Detecting, Identifying, and Correcting Power Quality Problems

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Abstract

Power quality monitors assist the troubleshooter to identify and solve many power quality problems. Disturbance waveshapes from these monitors provide important clues toward locating the source of these problems. The paper presents examples showing how to analyze these clues, but also shows that similar disturbance waveshapes may still have radically different causes. It illustrates that engineering judgement cannot be replaced in this process. The author also comments on the most common method of summarizing power quality data over extended periods of time, and offers important suggestions to insure that this analysis is relevant to the end user.

Introduction

Modern industrial machinery and commercial computer networks are prone to many different failure modes. When the assembly line stops, or the computer network crashes for no apparent reason, very often the electric power quality is suspected. It is a convenient culprit, as it is invisible and not easy to defend. Power quality problems may be very difficult to troubleshoot, and often the electric power may not have any relation to the actual problem. For example, in an industrial plant the faults of an automated assembly machine may ultimately be traced to fluctuations in the compressed air supply or a faulty hydraulic valve. Or in an office building, the problems on a local area network may be find their root cause with coaxial cable tee locations that are too close together, causing reflections and signal loss.

The role of monitors for troubleshooting power quality problems is undeniable. Industrial plant electricians will use disturbance analyzers to settle arguments about the quality of power, especially during the installation of new plant equipment when there are inevitably a number of problems associated with the normal commissioning process. Disturbance analyzers, set to trigger on abnormal voltage conditions, allow the troubleshooter to determine if the electric power is to blame for the problem.

Installing a power quality monitor after the event has already occurred does nothing to tell us about what had already happened. This is one of the chief frustrations of the power quality engineer. Monitoring after the event has already happened tells us little about the past. So power quality disturbance analyzers are becoming a permanently installed feature of plant and substation equipment. This is done to respond to the important role power quality maintains in our increasingly automated society. It is done so that we have a record when things go wrong. Power quality monitoring can tell us a great deal about our power system health. We only need to be able to read and interpret the clues correctly. The paper provides examples of how do recognize these clues. It also gives guidelines for summarizing these results over a period of time.

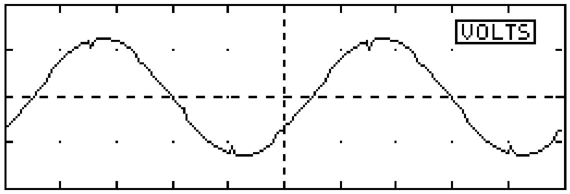

Figure 1. *Example of voltage notching due to power electronic devices.*

Voltage Notching

Figure 1 shows a typical case of voltage notching. This notching is caused by the operation of a controlled rectifier that commutates current from one electrical phase to another during the ordinary operation of the power electronic drive. This action causes the notching disturbance in the waveshape. Generally these problems are solved by introducing inductance, such as with an isolation transformer or reactive choke, into the circuit between the rest of the power source and the drive. In order to recognize these clues we may decide to define a rule that declares that a waveshape with notching is being affected by a power electronic rectifier or motor drive.

Loose Connections

However, rules nearly always have exceptions! Look at figure 2. It is another waveshape that exhibits voltage notching, but this time the cause of the disturbance is very different. It was caused by a faulty connection in a distribution transformer. Notice that the notches in figure 2 are not at the same angular location of the waveshape discussed previously in figure 1.

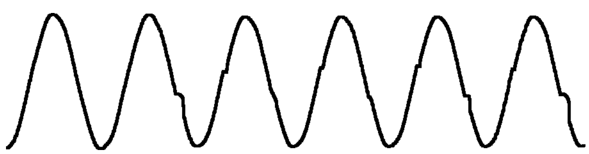

Figure 2. *Waveshape with notching caused by a loose connection.*

Are you convinced that figure 2 is caused by a loose connection? When the power quality engineers at the utility company first examined it, they were not sure at all. After a couple of days the loose connection progressed further and the evidence was more convincing as shown in figure 3. Yet a day further and the transformer failed catastrophically due to an internal loose lug connection.

