Measurements of Voltage and Current Surges on the AC Power Line in Computer and Industrial Environments

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Significance:

Part 3: Recorded surge occurrences and surveys
Part 5: Monitoring instruments

This paper was approved for presentation at the 1985 PES Winter Meeting to foster discussion of a new approach for recording the occurrence of voltage surges as well as current surges, the latter being a new contribution to characterization of the surge environment.

Unfortunately, according to the discussions resulting from the presentation, some limitations or possible artifacts of the instrumentation raised question on the validity of the data. For that reason, the complete paper and its discussion have been included in the anthology

Measurements of Voltage and Current Surges on the AC Power line in Computer and Industrial Environments

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Abstract - Special computerized instrumentation was developed for monitoring and recording voltage and current surges on the A.C. power line in computer and industrial environments.

From January, 1982, until December, 1983, locations in nine cities were surveyed. The total number of surge occurrences measured during the test period was 277,612. Monitoring and recording of data was accomplished utilizing computer based equipment. At a later time the data was transmitted to a central computer to tabulate.

Two important factors measured and recorded by the computerized systems were: (1) the system measured both voltage and current peak values during the transient occurrence, and (2) the time to peak voltage and current and time to 50% of peak. This provided a correlation between the voltage and current of a specific surge occurrence.

Measurements were made at different points in AC power systems from a 15A/120VAC service outlets to an AC power mains.

This report provides the tabulated data, calibration tests, describes the site installation and the conditions of the environment when the measurements were taken.

The results show that the composite voltage and current waveforms represented a 1.07 x 1002.01 us voltage wave and a 60.4 x 999.34 us current wave.

INTRODUCTION

Voltage and current surges occurring on the AC power line has caused considerable problems to both users and manufacturers of electronic systems. The need to eliminate this problem is essential today for efficient operation.

The earliest reports on transients appear in published papers [1] 1969, [2] 1974, and a more current report [3] 1980.

These reports discuss and describe only the voltage characteristics of the transient and no data is provided on the current characteristics of the same transient.

This paper provides data taken in the field on the composite waveforms of peak voltage and current together for each transient occurrence. Special equipment was developed for detection and measurement of these occurrences.

The sensing circuits (current and voltage) were designed to have conditioned signals for an input to a computer based system. The purpose of this paper is to present the data. With this information, improved testing for the susceptibility of electronic equipment and systems can be accomplished.

85 WM 243-1 A paper recommended and approved by the IEEE Surge Protective Devices Committee of the IEEE Power Engineering Society for presentation at the IEEE/PES 1985 Winter Meeting, New York, New York, February 3 - 8, 1985. Manuscript submitted August 31, 1984; made available for printing November 28, 1984.

INSTRUMENTATION

There are several problems in measuring voltage and current surges and currents in the field [1]. First, the instrumentation cannot be monitored all the time. The system incorporated a memory to store data until the data was transmitted to the main computer. The second problem is sensing and recording voltage and current values in microsecond times and maintaining the accuracy of the time base. The third problem is possible distortion of the transient waveforms by the sensing circuits. These problems were experienced during prototype testing and were compensated for in the subsequent equipment design. Tests were performed on the systems to verify results, as shown in the calibration section.

Waveform Format - The format of sensing and recording the data was chosen to be consistent with the waveforms presented in ANSI/IEEE C62.41-1980.[5] (See Figs. 1 and 2). These waveforms (1.2 x 50 us voltage and 8 x 20 us current) are described by two points, a calculated time to peak and a time to 50% delay. There are no other points described in these waveforms. The waveforms presented in this paper Fig. 3 are the peak values, the measured time to peak and the measured time to 50% of peak value.

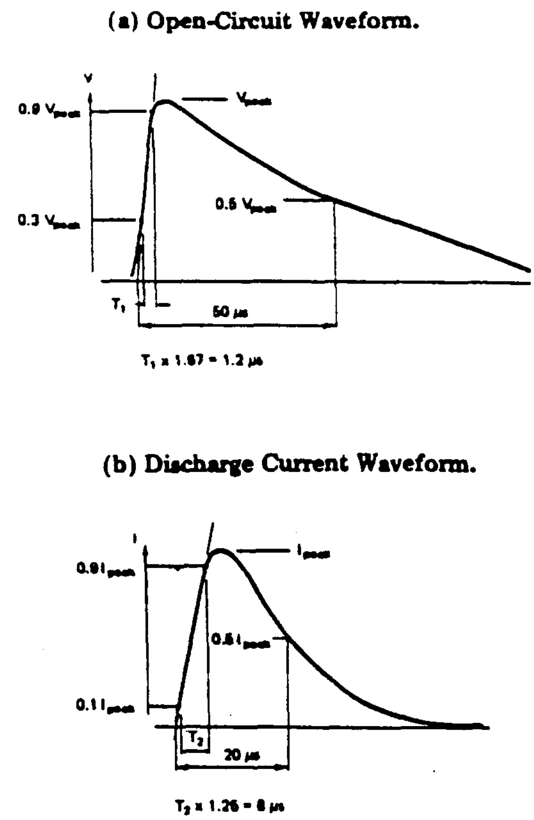

FIG. 1 Waveforms From ANSI/IEEE C 62.41-1980

Location Category	Comparable to IEC No 664 Category	Impulse: Waveform	Impulse: Medium Exposure Amplitude	Type of Specimen or Load Circuit	Energy (joules) Deposited in a Suppressor* with Clamping Voltage of 500V (120 V System)	Energy (joules) Deposited in a Suppressor* with Clamping Voltage of 1000V (240 V System)
A Long branch Circuits and outlets	II	0.5 μs-100 kHz	6 kV	High impedance†	—	—
			200 A	Low impedance‡, §	0.8	1.6
B Major feeders, short branch circuits, and load center	III	1.2 X 50 μs	6 kV	High impedance†	—	—
		8 X 20 μs	3 kA	Low impedance‡	40	80
		0.5 μs-100 kHz	6 kV	High impedance†	—	—
			500 A	Low impedance‡, §	2	4

*Other suppressors having different clamping voltages would receive different energy levels.

