"ELECTRICAL PROTECTION BY USE OF GAS TUBE ARRESTERS"

CONTENTS

1. GENERAL

1.1 This section provides equipment suppliers, REA Borrowers, consulting engineers, contractors, and other interested parties with information for use in the design, construction and operation of equipment and of REA Borrowers' telephone systems. It discusses the use of gas tube arresters and the criteria applied in selecting the best arrester for any given application.

1.2 The gas tube arrester is a voltage limiting device, as described in TE & CM-801, with two or more electrodes providing a gap or gaps in a sealed discharge medium other than air at other than atmospheric pressure. This permits much wider spacing of electrodes than that required in arresters using air at atmospheric pressure, for comparable values of gap breakdown. The wider electrode spacing provides longer life by largely eliminating failure due to short circuiting of the gap.

1.3 The characteristics for various designs of gas tube arresters differ greatly. A detailed discussion of gas tube characteristics is given in Paragraph 3. Since the second issue of the Section in 1976, considerable progress has been made in defining and standardizing on tests of these characteristics. REA has been active with the Institute of Electrical and Electronics Engineers, and the USITA Protection Engineers Group in developing universal standards reflected herein.

1.4 REA is recommending the increased use of gas tube protection because the reliability of gas tubes has been increasingly demonstrated, and the initial price has decreased significantly.

2. APPLICATION OF GAS TUBE PROTECTION

2.1 While REA does not recommend the complete replacement of carbon block arresters with gas tube devices for all borrowers, the reliability, lower maintenance costs, and decreasing initial costs lead to the recommendation that gas tubes be applied in specific areas as shown in Table I.

TABLE I: MINIMUM GAP PROTECTOR SELECTION GUIDELINES FOR LIGHTNING PROTECTION

Exposure Fig. 1 Use	Very Low	Low	Average	High	Very High
Carrier	Med. Duty Gas	Med. Duty Gas	Med. Duty Gas	Max. Duty Gas	Max. Duty Gas
Unattended CO's	Carbon/ Lt. Duty Gas	Carbon/ Lt. Duty Gas	Med. Duty Gas	Heavy Duty Gas	Max. Duty Gas
Attended CO's	Carbon/ Lt. Duty Gas	Carbon/ Lt. Duty Gas	Carbon/ Lt. Duty Gas	Med. Duty Gas	Heavy Duty Gas
Priority Ckts. (Fire Alarm etc.)	Heavy Duty Gas	Heavy Duty Gas	Max. Duty Gas	Max. Duty Gas	Max. Duty Gas
Remote Sub-scribers (over 3 mi. from CO)	Med. Duty Gas	Heavy Duty	Heavy Duty	Max. Duty Gas	Max. Duty Gas
Close in Sub-scribers	Carbon/	Carbon	Carbon/ Med. Duty Gas	Heavy Duty Gas	Max. Duty Gas

Details of gas tube classification in this table are explained in paragraph 3.

2.2 Four basic factors need to be considered in determining the general areas in which to use gas tube protection. They are (1) earth resistivity, (2) lightning incidence, (3) long exposures to power systems with high fault currents, (See TE & CM Section 825 App. "A") and (4) the maintenance costs of replacing a grounded protector, (Table I considers only the first 2, thus should be applied only as a broad guideline). The reasons for their consideration are as follows:

2.2.1 As earth resistivity increases, the area of earth potential rise created by lightning strokes also increases. Thus, cables within a given distance of the ground termination of a lightning stroke will be exposed to higher voltages in areas of greater earth resistivity than of low earth resistivity, and the probability that the stroke will arc to the cable is increased correspondingly.

2.2.2 As the frequency of thunderstorms, and hence of lightning strokes, increases the probability that a given facility will be struck during a given time period becomes greater. (e.g., Plant in an area with 100 thunderstorm days per year would be ten times more likely to receive a damaging stroke in a given time period than one in a ten thunderstorm days per year area if all other variables were the same).

2.2.3 The greatest amount of lightning damage to telephone plant occurs in areas of generally high earth resistivity and high lightning incidence. Using these data, the map in Figure 1 was developed to serve as a broad gauge indication of anticipated damage. See TE & CM Section 801 for a more detailed discussion of this map.

2.2.4 While Figures 1 and 2 indicate geographical areas where telephone systems probably experience protection problems due to the above, the duty to which the arrester is subjected will vary widely within a small geographic area; e.g., one circuit route confined to a valley with tall trees for shielding may require minimal protection because it serves an exposed hilltop location. Protection experience gained from circuits serving similar locations within the area should be taken into account when considering the application of gas tube protection.

2.2.5 Power fault current problems are generally associated with telephone plant located in close proximity to and having long parallels with power circuits capable of delivering high fault currents. The incidence of the faults on power systems are generally related to the incidence and severity of lightning. The anticipated number of lightning strikes in a given area is a function of the number of thunderstorms anticipated during the thunderstorm season. Figure 2, "Mean Number of Days with Thunderstorms, Annual", provides a guide to this consideration.

2.2.6 In considering gas tube applications for induced surges from power fault currents, some plant routes, either aerial or buried, are exposed to paralleling power lines while others are not. Power contacts will be a factor only in the following situations: (1) where aerial cable or open wire is used and where they are involved in joint use with, or built in close proximity to power lines, (2) where our facilities are exposed via line crossings, and (3) joint buried facilities. Again, experience in each specific area and for each plant route, or, if experience is lacking, sound engineering judgement, should determine the need and benefits that can be derived from the use of gas tubes. (Calculations, as described in Appendix A to TE & CM-825, will be of value in formulating engineering judgements).

