AEMC® INSTRUMENTS
CHAUVIN ARNOUX GROUP

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Clamp-On Ground Resistance Testing

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Featured Product:

Clamp-On Ground Testers Theory of Operation

In locations where space is limited, access to the earth is unavailable, or the grounding system cannot be disconnected, clamp-on ground resistance testing instruments may be the best option. Clamp-on testers, such as AEMC’s Models 6416, 6417, and 6418, offer the advantage of measuring ground resistance without disconnecting or de-energizing the system or requiring auxiliary electrodes.

Clamp-on ground resistance testers can be used in multi-grounded systems -- simply clamp the instrument around the ground conductor or rod below all metal return paths and measure its effective grounding electrode resistance.

By performing measurements on intact ground systems, you can also verify the quality of the grounding connections and bonds. Resistance and continuity of grounding loops around pads and buildings can also be measured.

Advanced clamp-on instruments such as the Models 6416, 6417, and 6418 enable you to:

- measure leakage current into the grounding system
- determine ground voltage as an indicator of a potential unsafe condition (Model 6416 and 6417)
- measure resistance, impedance, inductance, current, and voltage
- determine the bonding integrity of the grounding system
- store test results for later review and analysis
- designed to EN 61010-1, 600V CAT IV safety standards

Another advanced feature is data storage. For example, the Model 6417 stores up to 2000 measurements. This enables you to conduct field surveys, which can then be downloaded to a computer for further analysis.

The Model 6417 also includes Bluetooth connectivity, allowing you to communicate with the instrument via a computer or Android app.

How Clamp-On Instruments Work

When determining whether or not a clamp-on instrument is suitable for your application, consider the following.

- **Clamp-ons require a complete electrical circuit to measure resistance.** Other methods, such as the Fall-of-Potential test, use auxiliary electrodes and leads to set up a temporary electrical circuit.

  Clamp-ons are designed to be used with no additional electrodes or leads. Instead they operate by injecting a repetitive burst AC signal into the grounding system to be tested at a frequency that does not conflict with the fundamental frequency current. This requires a complete circuit, with earth as part of the return path. As a result, clamp-ons cannot measure the resistance of isolated electrodes, unless you create a temporary path using a jumper cable to a low-resistance established grounding system. These instruments also should not be used if you are unable to clamp on below an alternate lower-resistance return path that does not include earth. (Instruments such as the Model 6417 report a "LOOP" message in these situations.)

- **Clamp-ons measure the resistance of the entire loop**. This includes the grounding electrode under test, as well as all other electrodes in the system and the conductors and bonds that connect them.

  In a typical municipal electrical distribution network, this may include literally hundreds of utility pole grounding rods, light poles, and more. It may seem logical that the presence of these additional rods in the loop would affect measurement accuracy. Instead (and perhaps counterintuitively), the more electrodes in the loop the more closely the reading matches the individual resistance of the electrode under test. We explain why this is true later in this article.

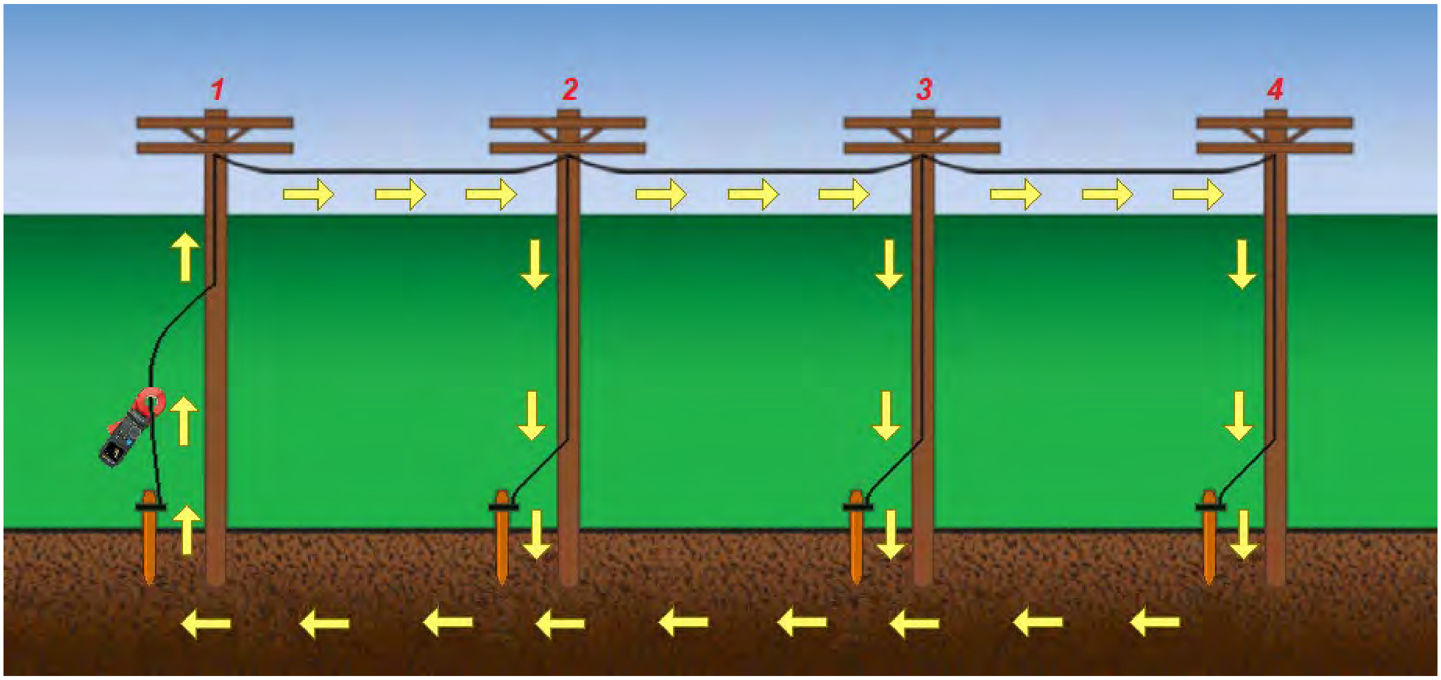
The jaws of clamp-on instruments are designed with two independent shielded magnetic assemblies. One side is a transmitter that injects the repetitive burst AC signal into the grounding system to be tested. The burst voltage of the transmitter is kept constant, so the current actually induced into the test circuit is directly proportional to the loop resistance. The other side is a receiver that acts as a detector to measure the resultant current.