†For high-impedance test specimens or load circuits, the voltage shown represents the surge voltage. In making simulation tests, use that value for the open-circuit voltage of the test generator.

‡For low-impedance test specimens or load circuits, the current shown represents the discharge current of the surge (not the short-circuit current of the power system). In making simulation tests, use that current for the short-circuit current of the test generator.

§The maximum amplitude (200 or 500 A) is specified, but the exact waveform will be influenced by the load characteristics.

FIG. 2 Table From ANSI/IEEE C 62.41-1980

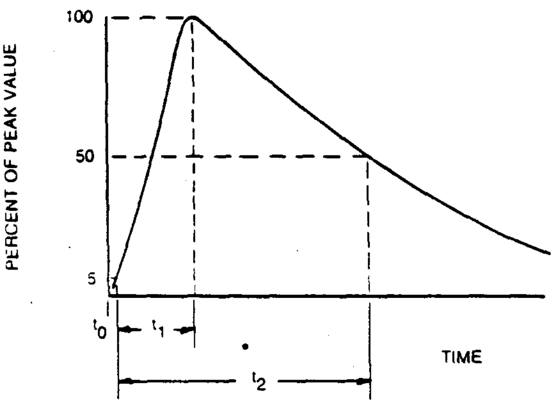

FIG. 3 Definition of Waveform Time Points

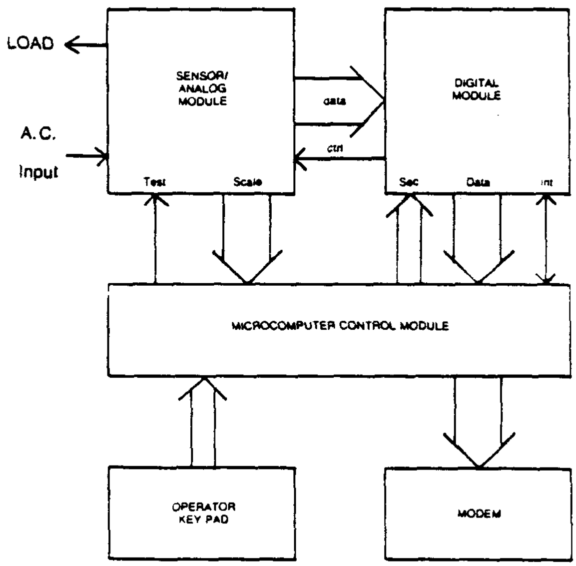

FIG. 4 Transient Voltage/Current Analyzer Block Diagram

Voltage and Current Measurements - The voltage surge measurements were made line to neutral, excluding the A.C. line voltage. The current surge measurements were made with a sensing circuit in series with the A.C. line. The system nulls out the AC line current.

Correlation of Voltage and Current Surges - The computer system looks at the time between voltage and current surges and decides whether they are associated with each other. They are correlated as the same occurrence when the time between a voltage and a current surge is less than 50 us. This is true whether the voltage leads or lags the current surge.

Description of Surge Analyzer - The surge analyzer will sense, digitize and record voltage and current transients appearing on the AC power line. A block diagram of the system is shown in Fig. 4. The complete system is powered by batteries. The system senses either positive or negative surges. As each voltage/current surge occurs, the following parameters are captured and stored: (1) peak voltage (V_p), time to peak, time to 50% of V_p, (2) peak current (I_p), time to peak, time to 50% of I_p, (3) date of occurrence.

Analog and Digital Modules - (Fig. 4). The Analog Module receives from the sensors transient voltage and current on an AC power line by converting the voltage and current inputs to digital signals. The Digital Module processes the digital information to the system microprocessor.

Microcomputer Control Module (Fig. 4). This module has overall control of the Analyzer. It receives the peak values and time collected by the Digital Module for each transient and along with the scale factors from the Analog Module, determines the characteristic of the transient. It records the date of occurrence of each transient. It contains a real time 24 hour clock which can be set by an operator using the numeric keypad.

Voltage and Current Sensors - Fig. 5 shows separate voltage and current inputs to the computer. The sensors provide the means to conduct only the surge voltage and current into the Analog Module. Both voltage and current values have an accuracy of ±5%; i.e., a recorded 300 volt transient could really be 285 volts or it could be 315 volts. The time to peak and to 50% of peak has an accuracy of ±5%. The sensing circuits measure the peak voltage and current related to time and the return of both to 50% of the peak value of both.

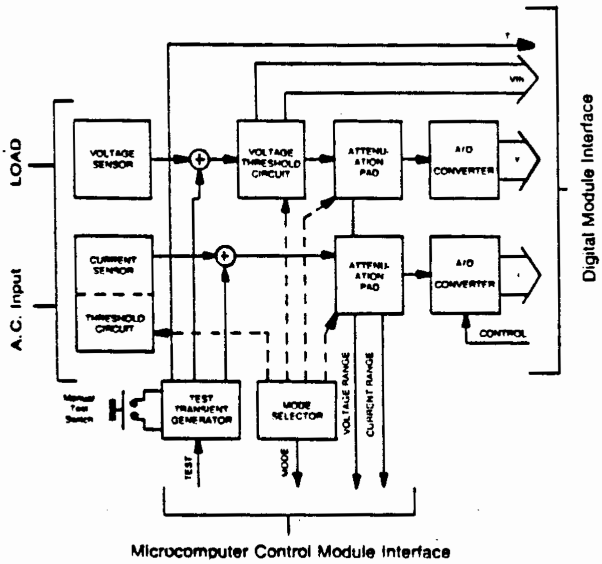

FIG. 5 Sensors/Analog Detailed Block Diagram

Figures 6, 7, and 8 are photographs of three different AC power transient analyzers.

