Systems and instruments in site surveys

François D. Martzloff
National Institute of Standards and Technology

Thomas M. Gruzs
Liebert Corporation

Reprinted from Powertechnics Magazine, March 1990

Significance
Part 6: Tutorials, texbooks and reviews

A trade magazine article excerpted from the IEEE paper “Power Quality Site Surveys: Facts, Fiction and Fallacies”

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François D. Martzloff
National Institute of Standards and Technology
Gaithersburg, Maryland
Thomas M. Gruzs
Liebert Corporation
Columbus, Ohio

Every on-site survey of power quality utilizes a variety of methods and instruments, requiring careful interpretation of survey results. A close examination of underlying assumptions in nine published surveys shows that some differences can be reconciled, but indicates the need for new or improved standards.

Power quality surveys have been conducted for two reasons: 1) to identify potential problems or causes of equipment disturbances at a specific site, and 2) to develop a broad data base with the hope that the general findings will be applicable in specific cases. This article gives a review of nine papers reporting broad data base surveys, but the conclusions are also applicable for site-specific surveys. The review shows problems that readers encounter when different authors use different instruments, different definitions, and as a result sometimes reach contradictory conclusions. The nine surveys were conducted in the United States and Europe over the last 25 years. Power systems have not changed much, but the load equipment characteristics, as well as the capabilities of disturbance monitoring instruments, have changed considerably. **Table 1** shows details of the locale, system voltage, instrument type, and connection mode as described in the papers.

Bull and Nethercot, in a 1964 article [1], report monitoring performed in the mid 1960s on 240-V systems in Great Britain with instruments of their design. Their initial instrument used vacuum tubes, leading to the development of a solid-state circuit which may be considered the forerunner of modern monitors. The instrument had several channels, each with a different threshold.

The monitoring locations were selected to include a variety of conditions, with data being collected for several weeks at each location over a total period of 2 years. The results do not mention transients above 600 V; it seems that no channels were provided above that level because the authors were only concerned with the range of 50-600 V.

Martzloff and Hahn, in a 1970 paper [2], report the highlights of measurements made in the 1963 to 1967 period on residential, commercial, and industrial circuits, mostly single-phase 120 V. Waveform data were obtained with commercial, custom-modified oscilloscopes fitted with motor-driven cameras. These oscilloscopes were installed at various locations where transient activity was suspected, not at randomly determined locations. In addition, a peak counter circuit was developed, and 90 units with a 1200- or a 2000-V threshold were deployed at 300 locations where there was no prior suspicion of unusual transient activity.

The oscilloscope data gave one of the first indications that the traditional unidirectional impulse, long used for dielectric testing, might not be representative of surges occurring in low-voltage circuits. The threshold data indicated locations where surges above 1200 V occur frequently (about 3 percent of the sample), while other locations appear far less exposed to surges. The 100:1 reduction of an alarming failure rate of clock motors, achieved by increasing the surge withstand capability of the motors from 2000 to 6000 V, is documented in that paper.

Cannova, in a 1972 paper [3], reports the monitoring of surges on U.S. Navy shipboard 120- and 450-V power systems in the late 1960s. Instrumentation used for the initial phase of the monitoring program consisted of oscilloscopes similar to those used by Martzloff. Provision was also included for the option of measuring the transients alone (through filters) or superimposed on the ac line voltage; this option reflects the old dichotomy, still unsettled to this day, as to whether the transients should be measured as an absolute value or as a deviation from the instantaneous value of the ac sine wave (see the last column of Table 1).

The results are not reported separately for 120- and 450-V systems; therefore, it is not possible to express them in terms of per-unit or percentage of nominal system voltage. Cannova's statistical treatment aims at fitting the recorded transients to a normal distribution and concludes that a log normal distribution is a better fit. A brief statement is made on the durations of the recorded transients (without a statement on how those durations are defined), citing a majority of durations between 4 μs and 6 μs, with a few at 19 μs.