2.2.7 With maintenance and related labor costs soaring, eliminating long, time consuming trips to replace grounded protectors is a sound investment. Thus the trend should be to more gas tubes of a higher rating than the minimum recommendations given in Table I. This upgrading should not, however, be done without considering first cost. Any such transition must be done on a cost-effective basis.

3. GAS TUBE ARRESTER CHARACTERISTICS AND SURGE AND ARRESTER NOMENCLATURE

3.1 Basic Types of Gas Tubes - At the present time there are two basic types of gas tubes listed by REA. They are "Two Electrode" and "Multi Electrode" types. Two electrode tubes are applied as totally separate and independent gaps between each side of the pair and ground. The devices operate independently of each other whenever the voltage to ground exceeds the breakdown rating of the gaps. Thus, the tip side of a pair could breakdown and effectively short the tip side to ground. This then could create a voltage difference between the tip and ring conductors, which could be fairly large. If this voltage is sufficient to breakdown the ring conductor gap, it in turn will short the ring side to ground. The multi element tubes have 3-5 electrodes in the same gas chamber. In theory, when the voltage to ground on any line exceeds the breakdown voltages of the tube, the tube breaks down and the resulting ionization of the gas shorts all gaps of the lines to ground nearly simultaneously. With such tubes, the voltage between the tip and ring (transverse voltage) should generally be held to very low values.

3.2 Surge Characteristics

3.2.1 A typical lightning surge is illustrated in Figure 3. The surge tends to be nonlinear in the early portion of its rise and also as the crest is reached. As a result, the rate of rise is defined as the slope of the curve from 10 percent of its voltage or current amplitude (A) to 90 percent A. For example, assume a surge with a crest voltage of 2,000 volts requires three microseconds for the voltage to build to 200 volts, another four microseconds to reach 1,800 volts, and three additional microseconds to reach 2,000 volts. Using the crest voltage, the total time to reach crest, the result is a rate of rise 2,000 volts divided by 10 microseconds, or 200V/μs. This is not typical of the major portion of the wave's rise. The 10 to 90 percent portion of the rise time takes four microseconds to rise 1600 volts; thus the rate of rise as defined by REA would be 400V/μs during this "typical" time. This latter is the figure usually given as "Rate of Rise" by manufacturers.

3.2.1.1 The typical surge decays exponentially after the crest voltage or current is reached. The standard industry practice is to describe this rate of decay by giving the time from initiation of the surge until the surge has decayed to 1/2 its crest value. Other methods, such as specifying the time from crest to 1/2 value, are used by some. In the interest of clarity and standardization we recommend use of the terms in Figure 3.

3.2.1.2 A surge is described by the crest voltage or current, followed by its wave shape, first the rise time then the time to decay to 1/2 value: e.g., 500 volts 5/1000 microseconds as illustrated in Figure 3.

3.2.2 Figure 4 - "Arrester Breakdown Nonmenclature" shows a plot of voltage versus time for an arrester operation.

3.2.2.1 Most arresters break down, and ground the circuit at a higher voltage when subjected to a rapidly rising surge or impulse, than when subjected to slowly rising dc voltage. As a result, both impulse and dc breakdown voltages are important. As impulse break down voltage is a function of rate of rise, an impulse break down voltage should not be specified unless the rate of rise is also given; e.g., an impulse break down voltage of 1000 volts on a 500V/microsecond rise.

3.2.2.2.1 Breakdown - Defined as that point at which the arrester changes from a nonconducting to a conducting condition, where current is discharged through the arrester.

(Note: Breakdown should not be confused with failure).

3.2.2.2.2 Breakdown Delay Time - REA defines this as the time that equipment protected by an arrester will be subjected to voltages in excess of the dc breakdown voltage of the arrester, e.g., a device protected by a 350V arrester may be subjected to rising voltages (above the dc breakdown) of up to perhaps 1200V or more for two to three microseconds on a 500V/microsecond rise. While the time is small, the excessive voltage may damage the equipment. (NOTE: Electronic equipment generally contains secondary lower voltage protection, such as zener diodes plus resistors, which can withstand substantial voltage and current surges for a few microseconds). This secondary protection has a much shorter breakdown delay time than the gas tube so that the electronic equipment is protected.

3.2.2.2.3 Transition Time - The time required for the voltage across a conducting gap to drop into the arc region (arbitrarily defined as below 50V) after the gap initially begins to conduct. The sum of transition time and rise time from dc breakdown voltage to surge breakdown voltage represents the period during which a circuit will be subjected to greater than the normal dc breakdown voltages. Normally, the transition time should be less than one microsecond, however, the voltages encountered for this period may be substantially above the tubes rated dc breakdown.

3.3 <u>"Fail Safe" Operation of Arresters</u> - The term "Fail-Safe" operation of arresters has many different meanings within the industry. As a result, use of this term should be avoided to reduce confusion.

3.3.1 In place of the term "fail safe", REA recommends the following failure modes, derived from those developed by the IEEE.

