Power Quality Site Surveys: Fact, Fiction, and Fallacies

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Significance
Part 5 – Monitoring instruments, Laboratory measurements, and Test methods
Part 6 – Textbooks and tutorial reviews

Presents a comprehensive review of surge monitoring surveys over the period 1960-1990, explaining apparent differences in the results caused by instrument artifacts of different threshold settings of the instruments.

Because of the ambiguity in the meaning of “surge” as reported by some power quality monitoring instruments, the paper introduces the new term “***swell***” to differentiate a temporary overvoltage at the power frequency from a microseconds-long surge.

The significance of this paper was recognized by three awards, from the sponsoring Power Systems Committee, the I&CPS Ralph Lee Award, and the IAS Transactions prize.

Power Quality Site Surveys: Facts, Fiction, and Fallacies

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Abstract—**The quality of the power supplied to sensitive electronic equipment is an important issue. Monitoring disturbances of the power supply has been the objective of various site surveys, but results often appear to be instrument-dependent or site-dependent, making comparisons difficult. After a review of the origins and types of disturbances, the types of monitoring instruments are described. A summary of nine published surveys reported in the last 20 years is presented, and a close examination of underlying assumptions allows meaningful comparisons which can reconcile some of the differences. Finally, the paper makes an appeal for improved definitions and applications in the use of monitoring instruments.**

INTRODUCTION

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 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), isolating 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 often caused by users themselves, through switching of loads, ground faults, or normal operation of equipment. Computer systems, as one example of these so-called sensitive loads, are not only sensitive loads but also can generate some disturbances themselves. Their nonlinear 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. The nature of these power disturbances, their severity, and their incidence rates will vary from site to site.

To place the problem in perspective, however, one should keep in mind that poor-quality power is only one of the many causes of computer downtime. Hardware problems, software problems, and operator errors also contribute to computer downtime.

Sometimes there is too great a tendency to attribute operational difficulties to power supply problems. For example, studying power-related computer problems at U.S. Navy installations, Key [1] found that only 5–10 percent of the observed computer downtime was attributable to power problems. Reviewing case histories, Martzloff [2] described a safety problem created by panic actions of the computer system operators who pulled out power cords of the remote terminals (including the safety grounding conductor) because they suspected power line surges when, in fact, the problem was incorrect grounding practices for the shields of the data lines.

Historically, transient overvoltage effects on novel semiconductor systems were the first concern; by now, the importance of undervoltages or loss of power has also been recognized. In the nine surveys reviewed in this paper, four address all types of disturbances and five are concerned exclusively with the transient overvoltages. While this review is mostly concerned with the reports of transient overvoltages, this limited discussion does not mean that other disturbances are less significant.

Power quality surveys have been performed, reported, and discussed by many authors, but their results or conclusions are

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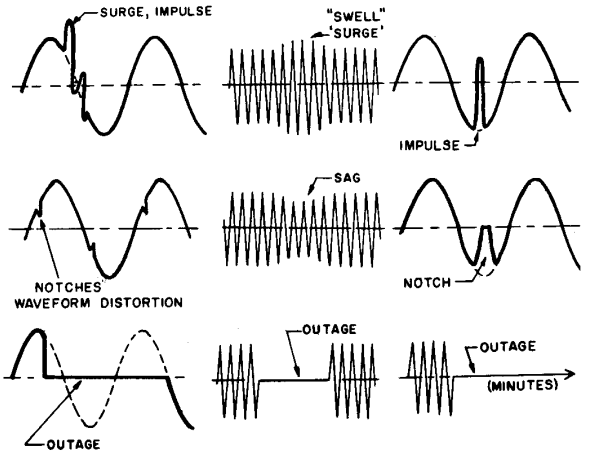


Fig. 1. Graphic definitions of disturbances.

not consistent [3]–[14]. Quotations from these surveys, out of context, have perhaps also contributed to the confusion. In an attempt to clarify the issues, this paper presents a brief review of the origins and definitions of disturbances, and then it describes the development of monitoring instruments. Comparisons are made among nine published surveys with attempts at reconciling results. Finally, an appeal is made for improved measurement methods to provide more consistent reporting of recorded power disturbances.

Definition Deficiencies

As will become painfully apparent in the 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* [15] and with established usage within the community of surge protective devices engineers. Two examples of this lack of consensus are described here to make the point; resolving them is beyond the scope of this paper.

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. In this paper, this second meaning of the word "surge" (a momentary overvoltage) will be signaled by the use of quotation marks. What the surge protective devices engineers call surge is called "impulse" or "spike" by the monitoring instrument community. Fig. 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 agreed that it meant a complete loss of line voltage, but the duration of this outage was quite different when it was defined by computer users (as short as one half-cycle) or power engineers (seconds, perhaps minutes). Now, the 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. Part of the problem may be that the definition of "outage" has regulatory implications for evaluating the performance of public utility companies. No such distinction has been made in this paper, because taking sides on that issue is not within its scope.

