2 and the new international labeled S. See Figure 1 for a typical test set up. Hereafter we will use the international H, S, E and Es labeling for simplicity.

Note: typically E and Es are tied together at the instrument.

Knowing the injected current and measuring the voltage provides the variables needed to internally calculate the resistance using Ohms law R=E/I. The instrument divides the voltage measured between points S and E by the current injected at point H. It then calculates and displays the resistance value of the grounding electrode system under test. Simple enough. Yes, but there are many factors to be considered to get good test results. First and foremost the distance between E and H must be great enough to prevent influence from one to the other. Typically it is initially calculated to be eight to ten times the depth of the rod or the diagonal distance of the grid under test. This could be hundreds and even thousands of feet. Quite often this distance is not attainable for a variety of reasons not the least of which is adjacent private property. A consideration for the instrument used is the available test current when long distances are required particularly in soils with high resistivity or asphalt. The higher the test current the better. Fall-of-Potential test instruments are available with test currents of a few milliamps to several hundred milliamps.

The best way to confirm that the spacing is correct is to take measurements at 10 percent increments between points E and H. Measurements where S and E are close together will be low. As you move towards H the readings will increase in resistance and will plateau at generally between 50 to 70 percent of the distance and begin to rise again as you move closer to H. If you see the plateau then you can be confident that there is no influence between the rod under test E and the injector H. If the resistance continues to rise at all points along the test then you can assume that there is interference between E and H. See Figure 2.

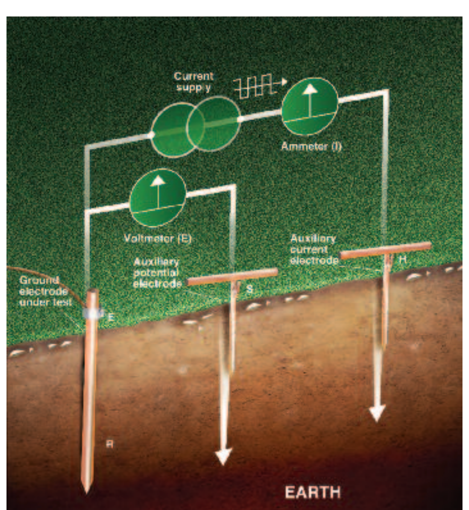
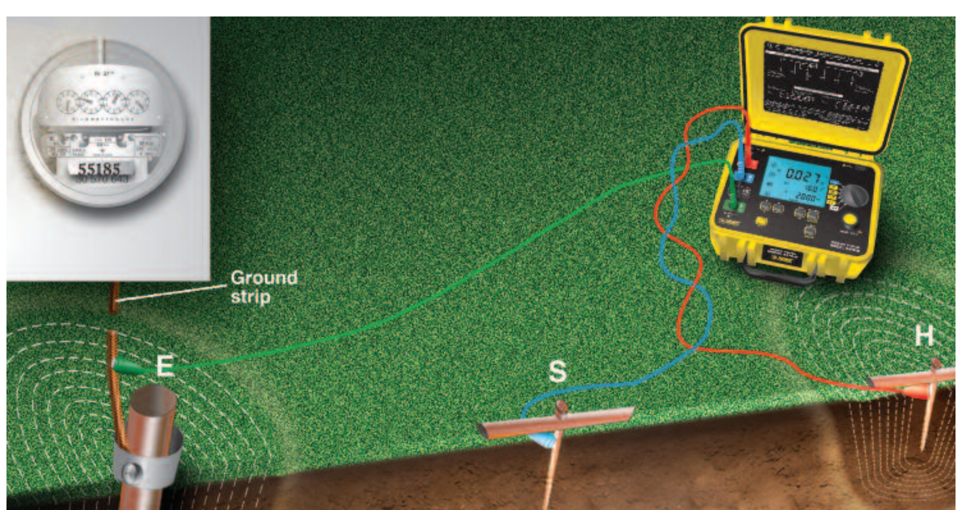


