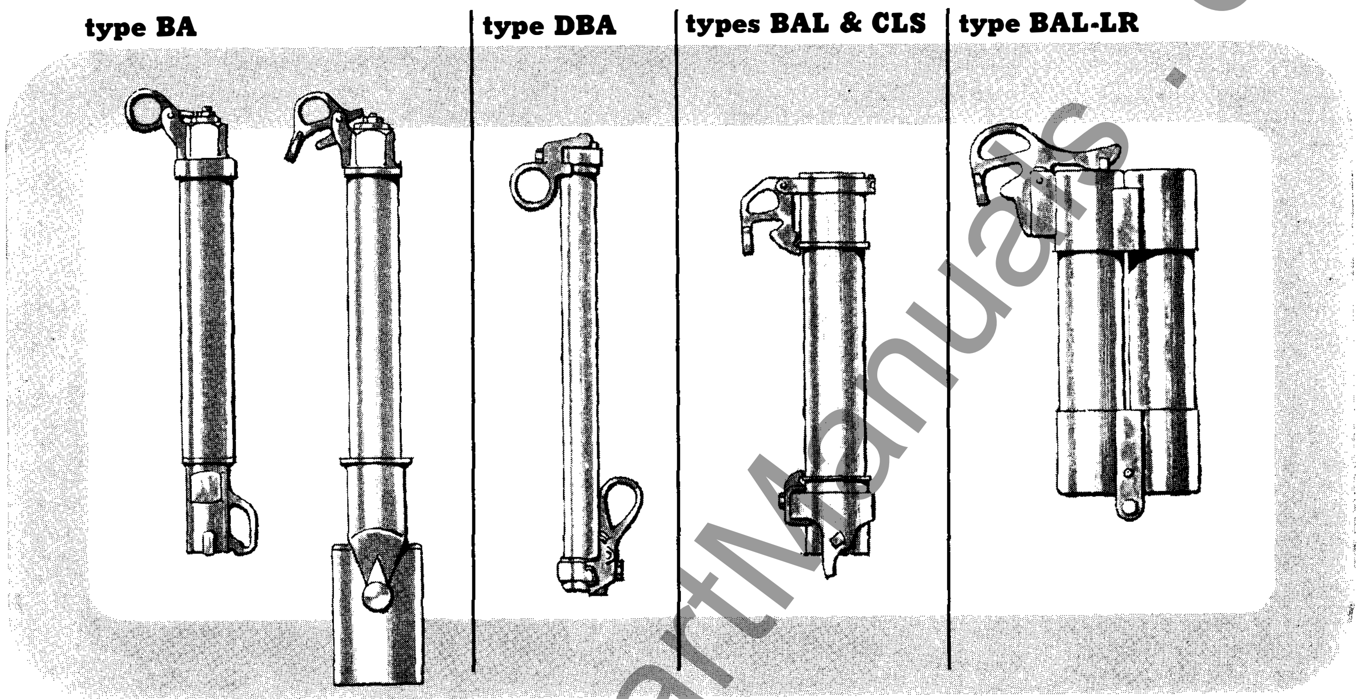
high-voltage power fuses
types BA, DBA, BAL, BAL-LR and CLS

601 to 138,000 volts



in this application data

general information

Westinghouse offers a wide selection of power fuses of diverse characteristics so as to satisfy almost any kind of application within the practical range of such interrupting devices. The principal types of Westinghouse power fuses are:

refill power fuses (type BA)
dropout power fuses (type DBA)
current limiting power fuses (types BAL, BAL-LR and CLS)

These different types have been developed to meet widely differing application requirements. Because of the limitations of their individual design features, no single type can cover the full range of system voltages, continuous load and available fault currents. Nevertheless, the areas of applicability overlap to a considerable extent. In these areas, space and service requirements, as well as economical considerations, govern the selection. The fuse whose interrupting rating exceeds the available fault current by the least amount usually is the most economical one. One spare fuse unit or refill per phase should be included when calculating the first cost of the installation.

Fuses are selected on the basis of interrupting ability, continuous current ratings and melting characteristics. The melting characteristics are described chiefly by the minimum melting current and by the slope of the melting time-current curve as illustrated in figure 1. The average requirements of general-purpose high-voltage fuse applications combined with the inherent features of conventional fuses have long ago led to the realization that a ratio of approximately 2:1 between minimum melting current and continuous rated current satisfies the majority of service conditions. This realization has crystallized in the long established standard (NEMA SG2-20.13 of April 1960 and earlier issues) for general-purpose high-voltage power fuses which reads as follows:

a. The current-responsive element of a power fuse rated 100E amperes or below shall melt in 300 seconds at an rms current within the range of 200 to 240 percent of the continuous current rating.

b. The current-responsive element of a power fuse rated above 100E amperes shall melt in 600 seconds at an rms current within the range of 220 to 264 percent of the continuous current rating.

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general information continued

In conventional manner, melting time-current characteristics are drawn through, or rather start at the minimum time-current values defined above which might be called pivot points. The general relations are illustrated in figure 1. The melting curves themselves may be characterized as "fast" or "standard", and "slow" or "time-lag". They are more specifically defined by speed ratios which, according to Standard SG2-1.49 are the ratios between the 0.1 and 300 or 600 second melting currents, whichever applies. The speed ratios of E-rated Westinghouse power fuses are shown in table 1. The ratio of 19 is about the highest that can be obtained in any conventional type fuse, it thus sets a limit to the short-time (less than 300 seconds) overload-carrying ability of E-rated fuses.

If, for a given continuous current rating, a higher short-time overload capacity is needed—a case encountered particularly with motor starter applications—one has to depart from the conventional characteristics of E-rated fuses especially if the limiting of high fault currents is demanded at the same time. As in the earlier establishment of the "E" ratings, service requirements and the inherent characteristics of current limiting fuse elements combine to suggest certain new pivot points for the time-current curves of such fuses. These new points are found in the region of three to five times the continuous current rating at 100 seconds as illustrated by curve C in figure 1.

In most fuses, the melting current pivot point is close to the lowest current at which the fuse will melt at all. If currents below this pivot value, but substantially above the continuous rating, are applied for an excessive length of time any fuse will be damaged and possibly be made inoperative altogether. The extent to which fuses may be overloaded below the melting range on an emergency basis is given by emergency overload characteristics. Their course is indicated by curve D in figure 1. They are presented in detail on curve 22, application data 36-660-A for E-rated fuses and on curve 20 for the types CLS and BAL-LR.

table 1: **fuse speed ratio-S**

cont. current amps.	standard BA-200	standard BA-400	time-lag BA-200	time-lag BA-400	standard DBA	time-lag DBA	E-rated BAL
5	6.5	6.5			8.5		8.5
7	6.5	6.5			8		
10	7	8			7		8.5
15	7.5	8.5	9.5		6	19	9
20	7.5	8	8.5	18	5.5	18.5	9
25	7	7.5	8.5	18	5.5	18.5	9.5
30	7	7	8.5	18	6	18.5	
40	7	6	8	18	6	18	
50	7	6	8	18	6.5	18	6.5
65	7	6.5	8.5	18	6.5	18	7
80	7	7	9	19	7	19	7.5
100	7	8.5	9.5	19	7	19	8
125	7	8.5	10	16	7.5	16	7.5
150	7.5	9	10	16	10	16	7.5
200	8	9	10	15	11.5	14.5	7.5
250		9					7.5
300		11.5					
400		12.5					

The speed ratio of a fuse is the ratio between the melting current at 0.1 second and at 300 or 600 seconds melting time. The 300 second melting time applies to fuses of 100 amp rating or less; 600 seconds applies to fuses of higher rating.

The applications and operating conditions of E-rated fuses usually are such that the emergency overload limits of the fuses are not likely to be infringed. Types CLS and BAL-LR fuses are more in need of protection against long overloads below their minimum melting current. Such protection may be provided by means of a relay whose characteristics lies below the emergency overload curve of the fuse. This relay normally serves the dual purpose of safeguarding the fuse as well as the apparatus which is to be protected in the region where the fuse cannot do so.

