Monitoring Power Quality

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Significance:
Part 5 – Monitoring instruments, laboratory measurements, and test methods
First part of a two-part trade magazine version of the IEEE paper "Power Quality Site Surveys: Facts, Fiction, and Fallacies." (See file "PQ surveys FFF" for the original IEEE paper and file "Site surveys" for the second part of the trade magazine publication.)

Provides background on the motivation for site surveys and a brief description of the types of monitors that have been used, concluding with remarks on how future site surveys should be conducted.

Introduces to the trade literature the term of "swell" – as opposed to "surge" to descrive a momentary overvoltage at the power frequency.

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Power disturbances that affect sensitive loads have a variety of sources. Results of site surveys can assist in determining which line conditioning methods are most appropriate.

Site surveys are generally initiated to evaluate the quality of the power available at a specific location with the aim of avoiding equipment disturbances in a planned installation or of explaining (and correcting) disturbances in an existing installation. In either case, survey results constitute one of the inputs in the decision-making process of providing supplementary line conditioning equipment, either before or after power disturbances have become a problem. Depending on the reliability requirements of the load equipment, its susceptibility, and the severity of the disturbances, various line conditioning methods have been proposed: surge suppressor (with or without filter), isolation transformer, voltage regulator, magnetic synthesizer, motor-generator set, or uninterruptible power supply (UPS).

Because this additional line conditioning equipment may require significant capital investment, the choice of corrective measures is generally made by economic trade-off which is the prerogative and responsibility of the end user. However, if technical inputs to this trade-off are incorrect because erroneous conclusions were drawn as a result of a faulty site survey, the whole process is worthless – or worse yet, misleading.

For this reason, a good understanding of the merits and limitations of site surveys is essential for reconciling expectation with reality before expensive line conditioning equipment is called for; one should deal, not with fiction or fallacies, but with facts.

Power disturbances that affect sensitive electronic loads have a variety of sources. Lightning, utility switching, and utility outages are often-cited sources of power disturbances. However, power disturbances are frequently caused by users themselves, through switching of loads, ground faults, or normal operation of equipment. As one example, computer systems are not only sensitive loads, but can also generate disturbances themselves. Their non-linear load characteristics can cause interactions with the power system such as unusual voltage drops, overloaded neutral conductors, or distortion of the line voltage.

Utility systems are designed to provide reliable bulk power. However, it is not feasible for them to provide continuous power of the quality required for a completely undisturbed computer operation. Because normal use of electricity generates disturbances, and because unexpected power system failures will occur, every site will experience some power disturbances, but their nature, severity, and incidence rates will vary from site to site.

Confusion in Term Definitions

As will become painfully apparent in next month's review of site surveys, the terms used by the workers reporting their measurements do not have common definitions. An effort is being made within the IEEE to resolve this problem, as described later in this paper, but consensus has yet to be reached. In this paper, terms describing disturbances are consistent with the IEEE *Standard Dictionary of Electrical and Electronics Terms* [1] and with established usage within the community of surge protective devices engineers.

The generally accepted meaning of surge voltage, in the context of power systems, is a short-duration overvoltage, typically less than 1 ms or less than one half-cycle of the power frequency. This meaning is not that which has been established by manufacturers and users of monitoring instruments and line conditioners. This unfortunate second meaning is a momentary overvoltage at the fundamental frequency with a duration of typically a few cycles.

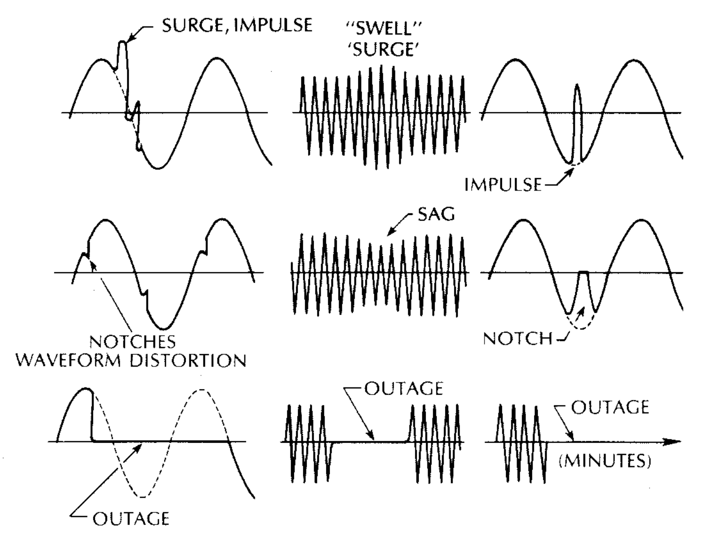

Figure 1.
Graphic depictions of disturbances with multiple meanings

In this article, this second meaning of the word "surge" (a momentary overvoltage) will be signaled by the use of quotation marks. What power engineers call surge is referred to as "impulse" or "spike" by the monitoring instrument community. **Figure 1** shows by graphic descriptions the confusion created by the dual meaning of the word surge. Acknowledging the desire of users for terse labels, we propose for consideration the word "swell" instead of "surge" for a momentary overvoltage.