Figure 1 - Fall-of-Potential system



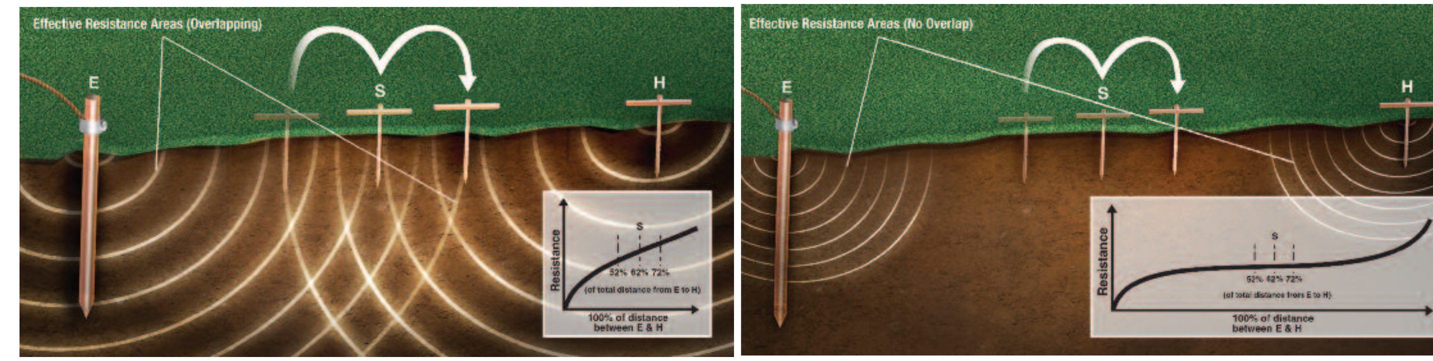


Figure 2 top graph indicates interference between rods by the continually increasing resistance reading (shown in the graph) while the bottom graph indicates good separation between the rods as shown by the plateau in the middle of the graph.

A true Fall-of-Potential test will require a minimum of nine measurement points (one every 10% of the distance) between E and H. A simplified method often used to save time requires only three measurements, one at 52, 62 and 72% of the distance. This test is known as the 62% method. Using either method requires taking the three readings obtained in the plateau area and averaging them to obtain the effective grounding resistance of the test site.

Another important point to consider is that the rod or grounding system to be tested must be isolated and disconnected from other grounding systems such as building steel and the GEC (grounding electrode conductor). Often this is not practical or safe and is usually only an option if the site is shut down for preventative maintenance or other reasons.

This test can be conducted by a single person in roughly an hours' time but is more practical with two people. Placement of the leads for long runs can also cause errors if they run parallel and close to each other.

Recapping this test method we see that it is easy and straight forward to use but has a few limitations. It requires a sizable amount of real estate for running wires and test rods. Isolation of the grounding electrode system under test is necessary to get good results and it takes a fair amount of time even with two people to perform.

Let's now look at the Clamp-On test method to do the same job. This method has been in use since the mid-1980s. The testing principal is similar to the Fall-of-Potential in that a signal is injected and a result is measured. The difference is that, in the case of the Clamp-On method, a voltage is injected and a current is measured. The Clamp-On ground tester has two coils in the head that clamps around the grounding electrode or lead wire connected to the rod. One coil transmits (injects) a burst voltage signal (E) at a known frequency in the kilohertz range into the grounding system. The other coil measures the current flow (I) using highly selective filtering to only allow the current at the test frequency through. See Figure 3 for clarity. Again Ohms law applies to calculate the resistance of the system. There is no need for auxiliary rods to be placed in the ground or wires to connect them to the instrument. Measurements literally can take less than a second. Another significant difference is that, unlike the Fall-of-Potential method, you do not disconnect or isolate the grounding electrode under test from other grounding systems. To achieve good test results two important criteria must be considered. First, you must clamp onto the rod or system to be tested below any point that would facilitate the injected voltage signal to only travel through wire. The earth must be the return path to the clamp-on ground resistance tester. Secondly, and equally important is the fact that with the Clamp-On method you will be measuring the total system resistance and therefore the series/parallel resistance component downstream from the test point should be significantly lower than the rod under test. For example, if you are measuring a ground rod connected to the service entrance of the building that is connected to both building steel and the grounding electrode conductor and tying it to everything else on the line connected to the electric utility you will have a very low downstream resistance. In our example if the ground rod is known to be 12 ohms and the series/parallel resistance downstream was 0.6 ohms, the clamp-on ground tester would measure 12.6 ohms. If the downstream path was higher in resistance because fewer grounding objects were connected and therefore its' effective resistance was 9 ohms, you would then measure