Applying Ohm's Law (***R = V/I***), the instrument divides the test voltage by the measured current to calculate resistance.

The test voltage is transmitted at a specific frequency. This allows the clamp to distinguish the induced current from other currents that may be present, such as leakage.

Operation

As noted previously, clamp-on ground testers require the electrode under test to be part of a conductive loop consisting of other grounding electrodes. The path of this loop must include earth, as shown below.



Placing the clamp around any one of the electrodes measures the resistance of the entire loop. For instance, in the preceding illustration the instrument has been clamped around electrode #1. The reading combines the resistance of #1 plus the series/parallel resistance of the group consisting of #2, #3, and #4.

Mathematically this is expressed as.

$$R_{LOOP} = R_1 + \left(\frac{1}{\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}} \right)$$

Where:

R_{LOOP} = resistance of the entire loop

R_1, R_2, R_3, and R_4 represent the individual resistances of electrodes #1, #2, #3, and #4 respectively

Since the other electrodes in the circuit are in a series/parallel arrangement, adding electrodes lowers the resistance of this group – in essence, the group collectively functions as a single grounding grid. Thus the larger the number of electrodes in the loop, the smaller the resistance of the group and the closer the reading matches the resistance of the electrode under measurement.

To demonstrate this point, assume that each electrode in the illustrated loop has a resistance of 10Ω. Applying this value to the formula (and ignoring the resistance of connecting conductors and bonds) results in the following:

$$R_{LOOP} = 10\Omega + \left(\frac{1}{\frac{1}{10\Omega} + \frac{1}{10\Omega} + \frac{1}{10\Omega}} \right)$$

$$= 10\Omega + \left(\frac{1}{0.3\Omega} \right)$$

$$= 10\Omega + 3.33\Omega$$

$$= 13.3\Omega$$

In this case, the instrument reading will be 13.3Ω, which is 3.3Ω more than electrode #1's actual resistance of 10Ω.

Now let's add three more 10Ω electrodes to the loop:

$$R_{LOOP} = 10\Omega + \left(\frac{1}{\frac{1}{10\Omega} + \frac{1}{10\Omega} + \frac{1}{10\Omega} + \frac{1}{10\Omega} + \frac{1}{10\Omega} + \frac{1}{10\Omega}} \right)$$

$$= 10\Omega + \left(\frac{1}{0.6\Omega} \right)$$

$$= 10\Omega + 1.67\Omega$$

$$= 11.7\Omega$$

This shows that adding three 10Ω electrodes in parallel to the loop actually lowers the reading and brings it closer to that of the electrode under measurement.

In electrical grids with high numbers of connected grounded utility poles, the loop resistance reading is only slightly higher than the individual electrode under measurement. This difference can provide a margin of safety, to ensure the tested electrode meets local ground resistance guidelines. This makes clamp-on instruments ideal for applications such as testing the grounding systems of utility poles connected to municipal electrical grids

In Summary

- Clamp-on ground testers provide a quick and easy method for testing an electrode connected to multi-electrode systems.
- These instruments work on both energized and de-energized ground electrode systems.
- Clamp-on ground testers do not require the use of auxiliary test rods.
- These instruments require a complete electrical circuit to operate. The circuit must include earth as part of the return path.
- Clamp-on instruments measure the resistance of the entire loop. This is always higher than the actual resistance of the individual electrode under test.
- The more electrodes included in the loop, the more closely the measurement matches the resistance of the electrode under test.
- AEMC's Models 6416, 6417, and 6418 provide additional advanced features including measuring leakage current, checking bonding, user configurable alarm detection, data storage, and (Model 6417) Bluetooth connectivity.

For more information about AEMC's family of clamp-on ground testers, please visit our web site.

Power Factor and Reactive Power

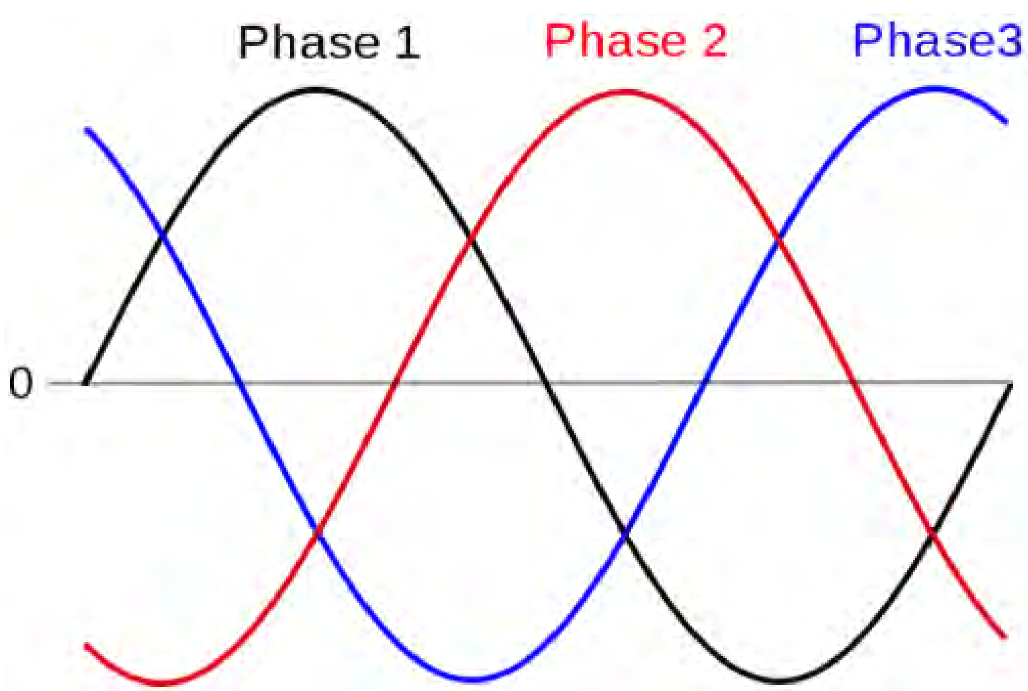
How efficient is my electrical network? This is one of the more basic and critical questions related to your distribution system. Yet determining a precise answer can be a little tricky if you're unfamiliar with concepts such as active power, reactive power, and Power Factor.

