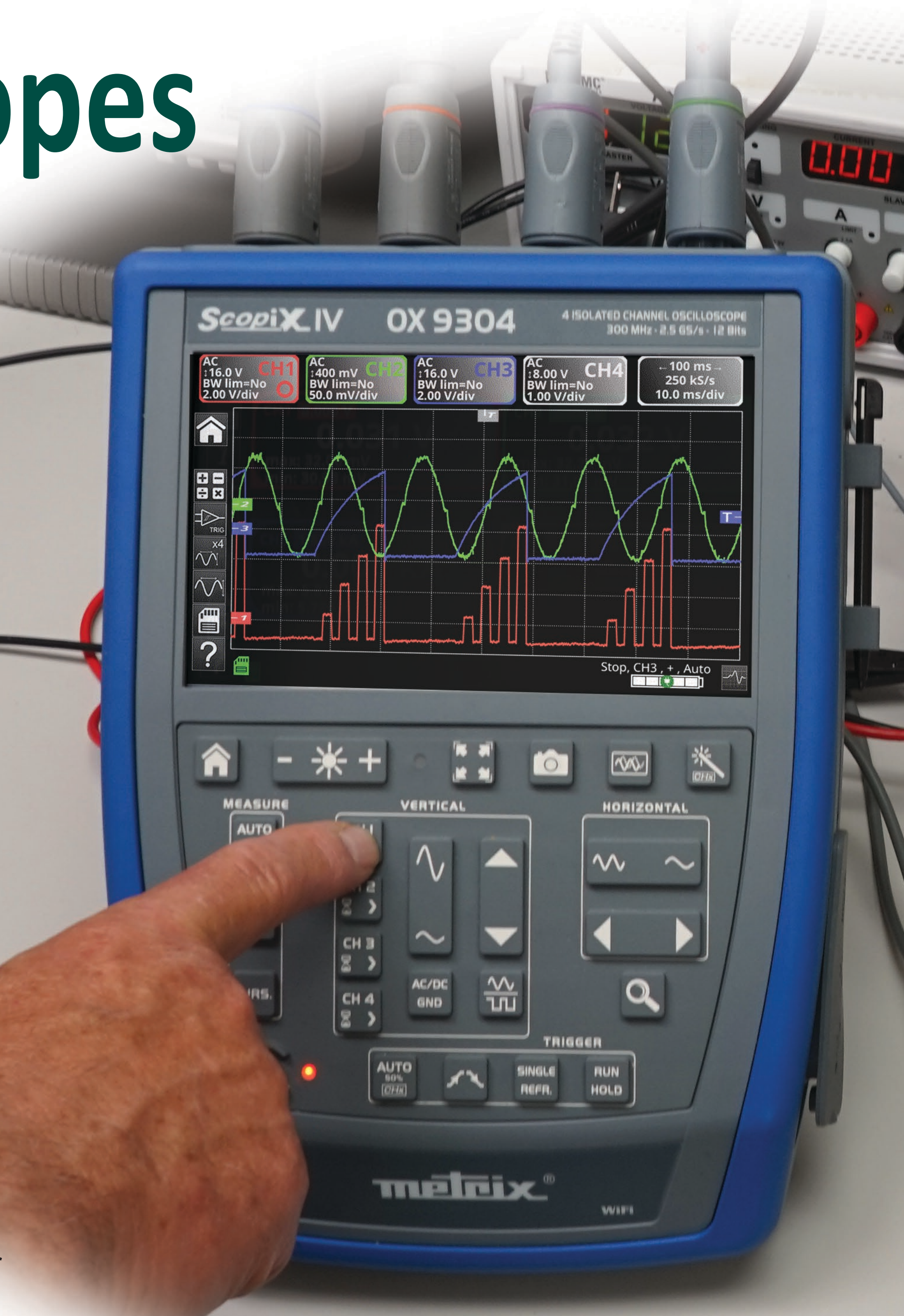
AEMC® INSTRUMENTS
CHAUVIN ARNOUX GROUP

Chauvin Arnoux® Inc.
15 Faraday Drive • Dover, NH 03820 USA • (603) 749-6434 • Fax (603) 742-2346 • www.aemc.com

