Surge Voltages in Residential and Industrial Power Circuits

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Significance:
Part 3 – Recorded occurrences

At the invitation of the Surge Protective Devices Committee, the 1967 Conference Paper was resubmitted for consideration as a Transactions paper, with additional information presented on industrial case histories acquired since publication of the conference paper.

Both waveform information and frequency of occurrence marked the beginning of the IEEE effort toward characterizing surge voltages in low-voltage ac power circuits, a departure from the traditional unidirectional and separate 1.2/50 and 8/20 waveforms in use for high-voltage equipment testing. One of the outcomes of that effort was IEEE Std 587, which eventually evolved into IEEE Std C62.41 and its successive 1980, 1991, and 2002 versions.

Note that the title still refers only to ***surge voltages***, not surge currents. In the mid-sixties, when these recordings took place, there were very few, if any, surge-protective devices (SPDs) installed in residential power circuits and the threat was indeed one of surge voltages. After the emergence of ubiquitous consumer-type SPDs, the results of subsequent monitoring campaigns were drastically changed (See pdf file “Galore” in Part 2) but the information is still valid for the frequency of occurrences to the extent that the origins of surges have not changed, only the observed levels are now considerably reduced by the proliferation of SPDs (for which the available ***surge current*** becomes a matter of interest).

Surge Voltages in Residential and Industrial Power Circuits

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Abstract—Special instrumentation was developed for monitoring the magnitude and frequency of occurrence of surge voltages in residential and industrial circuits. Over a period of 2 years, more than 400 locations in 20 cities were surveyed. Monitoring was accomplished by automatic recording cathode-ray oscilloscopes and simple surge counters. In residential circuits, two significant sources of surge voltages were identified: load switching within the house, and external surges, most likely associated with lightning, coming through the service drop. In industrial circuits, the levels of surges are lower than in residential circuits. However, switching surges on the load side of the switch can be severe. Internally generated surges as high as 2500 volts were recorded during this test program, and surges due to lightning reaching 5600 volts have been recorded on a 120-volt overhead distribution line.

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Introduction

THE successful operation of semiconductors and new insulation systems in appliances and consumer electronic devices may be adversely affected by transient overvoltages occurring on the 120-volt power supply. Detection and measurement of these transient surges permits a designer to provide suitable built-in tolerance, or at least to recognize that there is a need for appropriate suppression or protection.

Special instrumentation has been developed for detection and measurement of surge voltages. In the first phase of testing, automatic recording cathode-ray oscilloscopes (CRO) provided complete information on waveshape, and on magnitude and frequency of occurrence at a small number of arbitrarily chosen locations. These data, although statistically restricted, were adequate to demonstrate the existence of the problem, define some sources, and indicate typical waveshapes. It also became clear that there was a need for a larger sample that would be more statistically valid. In the second phase of testing, 100 surge counters, simple in design and easy to install, were developed especially for this program. These counters were installed in several hundred homes in various cities located in the East and Midwest of the United States.

The purpose of this paper is to discuss recordings obtained during the two phases of this program and the statistical aspects of the results. It is hoped that publication of this paper will encourage other investigators to publish their findings. This would provide a broader statistical base for verification of the frequency and magnitude of surge voltages.

In regard to industrial circuits, less data have been accumulated, but a number of significant case histories are presented to illustrate the problems likely to be encountered in that field.

Instrumentation

Recording surge voltages in the field poses special problems. For example, the instruments cannot be continually attended, and the signals to be recorded are unpredictable in magnitude, polarity, and frequency of occurrence.

In cooperation with Tektronix, Inc., a type 515 CRO was modified to record transients on film, with automatic advance of the film after a recording.

The modifications involved a change in the trigger and sweep circuits, as well as removal of all knobs (an important detail for an instrument to be left in all types of locations).

Most oscilloscope trigger circuits are polarized. This often causes a loss of recording when the polarity of the initial signal is not known. For surge recording, the trigger circuit was modified by feeding to the time base trigger through two OR logic diodes the push–pull signal that is applied to the input of the oscilloscope delay line. With this modification, the sweep is started for either polarity, while the signal is delayed before reaching the deflection plate of the cathode-ray tube (CRT). In addition, the conventional blanking circuit holds the beam in low intensity before the sweep starts.