From the data base, acknowledged to be a small total number of events, a protection level of 2500 V was defined. The specification of a 2500-V 1.2/50-μs voltage withstand by DOD STD 1399 was derived from this survey.

Two aspects of the conclusions are especially worth noting: 1) there was no information on the source impedance of the surges, and yet the data eventually served to specify requirements for surge protective devices; and 2) a large difference in frequency of occurrence was noted among ships of the same type and class, similar to the observations on land surveys.

Allen and Segall, in a 1974 paper [4] report the monitoring of several types of power disturbances at computer sites, performed with oscilloscopes, oscillographs, and digital instruments, in the 1969-1972 period. Details of the instrumentation were described in a separate paper [5]. Disturbances are described as overvoltages and undervoltages, oscillatory decaying disturbances, voltage spike disturbances, and outages. The terms sag and "surge" ("swell") had not yet made their appearance in the jargon.

The survey was conducted in two phases. In a first phase, preliminary information was obtained on ranges of disturbances, leading to the development of a second generation of monitors deployed in the next phase. The recorded disturbances are described by plots and histograms. The highest surge recorded in the first phase is shown as 350 V. In the second phase, the monitors grouped all surges into three categories, the highest having a range of 100 percent (of line voltage) to infinity, so that no detailed information is provided to describe high peak values. The survey does report in detail the occurrence of undervoltages and overvoltages, providing a basis for the comparisons with the Goldstein-Speranza results.

Goldstein and Speranza, in a 1982 paper [6], report the monitoring of several types of disturbances at a variety of locations in the Bell system, with digital multiparameter instruments, in the 1977 and 1979 period. The conditions of the survey are documented, including instrument locations and definitions of the parameters as well as the methods of data processing.

The findings are briefly reported with emphasis on predictions for disturbances expected at specific sites. The prediction is obtained by using a statistical model derived for all sites and making adjustments reflecting specific site conditions determined by a limited survey at that site. The authors are emphatic on the point that the lack of correlation between sites prevents blanket application of the overall findings to any specific site, but that useful predictions are possible by combining the overall data with limited knowledge on specific site data.

Wernstrom, Broms, and Boberg, in a 1984 report published in Sweden and circulated in the United States as an English draft translation [7], report monitoring of industrial 220/380-V systems by digital multithreshold instruments, corroborated by waveform recording with digital storage oscilloscopes. The parameters to be recorded and reported are defined in an introductory section; however, their description of "common mode" and "differential mode" in the English translation does not correspond exactly to symmetrical and asymmetrical voltages defined by the IEC.

The range of surges recorded extends from 200 to 2000 V.