3.3.1.1 <u>"Short Circuit or Low Breakdown Failure Mode"</u> - Tubes having this failure mode should always fail from effects of operations by a decrease in breakdown voltage (to the point where normal line voltage causes the tube to fire, thus signalling a problem) or by a low resistance path which grounds the circuit. These units when mechanically intact should never be used where personal shock hazard is a consideration. Some main frame protectors and field mounted electronic equipment protectors may utilize tubes with this failure mode.

3.3.1.2 <u>"High Breakdown Voltage Failure Mode"</u> - Tubes having this failure mode should always fail as a result of operating duty by significant increase in breakdown voltage. Tubes with only this failure mode should never be used where personal shock hazard is a consideration. Some main frame protectors and field mounted electronic equipment protectors may utilize tubes with this failure mode.

3.3.2 Many gas tube arresters are not designed to fail exclusively in the short circuit or low breakdown mode. Their breakdown characteristics depend on the presence of a particular gas and pressure, which in turn depends on an intact seal of the enclosing tube. Use of these tubes should be restricted to applications where human life is not normally at risk and equipment damage is offset by the lower initial cost of the tubes.

3.3.3 Some gas tubes are designed to meet the failure criteria of Paragraph 3.3.1.1 under all conditions. This can be done either by employing a small gap, which provides an acceptable breakdown in the vented mode, or by providing a backup air gap with a breakdown in the more expensive gas tubes which provides a slightly shorter life than equivalent tubes without this feature. But the added security provided justifies the added expense in many applications, including all applications at subscribers' premises.

3.3.4 While gas tubes have been designed to minimize the possibility of seal breakage, consideration should be given to sample testing of gas tubes in telephone plant periodically to determine breakdown characteristics. Where the samples tested indicate a higher percentage of failures, the testing should be increased to include other protectors with the same general exposure. The time interval at which tubes should be sample tested will vary depending on a number of factors. They include:

3.3.4.1 Severity of Lightning Problems in the Area - Tubes on a carrier route in North Dakota (a less than average problem area) should, for example, require less sampling than those protecting a similar route in Georgia.

3.3.4.2 Importance of protector remaining operational. Tubes in station protectors (when human shock is a potential hazard) or on fire alerting circuits, should receive more frequent attention than in single field mounted VF repeaters, for example.

3.3.4.3 Classification of Tube Employed - REA rates tubes as light, medium, heavy, and maximum duty depending on energy handling ability and life. The tests for these characteristics and the requirements for each classification are detailed in REA Bulletin 345-83 (PE-80), "Specification for Gas Tube Surge Arresters". Essentially a tube's classification is determined by its performance on three tests: (1) Maximum single impulse discharge current, (2) AC discharge current, and (3) impulse life. A tube rated as maximum duty will handle much greater quantities of energy than a light duty and, as indicated by the tests, should survive for a much longer period under field conditions than a light duty tube. Higher duty tubes are generally more costly than their lighter counterparts; however the required service life may offset this greater initial cost. Good engineering judgement is essential in selecting the most cost-effective tube for a given application.

3.3.4.4 Occurrence of Power System Faults - If tubes are exposed to severe power system faults, either by induction or conduction as indicated by damage to plant, consideration should be given to sample testing along the route where the fault or faults occurred.

3.3.4.5 Gas tube test equipment for testing dc breakdown is available from several manufacturers. These devices are intended primarily to locate tubes which have failed in the high breakdown, low breakdown, or short circuited mode. Usually tubes must be removed from the circuit in order to be tested properly.

3.4 Arrester Breakdown - When selecting an arrester, the dc breakdown and impulse breakdown on surges rising at 100 and 10,000 volts per microsecond are usually of interest.

3.4.1 Dc breakdown is of concern because if it is too low, the arrester may break down at a lower voltage than used to power the circuit associated with the arrester; e.g., an arrester breaking down at 90V would be a poor selection for a carrier with a 130V dc power supply, or a voice frequency line employing 96V boosted battery and 155V rms ringing.

3.4.2 Impulse breakdown voltage is of interest because the arrester will not provide the required protection if its surge breakdown voltage is too high. The characteristics of surges induced in telephone plant vary widely. Rates of rise may be as slow as several volts per millisecond, or as rapid as many thousands of volts per microsecond. In general, the voltage at which an arrester will break down becomes greater as surge rate of rise increases. This is not, however, a simple linear relationship. In addition, the higher capacitance of cable plant to ground tends to slow the surge rate of rise and increase the decay time greatly compared to open wire plant. As a result, REA requests surge breakdown data on only two rates of rise: 100V per microsecond and 10KV per microsecond. A study of the available information indicates that the former is typical of surges in cable while 10KV/ microsecond is appropriate for open wire, or for strikes near the arrester's location on cable plant.

3.5 Single Surge Capability - This parameter is a measure of the largest single current surge an arrester can be expected to survive without significant damage. In order to obtain an objective comparison between several arresters, the surge test waveshape must be the same for all samples. The fallacy of comparing single surge capability on different wave shapes is illustrated by the following example:

3.5.1 The energy delivered to the arrester is approximately proportional to the product of $I^2 \times T$. The energy in a 10KA 10/50 wave is shown by the cross-hatched area in Figure 5, while Figure 6 illustrates that in a 10KA 10/20 wave. From these figures, it becomes readily apparent that an arrester rated at 10KA on a 10/50 wave will handle much more energy than one rated similarly on a 10/20 wave.