A second modification changed the sweep from a constant speed to a logarithmic speed, fast at the start and slow toward the end. This allows the recording of an impulse front with good resolution, while providing sufficient duration of the sweep to record a long tail.

Finally, a relay was added with its coil energized whenever the beam sweep is triggered. Through a set of contacts on this relay, the film advance sequence in the camera is activated.

The camera, attached to the scope bezel is a Beattie–Coleman system, accommodating 100 feet of 35-mm film, with no shutter, and recording on a 24- by 36-mm frame the trace displayed on the CRT. Following the sweep, the contact mentioned above closes the motor circuit, advancing the film to the next frame in a few seconds. This film transport duration is matched in the oscilloscope trigger circuit by a hold off so that no sweep will occur during film advance.

In order to prevent the film from being fogged by extended exposure to the faint glow on the phosphor (caused by imperfect blanking of the beam, cathode glow, or light leaks) a built-in timer in the oscilloscope advances the film by one frame every hour. This provides an approximate method for timing the occurrence of surges. Since the surge-voltage survey was conducted, an automatic time recording feature has been added to give a more precise recording of time at each event.

Fig. 1 shows this oscilloscope camera system. The relatively high cost of this system, its conspicuous presence (e.g., size, camera noise, etc.) in a home, and the amount of film to be scrutinized frame by frame limit the number of locations at which recordings can be made. However, for conclusions to rest on a sound statistical basis, it is necessary to investigate a large number of locations. To be acceptable to cooperative home owners, a transient detector should therefore lend itself to inconspicuous installation and simple data handling. Thus a device which can merely be plugged into a wall receptacle, and that has a digital counter indicating the number of surges occurring above a specified threshold is satisfactory for widespread recording.

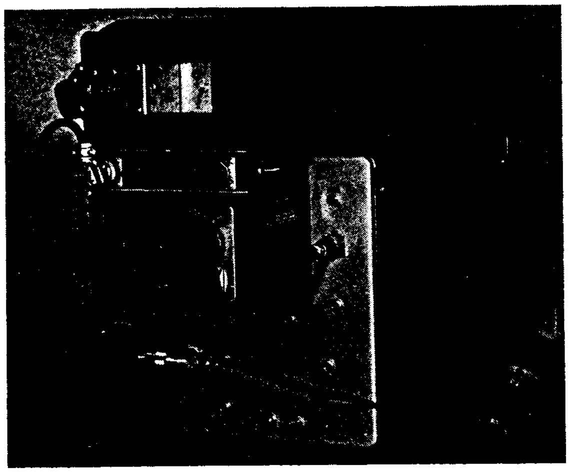

Fig. 1. Oscilloscope and camera.

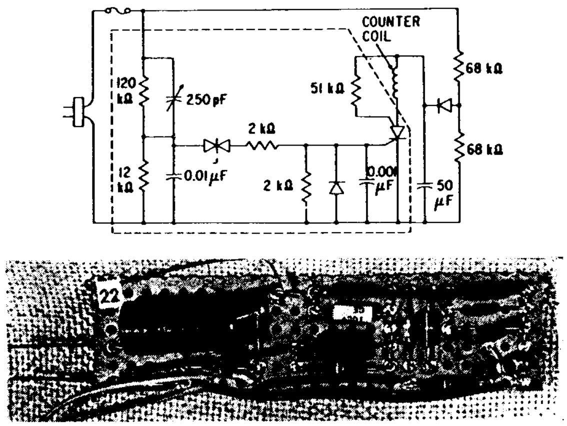

Fig. 2. Surge-counter circuit.

The circuit shown in Fig. 2 was developed for this purpose. This device is connected to a wall receptacle by a conventional appliance cord, not a special probe. This connection is simple, establishes a typical final path for a surge impinging upon any appliance connected to this particular wall receptacle, and provides power for the high-impedance rectifier circuit and a signal input to the trigger-sensor circuit.