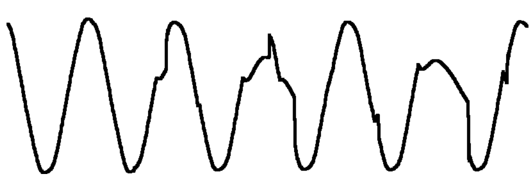

Figure 3. *Waveshape as loose connection progressed.*

Many times in power quality monitoring, information about the cause of a voltage disturbance may be determined from examination of current in the circuit. In this case it was particularly instructive. Figure 4 shows both the voltage and current waveshapes on the same plot. Notice that the voltage disturbance occurs at the time of the zero crossing of the current. This indicates that the current is tending to extinguish itself (go to zero) at this zero crossing due to the loose circuit condition. In fact, we can see that the current tends to be zero for several degrees. Also, the voltage is not disturbed at exactly its zero crossing because it is not in phase with the current due to a lagging power factor, typical of an inductive load.

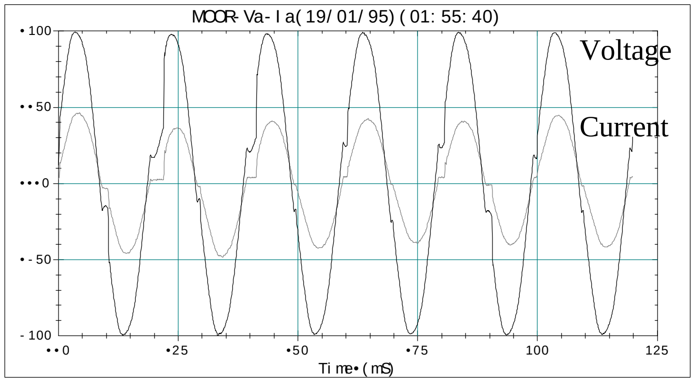

Figure 4. *Voltage and current waveshapes from circuit with a loose connection.*

So now we might be able to define a rule about loose connections. If the disturbance in the voltage is simultaneous with the zero crossing, then this condition indicates the possibility of a loose connection or open circuit. We might modify this rule for a circuit with lagging (leading) power factor to state that the loose connection is indicated when the voltage disturbance follows (leads) the zero crossing of the waveshape.

Detecting Insulation Failures

Let's take a look at another example. Figure 5 shows a waveshape disturbance where the fault occurs at the peak of the voltage. This particular disturbance was caused by a fault in an underground cable. Typically underground cable faults begin with small leakage currents and progress as the insulation further deteriorates. This process can take several days, as the cable "cooks" the insulation until the failure is finally catastrophic. Our experience at one utility shows us that this type of waveshape fault is very typical with underground cable failures.

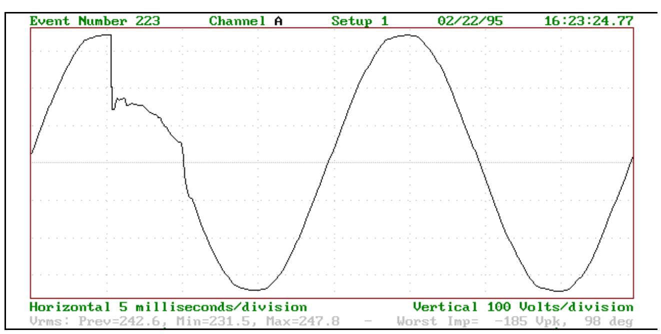

Figure 5. *Waveshape accompanying an underground cable failure breakdown.*

Now we might define a rule for an expert system that states "When a voltage waveshape disturbance occurs at the peak of a sine wave, the likely cause is insulation breakdown." This intuitively makes sense to us since the voltage stress on the insulation is greatest during the peak of the sinewave, therefore that is the likely point of insulation breakdown. However, before we get too comfortable with our rule, consider figure 6.

Capacitor Switching Disturbances

Figure 6 shows the disturbance to a waveshape during the energization of a large capacitor bank on a utility transmission substation. The capacitor bank is being switched on to compensate for reactive power losses to support the voltage and energy transmission capability of the transmission grid. Notice that this waveshape also has the waveshape disturbance occurring at the peak of the sinewave. But can we detect these capacitor switching transients by the oscillatory ringing that is characteristic of the natural frequency of the power system?

