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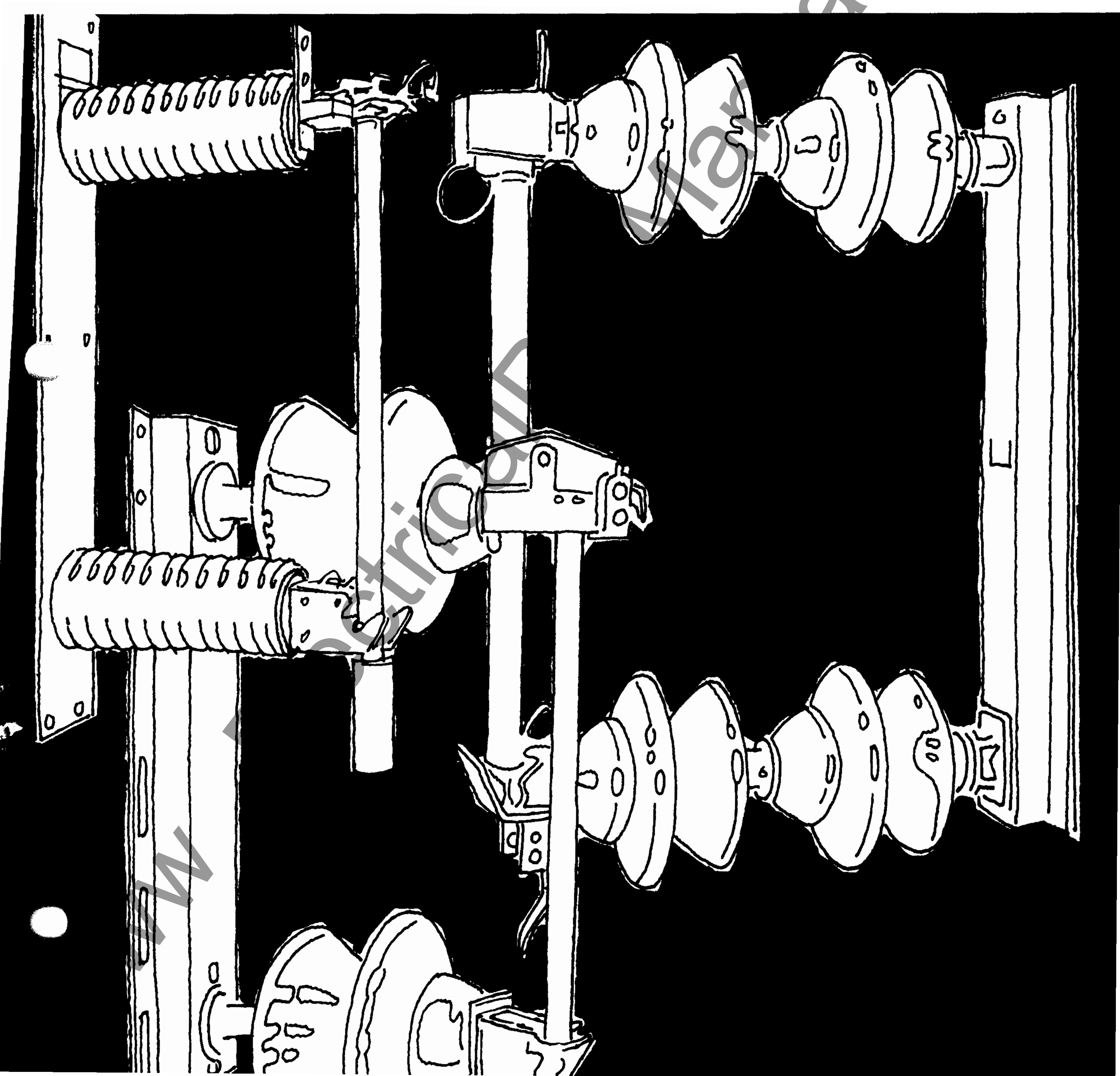
# High Voltage Expulsion Type Power Fuses



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## Introduction

Westinghouse power fuses offer such diverse characteristics that almost any fuse application, within the practical range of such interrupting devices, may be satisfied. These diverse characteristics are offered, in part, by the production of both expulsion and current limiting power fuses. Expulsion and current limiting fuses provide diverse characteristics by employing different areas of fuse technology. This difference in technology along with the diverse characteristics require that different questions be answered when applying expulsion and current-limiting fuses. For this reason, and in an attempt to avoid confusion, this application data pertains only to expulsion fuses. See Application Data 36-686 for information on the application of current-limiting fuses.

## General Information

The main types of expulsion fuses produced by Westinghouse are the indoor RBA, the outdoor dropout RDB and the indoor/outdoor DBU. Westinghouse also produces the DBA and the BA, however, with the exception of the outdoor dropout DBA rated 46 and 69 KV both lines have been made obsolete by the RBA and the RDB.

The latest addition to the Westinghouse expulsion fuse line is the DBU. It is lighter and less expensive than the higher rated RBA/RDB fuses and is well suited for the protection of overhead distribution transformers, substation equipment, industrial transformer installations and radial distribution circuits. A full line of Westinghouse mountings is available for outdoor installations. The fuse is also utilized as a replacement in metal enclosure applications where a "fuse condenser" (ANSI C37-100-1981) is utilized.

With the exception of the mounting and the addition of a kickout pin to the RDB, the construction of the RBA and RDB is identical. The fuse unit is comprised of a mounting, fuse holder which includes the spring and shunt assembly, refill and a discharger filter or condenser for indoor applications. These parts are shown in DB 36-634.

Indoor RBA or DBU fuses may employ either a disconnect or a nondisconnect mounting. Each of these mountings has the terminals front connected. Indoor, nondisconnect mountings may be equipped with indicators. Outdoor mountings for the RDB, and DBA, on the other hand, must be disconnecting due to the dropout feature.

Concerning the outdoor mounting and the DBU, RDB and DBA fuses it must be emphasized that unblown fuses should not be left hanging in the disconnected position for long periods of time. If the weather seal on these fuses is broken or damaged, water may damage the fuse. The integrity of these seals is directly related to the integrity of the fuse and these seals should be checked periodically and replaced, if necessary.

Westinghouse expulsion fuses use boric acid for the interrupting medium. When a fuse element melts, the heat of the arc decomposes the boric acid producing water and boric anhydride which extinguishes the arc by blasting through it and exciting out the bottom of the fuse. This interruption process produces both an exhaust and a good deal of noise. To moderate this exhaust a discharge filter or condenser is added to indoor fuses. The discharge filter limits the exhaust to a small and relatively inert amount of gas and lowers the noise level with no effect on the interrupting rating of the fuse. A condenser almost completely absorbs and contains the exhaust while further lessening the noise level; however, the condenser requires a reduction of the interrupting rating of the fuse.

**Fuse Selection**
There are four considerations involved in the selection of a power fuse. The first three considerations are the voltage rating; the interrupting rating including rate of rise of recovery voltage considerations, and the continuous current rating of the fuse. Proper attention should be given to each of these considerations as improper application in any one area may result in the fuse failing to perform its intended function. The fourth consideration is coordination with line and load side protective equipment which is needed to give selectivity of outage and to prevent premature fuse blowing. Each of the four areas are discussed in detail in the following information.

**Voltage Rating**
The first rule regarding fuse application is that the fuse selected must have a maximum design voltage rating equal to or greater than the maximum normal frequency recovery voltage which will be impressed across the fuse by the system under all possible conditions. In most cases this menas the maximum design voltage of the fuse must equal or exceed the system maximum line-to-line voltage. The only exception to this rule occurs when fusing single-phase loads connected from line-to-neutral on a four-wire effectively grounded system. Here the fuse maximum design voltage need only exceed the system maximum line-to-neutral voltage providing it is impossible under all fault conditions for the fuse to experience the full line-to-line voltage.

A good rule of thumb is that if more than one phase of the system is extended beyond the fuse location, the fuse maximum design voltage should equal or exceed the system maximum line-to-line voltage regardless of how the three-phase system is grounded on the source side of the fuse or how the transformers or loads are connected on the load side of the fuse. Many people, however, choose to fuse wye grounded wye transformers with fuses with a voltage rating which only exceeds the system line-to-neutral voltage. In most cases this presents no problems but the user should be aware of the remote possibility of a secondary phase-to-phase ungrounded fault which could impose full line-to-line voltage across the fuse. When only one phase of a four-wire effectively grounded system is extended beyond the fuse to supply a load connected from phase-to-neutral it is usually acceptable to have the fuse maximum design voltage equal or exceed the system maximum line-to-neutral voltage.

It is permissible for expulsion fuse voltage ratings to exceed the system voltage by any desired amount but under no circumstances may the system voltage exceed the fuse maximum design voltage.

**Interrupting Rating**
The rated interrupting capacity of power fuses is the rms value of the symmetrical component, AC component, of the highest current which the fuse is able to successfully interrupt under any condition of asymmetry. In other words, the interrupting rating denotes the maximum symmetrical fault current permitted at the fuse location.

Another way of rating the interrupting rating of power fuses concerns the asymmetrical fault current. Asymmetrical currents are related to symmetrical currents by the asymmetry factor which is the ratio of the rms value of the asymmetrical current, which includes a DC component, at some instant after fault initiation to the rms value of the symmetrical component of current.

Asymmetry factors for a time corresponding to 1/2 cycle after fault initiation are a function of the circuit X/R ratio and this relationship is shown in Figure (1). Theoretically, the maximum asymmetry factor in a purely inductive circuit is 1.732; however, with the X/R ratios encountered in power circuits it is rarely ever more than 1.6 at 1/2 cycle. Fuse standards, ANSI C 37.46-2.5, Table 1, call for asymmetry factors of 1.56 to 1.6. The mimimum asymmetry factor at which Westinghouse power fuses are tested to determine their maximum interrupting rating is 1.6. In general, asymmetrical currents can be converted to their symmetrical counterpart by dividing the asymmetrical value by 1.6.

A third way to rate the interrupting rating of power fuses is with nominal three-phase KVA ratings. Three-phase KVA ratings are calculated by the formula I X KV X 1.732 where I is the interrupting current in symmetrical rms amperes and KV is the fuse nominal voltage rating. With this method it should be kept in mind that power fuses are not constant KVA devices, that is, if the voltage is half the fuse rating the interrupting current does not double but remains the same. The fuse will interrupt any current up to the maximum rated interrupting current as long as the normal frequency recovery voltage does not exceed the fuse maximum design voltage rating. Using the KVA rating for anything other than rough overall classification is contrary to the design principles of expulsion power fuses.