The term "outage" is another example of confusion created by unsettled definitions. Most users agree that it means a complete loss of line voltage, but the duration of an outage can be quite different when defined by computer users (as short as one half-cycle) or power engineers (seconds, perhaps minutes). Part of the problem may be that the definition of "outage" has regulatory implications for evaluating the performance of public utility companies. Users and manufacturers of line conditioners do not make a clear distinction between complete loss of line voltage (zero voltage condition), severe undervoltages ("deep sags"), or the single-phasing of polyphase power systems. For example, a momentary flicker of fluorescent lighting caused by a brief loss of voltage might be considered an outage; however, a brief sag to less than 80 percent of nominal voltage will produce the same visible effect. Some UPS manufacturers consider input voltage sags that cause transfer to the battery backup operation as outages.

The term "sag" has not yet been defined in the *IEEE Dictionary*, but it is now generally accepted as meaning a momentary voltage reduction at the ac power frequency. However, details (threshold, duration, etc.) of what characterizes a sag are not well defined.

Motivation For Site Surveys

With the increasing dependency on computer-based systems for industry, commerce, and consumers, disruptions from power disturbances are less and less acceptable. Operational problems such as hardware damage, system crashes, and processing errors are the most visible indications of power disturbances. Some computer system users may accept (albeit reluctantly) such problems because they see them as unavoidable. Others may be unaware that otherwise invisible power disturbances could be the cause of these problems. A single power disturbance can cost more in downtime and hardware damage than the investment in power protection that would have prevented the effect of the disturbance. Nearly all sites can benefit from a reduction of operational problems by improving the quality of power supplied to the computer systems [2].

Power line monitoring with sophisticated power disturbance recorders has often been advocated as a way of determining if any line conditioning is required. While monitoring appears to be a logical first step, it has limitations. For example, severe disturbances occur infrequently or on a seasonal basis. Therefore, monitoring periods of less than a year might not produce an accurate profile of power disturbance, and most users are unwilling to wait at least a year to characterize the problem. Also, power line monitoring only produces data on past performance. Changes within the site (or at neighboring sites) or by the utility can

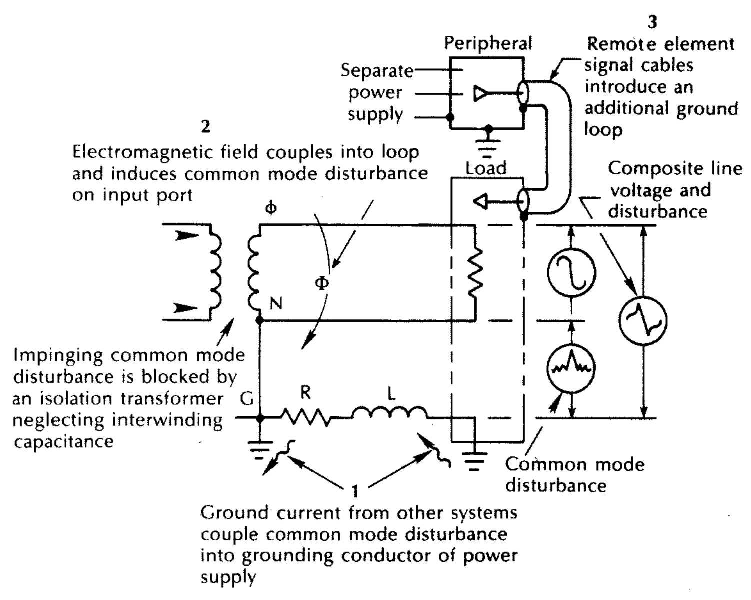

Figure 2.
Origins of common mode disturbances, including ground current from other systems (1), electromagnetic field coupling into loop to induce input port disturbance (2), and introduction of an additional ground loop from remote peripherals (3)