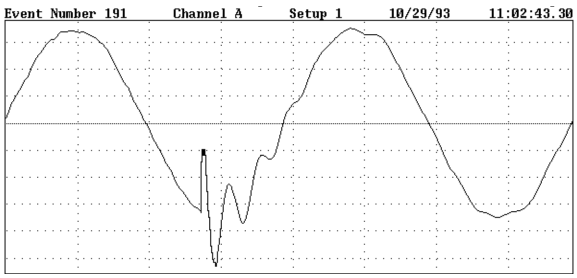

Figure 6. *Typical disturbance caused by the energization of a capacitor bank.*

Figure 7 shows us that capacitor switching transients are not always accompanied by the oscillatory ringing due to damping of the system and distance on the power system. It teaches us an important lesson. The power system transmits low frequency disturbances, but higher frequency (10kHz and greater) are usually dampened out very quickly with any electrical distance.

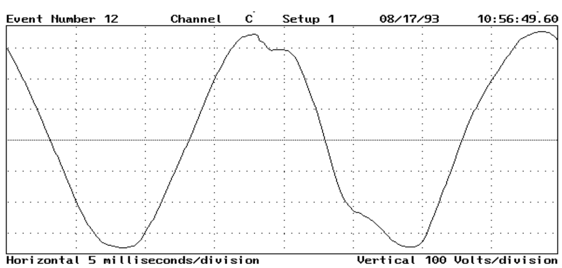

Figure 7. *Energization of a capacitor bank as seen from a distance.*

So once more, experience shows us to amend our rule about insulation failure. We might state it that "waveshape faults that initiate near the peak of the waveshape, where the voltage approaches rapidly an instantaneous value of zero are indicative of cable faults and other insulation breakdown." But let's see another exception to our rule.

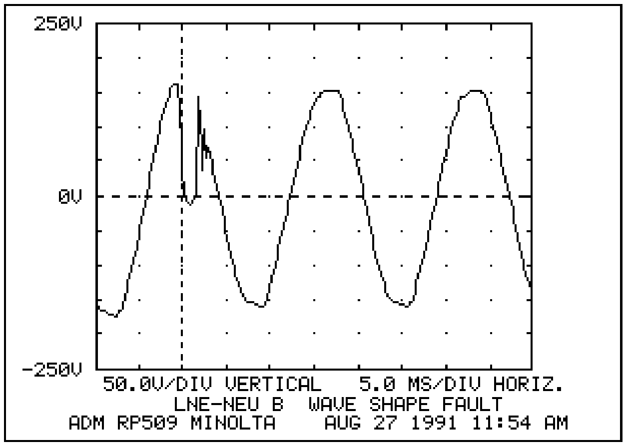

Figure 8. *Waveshape fault during the operation of a voltage regulator.*

Figure 8 shows a waveshape fault that corresponded to the operation of a voltage regulator. The subject voltage regulator was rated for 120V and 15amps, intended for small office loads. The operation of the device appeared to be suspect. It was possible that a "make before break" connection was malfunctioning. However, when the waveshape was sent to the manufacturer, their representative responded that this type of disturbance should not affect computers. They made no comment on whether the device was operating properly!

Summarizing, a certain type of fault on the power system may be accompanied by a certain type of waveshape "signature". However, a specific type of waveshape signature may well have many different possible causes. Knowledge about the location and nearby loads is usually important when interpreting the output of power disturbance analyzers.

Understanding Summary Plots

Some power quality analyzers allow the capability of summarizing multiple events on one plot. Many users have found this a convenient way to characterize the power quality over an extended period of time. An example of a voltage sag is shown in figure 9.