A crudely compensated divider attenuates the incoming surge before application to the silicon symmetrical switch (SSS). This device has the characteristic of turning on abruptly whenever the voltage across it reaches a threshold, such as 250 volts. This threshold remains constant for durations as short as 0.1 μs. When the SSS turns on, the attenuated surge is applied to the gate of the very-sensitive fast-switching silicon controlled switch

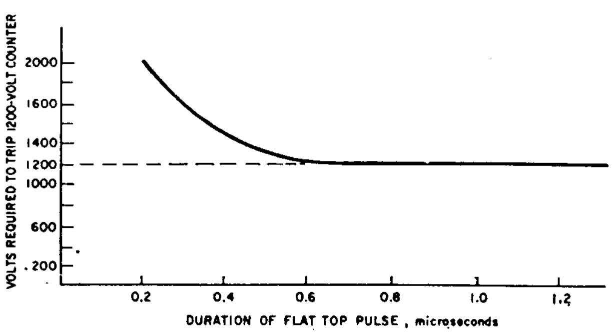

Fig. 3. Response characteristic of counter.

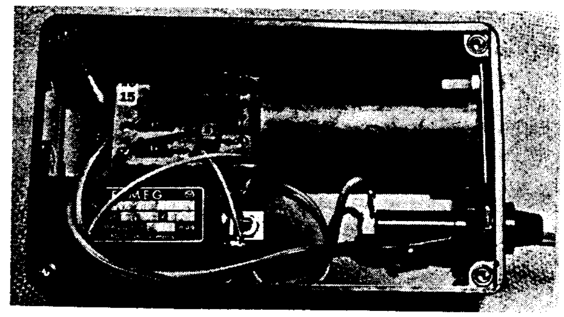

Fig. 4. Surge-counter package.

(SCS). If the polarity of this surge is positive, the SCS turns on, allowing the 50-μF capacitor to discharge through the coil of the solenoid-actuated counter. A high-impedance divider and half-wave rectifier provide a trickle charge 15-volt supply for the 50-μF capacitor. The resistance of this divider represents a negligible load for the house wiring system, yet is sufficiently low to allow some leakage in the electrolytic capacitor. The long charging time (several seconds) of the capacitor is not objectionable since the transients to be detected do not have a high repetition rate.

Calibration of the circuit is obtained by adjusting the value of the divider elements. In these tests, the threshold level was set at 1200 volts for one group of counters and at 2000 volts for another group. A bench circuit was set up, whereby a surge with adjustable level and duration could be superimposed on a 60-Hz 120-volt power supply. Some consideration was given to the need to segregate, or filter out, the surge from the 60-Hz power voltage; in this case, however, with the minimum level at 1200 volts, the base 170-volt crest represented a small contribution and was included in the signal detected by the circuit. Surges with approximately flat top and durations from several to 0.2 μs were applied to determine the variation of the threshold voltage as a function of surge duration. A typical response curve is shown in Fig. 3. The response of this crest-indicating counter can be considered satisfactory since the oscilloscope recordings in homes, as will be discussed later, have indicated that the shortest half-period of oscillatory surges is in the order of 2 μs.

Recording Procedure

In the first phase, oscilloscopes were installed at the basement service entrance of homes in the Schenectady, N. Y., area. These locations do not represent a statistician's ideal sampling, but during the initial phase of the program, the nature of transients, rather than statistical accuracy, was the major subject of interest. Later in the program, the range of locations was broadened to include homes in other urban and rural areas, particularly in Florida and South Carolina.

In the second phase, surge counters were installed at unspecified outlets in the homes of engineers in 20 cities in the Northeast and Midwest. Two distinct recording periods were scheduled: winter, because there is usually a minimum of lightning activity at that time of year; and summer, which ordinarily includes a maximum of lightning activity.

Since the oscilloscope input circuit operates at a level of a few volts, it is somewhat sensitive to direct radiation of electromagnetic noise in the preamplifier, even if there is no signal from the probe. In order to discriminate against this type of spurious

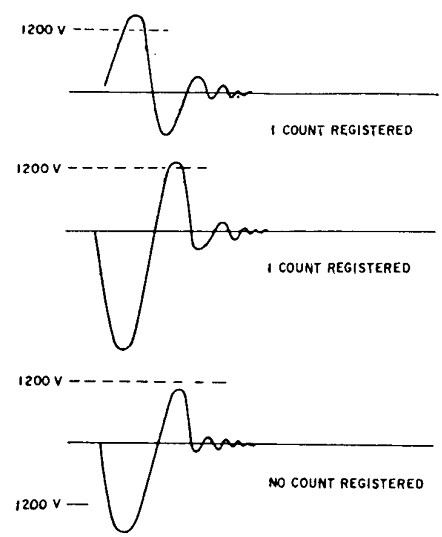

Fig. 5. Recording with single-polarity counter.

indication, the recording procedure included a period during which the oscilloscope probe was shorted with the ground terminal remaining connected so that spurious signals due to ground loops would be detected. In this manner, any noise entering the system could be recorded and later recognized for what it was in the analysis of the recordings made with the short circuit removed from the probe.

