

Power quality troubleshooting at the service panel

Application Note



Note

Prior to making any measurements, always familiarize yourself with the equipment you will be using. Read the instrument users manual paying particular attention to the **WARNING** and **CAUTION** sections. Do not use the measurement instruments in applications for which they are not intended. Always be aware that if the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

Voltage sags, tripping breakers, overheated electrical panels, and excessive voltage levels are all indications of possible trouble in an electrical distribution system. It is helpful to understand that these symptoms are telling us something is wrong with the power system. But where oh where do you begin the search to isolate the exact cause of these power quality problems?

Just like cars have a single connection point to monitor vital functions, the electrical system has a similar connection point: the electrical service panel. As a common point for branch circuit distribution, the service panel is also a convenient place to take the pulse of your electrical system. A number of problems can be located right in the service panel itself. For problems elsewhere in the system, measurements at the service panel can tell you where to look next. Some problems can be caught by a quick visual inspection, while others require that measurements be taken.

Finding the cause of the problem

This article outlines a step-by-step process for locating and fixing potential trouble spots.

1. Voltage level (steady state) and voltage stability (sags)
2. Current balance and loading
3. Harmonics
4. Grounding
5. Hot spots: loose connections/terminals
6. Bad or marginal branch circuit breakers

Depending on the voltage and measurement requirements, you can use a variety of tools for power quality troubleshooting, from digital multimeters to handheld single and three phase power quality analyzers that perform many calculations automatically.

Voltage level and stability

The first step in checking to see if voltage levels and stability are the culprits is to measure voltage levels of the branch circuits, phase-to-neutral, at the load side of the branch circuit breakers.

Note: For safety's sake, when making voltage measurements always keep a circuit breaker between you and the fault current ampacity of the feeders.

If voltage levels are low at the breaker, they'll be even lower at the receptacle. This could be caused by low tap settings at the transformer. Other likely culprits include loose connections, long feeder runs, and overloaded transformers, which create excessively high source impedance (impedance from the load to the source). Source impedance and voltage drop are two sides of the same coin.

If intermittent voltage sags are suspected, start at the panel to isolate the cause of sags: Are the sags the result of loads on the same branch circuit or are they caused by loads elsewhere in the distribution system (including utility-generated sags)? We can start to isolate the source of the sag with a multi channel recording instrument, such as a Fluke power quality analyzer, that can trend voltage and current simultaneously.

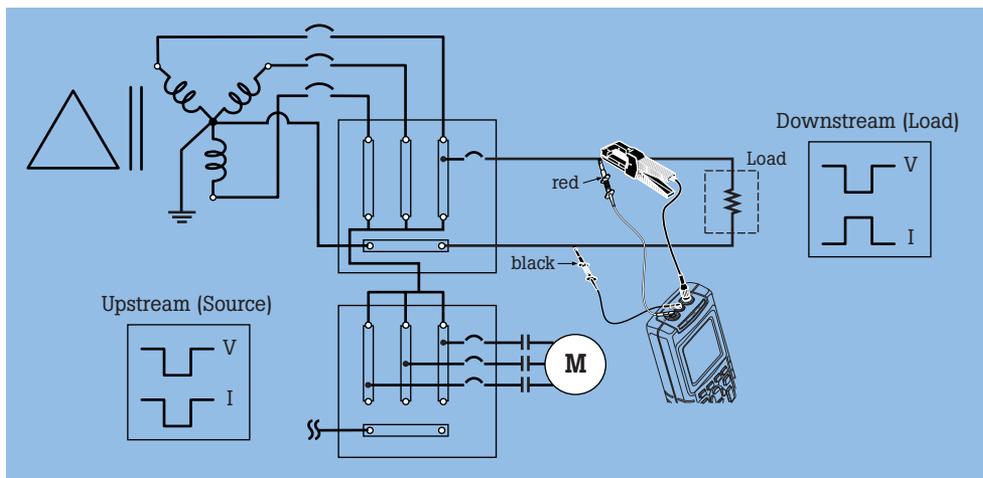


Figure 1. Isolating source of disturbance.

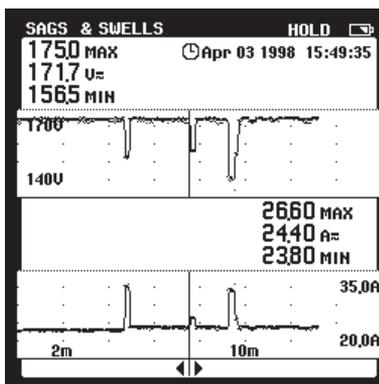


Figure 2. Voltage on top, current on the bottom. Real-time stamp on top.