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

Protection from power disturbances is now essential because increasing dependency on computer-based systems for industry, commerce, and consumers makes disruptions less and less acceptable. The most visible indication of power disturbances is the occurrence of operational problems such as hardware damage, system crashes, and processing errors.

Some users of computer systems may accept, albeit reluctantly, operational problems because they see them as unavoidable. Other users may be unaware that otherwise invisible power disturbances could be the cause of operational problems. A single power disturbance can cost more in downtime and hardware damage than the investment in power protection that would have prevented the disturbance; almost all sites could benefit from a reduction of operational problems by improving the quality of the power supplied to the computer systems [13].

Power line monitoring with sophisticated power disturbance recorders has often been advocated as a way to determine 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 power disturbance profile; most users are unwilling to wait at least 1 year. Also, power line monitoring produces only past performance information, for changes within the site, at neighboring sites, or by the utility can drastically alter the power disturbance profile.

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 [16] or specifications reflecting expected disturbances [17]–[19]. Users, however, generally seek specific data for their particular case; hence 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.

Causes of Power Line Disturbances

Transient overvoltages, historically among the first disturbances to be recorded by users, have two major causes: lightning and load switching. Depending on local conditions one can be more important than the other, but both need to be recognized.

Lightning surges are the result of direct hits to the power system conductors as well as the result of indirect effects, where the lightning bolt strikes an object close to the conductors but not the conductors themselves. A lightning strike to the power system may cause the operation of gap-type surge arresters, producing a severe reduction or a complete loss of the power system voltage for one half-cycle. A flashover of line insulators can cause a breaker to trip, with reclosing delayed by several cycles, causing a power outage. Thus lightning can be the obvious cause of overvoltages near its point of impact but also a less obvious cause of voltage loss or sag at a considerable distance from its point of impact. This latter effect has been clearly observed in the Goldstein-Speranza [8] study.

Power system load switching is also a major cause of disturbances. Switching large loads on or off can produce long-duration voltage changes beyond the immediate transient response of the circuit. Whether the switching is done by the utility or by the user is immaterial from the technical point of view, although the responsibility may be the subject of a contractual dispute. When power factor correction capacitors are switched, high-frequency (500 Hz–5 kHz) oscillations occur which can reach 120-percent overvoltages (2.2 pu) for milliseconds [20]. Fault clearing by current-limiting fuses can also create substantial overvoltages [21].

In a study of 100 computer system failures attributable to power supply disturbances, Key [1] considered power line monitoring, computer operation logs, data from the National Weather Service, and local utility data to determine the cause of the power disturbance (Fig. 2).[1] Weather was cited as the major cause of disruptive sags and outages; sags were found to disrupt computer operations four times as often as outages, a finding that agrees with the results of the comparison between the Allen–Segall and Goldstein–Speranza studies discussed later.

The type of power distribution system also has a strong influence on the incidence of disturbances. In his study, Key compared the rates of incidence of sags and outages (Fig. 3).[1] A similar analysis was performed by Allen and Segall in another study [22], reaching essentially the same conclusions. Both studies found that the rate of occurrence of disturbances is significantly lower for underground and network systems than for overhead and radial systems, respectively.

[1] Data reproduced from T. S. Key, "Diagnosing power quality-related computer problems," *IEEE Trans. Ind. Appl.*, vol. IA-15, no. 4, July/Aug. 1979.

RECORDED CAUSES OF 100 POWER-RELATED COMPUTER FAILURES, NORTHERN VIRGINIA 1976

Recorded Causes	Disturbance		Computer Failures
	Sags	Outages	
Weather (Wind & Ligntning)	37	14	51
Utility Equipment Failure	8	0	8
Construction or Traffic Accident	8	2	10
Animals	5	1	6
Tree Limbs	1	1	2
Unknown	21	2	23
	80%	20%	100%

Fig. 2. Causes of computer failures as reported in the Key study [1].

PREDICTING POWER-RELATED COMPUTER FAILURES BY POWER DISTRIBUTION SYSTEM CONFIGURATION

II. U. S. Navy Monitoring at Washington, D. C. Area (10 Sites) Norfolk, Virginia Naval Base and Charleston, S. C. Naval Base

Power Distribution System Configuration	Type of Disturbance Causing Failures		Recorded Computer Failures Per Year	
(Months/Sites Monitored)	Sags**	Outages**	Range	Ave**
Overhead Radial (53/5)	12	6	10-30	18
Overhead "Spot" Network (53/3)	22	1	20-48	23
Combined Overhead (88/8)	16	4	10-48	20
Underground Radial (30/2)	6	4	6-12	10
Underground Network (39/2)	5	0	5	5
Combined Underground (69/4)	5	2	5-12	7
Total Combined (157/12)	11	3	5-48	14

** The average is weighted based on months monitored.

Fig. 3. Effect of power distribution system configuration on incidence of disturbances as reported in the Key study [1].