The surge counters record only one polarity; in order to minimize record keeping by the homeowner, the connection of the cord was not polarized. In the event of an oscillatory surge (which is always quickly damped in these systems), two cases of counting can occur. For instance, the high side of the divider can be connected to the "hot" terminal of the receptacle (Fig. 5). If the first half-cycle is positive and exceeds 1200 volts, a count is registered. If the first half-cycle is negative, and the second, positive half is highly damped, no count is registered. If the first half-cycle is well above 1200 volts causing the second half, in spite of some damping, to exceed 1200 volts, a count is registered. For the reverse connection, the same would occur for reverse polarity. Thus the actual number of surge occurrences of both polarities in excess of 1200 volts is between 1 and 2 times the number indicated by the counter. The objective of the recording in this test series was only to determine whether or not surges occurred rather than their exact number. Consequently, the value of the multiplying factor is not very significant.

TABLE I
DETAILED ANALYSIS OF RECORDED SURGES

House	Most Severe Surge			Most Frequent Surge			Average Surges per Hour	Remarks
	Type*	Crest (volts)	Duration (μs or cycles)	Type*	Crest (volts)	Duration (μs or cycles)		
1	A-1.5	700	10 μs	A-1.5	300	10 μs	0.07	
2	A-2.0	750	20 μs	A-2.0	500	20 μs	0.14	fluorescent light switching
3	B-0.5	600	1 cycle	B-0.5	300	1 cycle	0.05	
4	B-0.5	400	2 cycles	B-0.5	300	2 cycles	0.2	
5	C	640	5 μs	too few to show typical			10 total	
6	B-0.3	400	1 cycle	B-0.3	250	1 cycle	0.01	
7	B-1	1800	1 cycle	B-1.0	800	1 cycle	0.03	lightning storm
8	C	1200	10 μs	B-0.5	300	4 cycles	0.1	
9	B-0.25	1500	1 cycle	same as most severe			0.2	oil burner
10	B-0.25	2500	1 cycle	B-0.25	2000	1 cycle	0.4	oil burner
11	B-0.2	1500	1 cycle	same as most severe			0.15	water pump
12	B-0.2	1700	1 cycle	B-0.2	1400	1 cycle	0.06	oil burner
13	B-0.1	350	1 cycle	too few to show typical			4 total	house next to 12
14	C	800	15 μs	—	—	—	1 total	lightning
15	B-0.25	800	3 cycles	B-0.25	600	3 cycles	0.05	rural area
16	B-0.15	400	15 μs	B-0.13	200	30 μs	0.4	surges
Street pole	B-0.5	5600	4 cycles	B-0.3	1000	1 cycle	0.1	lightning stroke nearby
Hospital	C	2700	9 μs	C	900	5 μs	0.1	lightning storm
Hospital	B-0.3	1100	1 cycle	too few to show typical			4 total	
Department store	B-0.5	300	1 cycle	B-0.5	300	1 cycle	0.5	
Street pole	B-0.2	1400	4 cycles	B-0.2	600	4 cycles	0.07	lightning storm

* A—long oscillation; B—damped oscillation; C—unidirectional. Number shows frequency in megahertz.

RESULTS OF THE RECORDINGS

Oscilloscopes

The first recording analysis revealed that some homes were subject to frequent surge voltages, some experienced only a few isolated surges, and others did not experience any surges in excess of the trigger level (300 to 400 volts). Furthermore, among those installations where surge voltages frequently occurred, the surges at some houses were relatively low (rarely in excess of 800 volts), while other houses had surges in the range of 1200 to 2500 volts. Rates of surge occurrence ranged from 0 (no surge in 1 to 2 weeks) to 0.5 per hour, with peak values from 300 volts (trigger threshold) to 5600 volts.