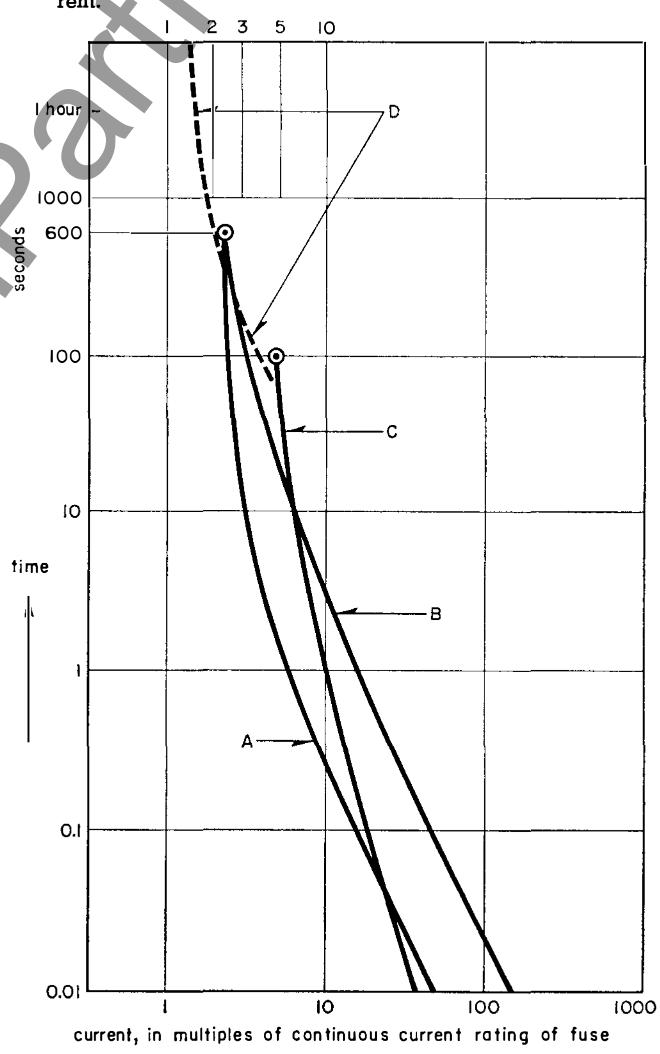
figure 1: **typical melting time-current characteristics and emergency overload limits of high voltage power fuses**

A—Melting time-current charactersitic of a "fast" or "standard speed" fuse rated 125-E or higher.

B—Melting time-current characteristic of a "slow" or "time-lag" fuse, rated 125-E or higher.

C—Melting time-current characteristic of a high overload current-limiting fuse (type CLS).

D—Emergency overload limits at less than minimum melting current.



rating range and type description

Table 2, page 4, shows the full range of continuous current ratings and voltage classes of Westinghouse power fuses. The significance of the letter E attached to continuous current ratings is discussed in the foregoing section.

Table 3, page 4, shows the interrupting ratings of all Westinghouse power fuses in symmetrical current rms values.▲

Short descriptions of the types of fuses featured in these two tables are given below.

Physical appearance, dimensions and mounting requirements are covered in dimension section 36-670.

type BA refill power fuses: Available for indoor and outdoor service and are applicable to service voltages from 2400 to 34,500 volts. As the name indicates, the fuse holders are refillable. The fuses are of the expulsion type, using boric acid (BA) as the arc extinguishing medium. The fuse holders can be equipped with condensers or with discharge filters. The former completely absorb and contain the exhaust gases but also reduce the interrupting capacity; the latter permit a small and relatively inert amount of gas to escape and do not lower the interrupting capacity of the unit. In contrast to type DBA, the fuse holder of BA fuses remains in the connected position after the fuse is blown; it does not drop out automatically.

type DBA dropout power fuses: Built specifically for outdoor service and for application at the higher voltage classes, but available also in the voltage range of BA fuses. The fuse units are of the expulsion type and are not refillable; upon blowing, they drop automatically into the open (disconnected) position. This is particularly necessary at voltages above 34.5 kv inasmuch as electrically open but not disconnected fuses cannot be expected to hold service voltage indefinitely.

current limiting fuses: Interrupt high currents before the first loop of fault current has reached its natural crest value. The action depends on the production of arc voltages which exceed the electromotive force of the system and which thereby force current zero as illustrated in figure 4. For any given fuse the degree of current limitation depends on the available fault current and on the timing of fault initiation. If the fuse melts after the current has crested, it can of course not limit the peak current which has passed already. With a fully asymmetrical fault, the current crests at about one half cycle; with a symmetrical fault in exactly one quarter cycle. Obviously, the current limiting action, usually described by the let-through current curve, changes with the degree of asymmetry of the fault. Conventional let-through current curves for high voltages fuses are drawn for faults of an asymmetry factor† of 1.6; so is the curve presented in figure 3. The current which melts the fuse the moment it reached its first natural crest is called the threshold current; in the case presented in figure 3 it is an asymmetrical current.

Let-through current curves drawn for a given asymmetry factor all have the same shape; their only distinguishing feature for fuses of different ratings is the value of the threshold current. Therefore, curve figure 3, plotted on the per-unit basis of threshold current holds for all current limiting fuses.

The threshold currents of Westinghouse current limiting fuses are given in table 4. In combination with figure 3 they suffice for the determination of let-through current at any fault current. As the let-through current at rated interrupting capacity is of particular interest, this let-through current is listed in table 4 although it can be read from figure 3 as well.

The silver-sand construction of basic current-limiting fuses does not lend itself to clearing currents of only two times the continuous rating, a ratio which is characteristic to E-rated fuses. Melting and clearing at such low currents is accomplished in current limiting fuses by special design features.

type BAL fuses: Interruption at low currents is performed by a series connected boric acid fuse housed in a common tube with the current limiting section.

types CLS and BAL-LR fuses: Means which produce melting at about two times rated current are omitted because such features are sensitive to high overloads as encountered, for instance, in motor starting. This, on the other hand, widens the range in which the fuse itself is "unprotected", that is, subject to damage by excessive duration overloads below the safe melting point. Therefore, if such fuses are employed in circuits where excessive duration overload currents below their 100 (or 25) second melting points are anticipated, such currents must be interrupted in time by another suitable device such as a relay-controlled contactor.

current limiting resistors: Employed in series with ½ ampere fuses where the expected fault current exceeds the interrupting rating of available fuses. They restrict the fault current to about 200 amperes. At full current rating (½ ampere) they produce a voltage drop of approximately 0.25% of the line-to-ground potential.

The use of such resistors not only permits the application of lowest interrupting capacity fuses but it also has the advantage that the exhaust gas jet is reduced greatly, as shown in dimension section 36-670.

▲ The listing of symmetrical values is in accordance with the new (1960) NEMA fuse Standard SG2-20.07.

† The asymmetry factor is the ratio between the rms values of the asymmetrical current which includes a d-c components and that of the symmetrical current. The theoretical maximum of the asymmetry factor is 1.73. With the X/R ratios encountered in power circuits it is hardly ever more than 1.6.

rating range and type description continued

table 2: continuous current ratings of Westinghouse high voltage power fuses

1—type BA refill power fuses, standard speed, indoor and outdoor
2—type BA refill power fuses, time-lag, indoor and outdoor
3—type DBA dropout power fuses, standard speed, outdoor
4—type DBA dropout power fuses, time-lag, outdoor
5—type BAL current limiting fuse, E-rated, indoor
6—type CLS current limiting, high overload fuses, indoor
7—type BAL-LR current limiting, high overload fuses, indoor
8—type BA-800; two type BA-400 refill power fuses in parallel, indoor and outdoor

amps	kv .6✛	.85✛	.6	2.4	4.8	7.2	14.4	23	34.5	46	69	92	115	138
½E & PT♣	...	...	...	5	5	1-3-5	1-3-5	1-3-5	1-3	3	3	...	...	...
1E	5	5	...	5	...	...	...	...	...	...	...	...	...	...
2E	...	...	5	5	...	...	...	...	...	...	...	...	...	...
3PT♣	...	...	...	...	...	3	3	3	3	3	3	...	...	...
5E	5	...	5	...	5	1-3-5	1-3-5	1-3	1-3	3	3	3	3	3
6E	...	5	...	...	...	...	...	...	...	...	...	...	...	...
7E	...	...	5	...	...	1-3	1-3	1-3	1-3	3	3	3	3	3
10E	...	...	5	...	5	1-3-5	1-3-5	1-3	1-3	3	3	3	3	3
15, 20, 25, 30, 40 & 50E	...	...	...	5	5	1-2-3-4-5	1-2-3-4-5	1-2-3-4	1-2-3-4	3-4	3-4	3-4	3-4	3-4
50/170■	...	...	...	6	6	...	...	...	...	...	...	...	...	...
65, 80 & 100E	...	...	...	5	5	1-2-3-4-5	1-2-3-4-5	1-2-3-4	1-2-3-4	3-4	3-4	3-4	3-4	3-4
70/255■	...	...	...	6	6	...	...	...	...	...	...	...	...	...
90/340■	...	...	...	6	6	...	...	...	...	...	...	...	...	...
110/425■	...	...	...	6	6	...	...	...	...	...	...	...	...	...
130/510■	...	...	...	6	6	...	...	...	...	...	...	...	...	...
125, 150 and 200E	...	...	...	5	5	1-2-3-4	1-2-3-4	1-2-3-4	1-2-3-4	3-4	3-4	3-4	3-4	3-4
200/765■	...	...	...	6	6	...	...	...	...	...	...	...	...	...
250E	...	...	...	5	...	1	1	1	1	...	...	...	...	...
225/1020■	...	...	...	6	6	...	...	...	...	...	...	...	...	...
300E	...	...	...	...	...	1	1	1	1	...	...	...	...	...
300/2200▪	...	...	...	7	7	...	...	...	...	...	...	...	...	...
400E	...	...	...	...	...	1	1	...	...	...	...	...	...	...
400/3000▪	...	...	...	7	7	...	...	...	...	...	...	...	...	...
450E⁑	...	...	...	...	...	8	8	8◉	8◉	...	...	...	...	...
540E⁑	...	...	...	...	...	8	8	8◉	8◉	...	...	...	...	...
720E⁑	...	...	...	...	...	8	8	8◉	8◉	...	...	...	...	...

