Lightning Protection of Residential AC Wiring

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Significance:
Part 4 – Propagation and coupling of surges
Part 8 – Coordination of cascaded SPDs

Laboratory tests on the coupling of lightning current (flowing in the service drop grounded neutral conductor) onto the phase conductors, inducing overvoltages that were limited by candidate surge suppressors.

While the injected lightning-simulation current was unidirectional, the induced voltages in the house wiring circuits had oscillatory components. This observation was used in support of the development of the "Ring Wave" concept that was adopted by IEEE 587 (now C62.41).

Three possible types of service entrance SPD of 1960-1970 vintage were investigated
- The then-commercially available silicon carbide/gap arrester
- Metal oxide varistors mounted external to the load center
- Metal oxide varistors fitted in a panel breaker housing for easy plug-in connection

The branch circuit SPD consisted of a simple MOV disc incorporated in a modified plug-and-receptacle combination, probably the first attempt at packaging an MOV for residential surge protection.

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* *The experimental work, reported by F.D. Martzloff, involved performing the tests , recording of nearly 300 Polaroid oscillograms, and was conducted by K.E. Crouch at the General Electric High Voltage Laboratory prior to his change to Lightning Technologies, Inc.*

GENERAL ELECTRIC

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LIGHTNING PROTECTION OF RESIDENTIAL AC WIRING

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Automation and Control Laboratory

ABSTRACT

New transient suppressors using metal oxide varistors offer improved protection of appliances and consumer electronics against overvoltages. This improvement, however, could be at the risk of imposing excessive duty on the suppressor in case of a very severe lightning stroke near the house where these suppressors are installed.

A simulated house wiring system was subjected to three levels of lightning currents injected into the ground wires (moderate, severe, extremely severe), with various combinations of suppressors installed alone or in a coordinated combination.

Test results show that an effective and safe combination of devices can be specified for full protection of the loads in the house.

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November 16, 1987
Building K-1, Room 2A16

Dr. F.D. Martzloff
Room B162, Building 220
National Bureau of Standards
Gaithersburg, MD 20899

Dear Dr. Martzloff:

Attached are copies of technical information series reports that you requested from Dr. Bernstein. Several other reports that were requested by you have not been reclassified to Class 1, and therefore, may not be released.

If you have any questions or if I can be of further assistance, please do not hesitate to contact me.

Sincerely,

B.J. Ortman

B.J. Ortman, CRD Technical
Report Administrator

Attachments

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July 1978

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LIGHTNING PROTECTION OF RESIDENTIAL AC WIRING

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INTRODUCTION

The development of metal oxide varistors has opened new opportunities for transient suppression in residential power circuits. The Wiring Device Department of the General Electric Company has introduced the VSP-1 protector, which contains a 14 mm GE-MOV ® varistor. The HLP (Home Lightning Protector) has been available for many years, but the hot-line work required for its installation has been a deterrent; and, consequently, this protector has not been very widely applied. The new 32 mm GE-MOV ® varistor offers higher capacity than the 14 and 20 mm discs. Prior to reassignment of the product scope to the Distribution Transformer Department and later the Circuit Protective Devices Department, tests made in Pittsfield by J.S. Kresge had demonstrated that this 32 mm disc could meet the ANSI secondary requirements. By different packaging, the hot-line work might be eliminated and performance improved, opening the opportunity for greater acceptance.

Therefore, the possibility of a coordinated protection system in residential power circuits meeting ANSI requirements became a more likely prospect than an earlier investigation had predicted for coordination between the present design of the HLP and the VSP-1.(1) While there is little evidence that extremely high currents caused by lightning strokes enter far into the house wiring, it seemed worthy of investigation to postulate a condition of "severe" lightning discharge near the house and to attempt recording on a simplified model wiring system how the currents and voltages would be distributed. This report describes the assumptions, test procedures, results, and conclusions of such an investigation.

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OVERVIEW

The injection of a high current — presumably a lightning discharge — into the ground conductor of the service drop, without direct injection into the phase wires, is sufficient to induce voltage in excess of the clearance withstand of wiring devices. The transmission characteristics of the model and the relative sparkover levels were such that internal devices (receptacles) flashed over before the watt-hour meter gaps could flash over.

Coordination between a centrally located surge arrester and an outlet-connected protector is possible; substantial, but within rating, currents flow in the outlet protector (VSP-1) when coordinated with a Home Lightning Protector (silicon carbide and gap) or its candidate successor, the 32 mm GE-MOV® varistor.

For extreme strokes (100 kA at the pole), current in excess of rating can flow in VSP-1 protectors located close to the service entrance without other arresters. While they could fail there, the protectors do not present a greater hazard than an air clearance, which would flash over were there no protector; and, in fact, the presence of the VSP-1 is more likely to reduce the hazard of a flashover with subsequent 60 Hz power-follow.

The addition of a 32 mm varistor to the system, either in a plug-in (inboard) version or as an external addition (outboard) to the load center, will provide protection consistent with the ANSI requirements for secondary arresters.

1.0 ASSUMPTIONS

1.1 Current Magnitudes

It was postulated that a lightning stroke attaching to the primary side of an overhead distribution system would produce a branching of the current flow into the ground, following sparkover of the surge arrester, which was presumed connected at the pole-mounted distribution transformer. Figure 1 shows the assumed circuit and the division of current flow.

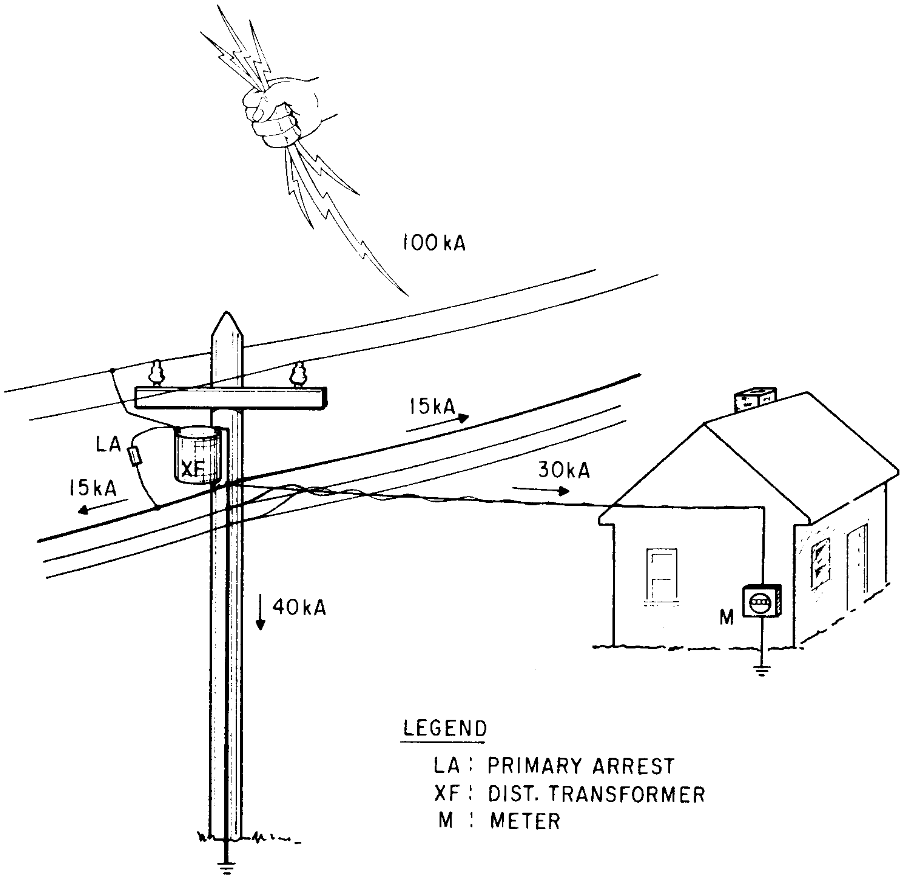

Figure 1. Division of Current Assumed for a 100 kA Stroke

In their study of lightning environments, Cianos and Pierce[2] indicate that only 5% of all ground strokes exceed a peak current of 100 kA. The frequency of the strokes is quite dependent upon geographic location (isokeraunic levels),[3] as well as upon local configurations. An average expectation of a stroke involving the utility pole near a house with no adjacent tall trees or buildings may be in the order of one per 400 years for most of the U.S. Thus, for a 5% probability, the likelihood is one stroke in excess of 100 kA per 8,000 years. With nearby tall objects, this likelihood can be reduced 10 times; in areas of high lightning activities, this likelihood can be increased 10 times. The level of 100 kA, then, represents an expectation of being exceeded at one location only one time in perhaps 10,000 years (but there are millions of poles in the U.S.).