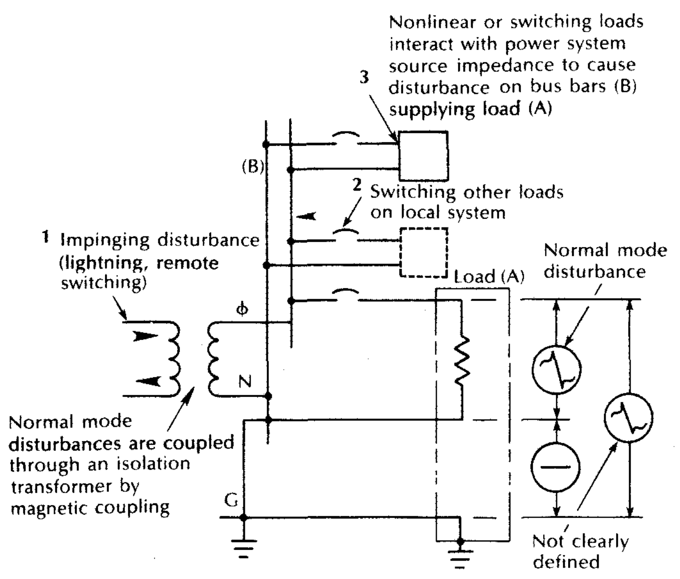

Figure 3.
Origins of normal mode disturbances include impinging disturbances such as lightning (1), switching of other loads on local systems (2), and interaction between nonlinear/switching loads with power system source impedance (3)

drastically alter the power disturbance profile in ways that line monitoring cannot predict.

While exact prediction of the disturbances to be expected at a specific location is almost impossible – and attempting it would be a fallacy – general guidelines can be formulated. An attempt has been made by standards-writing groups to provide guidance [3] or specifications reflecting expected disturbances [4-6]. However, users will still seek specific data for their particular case, and site surveys will still be necessary. Another fallacy would be to attempt correction of power line disturbances revealed by monitoring and then to expect operational problems of equipment to disappear without having first determined the exact susceptibility of the equipment. Operational problems are the results of more than just power disturbances.

Types Of Disturbances

Power line disturbances can be classified into two categories: common mode and normal mode disturbances. The two terms were first defined in the context of communication circuits; a recent **IEEE Guide** [7] has established an expanded definition which is used in this article, as outlined in the following paragraphs. The **IEEE Dictionary** [1] and the **IEC Dictionary** [8] define symmetrical and asymmetrical voltages akin to, but not interchangeable with, the definitions of normal mode and common mode, respectively.

Common mode disturbances are defined as unwanted potential differences between any or all current-carrying conductors and the grounding conductor or earth. In three-phase grounded-wye power supplies typical of large computer systems, common mode disturbances can also be defined as the potential difference between neutral and ground.

Two different types of common mode disturbances can affect a sensitive load. The first type is a disturbance on the input power conductors relative to the input power grounding conductor. Points 1 and 2 of **Figure 2** show examples of the origins for these disturbances. This type of disturbance can be limited somewhat by a line conditioner, but it is also influenced by the location of the line conditioner and the wiring practices.

The second type is a ground potential difference between elements of the computer or remote peripherals connected to the computer. Point 3 of Figure 2 is an example of this type of disturbance, which is more difficult to limit because it is influenced by factors such as system configuration and the impedance of the grounding system. These two factors are generally beyond the direct control of the user except in the construction of a new facility.

Because of the broad frequency band involved, wiring resonances can make equalizing ground potentials difficult. Proper computer system grounding, including a signal reference grid, has been found to be effective against most common mode disturbances [9]. However, when remote elements are connected to the computer systems by data cables, large ground potential differences are possible. Proper surge protection of the power supply and proper grounding of data cables will help eliminate hardware damage but might not prevent data corruption. When dealing with the situation of example 3 in Figure 2, fiber optic links are very effective because they provide complete metallic separation of the various elements in the system – a separation that might not be sufficiently achieved by the discrete opto-isolation devices sometimes proposed for that function [10].

Normal mode disturbances are defined as unwanted potential differences between any two current-carrying circuit conductors. **Figure 3** shows three examples of the origins of such disturbances. Usually a sine wave of nominal voltage is desired for a computer power supply; any deviation from this sine wave is a normal mode disturbance. Computer users and monitoring instruments designers characterize these disturbances by a variety of terms not always clearly defined such as sags, surges ("swells"), outages, impulses, ringing transients, waveform distortion, and high-frequency noise. Unfortunately, there is no consensus at the present time on the exact meaning of these terms and their underlying quantitative definitions such as amplitude, duration, and thresholds.