3.6 Dc Holdover - When an arrester is on a line which has dc impressed on it, and is subjected to a surge, there is a tendency for the dc to force the arrester to remain in the low impedance, or short circuited state after the surge has passed to ground. The dc holdover voltage is defined as the maximum level of dc under which an arrester may be expected to clear and restore the circuit to normal operation after being subjected to a breakdown while dc voltage is standing on the line. Holdover is a function of both voltage across the arrester and available current. As a result, REA recommends that carrier suppliers design power feeds that limit or remove current when nearby gas tubes operate. REA recommends a rather complex circuit and a series of waveshapes for testing this characteristic. These arrangements are discussed in PE-80. Holdover capability of a tube should always exceed the maximum steady state dc applied on the circuit being protected. For example, a tube with dc holdover of 90V would be a poor choice for a circuit employing a loop extender which is powered by 110V.

3.6.1 Special consideration should be given to dc holdover when using multi-electrode gas tubes with some carrier systems. As the two electrodes, one connected to tip and ring, share a common gas chamber, there is a possibility of dc holdover from line to ground and a negative voltage from the other line to ground. For example, a three electrode gas tube used with a carrier system powered by a ± 125 volts line to ground would be required to withstand 250 volts from line to line, unless special circuitry is incorporated in the power feed to limit the current available under breakdown conditions.

3.7 Surge Life - While some gas tubes have excellent single surge capability, experience has shown they can be made to fail by repeated applications of lesser surges. As the primary reason for using gas tubes in place of carbon is to obtain an increased service life, the number of surges an arrester can survive without failure is very important. In order to obtain an objective comparison between several arresters, the surge test waveshape must be the same for all samples. REA has selected the 500 amperes 10/1000 microsecond waves. NOTE: When checking surge-life, the mode of failure (arrester shorted, or arrester strike voltage increased beyond tolerance) is very important.

3.8 60Hz Current Carrying Ability - An arrester may be subjected to 60Hz either through direct contact when a power line falls on aerial cable fault or a phase-to-ground fault on a nearby power system that does not contact the telephone plant. As a result, the 60Hz current carrying ability of an arrester is of interest. A typical power circuit breaker requires up to about 11 cycles (0.18 second) maximum to trip. Therefore, data furnished by manufacturers of the gas tube on characteristics should cover tests made for this duration time.

3.9 First Time Effect - Field experience has shown that some gas tubes exhibit "First Time Effect". That is, when placed in a darkened environment for two weeks or more without being energized, the tubes may demonstrate an initial breakdown well in excess of their rated breakdown (e.g., a tube at 350V, dc normally breaks down at about 750V on a 100V/μs surge. Due to First Time Effect this tube may not break down until 2100V on the first surge after an inactive period). Subsequent breakdowns, unless the extended unenergized storage period is repeated, should be normal. The initial elevated breakdown may be sufficient to permit electronic equipment to be damaged. Tubes meeting REA specifications are free from this characteristic.

3.10 Physical Construction - The ability of a gas tube arrester to retain gas is of primary importance if it is to serve its function as an arrester. As a result, the physical construction of the tube should be considered carefully when specifying a gas tube arrester for specific applications. In general, tubes of metal and ceramic construction will prove more rugged than those primarily of metal and glass.

4. SELECTION OF AN ARRESTER

4.1 The best arrester for any given application can be determined by considering the major characteristic of the available arrester (Paragraph 3) and the characteristics of the equipment that is to be protected as well as the economics of the situation. See Table 1 for broad gauge recommendations for the application of gas tubes.

4.1.1 The provision for adequate electrical protection for special electrical equipment such as carrier, voice frequency repeaters, etc., used in telephone systems is the responsibility of the equipment supplier.

4.1.2 It is the responsibility of the telephone company to provide adequate subscriber station protectors. If a decision, based on information contained in Paragraph 2, has been made to replace carbon protectors with gas tube protectors, there are overriding human and subscriber property safety considerations that should be given careful thought. If replacement of the complete protector is involved, the replacement should be one of those listed on Page "ni" of the "List of Materials Acceptable for Use on Telephone Systems of REA Borrowers." To have such a listing the protector must meet all applicable requirements of REA Specifications PE-42 and PE-80. If replacement of only the arrester unit is contemplated the resulting combination of arrester units and mounting should be listed by UL and meet all applicable requirements of REA specifications mentioned above.

4.1.2.1 In order for a gas tube to be listed for use in station protectors, it must meet the requirements set forth in PE-80. Station protectors employing both classifications are available and their listing in the List of Materials designates which classification each meets. In general, maximum duty protectors are more expensive than heavy duty units; however, their energy handling ability and life expectancy are also greater. Thus, in situations where power crosses, induction, or lightning strokes are unusually heavy, the use of maximum duty tubes should be considered. Engineering judgement will be required in making the decision between the different classes of tubes, depending on the anticipated exposure.

4.1.3 In the case of a cable carrier system outage time becomes the prime consideration. Breakdown voltage on a surge rising at a rate of 100/μs simulating lightning in cable, as discussed in Paragraph 3.2, is of concern. Dc holdover is another characteristic of concern with carrier because some systems are powered from the central office by dc in excess of $\pm$ 130 volts to ground. With cable carrier, generally the chance of a 60Hz power contact is small, so tubes without a high 60Hz current carrying ability could be used.