In this article, we briefly explain some of the parameters that help determine how effectively your network delivers useful electrical power.

Active vs Apparent Power

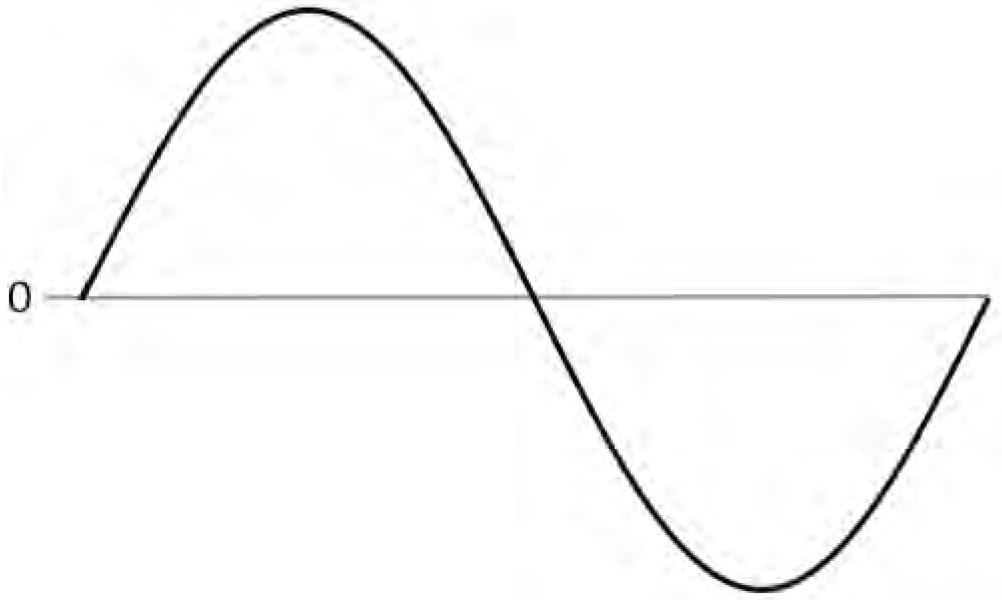
To begin, it's important to distinguish **active power** (the amount of energy being transferred to the network's load and/or dissipated by the network itself, represented by **P** and measured in watts) and **apparent power** (the total amount of power delivered by the network, represented by **S** and measured in volt-amps). Active power is also known as actual power, true power, "watt-full" power, useful power, and real power. Apparent power is also known as total power.

In a DC system, where voltage and current are essentially linear, active power and apparent power are more or less equivalent. In AC systems, the situation is more complicated. To understand why, consider the familiar sine waves typically used to represent 3-phase AC electricity:



Each wave represents electricity periodically oscillating between its positive and negative values.

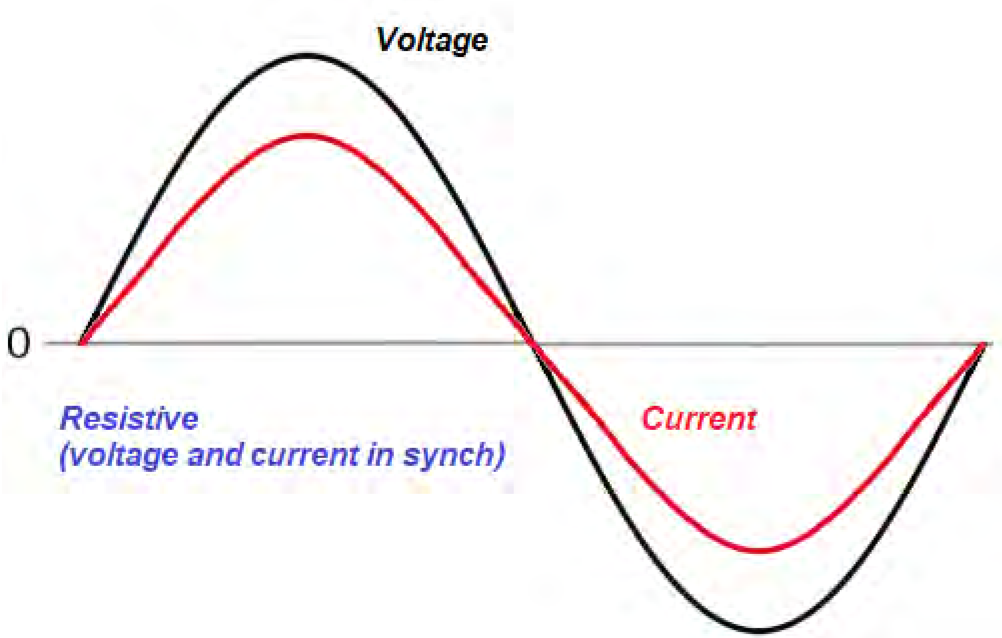
To simplify things a bit, we'll focus on a single phase, while bearing in mind that the remainder of this article applies equally to the other two phases.



For "clean" AC power undistorted by factors such as harmonics, the sine wave is perfectly symmetrical and spends as much time above zero as below it.