Issue 20 “WATTS CURRENT” TECHNICAL BULLETIN Fall 2019

Oscilloscopes OX 9000 Series



Inside This Issue:

Featured Product:

Megohmmeter Insulation Testing after Water Damage

One of the first things we learn about electrical systems is that they don’t mix well with water. Water containing dissolved minerals and other contaminants is an excellent conductor. This allows currents to flow through normally non-conductive media, and across points in a circuit for which it was not designed. Obviously, this can be extremely dangerous for personnel, equipment, and facilities. In addition, water can cause physical damage to conductors, insulation, and mechanical components.

Even small amounts of water can be problematic. As we explain in a previous issue, high humidity can adversely affect system performance. Humid conditions can also produce condensation within electrical components.

More serious are situations in which circuits are inundated or submerged in water, requiring extensive repair and replacement. The most extreme example is flooding produced by severe weather. Floodwaters can be especially damaging, since they often contain contaminants such as sewage, oil, chemicals, and particles that can continue to compromise systems long after the water recedes.

This is particularly true for coastal saltwater flooding. Even after flooded components are completely dried, salt and mineral residue can continue to coat surfaces, corroding conductors and insulation. The detrimental effects of floodwater include:

- **Circuit breakers and fuses** can be damaged both electrically and mechanically, to the point where they no longer provide protection against electrical faults. For example, water can infiltrate the filler material within fuses, negating their “interrupting” capabilities. It can remove lubrication from switches and breakers, affecting their actuation ability. Moisture can also over time affect other protective devices such as meters, electromechanical relays, and support structures.

- The exposed ends of **electrical cables** can wick up water throughout the entire length of the cable, acting as a conduit and transporting water into live switchgear. Further, moisture can remain within the cable even after it appears completely dry externally. Water can also accelerate cable insulation deterioration, causing premature failure. When wires and cables subjected to these conditions are subsequently energized, they can present a shock hazard.

- **Transformer** cores and windings can be significantly impaired by insulation damage and corrosion. Transformer fluid may be contaminated, and foreign materials deposited internally. **Under these circumstances, restoration of power could result in a catastrophic explosion**.

- **Motors** flooded by water are subject to damage to insulation, capacitors, and internal components. In addition, the efficacy of motor control devices can be reduced by exposure to water and dissolved contaminants. Contacts and dielectric insulation materials may be damaged, severely affecting solid-state motor controllers, adjustable speed drives, and starters.

- **Switchgear** connection terminals, especially those with positive polarity, may continue to corrode even after drying and cleaning. This is due to the effects deposits of acidic materials have on metal. Reactions between acid, metal, and air can produce corrosive salts. In addition, contaminants from floodwater can propagate throughout stranded copper control wiring, causing corrosion and insulation breakdown.

Drying Out and Cleaning

As a general rule, it's a good idea to simply replace all electrical systems damaged by floodwater. For example, when wiring is flooded for hours or days, total replacement is the most common remedy. Even if the wiring has been completely dried and cleaned, and appears to be operating normally, contaminants left behind by the floodwater can eventually impair performance, especially when seawater is involved.

On the other hand, water damage due to "clean" fresh water (such as from a burst pipe or fire hose) may provide more opportunities to save and reuse electrical components.

Irrespective of the cause of the flooding, all electrical components require a prompt and thorough cleaning followed by a dry-out period. This includes drying the room in which the components are located – lingering high humidity can cause dry components to reabsorb moisture. Low humidity is also essential for meaningful spot testing of insulation (described below).

Unfortunately, there aren't many resources available to guide flood-damaged electrical equipment remediation. One important source is NEMA's free guide "Evaluating Water-Damaged Electrical Equipment," available for download on the organization's web site.