**Figure 1: Asymmetry Factor**

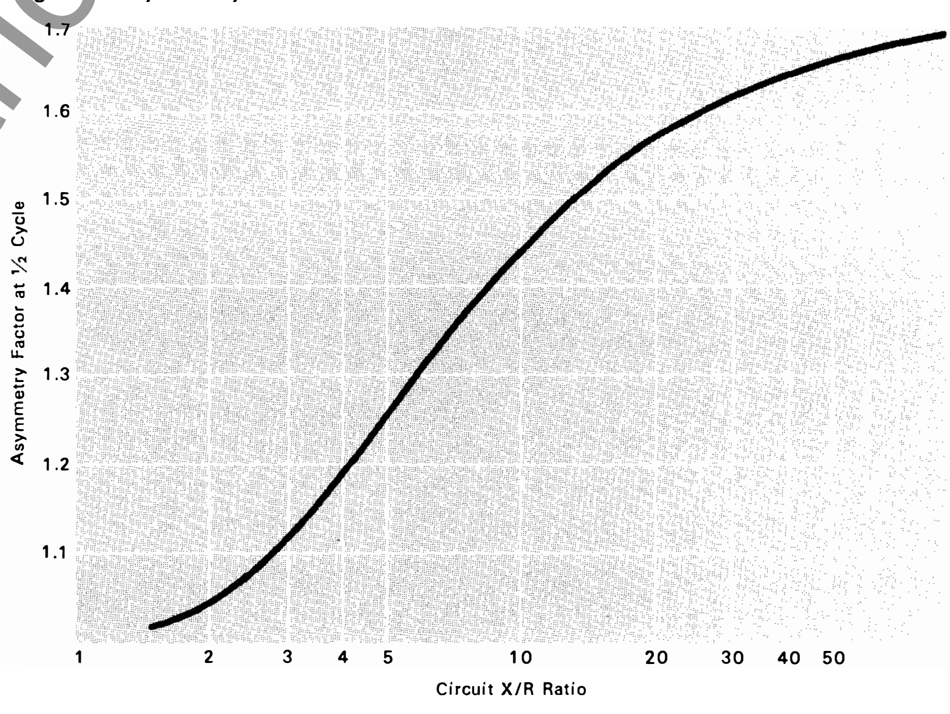


Table (1) lists the symmetrical, asymmetrical and nominal three-phase KVA interrupting ratings of expulsion fuses produced by Westinghouse. Note that use of the condenser reduces the interrupting rating. Values listed in the table are valid for both 50 and 60 hertz systems. For application on 25 hertz systems use the derating factors given in Table (2) to determine the interrupting rating.

When the fusible element in an expulsion fuse melts as the result of a fault, an arc is established within the fuse. Normal operation of an expulsion fuse causes elongation of the arc but the current continues to flow in the circuit and in the fuse until a current zero is reached. When the arc is extinguished at a current zero, the voltage across the fuse terminals changes from the relatively low arc voltage to the steady state power frequency recovery voltage. This recovery voltage is determined by the system configuration and type of fault and/or load connections. The voltage waveform across the fuse terminals during the transition from arc voltage to power frequency recovery voltage is referred to as the transient recovery voltage. Transient recovery voltages can produce high voltage stresses across the fuse terminals, thus the dielectric strength between the fuse terminals must rise faster than the transient recovery voltage if a successful interruption is to occur. Impedance within the circuit determines the resonant or natural frequency of the transient recovery voltage after the arc is extinguished. This refquency of oscillation and the amplitude factor, defined as the ratio of the highest peak value of transient recovery voltage to the peak of the power frequency recovery voltage, define the transient recovery voltage impressed across the fuse terminals.

Primary faults, or faults on the primary side of a transformer, generally produce higher short circuit currents and less severe transient recovery voltages while secondary faults produce lower short circuit currents and more severe transient recovery voltages due to the insertion of the transformer impedance in the circuit. Westinghouse recognizes the effects of different parameters involved in primary and secondary fault phenomenon and has tested its RBA and RDB line of fuses to prove their integrity at successfully clearing against the transient recovery voltages associated with both types of faults. Table (3) lists the transient recovery voltage natural frequencies and amplitude factors to which the fuses were tested, all of which are move severe than the recommended standards for high voltage expulsion fuses proposed by the International Electro-Technical Commission.

Another consideration in applying power fuses is the altitude at which the application is made. The dielectric strength of air decreases with increases in altitude, necessitating a reduced interrupting rating above 3300 feet. Table (4) gives the correction factors for different altitudes as listed in ANSI C37.40-2.3.

Power fuses also have limits on interrupting low currents. These devices are fault protective devices and not overload protective devices. No 'E' rated fuse provides protection for all values of overload current between the range of one to two times its continuous current rating. Refer to the following section on continuous current for additional details.

Remember that under no circumstances may a fuse be applied where the available fault current exceeds the interrupting rating of the fuse.

**Table 1 – Expulsion Fuse Interrupting Ratings**

| Voltage KV | | Indoor With Discharge Filter & Outdoor Vented | | | Indoor with Condenser | | |
|---|---|---|---|---|---|---|---|
| Nominal | Max. Design | Sym. Amps | Asym. Amps | 3-Phase Sym. MVA | Sym. Amps | Asym. Amps | 3-Phase Sym. MVA |
| RBA-RDB-200 | | RBA-200 | RDB-200 | | RBA-200 | | |
| 2.4 | 2.75 | 19000 | 30000 | 80 | 10000 | 16000 | 42 |
| 4.16 | 4.8 | 19000 | 30000 | 137 | 10000 | 16000 | 72 |
| 4.8 | 5.5 | 19000 | 30000 | 158 | 10000 | 16000 | 83 |
| 7.2 | 8.25 | 16600 | 26500 | 205 | 10000 | 16000 | 125 |
| 13.8 | 14.4 | 14400 | 23000 | 345 | 8000 | 12800 | 191 |
| 14.4 | 15.5 | 14400 | 23000 | 360 | 8000 | 12800 | 200 |
| 23.0 | 25.5 | 10500 | 16800 | 420 | 6300 | 10100 | 250 |
| 34.5 | 38.0 | 6900 | 11100 | 410 | 5000 | 8000 | 300 |
| RBA-RDB-400<br>RBA-RDB-800 | | RBA-400<br>RBA-800 | RDB-400<br>RDB-800 | | RBA-400<br>RBA-800 | | |
| 2.4 | 2.75 | 37500 | 60000 | 150 | 20000 | 32000 | 84 |
| 4.16 | 4.8 | 37500 | 60000 | 270 | 20000 | 32000 | 144 |
| 4.8 | 5.5 | 37500 | 60000 | 310 | 20000 | 32000 | 166 |
| 7.2 | 8.25 | 29400 | 47000 | 365 | 16000 | 25600 | 200 |
| 13.8 | 14.4 | 36000 | 57600 | 859 | 12500 | 20000 | 300 |
| 14.4 | 15.5 | 29400 | 47000 | 730 | 12500 | 20000 | 312 |
| 23.0 | 25.5 | 21000 | 33500 | 840 | 10000 | 16000 | 400 |
| 34.5 | 38.0 | 16800 | 26800 | 1000 | 10000 | 16000 | 600 |
| DBU | | DBU | Outdoor Vented | | DBU | Indoor with Condenser | |
| 2.4 | 2.75 | 14000 | 22400 | 58 | 14000 | 22400 | 58 |
| 4.16 | 4.8 | 14000 | 22400 | 100 | 14000 | 22400 | 100 |
| 4.8 | 5.5 | 14000 | 22400 | 116 | 14000 | 22400 | 116 |
| 7.2 | 8.25 | 14000 | 22400 | 174 | 14000 | 22400 | 174 |
| 13.8 | 14.4 | 14000 | 22400 | 334 | 14000 | 22400 | 334 |
| 14.4 | 17.1 | 14000 | 22400 | 349 | 14000 | 22400 | 349 |
| 23.0 | 27.0 | 12500 | 20000 | 500 | ..... | ..... | ... |
| 34.5 | 38.0 | 10000 | 16000 | 600 | ..... | ..... | ... |
| DBA-1 | | DBA-1 | Outdoor Vented | | | | |
| 2.4 | 2.75 | 6300 | 10100 | 26 | | | |
| 4.16 | 4.8 | 6300 | 10100 | 45 | | | |
| 4.8 | 5.5 | 6300 | 10100 | 52 | | | |
| 7.2 | 8.25 | 6300 | 10100 | 78 | | | |
| 13.8 | 14.4 | 6300 | 10100 | 150 | | | |
| 14.4 | 15.5 | 6300 | 10100 | 157 | | | |
| 23.0 | 25.5 | 6300 | 10100 | 251 | | | |
| 34.5 | 38.0 | 5000 | 8000 | 298 | | | |
| 46.0 | 48.3 | 4000 | 6400 | 318 | | | |
| 69.0 | 72.5 | 2500 | 4000 | 298 | | | |
| DBA-2 | | DBA-2 | Outdoor Vented | | | | |
| 23.0 | 25.5 | 12500 | 20000 | 497 | | | |
| 34.5 | 38.0 | 12500 | 20000 | 746 | | | |
| 46.0 | 48.3 | 12500 | 20000 | 995 | | | |
| 69.0 | 72.5 | 10000 | 16000 | 1194 | | | |
| DBA-5 | | DBA-5 | Outdoor Vented | | | | |
| 23.0 | 25.5 | 8000 | 12800 | 318 | | | |
| 34.5 | 38.0 | 8000 | 12800 | 477 | | | |
| 46.0 | 48.3 | 6300 | 10100 | 501 | | | |
| 69.0 | 72.5 | 5000 | 8000 | 597 | | | |

### Table 2 – Derating Factors for 25 Hz

To find the interrupting rating at 25 hertz multiply the desired rating from Table 1 by the appropriate value from the following list.

| Voltage KV Nominal | Max. Design | RBA-200 RDB-200 DBS | RBA-400 RDB-400 RBA-800 RDB-800 | DBA-1 DBA-2 DBA-5 |
|---|---|---|---|---|
| 2.4 | 2.75 | .45 | .37 | .75 |
| 4.16 | 4.8 | .45 | .37 | .75 |
| 4.8 | 5.5 | .45 | .37 | .75 |
| 7.2 | 8.25 | .45 | .37 | .70 |
| 13.8 | 14.4 | .47 | .35 | .70 |
| 14.4 | 15.5 | .47 | .35 | .70 |
| 23.0 | 25.5 | .53 | .35 | .60 |
| 34.5 | 38.0 | .69 | .40 | .62 |
| 46.0 | 48.3 | ... | ... | .67 |
| 69.0 | 72.5 | ... | ... | .71 |

