# 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 occyrrence.

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  $1.07 \times 1002.01$  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.

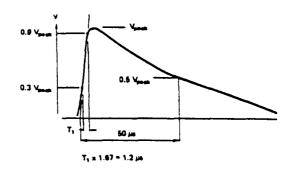
85 Wi 243-1 A paper recommended and approved by the IEEE Surge Protective Devices Committee of the IEEE Power Engineering Society for presentation at the IEEE/PES 1985 Winter Meeting, New York, New York, February 3 - 8, 1985. Manuscript submitted August 31, 1984; made available for printing November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

<u>Waveform Format</u> - 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.

### (a) Open-Circuit Waveform.



### (b) Discharge Current Waveform.

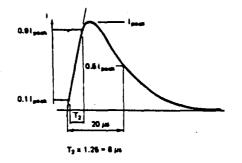


FIG. 1 Way

Waveforms From ANSI/IEEE C 62.41-1980

B.J. Braskich

Location Category	Comparable to IEC No 664 Category	Impulse		Type of Specimen	Energy (joules) Deposited in a Suppressor* with Clamping Voltage of	
		Waveform	Medium Exposure Amplitude	or Load Circuis	500V (120 V System)	1000V
A Long branch Circuits and outlets	ш	0.5 µm-100 kHz	6 LV 200 A	High impedance <sup>†</sup> Low impedance <sup>‡</sup> , §	0.8	1.6
B Major feeders, sbort branch circuits, and load center	ш	مسر 50 × 50 مسر 1.2 × 50 مسر 20 × 8 × 20 0.6 مسر 100 kHz	6 kV 3 ka 6 kV 500 a	High impedance <sup>†</sup> Low impedance <sup>‡</sup> High impedance <sup>†</sup> Low impedance <sup>‡</sup> ,§	40	80 -

\*Other suppressors having different clamping voltages would receive different energy levels. \*Por 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 shortcircuit current of the power system). In making simulation tests, use that current for the short-circuit current of the test generator. SThe maximum amplitude (200 or 500 A) is specified, but the exact waveform will be influenced by the load characteratuca.

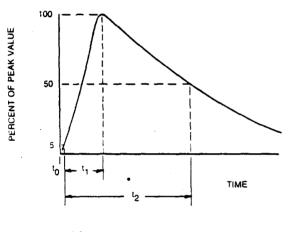
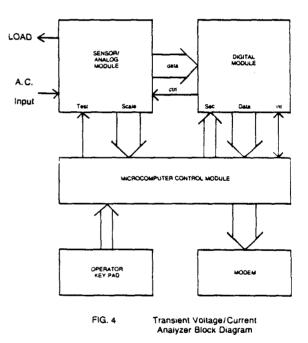


FIG. 3 Definition of Waveform Time Points

<u>Voltage and Current Measurements</u> - 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.

<u>Correlation of Voltage and Current Surges</u> - 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 laos the current surge.

whether the voltage leads or lags the current surge. <u>Description of Surge Analyzer</u> - 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.



<u>Analog and Digital Modules</u> - (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.

<u>Microcomputer Control Module</u> (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.

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

<u>Voltage and Current Sensors</u> - 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.

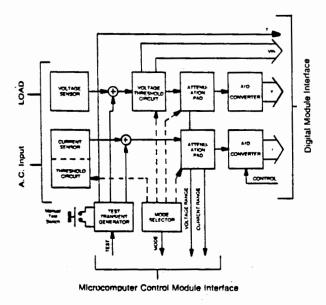
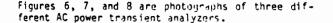


FIG. 5 Sensors/Analog Detailed Block Diagram



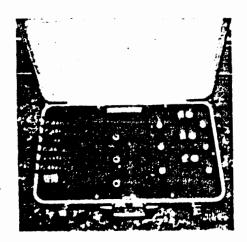


FIG. 6

Transient analyzer - single phase/3 wire



FIG. 7

Transient analyzer - single phase/2 wire

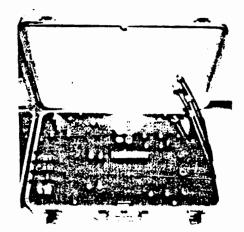


FIG. 8 Transient analyzer - 3 phase/4 wire (part 1 of 2 pieces)

<u>Calibration Tests</u> - To verify that each surg analyzer correctly recorded and reproduced the waw 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.