A few general guidelines include:

- **Conductors**: Thoroughly clean and dry conductor surfaces before corrosion can occur. Shallow surface corrosion can be removed if you can avoid removing plating.
- **Cables:** Completely cleaning the cable internally from all possible contaminants can be very difficult, and may require purging the cable with nitrogen. In many instances, cable replacement may be the only option.
- **Insulation:** Some insulation types (for example porcelain) do not absorb water and require only a simple cleaning to remove residue and restore operation. Other types may be compromised by moisture and therefore need to be carefully dried and cleaned (or in many instances replaced).
- **Circuit breaker mechanisms:** These components are the heart of all circuit breakers, and optimum mechanism performance is essential for safety and protection. They incorporate multiple moving parts, which must all interoperate seamlessly. Even a small amount of contaminants can render a mechanism inoperable.

One point to bear in mind when deciding whether or not a component can be repaired or should be replaced: In most cases, flooding significantly reduces the remaining lifetime of electrical components by up to 50%. It may therefore make sense to replace the component now, if it will need to be replaced anyway in a relatively short time.

Insulation Testing with a Megohmmeter

Several types of tests can help assess insulation integrity after a flooding event. These include the Spot Reading test, the Time Resistance test, and the Step Voltage test. These can help determine whether or not repair and/or replacement of insulation is required. Even if you completely replace the circuit, insulation testing can help evaluate the quality of repairs performed before equipment is put back into operation.

Spot Reading Test is the simplest type of insulation testing: simply connect the megohmmeter leads across the insulation to be tested, apply test voltage for a fixed period of time (typically one to ten minutes), then take a resistance reading. Normally, a single Spot Reading test is of limited value. However, it can be particularly useful GO/NO GO test after a flooding event. If you have been previously performing regular Spot Reading on the circuit, a test immediately after the flood can indicate whether or not the water had a significant impact on resistance. Regular testing after the event can also indicate whether or not the insulation is now degrading at an accelerated rate.

Time Resistance Test (also referred to as the dielectric absorption test) involves conducting a 10 minute test. For the first minute, during which absorption current will have the highest effect on resistance, measurements are taken every 10 seconds. After the first minute, measurements are taken once per minute. When you plot the results, you should see a curve that rises relatively rapidly at first, and then continues to gradually rise throughout the testing period. If instead the curve is relatively flat or begins to turn down as the test progresses, moisture, contaminants, or other aftereffects of the flood may be compromising your insulation.

Step Voltage Test involves testing at least two or more test voltages and comparing the results. The test begins at an initial test voltage. At a specified interval, typically one minute, a measurement is recorded, after which the test voltage is increased. This increase is usually to five times the initial voltage. This process may be repeated through several steps, with measurements taken after one minute and the test voltage increased at a five to one ratio over the previous voltage. Insulation that is thoroughly dry, clean, and in good physical condition should provide roughly the same resistance measurements across the voltage range. If instead you observe a significant decrease in resistance at higher voltage, your insulation may be damp, contaminated, or deteriorating. Note that Step Voltage testing is often used to dry wet cables or equipment. Gradual voltage steps, applied for increasingly longer durations (which in some cases can be hours or even days), can facilitate drying through heating. For example, AEMC's Megohmmeter Model 5070 includes a 50-hour timer feature especially useful for drying cables.

To perform these tests, you will need a megohmmeter with a timed test function. A megohmmeter is essentially a high resistance ohmmeter, providing a high DC potential (up to 15,000V depending on model) and designed to read in the meg-ohm or higher range. This high potential causes small amounts of current to flow through and over the insulation under test. With a known test voltage and measured current flow, the instrument calculates insulation resistance via Ohm's law.

AEMC Instruments offers a complete line of megohmmeters designed for insulation testing, ranging from 100V handheld instruments to heavy-duty models providing test voltages up to 15,000V. And with some models, you can download and analyze the results on a computer running AEMC's DataView® software.

For example, AEMC's Model 6503 is a compact, self-contained, hand-cranked megohmmeter designed for a broad range of plant and field service applications. Its hand-crank feature is especially useful in flooding situations where electrical power is not available and batteries are scarce.