Types of Disturbances

Power line disturbances can be classified into two categories: common mode disturbances and normal mode disturbances. The two terms were first defined in the context of communication circuits; a recent *IEEE Guide* [23] has established an expanded definition which is used in this paper, as outlined in the following paragraphs. The *IEEE Dictionary* [15] and the *IEC Dictionary* [24] define symmetrical and asymmetrical voltages akin to but not interchangeable with the definitions of normal mode and common mode, respectively.

Common Mode Disturbances

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 could also be defined as the potential difference between neutral and ground.

Two different types of common mode disturbances can

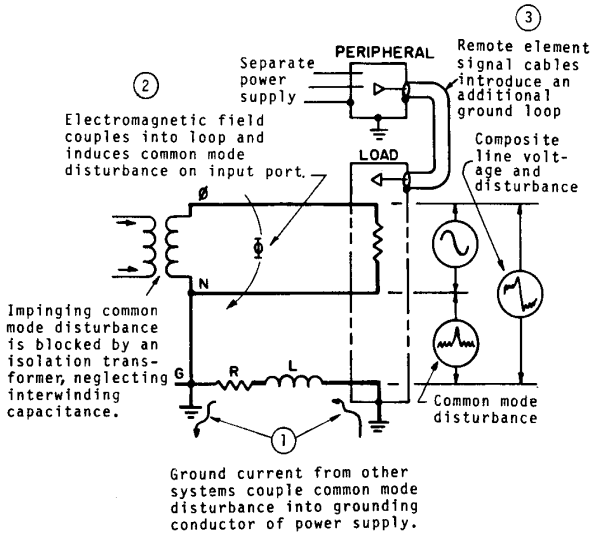


Fig. 4. Three examples of origins of common mode disturbance on power input.

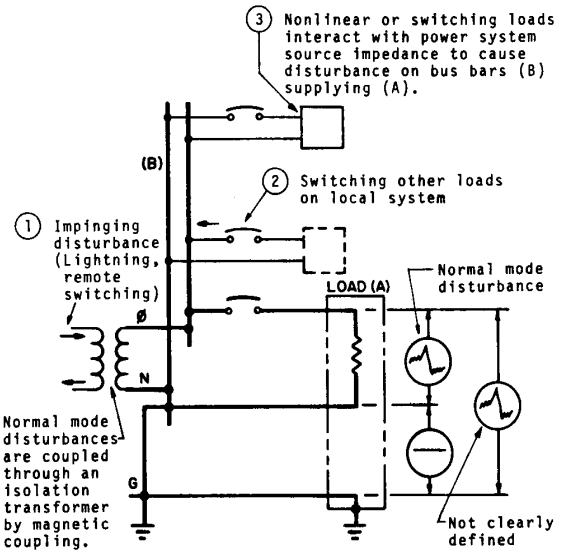


Fig. 5. Three examples of origins of normal mode disturbance on power input.

affect a sensitive load. The first type is a disturbance on the input power conductors relative to the input power grounding conductor. Fig. 4 shows in ① and ② examples of 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. Fig. 4 shows in ③ an example of this type. This type of disturbance is more difficult to limit because it is influenced by factors such as the 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 [25]. 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 Fig. 4, 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 [2].

Normal Mode Disturbances

Normal mode disturbances are defined as unwanted potential differences between any two current-carrying circuit conductors. Fig. 5 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, Later in this paper, a new effort to remedy this situation is described.

History of the Development of Disturbance Monitors

Historically, the first (unintended) disturbance monitors were the actual load equipment; only later, when confronted with unexplained failures or malfunctions, did the users start monitoring the quality of their power systems. Monitoring power quality at the fundamental frequency had long been performed by utilities, but the precise characterization of microsecond-duration surges in the early 1960's required special oscilloscopes. For the next 15 years, combinations of oscilloscopes or simple peak-detecting circuits were the basic instruments for monitoring transient overvoltages. In the 1970's commercially-produced digitizers became available, and the technology has made continuing progress as experience has been accumulated and faster digitizing circuits have been developed.

Early site surveys were generally limited to voltage measurements in the normal mode. This limited scope reflected concerns for damage to sensitive electronic components connected across the line. The fact that the source impedance of the surge was not recognized as being important in these surveys led to the generation of some performance standards that do not specify the current-handling requirements for the surge protective devices [19]. With the introduction and widespread application of clamping protective devices (silicon avalanche diodes or metal oxide varistors), the surge current diverted through these devices became a very important factor

for proper device selection. Therefore, the need emerged for characterizing current as well as voltage surges, but few surveys to date have addressed this need. This need offers a challenge to designers of monitoring instruments and to would-be surveyors.

This challenge has produced attempts to define an "energy" measurement with an instrument which is only a voltmeter. By assigning a parametric value to the source impedance of the surges and integrating the product $(\text{volts})^2 \cdot \text{seconds}$ of the surges, some knowledge on the energy involved would be obtained as suggested in [14]. However, the real question concerns the sharing of energy between the impedance of the source and the impedance of the load, in this case the nonlinear impedance of the protective device. A lengthy discussion of the energy contained in the surge versus the energy delivered to the protective device is beyond the scope of this paper, but the difference needs to be recognized to prevent further confusion as future monitoring instruments include an "energy" parameter in their readouts.