### Table 3 – Transient Recovery Voltage Values for RBA, RDB and DBU Fuses

| Voltage KV Nominal | Max. Design | Primary Fault Recovery Frequency in KHz | Amplitude Factor | Secondary Fault Recovery Frequency in KHz | Amplitude Factor |
|---|---|---|---|---|---|
| 2.4 | 2.75 | 9.0 | 1.6 | 26.0 | 1.6 |
| 4.16 | 4.8 | 9.0 | 1.6 | 26.0 | 1.6 |
| 4.8 | 5.5 | 9.0 | 1.6 | 26.0 | 1.6 |
| 7.2 | 8.25 | 9.0 | 1.6 | 26.0 | 1.6 |
| 13.8 | 14.4 | 5.5 | 1.6 | 17.4 | 1.6 |
| 14.4 | 15.5 | 5.5 | 1.6 | 17.4 | 1.6 |
| 23.0 | 25.5 | 4.2 | 1.6 | 13.0 | 1.6 |
| 34.5 | 38.0 | 3.9 | 1.6 | 8.5 | 1.6 |

### Continuous Current Rating

Power fuses are designed so that they can carry their rated current continuously without exceeding the temperature rises permitted by NEMA and ANSI standards. The continuous current ratings available in Westinghouse fuses are shown in Table (5). These current ratings carry an 'E' designation defined in ANSI C37.40 to C37.47 of 1981 and NEMA SG2 as:

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

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

Although the 'E' rating does not make time-current curves identical, it does produce a similarity among different manufacturer's fuses as they all must satisfy the above requirements. The 'E' rating also reflects the 2:1 minimum melting current versus continuous current rating ratio which is a design feature of power fuses resulting from the average requirements of general purpose high voltage fuse applications and inherent features of conventional fuses.

### Table 4 – Altitude Corrections from ANSI C37.40-2.3

| Altitude Above Sea Level Feet | Meters | Interrupting Rating Times | Continuous Current Times |
|---|---|---|---|
| 3300 | 1000 | 1.00 | 1.00 |
| 4000 | 1200 | .98 | .99 |
| 5000 | 1500 | .95 | .99 |
| 6000 | 1800 | .92 | .98 |
| 7000 | 2100 | .89 | .98 |
| 8000 | 2400 | .86 | .97 |
| 9000 | 2700 | .83 | .96 |
| 10000 | 3000 | .80 | .96 |
| 12000 | 3600 | .75 | .95 |
| 14000 | 4300 | .70 | .93 |
| 16000 | 4900 | .65 | .92 |
| 18000 | 5500 | .61 | .91 |
| 20000 | 6100 | .56 | .90 |

### Table 5 – Continuous Current Ratings Available in Westinghouse Expulsion Fuses

| Max Design Kv | RBA-RDB-200 Standard | RBA-RDB-200 Time Lag | RBA-RDB-400 Standard | RBA-RDB-400 Time Lag |
|---|---|---|---|---|
| 2.75 | 10E to 200E | 20E to 200E | ½E to 400E① | 20E to 400E① |
| 5.5 | 10E to 200E | 20E to 200E | ½E to 400E① | 20E to 400E① |
| 8.25 | 10E to 200E | 20E to 200E | ½E to 400E① | 20E to 400E① |
| 14.4 | 10E to 200E | 20E to 200E | ½E to 400E① | 20E to 400E① |
| 15.5 | 10E to 200E | 20E to 200E | ½E to 400E① | 20E to 400E① |
| 25.5 | 10E to 200E | 20E to 200E | ½E to 300E② | 20E to 300E② |
| 38.0 | 10E to 200E | 20E to 200E | ½E to 300E② | 20E to 300E② |

| Max. Design Kv | DBU Standard③ | DBU Fast④ |
|---|---|---|
| 17.1 | 15E to 200E | 1.0 to 200K |
| 27.0 | 15E to 200E | 1.0 to 200K |
| 38.0 | 15E to 200E | 1.0 to 200K |

| Max. Design Kv | DBA-1, 2, 5 Standard |
|---|---|
| 8.25 | ½E to 200E |
| 15.5 | ½E to 200E |
| 25.5 | ½E to 200E |
| 38.0 | ½E to 200E |
| 48.3 | ½E to 200E |
| 72.5 | ½E to 200E |

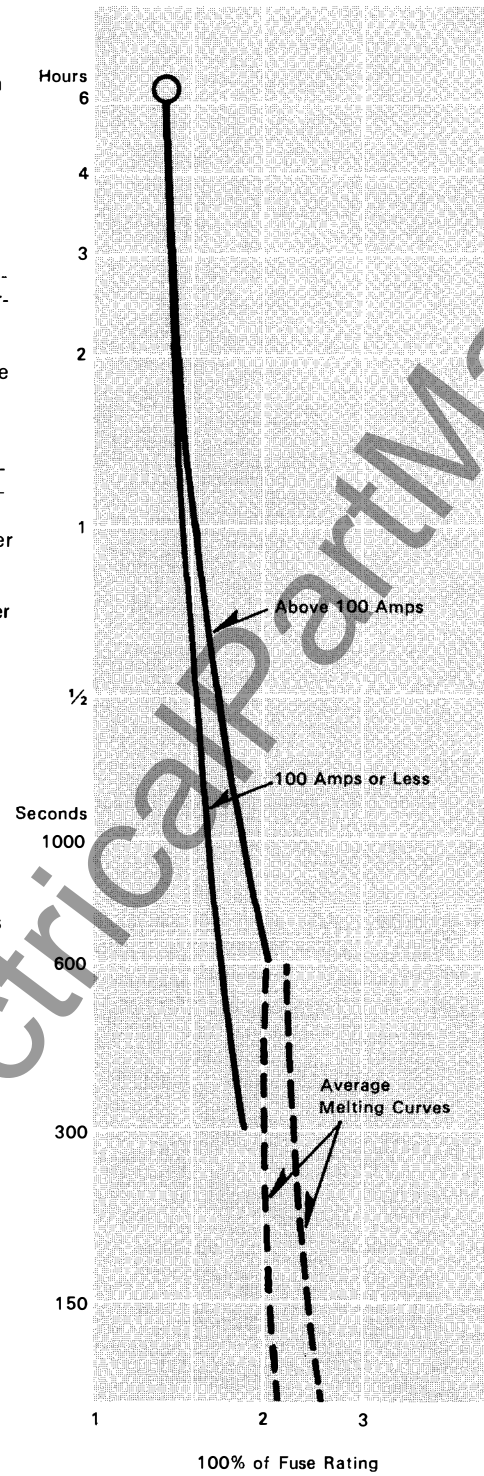
① Using the 2 paralleled 800 fuse design, which has a 10% derating factor, ratings of 450, 540 and 720 are available.
② Using the 2 paralleled 800 fuse design, which has a 10% derating factor, ratings of 450 and 540 are available.
③ E ampere rating sizes, ½, 1, 15, 20, 25, 30, 40, 50, 65, 80, 100, 125, 150, 175, 200.
④ K ampere rating sizes, 3, 6, 8, 10, 12, 15, 20, 25, 30, 40, 50, 65, 80, 100, 140, 200.

As previously mentioned, power fuses are designed to continuously carry their rated current without exceeding temperature rise restrictions. If the rated current is exceeded by a small amount, an overload situation is encountered. An overload situation is when the fuse is subjected to a current below the 300 or 600 second melting current but substantially above the continuous current rating for an excessive length of time. This type of condition generates a large amount of heat and may cause damage to the fuse. This problem is less severe in the DBU and RBA/RDB standard fuses as they employ silver elements which are, for all practical purposes, undamageable; however, caution should still be exercised when overloading the fuse as the heat generated may produce deterioration of the boric acid interrupting medium and charring of the fuse wall before the fuse element melts. Figure (2) which is also found on Curve 22 of Application Data 36-623 gives overload characteristics of Westinghouse expulsion fuses. Do not exceed these overload restrictions under any circumstances.

In the practical application of expulsion power fuses they are used to protect transformers and other equipments where overloads and inrush currents are common. As mentioned above, expulsion fuses have a rather low thermal capacity and cannot carry overloads of the same magnitude and duration as motors and transformers of equal continuous current. For this reason a general fuse application ratio of 1.4:1 fuse continuous current rating to full load current is suggested so the fuse will not blow on acceptable overloads and inrush conditions. Remember that this ratio is a general figure for typical applications and that a ratio as low as 1:1 can be used if the system current will never exceed the rated current of the fuse or a much higher ratio may be needed in other specific applications. More specific application information can be found in the individual equipment application sections which follow.

At times it is desirable to have a continuous current rating larger than any single fuse can provide. Higher ratings may be obtained by paralleling fuses. This practice may be extremely dangerous if the fuses are arbitrarily paralleled as the probability is great that the fuse elements of paralleled expulsion fuses will not melt at the same instant. An occurrence of this nature creates a situation in which the progress of the spring accelerating arcing rod of each of the fuses in parallel will not be uniform. Such a situation could cause a restrike in one of the fuses with the total arcing energy in that fuse exceeding the design level and resulting in a failure to clear the circuit. Under no circumstances should fuses be paralleled unless the paralleling is the extensively tested Westinghouse design or the specific application receives engineering approval from East Pittsburgh.

**Figure 2: Overload Characteristics for Westinghouse Expulsion Fuses**




Corrections for applying expulsion fuses above 3300 feet apply to the continuous current rating as well as the interrupting rating. Refer to Table (4) in the interrupting rating section for correction factors for different altitudes as listed in ANSI C37.40-2.3.

Remember that under no circumstances must the continuous rating be less than the continuous load current and that 'E' rated fuses may not provide protection for currents in the range of one or two times the continuous current rating.

### Coordination

In addition to selecting a fuse which meets the voltage, interrupting and continuous current ratings, it is important to examine the melting and total clearing time-current characteristics of the fuse. The melting characteristics are expressed as time-current relationships. These relationships are designated as minimum melt curves and as total clearing curves. The minimum melt curve gives the minimum amount of time in seconds required to melt the fuse elements at a particular value of symmetrical current under specified conditions. Total clearing curves give the maximum amount of time in seconds to complete interruption of the circuit at a particular value of symmetrical current under specified conditions. Arcing time is defined as the amount of time in cycles elapsing from the melting of the fusible element to the final interruption of the circuit. It is important to examine these characteristics to assure proper protection and selectivity with other over-current protective devices. These curves are located in application data 36-635 for RBA and RDB fuses, 36-643 for DBU fuses and 36-623 for BA and DBA fuses.

