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PRELIMINARY

Lightning And 60 HZ Disturbances at the Bell System Network - Terminal Interface

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Bell System Technical Reference

Lightning and 60 Hz Disturbances at the Bell System Telecommunication Network-Terminal Equipment Interface

LIGHTNING AND 60 HZ DISTURBANCES AT THE BELL SYSTEM

NETWORK-TERMINAL EQUIPMENT INTERFACE

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1.0 INTRODUCTION

This Technical Reference is intended to provide description of the non-telephone voltages and currents that may be encountered at Bell System network facility interfaces. There are in general two interfaces to such equipment: (1) between the Bell System network and the terminal equipment* and (2) between the locally provided ac power system and terminal equipment. Non-telephone voltages and currents at the first interface are caused by disturbances to the Bell System network from power systems and lightning and are covered in this document. Voltages and currents at the second interface are caused by disturbances to the power system and are not covered herein. Although the effects of these disturbances may be reduced by electrical protection devices at the interfaces, terminal equipment may still be subjected to voltages or currents of significant magnitudes. This Technical Reference describes the characteristics of the disturbances on the communication network facilities. This locument may be revised as additional information is obtained.

2.0 STATION PROTECTOR LIMITING VOLTAGES

At customer stations in areas subject to lightning or power disturbances, the ring and tip conductors are connected to a station protector which contains voltage limiters connected between each conductor and a grounding electrode. Station wiring (inside wire) connects the tip and ring terminals of the station equipment to the station protector. In the Bell System the protector achieves voltage limiting by means of 3-mil carbon blocks,** certain gas tubes, or gas tube/carbon block combinations.

Since the voltage limiting characteristics of the station protector have considerable impact on voltages impressed on the station equipment, knowledge of the protector breakdown voltage distribution is useful. A sample of unused 3-mil carbon protector units was tested using a surge generator arranged to produce 10x1000 μs open circuit voltage impulses (Figure 1) and charged to 1200 volts. The results approximated a normal distribution. The extrapolated upper 3-sigma breakdown voltage was 1000 volts, the 50-percent point was 700 volts, and the extrapolated lower 3-sigma point was about 400 volts. With a sample tested for initial 60-Hz sparkover,*** the extrapolated upper 3-sigma point was 800 volts peak, the 50-percent point was approximately 520 volts, and the lower extrapolated 3-sigma point was about 240 volts peak.

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* Pursuant to orders of 4/29/76 and 6/16/76, customer provided ancillary and data equipment may be directly connected to the network in accordance with part 68 of FCC rules. These rules are not effective as to main and extension telephones, PBX and key systems and registered protective circuitry associated therewith.

** The interelectrode gap is approximately 0.003 inch.

*** For the purposes of this test, initial 60-Hz sparkover was defined as the peak value of a 60-Hz sinusoid whose amplitude was just sufficient to cause conduction in a previously unused carbon block unit.

In general, Bell System approved gas tube protectors have breakdown voltages lower than the carbon block units. However, under certain conditions, these protectors may have breakdown voltages approaching those of protectors employing carbon blocks; therefore, the characteristics of carbon blocks must be assumed in developing equipment requirements.

In addition to a voltage limiting role, the station protector may also provide a current limiting function.

Protectors used at stations served by open or multiple line wire employ a 7-ampere fuse in each side of the line for certain infrequently encountered combinations of drop wires and/or grounding electrodes. PBX lines exposed to power or lightning disturbances under most circumstances employ fuses on the customer side of the protector which open the loop, or heat coils which ground the loop for currents in excess of 0.35 ampere. If the protector does not provide current interruption, a fusible wire (typically 24 gauge or 26 gauge) connection provides this function.

3.0 METALLIC SURGES - LIGHTNING

A metallic (or transverse) voltage is defined for the purposes of this Technical Reference as one producing a difference of potential between the tip and ring terminals of terminal equipment. Lightning currents, in the absence of protector operation and assuming balanced terminal equipment and telephone loop, cause tip and ring conductors to attain the same potential and hence do not produce metallic transients. If simultaneous protector block operation occurs, again no metallic transients are produced. On the other hand, balanced excitations of the telephone loop may be partially converted to metallic potentials through imperfect balance of any component of the telecommunication circuit.