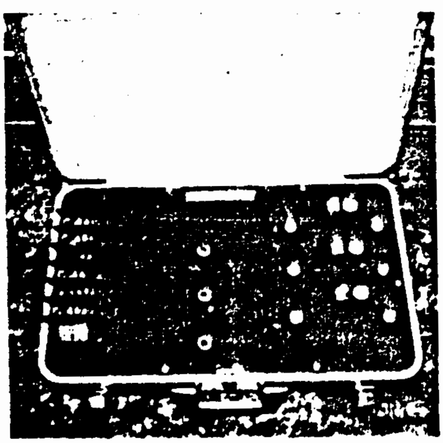

FIG. 6 Transient analyzer - single phase/3 wire

FIG. 7 Transient analyzer - single phase/2 wire

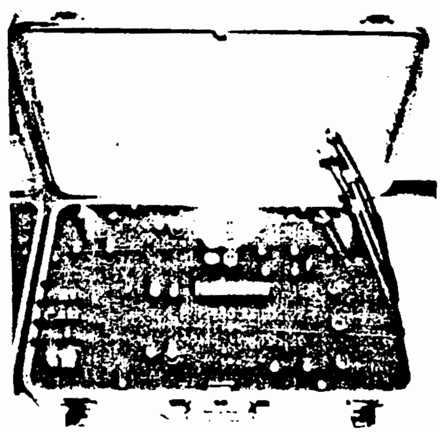

FIG. 8 Transient analyzer - 3 phase/4 wire (part 1 of 2 pieces)

Calibration Tests - To verify that each surg analyzer correctly recorded and reproduced the wav forms measured, a calibration test was performed The setup is shown in Fig. 9. The calibration con sisted of nine waveform tests, four voltage, fou current, and one combined voltage and current wave forms. They are shown in Fig. 10 through 18 and th output results from the transient analyzer is show in Fig. 19.

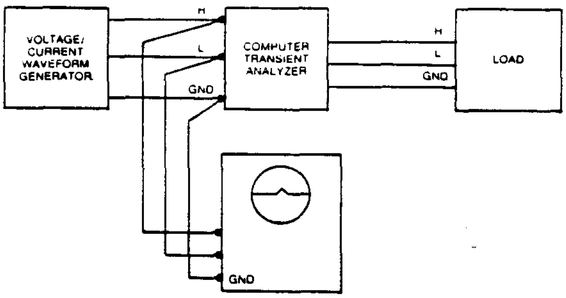

FIG. 9 Block Diagram for Calibration Tests

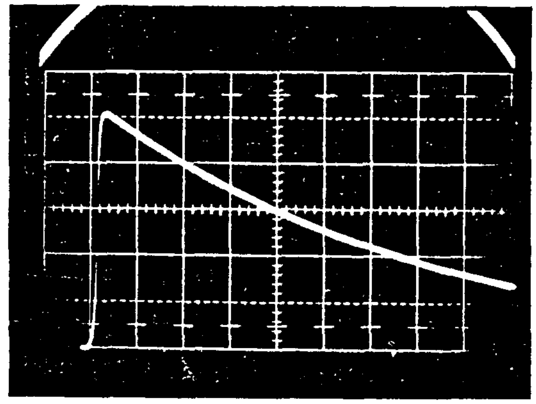

FIG. 10 Calibration Test #3: Voltage
Horizontal scale: 10us/Div
Vertical scale: 1000V/Div

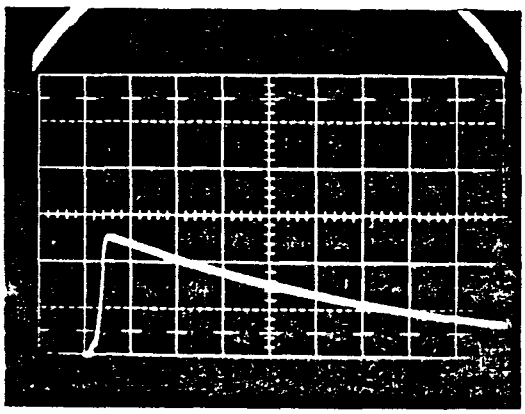

FIG. 11 Calibration Test #1: Voltage
Horizontal scale: 10us/Div
Vertical scale: 200V/Div

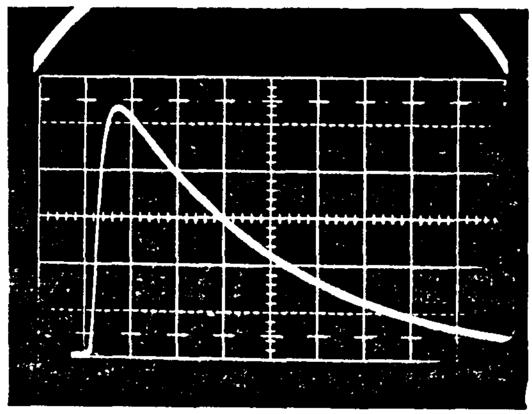

FIG. 12 Calibration Test #4: Current
Horizontal scale: 10us/Div
Vertical scale: 10A/Div