♣ Certain potential transformer fuses melt at as low as 1.42 times rated current. See melting time-current characteristics.

■ Second figure designates 100 second melting current.

▪ Second figure designates 25 second melting current.

⁑ Minimum 600 second melting current depends on resistance balance between the two branches. See melting time-current characteristics, application data 36-660-A, curve #9.

◉ Outdoor only.

✛ D-c ratings only.

table 3: power fuse interrupting ratings at 60 cycles per second

voltage◉ nominal kv	max. design	BA-200▲ vented or with discharge filter	BA-200▲ with condenser	BA-400▲ vented or with discharge filter	BA-400▲ with condenser	DBA-1 ▲	DBA-5 ▲	DBA-2 ▲	BAL-1 BAL-PT BAL-10 BAL-25 BAL-200 BAL-300	BAL-LR and CLS-1
		interrupting ratings in amperes rms symmetrical ✛ for corresponding kva, see kva chart, fig. 2								
0.6	...	...	...	...	...	...	...	...	63,000	...
2.4	2.75	17,500◆	10,000◆	25,000◆	20,000◆	6,300◆	...	...	40,000	40,000
4.8	5.5	17,500◆	10,000◆	25,000◆	20,000◆	6,300◆	...	...	40,000 50,000♣	40,000
7.2	8.25	16,000	10,000	25,000	16,000	6,300	...	...	50,000	...
14.4	15.5	12,500	8,000	20,000	12,500	6,300	...	...	31,500 80,000♣	...
23	25.8	10,000	6,300	16,000	10,000	6,300	8,000⁑	12,500⁑	50,000♣	...
34.5	38	6,300	5,000	12,500	10,000	5,000	8,000	12,500	...	...
46 69	48.3 72.5	...	...	...	...	4,000 2,500	6,300 5,000	12,500 10,000	...	...
92 115 138	 121 145	...	...	...	...	...	...	6,300 5,000 4,000	...	...

◉ For interrupting currents and kva at voltages other than listed here see figure 2.

✛ For interrupting ratings in amps rms asymmetrical (old standard) multiply listed figures by 1.6
The listed interrupting currents apply to both nominal and maximum design voltage.

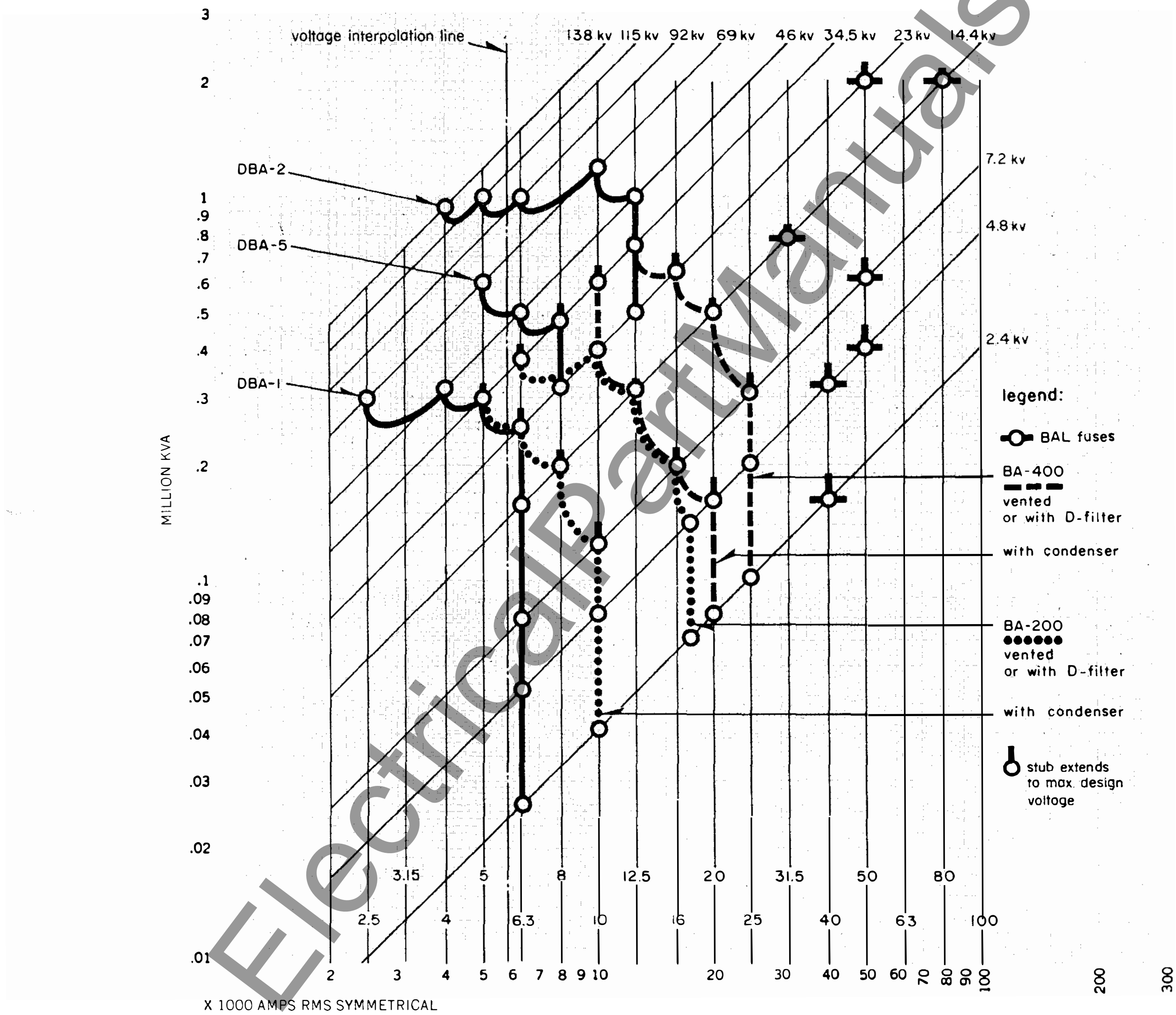
▲ The interrupting ratings of BA and DBA fuses listed at the various voltage classes hold for all such fuses applied at that voltage even if they carry a higher voltage rating.

◆ Use 7.2 kv fuse units.

⁑ Use 34.5 kv fuse units.

♣ For ½ ampere fuses only.

figure 2: **three-phase kva interrupting capacity**



Equivalent kva (kv x amps x 1.73) are read at the intersections of the slanted voltage lines with the vertical current lines.

Circles designate the fuse ratings listed in table 2. The stub lines above the circles extend to the maximum design voltage.