From these assessments, the maximum current to be injected for the house model under discussion was selected to be 30 kA. From this maximum of 30 kA injected into the ground wire of the house service drop, two more values were used during the test series: 10 kA, corresponding to the requirement for the ANSI high-current, short-duration test; and 1.5 kA, corresponding to the requirement for the ANSI duty-cycle test — both specified by ANSI Standard C 62.1 for secondary valve arresters.[4]

Another reason for selecting this low level (1.5 kA) is that no sparkover occurs in the wiring at this level. For the 10 and 30 kA levels, multiple flashovers would occur at variable times and locations, making exact duplication of tests impossible. By staying below sparkover levels, repeatability of the results was ensured, allowing comparisons among several alternate circuit configurations.

1.2 Waveshape

From ANSI Standard C 62.1, a waveshape of 8 x 20 μs would have been desirable. However, limitations in the test circuit required for driving 30 kA in the model loop forced a compromise of 10 x 25 μs as the test wave.

1.3 Lightning Current Path

It should be noted that, in this test series, the assumption was made that the lightning current, applied first to the distribution primary (the highest wire on the pole) is transferred to the ground system by sparkover of an assumed surge arrester on the primary at the pole. In fact, if there were no arrester, an equivalent effect by direct flashover could be expected.

For the secondary side, however, the assumption was made that both sides (phases) of the center-tapped (grounded) secondary remained uninvolved in conducting the direct lightning current, while the ground wire (messenger) from pole to house carried its share, as defined in Figure 1.

1.4 Induced Voltages

The generation of transient voltages in the house is attributed to electromagnetic coupling of the field established by the lightning current flowing in the messenger into the loop formed by the two phase wires encircling the messenger. In addition, there is some capacitive coupling between the wires (Figure 2).

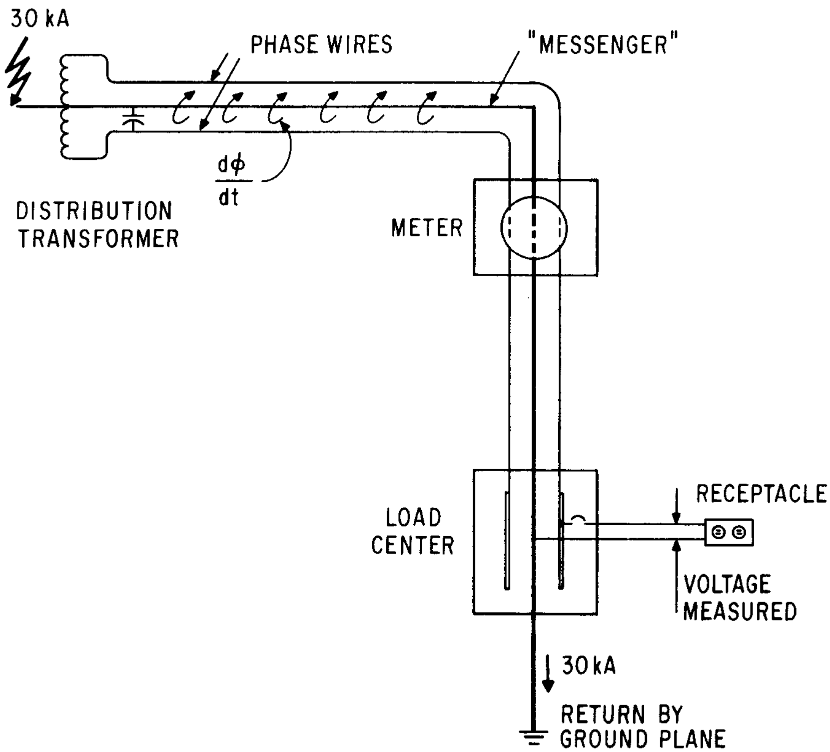

Figure 2. Voltages Induced in the House Wiring Systems

2.0 TEST CIRCUIT AND TEST PROCEDURE

2.1 Power Circuits

The test circuit consisted of a high-current impulse generator, a distribution transformer with service drop, a simulated simplified house wiring system, and the necessary shielded instrumentation (Figure 3). Details of the catalog numbers, characteristics, etc., are given in the Appendix.

The service drop connection between the distribution transformer and the meter socket was made with three AWG #6 wires, twisted at a pitch of about 5 turns/m (1.5 turns/ft), 13 m (45 ft) long. This service drop was folded in a loose "S" shape, at about 0.5 m (1.5 ft) above the ground plane serving as the return path for the lightning current, in order to reduce the loop inductance seen by the generator. This configuration does not influence the coupling between the messenger and the wires wrapped around it, coupling which has been identified as the voltage-inducing mechanism.

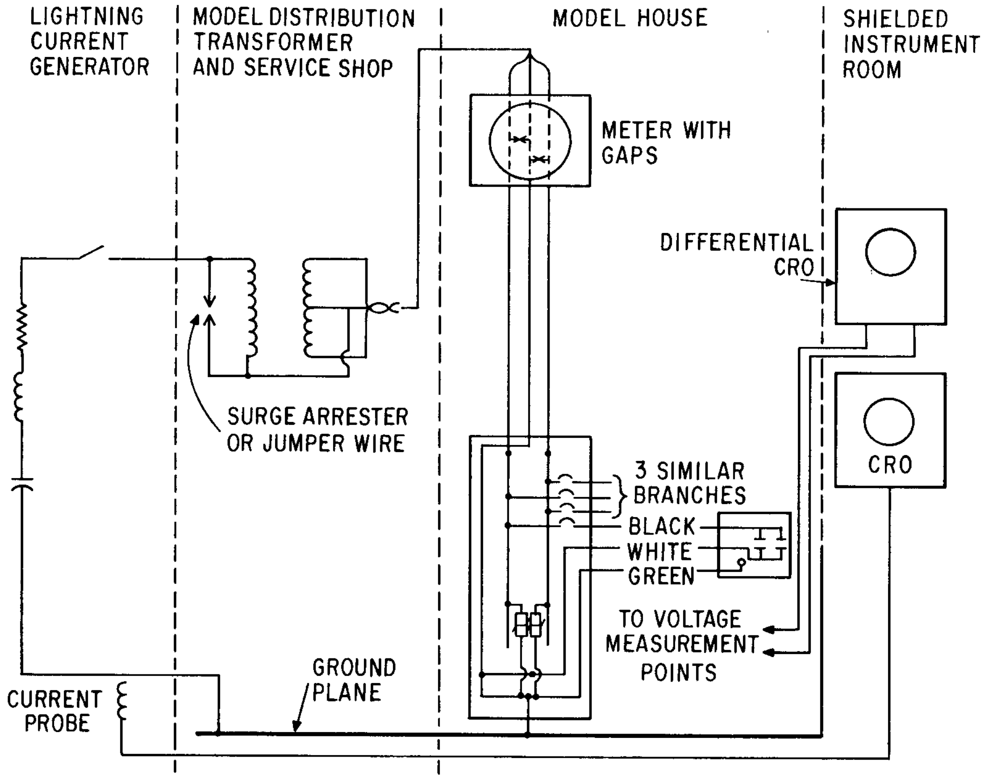

Figure 3. Schematic Representation of Test Circuit

The simulated house wiring started at the meter socket and continued to a load center by a 3 m (10 ft) length of AWG #6 aluminum entrance cable. The meter socket, watt-hour meter, and load center were typical General Electric Company hardware (see Appendix), except as noted in the detailed procedure description. From this load center, four "branch circuits" connected to the load center breakers were established, each terminating at a wall receptable mounted on the same 1.2 by 2.4 m (4 by 8 ft) plywood panel on which the watt-hour meter and load center were also mounted. The branch circuits' lengths were (one each) 6, 12, 24, and 48 m (20, 40, 80, and 160 ft), the wire being loosely coiled between the load center and receptacles (Figure 4).