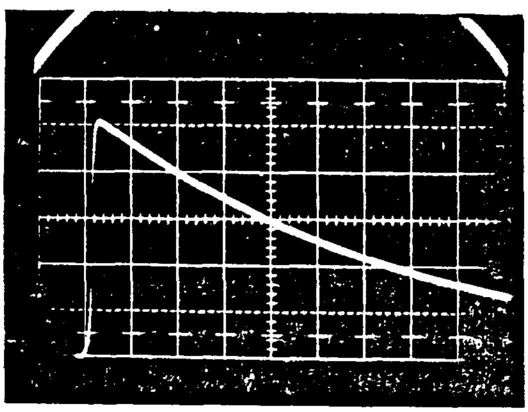

FIG. 13 Calibration Test #2: Voltage
Horizontal scale: 10us/Div
Vertical scale: 500V/Div

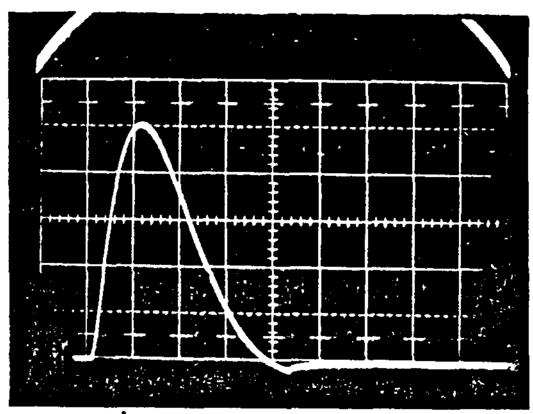

FIG. 14 Calibration Test #5: Current
Horizontal scale: 10us/Div
Vertical scale: 100A/Div

Description of Sites and Installation of Analyzer - A variety of locations were selected in computer and industrial facilities. These facilities were selected because they were unprotected environments. The only suppression that was installed at these environments were on the primary side of the building transformer and were either gas tube or air gap type. Location codes were established as shown below:

Code	Location
1 =	15A/120 VAC receptacle
2 =	30A/120 VAC receptacle
3 =	100A/208/120 3 phase 4 wire subpanel
4 =	400A/240/120 1 phase 3 wire subpanel
5 =	800A/208/120 3 phase 4 wire main
6 =	1200A/208/120 3 phase 4 wire main
7 =	800A/480/277 3 phase 4 wire main

A typical electrical installation of the surge analyzers is shown in Fig. 20.

All of the circuits that the analyzers were connected to were under load. All power conductors under test entered and exited the analyzer.

RESULTS

A computer random sampling, one selection per test site per test period is shown in Fig. 21. The total number of occurrences recorded over the two year period was 277,612. The summary of all 277,612 measured voltages, currents and times are shown in Fig. 22 and Fig. 23.

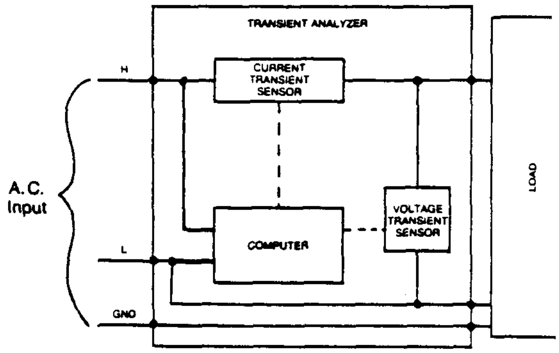

FIG. 20 Example of a Single Phase Installation

The composite waveforms voltage and current
the total numbers of occurrences is 1.07 x 1002.0
voltage and a 60.4 x 999.34 us current. The cal
lated percentage of waveforms that fall within
of this composite waveform is 89.4%. A comp
printout of the composite waveform is shown in F
24 voltage waveform and Fig. 25 current wavef
Rounding off the numbers, the waves then reduce t
x 1000 us voltage and 60 x 1000 us current.

LOCATION CODE	TIME (uS) TO PEAK [1] MIN	TIME (uS) TO PEAK [1] MAX	TIME (uS) TO '50% OF CURVE' [2] MIN	TIME (uS) TO '50% OF CURVE' [2] MAX	VOLTAGE (V) AVERAGE
1	0.3	21.1	2.1	1231.2	347.1
2	0.6	20.7	3.4	1124.8	399.5
3	0.8	18.4	3.2	1177.1	550.2
4	0.7	23.1	8.3	1302.7	651.4
5	0.4	17.7	4.6	1153.7	1520.3
6	0.5	19.1	2.2	1221.8	1633.7
7	0.5	15.6	4.3	1098.6	1230.3

FIG. 22 TABLE III SUMMARY OF VOLTAGE WAVEFORM VALUES

LOCATION CODE	TIME (uS) TO PEAK [1] MIN	TIME (uS) TO PEAK [1] MAX	TIME (uS) TO '50% OF CURVE' [2] MIN	TIME (uS) TO '50% OF CURVE' [2] MAX	CURRENT (A) AVERAGE
1	3.3	98.1	7.0	1271.3	40.5
2	7.4	92.3	13.6	1401.2	137.6
3	4.2	101.1	9.7	1156.7	318.2
4	2.1	87.2	6.2	1086.4	412.8
5	3.6	99.6	7.8	1432.6	1172.2
6	2.7	92.7	5.3	1227.1	2026.4
7	1.8	83.4	4.8	1123.4	612.7