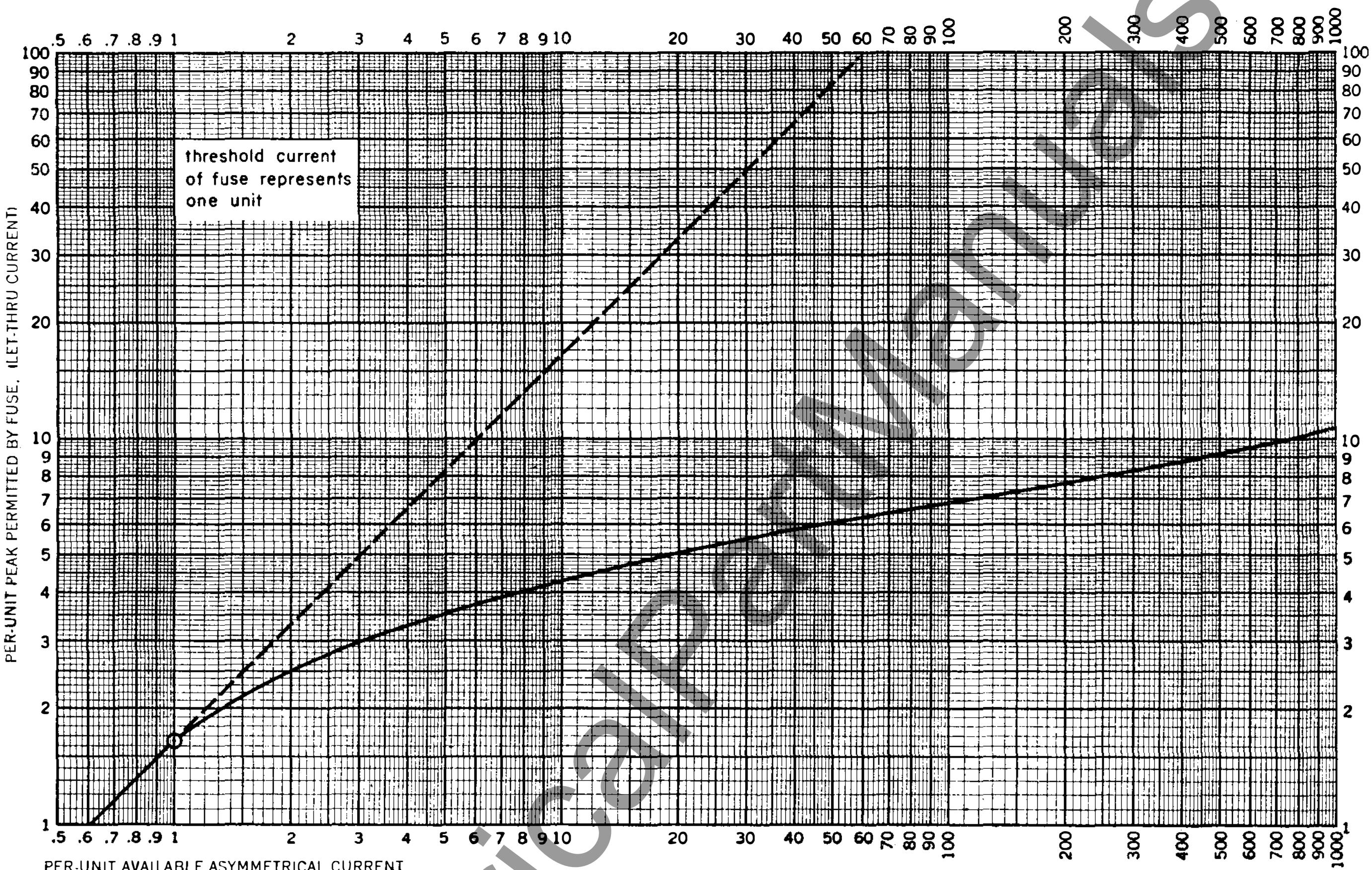
The scalloped fuse type lines are the envelopes of the interrupting range of the various models of types BA and DBA fuses.

The voltage interpolation line (at 5.8 x 1000 amps) is an auxiliary line only. It intersects the voltage lines at points at which the numbers on the kva scale (multiplied by 100) are the same as the kv figures of the voltage lines.

For finding interrupting currents and kva at intermediate voltages mark the intermediate voltage on the voltage interpolation line and draw a voltage line parallel to the others. Its intersection with the respective fuse type line marks current and kva rating at the intermediate voltage.

rating range and type description **continued**

figure 3: **let-through current characteristics of current limiting fuses at asymmetrical short-circuit (1.6 x rms value of a-c component of first half cycle)**



To find the let-through current at an available fault current given in amps rms symmetrical multiply fault current by 1.6 and divide by threshold current listed in table 4. This then is the per-unit available asymmetrical current at which the per-unit peak is to be read. Let-through current of fuse is per-unit peak times threshold current.

table 4: let-through current characteristics for asymmetrical fault condition (1.6 asymmetrical factor)

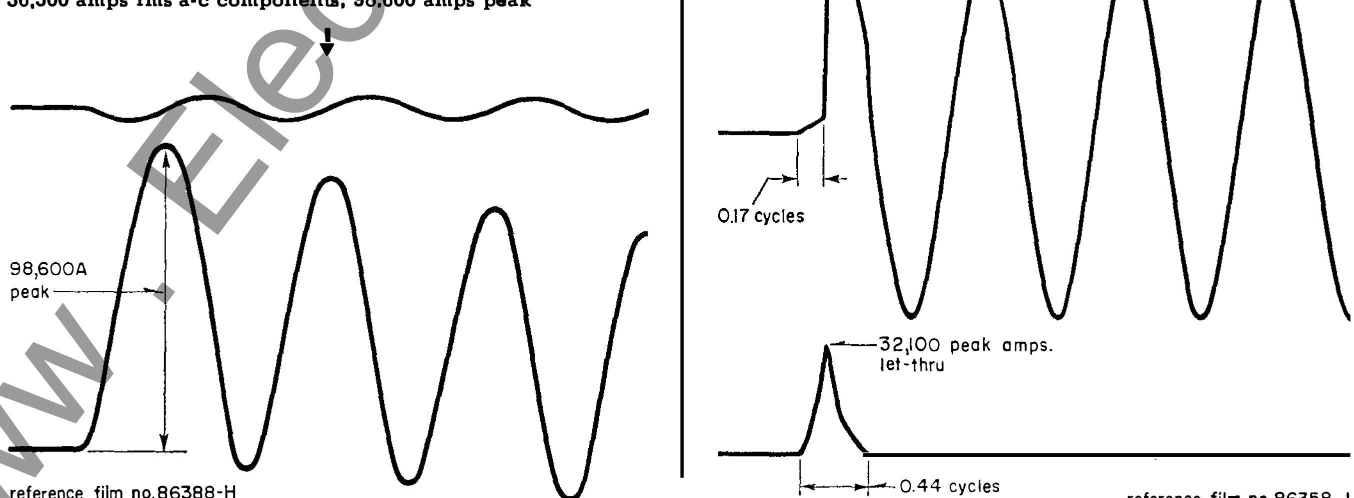
fuse type	fuse kv	fuse amps	interrupting rating amps—rms symmetrical	threshold current amps—rms asymmetrical	let-through current at rated interrupting current asymmetrical condition amps
BAL	2.4 and 4.8	.5	40,000*	30	375
		5,10		350	2650
		15,20,25		830	4950
		50		2500	13000
		65		3300	16500
		80,100		4150	19500
		125		5800	25200
		150		6650	28000
		200		8300	33000
BAL	7.2	.5	50,000*	30	400
		5,10		350	2730
		15,20,25		830	5500
		50,65		2500	13500
		80,100		3300	17000
BAL	14.4	.5	31,500*	30	360
		5,10		350	2500
		15,20,25		830	5100
		50,65		2500	12500
		80,100		3300	15700
CLS	2.4 and 4.8	50	40,000*	1500	8650
		70		2200	11900
		90		2950	14750
		100		3700	18000
		130		4450	21000
		200		6650	28000
		225		8850	34500
BAL-LR	2.4 and 4.8	300	40,000*	10000	38000
		400		20000	61000

* Multiply by 1.6 for use in curve figure 3.

figure 4: current limiting action of a 225 amp 4.8 kv type CLS fuse clearing a 5050 volt 36,500 amp fault, equivalent 3-phase kva—320,000

Current limited by fuse to 32,100 amps peak; melting time, → 0.17 cycle; total clearing time, 0.44 cycle

Bolted fault oscillogram; 58,500 amps rms asymmetrical; 36,500 amps rms a-c components; 98,600 amps peak



fuse selection

1. voltage rating

a. The first rule regarding fuse selection is that the maximum line-to-line voltage of the system must not exceed the maximum design voltage of the fuse● regardless of the system grounding conditions. The fuse voltage rating, on the other hand, is permitted to exceed the system voltage by any desired amount except for limitations applying to current limiting fuses.

b. Current limiting fuses perform their function by producing arc voltages which exceed the system voltage by a significant amount. These arc voltages, of course, must not be higher than the basic insulation level of the associated equipment, nor must they cause interconnected lightning arresters to operate since a relatively high current would thereby be shunted into lightning arresters not designed for such interrupting duty.

Westinghouse current limiting fuses are designed so that the arc voltage peak at rated interrupting current is less than two times that of the nominal voltage rating. For a 4800 volt fuse, for instance, this would be $2 \times 4.8 \times 1.41 = 13.6$ kv. If short time application of such a voltage is not harmful to associate equipment of a lower voltage class (say 2400 volt) apparatus, a 4800 volt fuse may well be employed on a 2400 volt circuit. Lightning arresters are the principal equipment to check in connection with the application of current limiting fuses which have a rating higher than the circuit voltage.