2.2 Instrumentation

Recordings of currents and voltages were made at several points on the wiring system with cathode ray oscilloscopes (CRO); differential measurements were made for the voltages with especially built 100:1 probes. These probes were built by placing a 5000 Ω resistor in series with a terminated 50 Ω coaxial cable — all of these contained

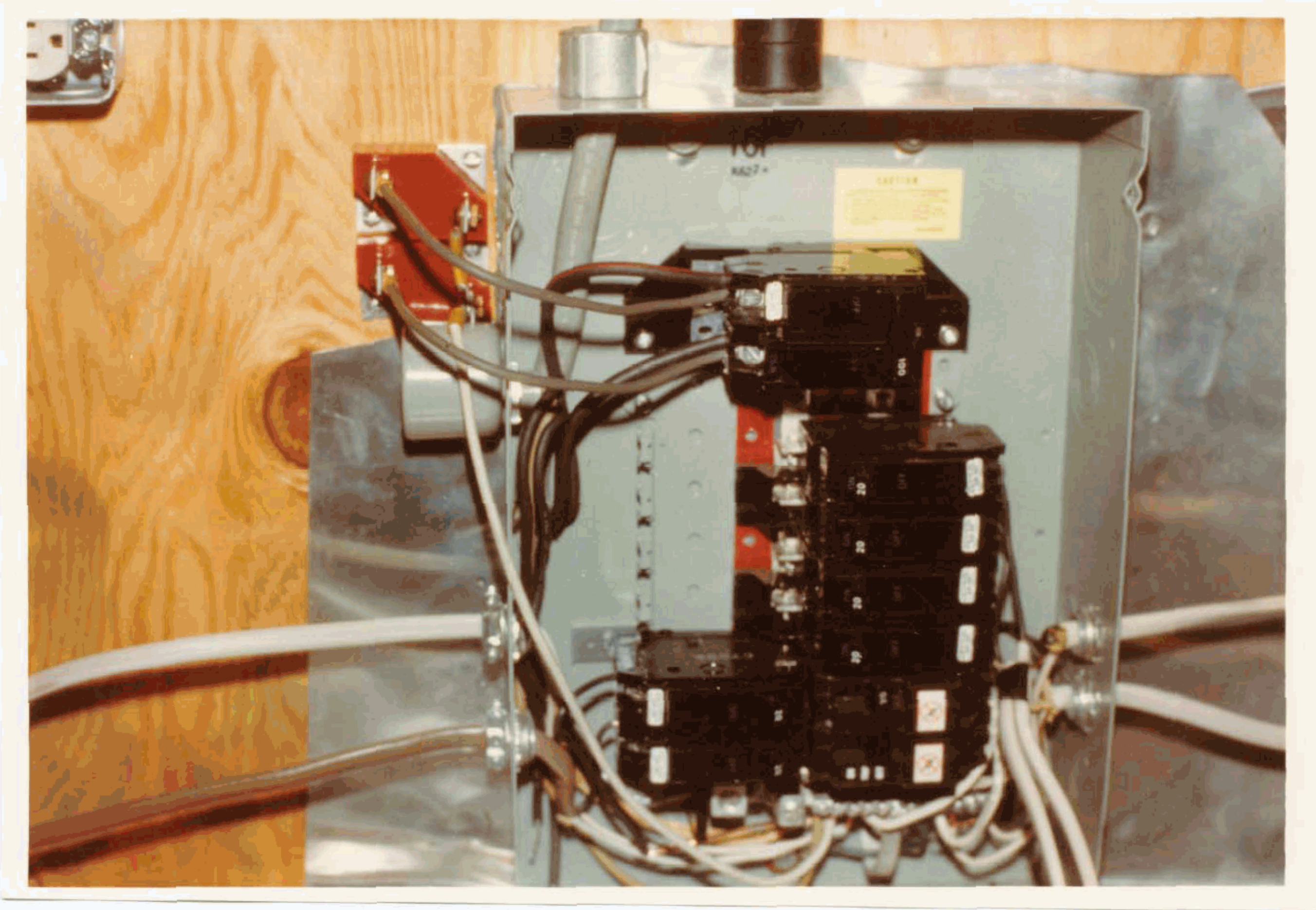

Figure 4. Connections at Load Center

in a shield tied to the ground plane part of the shielded instrument room. Currents flowing in the suppressors were measured by means of a Pearson Model 110 A wide-frequency-band current transformer. The oscilloscopes were located inside the shielded control room adjacent to the test area, providing satisfactory protection against spurious signals (see Figure 6 in Section 2.4).

2.3 Candidate Suppressors

Four candidate suppressors were installed at various locations in the system, for various comparisons of performance:

1. One Home Lightning Protector (HLP, GE Cat. 9L15DC B002) was installed at the load center; when connected to the circuit, the connection was at

the incoming lugs of the load center, as it would normally be when connected by an electrician.

2. Two V250HE80 varistors were mounted near the load center and connected to the incoming lugs of the load center. This connection required about 45 cm (18 in) of #10 copper wire. The return to ground was common to the two discs, as it is for the HLP device.

   (The varistor package contains a 32 mm disc with characteristics suitable for secondary arrester duty.[4] It is the candidate metal-oxide varistor substitute for, or successor of, the Thyrite®- gap combination currently used in the HLP, and has an RMS voltage of 250 V.)

3. Two 32 mm varistor discs of the same characteristics as (2) (above) were installed by the Circuit Protective Device Department in a breaker housing so that they could be connected to the load center bus with a minimum of lead (10 cm, or 4 in). This connection can be made while the load center is energized without requiring "hot work," in the same manner as inserting additional breakers on the load center.

4. VSP-1 spike protectors, produced by the Wiring Device Department, were inserted in the receptacle at the end of the branch circuits. (The VSP-1 protector contains a 14 mm GE-MOV® varistor with a voltage rating of 170 V RMS.[5]

5. In addition, the meter contained its standard gaps rated for a 10 kV sparkover.

2.4 Test Procedure

Preliminary tests indicated that flashover at the receptacles would occur with 10 kA injected into the ground messenger, but no sparkover of the meter gaps was apparent. Therefore, a first test series was conducted at only 1.5 kA in order to provide consistent patterns of wave propagation undisturbed by flashover (Figure 5).

It was also found that the auxiliary impulse generator used to trigger the main gap of the high-current generator induced voltages into the test circuit that could exceed those induced by the main discharge. A mechanical switch for closing the circuits was then substituted for the triggered gap.

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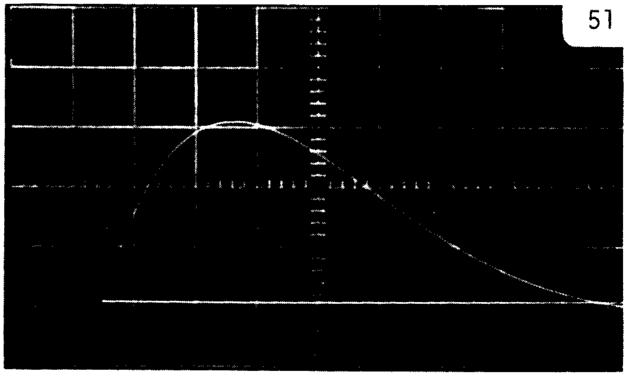
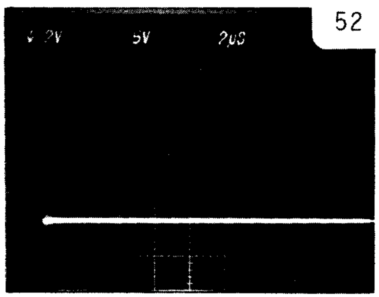


VERTICAL - 500 A/div

HORIZONTAL - 5 μs/div

Figure 5. Applied Current Waveshape - 1.5 kA Crest, 10 x 25 μs

Noise checks were made for the voltage measurement system by shorting the probes together and attaching them to the neutral point on the circuit under test. Similarly, the center conductor of the cable to the current transformer was removed from the transformer output and connected to its sheath. No significant voltages (greater than 5% of measured signal) were measured. A typical noise check oscillogram is shown in Figure 6.



VERTICAL - 5 V/div

HORIZONTAL - 2 μs/div

Figure 6. Typical Noise Response of Measurement System with 1.5 kA Injection

Since the worst case (little attenuation) is expected when there is little load connected to the system, most test measurements were made without loads attached to the outlets in the simulation. Measurements were also made with typical house loads connected to the outlets. These loads were a 100 W light bulb, which was represented by a 130 Ω resistor, a 1/2 hp single-phase induction appliance motor, and the input stage of a television circuit, as shown in Figure 7.