Connect the instrument's voltage probes and current clamps on the load side of the breaker, as shown in Figure 1. Using a single phase analyzer's Sags & Swells mode, voltage events can be trended on the top half-screen and current events on the bottom half-screen (Figure 2). Each point on the trendplot (240 total points for the full-screen trend) represents three values in the sample period: The lowest single cycle (min or sag), the highest single cycle (max or

swell/surge), as well as the average value of all the cycles in the sample period. The sample period is the elapsed time between one point and the next. The analyzer allows you to select the sample time you want, with one second being the minimum period (this corresponds to a recording time of four minutes). The cursor can be moved to the desired point on the trend and, along with the min/max/average values, the real-time stamp of the event is displayed.

On a three phase power quality analyzer, the dips and swells function can measure all three phases simultaneously (Figure 3).

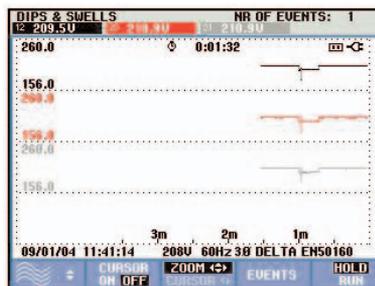


Figure 3. Voltage dip on three phases.

Upstream, downstream

What information are you looking for from the trendplots?

- If a *voltage sag* occurs simultaneously with a *current surge*, the sag was caused by a load on the branch circuit (Figure 2). In other words, the cause of the sag was *downstream* of the measurement point and therefore can be thought of as a *load-related disturbance*.
- If, on the other hand, the voltage sag coincides with a very small change in current, the sag was likely caused by something *upstream* of the measurement point and can be thought of as a *source-related disturbance*. Typical source-related disturbances are heavily loaded three-phase motors started across-the-line or sags originating on the utility feed. If the sag is deep and approaches an outage, the cause is more likely to be the utility. The event probably reflects a fault and breaker trip followed by automatic breaker reclosure.

Current balance and loading

To check current balance and loading, measure each feeder phase as well as current on each branch circuit. When making these measurements, it is critically important to use a true-rms clamp or true-rms digital multimeter (DMM) with a clamp-on accessory. An average responding clamp-on meter will not provide an accurate measurement as the combination of fundamental and harmonic current makes this a distorted waveform. A lower-cost average-sensing meter will tend to *read low*, which would lead you to assume that the circuits are more lightly loaded than they actually are. Here's what we're looking for when making this measurement:

- The loading among the three phases should be as balanced as possible. Unbalanced current will return on the neutral and, as we shall see, the neutral already has enough to deal with.
- Neither feeder nor branch circuits should be loaded to the maximum allowable limit. There should be some derating to allow for harmonics.

So how do you measure for CF? You need a true-rms DMM or clamp, and in addition, the meter needs to be able to measure the peak value of the current waveform. Harmonics analyzers or ScopeMeter® test tools will also give you this measurement.

A three phase power quality analyzer will calculate crest factor and balancing automatically (Figure 4).

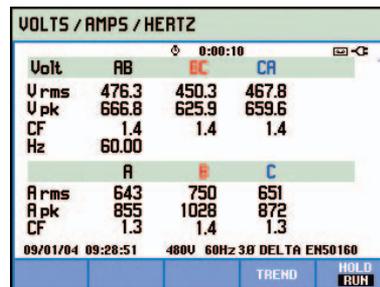


Figure 4. Crest factor (CF).

As a safe and conservative rule-of-thumb, a short-cut formula used for derating of transformers serving single-phase dc power supply loads can be applied to conductors:

$$\text{Harmonic Derating Factor (HDF)} = \frac{1.4}{\text{Crest Factor}_{\text{Amps}}} = \frac{(1.4) \text{ (RMS)}}{\text{Peak}}$$

This is a pretty straightforward concept. Crest Factor (CF) is the ratio of peak to rms. For a sine wave, that value is 1.4. So for a sine wave, which by definition has no harmonic content and no distortion, HDF = 1, meaning that no derating is necessary. It only goes downhill from there. If CF = 2, which is a more likely value for branch circuits in offices, then HDF = 1.4 / 2 = 0.70. So a conductor rated for 20 A should only be loaded to 70 percent capacity, or 14 A max.

Harmonics

To check for the presence and level of harmonics, measure current on the *feeder neutral*. This will typically be in the 80 to 130 percent range of the feeder current, due to the fact that the third harmonic will add up in the neutral. Figure 5a shows some readings that were made in an office, at a lightly loaded panel. These waveforms were captured with a single phase power quality analyzer. Note that the neutral current (Figure 5b) is far in excess of what would be expected from unbalanced currents alone.