You will also need a thermometer or similar temperature measurement device. And if the equipment temperature is below the dew point, a humidity measuring instrument will be necessary, especially when performing a spot test.

Note that dry circuits will require testing at increasing step voltages for sufficient times to allow heating to occur to assist the drying process. Any components that cannot tolerate this voltage should therefore be disconnected from the network under test. Circuits must be tested from ground to each insulated conductor, as well as insulated conductor to insulated conductor.

For a general review of insulation testing in general, see the AEMC Application Note, "An Introduction to Insulation Resistance Testing."

Final Thoughts

Be prepared to be perceived as "taking a hard line" when deciding whether or not flood-damaged electrical components can be restored or whether they require replacement. Most facilities are naturally interested in saving money, and will opt for reuse of equipment if at all possible. However, restoring irreparably damaged components that will soon need to be replaced anyway – or even worse, may represent a hazard to personnel – would be irresponsible. Your primary job is to comply with all relevant standards and guidelines, while ensuring a safe environment that minimizes legal liability.

If you prefer to err on the side of caution, we suggest you strongly consider replacing any of the following that have been submerged in floodwater:

- Switches
- Circuit breakers
- Outlets
- Motors and motor control devices
- Wire or cable listed for dry locations such as NM-B
- Smoke detectors and other protective equipment
- Circuit breakers
- Light fixtures, ballasts
- Fuses
- Appliances

Whether you're replacing or repairing components, be sure to consult the appropriate governmental authority with jurisdiction over electrical systems in your area. Each locality may have its own requirements and guidelines for remediation, testing, and inspection.

One final note: flooding produced by severe storms may also be accompanied by lightning. Therefore facilities where flooding remediation has been performed should also be inspected for lightning strike damage.

See also the AEMC video "Understanding Insulation Resistance Testing," available on our YouTube channel.

Using a Time Domain Reflectometer (TDR)

A TDR (Time Domain Reflectometer) measures cable length and locates faults on virtually all types of cable including twisted pair, coaxial and parallel conductors.

The TDR transmits pulses of a known shape and amplitude into one end of a cable; the pulses travel along the cable at a speed determined by its Velocity of Propagation (Vp, see **Sidebar** below). When the pulses encounter impedance changes in the cable insulation (indicative of either a fault or the end of the cable) they produce reflections that travel back along the cable and return to the TDR.

The size, shape and general nature of the reflected pulses indicate the type of fault encountered; and the time taken for the pulse to be reflected enables an accurate measurement of distance to the fault.

AEMC offers several TDR instruments including the Wire Mapper Pro Model CA7028, Fault Mapper Pro® Model CA7027, and Fault Mapper Model CA7024.

It is critical for modern communications systems to provide reliable high-quality connectivity, and all new installations and modifications to existing installations should be tested to ensure trouble free operation.

Additionally, any cable faults need to be identified, located, and rectified as quickly as possible, ensuring rapid return of service.

Typical TDR applications include:

- Electrical, communication, and telecommunication engineers and contractors for testing cable installations as part of a routine preventative maintenance program.

  In addition, during or after work is performed on new/modified cable installations, tests can be made to ensure performance criteria are met.

- Personnel involved in the location of cable faults as part of a troubleshooting or regular maintenance program.

- Electrical Inspectors performing quality checks following work on all new cable installations, and modifications to existing cable installations.

Sidebar: Velocity of Propagation

This is a measure of how fast a signal travels along a line. A radio signal travels in free space at the speed of light, approximately 3 x 10^8m/sec. A signal travels in a transmission line at much less than this. In twisted pair cable the Velocity of Propagation may be between 40% and 75% of the velocity in free space.

There is a direct relationship between Velocity of Propagation (V) and Wavelength:

$V = lf$

Vp is often stated either as a percentage of the speed of light or as time-to distance. When the time-to-distance figure is used, it is sometimes known as Propagation Delay, and is expressed as ns/100m or ms/km.