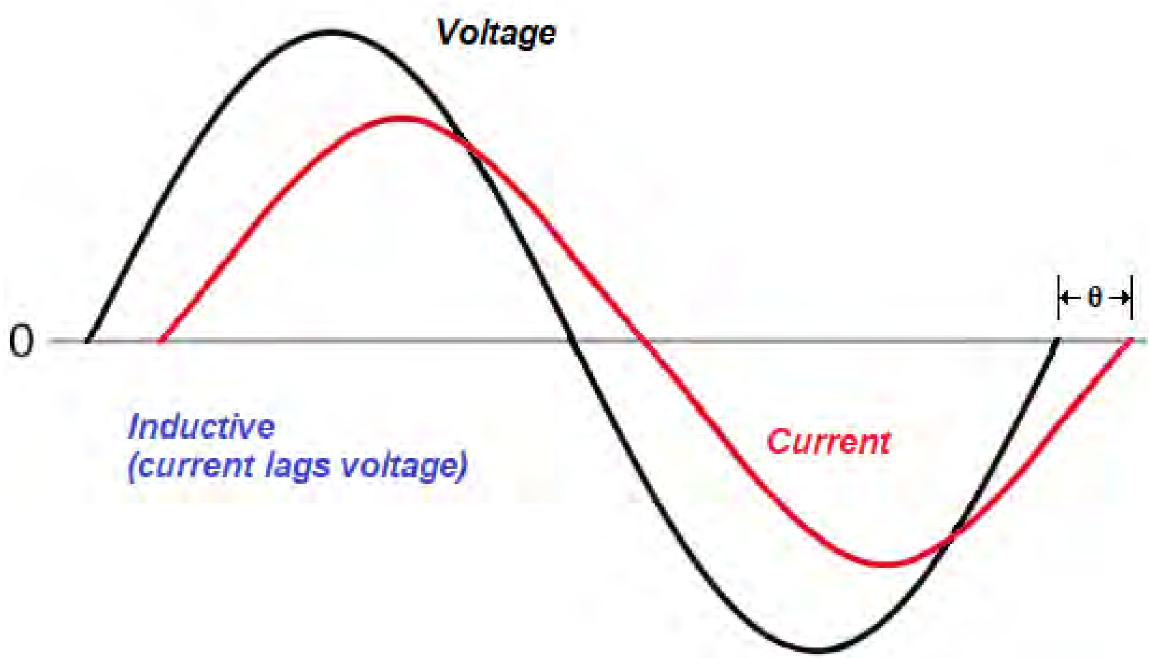
Capacitive vs Inductive

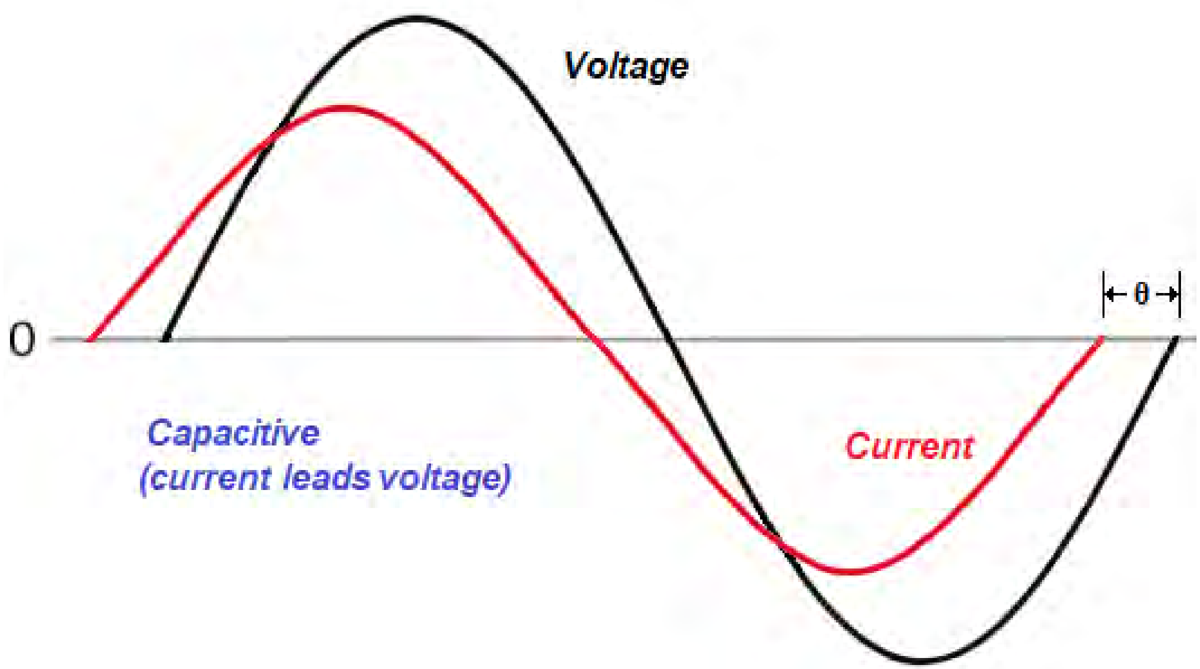
Each phase of AC power consists of two waves, one for voltage and the other for current. Ideally, these waves are in phase (i.e. the peaks align), a situation known as a **resistive** network. Multiplying **V x I** at any point in the cycle other than zero results in a positive **S** value.



In a resistive AC network, all non-zero points in the wave yield usable power. In this case, the network's apparent power equals its actual power (**P = S**), the same as in a DC circuit.

In practice, various loads on the distribution system such as transformers, motors, electronics, and other components can cause the voltage wave to either lead or lag the current wave, a difference represented by the symbol **θ**. A network with current leading voltage is called **capacitive**; lagging current is known as **inductive.**