The characteristics of metallic transient waveshapes at a station depend on telephone loop, central office, station, and protector characteristics in addition to the nature and proximity of the lightning stroke. Little generally applicable information concerning metallic transients is available. For the special case in which one protector voltage limiter has operated (the case which can produce the maximum possible voltage), limited information derived from References 1, 2, and 3 may be applied.

Under the assumption that one voltage limiter has operated, metallic waveforms have been observed to be double exponential impulses, damped sinusoids, or a variety of other more complex waveforms. Most data may be approximated for test purposes in terms of double exponential impulse waveforms which may be described in terms of peak value, rise time (or virtual front time), and decay time (or virtual time to half-value) as illustrated in Figure 1. Values for each of these parameters will now be discussed.

The maximum metallic voltage not limited by the protector occurs when one protector block grounds either the ring or tip conductor while the other conductor reaches a level just below the breakdown voltage of its corresponding voltage limiter. As discussed in the preceding section, this maximum surge breakdown may approach 1000 volts in the extreme case, or more frequently be about 800 volts.

A lower bound on rise time for double exponential pulses may be obtained from a consideration of lightning current impulses which are also approximated by the double exponential waveform. According to Reference 1, most investigators have found that 95 percent of all rise times of lightning currents to ground are in excess of 1 microsecond. A double exponential metallic transient with so short a rise time may be considered the result of a lightning stroke very close to the terminal equipment and provides a lower bound on rise time in the case under consideration.

Normally, however, the voltage will be produced by more distant strokes coupled to the serving loop by various mechanisms which cause a lengthening of the rise time. For this type of event, data collected on trunk and toll plant facilities and reported in References 2 and 3 may be applied. Bodle and Gresh, in studies on aerial and buried trunk cable facilities, report lower 3-sigma rise time limits of approximately 10 μs. In open wire plant, Bennison, Ghazi, and Ferland report minimum measured rise times of 5 μs (approximately the lower 2-percent point of the extrapolated distribution), which is consistent with the reduced dispersion associated with open wire plant.

The longest decay times for double exponential impulses are produced by distant lightning events which have undergone propagation dispersion and again the trunk and toll circuit data may be used to provide upper bounds. Bodle and Gresh reported upper 3-sigma limits of about 2500 μs. The Bodle-Gresh data indicated that approximately 70 percent of the decay times were less than 560 μs. For open wire, Bennison reported an extrapolated upper 3-sigma limit of about 600 microseconds.

The foregoing can be used to compose a metallic voltage waveshape. Combining the extreme cases of rise time, decay time, and protector block operating level, a bounding surge at interfaces with telephone cable plant is 1000V, 10x2500 μs. This composed surge is unlikely to be encountered in the field. A more frequently occurring surge is 800V, 10x560 μs.

The lightning-produced current which can be driven through terminal equipment by a metallic surge is bounded in magnitude by $1000/Z_M$, where Z_M is the effective metallic impedance in ohms which the terminal equipment presents to the surge. This impedance is not necessarily the same as the equipment impedance under normal operating conditions. This bound assumes the maximum protector limiting voltage and further assumes that the source impedance is zero. It applies for a nearby lightning strike. In a recent 5-month study of a single telephone loop composed of grounded metallic sheath cable with a severe lightning exposure, approximately 1000 current surges were recorded. The maximum short circuit current per conductor to ground was approximately 50 amperes with a typical current of about 2 amperes. The currents were limited by ground and cable impedances, and may have resulted from strokes attenuated by several miles of cable. Because of the limited scope of this study, it is unlikely that worst-case currents were encountered. Currents of 100 amperes or greater may be expected on infrequent occasions.

4.0 LONGITUDINAL SURGES - LIGHTNING

A longitudinal voltage is defined as one-half the sum of the potential difference between the tip connection and earth ground, and the ring connection and earth ground. Relatively low longitudinal voltages may be produced by lightning transients propagated for some distance over the telephone loop conductors. Higher magnitude voltages may be produced by fast rate-of-rise or high magnitude currents flowing in the telephone or power grounding conductors. Both mechanisms are discussed in succeeding paragraphs.

For relatively low currents propagated over cable, the situation is essentially the same as that considered for similar metallic events. Both conductors may be raised in potential above local ground to slightly less than the lower of the two voltage limiter breakdown voltages. In the event that both voltage limiters have breakdown voltages at the carbon block 3-sigma limit, a longitudinal voltage of 1000 volts may be obtained.