Types Of Monitors

The instruments used in the various surveys reflect technological progress as well as logistics constraints resulting in a diversity of approaches. Nevertheless, all monitoring instruments used in past surveys were voltmeters (with one exception, combining voltage and current measurements) from which disturbance parameters were derived. Some of the monitors recorded a single parameter such as the actual voltage peak or the fact that the voltage exceeded a preset threshold. Other monitors combined time with voltage measurements describing voltage waveforms. The recording functions of instruments used in the surveys may be classified in broad categories:

Threshold counters – The surge is applied to a calibrated voltage divider, triggering a counter each time a preset threshold is exceeded. The early types were analog; more recent types are digital.

Digital peak recorders – The surge is converted to a digital value which is recorded in a buffer memory for later playback or printed out immediately after it occurs. In the early types of recorders, only the peak was recorded; in later types, the duration of the surge was also recorded, opening the way to the more complex digital waveform recorders now available.

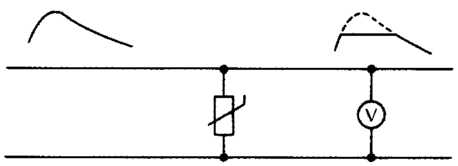

Figure 4.
Effect upon voltage peak and waveforms with varistor placed upstream of monitor

Oscilloscope with camera – The surge triggers a single sweep on the oscilloscope's CRT, which is recorded as it occurs by a shutterless camera with automatic film advance. The oscilloscopes available at that time (the early 1960s) did not allow differential measurements.

Screen storage oscilloscope – The surge is displayed and stored on the cathode ray tube. The writing-speed capability of these oscilloscopes was a limitation in the late 1960s.

Digital storage oscilloscope – The surge is digitized and stored in a shift register for subsequent playback and display whenever a preset threshold is exceeded. An important feature is the capability of displaying events prior to the beginning of the surge.

Digital waveform recorder – The surge is digitized and stored in a manner similar to the digital storage oscilloscope, but additional data processing functions are incorporated in the instrument, allowing reports of many different parameters of the disturbance relating voltage to time.

Although some surveys might aim at great accuracy, the real world experiences such a variety of disturbances that any attempt to describe them in fine detail only restricts general usefulness of the data. Seeking such fine and definitive detail is another fallacy. Some simple instruments are useful (and inexpensive) indicators of frequent disturbances; other, more sophisticated (and more expensive) instruments can provide quite comprehensive data on disturbances (but only on past events from which future disturbances can be extrapolated only by assuming that the causes will remain unchanged). Thus there is a practical limit to the amount of detail that a survey can yield, and unrealistic expectations of very precise information should be avoided.

Previous And Future Surge Recordings

Before attempting yet another broad survey of power quality, would-be surveyors need to consider not only improvements in instrumentation but also changes that have occurred in modern power systems – in particular the proliferation of surge protective devices. These two differences between earlier surveys and the more recent surveys should be kept in mind when comparing results and when planning future surveys.

Prior to the proliferation of surge protective devices in low-voltage systems (those defined by IEEE and IEC as 1,000V or less), a limitation had already been recognized [4] for peak voltages: the flashover of clearances, typically between 2 and 8 kV for low-voltage wiring devices. For that reason the expected maximum value cited in the *IEEE Guide on Surge Voltages* [3] reflects this possible truncation of the distribution around 6 kV. Unfortunately, some readers of this *Guide* interpreted the upper practical limit of 6 kV as the basis for a withstand requirement, and they have included a 6-kV test requirement in their performance specifications. A new version of this *Guide*, currently under preparation as a *Recommended Practice*, will attempt to avoid this misinterpretation.

The number of surge-protective devices such as varistors used in the United States since their introduction in 1972 on low-voltage ac power circuits may be estimated at 500 million. Therefore, a new limitation exists in the voltage surges that will be recorded. A surge-recording instrument installed at a random location might be close to a varistor connected near the point being monitored. Such a proximity of surge protective devices and recording instruments may impact present and future measurement campaigns. Four are outlined below.

1) Locations where voltage surges were previously identified – assuming no change in the source of the surges – are now likely to experience lower voltage surges, while current surges will occur in the newly installed protective devices.

2) Not only will the peaks of the observed voltages be changed, but also their waveforms will be affected by the presence of nearby varistors as illustrated in **Figures 4, 5**, and **6**.