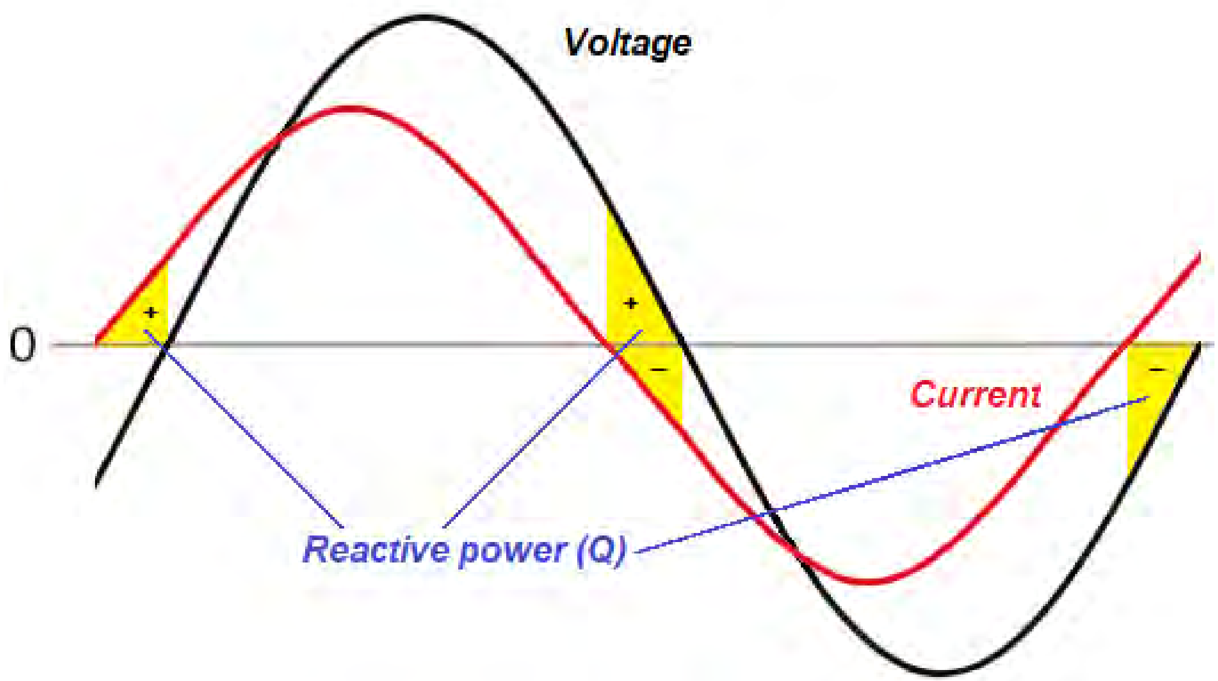




Reactive Power

The preceding two graphs show that for portions of each cycle, voltage and current have different signs – in other words one is positive and the other negative. At this point multiplying **V x I** results in a negative **S** value.

If we shade in these regions, we see the graphic below:



The shaded regions represent the difference between apparent power and actual power. This difference is known as ***reactive power*** (also called "useless power" or "watt-less" power) and is represented by the symbol **Q**. Reactive power is not consumed by the load; it simply "bounces" back and forth between the load and the source without being transformed into mechanical, heat, light, or other forms of energy.

The remainder of the cycle (the unshaded regions in the preceding graph) represents active power. As we can see, the more that voltage leads or lags current, the larger the reactive power and thus the less active power.

In simple mathematical terms:

S (apparent power) = P (active power) + Q (reactive power)

P = S – Q

Q = S – P

Power Factor

We can now turn our attention to answering the question asked at the beginning of this article: *How efficient is my electrical network?*

To determine this mathematically, we divide active power by apparent power to derive a value called ***Power Factor***.

Power Factor (PF) = P / S

Power Factor is expressed as a ratio between 1 (unity) and zero. The higher this ratio, the more efficient the circuit is for transferring power to the load.

For example, in resistive AC circuits where no reactive power is present, **PF = 1**. In capacitive and inductive circuits, **PF < 1**; the higher the reactive power in the circuit the lower the **PF**.

Low Power Factor can cause multiple problems, including higher energy costs. Since reactive power cannot be used by your loads, you may end up paying for more electricity than is actually consumed by your facility. Improving Power Factor can help ensure the apparent power for which you are billed is more closely equivalent to the active power used.

Low Power Factor can reduce the electrical capacity of your system. It can also produce overloads, overheating, and shorter service life for your equipment.

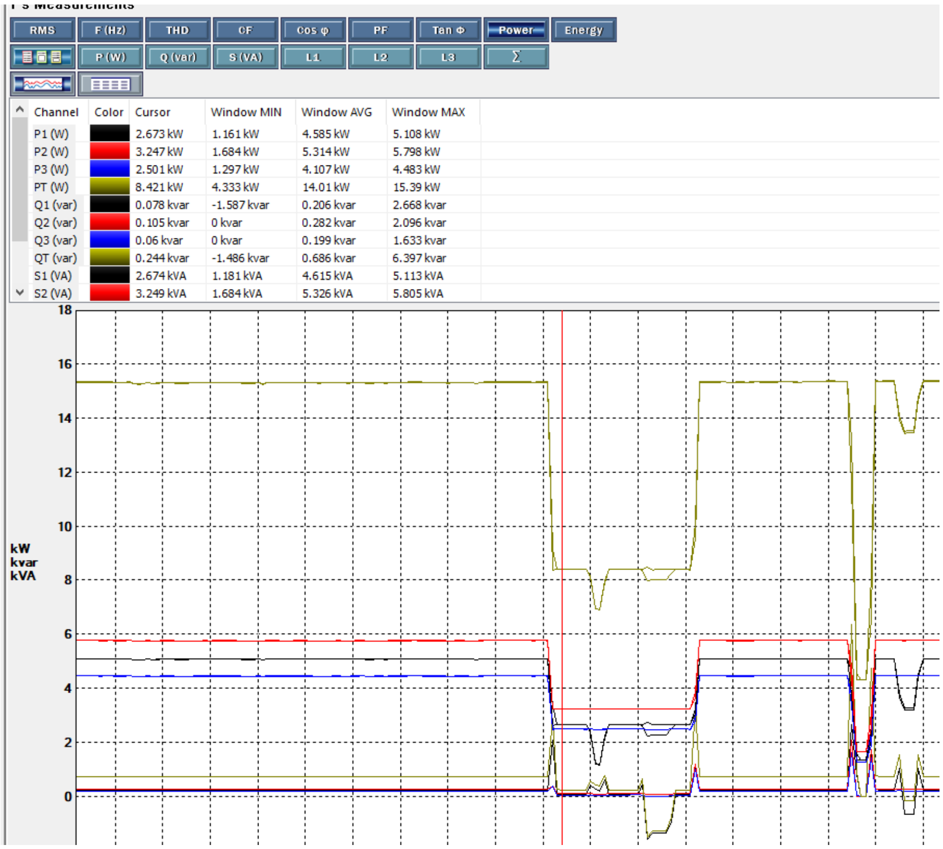
Fortunately, there are a number of steps you can take to help increase Power Factor and improve the efficiency of your electrical network. For example, you can minimize the amount of time your inductive equipment (such as motors) operate on idle or with light loads. Replace older motors with energy-efficient models, and run them near (but never above) their rated capacity as much as possible.