Viewing Unbalance Data in the DataView® PEL Control Panel

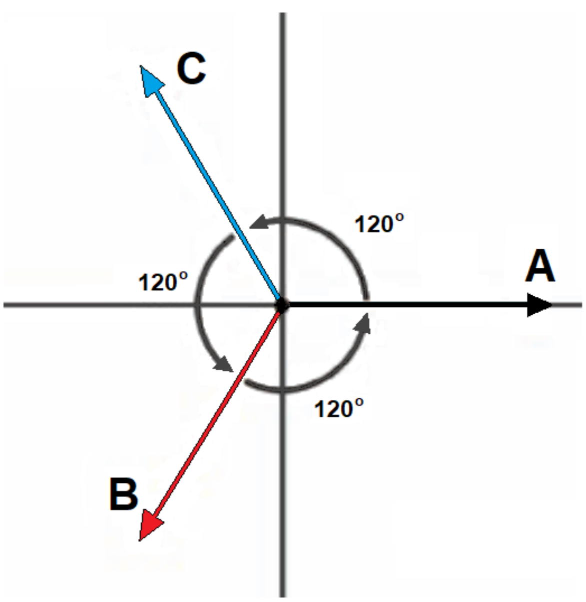
When viewing PEL 105 real-time data in the DataView® PEL Control Panel, you now have the option to display unbalance data. In three-phase AC distribution networks, unbalance (sometimes referred to as imbalance) is the ratio of the negative-sequence or zero-sequence component to the positive-sequence (fundamental) component. This ratio is expressed as a percentage between 0 and 100%, and can be applied to either voltage or current.

Unbalance percentage indicates the efficiency of your distribution network. Reducing unbalance can save significant energy costs. For example, the power quality standard EN50160 (used primarily in Europe and also applicable in other regions) specifies that unbalance should not exceed 2% at the point of common coupling (PCC).

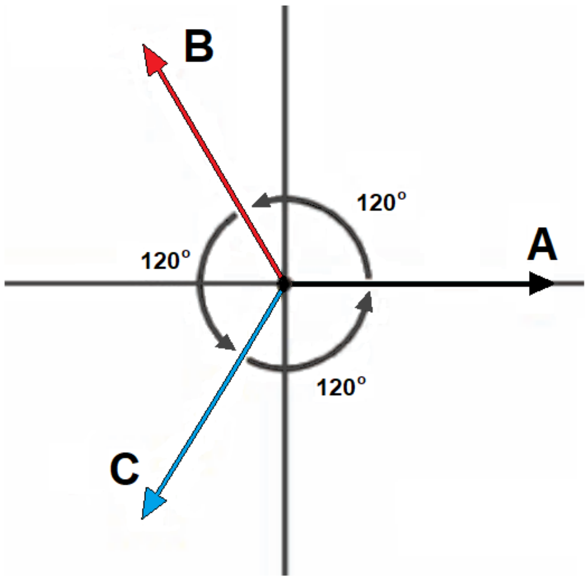
Positive, Negative, and Zero Sequence

To understand what unbalance data means for your distribution system, it's important to be familiar with the concept of phase sequence. In three-phase networks, there are three sets of independent components for both current and voltage. These are called positive sequence, negative sequence, and zero sequence:

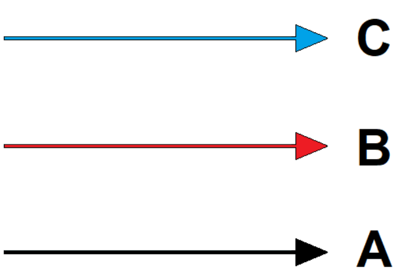
- **Positive sequence** (also called fundamental) represents three equal phasors phase-displaced by 120° with the same phase sequence as the original phasors supplied by generators ("A-B-C" sequence). The positive sequence component is always present and indicates the current flowing from source to load.