The minimum melt curve of all 'E' rated fuses must lie within the range defined in ANSI C37.46 at either the 300 or 600 second point, but there are no limitations placed on the melting time at high currents. To take advantage of this, Westinghouse increases the applicability of their fuses by producing a 'fast' or 'standard' fuse and a 'slow' or 'time-lag' fuse. The curves for the 'time-lag' fuse are less inverse and allow for more of a time delay at high currents.

Low currents below the 300 or 600 second melting current are termed overload currents. Overload currents are discussed in the section on continuous current rating where Figure (2) gives the fuse overload characteristics which should not be exceeded under any circumstances.

Properly coordinating power fuses is basically a problem of keeping the fuse minimum melting curve above the total clearing curve of any downstream overcurrent protective device, and keeping the total clearing curve beneath the minimum melting curve of any upstream protective device. Manufacturer's published time-current curves are based on standard conditions and do not allow for such variables as preloading or ambient temperature. For this reason it is recommended that a safety zone be used when coordinating power fuses so proper coordination is maintained even when there are shifts in the curves due to changes in the above mentioned variables. There are two approaches used to achieve this safety zone and both produce similar results. One approach employs a 25 percent safety zone in time for a given value of current and the other uses a 10 percent safety zone in current for a given value of time. Westinghouse uses the second method as it allows the safety band to be published on the left hand side of all the time-current curves. Coordination is then achieved by overlaying curves and shifting one by the width of the published safety zone.

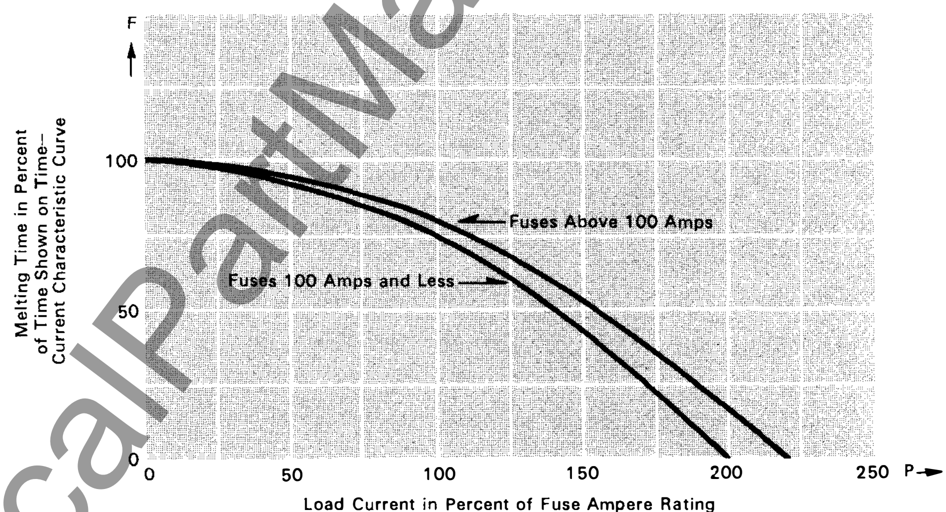
When discussing coordination and time-current curves it should be pointed out that ANSI Standards C37.46-3.1.1 allow the total clearing curves to be drawn at a distance corresponding to 20 percent on the scale to the right of the minimum melting curve. Westinghouse uses this 20 percent figure in its published curves but testing has verified that a 10 percent tolerance is more than sufficient for all currents less than that which causes melting in .5 seconds for a given fuse rating.

If desired or if unusual conditions exist, shifts in the time-current curve due to preloading may be examined individually. Westinghouse time-current characteristics are derived from tests on fuses in an ambient of 25 deg. C and no initial loading as specified in ANSI C37.46. Fuses subject to conditions other than the above will experience shifts in the time-current curves. Figure (3) gives the adjusting factor for preloaded fuses. These adjusting factors are valid only for Westinghouse power fuses.

Figure (4) gives an example of tightly coordinated fuse application. The figure shows a standard speed RBA fuse protecting the primary of a 1000 KVA transformer with Westinghouse type DS low voltage air circuit breakers protecting secondary equipments.

Coordination with reclosing circuit breakers may be performed with the aid of the coordination chart found as Curve 23 in application data 36-623. This curve is explained in the repetitive faults section of this application data.

**Figure 3: Preloading Adjustment Factor for Power Fuses**



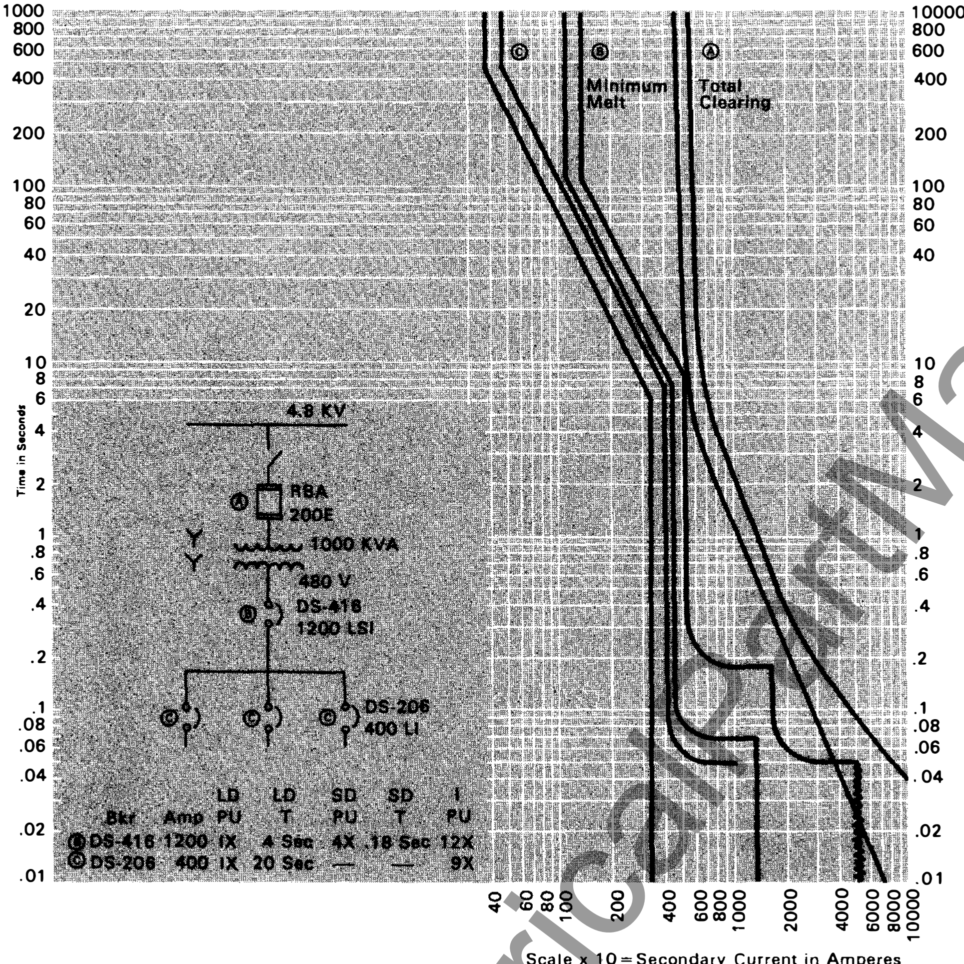

Formula for above curves:

$F = 1 - (P/P_m)^2$

$P_m$ = Percent of minimum load current causing melting which is
200% for fuses 100 amps and less.
220% for fuses above 100 amps

For permissible duration of load currents above 100% see Figure 2.

**Figure 4: Typical Fuse Coordination**

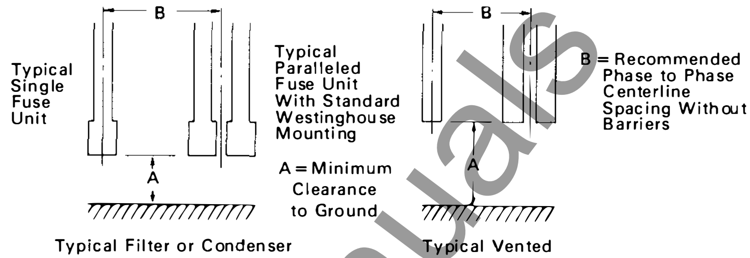


## Application

When applying expulsion fuses, physical as well as electrical properties must be considered. By their nature expulsion fuses emit gases from the bottom of the fuse. Care should also be given to maintaining minimum phase-to-phase and phase-to-ground spacing when mounting the fuse. Indoor fuses employ either a discharge filter or a condenser, but specified clearances must still be maintained. Outdoor fuses are vented and thus have a high noise level and expel a greater amount of gas making clearance from ground an important consideration. When applying outdoor fuses, space must be allowed for the arc the fuse swings through during dropout. Table (6) gives the minimum clearance to ground and the minimum phase spacing.

Outdoor fuses, as mentioned above, are vented. The venting of the hot gases resembles a cylindrical column in nature. Height above the minimum ground clearance is not really a factor except as related to rebounding from the ground of hot particles and gases. Figure (5) shows the nature of the discharge and allows the user to suggest specific safety zones for each particular application.