4.1.4 In the case of an open wire line serving a critical Forest Service fire tower, high atop a rocky ridge where outage time must be held to the minimum breakdown voltage at 10KV/µs would be very important, as explained in Paragraph 3.2.2. Also, greater energy handling ability would be desirable and, as there is a risk of 60Hz power contact, a heavy duty tube with 60Hz current carrying ability should be chosen.

4.1.5 In the case of a microwave installation on top of a hill, the overriding consideration would be assuring minimum channel outage. The location of the facility is such that it would probably receive many more than the average number of severe lightning strokes. Microwave systems usually carry a large number of circuits which should be protected where the circuits are terminated at carrier or voice frequencies. Under these conditions the cost of the arresters is a very minor consideration. The arrester having the greatest ability to withstand very large and repeated surges without becoming permanently grounded, or without being physically damaged, should be used.

4.1.6 In the case of the mainframe in an unattended central office serving a high lightning area through primarily buried plant, with no potential power fault problems, it might be possible to use medium duty gas tubes, and save money on the installation while gaining the advantage of gas protection. Conversely, if severe surges are reaching the office, either maximum or heavy duty tubes may be justified.

4.1.7 In choosing whether the multi-element or two-element types of gas tubes should be utilized, the nature and extent of exposure to lightning or power surges and the vulnerability of the equipment should be considered carefully. If the equipment protected is not particularly sensitive to transverse voltages then either type of tube could be used. The selection should then be made on the basis of total relative costs of the protection systems. On the other hand, transverse voltage susceptibility would favor the selection of the multi-element type.

4.1.8 The above are but a few examples in the process of selecting the proper gas tube for a given task. It would be impractical to provide a complete set of examples where gas tubes might be utilized. As a result, the above examples have been included to illustrate the methods and lines of reasoning employed.