- **Negative sequence** represents three equal phasors, phase-displaced by 120° with each other, with the opposite phase sequence to that of the original phasors. The negative sequence component displays "A-C-B" sequence, and indicates current flowing from load to source.



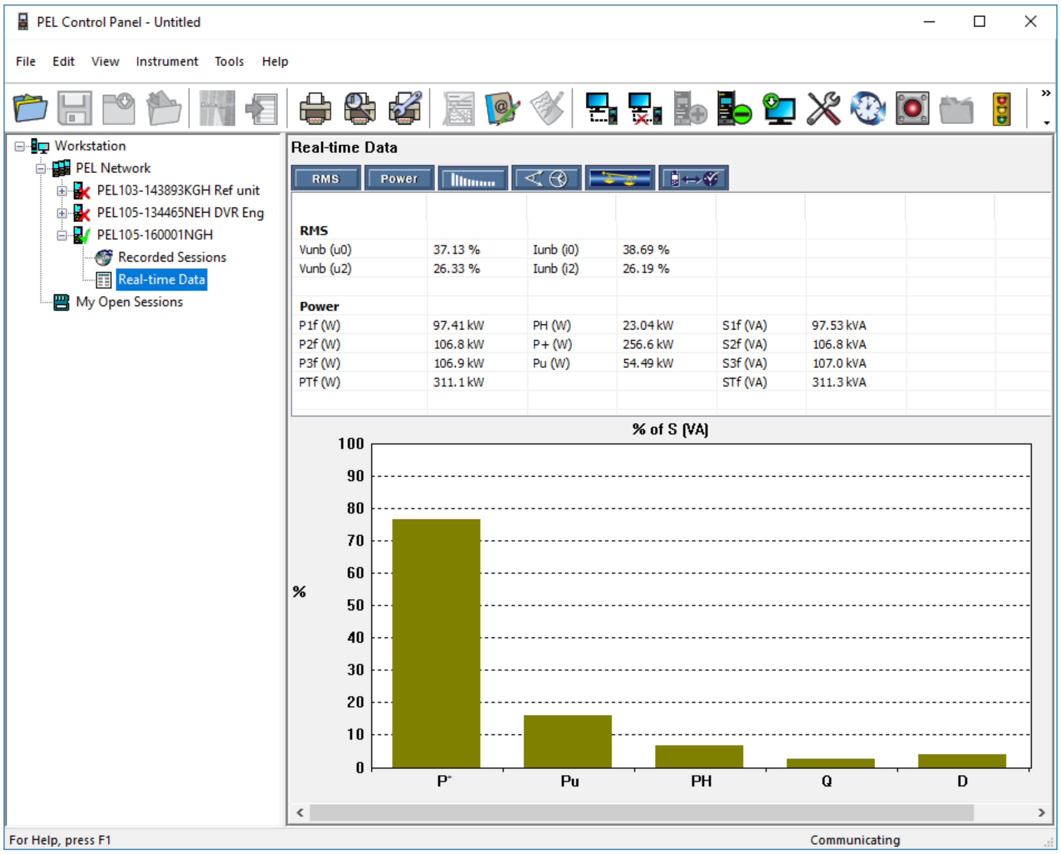
- **Zero sequence** represents the component of the unbalanced phasors that is equal in magnitude and phase.



In a balanced three-phase system operating in normal conditions, only the positive sequence component is present. In the real world, however, 3-phase systems are rarely perfectly balanced. Significantly unbalanced systems indicate the existence of a negative sequence that can be harmful to polyphase loads such as induction motors.

DataView PEL Control Panel

To view PEL 105 unbalance data channels in the PEL Control Panel, click the Unbalance  button in the Real-time Data frame. (Note that this button only appears for PEL 105 instruments.)