In some instances, you can install capacitors into your network to help decrease its level of reactive power

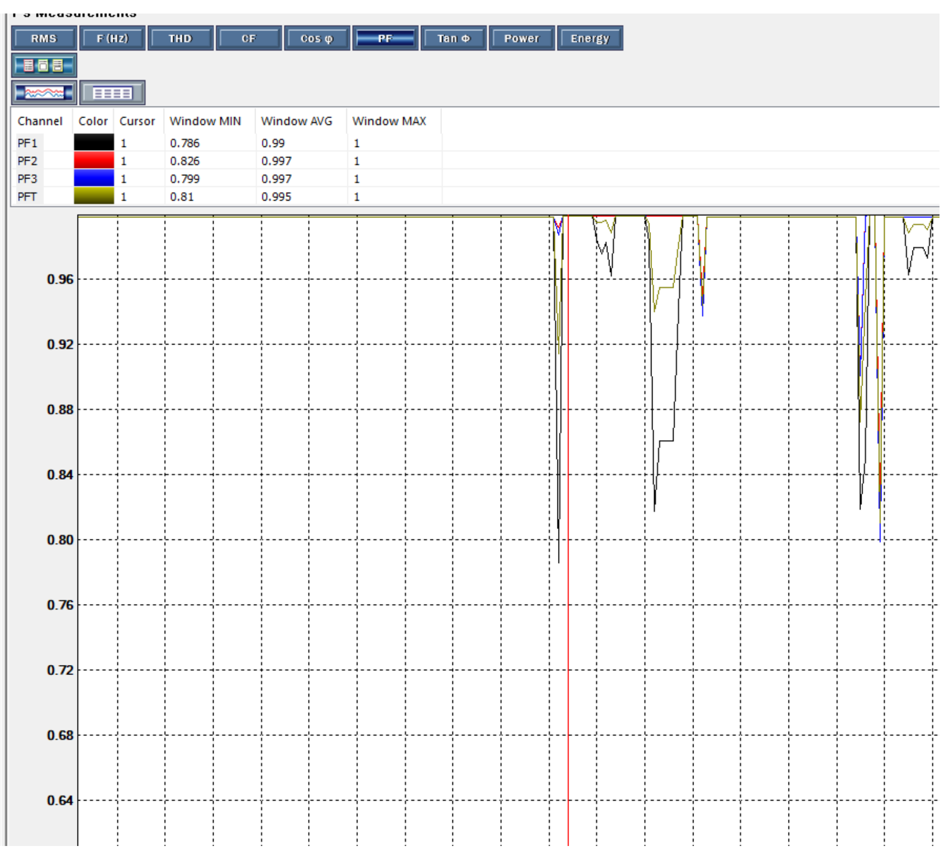
AEMC Power Quality Instruments

AEMC offers a variety of instruments that make it easy to determine apparent power, active power, reactive power, and Power Factor. These include the PowerPad® III and PEL families of instruments. These are supported by DataView® data analysis software.

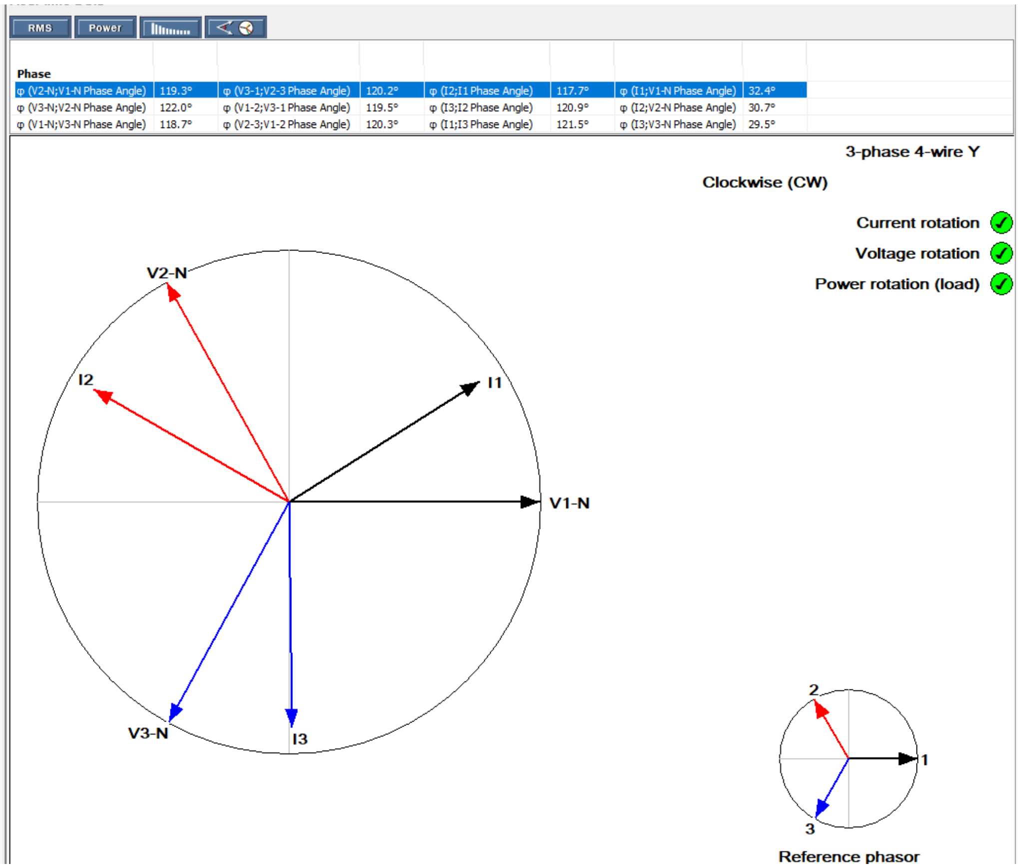
For example, the PEL connected to the DataView PEL Control Panel displays power quantities **P**, **Q**, and **S** for each network phase and total:



Buttons allow you to simplify the display to show only **P**, **Q**, or **S** values. Another button displays Power Factor for each phase and total:



You can also view a phasor diagram, showing at a glance how much voltage lags or leads current for each phase. This enables you to quickly determine whether the network is capacitive or inductive.