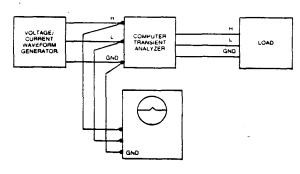


FIG. 9 Block Diagram for Calibration Tests

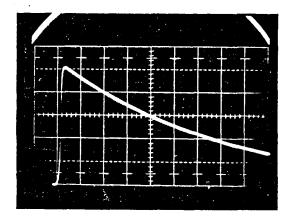


FIG. 10

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

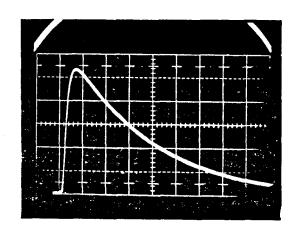
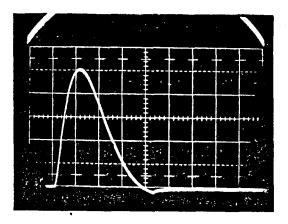


FIG. 12

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



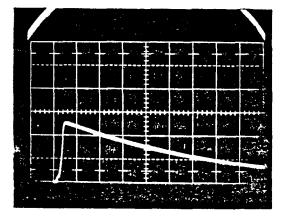
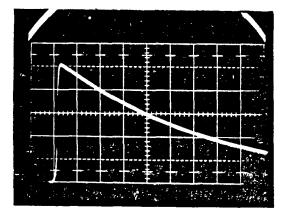


FIG. 11

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



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

.

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

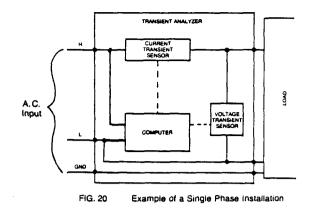
A computer random sampling, one selection per test site per test period is shown in Fig. 21. The total number of occurrences recorded over the two year period was 277,612. The summary of all 277,612 measured voltages, currents and times are shown in Fig. 22 and Fig. 23. The composite waveforms voltage and current the total numbers of occurrences is  $1.07 \times 1002.01$  voltage and a  $60.4 \times 999.34$  us current. The callated percentage of waveforms that fall within 1 of this composite waveform is 89.4%. A complication of the composite waveform is shown in F 24 voltage waveform and Fig. 25 current wavefor Rounding off the numbers, the waves then reduce t x 1000 us voltage and  $60 \times 1000$  us current.

LOCATION CODE 1		uS) TO AK (1 MAX 21.1		(uS) TO F <u>CURVE <sup>1</sup>2</u> <u>MAX</u> 1231.2	UOLTAGE (U) AVERAGE 347.1
2	0.6	20.7	3.4	1124.8	399.5
3	Ŭ.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 <u>PEAK <sup>1</sup>1</u> <u>MIN MAX</u> 3.3 90.1	TIME (uS) TO <u>'50% OF CURVE'</u> 2 <u>MIN MAX</u> 7.0 1271.3	CURRENT (A) <u>AVERAGE</u> 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