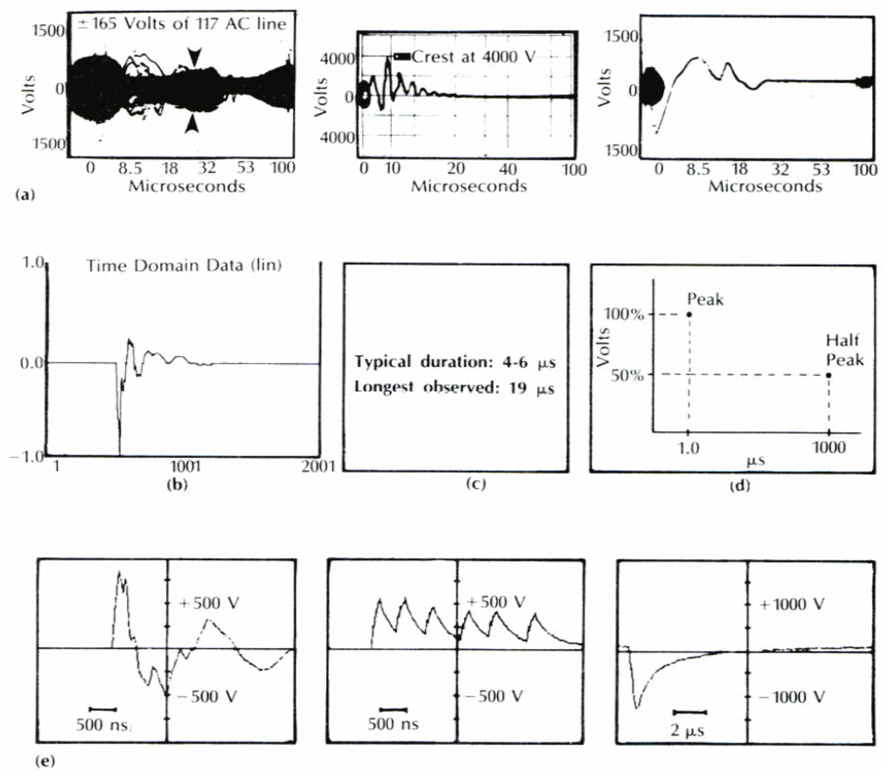

Figure 1.

"Typical" waveforms reported in site surveys include three examples of surges recorded by Martzloff (a); typical waveform according to Goedbloed (b); description of waveform by Cannova (c); description of waveform by Odenberg-Braskich (d); and three examples of surges recorded by Wernstrom, Broms and Boberg (e)

Power Quality Surveys

In a summary tabulation, rise times are shown as ranging from 20 to 200 ns and duration from 0.2 to 2.5 μs. The results show a wide difference of surge activity among sites but a relatively constant slope of the rate of occurrence versus level.

Aspnes, Evans, and Merritt, in a 1985 paper [8], report a survey of the power quality in rural Alaska at isolated power generation facilities. The monitoring instruments are identified as one of the contemporary commercial digitizing monitors. A very comprehensive summary of the recordings is presented including frequency deviations (a unique situation in these isolated systems), sags and "surges" ("swells"), impulses (i.e., surges,), and outages. Some ambiguity arose because of the possibility that built-in surge protection in the mônitors might have attenuated the surges being recorded.

Odenberg and Braskich, in a 1985 paper [9], report the monitoring of computer and industrial environments with a digital instrument capable of the simultaneous recording of voltage surges and current surges. This new capability for relating voltage and current shows a growing awareness of the need to monitor current surges – an improvement over previous surveys limited to the measurement of voltages. However, the reported surge currents are those of a current toward undefined loads downstream from the instrument; they do not include any measurement of the current through a shunt-connected surge diverter, a measurement that would have provided new information on the source impedance of the surges.

The digital processing applied by the instrument yields two points of the surge: the peak value with the time to reach peak and the time elapsed until decay to 50 percent of the peak value. From these two points, a "waveform" description is proposed without any other information on the actual waveform. From a large number of recorded surges (more 250,000 events) a startling finding is cited: 90 percent of the recorded surges have their 50-percent point in a narrow window of 900-1100 μs. Attempts to reconcile this singular finding with the observations reported by other surveys have not been successful.

Goedbloed, in a 1987 paper [10], describes in detail a custom-built automated measurement system monitoring 220/380-V networks in Europe. The automated measurement system reflects the progress made in digitizing techniques since the days of vacuum tubes. By combining two commercial recorders with a custom interface, the developers obtained detailed recordings with a 10-ns sampling interval and 20-μs window on the first recorder and a 1-μs sampling interval and 2-ms window for the second recorder.

The system included a provision for automated data reduction, yielding raw data as well as statistical information on amplitude, rate of rise, energy measure, spectral density, and conversions from time domain to frequency domain. With a relatively low threshold of 100 V above the line voltage, the distribution of occurrences is weighted toward low amplitudes; nevertheless, occurrences are reported above 3000 V.

Relative Occurrence of Different Types of Disturbances

Two of the surveys reviewed in this paper have been widely cited, one performed in the early 1970s by Allen and Segall (A-S for short) [4], and the other performed in the late 1970s by Goldstein and Speranza (G-S) [6]. However, the findings do not at first appear to be in agreement; a detailed comparison of these two surveys provides a good illustration of the pitfalls of superficial interpretation of survey results.