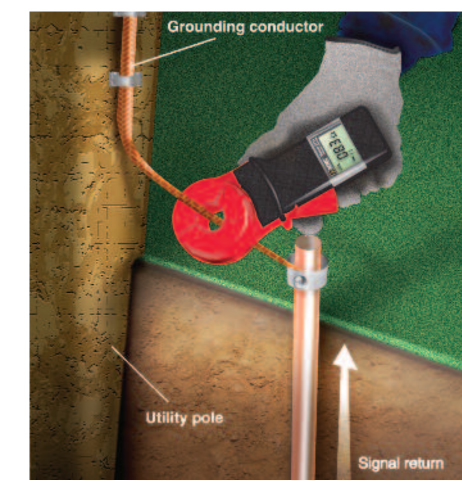
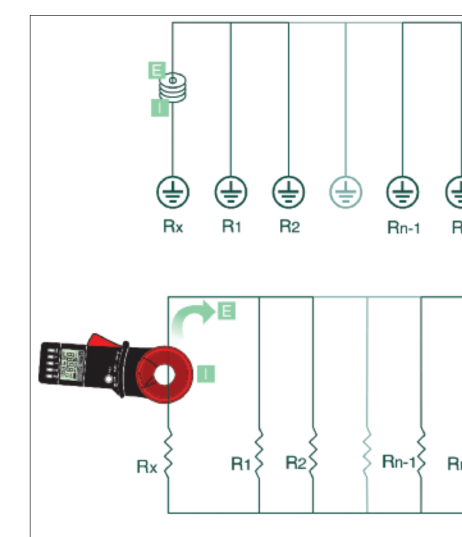


Figure 3 - Electrical diagram of the clamp-on ground tester measuring total system resistance.



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21 ohms. If you clamped around the conductor above a continuous metal path then the signal would not travel through earth but wire only providing a false low reading usually less than an ohm. Therefore a quality measurement requires good placement of the measurement head.

The Clamp-On method provides several advantages when employed properly. First, the system to be tested does not need to be de-energized or isolated eliminating down time at the facility and providing a safer electrical environment. An additional benefit is that you also verify the bonding is good throughout the system. Second, no auxiliary rods or wires are needed to conduct the test which means the task can be completed much faster and only requires one person.

The Fall-of-Potential method is a better choice if you must provide measurement data of an isolated system such as a single rod.

One element that both Fall-of-Potential and Clamp-On testers have in common is that the path the injected signal has to take for good results is the earth.

Comparison of test results using both the Clamp-On and Fall-of-Potential method requires some consideration in that the measurement is conducted at higher frequency typically in the 1300 to 2800 Hz range with the Clamp-On and at 128 Hz with the Fall-of-Potential tester. In general you can expect the measurement results to be somewhat higher using the Clamp-On method because of the frequency difference and the fact that you are reading a total system. Newer instruments available provide the ability to select a test frequency which results in closer comparative readings when the frequency selected on each type of instrument is in the same range.

With proper planning and observing a few rules, many sites can be tested using either method. There are conditions that will favor one method or the other and conditions that will be prohibitive for one method or the other. For example, the Fall-of-Potential method is not an appropriate choice to test an energized system that is connected to other grounding paths. Measurements taken under these conditions will yield false low values. Conversely, the Clamp-On test method will not provide accurate measurements on an isolated disconnected system. This condition, however, can normally be corrected by temporarily connecting to a nearby grounding system using a jumper cable.

Having said that, let's compare an actual field test on a grounding system using both methods that when conducted properly provided comparable results.

Recently, a ground resistance test was conducted on a new installation. Both the Fall-of-Potential 3-Point testing method and the Clamp-On testing method were employed and the results compared.