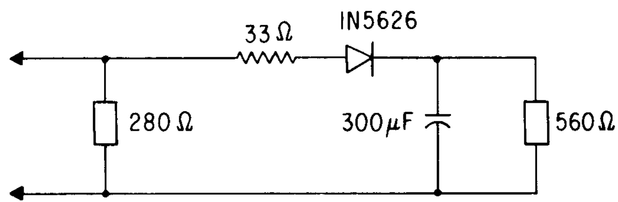


Figure 7. Television Input Stage

Various combinations of loads and suppressors at various locations were investigated. The specific test conditions are described for each particular test in Section 3, which presents the results and discussions of the tests.

3.0 TEST RESULTS AND DISCUSSION

3.1 Test Results

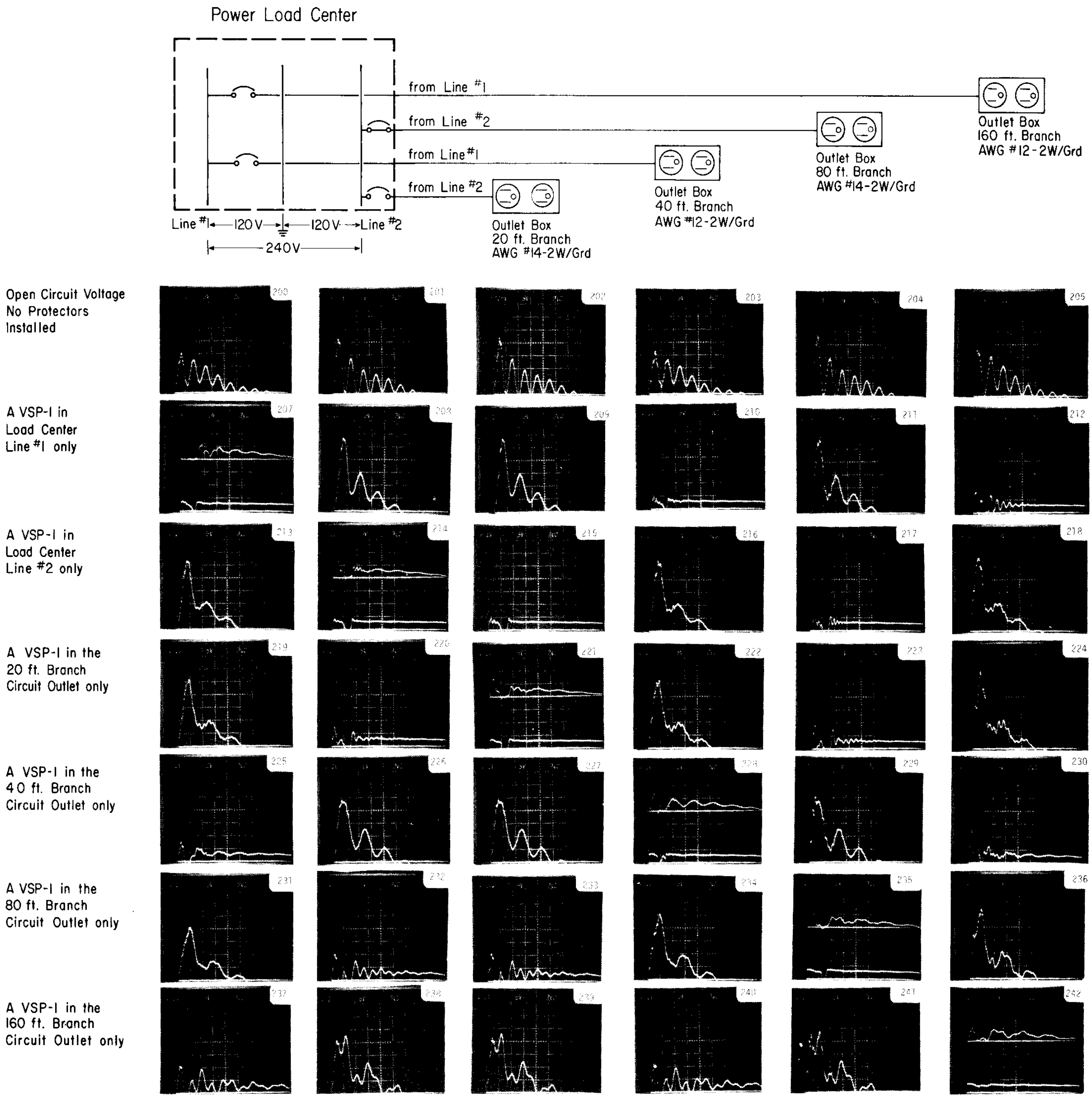
A large number of tests were performed to investigate the effects of various combinations. From several hundred recorded oscillograms, a selection was made, as shown in this section, to illustrate these effects. The results are presented in the form of a matrix of oscillograms with corresponding commentary, generally providing a comparison of voltage and currents with or without protectors installed. First, a qualitative summary is presented, then some comparative oscillograms are shown to illustrate various effects.

Figure 8 gives a qualitative summary of the effects obtained by installing a single protector at various locations in the system. The oscillograms are arranged in horizontal rows corresponding to the circuit configuration indicated in the legend. The vertical columns correspond to the location at which the oscillograms were recorded. From left to right appear Lines 1 and 2 of the load center, and the ends of the branch circuits at 6, 12, 24, and 48 m (20, 40, 80, and 160 ft), which will be referred to as B20, B40, B80, and B160. Quantitative information will be given in subsequent figures.

In the first row, open-circuit voltages are shown. Note that the voltages at three locations of the Line 1 conductor are very similar, while there is a small difference between Line 1 and Line 2.

The installation of a protector in Line 1 of the load center (second row of oscillograms) clamps the voltage on all Line 1 points, with some oscillations induced at the end of the B160 branch. While the initial peak of the Line 2 points is not changed, subsequent oscillations have lower frequency than in the open-circuit mode. For the oscillograms corresponding to the location where a protector is installed, the upper trace shows the current flowing in the protectors.

The installation of a protector in Line 2 of the load center (third row) produces results analogous to the Line 1 case. Installation of a protector at the end of a branch rather than at the load center (last four rows) produces clamping of the voltage at the point of installation. At the other points of the same line, the effectiveness of the clamping decreases as the protector is farther away. For the line with no protector, there is a minor voltage reduction and a frequency change similar to that noted in the first two rows.



Simulated Household Wiring System With Measurements at Various Branches With and Without a VSP-1 Protector Installed at a Single Point in the System.
1500 Amperes, 10 x 25 Microsecond Current Pulse Applied to Service Neutral.

Figure 8. Summary of Protector Effects

DISTRIBUTION TRANSFORMER ARRANGEMENT

In the simulation of the system, the circuit configuration at the pole and distribution transformer assumed that the lightning stroke had terminated on the primary conductor and that the primary arrester installed to protect the distribution transformer had sparked over.

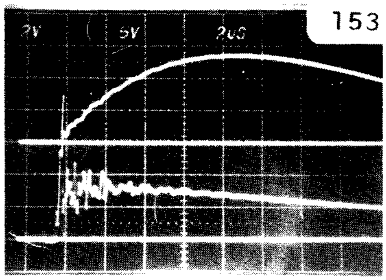
For all tests with no specific reference to that assumption, the simulation circuit had, in fact, the high side (H1) of the transformer primary connected to the neutral/ground of the transformer by a jumper wire (see Figure 4).

Replacing this jumper by an air gap (Oscillogram 156 in Figure 9) or by a distribution arrester (Oscillogram 157) did not produce a significant change in the voltage observed at the bus in the load center. Furthermore, the current injected for the case of the arrester (Oscillogram 157I) is slightly, but not significantly, affected during its rise time. These two observations validate the use of a jumper around the transformer primary.