With the present development of sophisticated multichannel digitizing instruments, it should be feasible in future surveys to monitor both voltage and current in the normal mode as well as in the common mode. Note, however, that the current of interest is that which the surge source (of otherwise unknown impedance) would force through a proposed surge protective device. This device would be shunt-connected at the point being monitored so that the current to be monitored is not the surge current in the direction of undefined downstream loads. The amplitude as well as the waveform of the surges needs to be characterized for correct application of surge protective devices. Peak-reading monitors provide useful information on surge activity at a given site, but assessment of the surge severity level for the proper sizing of protective devices requires waveform and source impedance information [20], [26].

Recent monitoring instruments offer the capability of recording potential differences between the neutral and the grounding conductor which constitutes one form of common mode disturbances. To our knowledge, no instrument has been offered for explicit monitoring of potential differences within the grounding system itself such as ① and ② in Fig. 4. Some types of monitors include current probes and could record current in grounding conductors, but this parameter has not yet been reported in published surveys.

One difficulty encountered by users of monitoring instruments in this fast-paced technology is that manufacturers introduce improved features in response to specific wishes of the users or as a result of their own research; data collected by different instruments become equipment-dependent. While this continuing progress is a welcome development, it makes comparison of survey results difficult without the details on the instrument characteristics and methods of measurement.

Occasionally, an instrument might have limitations or might introduce artifacts which are not immediately apparent so that the survey results suffer some loss of credibility when these possible limitations are discovered [11], [12]. Users may also have difficulty in interpreting complex instrument outputs, and excessive simplification of a complex data base can lead to some misunderstanding or misapplication of published documents; a tutorial effort is then necessary to avoid these pitfalls [27], [28].

Types of Monitors

The instruments used in the various surveys reflect technology 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.

Oscilloscope with camera—The surge triggers a single sweep on the CRT of the oscilloscope which is recorded as it occurs by a shutterless camera with automatic film advance. The oscilloscopes available at that time (the early 1960's) 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 1960's.

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 an infinite 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 can be considered 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.

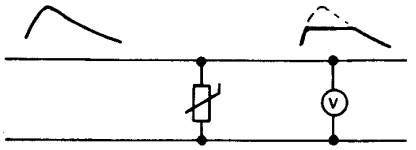


Fig. 6. Varistor upstream of monitor.

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[2] systems, a limitation had already been recognized [17] 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* [16] 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 on low-voltage ac power circuits since their introduction in 1972 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 measurements in several ways, as contrasted to previous 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 Figs. 6, 7, and 8.
   A) If a varistor is located between the source of the surge and the recording instrument (Fig. 6), 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

[2] Defined as 1000 V or less by IEEE and IEC.

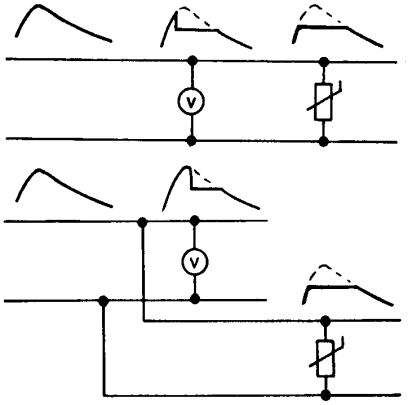
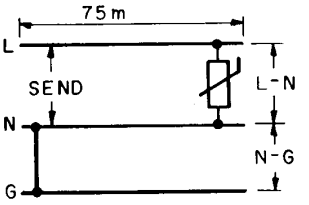
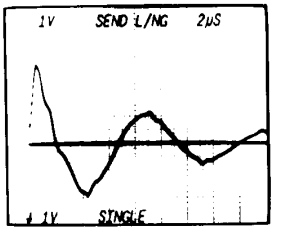


Fig. 7. Varistor downstream of recorder.



(a)



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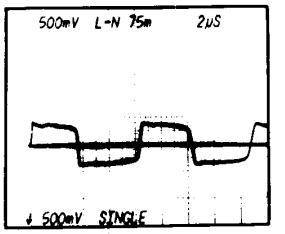

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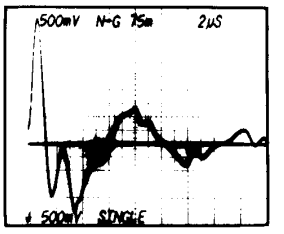


(d)

Fig. 8. Voltages measured at beginning and end of 75-m branch circuit for surge applied in normal mode at service entrance, with protective device installed between line and neutral conductors (from [29]). (a) Connection of varistor at end branch circuit. (b) Voltage at service entrance. Vertical: 1000 V/div. (c) Line-to-neutral voltage. Vertical: 500 V/div. (d) Neutral-to-ground voltage. Vertical: 500 V/div.