The grounding system consisted of four copper clad rods installed in an approximate 20 foot square. The rods installed were 5/8" in diameter and 10 feet in length. All rods were coupled together with #3 AWG solid wire with brass mechanical connections. (Figure 1) shows the schematic of the system. After installation a one week settling period was necessary to provide for better contact resistance between the soil around the ground rods before testing. The tests were conducted with a 4-Point Ground Resistance Tester, a Micro-Ohmmeter and a Clamp-On Ground Resistance Tester. The soil conditions in the test area were predominately loam with some gravel. Conditions on the day of the test were dry and sunny, some light rain had occurred the previous day. Therefore, the soil was somewhat moist at the surface.

The Micro-Ohmmeter was used to measure bonding resistance at each rod and was the first test completed. Measurements from each conductor to the rod were taken as well as measurements from conductor to conductor through the rod and clamp. Readings on the rod to conductor ranged from 615 to 733μΩ at the bonding points, indicating that all connections were good.

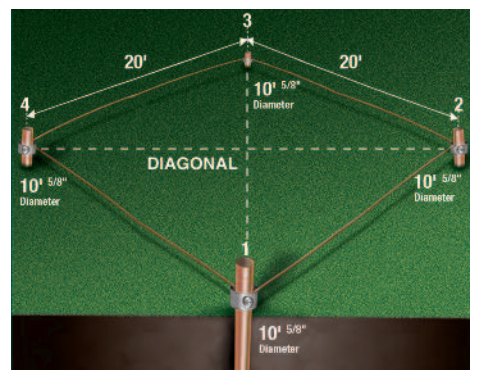


Figure 1 The Grounding System

Measurement Point	Resistance (μOhms)
1	713
2	615
3	733
4	687

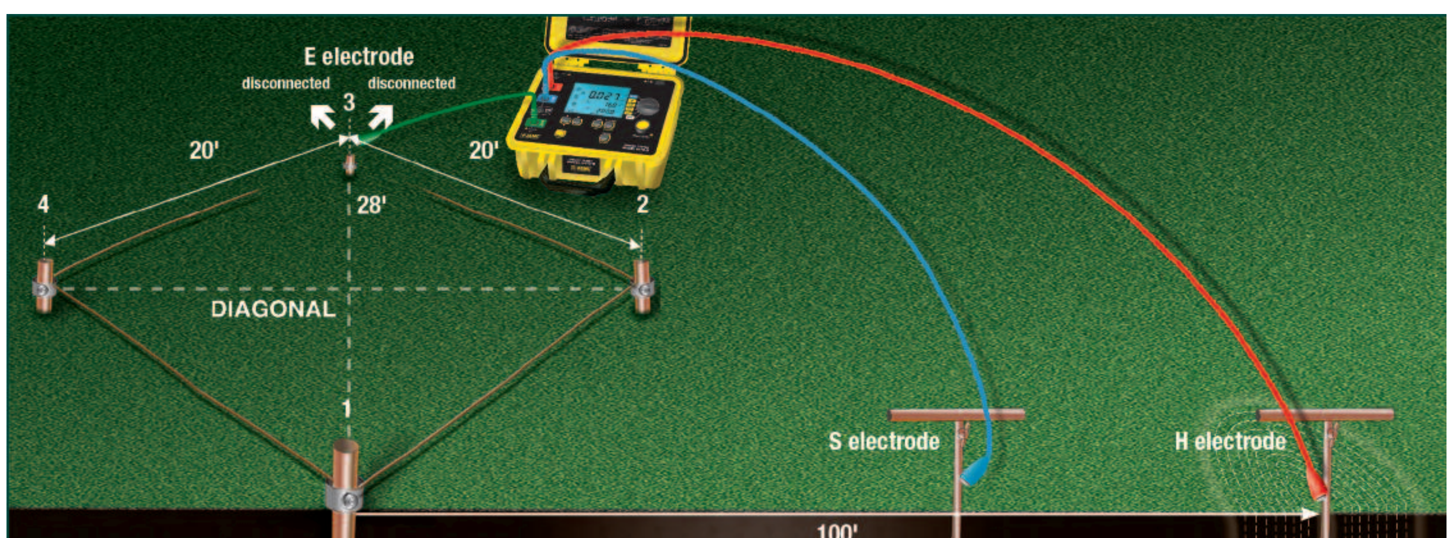
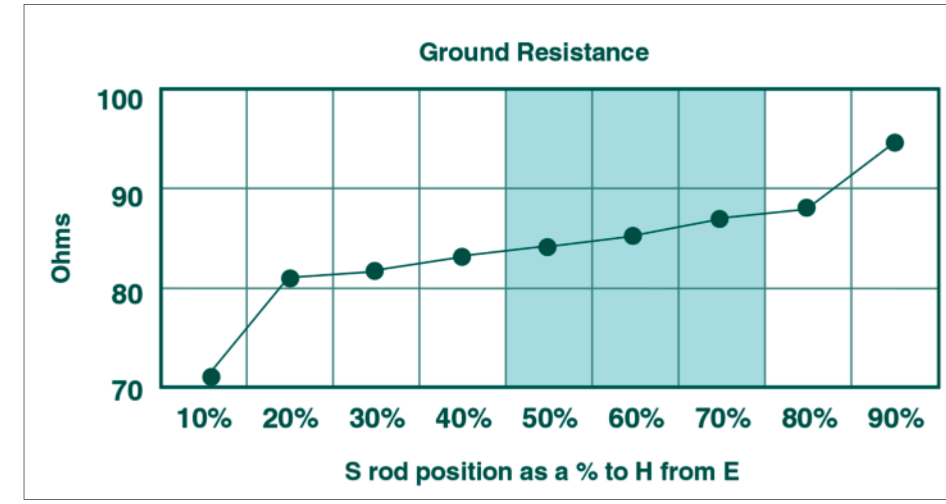