At the conclusion of the recording program, a total of 30 locations, including two overhead distribution poles had been monitored for a total of about 10 000 hours. Table I shows a detailed analysis of the recordings at 21 locations. Three homes and six industrial locations did not produce any triggering with the threshold as low as 400 volts.

Further analysis of some recordings was made by deliberate switching of loads in the houses where frequent surges had been observed. In some cases, the operation of a specific device (e.g., oil burner, fluorescent lamp, pump motor, refrigerator, food mixer, etc.) was found to be the cause of the surges. In other cases, no amount of deliberate load switching could reproduce surges such as those recorded during unattended monitoring. The home owner was occasionally able to correlate surge recordings with lightning or power system disturbances.

A pattern emerged from all this information, showing two definite causes of surge voltages in the homes: load switching within the house and lightning storms.

Load Switching: Load switching in the house occasionally produced transient surges; these affected only that particular house. For any particular house, these transient surges had a waveshape which was consistently repeated with variations in amplitude along the entire film recording. This probably resulted from a combination of the switch characteristics and the impedance of the house wiring system; the variations in amplitude were probably caused by variations of the switching angle and/or connected loads. In an industrial circuit, the same repetition of a particular pattern was also noted [1]. Typical waveshapes of the recorded surges are shown in Figs. 6–8.

In one case, it was possible to install an oscilloscope in a house adjacent to that where repetitive surges up to 1700 volts were being recorded. The service drops were connected to the same pole, yet no surges occurring simultaneously were recorded in the second house.

Lightning: Surge voltages not associated with load switching within the house were associated with lightning storms. In some cases, the home owner was able to correlate the film advance counts with the storm. Although recorded during lightning storms at two different locations, the surges shown in Figs. 9 and 10 present the interesting characteristic of being oscillatory at a frequency in the range of 300 kHz. The surge shown in Fig. 9 was recorded at the overhead distribution line (oscilloscope mounted on the pole), while the surge of Fig. 10 was recorded at the service entrance in a home. The first exhibits far less damping than the second; this might be explained by the lower damping due to lower resistance of the system at the pole than at the end of a service drop. Both of these surges, as well as most of the other surges recorded during lightning storms, exhibit this oscillatory characteristic at a frequency which is nearly constant for a particular locality. This constancy suggests that the oscillation of the system followed an excitation caused by the lightning stroke. A number of surges in the range of 800 to 1200 volts were observed during several storms. The maximum

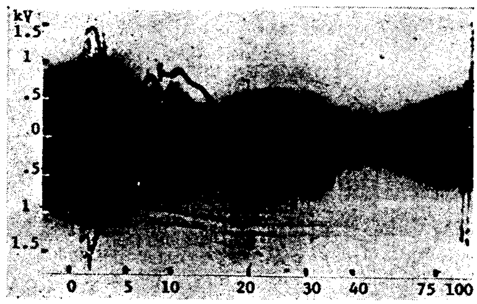

Fig. 6. Residential surges, 24-hour composite. Black band is ±170-volt sweeps at hourly intervals.

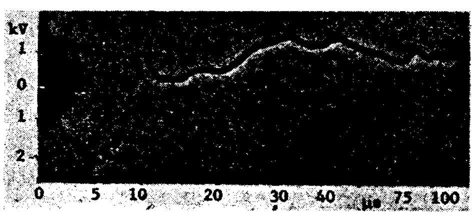

Fig. 7. Residential surge, oil burner ignition.

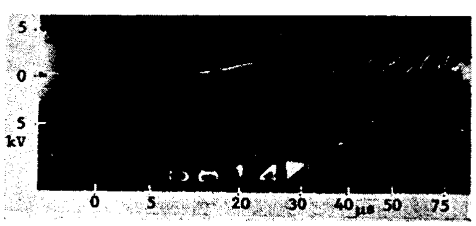

Fig. 8. Industrial circuit. Surge due to equipment maintenance; note digital timer record.

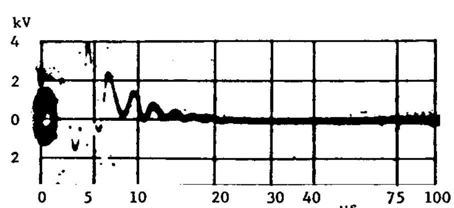

Fig. 9. Surge recorded on street pole in Charleston, N. C.