TABLE I
DETAILS OF THE LOCALES AND INSTRUMENTATION

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 multiparameter 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 (I)
Goe	Circa 1983–1984	Europe	220/380	Industrial & miscellaneous	Two digital waveform recorders (fast & slow)	L-G	Yes

* Principal type stated first.
** See detailed descriptions in text.

surge and a varistor, or if a parallel branch circuit contains a varistor (Fig. 7), the instrument 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 Fig. 8. The line-to-neutral voltage is clamped as intended; however, 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 [29].

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 suppressor with lower clamping voltage might be underestimated because some diversion is already being performed.

REVIEW OF PUBLISHED SURVEYS

This summary includes nine papers published in the United States and in Europe, with a brief description of instrumentation design, definition of parameters, and results. Papers are listed in chronological order.

Table I shows details of the locale, system voltage, instrument type, and connection mode as described in the papers. Other surveys may have been published, particularly in Europe, which did not come to the attention of the authors. Suggestions for including additional published data in the revision process for the *Guide on Surge Voltages* [16] are invited.

Bull and Nethercot, in a 1964 article [3], report monitoring performed in the mid 1960's 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. Eventually, the solid-state instrument was made available commercially, and several units were used in some of the monitoring performed in the United States and reported in the data base of [16].

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 [5], report the highlights of measurements made in the 1963 to 1967 period on residential, commercial, and industrial circuits, mostly single-phase 120 V. Further details, originally held proprietary, were eventually released [30] for sharing information with other interested parties. 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. 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 [6], reports the monitoring of surges on U.S. Navy shipboard 120- and 450-V power systems in the late 1960's. 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 surge and impulse descriptions in Fig. 1, and the last column of Table 1).

The results are not reported separately for 120- and 450-V systems, it is not possible to express them in terms of per-unit or percentage of nominal system voltage. The 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 6μs, with a few at 19 μs.

From the data base, acknowledged to be a small total number of events, a voltage 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 [7], 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 [31]. 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 study made later in the present paper.

Goldstein and Speranza, in a 1982 paper [8], 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. This concept is echoed in the *Guide on Surge Voltages* [16], where the frequency of occurrence is presented in graphic form with well-defined slopes but with a wide band of possible exposures, depending on the particulars of the site.

A Polya distribution is identified by Goldstein and Speranza as the best fit for this type of rare events data, in contrast to other surveys where their authors attempted to fit a normal distribution or a power or exponential law profile.

Wernstrom, Broms, and Boberg, in a 1984 report published in Sweden and circulated in the United States as an English draft translation [10], 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. In the section

discussing transient sources and propagation, they make a significant comment that "common mode voltages are the most interesting and at the same time are the voltages most difficult to defend against."

The range of surges recorded extends from 200 to 2000 V. In a summary tabulation, rise times are shown as ranging from 20 to 200 ns and duration from 0.2 to 2.5 μs. An interesting additional measurement was made by simultaneous recordings at two distant points of the power system, showing some aspects of the propagation and attenuation of a surge. The survey also shows 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 [11], report a survey of the power quality if 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.

Because the sites were in isolated systems (their installed capacity or system impedance is not stated), one would expect differences from the typical survey of interconnected power systems. In fact suspected differences were the motivation for conducting the survey. Thus finding differences in the results would not be particularly meaningful from the point of view of this paper aiming at comparisons. However, bringing up this survey serves the purpose of noting that some ambiguity surfaced in connection with the possibility that built-in surge protection in the monitors might have attenuated the surges being recorded. Knowing the source impedance of the surges (not the impedance at power frequency) would have settled the issue. This case history point out again the desirability of including surge current monitoring in future surveys as a method of characterizing the source impedance of the surges.

Odenberg and Braskich, in a 1985 paper [12], 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 (over 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 [14], 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 Bull-Nethercot 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.

The paper also addresses indirectly the question of normal mode versus common mode surges by discussing symmetrical voltage and asymmetrical voltage as defined in the *IEC Dictionary* [24]. An indirect definition is proposed for a third type identified as the "so-called non-symmetrical voltage" which was the mode of monitoring used in this survey: line to grounding conductor (called "protective earth" or "protective conductor" in Europe). This third type is currently incorporated in the more general definition of common mode proposed by the *IEEE Guide on Surge Testing*, which might leave some ambiguity on the definitions (see Fig. 5), or lead to considering "pure common mode" as opposed to some combined mode in which both normal and common (pure) modes are combined. Looking for guidance in IEC definitions does not help much; the IEC definition addresses delta networks, but the Goedbloed paper states that nearly all networks monitored were of the TN type—that is, phase, neutral (implying a wye), and protective-earth conductors. The paper clearly states the mode of connection so there is no ambiguity, but this instance serves again to illustrate the need to harmonize definitions.[3]

Comparisons Among Surveys

Relative Occurrence of Different Types of Disturbances

Two of the surveys reviewed in this paper have been widely cited, one performed in the early 1970's by Allen and Segall (A-S for short) [7], and the other performed in the late 1970's by Goldstein and Speranza (G-S) [8]. However, the findings do not a 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 (Table II) 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

[3] A related issue, now being addressed but not yet resolved, is the effect produced on the amplitudes of common mode surges by different practices for grounding the neutral (at the service entrance or at the remote substation). Comments are invited on this aspect of characterizing the environment.