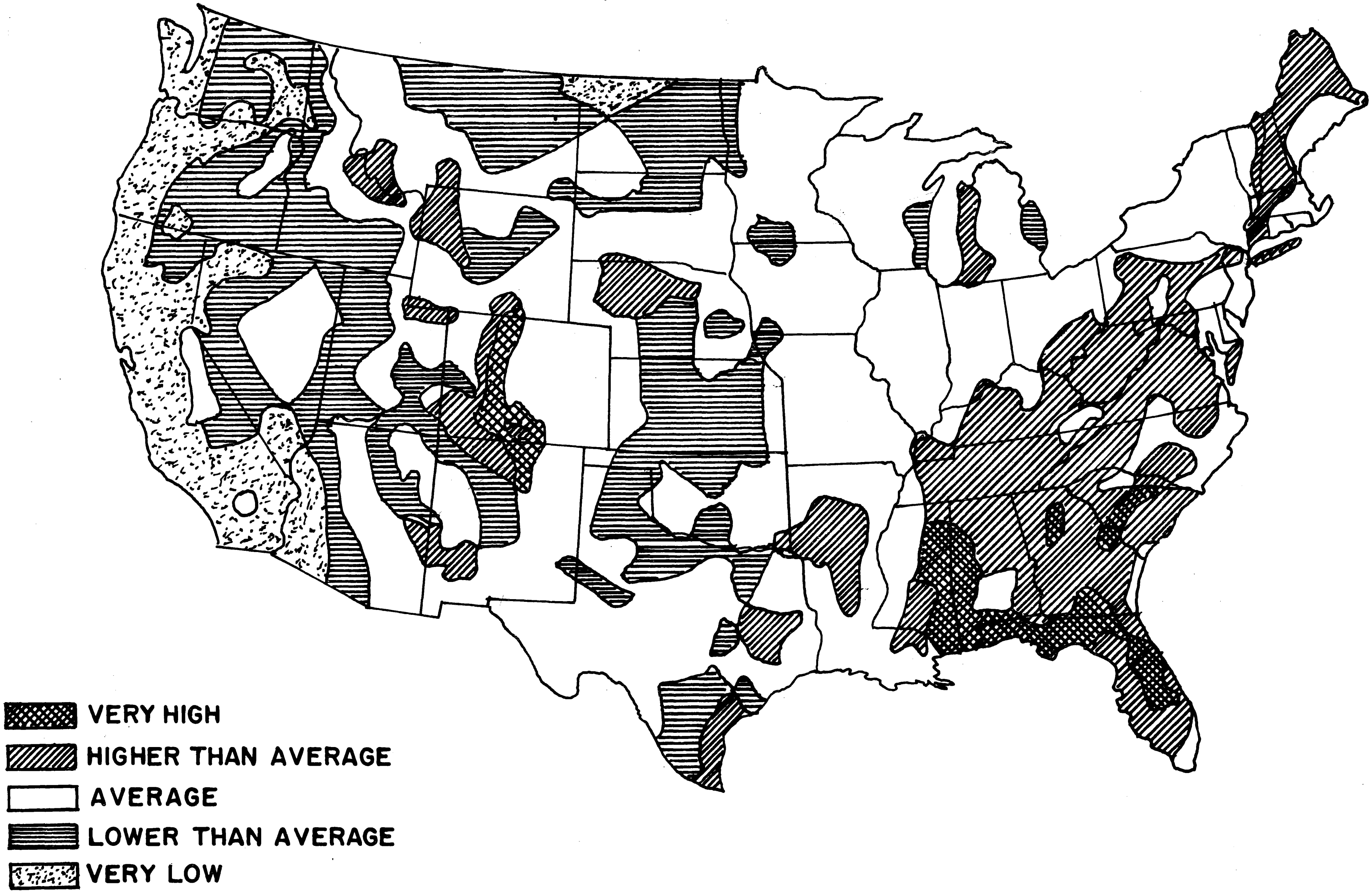


FIG. 1—LIGHTNING DAMAGE PROBABILITY MAP