VOLTAGE AT BUS WITH H1 OF TRANSFORMER TIED TO NEUTRAL (GROUND)

Current in HLP: 400 A/div

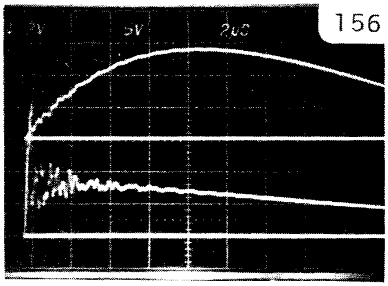
Voltage Across Bus: 500 V/div



VOLTAGE AT BUS WITH AIR GAP BETWEEN H1 OF TRANSFORMER AND NEUTRAL

Current in HLP: 400 A/div

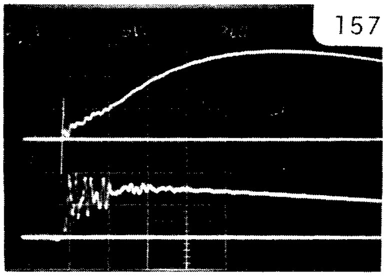
Voltage Across Bus: 500 V/div



VOLTAGE AT BUS WITH DISTRIBUTION ARRESTER ON TRANSFORMER PRIMARY

Current in HLP: 400 A/div

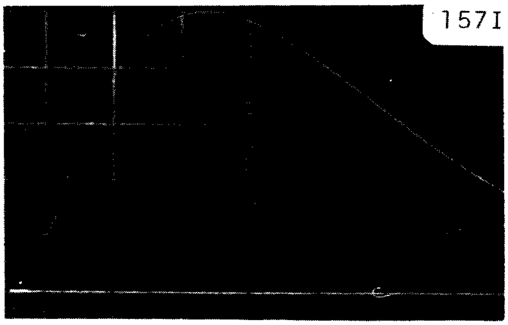
Voltage Across Bus: 500 V/div



CURRENT INJECTED FOR TEST 157 (The arrester affects the front of wave of the current)

Current in Arrester: 2 kA/div

(Sweep: 5 μs/div)



Test Condition: 10 kA injected.
All sweeps: 2 μs/div, except 157I

Figure 9. Comparison of Protector HLP Response for Various Protective Devices at the Primary of the Distribution Transformer

EFFECT OF TERMINAL IMPEDANCE

With no load connected at the end of the branch circuits, even with an outboard protector at the load center, there can be large "open-circuit" voltages at branch outlets. These voltages are caused by reflections as well as oscillations of the circuits.

Oscillograms 265 and 267 of Figure 10 show these open-circuit voltages reaching 1.5 and 2.3 kV. Loading the terminal with the 100 W bulb simulation reduces the open-circuit reflections to a maximum of 1.3 kV from the 2.3 kV level (oscillogram 269).

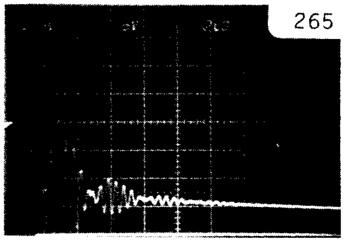
With the installation of a VSP-1 protector at each outlet (Oscillograms 266 and 268), the voltage is reduced to 400 V, with a maximum current of 900 A in the B-80 outlet and 600 A in the B-160 outlet. (Oscillogram 266A shows the complete waveform which was not obvious on Oscillogram 266.)

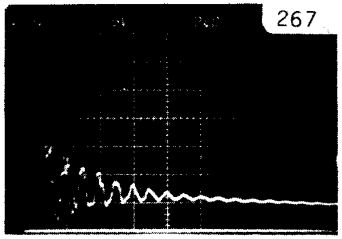
B-80
(LINE 2)

B-160
(LINE 1)

265/267
VOLTAGE AT OUTLET WITH
(1) OUTBOARD PROTECTOR
ONLY AT EACH BUS

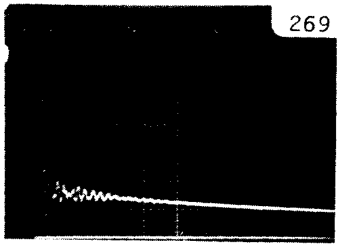
Voltage at Outlet:
500 V/div





269
VOLTAGE AT OUTLET WITH
(1) OUTBOARD PROTECTOR
AT EACH BUS, PLUS (1)
"100 W LOAD" AT B-160

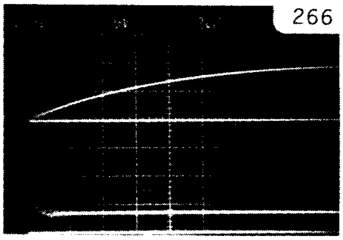
Voltage at Outlet:
500 V/div

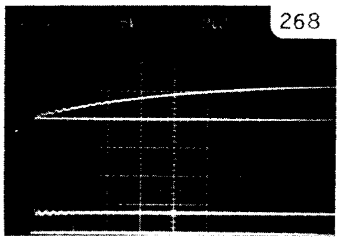


266/268
VOLTAGE AT OUTLET WITH
(1) OUTBOARD PROTECTOR
AT EACH BUS, PLUS (1)
VSP-1 AT EACH B-80 AND
B-160 OUTLET

Current in VSP-1: 500 A/div

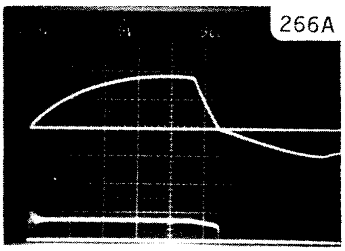
Voltage at Outlet:
500 V/div





266A
VOLTAGE AT OUTLET WITH
(1) OUTBOARD PROTECTOR
AT EACH BUS, PLUS (1)
VSP-1 AT EACH B-80 AND
B-160 OUTLET

Current in VSP-1: 500 A/div
Voltage at Outlet:
500 V/div



5 μs/div

Test Condition: 10 kA injected —
Protectors and loads.
All sweeps: 2 μs/div, except as noted.

Figure 10. Comparisons of Performances with Various Devices at Outlets, All with Protectors at Load Center

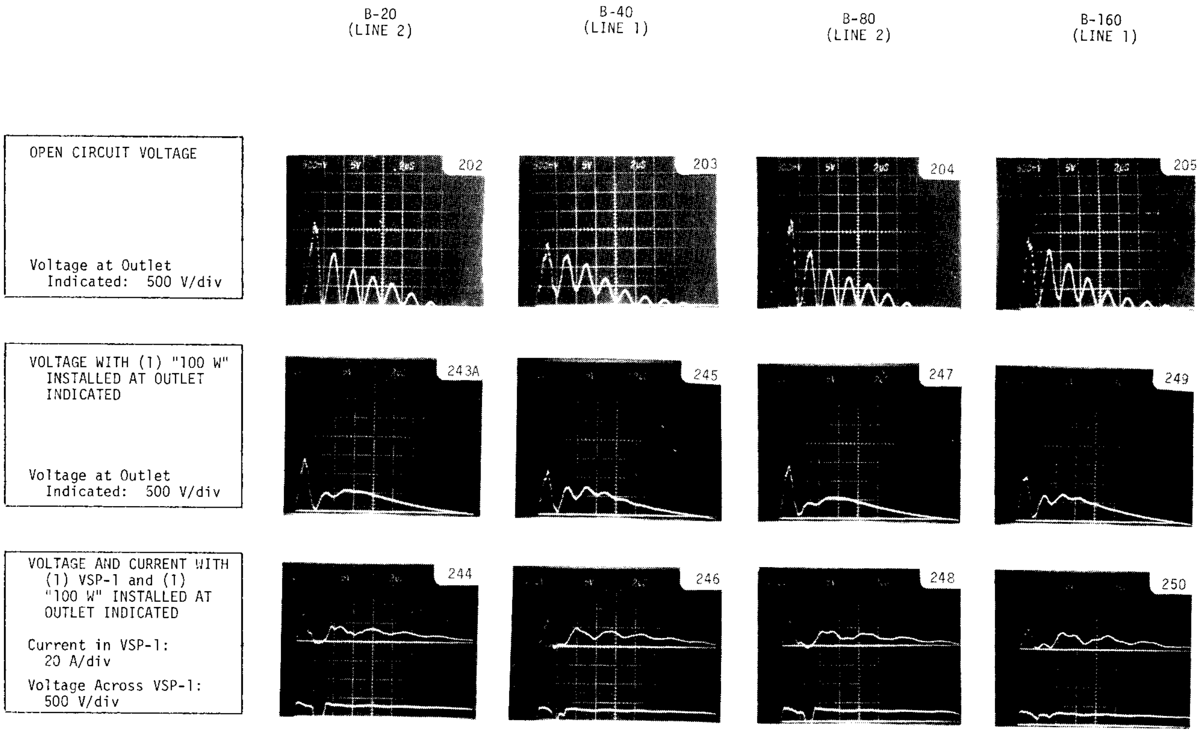
EFFECT OF BRANCH TERMINATIONS

Open-circuit voltages recorded as indicated in the preceding oscillograms show decaying oscillations. In Figure 11 a systematic comparison is presented of open-circuit voltages at the four line ends, as well as a comparison for each line end of the voltage without and with various loads.