Waveforms of longitudinal voltages or currents may be damped sinusoids, double exponential, or more complex shapes as discussed previously. For the exponential case, assuming the disturbance is propagated from some distance, the data of References 2 and 3 may be considered to apply with minimum rise times of about 10 microseconds and decay times as discussed in the previous section. The short circuit current available for this case is approximately twice that for the metallic case because two conductors are involved, so that a longitudinal current of 200 amperes may be expected. As in the metallic case, an upper current bound of $1000/Z_L$ amperes per conductor can be established if the source impedance is neglected, where Z_L is the effective longitudinal equipment impedance which the terminal equipment presents to the surge. This impedance is not necessarily the same as the equipment impedance under normal operating conditions.

For nearby lightning strikes, substantial currents approximating the lightning waveform may be conductively coupled to the station protector or power grounding conductors producing a longitudinal potential $V = RI + L\frac{dI}{dt}$, where R is the conductor resistance and L is the conductor self-inductance. The protectors are assumed to be in the arcing condition. The longitudinal voltage is controlled by ground lead characteristics rather than limited by protector characteristics. It should be emphasized that proper bonding and grounding of telephone and power conductors has been assumed. Since currents may flow in the station protector grounding conductor and not in the power grounding conductor or vice versa, these longitudinal voltages may occur between the two previously defined interfaces as well as to ground.

Under many conditions, the grounding conductor resistance in the above equation can be neglected. For instance, a 30-foot length of 14AWG copper grounding conductor has a total resistance of about 0.08Ω which is negligible except for cases of extremely high grounding conductor currents.

The voltage produced by the inductance term of the above equation depends on parameters of current waveshape. The lightning stroke current rise time lies in the range of 0.7 μs to 10 μs for most of the Fisher-Uman data. Figure 10 of that reference indicates that measured decay times of lightning stroke currents range from 10 μs to about 160 μs. Although the longitudinal voltage involves the derivative of the current waveform, the time constants of the double exponential describing the current also appear in the voltage waveform. As an approximation, the rise and decay times of the current may also be used for voltage.

The peak voltage produced by the inductance term of the above equation depends on assumptions made as to the lightning stroke waveshape and the proportion of the current flowing in the grounding conductor. For instance, if a 30-foot 14AWG grounding conductor which has a self-inductance of about 0.4 μH/foot experiences a 200-ampere peak current with a 1.6-μs time to peak (approximately the 98-percent point of the Fisher-Uman first-stroke data shown in Figure 7 of Reference 1), a peak voltage of 1500 volts would be produced.

The current used to obtain peak voltage in the above equation is bounded by the maximum current in a lightning stroke since it may directly strike the grounding conductor.

In such cases the ground conductor resistance may also be of significance. Because of the existence of various shunting paths, it is usually unlikely that more than a small fraction of this current will flow in the grounding conductor. Longitudinal voltages in excess of 5000 volts peak associated with grounding conductor currents of 2000 amperes or more will occasionally occur.

The preceding paragraphs have described longitudinal stresses which may be produced at the network interface with terminal equipment by currents flowing in telephone or power grounding conductors. It should be realized that voltages of large magnitudes may also occur between the network interface and objects grounded by means of separate grounding electrodes not bonded to the telephone grounding electrode.

5.0 POWER SYSTEM CAUSED VOLTAGES AND CURRENTS AT THE BELL SYSTEM NETWORK INTERFACE

Customer terminal equipment may be exposed to overvoltages caused by power sytems since the power conductors are often closely associated with outside telephone plant facilities. For example, power system unbalance and coupling to the telephone loop may induce voltages on tip and ring conductors. Power faults to ground or accidental contact between the telephone loop and power conductors may also produce overvoltages on tip and ring conductors.

5.1 Long-Term Induction on Telephone Conductors

A single-phase or unbalanced 3-phase power line operating in the vicinity of telephone circuits may induce longitudinal voltages to ground in the telephone conductors. Even a nominally balanced 3-phase multigrounded neutral 60-Hz power system may produce induction voltages as a result of 180-Hz harmonic current. These long-term induction voltages, normally below protector block limiting threseholds, may result in signal disturbance or low level sustained currents to ground through the equipment.