FIG. 23 TABLE IV SUMMARY OF CURRENT WAVEFORM VALUES

OCCURANCE DATE	AREA	PEAK VOLTAGE	TIME (uS) TO PEAK VOLTAGE	TIME (uS) TO '50% OF CURVE'	PEAK CURRENT	TIME (uS) TO PEAK CURRENT	TIME (uS) TO '50% OF CURVE'	LOCATION CODE
5/17/82	BOSTON	360	2.9	963	38	80	900	1
7/22/82	CHICAGO	345	3.1	1021	33	92	980	1
7/23/82	ST LOUIS	333	3.5	980	37	78	1050	2
8/15/82	MIAMI	385	2.8	1007	36	85	1023	1
8/27/82	LA	327	3.3	1031	28	87	1005	2
8/30/82	SEATTLE	500	2.9	800	77	57	801	2
12/03/82	BOSTON	700	1.8	990	360	72	989	3
12/06/82	CHICAGO	650	1.9	994	332	67	1023	4
12/02/82	ST LOUIS	674	2.3	1031	340	72	1050	3
12/07/82	MIAMI	900	1.7	700	560	38	799	4
12/08/82	LA	660	2.5	1100	310	98	1067	3
12/14/82	SEATTLE	410	2.1	998	278	75	915	3
2/03/83	BOSTON	1504	.9	1007	997	54	977	6
2/06/83	CHICAGO	1520	1.0	951	1010	61	1041	5
2/02/83	ST LOUIS	1978	.8	878	1200	49	860	6
2/07/83	MIAMI	1100	1.5	1212	617	98	1400	5
2/10/83	LA	1551	1.3	1050	985	57	1107	5
2/01/83	SEATTLE	1201	.9	971	221	50	912	7
4/12/83	BOSTON	371	2.6	1201	37	61	1011	1
4/10/83	CHICAGO	331	3.0	1131	31	84	981	1
5/03/83	ST LOUIS	351	1.9	977	36	57	997	2
4/29/83	MIAMI	368	2.3	1013	28	71	1213	1
5/12/83	LA	471	2.6	1011	51	47	903	2
5/01/83	SEATTLE	301	4.0	1202	27	54	950	2
4/13/83	ATLANTA	346	3.5	983	35	54	1018	1
5/21/83	HOUSTON	337	2.6	1112	40	63	1401	2
4/11/83	SLC	330	2.8	963	34	64	972	1
6/12/83	BOSTON	674	1.7	971	331	49	951	3
7/13/83	CHICAGO	551	2.2	1011	298	63	1023	4
6/02/83	ST LOUIS	898	1.9	1051	375	71	989	3
6/28/83	MIAMI	721	1.6	853	311	58	961	4
7/23/83	LA	651	1.7	1023	352	67	1031	3
6/15/83	SEATTLE	491	2.1	989	271	81	1024	3
6/01/83	ATLANTA	692	2.4	1024	340	65	995	3
7/12/83	HOUSTON	680	2.0	1303	397	57	989	3
7/21/83	SLC	857	1.1	899	422	51	1011	4
8/12/83	BOSTON	1459	.9	1102	997	53	971	6
9/11/83	CHICAGO	1487	.7	981	1132	72	1301	5
8/15/83	ST LOUIS	1571	1.4	1013	1123	68	1100	6
8/18/83	MIAMI	1526	1.2	1027	807	60	1037	5
9/14/83	LA	1471	1.4	902	932	67	982	5
8/17/83	SEATTLE	1600	1.5	1204	1021	74	1052	7
9/12/83	ATLANTA	2100	.8	897	1522	42	971	5
9/13/83	HOUSTON	1525	.9	987	1001	88	1312	5
8/24/83	SLC	1521	2.0	1351	976	71	1025	6

COMPOSITE WAVEFORMS: 1.87 X 1002.01(uS) VOLTAGE
68.41 X 999.34 CURRENT

89.4% WITHIN ± 10% ENVELOPE

FIG. 21 TABLE II RANDOM COMPUTER SAMPLING OF WAVEFORM DATA

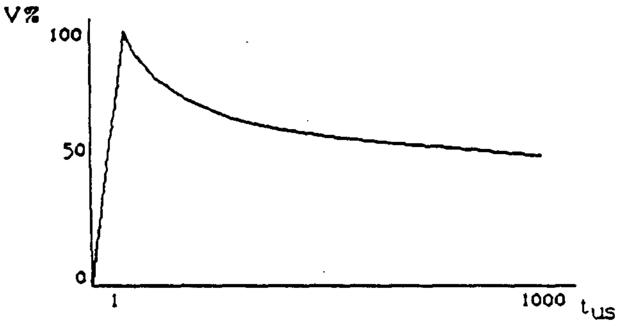

FIG. 24· Composite Voltage Waveform *

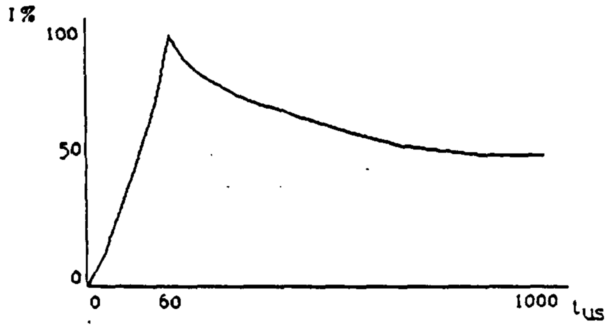

FIG. 25 Composite Current Waveform *

*** Note: These graphs are strictly a computer drawn waveform. The only places on the graphs that are accurate are the peak & 50% points voltage or current, and the time to reach these points.**

CONCLUSION

This data provides confirmation on the existence of longer voltage and current waves than has been traditionally used. It provides new guidance for testing for susceptibility and vulnerability of equipment. Further work is being continued in this area and as results become available they will be documented.

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The Quality of U.S. Commercial Power. Intelec Conference Proceedings, 1982, pp 28-33.

[4] General Electric Semi-Conductor Product Department, Transient Voltage Suppression Device Selector Guide, Publication 600.40, Page 3, 1983.

[5] ANSI/IEEE Std. C62.41-1980, IEEE Guide for Surge Voltages in Low-Voltage AC Power Circuits.