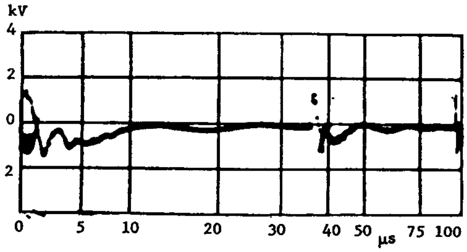

Fig. 10. Surge recorded at service entrance of Florida home.

TABLE II
NUMBER OF HOUSES WITH REPETITIVE SURGE ACTIVITY ABOVE 1200 VOLTS

Location	Number of Homes Surveyed	Recording Period (weeks)	Houses with Repetitive Surges
Providence, R. I.	4	2–6	none
Cleveland, Ohio	28	2–4	none
Auburn, N. Y.	12	2–3	none
Lynchburg, Va.	3	2–3	none
Syracuse, N. Y.	8	1–2	1
Chicago, Ill.	23	1–6	none
Ashland, Mass.	24	1–2	1
Holland, Mich.	6	2–10	none
Louisville, Ky.	10	2–6	none
Somersworth, N. H.	50	1–2	1
Plainville, Conn.	5	10	none
Asheboro, N. C.	24	1–2	none
Fort Wayne, Ind.	38	1–4	3
DeKalb, Ill.	14	3–12	none

TABLE III
SURGE COUNTER RECORDINGS ABOVE 1200 VOLTS (SPRING, SUMMER, AND FALL)

Location	Number of Homes	Total Homes × Weeks	Number of Surges
Providence, R. I.	6	60	1
Ashboro, N. C.	13	85	none
DeKalb, Ill.	11	60	2
Somersworth, N. H.	3	48	1
Chicago, Ill.	12	58	none
Cleveland, Ohio	8	106	1
Decatur, Ill.	12	72	2
Holland, Mich.	7	56	none
Auburn, N. Y.	3	70	none
Springfield, Pa.	1	24	none
Ashland, Mass.	6	72	none
Pittsfield, Mass.	3	60	1
Plainville, Conn.	3	60	none
Lynchburg, Va.	3	15	none
Total	91	846	8 in 8 homes

surge voltage recorded was 5600 volts; several other surges recorded during the same period were in excess of 4000 volts [-]

Counters

With the two causes of transients identified by the oscilloscope measurements, the surge counters were applied in two separate programs. First, during the winter months, the counters were installed in a large number of houses for periods of 1 or 2 weeks; the objective was to determine how many houses sustained repetitive surges. Second, during spring, summer, and fall, each counter was left at one or two locations for periods of 9 to 48 weeks; it was known from the first test that these homes were not subject to load switching surges. The objective was to determine the frequency and characteristics of externally generated surges, presumably caused by lightning.

The first period produced the data shown in Table II, and the results obtained during the second period are shown in Table III.

Statistical Analysis of the Recordings

Internally Generated Surges

The data in Table II show that 6 houses, or 2.4 percent, were subject to repetitive surges from among a total of 250 homes sampled. The true percentage doubtless differs somewhat from 2.4 percent due to statistical variations.

However, one may be 90-percent confident that the true percentage is between 1.0 and 4.7 percent.[1] This band could be narrowed by taking additional samples. However, it should be noted that the precision is proportional to the square root of the sample size. Thus four times the number sampled, or 1000 homes, would be necessary to cut the size of the statistical error band by approximately one half. Since the preceding results refer to statistical variations only, they do not take into account possible biases due to such factors as restrictions in selecting members of the sample (principally engineers in a number of designated locations) or the time of year (winter months).

The probability of internally generated surges undoubtedly varies among economic groupings (i.e., the devices in use in homes probably vary with the economic status of the resident); however, devices found to generate surges (i.e., furnaces, refrigerators, etc.) exist in most homes.

Externally Generated Surges

Results from the second testing period that was concerned with externally generated surges are shown in Table III. From 39 counters installed in a total of 91 homes in 14 localities, a total of 8 occurrences in 6 separate localities were observed during an equivalent exposure time of 846 weeks. A ninth occurrence was disregarded in this analysis because it occurred in the same home during the same storm. Of the two pairs of occurrences which took place in the same location, one pair occurred during the same storm and the second involved two occurrences at different times.