Figure 2 Three-Point test connection

S Rod	Resistance
10%	71.5
20%	82.3
30%	83.2
40%	83.6
50%	83.7*
60%	84.1*
70%	84.6*
80%	85.3
90%	94.8



*The average of the resistances between 50% and 70% is 84.6Ω

Next, a 4-Point ground Fall-of-Potential tester (in three point mode) was employed to test the individual rods as well as the total system. For the purpose of this article we will describe the test on one of the rods. The same test was actually conducted on each rod. Rod number three was disconnected from the other rods in the system so that its individual resistance could be measured. The E lead was attached to rod number three (see Figure 2). The H lead was attached to an auxiliary electrode 100 feet away and the S lead was initially connected to the auxiliary electrode 60 feet away. Readings were taken with the S electrode at 90, 80, 70, 60, 50, 40, 30, 20 and 10 feet. The table and graph shows the results of this test.

Finally, the clamp-on tester was used to measure the resistance at rod number three with all other rods detached from it. A temporary cable was installed between rod number three and the municipal grounding system thus setting up the required parallel paths necessary for accurate measurement (see Figure 3).

Under these conditions, the reading was 84.5Ω. The results of these tests showed that the clamp-on ground tester is an effective tool in measuring ground resistance when used under the proper conditions. The readings between the Clamp-On ground testing and the Fall-of-Potential ground testing method correlate together. This occurred because the reference grounding system, in this case the utility ground, was very low with respect to the rod under test. Therefore the measurement from the clamp-on tester which is always the combined resistance of all paths was close to the rod's resistance to earth. The advantages of using the clamp-on tester is the ability to test without disconnecting the rod from service and the ability to test without the need for auxiliary ground electrodes. These two points saved a considerable amount of time in conducting the test.