Inspection of the no-load oscillograms (202 to 205) reveals two interesting phenomena. First, the frequency of the major voltage oscillation is constant for all four line lengths (period = 2 μs). Thus, we can conclude that this frequency is not affected by the line length and that other circuit parameters, rather, are responsible for inducing this 500 kHz oscillation from a 10x25 μs current wave. Second, the minor oscillations visible during the first loop in each oscillogram are spaced apart at a distance which increases with line length. Thus, one can conjecture that these may be caused by reflections.

Loading the line termination with a 130 Ω resistor (Oscillograms 243A, 245, 247, and 249) eliminates the later oscillations and reduces the first peak to about 60% of the value without load. From this reduction, a Thevenin's calculation of circuit parameters (Figure 12), if applicable in an oversimplified form, would show that 130 Ω is 60% of the total loop impedance. Hence one can conclude that the source impedance is four/sixths of 130, or about 85 Ω.

When a VSP-1 protector is added to the 130 Ω resistor (Oscillograms 244, 246, 248, and 250), the clamping action of the varistor limits the voltage at the outlets to about 400 V, which is consistent for the currents of about 20 A flowing in the varistor.



Test Condition: 1.5 kA injected —
Protectors and load installed at outlets as shown.
All sweeps: 2 μs/div.

Figure 11. Effect of Load (100 W Light Bulb) on Voltages at Branch Outlets

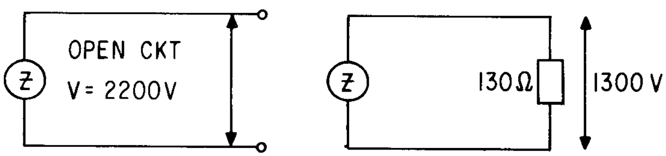


Figure 12. Thevenin's Equivalent for Oscillogram 202

LOAD CENTER PROTECTORS

With no protectors at the load center nor at any outlets, the wiring is flashing over at 10 kA injected current, but not before crests in the range of 8 kV have been reached (Oscillograms 143 and 145). (See also Oscillograms 271 and 272 on Figure 17.)

Installation of inboard protectors reduces the voltage peaks to 500 or 600 V, with about 1200 A drawn through the protectors (a substantial improvement), as shown in Oscillograms 261 and 262 of Figure 13.

With outboard protectors rather than inboard protectors, the peak voltages are in the 1000 to 1100 V range (Oscillograms 263 and 264). These higher voltages are attributable to the longer leads required to connect the outboard protector, compared to the inboard protector. (Figure 16 shows a comparison of lead length effects, which removes any question that the difference between inboard and outboard protectors might have been the result of an intrinsic difference in the varistors.)

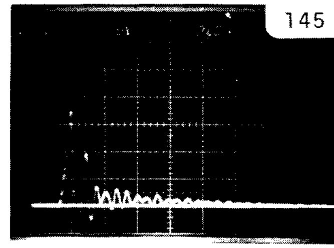
While not a recommended installation location, two VSP-1 were also installed directly at the load center (on the bus) in an arrangement that approximates the "inboard protector" geometry. Oscillograms 255 and 256 show the clamping voltage at 500 to 600 V with current crests at 1100 to 1200 A. Scaling up these varistor current values for higher lightning currents than the 10 kA injected would indicate probable excessively large currents in the 14 mm varistor used in the VSP-1 protector.

Finally, a HLP protector was installed at the center, as shown for one bus on Oscillogram 153. The voltage is higher and the initial rise before sparkover of the gap takes place at about 2.2 kV. The current crest, after the sparkover, is of the same magnitude (1100 A) as that of other tests.

	BUS 1 (LINE 1)	BUS 2 (LINE 2)

OPEN-CIRCUIT VOLTAGE

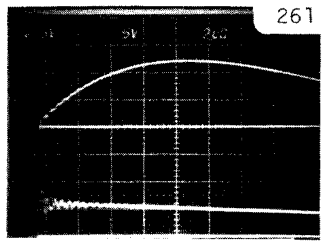
Voltage at Bus Indicated:
2 kV/div

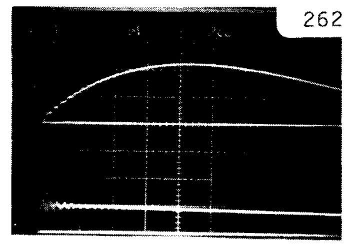


VOLTAGE AND CURRENT WITH (1) INBOARD PROTECTOR AT EACH BUS

Current in Protector:
500 A/div

Voltage Across Bus:
500 V/div

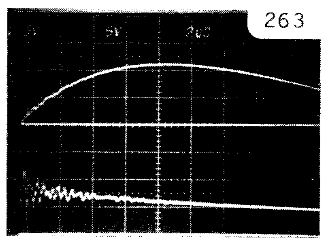


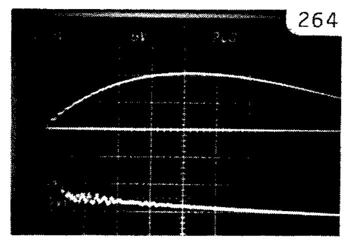


VOLTAGE AND CURRENT WITH (1) OUTBOARD PROTECTOR AT EACH BUS

Current in Protector:
500 A/div

Voltage Across Bus:
500 V/div

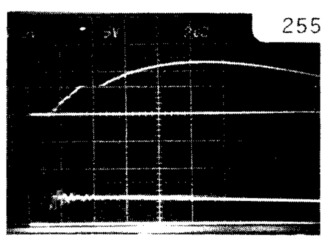


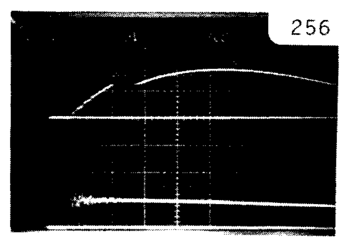


VOLTAGE AND CURRENT WITH (1) VSP-1 AT EACH BUS

Current in VSP-1:
500 A/div

Voltage Across VSP-1:
500 V/div

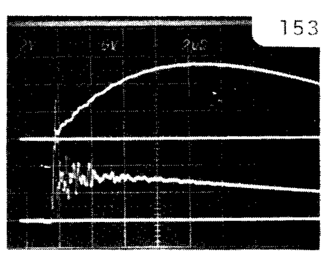




VOLTAGE AND CURRENT WITH (1) HLP ON LOAD CENTER

Current in HLP Line 1:
400 A/div

Voltage Across Bus:
500 V/div



Test Condition: 10 kA injected -
All sweeps: 2 μs/div.

Figure 13. Comparison of Alternate Protectors at Load Center

DUTY ON OUTLET PROTECTORS

While a properly coordinated protection scheme would certainly include installation of a high-energy protector at the load center, the VSP-1 spike suppressor is likely to be installed in locations where no other protector would be provided.

The three sets of oscillograms in Figure 14 illustrate the increasing duty imposed on the VSP-1 protector at short and medium distances (B-40, B-80) when the load center includes an effective protector, a less effective protector, and, finally, no protector. Note that for the 30 kA injection (a very pessimistic value) the current peak in the 14 mm varistor of the B-40 VSP-1 is about 2200 A, which is high but tolerable for infrequent lightning strokes.

The difference in current peak resulting from the branch circuit length (B-40 vs B-80) is also quite apparent, while the clamping voltages are not very different from those of the envelope, being at 400 to 600 V, with initial bursts at 800 to 1100 V.

In the case of Oscillogram 284, flashover of the wiring at the load center limited the current impressed on the VSP-1 protector. This is a result of an unintentional wiring flashover, which occurs frequently.