TABLE II
UNRECONCILED COMPARISONS BETWEEN THE GOLDSTEIN-SPERANZA AND ALLEN-SEGALL RESULTS

	G-S Study	A-S Study
Date of Study	1977-1979	1969-1972
Duration (monitor months)	270	147
Number of Sites	24*	29
Oscillatory, decaying	**	48.79%
Impulses	7.4%	39.52%
Sags	87.0%	11.22%
"Surges"	0.7%	**
Outages	4.7%	0.47%

* Sites confined to Bell System.
** Included in impulses.

TABLE III
MONITOR THRESHOLDS

	G-S Study	A-S Study (%)
Sags/"Surges"	±5 V (±4%)	±10
Oscillatory	200 V (118%)	±15
Impulses	200 V (118%)	±10

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 (Table III) 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.

Both studies present summaries and statistical analyses of their disturbance data in difference ways. A-S use only the observed disturbances as a data base and present results as incidence rate graphs. Incidence rates of sags and impulses at different thresholds are given by A-S, allowing a more direct comparison with the disturbance thresholds of the monitoring instruments used in the G-S study.

The G-S study presents a statistical model of the disturbance rates to predict the incidence rates at predefined disturbance levels, selected to correspond to those levels generally expected to cause computer systems problems: impulses greater than 200 V (118 percent of nominal peak voltage), sags greater than −20 percent of the nominal voltage, and "surges" ("swells") greater than 10 percent of nominal. The G-S model states the disturbance rates in terms of probability, such as 50 percent of the sites will have less that "x" disturbances per year or 90 percent of the sites will have less than "y" disturbances per year, but with a cautionary note that there is no firm correlation between sites, making specific predictions from overall results somewhat uncertain.

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 (Table IV). 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 insufficient information to attempt a statistical treatment of this truncated data base (censored data in statistical terms). 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 damages), the difference between the two definitions is not significant; however, when surges are in the range of a few hundred volts (the concern being malfunctions), the difference is significant.
2) Because the lower threshold of the recorder varies among surveys, and the frequency of occurrences increases dramatically with lower threshold, 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.

For these two reasons, any comparison at the present stage of inconsistency in report formats can only be qualitative. Conjecture or speculation, rather than hard facts, might

TABLE IV
RECONCILED COMPARISONS

	Normal Mode Power Disturbances Per Year					
	G-S Model		A-S Study		Combined Data	
	No. of Events	Percentage of Events	No. of Events	Percentage of Events	No. of Events	Percentage of Events
Impulses (greater than 100-percent peak)	8	15	12	27	10	21
Sags (greater than −20-percent rms)	36	68	25	57	30	62
"Surges" (greater than +10-percent rms)	2	4	0	0	1	2
Outages (0 V, on 1 or more phase)	7	13	7	16	7	14
TOTAL	53	100	44	100	48	100

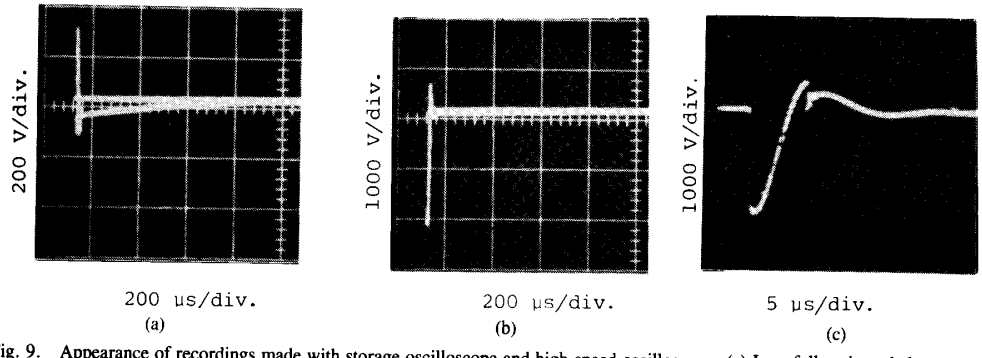


Fig. 9. Appearance of recordings made with storage oscilloscope and high-speed oscilloscope. (a) Low full scale and slow sweep. Screen storage oscilloscope, 1968 vintage (same type as used by Allen-Segall). (b) High full scale and slow sweep. Screen storage oscilloscope, 1968 vintage (same type as used by Allen-Segall). (c) High full scale and fast sweep. High-speed oscilloscope, 1968 vintage.

explain differences, as illustrated in the following two examples.

The relatively small number of high-amplitude surges reported by Allen-Segall compared to other surveys [16] might be explained by a limitation of their instrument. This explanation was submitted as a written discussion of the paper, but because of the "conference paper" status of the paper it was not published by the IEEE.