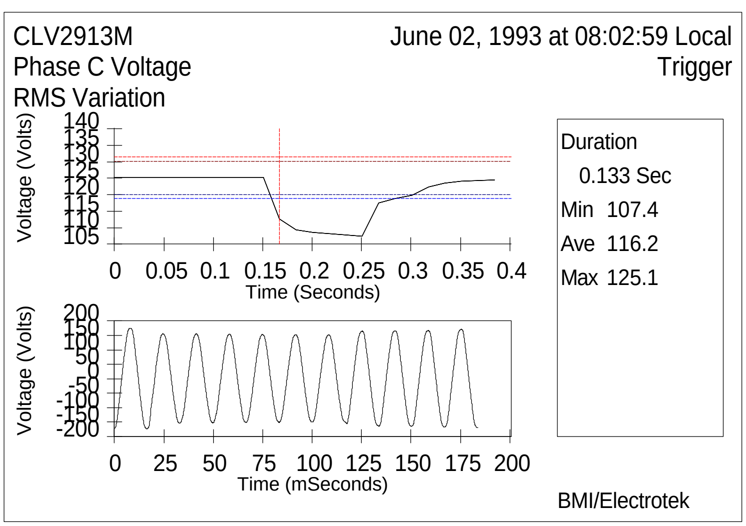

Figure 9. *Example voltage sag event with a magnitude of 107V and a duration of 0.133 second.*

Usually voltage sags are summarized with a magnitude (perhaps minimum value) and a duration (time that the signal is out of threshold values) so that these events can be compared against published equipment sensitivity limits. The most popular sensitivity curves have been those developed by the Computer Business Equipment Manufacturers Association (CBEMA). These curves represent the ability of the equipment to survive power disturbances of a given magnitude and duration. For example, in figure 10 a total of 74 events are summarized. Forty-four of those events are outside of the CBEMA limits and would be expected to cause a fault with equipment designed to the CBEMA tolerances.

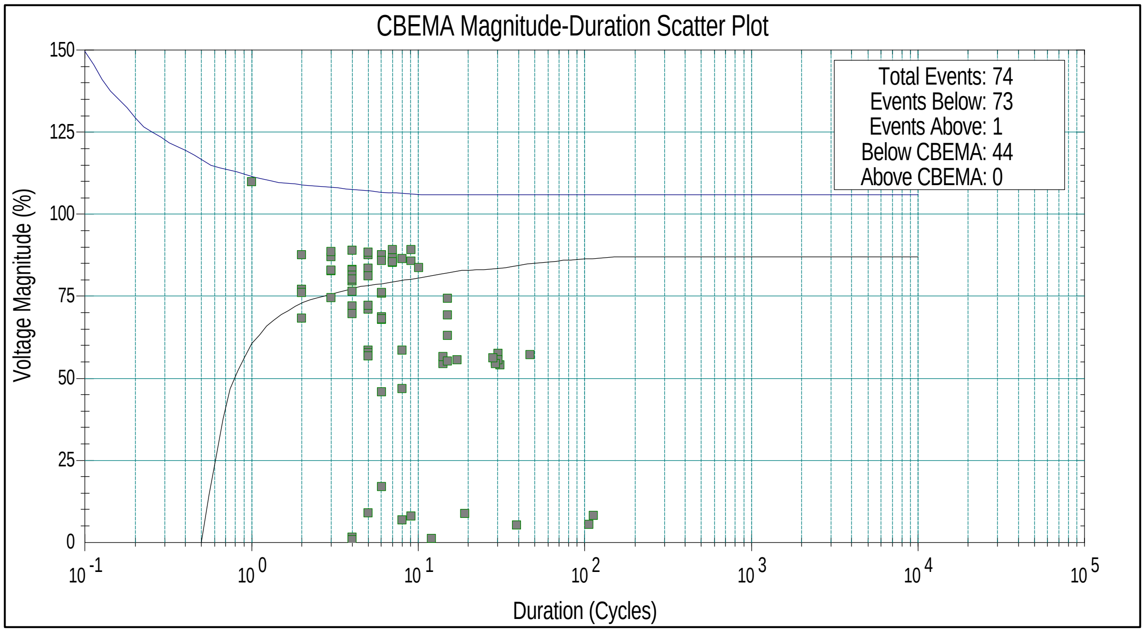

Figure 10. *Summary of RMS disturbance events on a CBEMA magnitude-duration plot.*

Unfortunately, summaries such as the one shown in figure 10 can be misleading. For example, some instruments will report on each individual phase that goes out of threshold. Therefore, one voltage sag event may be reported three times if all of the three phase voltages fall below the instrument threshold. In this case, the summary will show three events even though the lights blinked only once.