Machine protection arresters purposely are designed to have low spark-over values. They should, however, be connected directly to the machine terminals and not on the line side of the fuse. Therefore, if connected properly, the fuse arc voltage can have no effect on them. Correctly applied Westinghouse lightning arresters found on the line side of the fuse have sparkover values sufficiently high to remain unaffected by fuse operations.

2. interrupting rating

According to the 1960 revision of the NEMA Standard, the interrupting rating of power fuses is the rms symmetrical value (a-c component) of the highest current which the fuse is able to interrupt under any condition of asymmetry. In other words, the interrupting rating denotes the maximum fault current (symmetrical) permitted at the fuse location. Formerly assigned standard ratings in amps rms asymmetrical are converted to symmetrical values by dividing them by 1.6 which is the accepted asymmetry factor for power fuses. The interrupting ratings of Westinghouse power fuses are shown in table 2, page 4.

Inherently, power fuses are not constant kva devices. To identify them with round kva figures for anything else but rough overall classification runs counter to the character of these devices not only with regard to their operating principle but also in regard to the philosophy behind their application. Essentially, power fuses are employed instead of circuit breakers for reasons of economy. Once this is accepted, the economy principle should be carried to the point of ascertaining that the most economical fuse is used. This requires determination of the available fault current. The latter may well turn out to be much lower than what can be deduced from the rating of the nearest circuit breaker.

● See table 3—power fuse interrupting ratings

The three-phase interrupting capacity of a fuse installation is calculated in conventional manner by the formula $I \times kv \times 1.73$ where I is interrupted current in amps rms symmetrical and kv the system voltage. The kva so calculated can be read directly on the kva chart, figure 2.

3. continuous current rating

Power fuses are designed so that they can carry their rated current continuously without exceeding the temperature rises permitted by the Standards. In the majority of applications, however, the rated load current of the equipment which they are to protect should not be allowed to equal the current rating of the fuse. This is so because fuses, having a rather low thermal capacity, cannot carry overloads of the same magnitude and duration as motors and transformers of equal continuous current rating.

In principle, if a circuit is to be protected by fuses, its normal load as well as duration and frequency of permissible overloads should be known. The fuse must sustain these and it must, on the other hand, blow at specified fault currents. These requirements would make each fuse application a case of special study if it were not for the routine procedures worked out for the protection of distribution and substation transformers with conventional E-rated fuses, and for fuses in motor starters.

transformer protection

Within certain well defined areas in the field of electrical installations, guidance for the application of power fuses is provided by specific standards.▲ For general application one may state the requirements for fuses at the primary side of transformers in the order of their importance as follows: they should

1. Protect the system against outages.
2. Override (coordinate with) protection at the low voltage side.
3. Protect against bolted secondary faults.
4. Protect against higher impedance secondary faults to whatever extent is feasible.

In the routine process of supplying fuses on the basis of the kva rating of a transformer, one does assume that adequate secondary protection is provided. The ordinary procedure then is to employ a standard speed fuse and select its rating so that it does not blow, nor its structure is damaged by overheating, due to any inrush or overload current which the transformer permits and can carry safely. By way of such considerations based solely on transformer characteristics as known from standards, one arrives at minimum ratios between fuse rating and transformer full load current of

▲ E. G.: National Electric Code, ASA C1-1959 Article 450-3. NEMA Standard for Secondary Substations, section 213-1.04.

1.4:1 for standard speed BA and DBA fuses, and
1.6:1 for BAL fuses.

As shown in appendix, page 12, these ratios are based on the emergency overloads to which transformers may be subjected in accordance with the data presented in ASA appendix C57.92.

If provisions are made, by thermal relays or otherwise, to limit transformer overloads to a lower range, the fuse-to-load rating ratios can be reduced below the values indicated above. For checking the amount of reduction permissible without injury to the fuse, it is advisable to employ the fuse emergency overload diagram of curve #22 and the general method presented in appendix 1, page 12. This holds particularly for the use of slow speed or "time lag" fuses becomes feasible. They have the advantage of conforming better to transformer damage curves and of avoiding interference with the secondary side protection. It must, of course, be remembered that:

a. under no condition must the fuse current rating be allowed to be less than the continuous load current,

b. no E-rated fuse can provide any protection in the range between cne and two times the continuous load current.

c. With forced-cooled transformers, coordination must be based on the higher continuous current rating.

For the coordination with secondary protection, a sufficient margin of safety must be provided against melting of the primary fuse because, in service, the melting times are reduced below those shown in the standard characteristic by preloading and other variables. This margin commonly is introduced into the coordinating procedure by lateral or perpendicular shifting of the no-load melting curve, the amount of the shift to some extent being left to engineering judgment. The melting curves in application data 36-660-A make provision for a lateral shift; in the range of the 2:1 slope of the melting curves, it is equivalent to a reduction of the no-load melting times to about 65 percent.

The upper limit of the current rating of the fuse is determined by the degree to which the transformer is to be protected by the fuse against faults on the secondary side. The line current seen by the fuse depends primarily on the nature of the fault and on the impedance of the transformer. The relation between these variables and the degree of protection afforded by the fuse is covered in appendix 1, page 12. For routine applications it is sufficient to know that standard speed fuses can well protect standard impedance delta-wye transformers even against single-phase-to-neutral faults at the transformer secondary, if the fuse current rating is twice that of the transformer. For less critical cases, the fuse-to-load rating ratio can well be allowed to be considerably higher than 2:1.

motor protection

Since the continuous rated current of a fuse must be at least as high as that of the apparatus it is to protect, and since its minimum melting current in turn is at least twice its rated current, it follows that a power fuse cannot protect an apparatus against anything less than a 100 percent overload. In general, the "gap" in which protection cannot be supplied in this manner will be found to be considerably greater. If one is willing to forego protection in this gap and be satisfied with protection at higher currents only one can obtain it by means of fuses, with certain restrictions imposed by the fact that the damage characteristics of the apparatus and the clearing time-current characteristics of the fuse hardly ever coincide. Although "protected" the apparatus may be exposed to overloads of somewhat longer duration than desirable, or the fuse may limit the overload capacity otherwise available in the equipment.

Full range protection is afforded only by the combination of fuses and other sensing devices, such as relays covering the range up to and somewhat beyond the maximum possible load current of the equipment, while fuses furnish short circuit protection only. With motors this means that the fuses are not protecting the motor itself but rather the circuit up to the motor terminals, in particular the starting equipment. This being the objective, it is well to avoid altogether any possibility of the fuse becoming affected by long duration overloads (locked rotor condition). This is done by selecting the minimum melting current of the fuse equal to, or in excess of the locked rotor current. A 10 percent margin is a reasonable figure which means that the relay curve properly transposed into the fuse melting characteristic should intersect the latter at a current 10 percent or more in excess of the locked rotor current. Lacking specific information, the latter may be assumed to be six times the full load current.

Contactors in motor starter equipment employing current limiting fuses must be selected so that they can withstand the thermal and magnetic effects of the current permitted by the fuse. These currents and their duration are shown by the total clearing time-current curves of the fuses up to currents requiring .01 second to clear. The peak and rms values of higher currents are determined by means of the information on let-through currents in table 4 and figure 3. The let-through currents at rated interrupting current and maximum asymmetry are listed directly in the table. Figure 4 illustrates that the let-through current surge is more or less triangular. Therefore, its rms value is calculated approximately by dividing the peak value (let-through) current by $\sqrt{3}$. The duration of the current surge resulting from faults higher than the threshold current is of the order of one half cycle. Therefore, the thermal effects of high let-through currents are equivalent approximately to a half-cycle normal-frequency sine wave of an rms value calculated as indicated above.

The duty of fuses in motor starter circuits is characterized by the frequent application of high overloads, i.e., motor starting currents. Motor starter fuses, therefore, must be designed to withstand these frequent and severe heating and cooling cycles without fatigue failures. Types BAL-LR and CLS fuses are of such construction; as pointed out before, they contain no elements sensitive to low currents. The type CLS fuses in particular are designed so as to provide for highly uniform flexing of the fusible elements during heating cycles.