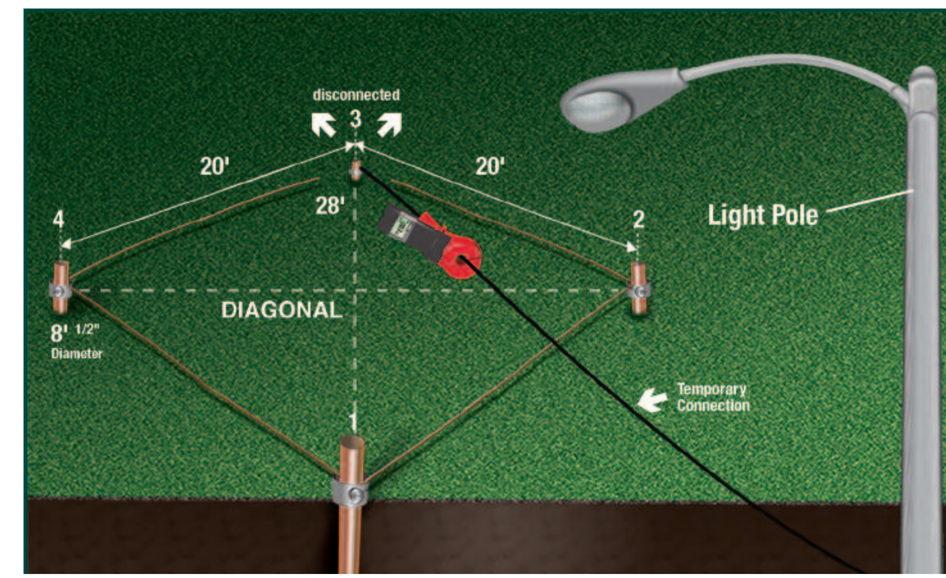


Figure 3 Single rod test using AEMC® Model 3731 Clamp-on Ground Resistance Tester

Choosing the right instrument for the job.

Let's discuss some things that should be considered when selecting a ground resistance tester for purchase. There are a wide variety of products available to you spanning a price range between several hundred to several thousand dollars. Spending some time to consider your testing needs now and in the future will pay dividends later by selecting the right instrument or, in some cases, instruments.

Here are some basic things to consider.

1. Will your current or future needs require soil resistivity testing? If your work requires the design and/or installation of new grounding systems, the ability to test soil resistivity is a necessity in providing the right tool. A four pole also referred to as four point ground resistance tester is required for this type of work. A basic four all tester will provide results in ohms. This value then needs to be applied mathematically to calculate soil resistivity generally expressed in ohm-centimeters or ohm-meters. More sophisticated instruments include built-in formulas for calculating soil resistivity using the Wenner or the Schlumberger method. If you do this type of testing on a regular basis it would be worth your while to consider purchasing an instrument that has formulas and calculations internally. This will save you time and eliminate potential errors using manual math calculations.

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2. Are your ground resistance testing requirements for small sites such as residential work or are they for larger more complex grounding systems found in commercial, industrial, telecommunication or for electric utility work? The answer to this question has many possibilities. First off let's consider the small site. Generally speaking, this consistent all one or two ground rods attached to the service entrance and generally driven 8 to 10 feet into the ground. A basic low-cost three or four pole ground resistance test instrument will suffice here. A clamp-on ground resistance tester may also be used in this application. If we first look at a three or four pole tester we must consider the distances required for auxiliary rod placement to properly select the length of wire needed for proper testing. A single driven rod 8 feet deep will require at least 80 to 100 feet test leads to properly perform a Fall-of-Potential test. If more ground rods are used then this distance requirement will increase. Ground resistance test kits are available that include the measurement instrument, the auxiliary electrodes (three or four depending on the test) and spools of wire to connect the auxiliary electrodes to the instrument. Typical wire lengths provided in these kits are 100, 150, 300, and 500 foot. It would be a wise decision to select a ground resistance test kit that is at least one size up from your immediate need. In this example where a hundred feet would be adequate, a better choice would be to select the 150 or the 300 foot kit. You will be thankful that you did later on. If you are working with larger sites that have multiple rods or ground grids you should consider the 500 foot spools of wire. If you are considering the Clamp-On method for either the small or large site, one benefit you have is that no auxiliary rods or wires are required. As mentioned previously, you do need to have a path for current flow in parallel/series with the Rod bus system you are testing to get a reliable measurement. The lower in resistance that this path provides, the more accurate the measurement with the clamp-on tester.