**Table 6 – Recommended Spacings**




A– Minimum clearance to ground in inches

| Max. Design KV | RBA Filter | RBA Condenser | RDB-200, DBU & DBA-1 Vented | RDB-400, 800 & DBA-2, 5 Vented |
|---|---|---|---|---|
| 2.75 | 7.5 | 3.0 | 17.5 | 22.0 |
| 4.8 | 7.5 | 3.0 | 17.5 | 22.0 |
| 5.5 | 8.5 | 4.0 | 17.5 | 22.0 |
| 8.25 | 8.5 | 4.0 | 17.5 | 22.0 |
| 14.4 | 11.5 | 6.0 | 21.0 | 26.0 |
| 15.5 | 11.5 | 6.0 | 21.0 | 26.0 |
| 25.5 | 15.0 | 8.5 | 26.0 | 32.0 |
| 38.0 | 19.5 | 12.0 | 33.0 | 42.0 |
| 48.3 (DBA only) | .... | .... | 40.0 | 54.0 |
| 72.5 (DBA only) | .... | .... | 54.0 | 84.0 |

B– Recommended phase to phase centerline spacing without barriers in inches.

| Max. Design KV | RBA Disconnect 200/400 | 800 | RBA Non-Disconnect 200/400 800 Piggyback | 800 | RDB 200/400 | RDB 800 | DBU | DBA |
|---|---|---|---|---|---|---|---|---|
| 2.75 | 11.75 | 27.51 | 11.16 | 19.92 | 18.0 | 26.76 | 17.0 | 17.0 |
| 4.8 | 11.75 | 27.51 | 11.16 | 19.92 | 18.0 | 26.76 | 17.0 | 17.0 |
| 5.5 | 11.75 | 27.51 | 11.16 | 19.92 | 18.0 | 26.76 | 17.0 | 17.0 |
| 8.25 | 13.25 | 29.01 | 12.56 | 21.32 | 18.0 | 26.76 | 17.0 | 17.0 |
| 14.4 | 14.75 | 30.51 | 13.06 | 21.82 | 24.0 | 32.76 | 19.0 | 19.0 |
| 15.5 | 16.25 | 32.01 | 15.56 | 24.32 | 24.0 | 32.76 | 19.0 | 19.0 |
| 25.5 | 20.25 | .... | 19.56 | .... | 30.0 | 38.76 | 23.0 | 23.0 |
| 38.0 | 25.25 | .... | 24.56 | .... | 36.0 | 44.76 | 30.0 | 30.0 |
| 48.3 | .... | .... | .... | .... | ... | .... | ... | 33.0 |
| 72.5 | .... | .... | .... | .... | ... | .... | ... | 44.0 |

**Figure 5: Nature of Expulsion Fuse Discharge**

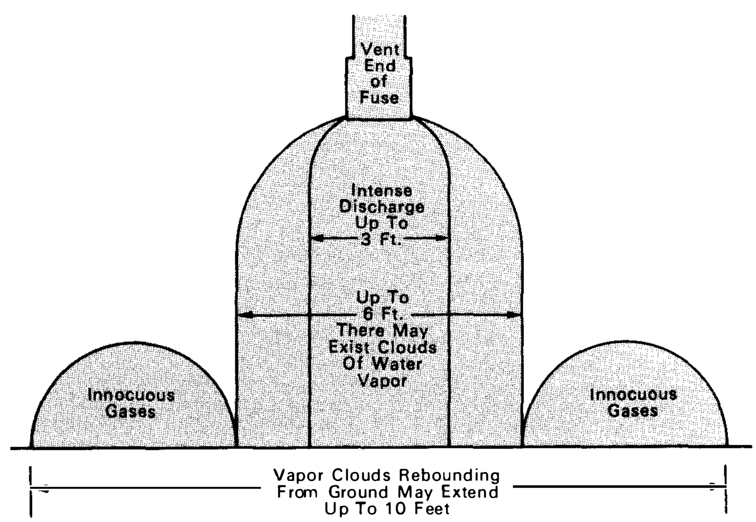


**Table 7A – Suggested Minimum Expulsion Fuse Current Ratings for Self-Cooled 2.4 to 15.5 Kv Power Transformer Applications**

| System Nom. KV | 2.4 | | 4.16 | | 4.8 | | 7.2 | | 12.0 | | 13.2 | | 13.8 | | 14.4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuse Max. KV | 8.3 | | 8.3 | | 8.3 | | 8.3 | | 15.5 | | 15.5 | | 15.5 | | 15.5 | |
| Transformer Kva Rating Self-Cooled | Full Load Current Amps | Fuse E-Ampere Rating | Full Load Current Amps | Fuse E-Ampere Rating | Full Load Current Amps | Fuse E-Ampere Rating | Full Load Current Amps | Fuse E-Ampere Rating | Full Load Current Amps | Fuse E-Ampere Rating | Full Load Current Amps | Fuse E-Ampere Rating | Full Load Current Amps | Fuse E-Ampere Rating | Full Load Current Amps | Fuse E-Ampere Rating |
| Three Phase Transformers | | | | | | | | | | | | | | | | |
| 9 | 2.16 | 3E | 1.25 | 3E | 1.1 | 3E | 0.72 | 3E | 0.43 | 3E | 0.40 | 3E | 0.38 | 3E | 0.36 | ½E |
| 15 | 3.6 | 5E | 2.08 | 3E | 1.8 | 3E | 1.2 | 3E | 0.72 | 3E | 0.66 | 3E | 0.62 | 3E | 0.60 | 3E |
| 30 | 7.2 | 10E | 4.2 | 7E | 3.6 | 5E | 2.4 | 5E | 1.44 | 3E | 1.32 | 3E | 1.25 | 3E | 1.20 | 3E |
| 45 | 10.8 | 15E | 6.2 | 10E | 5.4 | 10E | 3.6 | 5E | 2.16 | 3E | 1.98 | 3E | 1.88 | 3E | 1.80 | 3E |
| 75 | 18 | 25E | 10.4 | 15E | 9.0 | 15E | 6.0 | 10E | 3.60 | 5E | 3.30 | 5E | 3.1 | 5E | 3.00 | 5E |
| 112 5 | 27 | 40E | 15.6 | 25E | 13.6 | 20E | 9 | 15E | 5.4 | 10E | 4.95 | 7E | 4.7 | 7E | 4.51 | 7E |
| 150 | 36 | 50E | 20.8 | 30E | 18.0 | 25E | 12 | 20E | 7.2 | 10E | 6.56 | 10E | 6.2 | 10E | 6.01 | 10E |
| 225 | 54 | 80E | 31.3 | 50E | 27.2 | 40E | 18 | 25E | 10.8 | 15E | 9.9 | 15E | 9.4 | 15E | 9.02 | 15E |
| 300 | 72 | 100E | 41.6 | 65E | 36.0 | 50E | 24 | 40E | 14.4 | 20E | 13.1 | 20E | 12.5 | 20E | 12.0 | 20E |
| 500 | 120 | 200E | 69.4 | 100E | 60 | 100E | 40 | 65E | 24.1 | 40E | 21.9 | 30E | 21.0 | 30E | 20.1 | 30E |
| 750 | 180 | 250E | 104 | 150E | 90 | 125E | 60 | 100E | 36.1 | 50E | 32.8 | 50E | 31 | 50E | 30.1 | 50E |
| 1000 | 241 | 400E | 140 | 200E | 120 | 200E | 80 | 125E | 48.1 | 80E | 43.7 | 65E | 42 | 65E | 40.1 | 65E |
| 1500 | 360 | 540E① | 208 | 300E | 180 | 250E | 120 | 200E | 72.0 | 100E | 65.6 | 100E | 62 | 100E | 60.1 | 65E |
| 2000 | 481 | 720E② | 278 | 400E | 241 | 400E | 160 | 250E | 96.2 | 150E | 87.5 | 125E | 84 | 125E | 80.2 | 125E |
| 2500 | 600 | .... | 346 | 540E① | 301 | 450E③ | 200 | 300E | 120.0 | 200E | 109 | 150E | 104 | 150E | 100 | 150E |
| 3750 | .... | .... | .... | .... | .... | .... | .... | .... | 180.0 | 250E | 165 | 250E | 156 | 250E | 150 | 250E |
| 5000 | .... | .... | .... | .... | .... | .... | .... | .... | 241.0 | 400E | 218 | 300E | 210 | 300E | 200 | 300E |
| Single Phase Transformers | | | | | | | | | | | | | | | | |
| 5 | 2.08 | 3E | 1.20 | 3E | 1.04 | 3E | 0.695 | 3E | 0.416 | 3E | 0.38 | 3E | 0.362 | 3E | 0.35 | ½E |
| 10 | 4.17 | 7E | 2.40 | 5E | 2.08 | 3E | 1.39 | 3E | 0.832 | 3E | 0.76 | 3E | 0.724 | 3E | 0.69 | 3E |
| 15 | 6.25 | 10E | 3.60 | 5E | 3.13 | 5E | 2.08 | 3E | 1.25 | 3E | 1.14 | 3E | 1.085 | 3E | 1.64 | 3E |
| 25 | 10.4 | 15E | 6.0 | 10E | 5.2 | 10E | 3.47 | 5E | 2.08 | 3E | 1.90 | 3E | 1.81 | 3E | 1.74 | 3E |
| 37.5 | 15.6 | 25E | 9.0 | 15E | 7.8 | 15E | 5.21 | 10E | 3.12 | 5E | 2.84 | 5E | 2.71 | 5E | 2.60 | 5E |
| 50 | 20.8 | 30E | 12.0 | 20E | 10.4 | 15E | 6.95 | 10E | 4.16 | 7E | 3.80 | 7E | 3.62 | 5E | 3.47 | 5E |
| 75 | 31.3 | 50E | 18.0 | 25E | 15.6 | 25E | 10.4 | 15E | 6.25 | 10E | 5.7 | 10E | 5.43 | 10E | 5.21 | 10E |
| 100 | 41.7 | 65E | 24.0 | 40E | 20.8 | 30E | 13.9 | 20E | 8.32 | 15E | 7.6 | 15E | 7.24 | 10E | 6.94 | 10E |
| 167 | 70 | 100E | 40.0 | 65E | 35.0 | 65E | 23.2 | 40E | 13.9 | 20E | 12.7 | 20E | 12.1 | 20E | 11.6 | 20E |
| 250 | 104 | 150E | 60.0 | 100E | 52.0 | 80E | 34.8 | 50E | 20.8 | 30E | 19.0 | 30E | 18.1 | 25E | 17.4 | 25E |
| 333 | 139 | 200E | 80 | 125E | 69.5 | 100E | 46.3 | 65E | 27.7 | 40E | 25.2 | 40E | 24.1 | 40E | 23.1 | 40E |
| 500 | 208 | 300E | 120 | 200E | 104 | 150E | 69.6 | 100E | 41.6 | 65E | 38.0 | 65E | 36.2 | 50E | 34.7 | 50E |
| 667 | 278 | 400E | 160 | 250E | 139 | 200E | 92.6 | 150E | 55.4 | 80E | 50.5 | 80E | 48.2 | 80E | 46.3 | 65E |
| 833 | 347 | 540E① | 200 | 300E | 173 | 250E | 115.5 | 200E | 69.4 | 100E | 63.5 | 100E | 60.4 | 100E | 57.9 | 80E |
| 1250 | 521 | 720E② | 300 | 540E① | 260 | 400E | 174 | 250E | 104 | 150E | 95.0 | 150E | 90.6 | 125E | 86.8 | 125E |

① Two (2) 300 E Ampere fuse refills used in parallel with 10% derating factor

② Two (2) 400 E Ampere fuse refills used in parallel with 10% derating factor.

③ Two (2) 250 E Ampere fuse refills used in parallel with 10% derating factor.