In 1964 a survey conducted by Bell Laboratories and partially reported in Reference 4 resulted in the data on open circuit longitudinal induction voltages at stations shown in Figure 2. The long loop data represented loops exceeding 30 kft in length. From this figure it can be seen that these voltages are normally very low, although particularly on long loops, there is a small probability of exceeding 50 Vrms. Because of time variations in the inductive environment and occasional power system conditions, induction voltages may exceed 50 Vrms at a specific location. It has been found that switching equipment which must operate reliably during these rare occurrences will meet performance objectives if designed to operate in the presence of 120 Vrms. The waveforms associated with induction voltages consist mainly of components at 60 Hz and its odd harmonics. Information on the relative harmonic content as well as time variations of those voltages may be found in Reference 5.

The impedance associated with the open circuit voltage is determined by the conductor resistance and the central office impedance to ground. It may be expected on the basis of Figure 2 that significant induction is most often encountered on loops of more than 30 kft (less than 4%). The impedance per conductor of these loops is on the order of 500 ohms, which may be used as the induction source impedance. It should be realized, however, that significant long-term induction can occasionally be experienced on relatively short loops with correspondingly lower source impedance.

The induction source appears longitudinally in the affected telephone loop, and the resulting induction voltage normally appears longitudinally at the terminal equipment. In the case of a single shorted station voltage limiter or imperfectly balanced equipment, it may also appear metallically.

5.2 Fault Induction on Telephone Conductors

During power line ground faults or abnormal operation of 3-phase systems (e.g., 2-phase operation of a 3-phase system), inductive coupling to the telephone line may result in voltages of up to several thousand volts which are limited at the terminal equipment by the station protector. A lightning strike to the power system may result in a fault with equivalent results. Although the initial induction waveform is not necessarily sinusoidal, worst case maximum voltages prior to protector operation will lie between the 800-volt (peak) 60-Hz 3-sigma level and the 1000-volt surge 3-sigma level. As in the sections considering lightning transients, this implies that longitudinal and metallic voltages due to fault induction will be less than 1000 volts peak.

The short circuit fault induction currents are limited by telephone line impedances. Due to operation of cable protectors, these impedances may be lower than in the previous section. The majority of short circuit currents due to fault induction have been estimated to be less than 10 amperes rms per conductor.

It is also possible that a power fault to ground in the vicinity of a station ground can cause a rise in the ground electrode potential with respect to the telephone conductors. Under this condition a longitudinal potential of up to the maximum protector sparkover can be developed with respect to the tip and ring conductors. If one protector limits, and not the other, this potential is converted to a metallic voltage.

Duration of the fault condition may vary widely depending on the power circuit (transmission. subtransmission, distribution, etc.), fault characteristics, and the power company fault detection scheme. For example, overcurrent phase relays controlling circuit breakers on distribution feeders may be set to operate at 200 to 400 percent of the rated full load current. For faults to ground at points distant from the feeder source or for high fault impedances, the margin between fault and full load currents may not be large and the fault may remain indefinitely. If the fault current to full load current margin is large, or if ground relaying schemes are used, de-energization in a time ranging from a fraction of a second to 5 seconds may be obtained.

5.3 Power Contact to Telephone Conductors

Since power companies and telephone companies serve the same customers, their outside plant facilities are necessarily closely associated. Telephone facilities exposed to accidental contact with energized power lines, for example, after a storm, may constitute a hazard to the user unless terminal equipment is properly designed. When such crosses occur, carbon block protectors should limit 60-Hz potentials appearing between the tip and ring conductors or to ground to 800 volts peak.

As discussed in the previous section, fault current durations may range from a fraction of a second to 5 seconds in some circumstances to indefinitely large time intervals in others. Duration of current flow through the terminal equipment may be shorter than the fault duration if some element of the telephone plant between the fault and the terminal equipment fuses open.

Current magnitudes are normally determined by the impedance of the station equipment. Bounds on current waveforms are imposed by the fuse links discussed in Section 2.0.