At the top of the frame is a table displaying a variety of parameters. The first four are unbalance values:

- **Vunb (u0):** zero-sequence voltage unbalance
- **Vunb (u2)**: negative-sequence voltage unbalance
- **Iunb (i0)**: zero-sequence current unbalance
- **Iunb (i2)**: negative-sequence current unbalance

Each of these values is expressed as a percentage of its fundamental value. For example, in the preceding illustration, **Vunb (u0)** is 37.13%. This means that the zero-sequence voltage is 37.13% the size of the positive sequence voltage. Similarly, the **Iunb (i0)** value indicates the zero-sequence current is 38.69% the size of the positive sequence current.

In an efficient distribution system, the unbalance percentages should be close to zero. The percentages shown in the preceding example indicate that unbalance is a serious issue in the distribution network under measurement, with significant power being lost due to network inefficiency.

Below the unbalance data are a number of power parameters. Note that some of these may not be displayed, depending on the type of distribution under measurement:

- **P (P1 , P2, P3, PT)**: active power for phase 1, 2, 3, and total respectively
- **Pf (P1f, P2f, P3f, PTf)**: fundamental active power for phase 1, 2, 3, and total respectively
- **PH**: harmonics active power
- **P+**: total fundamental active power of the positive-sequence power (balanced power)
- **Pu**: total fundamental active power of the negative- and zero-sequence power (unbalanced power)
- **Q (Q1, Q2, Q3, QT)**: fundamental reactive power for phase 1, 2, 3, and total respectively
- **D (D1, D2, D3, DT)**: harmonic distortion power for phase 1, 2, 3, and total respectively
- **S (S1, S2, S3, ST)**: apparent power for phase 1, 2, 3, and total respectively
- **Sf (S1f, S2f, S3f, STf)**: fundamental apparent power for phase 1, 2, 3, and total respectively
- **V+**: Positive-sequence phase-to-neutral voltage
- **V^0**: zero-sequence phase-to-neutral voltage
- **V-**: negative-sequence phase-to-neutral voltage
- **I+**: positive-sequence current
- **I^0**: zero-sequence current
- **I-**: negative-sequence current

Below this table is a histogram (bar chart graph) displaying the percentage of P (active power) that is represented by P+, Pu, PH (harmonic active power), Q (fundamental reactive power), and D (harmonic distortion power) respectively.

The relationships between these parameters are as follows:

PTf (total fundamental active power) = **P+** (total fundamental balanced power) + **Pu** (total fundamental unbalanced power)

PT (total active power) = **PTf** + **PH** (harmonics active power)

S^2 (apparent power^2) = **PT^2** + **QT^2** (total fundamental reactive power^2) + **DT^2** (total harmonic distortion power^2)

Ideally, P+ should be at or close to 100%, while the sum of the remaining variables should be near zero. The lower the P+ percentage (and thus the higher the total sum of Pu, PH, Q, and D), the more your distribution system is wasting energy. For instance, in the preceding illustration P+ is around 77%. This indicates that inefficiencies in your distribution system are wasting approximately 23% of the power received from the source.

New Products

Hand-Held Oscilloscopes OX 9000 Series

The OX 9000 Series oscilloscopes are equipped with isolated channels. Each model is four instruments in one, operating as an oscilloscope, multimeter, harmonic analyzer, or logger. A simple press of a button or touch screen icon accesses the mode you want.

Model OX 9000 instruments are ergonomically designed and utilize keypad features originally developed for the automotive industry. Time base and scaling adjustments are made by a simple press of the Auto Set button. Input probe characteristics are automatically identified when the probe is plugged in.

Features include (among others):

- Two or four fully isolated 600V, CAT III rated channels, depending on model
- Scope, Multimeter and Harmonic Analysis and Recorder/Logger modes instantly available at the press of a button
- 8 hours of rechargeable battery life
- 60, 100 and 300MHz bandwidth models
- New triggering and recording options
- 12 bit resolution and 2.5GS/sec speed
- 7" WVGA wide color FFT touch screen with manual or automatic brightness
- WiFi, Ethernet and USB communication
- High storage capacity

Typical applications for OX 9000 instruments include:

- Field Troubleshooting
- Education
- Electronic and Industrial Maintenance

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www.aemc.com • techsupport@aemc.com