Discussion

Peter Richman, (KeyTek Instrument Corp., Burlington, MA): The authors state that 89.4% of the 227,612 observed surges in a total of nine cities had durations lying within a ± 10% band centered around their composite waves' approximately 1000 μs durations, for both voltage and current.

The 89.4% figure for the entire population implies that for every surge with duration less than about 900 μs or greater than about 1100 μs, there were nine with durations in the 900 to 1100 μs interval. Long waves have certainly been reported in prior literature. However, duration consistency of the sort reflected here would seem more likely to be an artifact than a characteristic of the random phenomena being monitored.

Manuscript received February 25, 1985

Francois D. Martzloff (General Electric Company, Schenectady, NY): "Measurements of Voltage and Current Surges on the AC Power Line in Computer and Industrial Environments" by R. Odenberg and B. J. Braskich is a welcome contribution toward a more complete characterization of the surge environment in low-voltage ac power circuits than had heretofore been available. Its value could be considerably enhanced, however, if the authors would provide in their closure the answers to the questions presented here, together with a clarification of some concepts.

Following general comments on concepts, questions will be presented as separate entities in order to facilitate the dialogue with the authors and the reading of the final *Transactions* document. Some of these questions, however, are interrelated in terms of the total impact of the paper.

General Comments

1. *Waveform versus Data Points*

The authors state in the "Introduction" that the paper provides data on waveforms recorded in the field. This statement raises great interests and expectations among the workers associated with the subject. Unfortunately, the data actually present only two points of the infinitely diverse waveforms that can occur in the real world.

When the authors state, in "Instrumentation," that *two* points...no other points are described...in the ANSI/IEEE C62.41-1980 waveforms....," there seems to be a confusion of interpretation. The C62.41 waveforms and those of other standards are indeed described by the citation of only two points, but these waveforms are defined mathematically by precise equations used in numerical methods. The two points cited to describe the wave merely form a shorthand label to represent a wave that has been produced, recorded, and accepted as completely defined.

In contrast, what the authors attempt to do is to fit the diverse real-world waveforms (none of which has been recorded by them) into a simplified "composite" envelope. The parallel suggested by the authors between the *two* points of Standard C62.41 and *their two* points is therefore inappropriate.

This simplification is more than the old issue of simplification of the world for the sake of repeatable and comparable results in the laboratory, because in this case we have no indication of what the waves which are being simplified actually represent. Attaching the qualifier "composite" to the word "waveform" is perhaps an attempt at clarification, but its use only adds to the confusion.

2. *Computer-Drawn Waveform*

The risk of confusion is further developed by the drawing of "composite waveforms" in Figs. 24 and 25. The warning note added to these figures might serve as a reminder of their computer origin. However, busy readers are likely to remember only that the paper has shown the world to contain 1 X 1000 or 60 X 1000 surges whereas, in fact, all the paper has shown is a recording of two points. To avoid misleading information, Figs. 24 and 25 should be deleted.

3. *Exclusively Linear Loads*

The authors state that the currents recorded are those associated with the loads downstream from the instrument. They say, further, that no surge suppressor was included in the loads.

Assuming that indeed the authors had complete access to and knowledge of the loads, which knowledge would guarantee the validity of the statement, it seems unfortunate that the measurements did not include a period of time with a known surge diverter connected across the line.

A very useful application of current recordings made possible by the authors' new instrument would be the determination of what current the unknown transient source would inject into a nonlinear surge diverter, in contrast to the linear loads described by all the data of the paper.

Question 1: Do the authors intend to extend their measurements to include some with known diverters installed downstream from the instruments?

Questions on Instrumentation Characteristics

1. *Frequency Response*

The authors state that the ac line voltage is "excluded" and the ac line current is "nulled." With the reported vast majority (90%) of the tails closely packed around 1 ms (the statement "89.4% within ± 10% envelope"), and with the 60 Hz ac signals having a half-period of only 8 ms, one wonders what this exclusion or nulling might do to the surge signals. A complete scan of the instrument response versus frequency would clarify this issue.

Question 2: Have the authors considered calling upon an independent laboratory, to characterize the instrument?

2. *Threshold and Voltage-Current Correlation*

The authors do not state a threshold in their measurements to help define what is being considered as a "surge" by the instrument.

Question 3: If the voltage-current correlation is being decided according to the criterion "the time between a voltage surge and a current surge is less than 50 μs," is this decision based upon the reaching of the unstated threshold for each current and voltage signal?

Since most current surges have a time to peak in excess of 50 μs, the peak presumably cannot be used as the basis for the decision. A more detailed explanation of the stated correlation would be helpful.

3. *Recovery after Recording — 50% Tail Definition*

The authors show in Figs. 16 and 17 simple decaying oscillations where it is apparent that the first passage through 50% of the crest after the peak will produce the recording of the time elapsed as the time to 50%.

Question 4: However, what would be the response of the instrument to complex waveforms such as those of Figs. A, B, C, D, and E, shown below?

Question 5: Would the instrument record points (a), (b), (c), (d), and (e), repectively, as 50% points on those waves or record a later 50% passage%

Question 6: When triggered by a threshold, and busy recording the 50% passage, does the instrument have a recovery time before it can record a subsequent peak of the same event, and then will it cite only the highest point of the total event?

Question 7: Does the instrument record an unconnected second event that occurs soon after the first?

Statistical Aspects of the Data

The following questions and comments reflect my own concerns as well as those of G.J. Hahn, coauthor of the 1970 paper cited as Ref. [1] of the Odenberg and Braskich paper.

1. *Sampling Procedures and Definitions*

Further clarification of the site sampling procedures and definitions of surges would be useful. In particular,

a. The survey involved nine cities and seven locations.

Questions 8:
- Does this statement mean that there were 7 locations in each of the 9 cities, or a total of 63 "places?" (Table II shows 45 combinations.)
- How were the locations in each city selected?
- Can these be regarded as a random sample?

b. The nine cities used should be specifically named in Tables III and IV and some statement made as to why they were selected.