The ratings and styles of current limiting fuses particularly suited for motor starting duty are listed below:

ratings and styles of current limiting fuses recommended for motor starters

type	continuous current amperes	melting current amperes		style	
		100 sec	25 sec	2.4 kv	4.8 kv
CLS	50	170	....	676C546G02	676C546G15
	70	255	....	676C546G03	676C546G16
	90	340	....	676C546G04	676C546G17
	110	425	....	676C546G05	676C546G18
	130	510	....	676C546G06	676C546G19
	200	765	....	676C546G09	676C546G22
	225	1020	....	676C546G12	676C546G25
BAL-LR	300	....	2200	1804 860	1804 862
	400	....	3000	1804 861	1804 863

All above listed fuses have an interrupting rating of 40,000 amperes rms symmetrical.

response of fuses to repetitive faults

In order to determine the performance of fuses under repetitive faults such as produced by the operation of reclosing circuit breakers one must take into account their heating and cooling characteristics. In a certain way, these are contained in, and expressed by the melting time-current curves. How the course of the temperature at the fusible element can be established with sufficient accuracy by means of the information contained in the melting curve is set forth in detail in appendix 2.

It is shown there that conventional (E-rated) fuses can with good approximation be regarded as bodies whose heating and cooling properties are described by the basic exponential curves A and B shown in figure 5. Except for being inverted, the cooling curve is the same as the heating curve; both have the same time constant. Every fuse has a specific time constant; the latter is closely related to the speed ratio S whose values are given in table 3. As shown in the appendix, the time constant Θ can be calculated with sufficient accuracy by the formula $\Theta = 0.1 \times S^2$ (seconds).

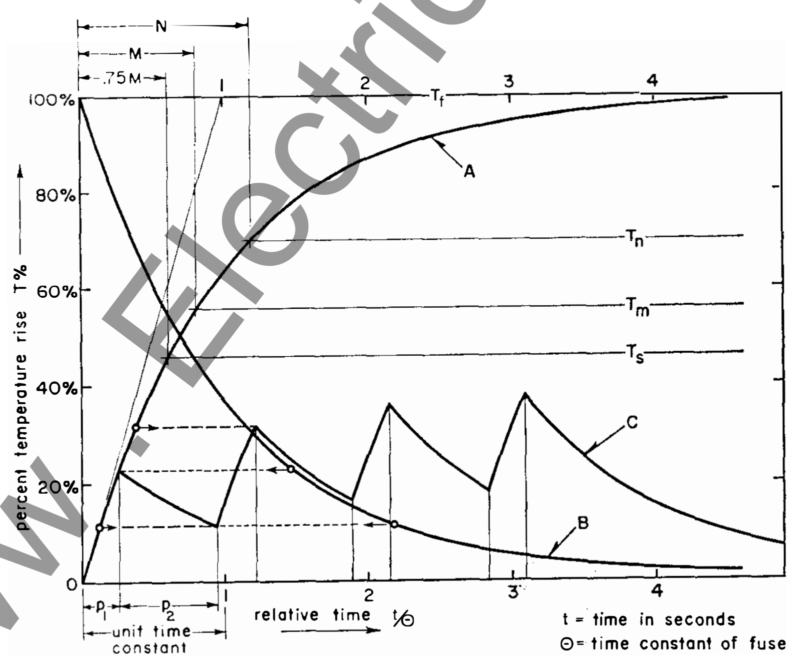
The time constant of a specific fuse, having been obtained in terms of seconds, gives to the general heating and cooling curves of figure 5 a specific time scale. It enables us to plot the course of the temperature (in percent values) if we know the sequence and the duration of the open and closed periods of the recloser. This is illustrated by curve C which simply is pieced together from proper sections of curves A and B.

It now remains to be determined at what temperature level the fuse will melt. For this purpose we enter into figure 5 the melting time M, as obtained from the regular fuse characteristic for a given fault current. Wherever the ordinate to the time M intersects curve A, there obviously lies the level of the melting temperature T_m. Its absolute value need not be known. It is sufficient to know its relation to the peaks of curve C. T_m marks the melting level of the fastest melting fuse of a given rating and design. This is in accordance with the standard definition of melting time-current characteristics. The level T_n where the slowest fuse of a certain group will melt is indicated by the total clearing time N applying to the same fault current. In this connection it should be remembered that the total clearing time-current characteristic is practically nothing else but the melting characteristic of the slowest fuse of a certain group, the spread between the slowest and the fastest fuse being fixed in the Standard by the definition of E-ratings (viz.: 200 to 240 percent and 220 to 264 percent). In comparison to this tolerance which is to cover manufacturing variations, the arcing times which should be added to the melting period are insignificant. The inter-section of curve C with T_n anywhere ahead of the last cycle, signifies that the fuse can be relied upon to melt (and clear) before the recloser locks out.

If the fuse is not to blow, curve C must remain below the level T_m by a safe margin. It is common practice to provide such a margin by coordinating the breaker with a fuse curve whose time ordinates are 75 percent of those of the melting curve. Thus, the intersection of the ordinate to 0.75 M with curve A in figure 5 designates the safe temperature level T_s.

Although the construction of the temperature diagram as outlined above basically offers no difficulties, the manipulation is made easier and more accurate by putting the graph on semilog coordinates as shown in figure 8, page 15. On such coordinates, the cooling curve B becomes a straight line. The recloser cycling schedule and all data required for the construction of the diagram are listed in condensed form on the same page. A blank for reprinting this form is contained in application data 36-660-A (curve no. 23).

figure 5: temperature cycle of fuse during recloser operation



curve A—Basic fuse heating curve: $T = T_f\ (1\text{-}e^{-t/\Theta})$

curve B—Basic fuse cooling curve: $T = T_f \times e^{-t/\Theta}$

curve C—Temperature rise curve of fuse subjected to recloser cycle.

M—Melting time of fuse at a given fault current.

N—Total clearing time of fuse at same fault current.

T_m, T_n—Levels of melting temperature of fastest and of slowest fuse.▲

T_s—Safe temperature level, considering service variables.

T_f—Hypothetical steady state temperature level (100%) attained if the fuse element did not open when melting temperature was reached but continued to be a resistance of constant value.

▲ The absolute temperature at which the elements of the fastest and of the slowest fuse melt is the same since both fuses are made of the same material. However, T_n and T_m are different if measured by the final temperature level T_f reached at a given current.

appendix 1

coordination between transformers and fuses

Fuses in the primary of transformers should not blow on transformer magnetizing or inrush current nor should they blow or deteriorate under long duration overloads to which the transformer is to be subjected in normal service and in cases of emergency. On the other hand, they must protect the transformer against short circuits. These considerations usually determine the upper and the lower limit of the fuse rating. The coordination with other protective devices often further limits the range. At this point, however, we concern ourselves only with the requirements imposed by the transformer. In general, results are expressed by the ratio between the current rating of the fuse and the transformer full load current, which ratio, in the following, is termed the "Fuse-to-Load Rating Ratio" and is designated by the letter R.

lower limit of fuse rating

The heating effect of the magnetizing inrush current usually is considered to be equivalent to a current twelve times the transformer full load current flowing for 0.1 second. Therefore, the 0.1 second fuse melting current $I_{0.1}$ should be related to the transformer full load current I_t by the expression

$$I_{0.1} > 12\ I_t$$

or, if we wish to introduce a 10 percent factor of safety,

$$I_{0.1} > 12\ I_t \times 1.1 \quad (1)$$

At this point it is helpful to recall that the relation between the 0.1 second melting current and the rated continuous current I_r of a fuse is defined by standard ratios and terminology. One such term is the "speed ratio", designated in the following by the letter S. This is the ratio between the 0.1 second melting current $I_{0.1}$ and the minimum melting current I_m at 300 or 600 seconds, depending on whether the fuse rating is 100 amps or less, or whether it is higher than 100 amps. In algebraic terms

$$S = I_{0.1}/I_m \quad (2)$$

Furthermore, according to Standards the minimum melting current I_m of E-rated fuses at 300 or 600 seconds, respectively, must have the following relation to the rated current I_r:

For E-rated fuses of 100 amps or less

$$I_m = 2\ I_r \quad (3)$$

For E-rated fuses above 100 amps

$$I_m = 2.2\ I_r \quad (4)$$

In accordance with the above formulas (1) to (4) the minimum fuse-to-load rating ratio R_m, based on magnetizing inrush current is:

For E-rated fuses of 100 amps or less

$$R_m = I_r/I_t = 6.6/S \quad (5)$$

and for E-rated fuses above 100 amps

$$R_m = I_r/I_t = 6/S \quad (6)$$

The speed ratio-S of all E-rated Westinghouse power fuses are shown on table 1.

The formulas (5) and (6) imply that the magnetizing inrush current poses no problem in the application of fuses whose speed ratio exceeds 6 (or 6.6) since I_r/I_t must not be allowed to be less than unity at any rate. For such fuses—which are the majority of the conventional types—the lowest practical fuse-to-load rating ratio is determined by other considerations such as the long time overloads the transformer must be allowed to carry. General information on this question is contained in the "Guide for Loading Oil-Immersed Distribution and Power Transformers", ASA Standard, appendix C57.92. As far as the application of fuses is concerned, the most significant data gleaned from this ASA guide are presented by the lines A, B, C and D of curve # 22 in application data 36-660-A. All these lines show transformer load-time characteristics under conditions stated in the figure. The selected cases are only a portion of those featured in the ASA guide; they are chosen because they represent severe service conditions in as much as 50 percent preloading allows heavy daily overloads, and as an estimated 1 percent loss of life in cases of emergency is a condition which most operators will not wish to exceed. Generally speaking fuses should be able to sustain these load limits.