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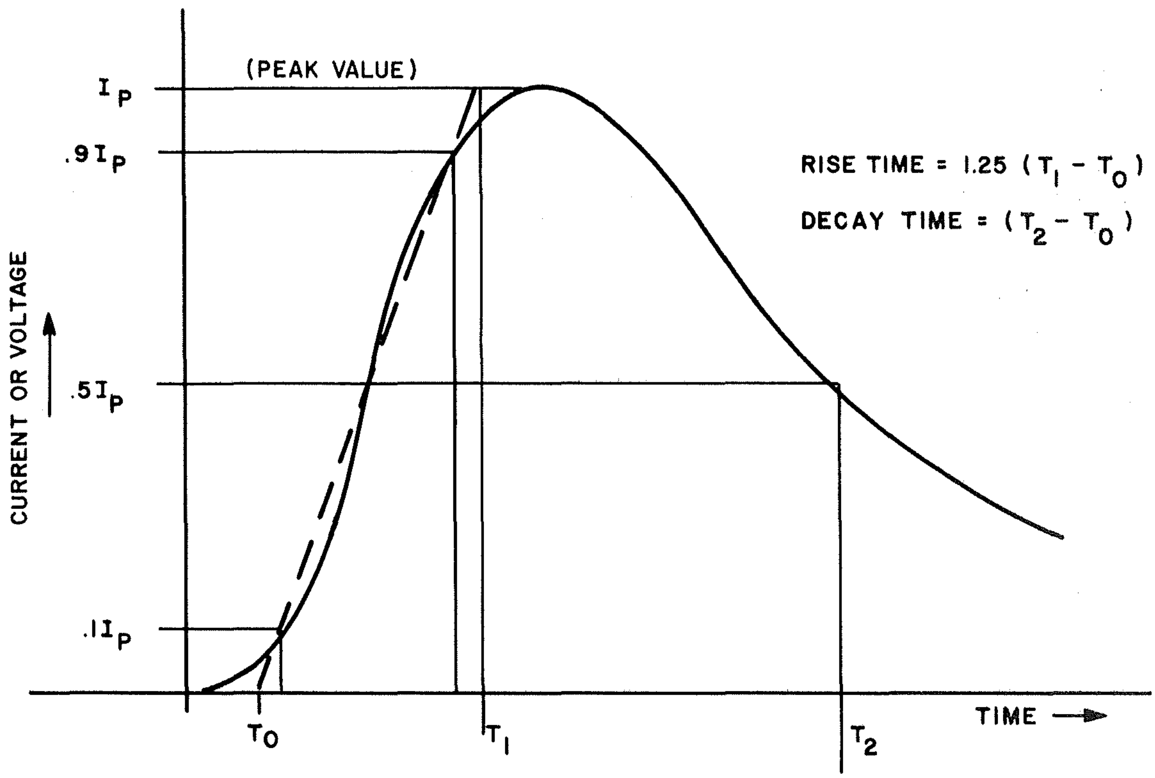

FIG. 1 — DEFINITION OF DOUBLE EXPONENTIAL IMPULSE WAVEFORM OF DURATION a x b SECONDS

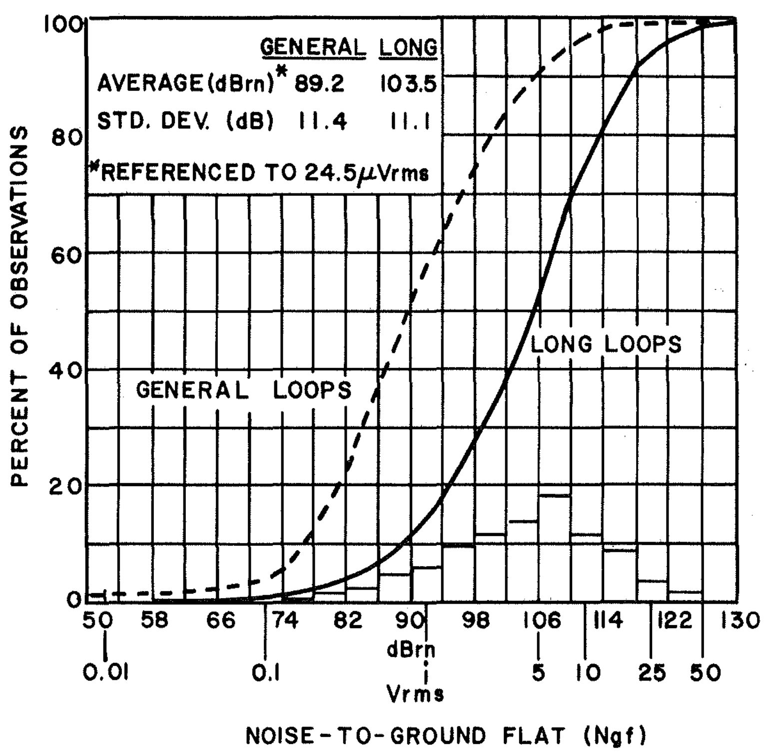

FIG. 2 — GENERAL AND LONG-LOOP 1964 SURVEYS