3. Is this soil resistivity high in the area that you will be testing or is the distance required for the auxiliary when using the Fall-of-Potential method very long? If the answer to either or both of these points is yes and you are selecting a Fall-of-Potential three or four point tester for the job you need to consider the injection current capability of the instrument and the test voltage. Typical injection currents provided by instrument manufacturers in their product offering range from a few milliamps to a few hundred milliamps. Soil resistivity usually equates to high contact resistance for the auxiliary electrodes. This can be of concern if the available test current and voltage is low. Under these conditions you would be better off with a three or four pole test instrument capable of delivering higher test tolerance. The typical 10 mA or lower test flown in lower-cost instruments may be insufficient for the task.

4. Another area to consider is the amount of potential interference from electrical systems in the area. This could cause unstable or inaccurate readings particularly at the lower test frequencies. The most common test frequency use is 128 Hz several instruments are available with automatic or user selectable test frequencies. These instruments would be more appropriate for testing in this type of environment. Instruments with automatic test frequency selection offer the advantage of scanning frequency range to find a clean test frequency without any decision-making on the part of the operator. The clamp-on ground resistance testers are generally best suited for these environments because they inherently test at higher frequencies. There are instances however in high inductive environments where low frequencies would provide better results. The newest clamp-on ground tester's available today offer test frequency selection as well.

5. Other areas of consideration, both the Fall-of-Potential ground testers and Clamp-On ground tester instruments available today offer some additional features to aid the testing requirements that you should consider. Quite often in a complex grounding system consisting of many components as well as a ground mat or grid, bonding of the various elements needs to be checked. This test is most often conducted using DC voltage and current. Several ground tester instruments offered include this function with test currents up to a few hundred milliamps. A more complete test can be performed by using an instrument known as a micro-ohmmeter. The advantage here is the ability to test at higher test currents typically up to 10 amps. Testing at the higher current will expose problem areas typically not shown when testing with only milliamps.

6. Data storage and report generation are other things to be considered. The newest instruments offered today, both three and four pole testers and clamp-on testers, have the ability to store test results in internal memory and through software provided for the PC or mobile apps for smartphones and tablets which offer significant time saving and reliable reporting capability of the test results. This can be very attractive for contractors conducting tests for clients. An added advantage for the mobile app is the ability to immediately send test results as an e-mail or text message to the interested party.

In conclusion, both testing methods are viable and reliable providing that they are employed correctly. Taking the time to understand the system to be tested and the conditions involved e.g. the system is energized and cannot be de-energized or it is isolated and not connected to other grounding paths will lead you to choose the right type of instrument for the measurement. If you regularly conduct ground resistance tests and soil resistivity tests you might consider owning both types of instruments. In all cases try to consider your future needs as well as what you need today. Later on you will appreciate knowing that you have the instrumentation required to perform the test correctly and reliably. ❑

John Olobri holds degrees in both Electrical and Industrial Engineering and has worked in the design and marketing of instrumentation for over 36 years. He began his career designing Oscillographic chart recorders in the mid 1970s. Since then he has held positions of Service Manager, Product Marketing Manager and Sales Manager for several instrument manufacturers. For the past seventeen years, John has been the Director of Sales and Marketing for AEMC® Instruments where he has been actively involved in the areas of Insulation Resistance, Ground Resistance, Power Quality Testing and Data Logging. He also conducts accredited seminars on ground resistance testing in various cities around the country.