A cursory comparison of the results might lead one to conclude that a significant change in power disturbances at computer sites occurred between 1972 (end of the A-S study) and 1979 (end of the G-S study). A-S reported 88.3 percent of observed disturbances as spikes, impulses, and transients, 11.2 percent as sags, and 0.47 percent as outages. G-S, on the other hand, reported 87 percent of the observed disturbances as sags, 7.4 percent as impulses, 0.7 percent as "surges" ("swells"), and 4.7 percent as outages (which they call power failures).

Taking a more careful look at the monitoring thresholds used in each study helps to explain why the number of impulses appear to have decreased and the number of sags appear to have increased. Since G-S use a threshold of −4 percent for sags while A-S use −10 percent, one can expect the G-S study to indicate a higher percentage of sags, because the sags between −4 and −10 percent are not included in the A-S study. Oscillatory decaying disturbances are not specifically identified in the G-S study but are included under the category of impulses. The threshold for impulses used by G-S (200 V for 120-V lines, or 118 percent) is higher than that used by A-S (±10 percent). Because the rate of occurrence increases steeply for lower amplitude disturbances, one can expect a drastic reduction in the percentage of impulses reported by the G-S study as compared to the A-S study.

The increase in percentage of power outages reported by G-S may be explained by the shift in the number of disturbances observed due to other threshold changes. Percentages can be a very misleading basis for comparison unless all conditions are equal. For example, the incidence of power outages observed in both studies is very similar, even though the percentages are one order of magnitude apart; A-S report 0.6 occurrence per month while G-S report 0.4 occurrence per month.

When the disturbance rates at the same thresholds are compared for the A-S data and the G-S model (for 75 percent probability), the results are surprisingly similar. The conclusions of these two studies are that deep sags contribute about 62 percent of the power system problems which are related to normal mode disturbances, severe impulses are responsible for 21 percent, outages for 14 percent and "surges" ("swells") for 2 percent.

Differences in Surge Amplitudes

The amplitudes of the surges reported in the surveys vary over a wide range, and comparisons are difficult because the data are not presented in a uniform format. An attempt was made to get a quantitative comparison of the amplitudes reported in the surveys; however, the exercise was quickly found to be futile because of the following two main reasons.

1) Looking at "maximum values," one finds that in some surveys the quoted maximum is actually a value in excess of the range of the instrumentation, while for others it is the measured value. There are too few points and information is insufficient to attempt a statistical treatment of this truncated data base. Furthermore, the quoted value in some surveys is the total voltage (instantaneous value of ac sine wave plus surge), while in others the sine voltage has been filtered out. When surges are in the range of several thousand volts (the concern being damage), the difference between the two definitions is not significant; however, when surges are in the range of a few hundred volts (the concern being malfunction), the difference is significant.

2) Because the lower threshold of the recorders varies among surveys, and the frequency of occurrences increases dramatically with lower thresholds, the labels of average, median, most frequent, typical, etc., are not meaningful for comparing amplitudes. The preceding discussion of A-S and G-S results has illustrated the profound effect of threshold selection on reported results when they are expressed in percentages.

A general explanation of differences in amplitudes found in the various surveys might be the observation by some of their authors of the lack of correlation between sites. Furthermore, some surveys include sites where equipment failures were experienced or expected, while other surveys were made at sites not singled out for particular problems. Thus the differences in overall results of various surveys might simply be the result of the different surge exposure at the points of monitoring. This explanation implies that surveys will still be needed where specific information is desired.