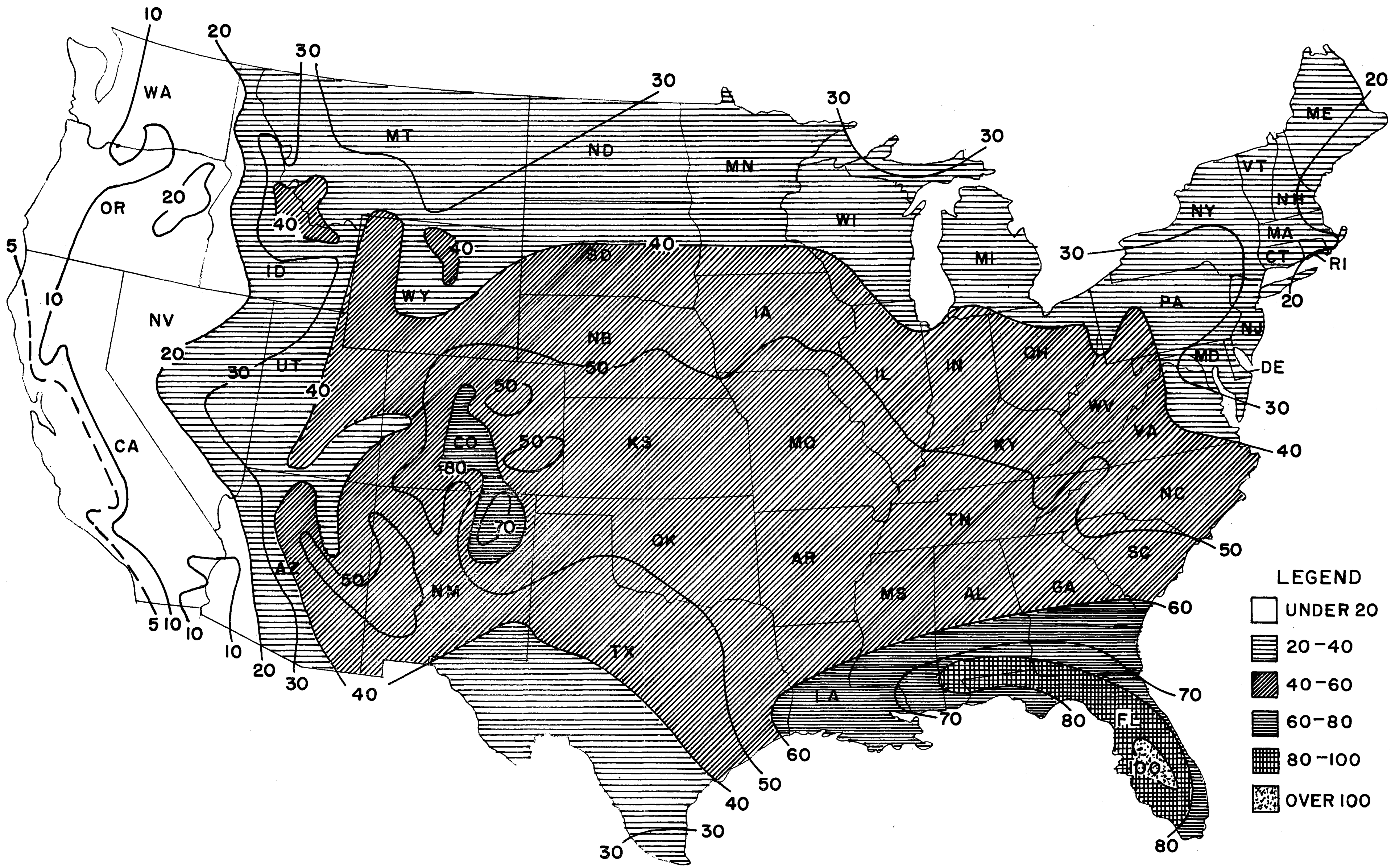
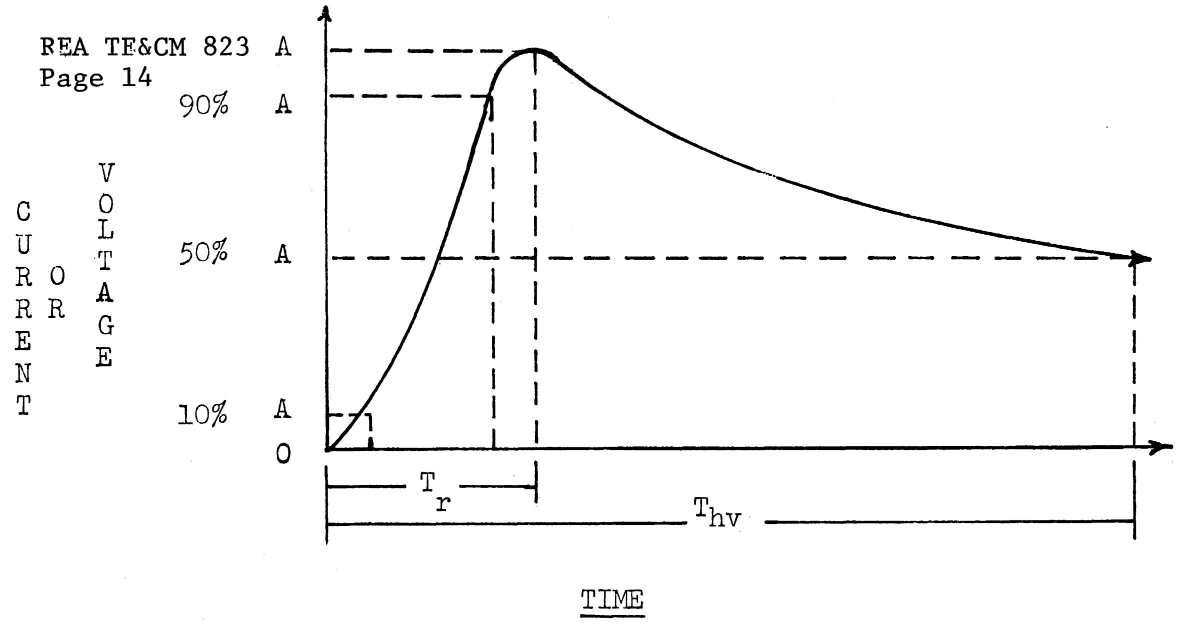