19.722.92   Digition   1.4.1   2.4   4.2.1   1.4 <th1.4< th="">   1.4   1.4</th1.4<>	DÉCURANCE	AREA	PEAK VOLTAGE	TIME (US) TO PEAK VOLTAGE	TIME (US) TO 150% OF CURVE!	PEAK	TIME (US) TO PEAK CURRENT	TIME (US) TO	LOCATION CODE
2722/42   ST LQUIS   333   2.5   483   32   78   1846   2     6/36/42   HAMI   345   2.6   1007   3.6   67   1003   1     6/32/42   LA   327   3.3   1031   2.6   67   1083   2     12/02/42   DOSTON   766   1.6   474   327   47   1023   4     12/02/42   DOSTON   766   1.6   474   337   47   1023   4     12/02/42   DOSTON   766   1.7   729   440   36   78   4     12/02/42   DOSTON   1.7   729   440   36   78   411     12/04/43   DOSTON   1.7   799   440   106   5     12/04/43   DOSTON   1.91   1.7   1097   44   1061   5     2/04/43   DOSTON   371   2.4   1021   10   7   441   1041	5/17/82	BOSTON	360	2.9 4	993 Z	14	e0 <sup>1</sup> 1	م ٥٥٥	1
P-15-02   HIAMI   385   2.0   1007   34   85   1023   1     P-27042   LA   327   3.3   1031   20   97   1009   2     P-27042   SERTLE   980   2.9   994   2.9   994   3     12/26724   BOSTOM   740   1.4   994   343   72   109   3     12/26727   ST LOUIS   474   2.3   1031   340   72   102   4     12/26727   ST LOUIS   474   2.3   1031   340   72   1067   3     12/26743   DEGTOM   194   1.0   101   10   97   44   977   4     2/26743   DEGUSM   197   101   971   101   971   101   971   101   971   101   972   44   977   45     2/26743   Nicolis   1971   1.0   971   24   101   971	7/22/82	CHICAGO	345	3.1	1021	33	92	980	1
# 272/42   LA   327   5.3   1031   28   #7   1087   2     # 256/42   SEATLE   #90   2.4   #96   77   47   401   2     12/04/25   DOSTON   749   1.4   #94   346   72   401   2     12/04/25   DECEMS   434   2.3   1031   348   72   1089   3     12/04/25   DECEMS   44   2.3   1031   348   72   1089   3     12/04/25   LA   448   2.5   1100   10   9   1067   3     12/04/25   LA   448   2.5   1100   10   9   1067   3     2/04/25   DECEMD   150   1.4   971   121   46   464   4     2/04/25   DECEMD   130   1.5   1212   417   96   1460   5     2/14/25   GEATLE   110   1.5   1212   41	7/23/82	ST LOUIS	333	3.5	980	37	78	1050	2
# /26.42   SEATLL   16   2.0   801   77   92   861   2     12.75.742   DOSTON   700   1.4   940   346   72   949   3     12.76.742   DOSTON   700   1.4   944   332   47   1053   4     12.76.742   DLOIS   474   2.3   1031   346   72   1053   4     12.76.742   DLOIS   474   2.3   1031   346   74   4     12.76.742   ST LOUIS   474   2.5   1108   316   98   1067   3     12.76.743   DOSTON   1964   .9   1007   977   54   977   6     2.76.743   DIGUIS   1978   1.6   971   1216   14   1461   9     2.76.743   Niculi   1.0   1.5   1212   61   940   6   2     2.716.73   Niculi   1.1   1.3   1096	8/19/82	HIAHL	385	2.8	1007	36	85	1023	1
12/29742 BOSTON 218 1.8 994 348 22 995 3   12/42/42 CHICAGO 458 1.9 994 336 22 1223 4   12/42/42 ST LOUIS 474 2.3 1031 340 72 1899 3   12/42/42 ST LOUIS 474 2.3 1031 340 72 1899 3   12/42/42 ST LOUIS 474 2.5 1100 310 96 1662 3   12/14/42 SEATTLE 418 2.1 494 75 418 3   12/14/42 SEATTLE 418 2.1 494 464 66 6   2/80/43 ST LOUIS 177 4 72 4100 5 1007 5   2/16/35 LA 191 1.3 1096 49 460 6 4000 5   2/16/35 LA 1931 3.1 114 4100 1017 5 4100 1017 5   2/16/35 SCATLE	8/27/82	LA	327	3.3	1031	28	87	1005	2
12-64-72 CHICAGO 498 1.9 974 332 4.7 12023 4   12-62-722 RILMIL 974 2.3 1031 340 72 1099 3   12-62-722 RILMIL 976 1.7 709 540 36 79 4   12-769-72 LA 448 2.5 1100 10 96 166-7 3   12-769-72 LA 448 2.5 1100 197 54 777 6   12-769-73 FUCUS 1978 .6 971 1200 44 64 6   2-767-73 RIAMI 1100 1.5 1212 417 98 1408 5   2-767-73 RIAMI 1100 1.5 1212 417 98 1408 5   2-767-73 RIAMI 1100 1.5 1212 417 98 1408 5   2-767-73 RIAMI 1.4 1201 37 41 1011 1 1408 1   2-767-73 RIAMI	8/30/82	SEATTLE	500	2.9	900	77	57	801	2