Differences in Waveform

From those surveys made with waveform recording capability, the "typical" forms suggested by each author have been collected in **Figure 1**. The finding of ringing waves, as opposed to the traditional unidirectional impulses, seems general in these low-voltage circuits.[4]

Martzloff and Hahn were among the first to report ring waves. Their reported measurements were incorporated into the data that resulted in the eventual selection of a 100-kHz Ring Wave with a 250- or 500-ns rise time for the UL Standard *Ground Fault Circuit Interrupters* [11] and the 0.5-μs 100-kHz Ring Wave of the **IEEE Guide on Surge Voltages** [12].

While Cannova does not report detailed descriptions of the waveforms, the statements "4 to 6 μs" and "up to 19 μs" could be interpreted either as a time to half-value or as the time between the initial rise and the first zero crossing of a ringing wave. Interestingly, that data base led to the specification of a unidirectional longer impulse, the classic 1.2/50-μs voltage impulse, for conservative rating of candidate surge protection devices to be installed in the shipboard environment [13].

Wernstrom, Broms, and Boberg show three examples of recordings. The first is indeed a ring wave with a frequency of about 500 kHz and a rise time of 200 ns. The second example is a burst of nanosecond-duration transients, similar in shape to the proposed IEC/TC65 Electrical Fast Transients [14]. The third example is (of all things) a unidirectional (almost) impulse.

The data reported by Odenberg and Braskich are different from the others in that only two points of the waveform are reported: peak and 50 percent of peak amplitude. As such, this description is not a complete waveform; furthermore, their report that 90 percent of their 250,000 recordings show the 50-percent point occurring between 900 and 1100 μs is

Survey	Period	Locale	System Voltage	System Type*	Instrument**	Connection Mode	Power Frequency Filtered Out
B-N	Circa 1962-1963	Great Britain	240	Industrial & residential	Analog multithreshold	Not stated	Yes
M-H	1963-1967	USA	120/240 277/480	Residential & industrial	Analog single-threshold Oscilloscope and Camera	L-N	No
Can	Circa 1969-1970	U.S. Navy	120 450	Shipboard	Oscilloscope and Camera	L-L (ungrounded)	No
A-S	1969-1972	USA	Not Stated	Computer sites	Screen storage oscilloscope Oscillograph Digital multiparameter	Not stated	Not clear
G-S	1977-1979	USA	120/208	Telephone facilities	Digital multiparameter	L-N	Yes
WBB	Circa 1982-1983	Sweden	220/380	Industrial	Digital mutiparameter Digital storage oscilloscope	Common (unclear)	Yes
AEM	1982-1983	USA (Alaska)	120/240	Isolated systems	Digital multiparameter	L-N	Yes
O-B	1982-1983	USA	120/240 120/208 277/480	Industrial & computer sites	2-point digital V & I: Peak amplitude & time Time to 50 percent of peak	L-N(V) Series(I)	No(V) Yes
Goe	circa 1983-1984	Europe	220/380	Industrial & miscellaneous	Two digital waveform recorders (fast & slow)	L-G	Yes

*Principal type stated first.
**See description in text.

Table 1.
Details of nine published on-site power quality surveys, including locale, type of system, voltage, instrument type and connection mode

unique among all the surveys.

The Goedbloed data presentation reflects concerns addressing interference rather than damage; hence, the emphasis was given to amplitude, rate of rise, and energy rather than waveform. An oscillogram characterized as "typical" is presented in **Figure 1**, a ring wave with a frequency of about 800 kHz.

Thus, the ambiguities plaguing the field of site surveys have become apparent to many interested workers, resulting in the formation of a new Working Group Monitoring Electrical quality sponsored by a new IEEE Standard Coordinating Committee on Power Quality. Stay tuned in this area; contributions to the development of a new standard by this working group are invited and welcome, and further information may be obtained from the authors.

Conclusion

A review of power quality site surveys conducted over the last twenty years reveals interesting facts, and close examination of the results can dispel some fictions and fallacies.

1) Considerable progress has been made in the recording capabilities of monitoring instruments, mostly as the result of progress in the hardware and software used in digitizing systems. Among the many improvements are multichannel synchronized recording of different parameters, fast data acquisition, automated data reduction, and improved resolution.