Analyses could be conducted based on the following alternative assumptions.

1) Voltage surges above 1200 volts occur only during the period of the year that the counters were installed in the homes. Thus although the counters were in homes for only part of the year, the time involved (i.e., the summer months) was so chosen that no further surges would have been noted even if each counter had been run for 52 consecutive weeks. The average number of surges per year would then be estimated as 8/39, or 0.205, with a 90-percent confidence band of 0.102 to 0.370.

2) Voltage surges occur randomly at a constant rate throughout the year. Thus a counter which was in use 9 weeks, on the average, would be subject to a third as many surges as a counter in use for a period of 27 weeks. Under this assumption, a total of 8 surges observed in a total time equivalent to 16 years (846 weeks) yield an estimated average of 0.5 surges per year, with a 90-percent confidence band of 0.25 to 0.90.

Using these two extreme assumptions, a range could be established for the estimated number of surges per year. The preceding calculations refer only to single-polarity surges. If all surges are being considered, the given value must be multiplied by a value corresponding to the additional proportion of opposite polarity surges above 1200 volts which do not also result in positive surges above 1200 volts. This multiplying factor is probably about 1.6.

Lightning-induced surges are likely to affect more than one house when they occur. Local geographical and meteorological conditions are critical influences on these surges; however, these factors could not be considered in this preliminary investigation.

To relate the preceding data to risk of appliance failure, the given values must be modified by the probability that a surge above 1200 volts would cause failure of operating appliances. Failure effects would vary with different appliances.

Possible Further Analysis

A more refined analysis to estimate the probability of voltage surges per lightning storm is possible if the geographical location of the homes, the occurrence rate of lightning storms during the testing period, and exact dates at which voltage surges occur is considered. The resulting values can then be used in conjunction with information given in [8], [9] to calculate the probability of a voltage surge in any specified geographic area and season. Such an analysis would remove the need for making one of the two alternative assumptions stated previously and lead to a single set of estimates. However, this would require more detailed data than could be collected in this program.

Finally, it is noted that if one has knowledge of the actual voltage surges, rather than merely the information concerning whether or not a surge above 1200 volts occurred, a more sensitive analysis is possible. In this case, for example, probability plotting and other techniques based upon the statistical theory of extreme values [5], [7] might well be applicable.

Effects of Surge Voltages on Connected Electrical Devices

The surges which have been recorded in this program occurred during normal operation of the household, with no knowledge of the connected load situation at the time of occurrence.

The question of energy involved in the surge is related to the impedance of the system since these recordings provide voltage data only. Surge impedance measurements of a house wiring cable indicate a value of 100 to 300 ohms for a typical branch circuit so that the surge impedance at the service entrance could be in the order of 5 to 10 ohms. However, this low value exists only for the travel time (i.e., a fraction of a microsecond). Connected loads will have a lower impedance than that of the branch circuit. This value will be dependent upon frequency whenever inductive components are present. These loads will absorb part of the energy of the surges and thus lower their peak.

Devices such as motors and transformers have solid insulation and such a long history of successful application that their performance is not in question. Perhaps unusual failures can be explained by extreme values of surges as indicated by the data.

Defective wiring practices (e.g., pinched insulation, reduced air clearances in wall boxes, etc.) will cause air flashover with or without 60-Hz power follow. In fact, one house was brought to our attention because of complaints of sparking in a light fixture. With the switch in the ground wire and the frame attached to a grounded pipe, flashover at 1700 volts was observed in correlation with the start of an oil burner in the house. This defective light fixture was acting as a voltage limiting gap for the house.

[1] This result is obtained by the well-known method of setting confidence intervals for a percentage from a sample. Further details may be found in statistical texts [3]–[5].

Appliances containing semiconductors and directly exposed to the line transients may be more vulnerable. Actually, the 1200-volt threshold level was selected as the result of this consideration. It is interesting to note that, although a number of surges above 2000 volts were recorded by the oscilloscopes, the few surge counters calibrated for 2000 rather than 1200 volts did not produce any recording above 2000 volts.