Fig. 2—MEAN NUMBER OF DAYS WITH THUNDERSTORMS, ANNUAL



A	Maximum, or crest, current or voltage
T_r	Rise Time
T_{hv}	Time to 1/2 crest value (Decay Time)
Rate of Rise	Slope of the curve from 10%A to 90%A

Surge Waveshape is specified as follows: A, T_r/T_{hv}
e.g.: 500 volts, 5/1000 Microseconds

FIGURE 3: SURGE WAVESHAPE NOMENCLATURE

Vss	Surge Striking Voltage				
Vsdc	dc Striking Voltage				
Va	Arcing Voltage				
Delay Time	$T_3 - T_1$	Transition Time	T_4	-	T_2

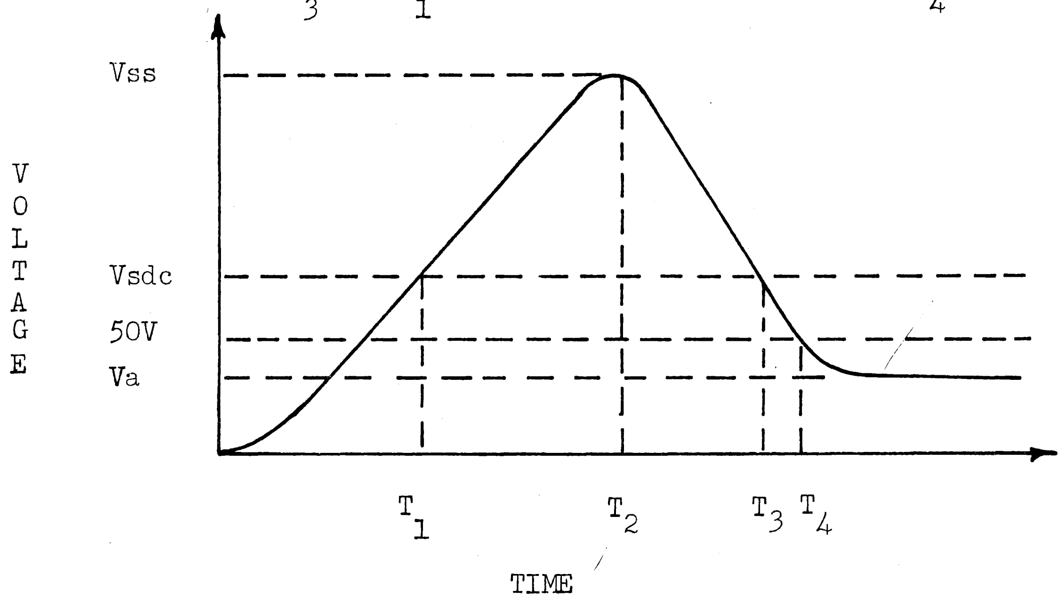


FIGURE 4: ARRESTER BREAKDOWN NOMENCLATURE

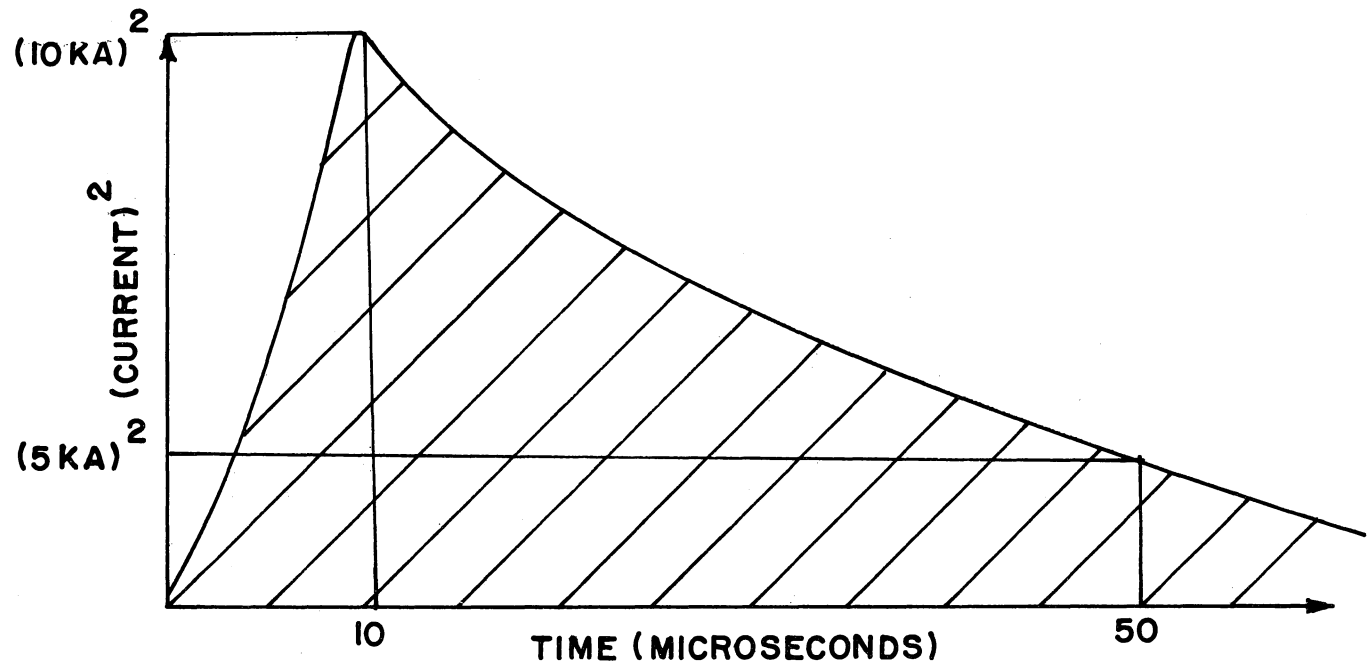


FIGURE 5: ENERGY IN A 10kA 10/50 WAVE

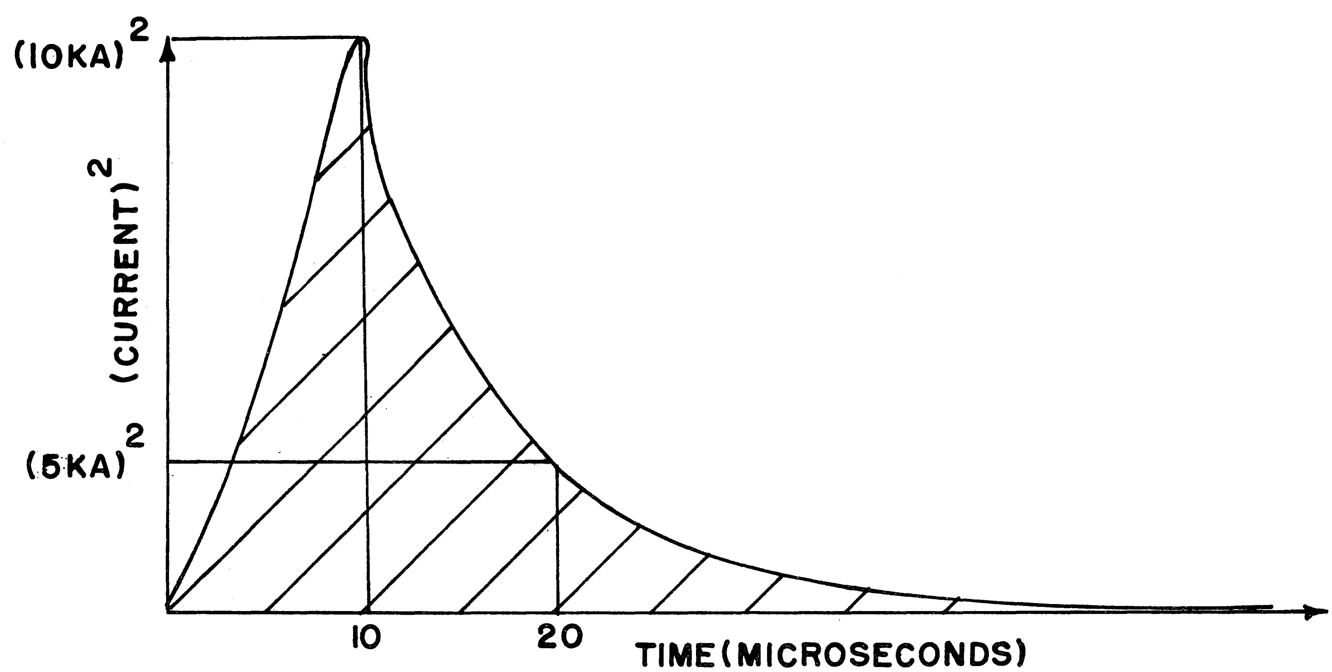


FIGURE 6: ENERGY IN A 10kA 10/20 WAVE