Questions 9:
- Is there a standard definition of a surge?
- Is it the same from one city, location, and place to the next?

It would be very useful to present the data of Table II with an indication of the per-unit levels of the peak voltage values recorded, because the system voltage varies with the location code.

2. *Summary of the Study Results*

The value of the information presented would be considerably enhanced if the authors could provide additional information. The limitation on page numbers imposed by IEEE on submitted papers is acknowledged, but the closure could be the opportunity for this enhancement, as follows:

a. Figs. 22 and 23 provide key information. The tabulation could be broken down by the 63 (?) places and summaries provided for location and, possibly, city (and also overall).

b. In a full documentation, Figs. 22 and 23 should be complemented to include:
- The number of surges at each location, city, and place.
- The following percentiles of the distribution: 1, 10, 25, 50, 75, 90, 95, and 99 at each location, city, and place (and totals); or
- A frequency table for each location, city, and place (and totals), showing the number, or percentage, of surge within specified frequency-of-occurrences classes.

- The mean and the standard deviation for each location, city, and place (and totals).
  for *each* of the following: time to peak current and voltage, time to 50% current and voltage, and peak voltage and current.
  Alternatively, some of this information can be provided by histograms, frequency curves, or both.

c. The information on "min" and "max" is inadequate to give a good picture; for one thing, min and max depend upon sample size. Thus, the minimum complementary information to Figs. 22 and 23 should be the percentiles.

3. *Differentiation Between Types of Surges*

It would be most interesting to be able to differentiate between surges due to lightning storms and power system switching surges, for improved understanding. We recognize that such information might not be available. However, if it is available, even on a sample basis, it warrants reporting. If it is not available, some insights might be provided by:

a. Breaking down Figs. 21 and 22 by city, as previously suggested. In particular, Miami versus Seattle should be interesting as a possible discriminator for lightning.

b. Breaking down Figs. 22 and 23 further by season.

4. *Other Questions*

a. Exactly how Figs. 24 and 25 were obtained is unclear. The term "composite waveform" used in the second paragraph of "Results" needs to be defined. If we assume that the front time value of 1.07 cited is the mean of all 277,612 occurrences, we have, by sheer sample size, a good estimate of the front time of all the occurrences.

Now, taking the mean of the 45 occurrences of front time shown in Table II, which we compute at 2.00, and applying Student's "t Test" to compare this mean of 2.00 to the overall mean of 1.07, we find a statistically significant difference at the 0.1% level between the two means. This difference should not be significant if the sample is a random sample from the total population. Thus, the statement that the values of Table II make up a random sample needs clarification.

Moreover, the value of 1.07 does not appear to be the median either, because only 8 of the 45 values given in Fig. 21 are below 1.07.

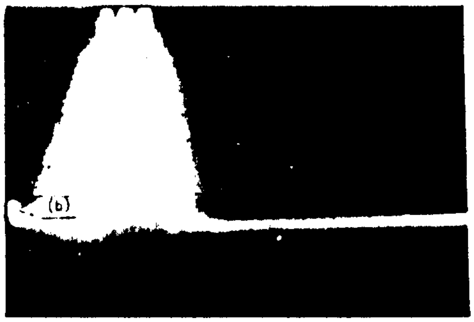
b. The statement " '89.4% within ±10% envelope" is ambiguous.

Questions 10:
- Does this statement refer to voltage or current?
- Time to crest or time to 50%?
- Peak value?
- All of the above (an amazing coincidence or an instrument artifact [see Question 2])?

Figs. 21 and 22 complemented, or revised as suggestted, would provide more meaningful summary values.

Conclusion

The measurements reported in this paper surely represent a major commitment of resources by the authors' organization, which the community of workers in the field of surge characterization can well recognize and appreciate. The ultimate value of this effort would be substantially enhanced, and the ambiguities removed, if the authors could provide a response to the questions raised in the present discussion and to any others that might be submitted.



Vertical: 40 A/div - Sweep: 0.5 ms/div

Fig. B. Current surge in a varistor, resulting from capacitor bank switching

Vertical: 20 A/div - Sweep: 0.2 ms/div

Fig. C. Current surge in a varistor resulting from capacitor bank switching

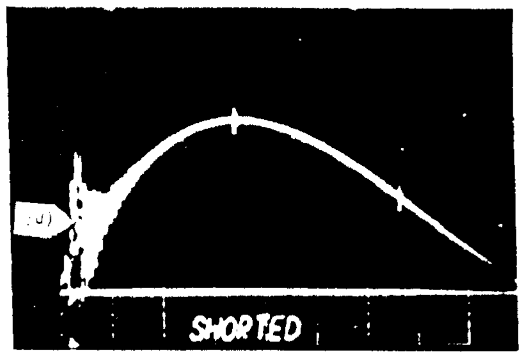
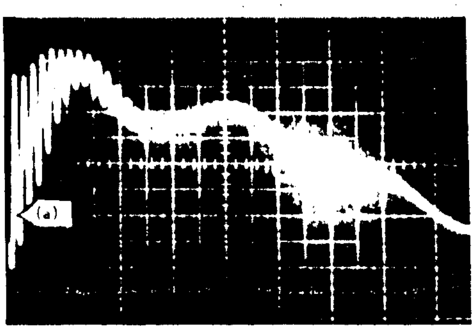
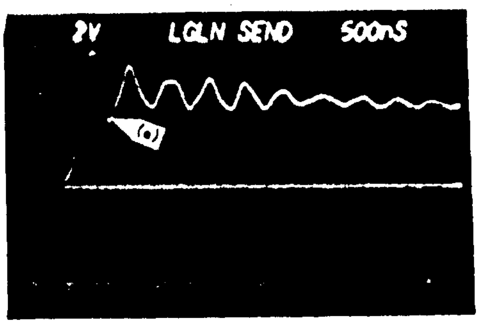


Fig. D. Voltage at terminals of shorted load with parasitic inductance, during conduction of a current surge



Vertical: 500 V/div - Sweep: 1 ms/div

Fig. A. Voltage transient caused by capacitor bank switching



Vertical: 2 kV/div - Sweep: 0.5 µs/div

Fig. E. Voltage at line terminals during application of a step function

REFERENCES

[1] F. D. Martzloff, *Varistor vs Environment: Winning the Rematch*, 85SM 365-2 IEEE/PES 1985.