It is important that summary data be understandable to the end user and their perceptions of power quality. Most users would prefer a summary that relates more directly to their perceptions of power problems, not one that gives three data points for every time that the lights blink during a voltage sag. The PQView Analysis software, developed by Electrotek for EPRI provides this capability by allowing the user to perform aggregation on summary data.

Aggregation, or grouping, allows the user to combine individual events according to some important criteria, and report the characteristics on the worst phase. So, if we use measurement aggregation to combine the results when multiple phases trigger at the same time, we might get the data in figure 11.

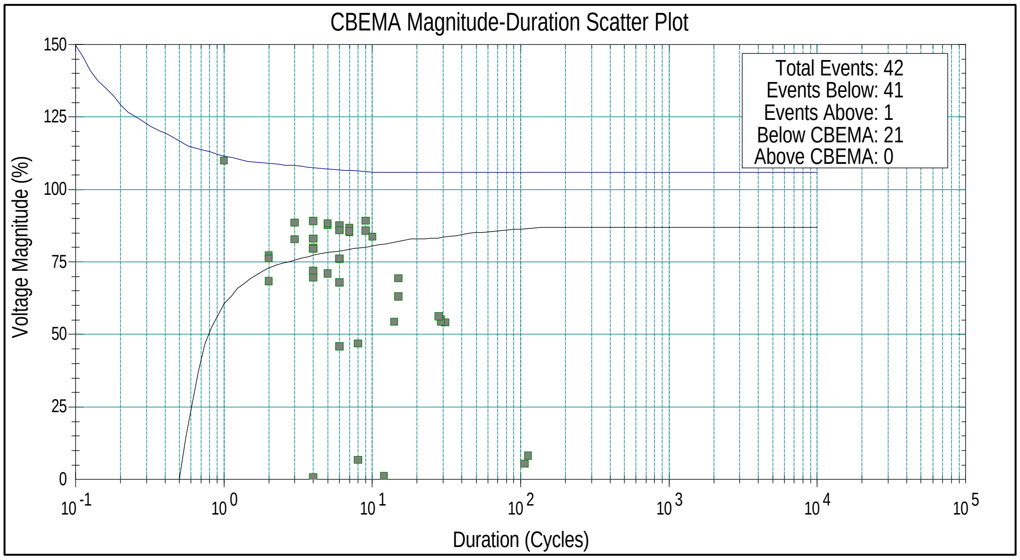

Figure 11. *Summary data revised by measurement aggregation.*

Future power quality contracts between utilities and large customers may well specify the number of voltage sags allowable. It is almost certain that these events will be counted using measurement aggregation so that a three-phase voltage sag will only count once.