12-02-02 FILANIE 474 2.3 1031 340 72 1898 3   12-02-02 FILANIE 908 1.72 708 440 39 794 4   12-04-02 LA 444 2.5 1100 316 98 106-7 3   12-14-02 SENTLE 10 2.1 979 74 4 677 4   12-14-02 SENTLE 10 1.6 971 1010 44 460 6   2-09-03 ST LQUIS 1978 .6 878 1220 44 640 6   2-09-03 LA 1991 1.3 1010 1.5 1212 47 98 1007 5   2-09-03 LA 1991 1.3 1011 37 41 1011 1   2-09-03 LA 1031 31 31 11 11 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 <	12/03/82	BOSTON	700	1.8	<b>99</b> 0	360	72	989	,
12/02/02 HIAHI 900 1.7 700 640 30 744 4   12/02/02 LA 440 2.5 1100 310 90 1067 3   12/14/02 SEATTLE 410 2.1 994 278 75 915 3   12/14/02 SEATTLE 410 2.1 996 1007 977 14 977 4   2/04/03 CHICAGO 1520 1.0 971 1010 61 1941 5   2/04/03 SEATTLE 100 1.5 1212 61 971 1007 5   2/07/03 HIAHI 1100 1.5 1212 61 97 1007 5   2/10/03 SEATTLE 1201 .5 971 2.1 7 640 912 7   4/12/03 SEATTLE 1201 .5 971 2.1 101 1 11 11 11 11 11 11 11 11 11 11 11 11 11 11 11<	12/04/82	CHICAGO	650	1.9	994	332	67	1023	4
12/40/42 LA 440 2.5 1100 310 40 1067 3   12/14/82 SEATTLE 410 2.1 978 278 25 915 3   2/06/83 BOSTOM 1904 .0 1002 987 54 977 6   2/06/83 CHICAGO 1970 .0 971 1018 61 11641 9   2/06/83 CHICAGO 1970 .0 971 1210 44 640 6   2/07/83 RIAHI 1100 1.5 1212 417 98 1400 5   2/07/83 RIAHI 1100 1.5 1212 417 98 1400 5   2/12/83 SEATTLE 1021 .9 971 221 50 412 1011 1   4/12/83 DESTON 371 2.4 1131 71 44 991 1   4/12/83 DESTON 371 2.4 1013 28 71 1213 1   4/12/83 RTUAHTA	12/02/02	ST LOUIS	674	2.3	1031	340	72	1050	3
12/14/82   SEATTLE   410   2.1   498   278   73   415   5     2/03/23   DOSTON   1504   .9   1002   962   14   972   4     2/03/23   DOSTON   1504   .9   1002   962   14   972   4     2/03/23   DEGTON   150   1.0   471   1010   41   1041   5     2/03/23   FLGUIS   179   .8   672   1200   44   640   6     2/07/23   FLGUIS   179   .8   672   1107   5     2/16/23   SEATTLE   1201   .9   671   221   50   412   7     4/16/23   CHICAGO   373   .0   1131   31   64   791   1     4/16/24   CHICAGO   373   .0   1131   31   64   71   1     4/16/23   CHICAGO   371   2.4   1011   51   42	12/07/02	HIANI	900	1.7	700	560	38	799	4
Z/23/33   BOSTON   1594   .9   1007   997   54   977   6     Z/06/43   CHICAGO   1520   1.0   491   1010   61   1041   9     Z/06/43   ST (GUIS   1778   .0   678   1200   44   660   6     Z/06/43   Hiami   1100   1.5   1212   617   96   1400   5     Z/16/03   Kiami   100   1.5   1212   617   96   1400   5     Z/16/03   Kiami   1.0   .9   471   221   50   412   7     L/12/03   MOSTON   371   2.4   1201   37   41   1011   1     4/12/03   MIAMI   54   2.3   1013   26   71   1213   1     4/12/03   KULACO   331   3.5   903   35   54   1018   1     4/12/03   KULACO   337   2.4   1112	12/00/02	LA	660	2.5	1100	310	98	1067	,
2/04/03   CHICAGO   1520   1.0   491   1010   61   1041   5     2/02/03   ST LQUIS   1970   .0   070   1200   44   060   6     2/02/03   HIAHI   1100   1.5   1212   617   96   1400   5     2/10/03   LA   1951   1.3   1050   945   57   1107   7     2/01/03   EGNTOR   1221   50   912   7     4/12/03   EGNTOR   371   2.4   1201   37   41   1011   1     4/12/03   EGNTOR   371   2.4   1011   51   47   987   2     4/12/03   ST LQUIS   591   1.4   1011   51   47   997   2     4/12/03   EMENTLE   501   4.6   1202   27   54   1018   1     9/1/03   HQUITOR   337   2.4   1112   64   3   1061	12/14/82	SEATTLE	410	2.1	998	278	79	<b>7</b> 15	3
2/02/03   ST LGUIS   177   .0   678   1200   44   660   6     2/02/03   HLMHI   1100   1.5   1212   617   96   1400   5     2/16/03   LA   1951   1.5   1212   617   96   1400   5     2/16/03   SEATTLE   1201   .9   471   221   50   412   7     4/12/03   SEATTLE   1201   .9   471   221   50   412   7     4/12/03   DESTON   371   2.4   1201   37   41   1011   1     4/16/03   CHICAGO   351   3.0   1131   31   84   981   1     5/03/03   ST LQUIS   551   1.9   977   34   57   993   2     4/13/03   REATTLE   791   4.4   1011   51   47   963   2     4/13/03   REATTLE   791   4.4   1018	2/,03/83	BOSTON	1504	. 9	1007	997	54	977	6