Briefly stated, the storage oscilloscopes used by A-S had the limited writing speed of contemporary technology; furthermore, the small amplitude set for full scale was such that a high-amplitude transient would have its peak off screen and the steep rise would not be seen on the phosphor. Fig. 9 shows a set of oscillograms recorded in the laboratory by Martzloff in 1974, with the same model of oscilloscope as used by A-S: an actual 2200-V transient overvoltage appears as a benign 400-V transient if the oscilloscope sensitivity is set in anticipation of relatively low-amplitude transients and relatively slow speed, as was the case in the A-S study [31].

Another difference in observed amplitudes is found in the results of the Alaska power survey [11]. One possible explanation for the relatively low surge level observed was suggested in the discussion of that paper: the built-in surge protection of the power supply for the internal electronics of the monitor might have reduced the levels of the surges observed by the monitors which had their power cord and monitoring probe connected to the same duplex receptacle.

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 Fig. 10. 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* [32] and the 0.5-µs 100-kHz ring wave of the *IEEE Guide on Surge Voltages* [16].

[4] The data base of the *Guide on Surge Voltages* [16] shows oscillograms of ring waves recorded in the Bell System during a survey before the Goldstein-Speranza study, but not otherwise published.

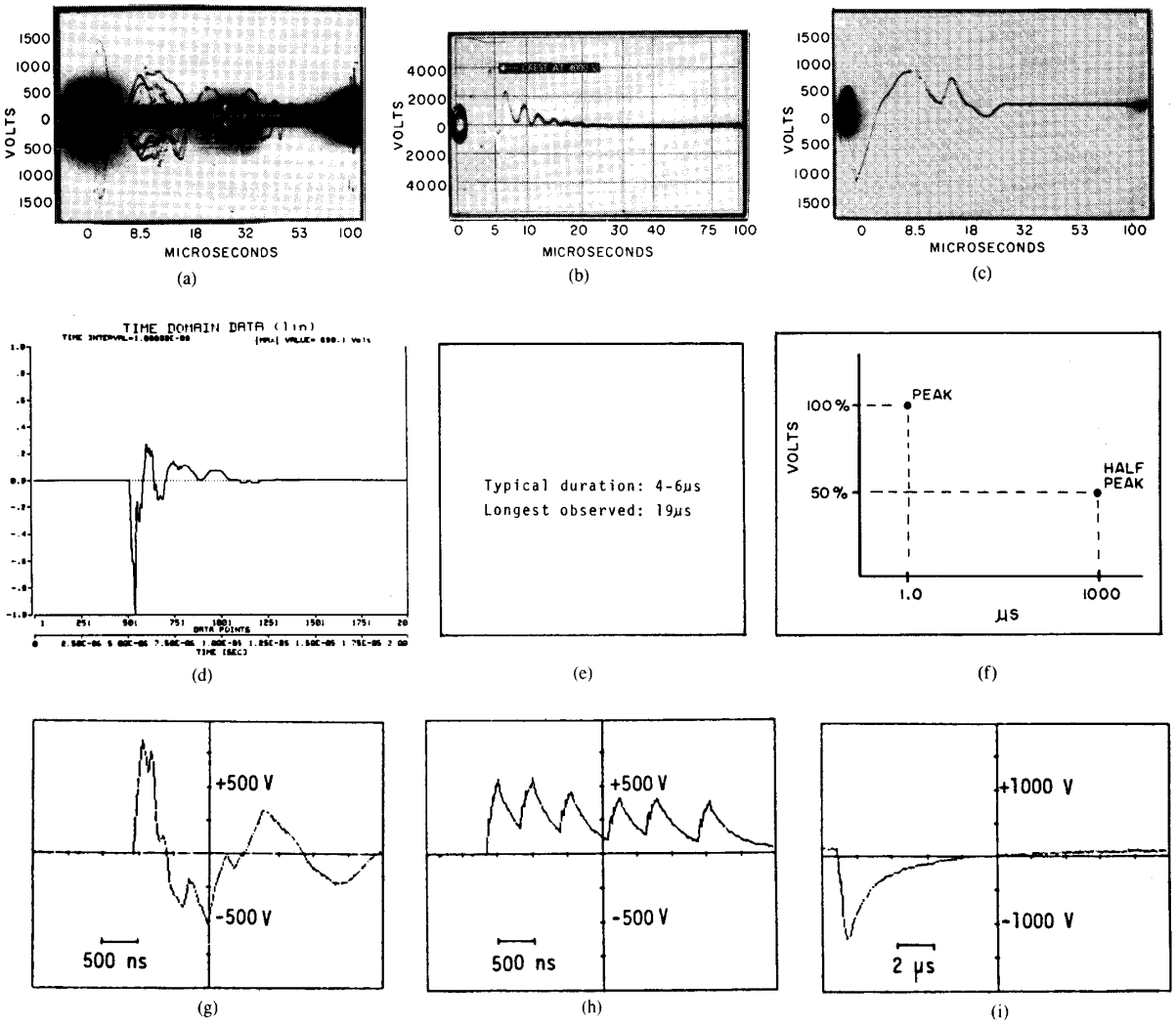


Fig. 10. "Typical" waveforms reported in site surveys. (a)–(c) Three examples of surges recorded by Martzloff. (d) Typical waveform according to Goedbloed. (e) Description of waveform by Cannova. (f) Description of waveform by Odenberg-Braskich. (g)–(i) Three examples of surges recorded by Wernstrom, Broms, and Boberg.

