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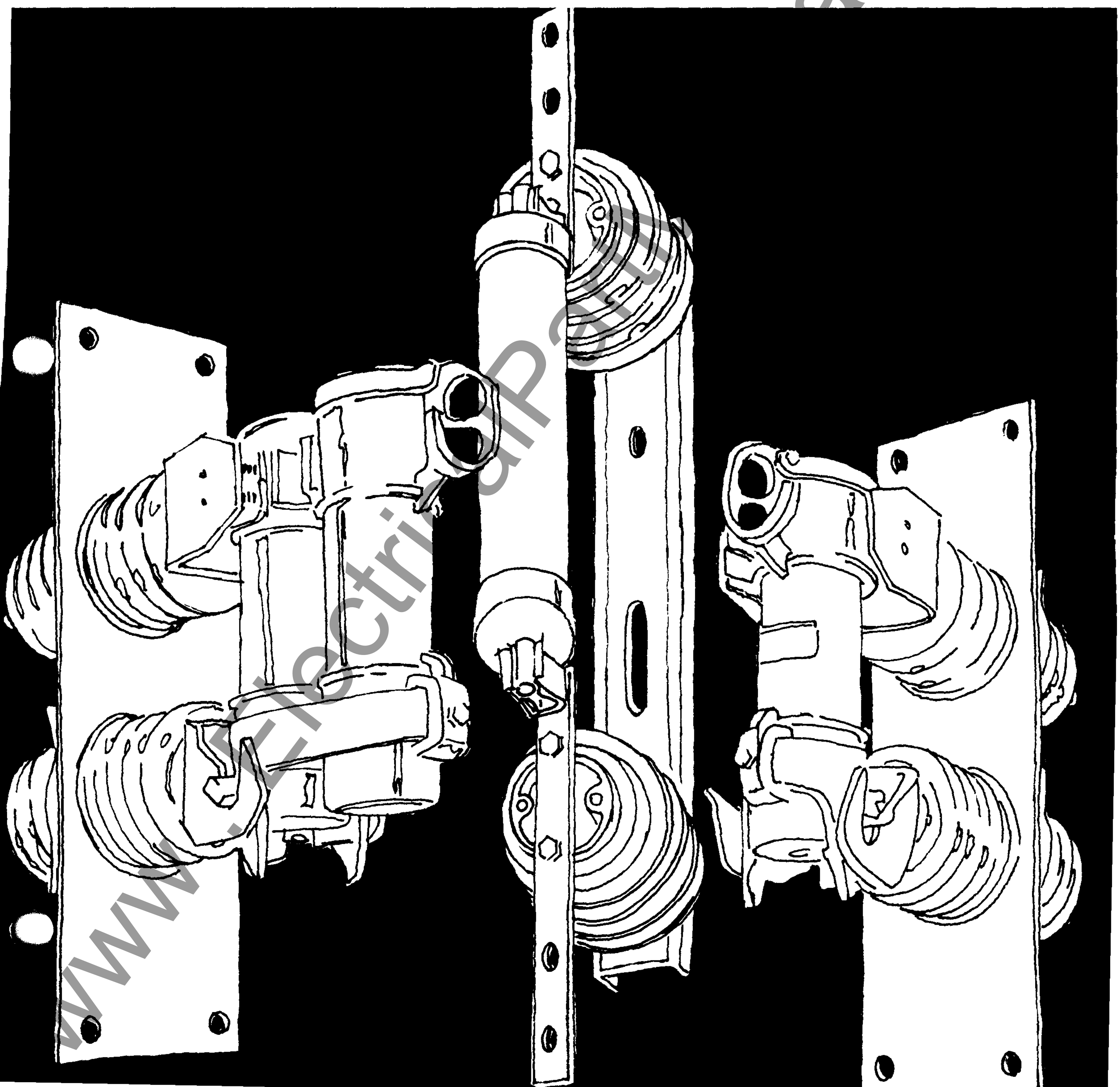
High Voltage Current Limiting Power Fuses



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Introduction

The Westinghouse selection of power fuses offers such diverse characteristics that almost any kind of application, within the practical range of such interrupting devices, may be satisfied. These diverse characteristics are obtained, in part, by the production of both expulsion and current limiting power fuses. Expulsion and current limiting fuses provide the diverse characteristics by employing different areas of fuse technology. Along with diverse characteristics, however, the difference in technology also requires that different questions be answered when applying the two different types of fuses. For this reason and in an attempt to avoid confusion this application data pertains only to current limiting fuses. See application data 36-664 for expulsion fuses.

General Information

Westinghouse provides a wide range of high voltage current limiting fuses. The CLE is a general purpose fuse which may be used to protect power transformers or in conjunction with a disconnect switch. It is available with either a disconnect or non-disconnect mounting. An outdoor version of this fuse is called the CLO and it is used with a disconnect mounting.

Distribution transformer protection is provided by the CLT and CX fuse lines. The CLT and CX may be employed in a submersible dry well in padmounted transformers, with the EFD switch or with conventional disconnecting or non-disconnecting type mountings. Other members of the CLT family include the CLTB, CLTO and the CLTX. Each of these fuses has been designed for specific applications. The CLTB is mounted in the bushing of a poletop transformer, the CLTO is mounted under oil, and the CLT is used with the T-Tap vacuum switch. The newest member of the distribution fuse family is the CX. In addition to the features provided by the CLT it adds mechanical interchangeability with other fuses on the market.