These instruments allow you to quickly determine whether or not reactive power is an issue in your network, and whether or not remediation efforts may be required to improve its efficiency.

For more information on PowerPad III, PEL, and other AEMC power quality instruments, please visit our web site.

Touch Potential and Step Potential

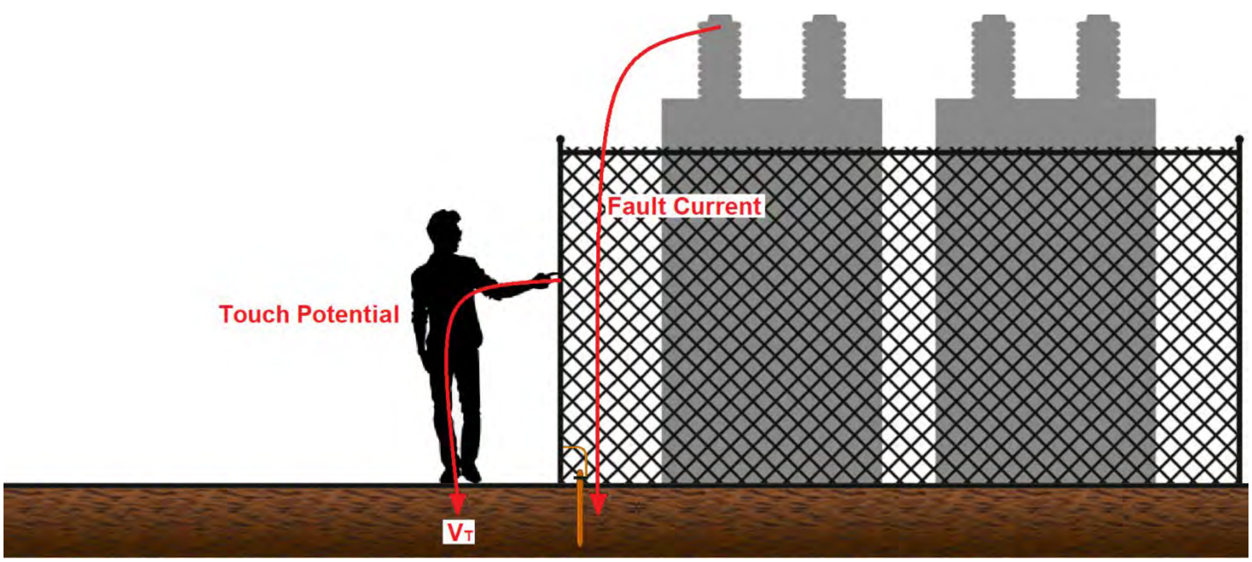
A grounding system is a conducting connection by which an electrical circuit or equipment is connected to earth. This connection establishes and maintains as closely as possible the potential of the earth on the circuit or equipment connected to it. The grounding system provides a low impedance path for electrical currents to travel under fault conditions, minimizing the possibility that the fault current will instead follow a path that endangers people and equipment.

Two critical concepts to consider when designing a grounding system are ***touch potential*** and ***step potential***. Both present risks to workers in close proximity to the grounded equipment or structure. And both are directly affected by local soil conditions, illustrating the importance of soil resistivity testing as part of your grounding system design and implementation.

Touch Potential

Of the two, touch potential is probably more familiar to the general public than step potential. An obvious (if extreme) example of touch potential occurs when a person standing on the ground comes in contact with a hanging power line. The voltage potential between the energized line and the ground upon which the person is standing is great, allowing a potentially fatal amount of electricity to flow through the person's body.

Even in grounded systems, dangerous touch potential may be present during fault conditions. Consider a grounded metal fence around a transfer substation. A fault current will travel down the fence and go to ground at its grounding system. If a person comes in contact with the fence during the fault, the soil resistance of the earth between where the person is standing and the fence will create a drop of potential (also known as a voltage gradient), causing current to flow through the person's body. The further the person's feet are from the grounded fence, the greater the touch potential and thus the higher the danger. In addition, higher soil resistivity increases touch potential.



Grounding systems should be designed to ensure touch potential stays below the level that can be withstood by the human body. This includes calculating the drop of potential between a reference point (for instance the fence grounding system) and a point one meter (3.28') away, the so-called "reach distance."

To do this, use a four-pole ground resistance tester to measure the resistance of the earth between the fence and reach distance point. Then using Ohm's Law, apply this value along with the anticipated fault current to calculate touch potential.

For example, suppose we measure the reach distance ground resistance as 1.5Ω. If we assume a fault current of 100A, touch potential (V_T) will be:

$$\begin{aligned} V_T &= R \times I \\ &= 1.5\Omega \times 100A \\ &= 150V \end{aligned}$$