Long time emergency load limits for fuses are shown on the inserts to curve #22. For coordination, these curves are to be placed on the transformer chart so as to coincide with, or be slightly to the right of the respective transformer emergency load curve. Their base points on the 300 or 600 second time level read in multiples of the transformer full-load current I_t; these multiples be designated by the symbol P. If, in order to provide a margin, the melting current I_m is tobe 10 percent higher than thevalue $P \times I_t$, and if the relations of equations (3) and (4) are considered, the rated fuse currents will be, for E-rated fuses of 100 amps or less

$$I_r = 1.10 \times P \times I_t/2 \quad (7)$$

and for fuses above 100 amps

$$I_r = 1.10 \times P \times I_t/2.2 \quad (8)$$

For routine applications, the matter of fuse selection is simplified by choosing a single representative overload condition, namely 200 percent load for 1.5 hours. Based on this reference point, the use of the fuse emergency limit lines of curve #22 results in the following ratios between fuse rating and transformer full-load current.

For types BA and DBA fuses

$$R_m = I_r/I_t = 1.4 \quad (9)$$

For current-limiting fuses

$$R_m = I_r/I_t = 1.6 \quad (10)$$

The fuse-to-load ratios of formulas (9) and (10), or those arrived at by closer analysis of specific cases, are based on the requirement that the fuses should not deteriorate under these emergency overload conditions. Considering the relation of the daily overload curves C and D to the emergency limits A and B, it is obvious that fuses coordinated on the basis of emergency loads will not suffer when subjected to normal daily overload cycles.

Whether the fuses so selected will withstand transformer inrush current is determined by applying formula (5) or (6). As mentioned before, no checking at all is necessary if S is larger than 6 or 6.6. However, if the speed ratio was 4 or thereabout, the R_m calculated for inrush current could well become the larger value. It is, of course, the larger of the two R_m values which governs the selection of the fuse rating.

upper limit of fuse rating

The upper limit of applicable fuses is determined by the extent to which the transformer is to be protected against secondary fault currents. The time limits to which short circuits are to be sustained by transformers are specified in the Transformer Standard ASA C57.12-08.112. They are represented by the line T in the transformer overload characteristic, curve #22. The upward continuation of this line as a curve obviously must lead in the direction of the emergency load limits A and B. The whole curve may be considered a generalized transformer damage characteristic. It holds for single phase transformers and also for three phase banks in the case of balanced three phase faults or overloads.

If only one or two phases are faulted on the secondary side, the primary-side line current which results in the same secondary winding current as the three phase fault differs from the three phase fault primary current by the factor N. For different transformer connections and fault conditions, this factor N is shown in the table below.

transformer connection all neutrals grounded		primary line current multiplier N for fixed secondary winding current in the case of		
primary	secondary	3 phase fault	phase-to-ground fault	phase-to-phase fault
Y	Y	1	1	1
Y	Δ	1	.	1
Δ	Y	1	$1/\sqrt{3}$	$2/\sqrt{3}$
Δ	Δ	1	.	$\sqrt{3}/2$

In as much as the basic transformer damage curve is drawn for the three phase fault, the damage curves for other fault conditions are obtained by shifting the basic damage curve sideways by a factor N. The various adjusted damage curves obtained in this manner are shown on curve #22. It is to be noted that this applies only for the coordination picture as seen at the primary side, into which the published fuse time-current characteristics are entered directly.

If the coordination curves are drawn on the basis of secondary line currents, the currents of the primary fuse time-current characteristic must be multiplied by the proper factor M which is

$$M = Q/N \qquad (11)$$

where Q is the system voltage ratio and N the value given in the above table.

Thus, a coordination diagram drawn for the primary side consists of direct reading fuse characteristics and up to three transformer damage curves one of which however, may not have any practical importance.

A coordination diagram drawn for the secondary side, on the other hand, consists of one transformer damage curve and, theoretically, up to three fuse characteristics (for the ΔY case). If the secondary is delta connected a second transformer damage curve is required to represent the phase-to-phase fault condition. Its multiplier N is $\sqrt{3}/2$.

Selection of an appropriate fuse and determination of the extent to which it protects the transformer is illustrated by the following example, employing the primary side diagram.

Fuses are to be provided for a 1000 kva 33 kv delta-wye transformer bank at a location where the available 3 phase fault current is 4000 amps rms symmetrical.

Table 3 shows that the interrupting rating of a DBA-1 fuse is sufficient. The transformer full-load current is
$\frac{1000}{33 \times \sqrt{3}} = 17.5$ amps.

Formula (9) indicates a minimum fuse rating of 17.5 x 1.4 = 24.5 amps.

The 25-E standard-speed fuse is selected. According to table 1 its speed ratio is 5.5. Checking for magnetizing inrush current capacity we apply formula (5) and find that $R_m = 6.6/5.5 = 1.2$. This means that the 25-amp fuse can withstand the inrush current of even a 25/1.2 = 20.8 amp full-load transformer.

To determine the extent to which the transformer is protected, read the 300 sec. total clearing current of the 25-amp fuse on curve sheet #12. It is 60 amps; thus the ratio to the transformer full-load current is 60/17.5 = 3.43. Mark this value on the 300-second time level of the transformer characteristic, curve sheet #22, and trace the total clearing curve of the 25-amp fuse through the same point, as illustrated. From the N table, at left, we know that the phase-to-ground fault is the most critical condition for a delta-wye transformer. The corresponding damage curve is that with the parameter $N = 1/\sqrt{3}$. Its intersection with the fuse characteristic indicates that this fuse protects against a single-phase secondary fault drawing as little as 3.7 times the transformer full-load current on the primary side. If coordination with other devices should call for a higher rating fuse, the protective range of a 30 or 40 amp fuse can be checked in the same manner. The transformer coordination point of the 40-amp fuse, for instance, would be 96/17.5 = 5.5 on the 300-second time level.

The selection of fuses depends to some degree on opinions regarding desirable safety factors, expected overloads, etc. In this connection, the basis on which the total clearing curves are drawn is worth noting. Total clearing curves generally are obtained by adding maximum arcing times to the maximum melting curve (see AIEE Standard 25-304 of February 1958). The maximum melting curve in turn is nothing else but the published (minimum) melting curve shifted to 20% higher current values in accordance with limits given in the Standard. The standard 20% band is meant to take care of manufacturing variations, but in general provides for more than the normally encountered tolerances.

Similarly, the transformer damage curve with which the total clearing curve is compared, is really not a line but a band of which the designated line is the lower boundary. To what extent this boundary may be transgressed depends more or less on the amount of loss of transformer life deemed acceptable.

It thus is seen that the selection of fuses for transformer protection allows for considerable flexibility if the significance of the various factors involved is assessed properly.

appendix 2

basis for calculating the response of fuses to repetitive faults

The heat generated in a fuse is dissipated through conduction, convection and radiation. All these processes depend on the temperature of the heat source in a different and rather complex manner. Therefore, if the heating and cooling cycle of fuses is to be dealt with in more or less routine calculations, the integrated effect of the complex heat dissipation processes must be expressed in a simple form though the latter may be approximative only. This simple form is presented by the assumption that the heat loss is proportional to the temperature rise T above ambient, of the fusible element.

Furthermore, the ohmic resistance of the heat source, which also varies with temperature, must be represented by a median value R supposed to hold for all temperatures. Under these conditions, the temperature (rise) of the fusible element when heated by a constant current is expressed with respect to time t by the formula

$$T = T_f\,(1 - e^{-t/\Theta}) \qquad (1)$$

where Θ is the thermal time constant of the fuse, and T_f the final temperature reached, assuming that the heating process is not interrupted by melting, and that the fusible element continues past the melting point to act as a constant resistance R. The fusible element need not actually do this; nevertheless this hypothetical condition constitutes a useful concept in this analysis. At the final steady state temperature T_f, whether theoretical or actual, a balance is reached between heat input and heat loss. This concept is expressed by the relation

$$I^2R = T_f\,K \qquad (2)$$

where K is the heat dissipation constant or the heat loss in watts per degree C.