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 [19].

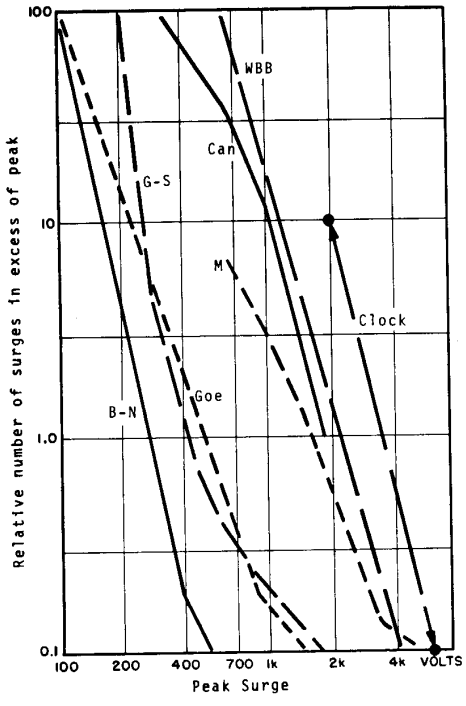
Wernstrom, Broms, and Boberg show three examples of recordings. The first is indeed a ring wave with a frequency of about 500 kHz and a rise time of 200 ns. The second example is a burst of nanosecond-duration transients, similar in shape to the proposed IEC/TC65 Electrical Fast Transients [33]. The 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 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 Fig. 10: it is a ring wave with a frequency of about 800 kHz. In the data processing by conversion of the recorded events to a standardized trapezoidal pulse, the median of the time to half-value is found to be about 2 μs, which is an indirect measure of the relatively short duration of the observed surges.

Agreement and Disagreement on Rate of Occurrence versus Levels

Several of the survey authors have attempted to fit a classic distribution or a simple relationship between the rate of occurrence and the amplitude of the surges. In making such



B-N = Bull & Nethercot (composite)
M = Martzloff (Ref.[30])
Can = Cannova
G-S = Goldstein & Speranza
WBB = Wernstrom et al (upper limit)
Goe = Goedbloed
Clock = 2 kV & 6 kV points only

Fig. 11. Comparison of slopes of frequency of occurrence versus level of surges among surveys.

attempts, the frequency of occurrence is presented in different forms such as histograms, cumulative frequency, or number of occurrences in excess of a stated surge level. Fig. 11 shows on a single chart the relative distributions of the findings, normalized for voltage level and frequency of occurrence for each survey result: the slope of the lines is what can be compared, not the absolute rate of occurrence. It is remarkable that slopes are similar among the surveys if one keeps in mind that the absolute frequency of occurrence is site-dependent.

Working Toward More Consistent Surveys

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 the Power Systems Instrumentation and Measurements Committee. The scope of the document being developed by this Working Group is as follows.

This Recommended Practice covers monitoring the electrical quality of single-phase and polyphase ac power systems.

- To obtain consistent descriptions of disturbances in the electrical quality of power systems, this document presents definitions of nominal conditions and of deviations from these nominal conditions that may originate within the source of supply or from interactions between the source and the load.
- To identify which deviations may be of interest, a brief generic description is presented of the susceptibility of load equipment to deviations from nominal conditions.
- To obtain comparable results from monitoring surveys performed with different instruments by different operators, this document presents recommendations for measurement and application techniques, and interpretations of results.
- While there is no implied limitation on the voltage rating of the power system being monitored, signal inputs to the instruments are limited to 1000 V or less. Fundamental frequencies of the ac power systems being monitored are in the range of 45 to 450 Hz.
- Although it is recognized that the instruments may also be used for monitoring dc supply systems or data transmission systems, details of application to these cases are under consideration and are not included in the present scope. It is also recognized that the instruments may perform monitoring functions for environmental conditions (temperature, humidity, high-frequency electromagnetic radiation). However, the scope of this document is limited to the conducted electrical parameters derived from voltage or from current measurements, or both.

Contributions to the development of this document 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 interest facts, and close examination of the results can dispel some fictions and fallacies.

1) Considerable progress has been made in recording capability of monitoring instruments, mostly as the result of progress in the hardware and software used in digitizing systems. Improvements include 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 definitions 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. This paper is presented in support of this effort and to promote greater participation among interested workers and users.

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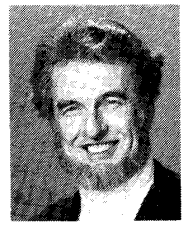

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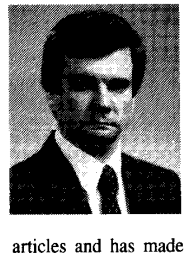

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