**Transformer Application**

One of the more common applications of power fuses is to protect the primary of transformers. When selecting a fuse to be installed at the primary terminals of a transformer, all application rules concerning voltage rating and interrupting rating, as mentioned in previous sections, should be followed. This section is concerned primarily with the selection of the fuse continuous current rating. Details discussed in this section will be general. A more detailed discussion of how the fuse continuous current rating should be determined is given in Appendix 1.

Fuses at the primary of a transformer should not blow on transformer magnetizing or inrush current, nor should they blow or deteriorate under long duration overloads to which the transformer is 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 lower limit of the fuse rating. Coordination with other protective devices on the system, such as secondary breakers, often places further restrictions on the fuse to be selected. In general, however, a knowledge of transformer type allows the fuse continuous current rating to be chosen on the basis of a multiple of full load current.

In the routine process of applying fuses on the basis of transformer KVA rating it is assumed that adequate secondary protection is provided. The ordinary procedure then is to employ a fuse rating such that the fuse is not damaged by overheating due to inrush or permissible overloads. Assuming the transformer to be protected is self-cooled and that the maximum 1.5 hour overload on the transformer would not exceed 200 percent of the transformer rating, then the minimum ratio of fuse current rating to transformer full load current should be 1.4:1.

Thus, a fuse rating is chosen by multiplying the transformer full load rating by 1.4 and then selecting the fuse which has a continuous current rating of that value. If there is no fuse rated exactly 1.4 times the transformer full load rating, the next larger rated fuse should be selected.

Tables (7A) and (7B) give suggested fuse ratings for single phase and three-phase power transformers based on the 1.4:1 ratio given above.

It should be remembered that the 1.4:1 ratio is a general value which may be varied in specific cases. Dry type transformers, for instance, have a smaller overload capacity and permit fusing closer to the full load rating while distribution transformers are traditionally overloaded more severely and could require a fusing ratio as large as 2:1. Further, if provisions are made by thermal relays or otherwise to limit transformer overloads to a lower range, the ratio can be reduced. If a transformer has provisions for forced cooling, then the application ratio should be 1.2:1 for the fuse rating to the forced cooled rating.

**Table 7B – Suggested Minimum Expulsion Fuse Current Ratings for Self-Cooled 25.8 to 38.0 Kv Power Transformer Applications**

| System Nom. KV | 22.9 | | 23.9 | | 24.9 | | 34.5 | |
|---|---|---|---|---|---|---|---|---|
| Fuse Max. KV | 25.8 | | 25.8 | | 25.8 | | 38.0 | |
| Transformer Kva Rating Self-Cooled | Full Load Current Amps | Fuse E-Ampere Rating | Full Load Current Amps | Fuse E-Ampere Rating | Full Load Current Amps | Fuse E-Ampere Rating | Full Load Current Amps | Fuse E-Ampere Rating |
| Three Phase Transformers | | | | | | | | |
| 9 | 0.22 | ½ E | 0.21 | ½ E | 0.20 | ½ E | 0.15 | ½ E |
| 15 | 0.38 | 3 E | 0.36 | ½ E | 0.35 | ½ E | 0.25 | ½ E |
| 30 | 0.75 | 3 E | 0.72 | 3 E | 0.69 | 3 E | 0.50 | 3 E |
| 45 | 1.14 | 3 E | 1.09 | 3 E | 1.04 | 3 E | 0.75 | 3 E |
| 75 | 1.89 | 3 E | 1.81 | 3 E | 1.74 | 3 E | 1.25 | 3 E |
| 112.5 | 2.84 | 5 E | 2,72 | 5 E | 2.60 | 5 E | 1.88 | 3 E |
| 150 | 3.78 | 7 E | 3.62 | 5 E | 3.47 | 5 E | 2.51 | 5 E |
| 225 | 5.68 | 10 E | 5.44 | 10 E | 5.21 | 10 E | 3.77 | 7 E |
| 300 | 7.58 | 15 E | 7.25 | 10 E | 6.94 | 10 E | 5.02 | 7 E |
| 500 | 12.6 | 20 E | 12.1 | 20 E | 11.6 | 20 E | 8.37 | 15 E |
| 750 | 18 9 | 30 E | 18,1 | 25 E | 17.4 | 25 E | 12.6 | 20 E |
| 1000 | 25.3 | 40 E | 24.2 | 40 E | 23.1 | 40 E | 16.7 | 25 E |
| 1500 | 37.9 | 65 E | 36.2 | 50 E | 34.7 | 50 E | 25.1 | 40 E |
| 2000 | 50.5 | 80 E | 48.3 | 80 E | 46.3 | 65 E | 33.5 | 50 E |
| 2500 | 63.1 | 100 E | 60.4 | 100 E | 57.9 | 80 E | 41.8 | 65 E |
| 3750 | 94.7 | 150 E | 90.6 | 150 E | 86.8 | 125 E | 62.8 | 100 E |
| 5000 | 126 | 200 E | 121 | 200 E | 116 | 200 E | 83.7 | 125 E |
| Single Phase Transformers | | | | | | | | |
| 5 | 0.22 | ½ E | 0.21 | ½ E | 0.20 | ½ E | 0.14 | ½ E |
| 10 | 0.44 | 3 E | 0.42 | 3 E | 0.40 | 3 E | 0.29 | ½ E |
| 15 | 0.66 | 3 E | 0.63 | 3 E | 0.60 | 3 E | 0.43 | 3 E |
| 25 | 1.09 | 3 E | 1.05 | 3 E | 1.00 | 3 E | 0.72 | 3 E |
| 37.5 | 1.64 | 3 E | 1.57 | 3 E | 1.50 | 3 E | 1.09 | 3 E |
| 50 | 2.19 | 3 E | 2.09 | 3 E | 2.00 | 3 E | 1.45 | 3 E |
| 75 | 3.28 | 5 E | 3.14 | 5 E | 3.01 | 5 E | 2.17 | 3 E |
| 100 | 4.37 | 7 E | 4.18 | 7 E | 4.01 | 7 E | 2.90 | 5 E |
| 167 | 7.31 | 10 E | 6.99 | 10 E | 6.70 | 10 E | 4.84 | 7 E |
| 250 | 10.9 | 15 E | 10.5 | 15 E | 10.0 | 15 E | 7.25 | 10 E |
| 333 | 14.6 | 20 E | 13.9 | 20 E | 13.4 | 20 E | 9.65 | 15 E |
| 500 | 21.9 | 30 E | 20.9 | 30 E | 20.1 | 30 E | 14.5 | 20 E |
| 667 | 29.2 | 40 E | 27.9 | 40 E | 26.8 | 40 E | 19.3 | 30 E |
| 833 | 36.4 | 50 E | 34.9 | 50 E | 33.4 | 50 E | 24.1 | 40 E |
| 1250 | 54.7 | 80 E | 52.3 | 80 E | 50.1 | 80 E | 36.2 | 50 E |

Magnetizing inrush is the other factor the fuse must be able to withstand without damage. The magnitude of inrush may vary but, in general, is of magnitude 12 times the transformer full load rating for a 1/10 of a second duration. Inrush should not present a problem for any applications using a ratio as low as 1:1. If, however, there are any extenuating circumstances or questions, then refer to the appropriate time-current curves and check to see that the inrush magnitude and duration never cross the fuses' minimum melting curve.

Remember that a fuse must not be applied where it can realize a continuous current greater than its rating and that the fuse may not provide protection for currents in the range of one or two times the continuous current rating. Refer to the continuous current section or Appendix 1 for further information.

### Capacitor Bank Protection

Another common use of power fuses is for the protection of capacitor banks. This application is unique in that the protected equipment, capacitors, are designed with a zero minus tolerance and some value of positive tolerance. For this reason a ratio of 1.65:1 fuse rating to full load current is suggested for all single bank protection. If two or more banks are paralleled with automatic switching, refer to East Pittsburgh for fusing information.

### Repetitive Faults

It is often desirous to determine the performance of fuses under repetitive faults such as produced by the operation of reclosing circuit breakers. This performance is determined by graphically simulating the fuses' heating and cooling characteristics which are found in and expressed by the melting time-current curves. The theory behind the above implications is available upon request, but in this section only the practical use of those implications will be discussed.

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 as shown in Figure (6). Except for being inverted the cooling curve is the same as the heating curve as both have the same time constant. Each fuse has a specific time constant $\Theta$ which can be calculated with sufficient accuracy by the formula $\Theta = .1S^2$ where S is the melting current at .1 seconds divided by the melting current at 300 or 600 seconds. The 300 seconds applies for fuses rated 100 amperes or less and the 600 seconds for fuses rated above 100 amperes.

The time constant of a specific fuse, having been obtained in terms of seconds, gives to the general heating and cooling curves of Figure (6) a specific time scale. It enables us to plot the course of the fuse temperature (in percent values) if we know the sequence and duration of the open and closed periods of the recloser. This is illustrated by Curve C which is formed by piecing together the proper sections of Curves A and B.

Next we must determine the temperature at which the fuse will melt. Here we refer to the standard time-current curves and find the melting time M for a specific value of fault current. The melting temperature $T_m$ lies where the ordinate to the time M intersects Curve A. It is not necessary to know the absolute value of this temperature as it is sufficient to know its relation to the peaks. A similar temperature $T_n$ can be found using the total clearing time for the specific fault current. What we have then are two temperatures where we can state that any time the fuse Curve C intersects line $T_m$ the fuse could blow and any time it intersects line $T_n$ the fuse will definitely blow. The gap between $T_m$ **and** $T_n$ indicates the tolerance range as set forth in ANSI and NEMA standards where 'E' rated fuses are defined.

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 safety margin by coordinating the breaker with a fuse curve whose time ordinates are 75 percent of those of the melting curve. Line $T_s$ represents this temperature on Figure (6).

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 semi-log coordinates as shown in Figure (7). On these coordinates the cooling curve B becomes a straight line. Curves as shown in Figure (7) may be found as Curve 23 in application data 36-623.

## Figure 6: Temperature Cycle of a Fuse During Recloser Operation

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

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.