GROUND RESISTANCE TESTER
Selection Chart

AEMC MODEL NUMBER	AEMC CATALOG NUMBER	RESISTANCE RANGE	POWER SOURCE	2 POINT TEST	3 POINT TEST	4 POINT/ SELECTIVE	SOIL RESISTIVITY TEST	EARTH COUPLING	2 CLAMP	BONDING	DISPLAY	VOLTAGE INDICATION	INDUCTANCE INDICATION	SWEEP FREQUENCY
6416	2141.01	0.01 to 1500Ω	Battery	Clamp-On Ground Resistance Tester				—	—	✓**	Digital	Voltage Displayed (noise icon, buzzer)	✓	—
6417	2141.02	0.01 to 1500Ω	Battery	Clamp-On Ground Resistance Tester w/Alarm, Memory & *Bluetooth* communication				—	—	✓**	Digital	Voltage Displayed (noise icon, buzzer)	✓	—
GroundFlex® Field Kit Models 6472 & 6474	2136.03	0.001Ω to 99.99kΩ	Rechargeable Battery	—	✓	✓	✓	✓	—	✓	Digital	Value Displayed	—	✓
6471	2135.49	0.01 to 99.99kΩ	Rechargeable Battery	✓	✓	✓	✓	✓	✓	✓	Digital	Value Displayed	—	—
6471 Kit 300FT	2135.50	0.01 to 99.99kΩ	Rechargeable Battery	✓	✓	✓	✓	✓	✓	✓	Digital	Value Displayed	—	—
6472	2135.51	0.01 to 99.99kΩ	Rechargeable Battery	✓	✓	✓	✓	✓	✓	✓	Digital	Value Displayed	—	✓
6472 Kit 300FT	2135.53	0.01 to 99.99kΩ	Rechargeable Battery	✓	✓	✓	✓	✓	✓	✓	Digital	Value Displayed	—	✓
6472 Kit 500FT	2135.54	0.01 to 99.99kΩ	Rechargeable Battery	✓	✓	✓	✓	✓	✓	✓	Digital	Value Displayed	—	✓
4620	2130.43	0.0 to 1999Ω	Battery	✓	✓	—	✓	—	—	—	Digital	LED/Buzzer	—	—
4620 Kit 150FT	2135.19	0.0 to 1999Ω	Battery	✓	✓	—	✓*	—	—	—	Digital	LED/Buzzer	—	—
4620 Kit 300FT	2135.20	0.0 to 2000Ω	Battery	✓	✓	—	✓	—	—	—	Digital	LED/Buzzer	—	—
4620 Kit 500FT	2135.21	0.0 to 1999Ω	Battery	✓	✓	—	✓	—	—	—	Digital	LED/Buzzer	—	—
4630	2130.44	0.0 to 1999Ω	Rechargeable Battery	✓	✓	—	✓	—	—	—	Digital	LED/Buzzer	—	—
4630 Kit 150FT	2135.22	0.0 to 1999Ω	Rechargeable Battery	✓	✓	—	✓*	—	—	—	Digital	LED/Buzzer	—	—
4630 Kit 300FT	2135.23	0.0 to 1999Ω	Rechargeable Battery	✓	✓	—	✓	—	—	—	Digital	LED/Buzzer	—	—
4630 Kit 500FT	2135.24	0.0 to 1999Ω	Rechargeable Battery	✓	✓	—	✓	—	—	—	Digital	LED/Buzzer	—	—
3620	2114.90	0.50 to 1000Ω	Battery	✓	✓	—	—	—	—	—	Analog	LED	—	—
3620 Kit 150FT	2135.10	0.50 to 1000Ω	Battery	✓	✓	—	—	—	—	—	Analog	LED	—	—
3620 Kit 300FT	2135.11	0.50 to 1000Ω	Battery	✓	✓	—	—	—	—	—	Analog	LED	—	—
3640	2114.92	0.0 to 1999Ω	Battery	✓	✓	—	—	—	—	—	Digital	LED	—	—
3640 Kit 150FT	2135.13	0.0 to 1999Ω	Battery	✓	✓	—	—	—	—	—	Digital	LED	—	—
3640 Kit 300FT	2135.14	0.0 to 1999Ω	Battery	✓	✓	—	—	—	—	—	Digital	LED	—	—
3711	2117.60	0.01 to 1200Ω	Battery	Clamp-On Ground Resistance Tester				—	—	✓**	Digital	Noise Icon	—	—
3731	2117.61	0.01 to 1200Ω	Battery	Clamp-On Ground Resistance Tester w/Alarm & Memory				—	—	✓**	Digital	Noise Icon	—	—

** Performing soil resistivity tests with this kit requires two additional auxiliary electrodes not supplied in the 150 ft kit and one additional test lead.*
*** Clamp-on Ground Resistance Tester can measure system continuity inclusive of all bonding points.*

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