2/07/03 HIAHI 1100 1.5 1212 417 98 1400 5   2/10/03 LA 1591 1.3 1090 965 57 1107 5   2/10/03 SEATLE 1201 .9 971 221 50 912 7   4/12/03 GOSTOM 371 2.4 1201 37 41 1011 1   4/12/03 GOSTOM 371 2.4 1201 37 41 1011 1   4/12/03 GOSTOM 371 3.0 1131 31 64 961 1   5/03/03 ST LQUIS 391 1.9 977 34 57 977 2   4/27/03 IA 471 2.4 1011 51 47 903 2   5/12/03 ATLANTA 344 3.5 903 35 1401 2   4/17/3 SLC 330 2.6 643 1401 2   4/17/3 SLC 330 2.2 1011 20 31 <	2/06/83	CHECAGO	1920	1.0	<b>*5</b> 1	1010	61	1041	5
2/10/05   LA   1591   1.3   1090   7495   57   1107   5     2/10/05   SEATTLE   1201   .9   471   221   50   412   7     4/12/05   SOSTCH   371   2.4   1201   37   41   1011   1     4/12/05   SOSTCH   371   2.4   1201   37   41   1011   1     4/12/05   STLCUIS   351   1.9   977   34   97   997   2     4/27/05   LA   471   2.4   1011   51   47   993   2     4/27/05   LA   471   2.4   1011   51   47   993   2     4/17/05   MOLSTON   337   7.8   7.9   54   1018   1     9/12/03   ATLANTA   344   3.7   993   35   54   1021   2     4/17/03   SC   358   2.8   75   34   44	2/02/03	ST LOUIS	1978	. •	878	1200	49	860	6
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4-12/03   BOSTON   371   2.4   1201   37   41   1011   1     4-18/03   CHICAGO   331   3.0   1131   31   84   981   1     5-03/03   ST LOUIS   351   1.9   977   34   57   997   2     4-78/03   HIANI   568   2.3   1013   28   71   1213   1     5/12/03   LA   471   2.4   1011   51   47   903   2     4/13/03   SEATTLE   301   4.4   1202   27   54   905   2     4/13/03   ATLANTA   744   3.5   983   35   54   1018   1     9/21/03   ATLANTA   744   3.5   983   34   64   972   1     4/12/03   SCC   330   2.8   963   31401   2     4/12/243   BOSTON   674   1.7   971   331   46   46	2/10/03	LA	1991	1.3	1090	985	\$7	1107	5
4-18/43 CHICAGO 331 3.0 1131 31 84 981 1   9-03/43 ST LQUIS 351 1.9 977 34 97 997 2   4-29-43 HIAMI 348 2.3 1013 28 71 1213 1   9-12/43 LA 471 2.4 1011 91 47 903 2   4-29-43 MIAMI 348 2.3 1013 28 71 1213 1   9-12/43 LA 471 2.4 1011 91 47 903 2   4-13/43 SKATTLE 301 4.6 1202 27 54 956 2   4-11/43 SUC 351 2.4 1112 40 63 1401 2   4-11/43 SUC 350 2.8 963 34 64 972 1   4-11/43 SUC 350 2.8 971 351 34 64 972 1   4-11/49 SUC 350 2.7	2/01/03	SEATTLE	1201	.•	<b>97</b> 1	221	50	+12	7
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#veltes   Stattle   Joi   4.0   1202   27   54   950   2     4/13/03   ATLANTA   J44   J.3   903   J5   S4   1018   1     9/21/03   ATLANTA   J44   J.3   903   J5   S4   1018   1     9/21/03   HOUSTON   J37   Z.4   1112   40   43   1401   2     4/11/03   SLC   J30   Z.8   963   J4   64   972   1     4/12/03   BOSTON   674   1.7   971   J31   49   951   3     7/13/03   CHICAGO   951   Z.2   1011   296   63   1023   4     4/02/03   ST LOUIS   898   1.9   1051   375   71   989   3     4/20/03   LA   451   1.7   1023   392   67   1031   3     4/13/03   SEATTLE   491   2.1   992   <	4/29/83	HIANI	368	2.3	1013	28	71	1213	1
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P/14/03   LA   1471   1.4   P02   932   67   P02   5     0/12/03   SEATTLE   1600   1.5   1204   1021   74   1052   7     9/12/03   ATLANTA   2100   .8   897   1522   42   971   5     9/13/03   HOUSTON   1525   .9   987   1001   08   1312   5									
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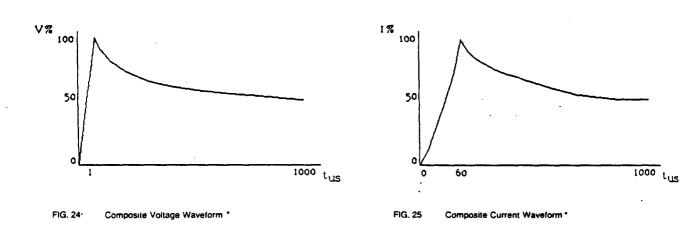
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89.4% WITHIN ± 10% ENVELOPE