Although most of us are increasingly aware of the fact that third harmonic currents (also called triplen or zero sequence) generated by non-linear, single-phase loads add up in the neutral, we often wonder why. Figure 6 tries to explain this phenomenon with an idealized graphic. Basically, while there is a 120-degree phase shift between the three phases of the fundamental, the third harmonic on *all three feeders* are *in-phase* with each other. That is, they all reach their peaks and zero-crossing points at about the same time (in reality, there is some phase shift, but it is very little as compared with higher order harmonics, and therefore there is not much cancellation). This means that, first of all, the triplens have nowhere to go but the neutral, and secondly, on the neutral all the peaks and all the valleys add up.

The size of the feeder neutral conductor becomes a matter of concern. The neutral must now return not only unbalanced fundamental current, but the sum of all the third harmonic current. The 2002 NEC 310.15(8)(4)(c) states that "On a four-wire, three-phase wye circuit where the major portion of the load consists of nonlinear loads, harmonic currents are present in the neutral conductor; the neutral shall therefore be considered. In effect, this requires that the neutral conductor at least equal the size of the phase conductor. But this may well be inadequate: For example, a 1990 survey of 146 sites nationwide found that 22.6

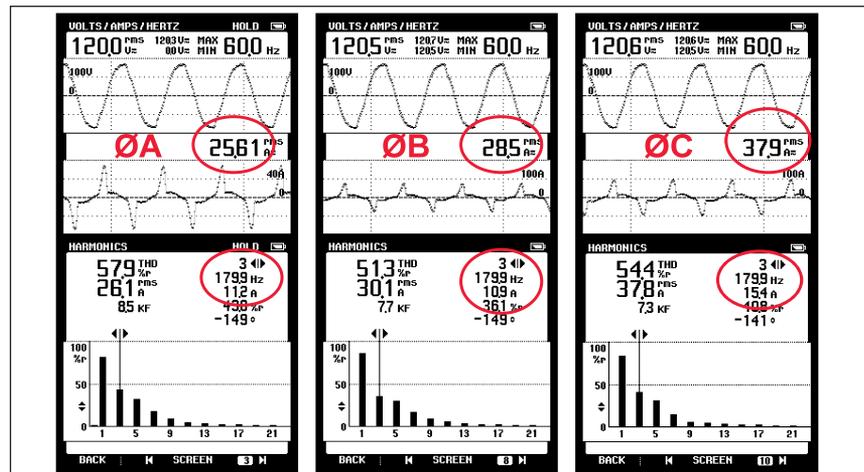


Figure 5a. Top screen shows waveform and rms amplitude of feeder phase current, bottom screen shows amplitude of third harmonic.

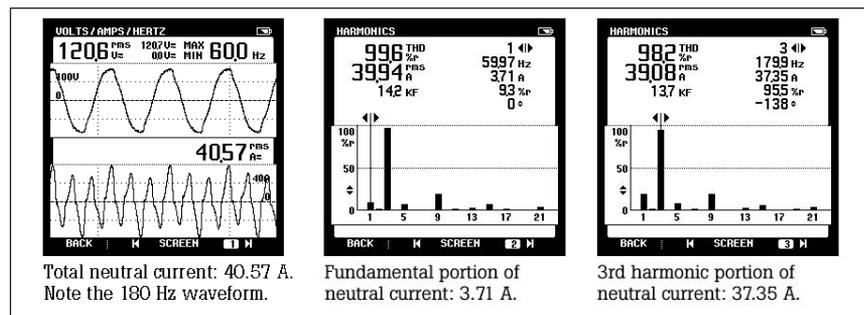


Figure 5b. Neutral current.

percent of them had neutral current in excess of 100 percent of phase current! The strong recommendation from the power quality community therefore is that the neutral be double the size of the phase conductor.

Count the black and white wires and if there are more black than white wires, there is a good possibility of shared neutrals. At that point, we should definitely measure the branch neutral currents. Basically, the same thing is probably happening on the branch circuit as on the feeder level; i.e., third harmonic currents will add up and possibly overload the shared neutral conductor. This is a distinct fire hazard. The neutral, after all, has no circuit breaker to protect it.

A neutral ground voltage measurement will also show if the neutral is too heavily loaded, or if its source impedance is too great. The neutral ground voltage is usually in the 0.25 V range at the panel, while the