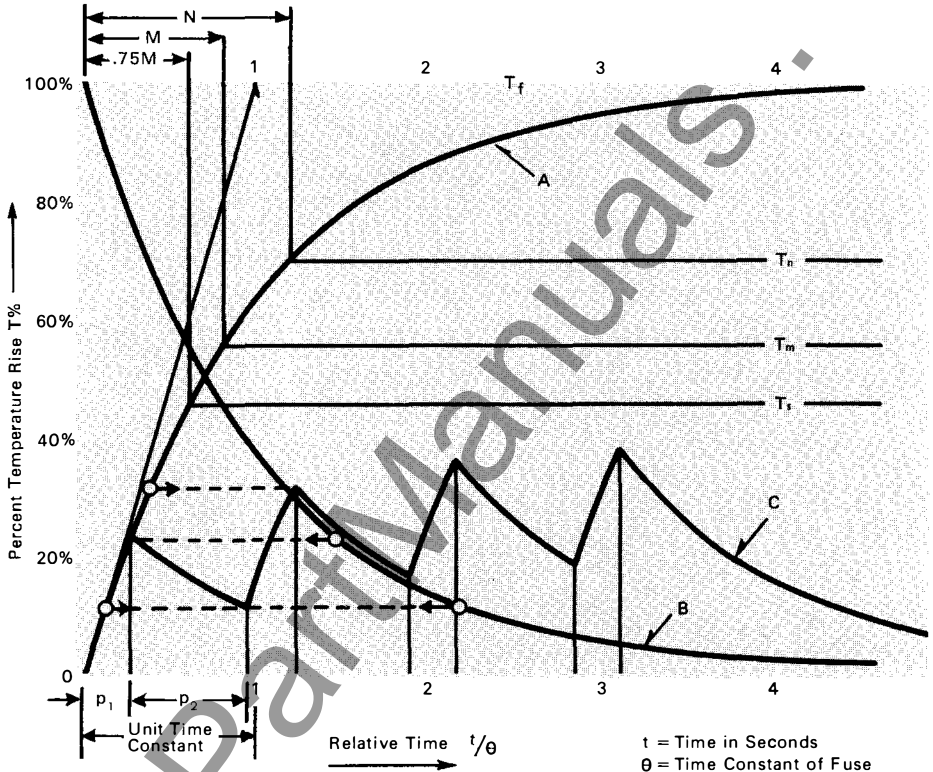
N – Total clearing time of fuse at same fault current.

$T_m, T_n$ – Levels of melting temperature of fastest and of slowest fuse.①

$T_s$ – 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.

① 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.



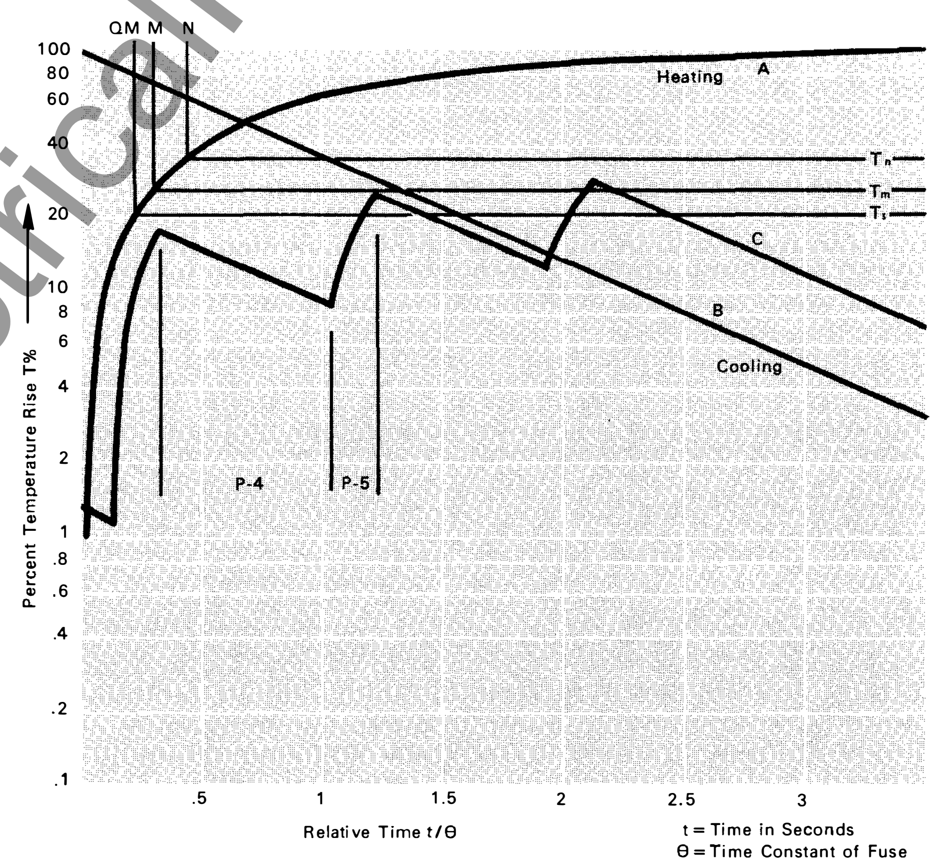

## Figure 7: Reclosing Circuit Breaker – Fuse Coordination Chart

Recloser data: 400 PR 100 (cycling code A1-3CH3)
Fuse type and rating: RBA/RDB 400 – 150E standard speed.
Fuse speed ratio, S-2200/340 = 6.5
Thermal time constant, $\Theta = .10\ S^2$, 4.2 seconds.
Fault current 800 amps.

| Period No. | Recloser Timing t Seconds Closed | Open | Total Time t | Relative Time $t/\Theta$ | Resulting % Temperature |
|---|---|---|---|---|---|
| 1① | .054 | | .054 | .013 | 1.3① |
| 2 | | .5 | .554 | .13 | |
| 3 | .8 | | 1.354 | .32 | |
| 4 | | 3.0 | 4.354 | 1.04 | |
| 5 | .8 | | 5.154 | 1.23 | |
| 6 | | 3.0 | 8.154 | 1.94 | |
| 7 | .8 | | 8.954 | 2.13 | 28 |
| Normal melting time | | | 1.2 | M = .29 | $T_m = 26$ |
| q② x M | | | | .218 | $T_s = 20.5$ |
| Total clearing time | | | 1.8 | N = .43 | $T_n = 35.5$ |

① 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 Fig. 6, 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 $T\% = 100 \times t/\Theta$.

② "q" is the coordination factor to take care of service variables. It is commonly estimated to be .75.



## Appendix 1
## Transformer Application

This appendix is to supplement the information presented in the 'Transformer Application' section of the application data. If general information is all that is required, then the section in the body of the application data should be sufficient. This appendix is an extension of that section and is more specific and detailed.

When selecting fuses to be installed at the primary terminals of a transformer, an understanding of the purpose of the fuse will aid in understanding the selection process. The purposes of the fuse in the order of their importance are as follows:

1. Protect the system on the source side of the fuses from an outage due to faults in or beyond the transformer.

2. Override (coordinate with) protection on the low-voltage side of the transformer.

3. Protect the transformer against bolted secondary faults.

4. Protect the transformer against higher impedance secondary faults to whatever extent is possible.

The selection process involves choosing the proper voltage, interrupting and continuous current ratings for the fuse. Application rules pertaining to voltage and interrupting rating are pretty straight-forward and are sufficiently covered in their respective sections of the application data. Selecting the fuse continuous current rating which best fulfills the purpose hierarchy listed above can be more involved and will be discussed in detail in this section.

There are two major areas of concern when selecting a continuous current rating for the fuse which is to protect a transformer. The rating must be large enough to prevent false or premature fuse interruption from magnetizing or inrush currents and it must also be large enough to prevent fuse damage or fuse interruption during normal or emergency overload situations. Remembering the above restrictions, the fuse rating must also be small enough to provide the protection listed in the purpose hierarchy. Inrush, overloading and suggested minimum and maximum ratings will be the topic of the remainder of the appendix.

Fuses on the primary side of transformers should not blow on transformer magnetizing or inrush current. The magnitude of the first loop of inrush current and the rate at which the peaks of subsequent loops decay is a function of many factors such as transformer design, residual flux in the core at the instant of energization, the point on the voltage wave at which the transformer is energized and the characteristics of the source supplying the transformer. When energizing, the heating effect of the inrush current in an expulsion fuse can be considered equal to 12 times the transformer full load current flowing for 1/10 of a second. Thus, when selecting the current rating for fuses used at the primary side of a transformer, the fuse minimum melting curve must lie above and to the right of the point on the time-current curve corresponding to 12 times full load current and 0.1 seconds. The fuse whose minimum melting curve lies just above and to the right of this point is the lowest rated fuse which can be used at the primary terminals. This criterion is usually satisfied for all Westinghouse expulsion fuses if the fuse current rating is equal to or greater than the transformer self-cooled full load current. Thus, a fusing ratio as low as 1:1 could be used in selecting primary side fuses if inrush or magnetizing current were the only concern.

It is common practice for most system operators to overload their transformers for short periods of time during normal and emergency situations. To allow this flexibility, it is necessary to select a fuse that can carry the overload without being damaged. When this is taken into account, a fusing ratio higher than 1:1 is almost always required when applying fuses for transformer protection. The fuse emergency overload curve (Figure 2 in this application data and Curve 22 in Application Data 36-623) along with a knowledge of the extent to which the transformer will be overloaded is used as a basis for determining the smallest fuse which can be applied. The fuse rating is determined by using the duration of the transformer overload on the overload curve (ordinate value) to obtain a multiple of current rating which should not be exceeded. If the transformer overload current is then divided by the multiple obtained from the overload curve, the result is the minimum fuse current rating. Select the fuse rating which equals or the one which is just larger than this value. The allowable time duration of the current in the primary side fuses during transformer overload should never exceed the values shown by the fuse overload curve in Figure 2.

Suggested minimum fuse sizes for protection of self-cooled transformers are given in Tables (7A) and (7B) which are found in this application data. These tables were based on the premise that the maximum 1.5 hour overload on the transformer would not exceed 200 percent of the transformer rating. This overload condition requires that the minimum ratio of fuse current rating to transformer full load current is 1.4:1. Fuse sizes listed in Tables (7A) and (7B) are those which are just higher than 1.4 times the transformer full load current. If higher or longer duration transformer overloads are to be permitted, a fuse with a higher continuous current rating may be required. The procedure described in the previous paragraph should then be used to find the smallest permissible fuse size.

If provisions are made, by thermal or other protective devices, to limit transformer overloads to a lower range, the ratio of fuse current to transformer full load current can be less than 1.4:1. To find the amount of reduction permissible without damage to the fuse, the procedure using the overload curve should be employed.

When the transformer has forced cooling, the minimum fuse size which can be applied should be based on the transformer top rating and the extent to which the transformer will be overloaded beyond the top rating.

It should be remembered that an 'E' rated expulsion fuse applied at the primary terminals of a transformer may not provide protection for currents between one and two times the continuous current rating of the fuse. That is, for currents in this range which exceed the time limits shown by the fuse overload curve in Figure (2), the fuse may be damaged before the fusible element melts. In order to dependably provide overload protection for the transformer, protection must be applied on the secondary side of the transformer.