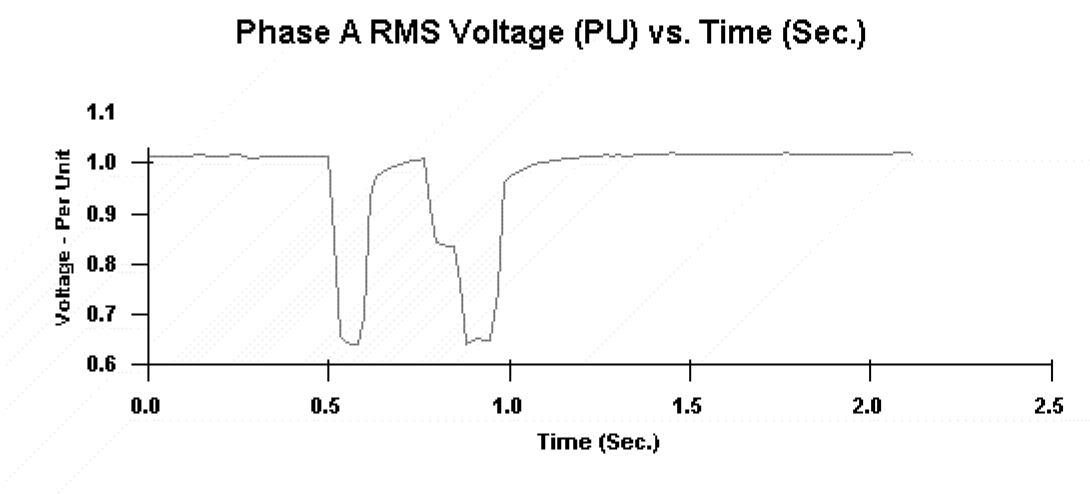

Figure 12. *Example reclosing event less than 0.5 second apart.*

Reclosing operations on the utility system are the process of automatically restoring tripped circuit interrupters. This process is very important to the reliable operation of the power system. However, these operations can lead to multiple voltage sags over a short period of time if the reclosing operation is unsuccessful. An example is shown figure 12. Because the reclosing times are very short, normally these operations affect the customer only one time. Power quality contracts will most likely also utilize some temporal aggregation – grouping the measurements by a period of time. This process insures that each event reported actually refers to a “customer” event – that which is actually significant to the end user.

Figure 13 shows the same data processed by temporal aggregation. It shows that on thirteen separate days there were severe events, and what the worst event was on each day.

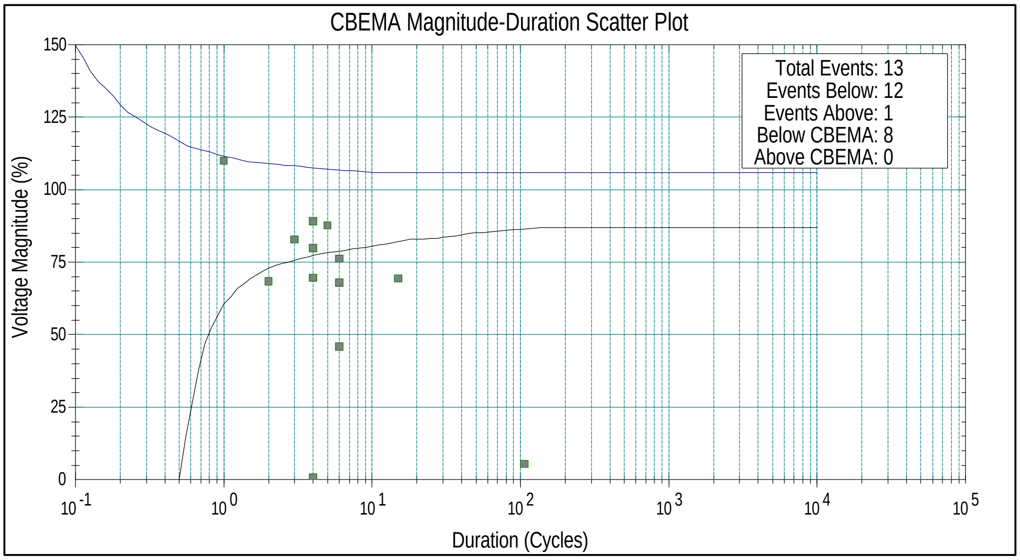

Figure 13. *Summary data revised by temporal aggregation (86400 seconds).*

Conclusions

There are several observations presented in the paper that help us identify the cause of power quality disturbances from waveshapes.

1. Insulation breakdown causes waveshape disturbances at the peak of the voltage.
2. Loose connection faults cause waveshape disturbances in the voltage waveshape near the zero-crossing of the current.
3. Capacitor energizing transients initiate a sharp transient toward the voltage zero, followed by a dampened oscillation at the power system frequency.
4. Higher frequency transients are dampened greatly by electrical distance. Normally waveshape disturbances that exhibit higher frequency characteristics indicate that the source of the disturbance is nearby.

Knowledge about the electrical environment is always essential in interpreting disturbance waveshapes because very different causes can lead to similar waveshape disturbance patterns.

Summary plots of rms disturbance events should reflect the end user's perceptions of "customer events". These plots should include aggregation of multiple events that occur concurrently on multiple phases or within a normal utility reclosing cycle, in order not to overstate the number of disturbances. This technique will be especially important in premium power contracts between utilities and their most important customers.

References for Further Information

1. McEachern, Alex. Handbook of Power Signatures, 2nd Edition, published by Dranetz-BMI.
2. Dugan, McGranaghan, and Beaty. Electrical Power Systems Quality, McGraw-Hill.