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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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#### Discussion

Pter 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  $\pm$  10% band centered around their composite waves' approximately 1000  $\mu$ s 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  $\mu$ s or greater than about 1100  $\mu$ s, there were nine with durations in the 900 to 1100  $\mu$ s interval. Long waves have artainly 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 realworld 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  $1 \times 1000$  or 60  $\times 1000$  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 in-

### 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  $\pm 10\%$  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  $\mu$ s," 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  $\mu$ s, 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 (c), 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.

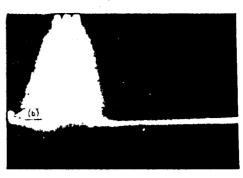
Moreover, the value of 1.07 does not appear to be the median either, because only 8 of the 45 values given in Fig. 21 are below 1.07. b. The statement " '89.4% within ± 10% envelope" is ambiguous. Questions 10: • Does this statement refer to voltage or current?

- 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.

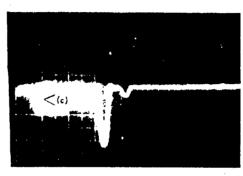
### Conclusion

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



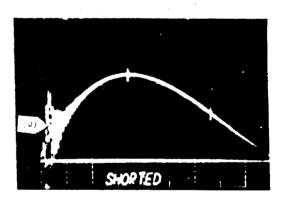
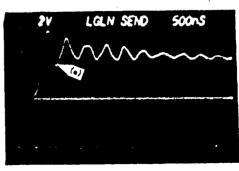
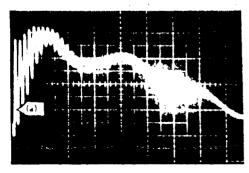


Fig. D. Voltage at terminals of shorted load with parasitic inductance, during conduction of a current surge



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



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

Fig. A. Voltage transient caused by capacitor bank switching

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

#### REFERENCES

IJ 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.

Manuscript received February 28, 1985

**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.

Ouestion 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? The analyzers were designed under general conditions; there

Answer 9;

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  $\pm 10\%$  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 ( $1 \times 1000\mu$ sec,  $60 \times 1000\mu$ sec) testing should enhance performance and reliability of surge suppressor products and techniques, and ensure more reliable operation of electronic equipment in the field.

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