*F. D. Martzloff is now associated with the Electrosystems Division of the National Bureau of Standards, Gaithersburg, MD.

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R. Odenberg and **B. J. Braskich**: To simplify the dialogue with the discusser and the reader of the *Transactions* document, the questions will be provided with the answers.

Discussion from — F. D. Martzloff

Comments to paragraphs on: 1. Waveform versus data points.
2. Computer — drawn waveforms.

It is the opinion of the authors that the discusser's comments regarding waveforms are inappropriate. It is our opinion that the technique utilized and the classification of the measurements as waveforms, are consistent with the waveform format as utilized in ANSI/IEEE C62.41. In addition, since there is a disclaimer attached to Figs. 24 and 25, we will not remove them from the paper.

Comments to paragraphs 3 and 4, titled, "Exclusively Linear Loads." Quote, "it seems unfortunate that the measurements did not include a period of time with a known surge diverter connected across the line." *Answer:* the purpose of this field study was to measure the uncontrolled environment, not the characteristics of a known surge suppressor that could be determined in a laboratory.

Question 1: Do the authors intend to extend their measurements to include some with known diverters installed downstream from the instruments?

Answer 1: No, what would be measured under these parameters would be strictly transient remnant, which can be accomplished in the laboratory using the waveforms described in the paper.

Question 2: Have the authors considered calling upon an independent laboratory, such as the National Bureau of Standards, to characterize the instrument?

Answer 2: No, during the calibration period for each analyzer, the frequency spectrum was analyzed to cover a broad band of frequencies; with a variety of standard laboratory test equipment. There were no effects within the tolerance provided on this nulling process to the signals.

Question 3: If the voltage-current correlation is being decided according to the criterion "the time between a voltage surge and a current surge is less than 50μs," is this decision based upon the reaching of the unstated threshold for each current and voltage signal?

Answer 3: Yes.

Question 4: However, what would be the response of the instrument to complex waveforms such as those of Figs. A, B, C, D, and E, shown below?

Question 5: Would the instrument record points (a), (b), (c), (d), and (e), respectively, as 50% points on those waves or record a later 50% passage?

Question 6: When triggered by a threshold, and busy recording the 50% passage, does the instrument have a recovery time before it can record a subsequent peak of the same event, and then will it cite only the highest point of the total event?

Question 7: Does the instrument record an unconnected second event that occurs soon after the first?

Answers to 4, 5, 6, and 7: When triggered by the threshold, the whole event is recorded and then the computer analysis for the peak of the event and the first 50% point of that peak. Therefore, points (a), (b), and (c) would not be recorded (from Figs. A, B, and C); point (d) on graph (Fig. D) is unclear, and point (e) (Fig. E) would be recorded.

Yes, after the recording and analyzation of the transient event, there is a recovery time to ensure accurate data storage. If a second event occurs during the analyzation and recovery time, it would not be recorded.

Question 8: This survey involved nine cities and seven locations.

- Does this statement mean that there were 7 locations in each of the 9 cities, or a total of 63 "places?" (Table II shows 45 combinations.)
- How were the locations in each city selected?
- Can these be regarded as a random sample?

Answer 8: Yes, there was a total of 63 "places" analyzed. Many factors were taken into account in the location selection process to consider a random sampling.

Yes, 63 locations can be regarded as random sampling, even though 63 locations is a small number to 630 or 6300 or 63,000 locations. It is far greater than 6 or 1 location.

The nine cities are:

Boston	Los Angeles
Chicago	Seattle
St. Louis	Atlanta
Miami	Houston
Salt Lake City	

Question 9: Table II shows only 45 combinations, to give the reader the example of how the data were presented by the computer.

- Is there a standard definition of a surge?
- is it the same from one city, location, and place to the next?

Answer 9: The analyzers were designed under general conditions; there was no set definition of a surge prior to the installation of these systems.

Yes, it was the same from one city, location, and place to the next; as defined by the transient analyzer and its standardized calibration for all analyzers.

Comments to: Summary of the Study Results

Based on the uniformity of 89.4%, there is no need to do that.

Question 10: The statement "89.4% within ±10% envelope" is ambiguous.

- Does this statement refer to voltage current?
- Time to crest or time to 50%?
- Peak value?
- All of the above (an amazing coincidence or an instrument artifact (see Question 2)?

Answer 10: Yes, all of the above. These numbers (89.4%) are not an instrument artifact based on the extensive calibration tests performed on each computer system.

Discussion From — **Peter Richman**

The Answer to Question 10 above should answer his concerns.

Summary

The authors appreciate the assistance and interest in the two discussers, Francois D. Martzloff and Peter Richman, in the questions they ask.

The data provided in this paper measuring voltage and current surge characteristics for the *same event*, should provide new methods and values for surge Standards, both current and future. In addition, the requirements for longer wave (1 x 1000μsec, 60 x 1000μsec) testing should enhance performance and reliability of surge suppressor products and techniques, and ensure more reliable operation of electronic equipment in the field.

Manuscript received April 15, 1985