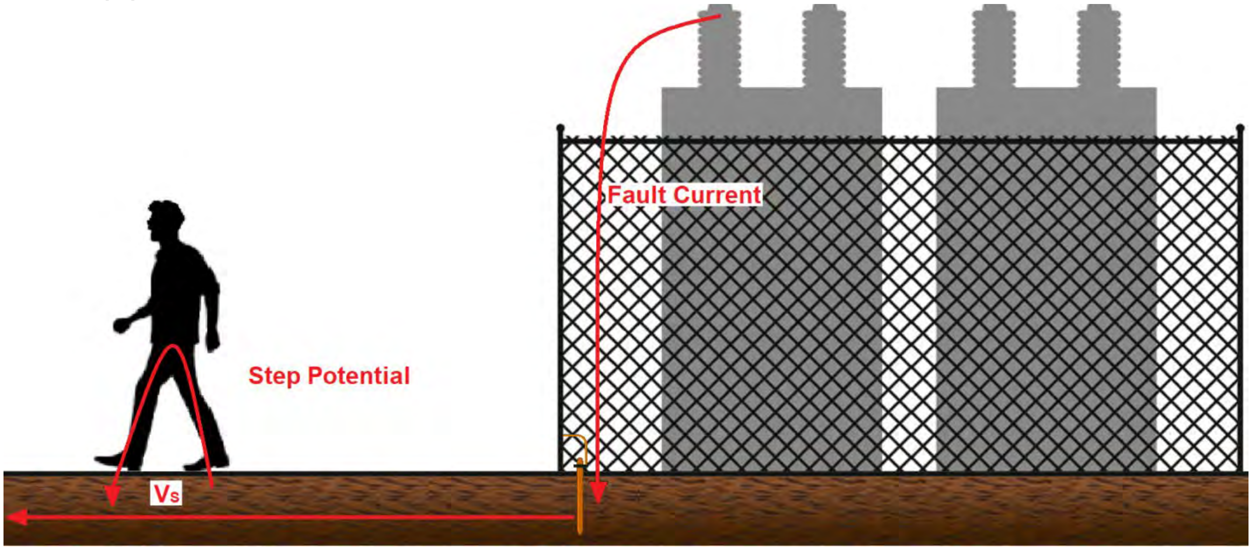
In this case, the touch potential of the fence will be 150V, a level considered dangerous. (Most utility companies consider touch potential exceeding 130V to be harmful.)

Step Potential

As noted above, grounding systems are designed to direct fault currents into the earth. The current then travels through the soil. As it does, resistance in the soil produces a drop in potential voltage gradient. The further apart two points along the current's path are, the greater the drop between them. Depending on soil resistivity, this drop can be relatively rapid, creating a difference in potential between points only a few feet from each other.

If during a fault current event a person walks near the grounding system, the potential at the point where one foot touches the ground can be significantly different from where the other foot touches. This difference is known as step potential, and it can cause current to flow up one leg and down the other. During high fault current events, step potential can present a serious shock hazard to nearby personnel. (This is why drivers in accidents involving live wires contacting their vehicles are advised to hop away, carefully keeping both feet together, if they must leave the scene. Simply walking away could be fatal if both feet touch the ground at different distances from the live wire.)

Utility workers in particular are concerned with step potential. Electrical substations are usually grounded by below-grade grid systems. Leakage currents and other factors can energize a grid, especially one compromised with age. Walking on the surface above the grid can expose workers to significant step potential.



Depending on conditions, dangerous step potential can exist a significant distance from the grounding system. Factors include the amount of fault current that enters the ground, along with soil resistivity – the higher the soil resistivity, the higher the step potential.

Soil composition can also play a role. For instance, if the surface layer has higher resistivity than the underlying soil, the more conductive lower layer draws more current out of the grounding system through the surface layer. This results in a large potential drop near the grounding system. Conversely, a more conductive surface over high resistivity underlying soil can produce dangerous surface currents for longer distances from the grounding system.

As with touch potential, step potential can be calculated by measuring the soil resistance. Typically this involves using a ground resistance tester to perform a 4-point test.

The instrument is connected to the grounding electrode system and an auxiliary electrode that injects current into the soil to simulate the fault. In between and in-line with these electrodes are placed two potential electrodes, typically one meter apart to simulate a human stride. These electrodes measure drop of potential to determine the resistance between them. This resistance and the fault current are then plugged into the Ohm's Law formula to calculate step potential (V_S).

Reducing Touch and Step Potentials

The primary way to decrease touch potential and step potential is to reduce the grounding system's resistance. Consider our earlier example of a system with a 1.5Ω resistance to ground and a 100A fault current, producing a touch potential of 150V. Reducing the ground resistance to 1Ω results in a corresponding decrease in touch potential to 100V.

There are a variety of ways to reduce the resistance of a grounding system. These include adding electrodes or using chemical enhancers to increase the conductivity of the local soil. This last measure (where permissible) can be particularly effective for reducing step voltage, since the drop in potential between each step will be smaller.

Deciding which measure(s) to consider involves carefully testing soil resistivity at the location. Computer simulation and modelling may also be helpful, especially at sites close to other grounded installations – modifications made to one site could impact touch and step potentials at neighboring facilities.

Correct placement of grounding systems is also essential. As mentioned earlier, touch potential rises in conjunction with resistance. Contacting an energized metallic structure connected to a distant grounding electrode results in a higher touch potential than touching it next to the electrode, due to the additional earth resistance. Placing grounding systems in locations where people are most likely to come in contact with energized metal helps reduce the danger of touch potential.

Other measures include applying a layer of non-conductive material, such as crushed blue stone, on top of the surface in locations where touch and step potentials may be present (for instance, on top of substation grounding grids). Workers in these areas should wear industrial-grade insulated footgear, gloves, and clothing to help ensure personal safety. This is often required by utility safety personnel.

New Products

AC Current Probes MR525/526

The Current Probes MR525/MR526 are Hall-effect current probes with a single (MR525) or dual (MR526) range designed for digital multimeters, data loggers, wattmeters, power analyzers, and other instruments. The probes include 5' (1.5m) lead terminated by 4mm safety banana plugs. They are powered by a 9V battery or by a standard 5V external power supply via a micro-USB connector (not supplied).

These clamp-on current probes measure DC currents up to 1400A, AC currents up to $1000A_{RMS}$ (1400A peak), and combined AC+DC currents without opening the circuit in which the currents flow. They indicate the shape and amplitude of the current measured in the form of a voltage.

The MR525 and MR526 include the following features:

- range overage indicator
- power supply indicator
- zero adjustment
- Auto Standby feature
- one or two ranges, depending on the model (sensitivity 1 and 10mV/A)
- micro-USB connector to connect an external power supply

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