2) With the steady progress and expanded capability of instruments, it becomes increasingly important to achieve greater consistency in definitions of the disturbance parameters and the methods of application of the monitoring instruments.

3) Site-to-site variations in exposures preclude making precise predictions for a specific site from an overall data base, but useful predictions can be made by adjusting the overall data base only slightly by limited data collection at the site of interest.

4) The steady increase in the number of surge protective devices being installed in low-voltage power circuits in the last several years can be expected to continue. The result might be a lowering of the mean values of observed surges but not necessarily the extreme values of the distribution.

5) Differences among results indicated by a cursory comparison can in many cases be resolved by a closer examination of the conditions under which the surveys were conducted. However, some differences appear less likely to be explained if raw data have been processed and the initial parameter measurements are no longer available for consideration. Providing greater detail in the published reports and sharing of experiences at technical meetings might help overcome this difficulty.

6) A new IEEE Working Group on Monitoring Electrical Quality has been formed with a broad scope that encompasses this process of improving consistency in the defini-

tions and interpretation of power disturbances. In addition, the IEEE Working Group on Surge Characterization is also attempting to obtain a broader data base for the revision of the *Guide on Surge Voltages*. These two groups are ready to provide counsel and forum to any would-be surveyor in planning and reporting the collection of new data on disturbances, thus avoiding later difficulties in incorporating the results in a shared data pool. □

References

[1] J.H. Bull and M.A. Nethercot, "The Frequency of Occurrence and Magnitude of Short Duration Transients in Low-Voltage Supply Mains," Radio Electronic Engineer, Sept. 1964.

[2] F.D. Martzloff and G.J. Hahn, "Surge Voltages in Residential and Industrial Power Circuits," IEEE Trans. Power App. Syst., vol. PAS-89, no. 6, July/Aug. 1970.

[3] S.F. Cannova, "Short-Time Voltage Transients in Shipboard Electrical Systems," in IEEE IAS 1972 Annual Meeting Conf. Rec.

[4] G.W. Allen and D. Segall, "Monitoring of Computer Installation for Power Line Disturbances," presented at the IEEE PES Winter Meeting conference, New York, Jan. 1974, Paper C74199-6.

[5] G.W. Allen, "Design of Power-Line Monitoring Equipment," IEEE Trans. Power App. Syst., vol. PAS-90, no. 6, Nov/Dec. 1971.

[6] M. Goldstein, and P.D. Speranza, "The Quality of U.S. Commercial AC Power," in Proc. INTELEC Conf., 1982.

[7] H. Wernstrom, M. Broms and S. Boberg, "Transient Overvoltages on AC Power Supply Systems in Swedish Industry," Foorsvarets Forskningsanstalt, Huvudavdelning 3, Sweden, Report FOA E 30002-F2, 1984.

[8] J.D. Aspnes, B.W. Evans and R.P. Merritt, "Rural Alaska Electric Power Quality," IEEE Trans. Power App Syst., vol. PAS-104, no. 3, Mar. 1985.

[9] R. Odenberg and B. Braskich, "Measurements of Voltage and Current Surges on the AC Power Line in Computer and Industrial Environments," IEEE Trans. Power App. Syst., vol. PAS-104, no. 10, Oct. 1985.

[10] J.J. Goedbloed, "Transients in Low-Voltage Supply Networks," IEEE Trans. Electromagn. Compat., vol. EMC-29, no. 2, May 1987.

[11] *UL Standard for Safety 943, Ground Fault Circuit Interrupters*, Underwriters Laboratories, 1976.

[12] *Guide on Surge Voltages in Low-Voltage AC Power Circuits*, ANSI/IEEE C62.41-1980.

[13] *Interface Standard for Shipboard Systems*, DOD-STD-1399, Sec. 300, 1978.

[14] *Electrical Fast Transients – Burst Requirements*, IEC Standard 801-4.

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