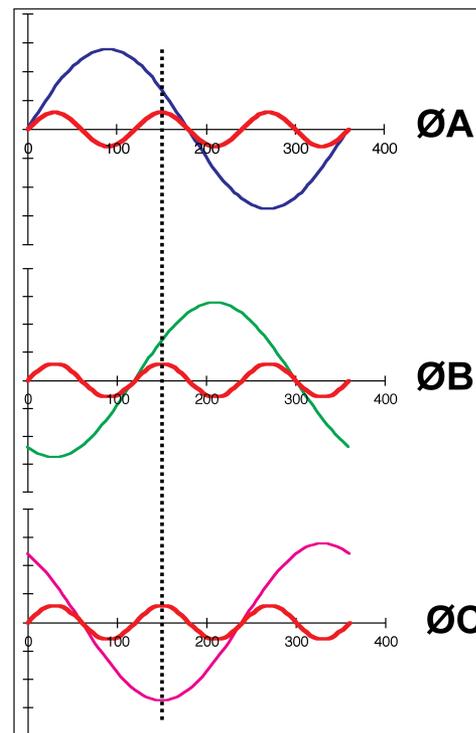


Figure 6. Why third harmonic adds up on the neutral. third harmonic in each feeder is in-phase. There is no vector cancellation as there is with the fundamental currents (which are 120 degrees out-of-phase).

actual value depends on the distance to the transformer. Anything above 0.5 V should be noted, and investigation made about whether loads fed from that panel have experienced problems. What if, under normal loading, the neutral ground voltage is close to zero? That leads us to the problem of illegal neutral ground bonds.

Grounding

Neutral ground bonds in subpanels are a violation of the NEC as well as of power quality performance wiring, but they are also quite common. Neutral ground bonds should be made at the transformer (although the NEC permits it to be made at the main panel). In any case, it should never be made downstream of the main panel, whether at a subpanel or a receptacle. When a neutral ground bond is made at a subpanel or receptacle, the ground path becomes a parallel return path for normal load current resulting in measurable current on the ground.

What is normal ground current and what is abnormal? A logical approach is to measure the neutral current and then the current on the green wire. If the neutral current is, let's say, 70 A, and the ground current is 2 A, the ground current is more likely to be normal leakage (and therefore unavoidable). If the neutral is 40 A and the ground current is 20 A, there are likely to be some hard-wired neutral ground bonds. The smaller the ratio of neutral to ground current, the more likely that an illegal neutral ground bond exists. Neutral ground bonds can also exist in receptacles and even in load equipment, so we might have to use this same technique to measure for individual branch circuit ground currents.

If an illegal neutral ground bond is found in one panel at a site, it's a good bet we'll find it at others as well. The installer may have been thinking that all panels are wired like residential service panels, or that the quickest way to reduce neutral ground voltage was to install a jumper. Or maybe he just felt that the

more grounds, the better. In any case, remove all illegal neutral ground bonds - *no exceptions*.

This is also a good time to check the tightness of *conduit connections*, especially if the conduit is being used exclusively as the grounding conductor. The recommended practice is for a green wire to be installed.

Hot spots

Poor connections and the resulting heat losses are the single greatest source of system inefficiency (according to a 1995 study by the then Washington State Energy Office). From the power quality point of view, loose terminations are a major contributor to excessive source impedance. Fortunately, they are easy to locate with a simple infrared thermometer.

Infrared (IR) measurements with tools like the Fluke 60 Series are a safe and effective technique for non-contact detection of panel hot spots. However, there are some key concepts that are crucial to understand if we're making these measurements:

- How big or small an area are we measuring?
Optical resolution is the ratio of the distance from the measured object to the sampling spot size. If the ratio is 4:1, it means that if you are four inches from the surface being measured, you're measuring a spot with a one-inch diameter.
- Handheld infrared probes like the Fluke 80PK-IR are most easily used for *comparative temperature measurements*, not absolute measurements. For example, if we scan a series of breakers or lugs with the probe, we can easily determine if one is significantly hotter than another.
- If we really need to make accurate measurements of *absolute* temperature with lower cost infrared instruments, the process gets more complicated. The short story is that *electrical tape should be used to cover any highly polished metallic surfaces*. The issue here is emissivity. Emissivity indicates the ability of an object to emit infrared

energy. Emissivity is the opposite of light reflection, in the sense that *darker, non-polished surfaces have higher emissivity*. Furthermore, most low-cost infrared instruments are fixed at an emissivity of 0.95, and the closer the surface being measured comes to this level of emissivity, the more accurate the measurement. That's why the surface of black electrical tape will result in more accurate readings than polished metal.

Circuit breakers

A lot of people don't think of breakers as having finite lifetimes. In reality, contacts and springs wear out. Measurements of circuit breaker voltage drop can help us determine the condition of the breaker. Measure across the line-to-load side of the branch breaker. If the voltage drop exceeds 100 mV, the breaker should be replaced. In the 35 to 100 mV range, readings should be documented and trended.

In summary, the service panel is the crossroad of the building's electrical system and the place where an experienced electrical troubleshooter can start down the right path to locate and fix any problems.

Fluke would like to thank Steve Uhrich of Valley Electric, Mt. Vernon, WA, for sharing his experience and insight in the writing of this article.

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Printed in U.S.A. 10/2004 1989143 A-US-N Rev B