An independent study of clock motor failures produced information on failure rates versus withstand levels. This study was very pertinent to the surge counter program since thousands of clocks are connected at all times to the power system. Over a period of 3 years, failure rates were correlated with the insulation level of the coils. A very significant 100 to 1 drop in failure rate resulted from an increase in withstand voltage from approximately 2000 to approximately 6000 volts. This shows that, even though no surges over 2000 volts were recorded by the 2000-volt counters, surges in excess of 2000 volts do indeed occur.

Industrial Circuit Case Histories

The authors have been associated with a number of investigations where surges were suspected to be the cause of equipment problems. In the industrial environment, isolated cases tend to attract more attention than in residential circuits. The few case histories briefly summarized in this paper illustrate the types of problems likely to be encountered, where often surges are not in fact the cause of the problem, but where the presence of the test crew at the site precipitates a more thorough evaluation of the problem and sometimes reveals an unsuspected new fact.

On the occasion of these investigations, the surge counters were installed at the same time on the system and left for several weeks or months at the site whenever possible. So far, in over 15 locations, no surge over 1200 volts has been recorded on 240- or 480-volt buses ("mains"). On the other hand, severe surges have sometimes been recorded on the load side of the switch. However, these load side surges are associated with the subsystem operation and can be controlled (if recognized) by the subsystem designer or operator, in contrast with the surges on the mains that affect all users in the house, building, or plant, and on which they have little control.

Problem

Occasional flashover in a 480-volt distribution system at a steel welding shop.

Suspect: Switching surges associated with arc welding.

Investigation: Install surge recording oscilloscopes on the bus.

Result: No surges recorded.

Second Investigation: Power factor capacitors had been installed on the bus, but this fact had not been revealed by the initial discussions; their presence on the bus practically eliminated the possibility of surges on the bus. (Switching the whole bus system was tested and produced no surges in this case.) Final conclusion was contamination of the insulation in the polluted atmosphere.

Problem

Failures of a 480-volt saturable reactor in a motor control system.

Suspect: Switching surges associated with contactor operation.

Investigation: Record surges on site during deliberate, controlled switching of the contactor.

Result: Contactor bouncing and restrike produce a number of steep front (0.1 μs) surges on the winding, causing excessive turn-to-turn stress.

Problem

Failures of rotor windings in 440-volt induction motors in a crane system.

Suspect: Switching surges associated with contactor operation.

Investigation: Record surges with monitoring oscilloscope during deliberate, controlled switching of the contactor.

Result: No excessive surges found; however the test crew notices during the on-site test that the overspeed protection of the motor control had been bypassed by the user.

Problem

Frequent blowing of fuses in a power factor correction capacitor bank.

Suspect: Switching surges.

Investigation: Record current in the fuse and system voltage during switching operation.

Result: Contactor bouncing produces a number of inrush current surges exceeding the rms capability of the fuse.

Problem

Failures of lamp ballasts in an industrial plant.

Suspect: Switching surges.

Investigation: Install monitoring oscilloscopes.

Results: No surges found in several weeks of monitoring, no further problem.

Conclusion: The best surge suppressor is a surge monitor.

Conclusions

1) Residential power circuits are subjected to surge voltages due to two distinct causes: load switching within the house, and externally generated surges that are most likely associated with lightning.

2) Internally generated surges caused by load switching are likely to be repetitive. They can generally be associated with a specific device, probably operating erratically or exciting some natural frequency of the wiring system. They are not related to lightning or disturbances from the utility. Peaks as high as 2500 volts have been observed. The best single statistical estimate is that 2.4 percent of households of the type sampled experience these internally generated repetitive surges in excess of 1200 volts. However, because of the statistical variability in the sample, this value may be as low as 1 percent or as high as 4.7 percent. Surges may be repeated several times a day.

3) The frequency of surges caused by lightning is not affected by household electrical devices but rather by local geographical and meteorological conditions. The limited data in this program reveal several lightning-caused surge occurrences above 3000 volts with one reaching 5600 volts.

4) Independent evidence shows that a significant number of surges above 2000 volts do occur periodically in residential power lines.

5) Industrial power circuits appear less likely to be subjected to surges on the mains. However, switching surges in subsystems can originate at the switch and affect the loads.

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