Up to now the discussion of fuses applied at the primary terminals of a transformer has been concerned with the lower limit of continuous current rating which can be safely applied. Equal concern should be given to the upper limit of continuous current rating which will provide protection for the transformer. The extent to which the fuses are to protect the transformer against secondary faults is one of several factors which determines the upper limit. Increasing the primary fuse size to allow for higher overloads decreases the protection afforded the transformer and vice-versa. Usually thru-fault protection is provided the transformer by a main secondary breaker or breakers and the main purpose of the primary fuses is to isolate a faulted transformer from the primary system. Although the primary fuses will isolate a transformer with an internal fault from the primary system, expulsion fuses generally are not fast enough to prevent extensive damage to the transformer.

When a main secondary breaker is not used, the primary fuses may be the only devices which provide through fault protection for the transformer. In these circumstances the fuse should operate before the transformer windings are damaged due to the heavy currents. The capability of transformer windings to carry these through fault or heavy currents varies from one transformer design to another. When specific information applicable to individual transformers is not available, the transformer 'heat curves' given in Figure (8) and on curve 22 of Application Data 36-623 can be used to evaluate the through fault protection offered the transformer by the fuses. The curve labeled N = 1 is drawn through the points defined in ANSI Appendix C57.92 (1962), Section 92-06.200 such that the curve has the same shape as shown in Figure 1 of IEEE publication 273 titled, 'Guide for Protective Relay Application to Power Transformers'. This curve applies to single-phase transformers and to three-phase faults on three-phase transformers and three-phase transformer banks. Curves for values of N other than 1 apply to unsymmetrical faults on three-phase transformers and three-phase transformer banks which have at least one delta connected winding. Ideally, the total clearing time-current curve of the primary fuse would lie below the 'heat curve' for all values of current up to 25 imes the transformer rated current. However, as discussed earlier in this appendix, this is not usually possible as the fuse has minimum limitations placed on the rating due to long time overloads impressed on the transformer and the fact that 'E' rated expulsion fuses do not generally provide protection for currents between one and two times their continuous current rating. In spite of these lower limitations, primary side fuses should protect the transformer for bolted secondary faults and higher impedance secondary faults to whatever extent is possible.

Wye connected transformer windings, regardless of whether the neutral is or is not grounded or tied to the system neutral, have line currents which are equal to the winding currents for faults external to the transformer. Thus a fuse connected to the terminal of a wye connected winding will see the same current that is in the winding for all faults external to the transformer. This is not the case when the transformer has a delta connected winding. With delta connected windings the current in the lines

**Table 8: Multiples of Primary Line Current for Fixed Secondary Winding Current**

| Transformer Connection All Neutrals Grounded | | N (N times secondary winding current gives multiples of primary line current) | | |
|---|---|---|---|---|
| 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 | .... | $\sqrt{3}/2$ |

(fuses) supplying the delta winding and currents in the delta windings generally are not equal, and of greater importance the ratio of line (fuse) current to winding current varies with the type of fault on the external system. Consequently, a fuse connected to the terminal of a delta connected winding will offer a degree of protection which is a function of the type of fault on the external system.

The relationship between rated line (fuse) current and rated winding current (referred to as the 'base current of the winding' in ANSI C57. 12.00 – 1980) is 1 for wye connected primaries and $\sqrt{3}$ for delta connected primaries. ANSI C57.12.00 – 1980 also indicates that the transformer winding shall be capable of withstanding 25 times rated winding current for 2 seconds and smaller multiples of rated winding current for longer periods of time. However, transformer overloads and faults are generally expressed in terms of line and not winding current. This could present a problem for fault conditions where the type of fault changes the relationship between the line and winding current. Table (8) gives a multiplier which will translate the line current in multiples of the winding current for different type faults for various transformer windings. This table leads us back to the transformer 'heat curves' shown on Figure (8) where it can be verified that the curve N = 1 passes through the point 25 times full load line current and 2 seconds. The curves for other than N = 1 are for unsymmetrical faults as can be seen from Table (8).

Coordination diagrams employ the transformer 'heat curves' and fuse time-current curves to determine which fuse rating may be safely applied. These diagrams are the tools used to apply the information previously cited. The most straight-forward diagram involves fuses applied at the terminals of transformers with wye primary windings. Table (8) shows that the fuse current is the same as the winding current for all faults external to the transformer. This means the coordination diagram consists simply of a direct reading of the fuse time-current curves and the transformer 'heat curve' N = 1 for coordination diagrams where the abscissa is labeled in amperes in the primary system. To coordinate with the abscissa labeled in secondary amperes the same two curves are shifted to allow for the ratio between primary and secondary amperes.

When fuses are employed at the terminals of a delta-wye transformer the coordination diagram becomes a bit more involved. In this instance Table (8) shows that the fuse current varies in relation to the winding current depending on the nature of the fault. Thus, when the coordination is with respect to primary amperes, the diagram consists of one direct reading fuse time-current curve and one or more transformer 'heat curves'. The number of 'heat curves' included would be determined by the types of secondary faults considered. Table (8) gives the N curve to be used for the different faults to be considered. When the coordination is with respect to secondary amperes the diagram consists of one transformer 'heating curve' (N = 1) and up to three fuse time current curves. The three time-current curves are again dependent on the possible faults to be considered. Table (8) shows that after the curve is translated to secondary amperes it must be shifted $1/\sqrt{3}$ when phase-to-ground faults are considered and $2/\sqrt{3}$ when phase-to-phase faults are considered to obtain proper coordination.

Regardless of whether a primary or secondary current abscissa is employed, a coordination diagram for a delta-wye transformer shows that the primary side fuses do not protect the transformer for high-impedance secondary faults and overloads. This type of protection can be obtained through the application of secondary side breakers. If a secondary breaker were used it would be added to the coordination diagram by plotting the breaker phase and ground trip characteristics. Selective coordination would exist if the breaker phase trip characteristic curve lies below the fuse characteristic for a phase-to-phase fault and the 'heating curve', and the breaker ground trip characteristic for a single line-to-ground fault and the 'heating curve'

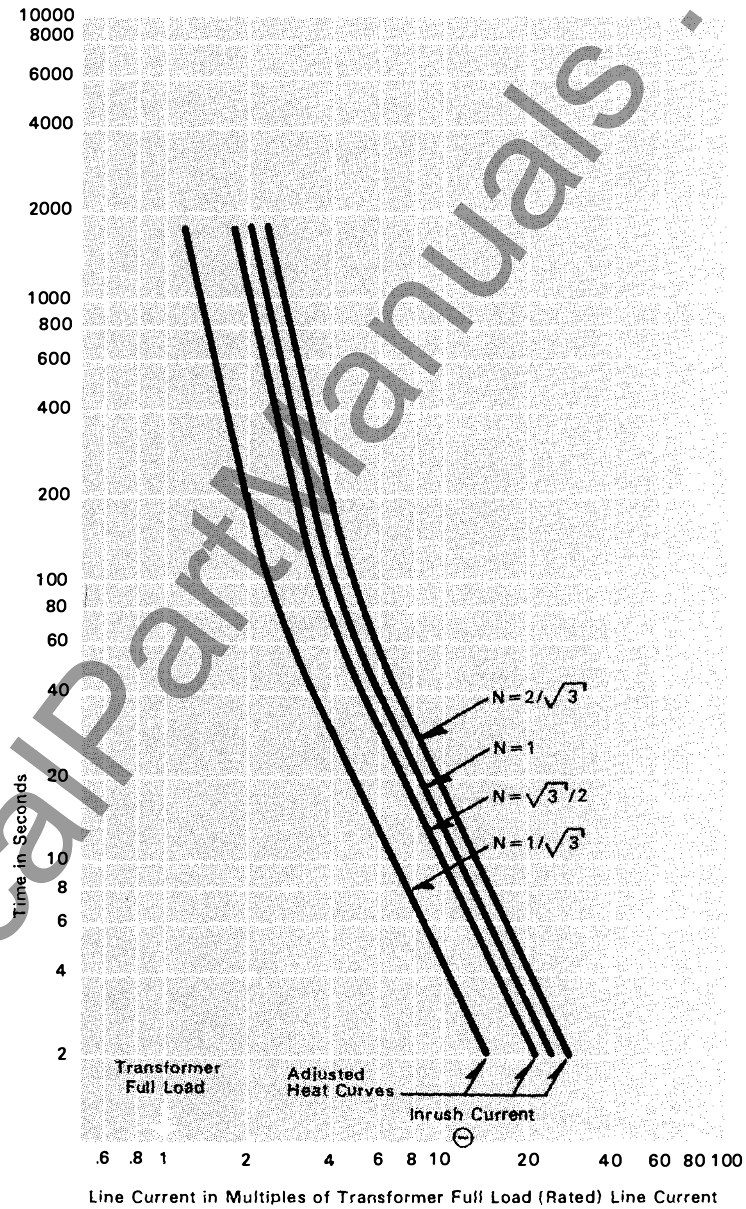
The preceding pertains to diagrams using secondary amperes. If the breaker characteristic is to be translated to primary amperes, its characteristics must lie beneath the fuse characteristic and the 'heating curve' for N = 1. For unsymmetrical faults the breaker characteristic will shift by the same multiple as the 'heating curve'. If further secondary protection is translated to the primary, the characteristic must lie beneath the secondary breaker characteristic for the different types of faults considered.

Fuses used at the terminals of a delta-delta transformer require one fuse time-current and two 'heating curves' if both three phase and phase-to-phase faults are to be considered. This agrees with information presented in Table (8). When the abscissa is in primary amperes the curves are direct read. An abscissa in secondary amperes uses the same curves but shifts them from primary to secondary amperes.

For all the coordination diagrams discussed above the vertical distance between the total clearing curve and the safe 'heat curve' indicates the margin of protection offered for different types of faults. It should be remembered, however, that the transformer 'heat curves' illustrated in this application data are drawn from the reference previously cited and they may not apply to all transformer designs.

The first part of this appendix pertained to the minimum fuse rating which should be employed while the latter part was concerned with the maximum permissible rating. In practicality it is not always possible to select a fuse large enough to allow for all the overloading required and still provide complete protection for the transformer. In these cases the user should decide how his priorities lie and trade off overloading ability for transformer protection.

**Figure 8: Transformer Heat Curves**①




① Heat Curve for N = 1 drawn thru points listed in ANSI C57.92-06.200 and as shown in IEEE No. 273, 'Guide For Protective Relay Applications To Power Transformers.'

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