This same relation also holds for the case where I is the minimum current I_m which will produce melting in the final stage, that is after a long time (300 seconds or more). In this case T_f is identical to the melting temperature T_m. Thus equation (2) attains the form

$$I_m^2R = T_m\,K \qquad (3)$$

It designates the current at which the melting time-current curve runs parallel to the time axis.

At the other end of the time-current curve, that is at very short times, only a very small portion of the heat input is dissipated; practically all of it is used to raise the temperature of the fusible element to the melting point. This is expressed by the equation

$$I^2Rt = C_hT_m \qquad (4)$$

where C_h is a median value of the heat capacity of the fusible element in watt seconds per degree C. The product $C_h\,T_m$ stands for the total work necessary to produce melting. Equation (4) holds for that part of the melting time-current curve which has an essentially uniform slope of 2:1.

With conventional (E-rated) fuses the 2:1 slope of the melting time-current curve extends for all practical purposes up to the 0.1 second level. Written for this time equation (4) takes the form

$$I_{0.1}^2 \times R \times 0.1 = C_h\,T_m \qquad (5)$$

Similarly, the 300 to 600 second melting current is practically the same as the minimum melting current defined by equation (3). Combining equations (3) and (5) results in the relation

$$C_h/K = 0.1 \times (I_{0.1}/I_m)^2 \qquad (6)$$

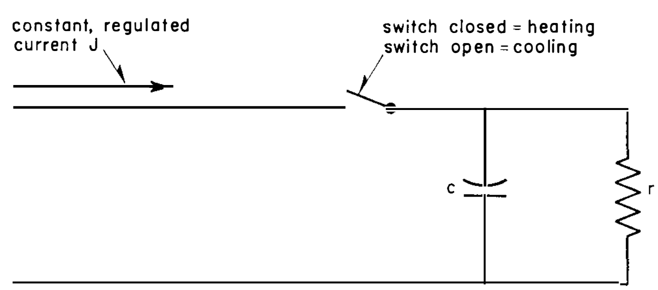
The term $I_{0.1}/I_m$ will be recognized as representing the fuse speed ratio S as defined by equation (2) of appendix 1 and as listed in table 1. Furthermore, as will be shown below, the term C_h/K represents the thermal time constant Θ. Therefore, equation (6) attains the form

$$C_h/K = \Theta = 0.1\,S^2 \qquad (7)$$

This is the key to utilizing commercially available fuse characteristics for the rational evaluation of fuse and recloser coordination. Admittedly, though, it still is only an approximation. It is, however, better than not having any means at all for the evaluation of the response of fuses to cyclic loads. It is believed that the routine of the procedure can be understood without further explanation from the example given in figure 8. A blank for reprinting this form is found as curve # 23 in application data 36-660-A.

It now remains to be shown that the term C_h/K actually represents the thermal time constant Θ. This can be demonstrated readily by the derivation of formula (1) from the basic heat balance equation in differential terms, but it can just as readily be seen from the electrical analog of the simplified heating and cooling process shown in figure (7). In it, the voltage at the capacitor is equivalent to the temperature rise at the fusible element, and the portion of the current J bypassed in the resistor r corresponds to the heat loss in the fuse. The resulting analogy between C_h/K and the familiar electrical time constant rc is evident from picture and tabulation.

figure 7: electrical analog of simplified version of heat flow in fuse



	analogs				
electrical circuit	constant, regulated current J	voltage at condenser e	current bypassed e/r	capacitor c (FD)	time constant rc
fuse	constant heat input I^2R	temperature rise at fuse element—T	heat lost T x K	thermal capacity C_h(Joules/°C)	time constant C_h/K

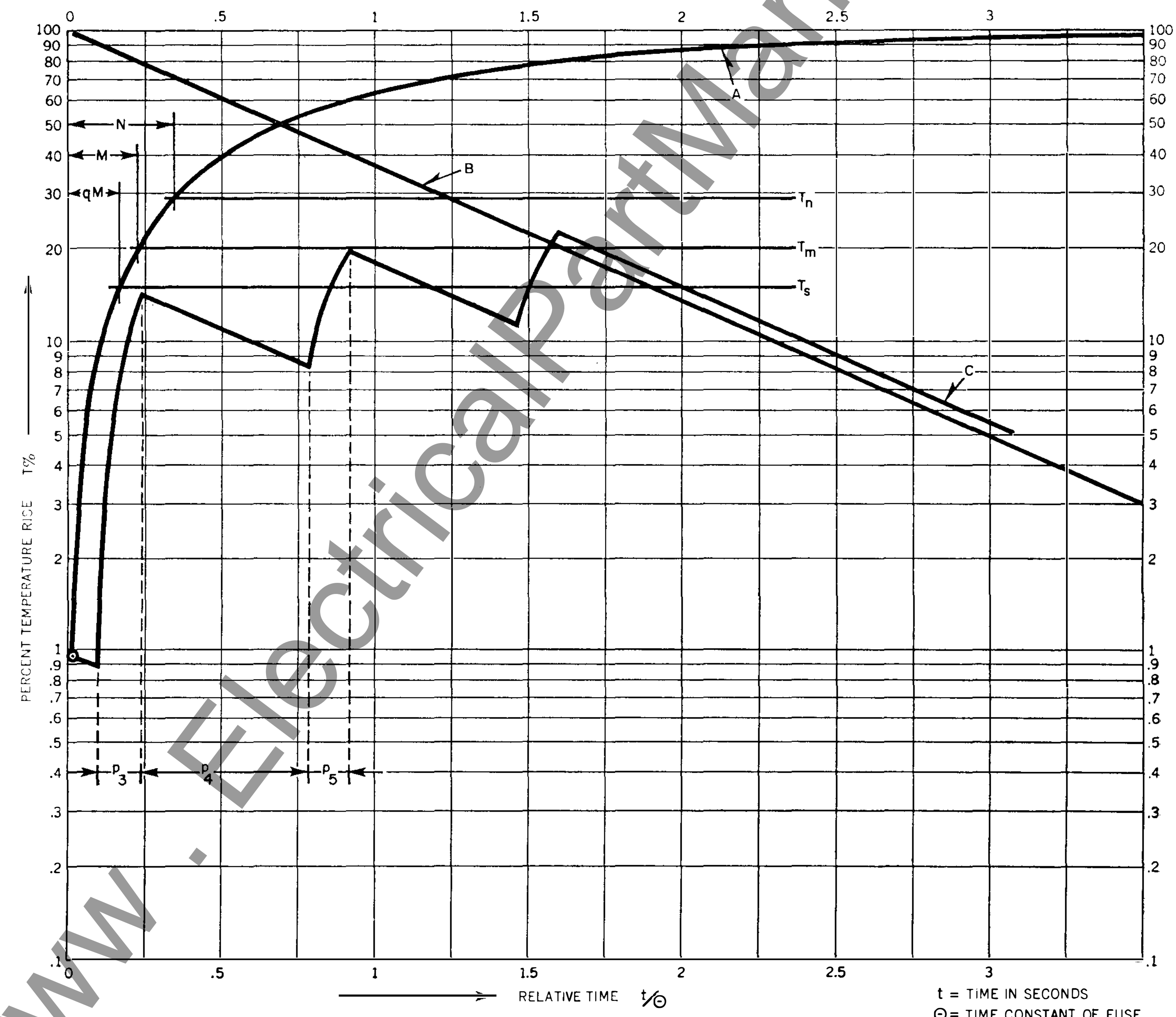
figure 8: **fuse-recloser coordination problem analyzed on coordination chart curve # 23**

recloser data: 400 PR 100 (cycling code A1-3CH3)
fuse type and rating: BA-200, 150-E standard speed
fuse speed ratio, S = 7.5
thermal time constant, Θ = .10 S^2 = 5.6 seconds
fault current: 800 amps

▲ The first period may be so short that the intersection with curve A may be difficult to pinpoint. It should, therefore, be noted that, in figure 5, the initial portion of curve A coincides with the tangent which intersects the 100% level at the unit time constant. Consequently, the temperature level attained within such short times is determined simply by the formula $T\% = 100 \times t/\theta$.

● "q" is the coordination factor to take care of service variables. It is commonly estimated to be .75.

period no.	recloser timing t—seconds		total time Σt	relative time $\Sigma t/\Theta$	resulting percent temperature
	closed	open			
1▲	.054		.054	.0096	.96▲
2		.5	.554	.099	
3	.8		1.354	.241	
4		3	4.354	.78	
5	.8		5.154	.92	
6		3	8.154	1.46	
7	.8		8.954	1.6	23
normal melting time			1.25	M =.224	T_m =20
q ● x M				.168(75%)	T_s =15.7
total clearing time			1.9	N =.34	T_n =29



This case analysis shows that the chosen fuse is likely, but not definitely sure, to blow under the selected recloser cycle.

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