B-40 (LINE 1) B-80 (LINE 2)

VSP-1 AT OUTLET SHOWN WITH
INBOARD PROTECTOR AT
LOAD CENTER

Current in VSP-1:
500 A/div

Voltage at Outlet:
500 V/div

VSP-1 AT OUTLET SHOWN WITH
OUTBOARD PROTECTOR AT
LOAD CENTER

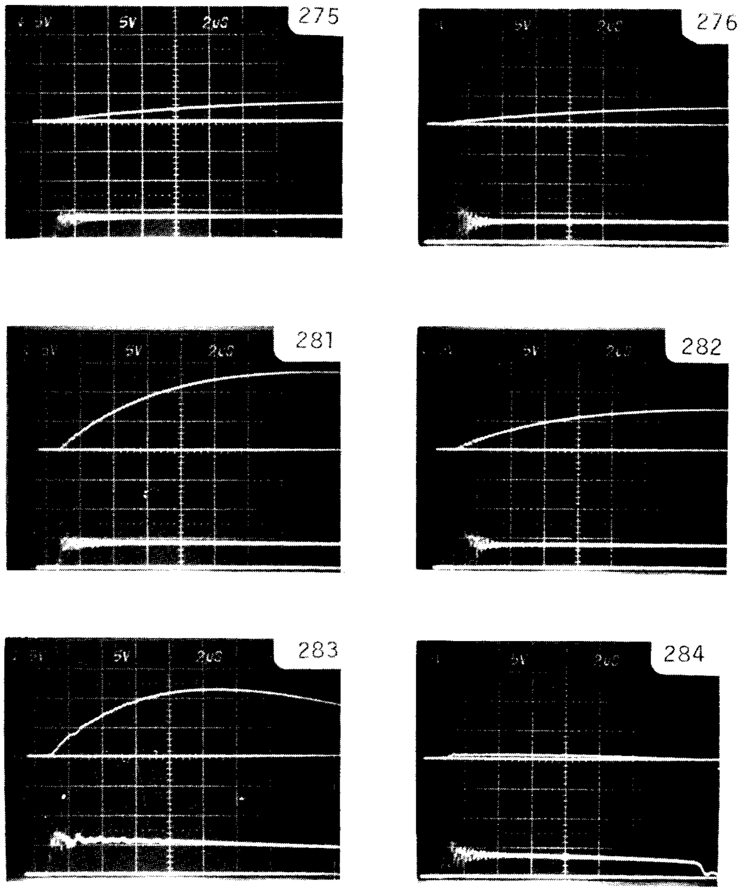
Current in VSP-1:
200 A/div

Voltage at Outlet:
500 V/div

VSP-1 AT OUTLET SHOWN WITH
NO OTHER PROTECTOR

Current in VSP-1:
1000 A/div

Voltage at Outlet:
500 V/div



(Flashover at B-20 limits the current.)

Test Condition: 30 kA injected
All sweeps: 2 μs/div.

Figure 14. Comparison of Duty Imposed on VSP-1 Installed at Outlets for Various Load Center Protections

COMPARISON OF INBOARD/OUTBOARD PROTECTORS

The difference in length required to connect the inboard or outboard protectors at the load center raises the question of induction effects on the clamping voltage achieved with one or the other protector. Oscillograms 273 and 274 of Figure 15 show a maximum voltage limited to less than 1000 V with the inboard arrangement, while the outboard arrangement (Oscillograms 277A and 278) shows as much as 2000 V maximum voltage.

(To remove any doubt on a possible difference caused by a difference in disc characteristics, the separate test discussed in conjunction with Figure 16 was performed, showing that indeed the additional voltage is attributable to lead length.)

BUS 1
(LINE 1)

BUS 2
(LINE 2)

(1) INBOARD PROTECTOR ON EACH BUS

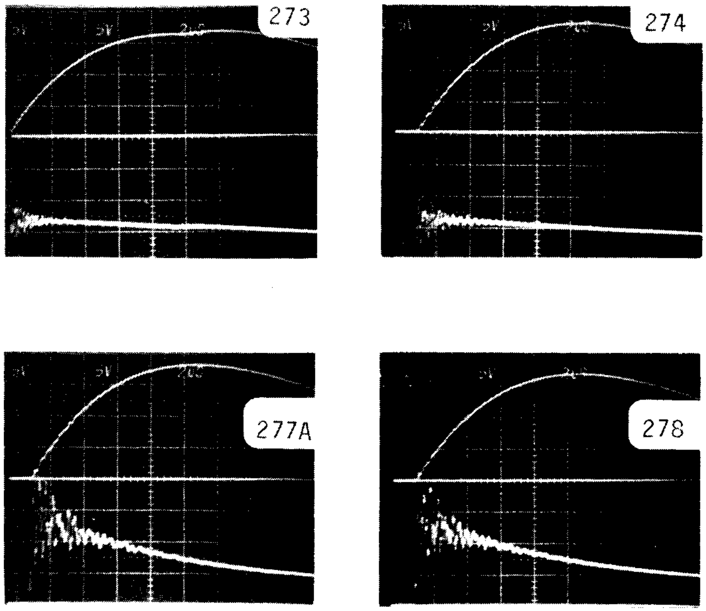
Current in Protector:
1000 A/div

Voltage Across Bus:
500 V/div

(1) OUTBOARD PROTECTOR ON EACH BUS

Current in Protector
1000 A/div

Voltage Across Bus
500 V/div



Test Condition: 30 kA injected —
Protectors at load center.
All sweeps: 2 μs/div.

Figure 15. Comparison of Performances Between Inboard and Outboard Protectors Installed at Load Center

EFFECT OF LEAD LENGTH

The oscillograms of Figures 13 and 15 show a difference in the performance of the outboard and inboard protectors. These two protectors, although identical for the disc size (32 mm), used discs from different production lots with potentially different characteristics. A separate test was made to determine if lead length or disc characteristic was the cause of this difference.

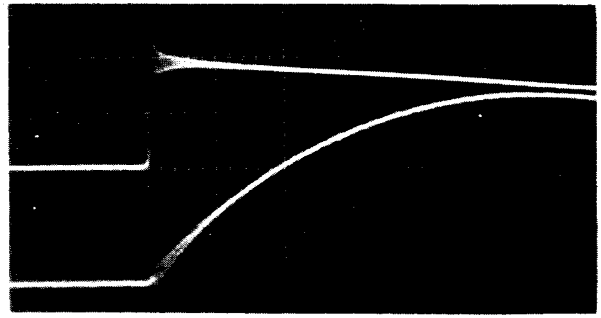
One each of the inboard and outboard protectors was removed from the simulation circuit. These were connected in series across the output of an impulse generator. The total lead length (60 cm, or 24 in) was approximately equal to that involved in separately connecting the outboard protector (45 cm, or 18 in) and the inboard protector (15 cm or 6 in) at the load center of the simulation circuit. Current pulses of constant magnitude (3.2 kA crest, 10μs rise time) were injected in the loop, and voltages across the protectors and their corresponding leads were recorded as shown in Figure 16.

Oscillogram 1 shows a 1000 V maximum voltage across the outboard protector and its associated 45 cm (18 in) lead, compared to only 600 V for the inboard protector and its 15 cm (6 in) lead (Oscillogram 2). Changing the lead of the inboard device to 45 cm (18 in) (Oscillogram 3) raised the voltage to 1000 V, demonstrating that the difference is attributable to lead length, not disc characteristics, and illustrating the benefits obtainable by making the protector an integral part of the load center.

(1)
VOLTAGE ACROSS "OUTBOARD SUPPRESSOR" PLUS 18" LOOP OF WIRE

Voltage: 500 V/div

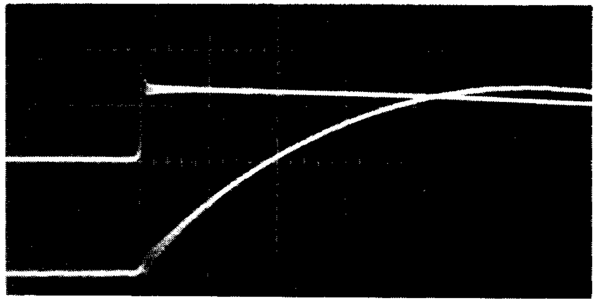
Current: 1000 A/div



(2)
VOLTAGE ACROSS "INBOARD SUPPRESSOR" PLUS 6" LOOP OF WIRE

Voltage: 500 V/div

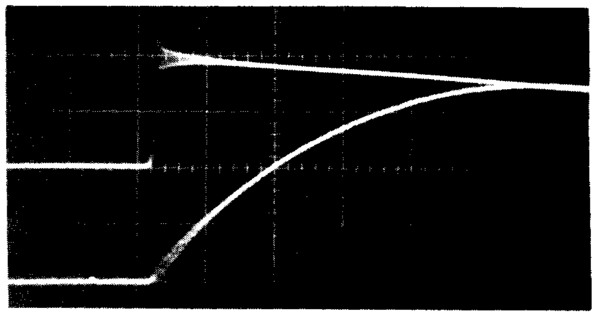
Current: 1000 A/div



(3)
VOLTAGE ACROSS SAME SUPPRESSOR AS (1) BUT 18" LOOP OF WIRE

Voltage: 500 V/div

Current: 1000 A/div



Test Condition: Laboratory bench, not house simulation.