A) If a varistor is located between the source of the surge and the recording instrument (Figure 4), the instrument will record the clamping voltage of the varistor. This voltage will have lower peaks but longer time to half-peak than the original surge.

B) If the instrument is located between the source of the surge and a varistor, or if a parallel branch circuit contains a varistor (Figure 5), the instrument

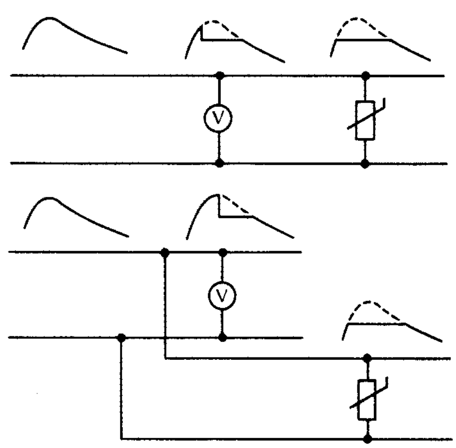

Figure 5.
Effect upon voltage peak and waveforms with varistor placed downstream of recorder

will now record the clamping voltage of the varistor, preceded by a spike corresponding to the inductive drop in the line feeding the surge current to the varistor.

C) If a varistor is connected between the line and neutral conductors, and the surge is impinging between line and neutral at the service entrance (normal mode), a new situation is created, as shown in Figure 6. The line-to-neutral voltage is clamped as intended, but the inductive drop in the neutral conductor returning the surge current to the service entrance produces a surge voltage between the neutral and the grounding conductors at the point of connection of the varistor and any downstream point supplied by the same neutral. Because this surge has a short duration, it will be enhanced by the open-end transmission line effect between the neutral and grounding conductors [11].

3) The surge voltage limitation function previously performed by flashover of clearances is now more likely to be assumed by the new surge protective devices that are constantly being added to the systems.

4) These three situations will produce a significant reduction in the mean of voltage-surge recordings from the total population of different locations as more and more varistors are installed. However, the upper limit will remain the same for locations where no varistors have been installed. Focusing on the mean of voltage surges recorded in power systems can create a false sense of security and an incorrect description of the environment. Furthermore, the need for adequate surge current handling capability of a proposed suppresser with lower clamping voltage might be underestimated because some diversion is already being performed. □

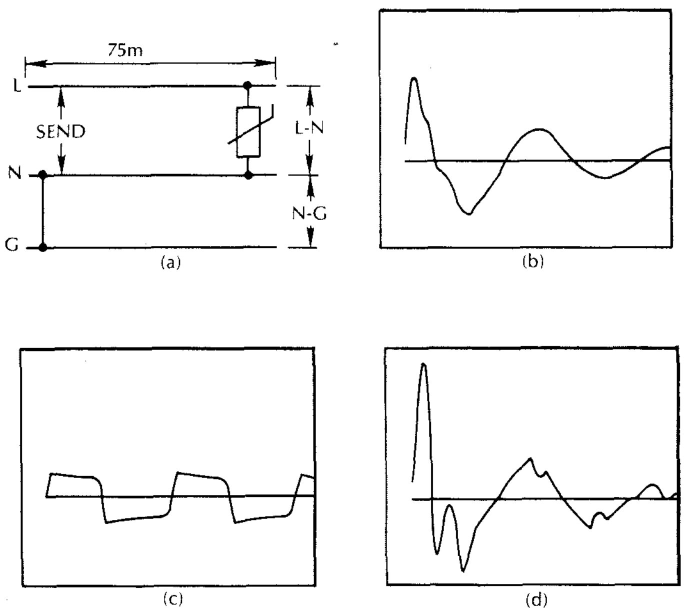

Figure 6.
Protective device installed between line and neutral conductors, for surge applied in normal mode at service entrance and varistor connected at end of 75-m branch circuit (a); surge applied at "send" end, 3 kV initial peak, 100 kHz oscillation (b);(c) shows surge clamped at L-N at end of line, maximum voltage 400 V (same time scale as b, but different amplitude scale); 2500 spike at N-G at end of line (d), created by surge current in neutral conductor (same scales as b) (d) will experience short duration surge

Part II of this article, a detailed review of several site surveys, will appear in the March issue of Powertechnics. This article was based on "Power Quality Site Surveys: Facts, Fiction, and Fallacies," by F.D. Martzloff and T.M. Gruzs, which first appeared in *IEEE Transactions on Industry Applications*, Vol. IA-24, No. 6, pp. 1005-1018, Nov./Dec. 1988. © 1988 IEEE.

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