Current injection in the two suppressors connected in series: 2.7 kA.
All sweeps: 2 μs/div.

Figure 16. Effect of Lead Inductance on Clamping Voltage

EFFECT OF WIRING SPARKOVER

With no protector at the load center and the only loads or suppressors installed at remote outlets, the induced voltages can reach such high values as 6 to 8 kV for the 10 kA injected current (Oscillograms 271 and 272 of Figure 17, and Oscillograms 143 and 145 of Figure 13).

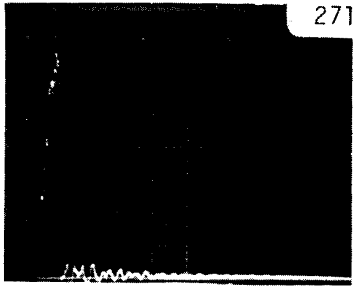
Oscillogram 272 shows that, with no relief produced by wiring flashover, the voltage envelope decays, becoming similar to that observed at lower current injection (Figure 14). However, as indicated in Oscillogram 271, flashover of the wiring (in this case the B-40 outlet) limited the voltage but not until a first crest of 7 kV had occurred and consequently started propagating in all branches of the system.

VOLTAGE AT BUS #2

(1) VSP-1 and "100 W" at B-160
(1) VSP-1 at B-80

(Outlet Sparking Over at B-40)

Voltage Across Bus:
1000 V/div



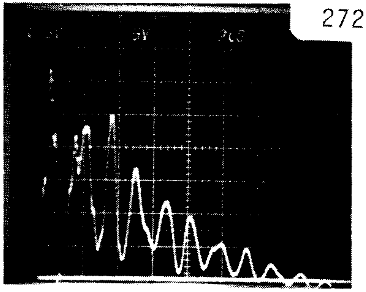
271

VOLTAGE AT BUS #1

(1) VSP-1 at B-160

(1) VSP-1 and "100 W" at B-80

Voltage Across Bus:
1000 V/div



272

Test Condition: Injected current 10 kA.
All sweeps: 2 μs/div.

Figure 17. Voltages at Load Center with VSP-1 and "100 W load," at Remote Outlets, No Protector at Load Center

3.2 Discussion of the Results

From the oscillograms collected during the test series, a summary of maximum values has been compiled as shown in Table 1. The three levels of current injection are included in this table, illustrating a mild, severe, and extremely severe lightning incident near the house. For the sake of simplicity in this table, only one protector is included in the arrangement matrix. A subsequent discussion will address the case of a coordinated scheme involving more than one protector.

Injection of the maximum values recorded on the protector current shows that no rated values are exceeded, even at 30 kA injection. Voltages observed are consistent with the corresponding currents, from the V-I characteristics of the varistors.

In the first group at 1.5 kA injection, voltages that are particularly damaging to appliances (2500 V) are observed throughout the system. Installation of a protector (on both lines) at the load center eliminates the hazard and would suffice to protect all of the house. Installation of a VSP-1 at only one close or remote outlet provides protection at that outlet and moderate protection on all locations of the same line. The other line is not protected.

The unsymmetrical load (diode) of the TV input circuit behaved in a predictable manner: when the polarity of the voltage was such that a forward bias was applied, the diode clipped the voltage, with the series resistance limiting the current. With reverse bias polarity, the diode failed when the 2500 V transient occurred at that outlet.

In the second group, representing a severe incident, flashover can be expected throughout the system in the absence of protection, with the associated fire hazards as well as damage to electronics during the initial voltage rise. Installation of a HLP at the load center eliminates the flashover hazard but does not lower the voltage sufficiently to assure protection of sensitive electronics, nor does an outboard installation of varistors assure protection. Installation of an inboard set of varistors is effective, for the voltage is limited at the load center (and consequently on the whole system) to 700 V. Installation of a VSP-1 at a close outlet (producing the maximum current flow, hence highest voltage) is effective for that outlet only; on the basis of the differential observed at 1.5 kA, one can presume that the voltage at the load center would be too great to consider any other point but that outlet as being protected.

In the third group, representing an extremely severe incident, the inboard protector at the center is, alone, still effective to protect the house, but the outboard protector is not. A VSP-1 installed at a close outlet is exposed to a high current (2500 A), still within its rating (4000 A), in excess of the maximum allowable 10-pulse value of the Pulse Lifetime Rating (1000 A), but still acceptable for 2 pulses. Installation of a VSP-1 alone, closer to the load center, would be likely to result in failure of the varistor when exposed to repetitive, severe lightning incidents. However, this failure hazard may still be less objectionable than the behavior of the wiring (flashover) in the absence of any protector, on an objective basis but not a subjective basis (the user is now expecting infallible protection).

Table 1

SUMMARY

MAXIMUM VALUES OF VOLTAGES AND CURRENT
OBSERVED DURING TEST SERIES

Protector Arrangement †	Injected Current kA	Load Center V	Protected Outlet V	Protector Current A
None	1.5	2500	2500	-
Inboard Protector at Load Center	1.5	500	500	100
Outboard Protector at Load Center	1.5	700	700	70
VSP-1 at B-20	1.5	800	400*	30
VSP-1 at B-160	1.5	1100	350*	20
None	10	8800	F/0	-
Inboard Protector at Load Center	10	700	700	1200
Outboard Protector at Load Center	10	1200	2000	1100
HLP at Load Center	10	2200	NR	1100
VSP-1 at B-20	10	NR	700*	950
VSP-1 at B-160	10	NR	600*	600
Inboard Protector at Load Center	30	950	NR	3500
Outboard Protector at Load Center	30	2200	NR	3500
VSP-1 at B-20	30	NR	800	2500
VSP-1 at B-160	30	NR	500	250

Notes -

NR - No Record

* "Protected outlet" is on same line as protector. Voltages on outlets of the other line close to unprotected values.

† Only one protector at a line in this table.

3.3 A Coordinated Protection Scheme

Installation of a varistor protector at the load center, if incorporated with very short leads, as in the "inboard" arrangement, effectively protects all of the wiring in the house. However, this installation is difficult to implement in existing systems and will continue to be difficult until a package is developed to allow connection to the load center bus bars with very short leads.

Until such an integral package is marketed for new systems, a coordinated protection scheme can be implemented, as a retrofit, that would still provide reliable protection for millions of sensitive appliances in existing systems.

The coordination involves a protector at the load center, either the commercially available HLP or a packaged 32 mm disc set (two lines) with reasonably short leads in a package similar to the HLP. This protector will limit the voltage at the load center to about 2200 V. This 2200 V level is below the flashover level of the wiring but can still cause damage to sensitive appliances. The currents passing through the protector at that location will not exceed the protector capability. In addition, VSP-1 protection should be installed at those outlets where a sensitive appliance is plugged. The voltages allowed by the VSP-1, typically 400 to 600 V, will be low enough to assure survival of all but excessively sensitive appliances, while the VSP-1 will not be exposed to currents that can lead to a failure in case of frequent exposure to severe lightning incidents.

Thus, a coordinated protection scheme is technically feasible. The cost should be acceptable to do-it-yourself homeowners, although it might be a deterrent to those owners who have to call in an electrician to install a protector at the load center. Based on increasing awareness in the technical and regulatory agencies community of overvoltage protection, the incorporation of protection to load centers offers the best approach to new installations.

REFERENCES

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2. N. Cianos and E.T. Pierce, A Ground-Lightning Environment for Engineering Usage, Stanford Research Institute, Menlo Park, Cal. 94025, August 1972.

3. Electrical Transmission and Distribution Reference Book, Westinghouse Electric Corporation, 4th edition, East Pittsburgh, Pa., 1950.

4. Surge Arresters for Alternating-Current Power Circuits, ANSI C62.1.1975, American National Standards Institute, 1975.

5. Specifications for GE-MOV II Varistors, General Electric Company, Semiconductor Products Dept., Syracuse, N.Y., 1978.

APPENDIX

DEVICES USED FOR SIMULATION

Meter: GE Cat. 720 x 070 G001

Meter Socket: GE Cat. 743 x 001 G003

Home Lightning Protector: GE Cat. 9L15DC B002

Load Center Suppressor
(Inboard and Outboard): GE CAT. V250 HE250

Outlet Suppressor: GE Cat. VSP-1D