Poletop transformers may also be protected with the FDL which is a current limiting fuse designed to be used in series with a link and mounted in a standard Westinghouse cutout mounting. The CLTX, or Pro-TEK, is a current limiting fuse which is easily placed between the line and the transformer bushing by mounting it directly on top of the transformer bushing or on a cutout mounting.

The last of the basic high voltage current limiting fuse categories is the CLS. It is used to protect high voltage motor starter circuits.

Current limiting fuses are also referred to as silver sand fuses. This reference comes from the fact that the basic design of the fuse incorporates a silver element which is placed in a sand medium. Very basically, the silver is a current responsive element and the sand a cooling and absorbing agent for the vaporized silver when a fault occurs. Interruption of the circuit is quiet and completely self-contained.

All Westinghouse current limiting fuses are designed to be fatigue proof. By this it is meant that the element of a properly applied fuse will not age, become brittle or deteriorate under the most severe duty cycling. This Westinghouse patented feature is provided by bending or spiralling the elements and thus allowing them to absorb the contractions and expansions created by the heating and cooling associated with severe cycling.

It is very important to realize that there are two basic types of current limiting power fuses. They are the general purpose, function class 'g', fuse which protects against both high and low values of fault current and the back-up, function class 'A', fuse which only protects against fault currents to a specified minimum value. The general purpose fuse should clear any value of fault current that will cause the element to melt but may be damaged by severe overloading. A fuse which would not be damaged by overloading might be termed self-protecting although standards do not define such terminologies. However, a fuse meeting the self-protecting requirements as stated above, may still be damaged if the element is melted or broken and then full load current or less is applied to the fuse. Back-up fuses, on the other hand, are only designed to protect against high fault currents and must be used in series with another protection device which protects against the lower values of fault current.

Current Limiting Description

Current limiting fuses interrupt high fault currents before the first loop of fault current has reached its natural crest value. This current limiting action is the result of the fuse producing arc voltages which exceed the system voltage and thereby forcing a current zero as shown in Figure (1). The means of producing the arc voltages varies among fuses but they all employ the same theoretical base, that is, that voltages are produced by introducing high resistance series arcs into a circuit and by changing the current in an inductive circuit. Generated arc voltages which exceed system voltages allow the limitation of fault current seen by the system but they can also produce problems if they become too large. Details of current limitation and means of safely applying current limiting fuses are given in the following information.

It should be obvious that for low values of fault current which take many seconds to melt the fusible element, the fuse is not current limiting. As the magnitude of the fault increases there is some value of current which melts the fuse the moment it reaches its first natural crest. This is the value of fault current where the fuse first becomes current limiting and is called the threshold value. For fault currents greater than the threshold value the fuse is current limiting and provides the important feature of limiting the fault current and energy.

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 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.

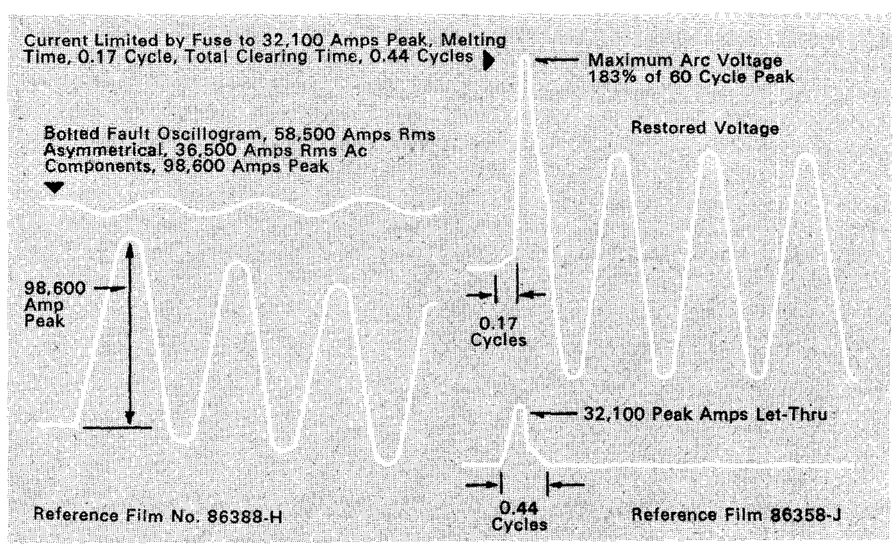
Voltage Rating

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 means 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 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.

As previously stated, the current limiting action of current limiting fuses produces arc voltages which will exceed the system voltage. Care must be taken to assure that these arc voltages do not exceed the basic insulation level of the system. If the fuse voltage rating is not permitted to exceed 140% of the

Figure 1: Current Limiting Action of a 225 Amp 4.8 Kv Type CLS Fuse Clearing a 5,050 Volt 36,500 Amp Fault, Equivalent 3-Phase Kva–320,000.



system voltage, the arc voltages will generally not create problems. This 140% limit on the voltage rating over system voltage does not restrict the use of a higher rated fuse if the system has a high enough BIL to withstand the short time application of the arc voltage. Westinghouse current limiting fuses are designed so that the arc voltage peak at rated interrupting current is less than three times that of the nominal voltage rating. If the system can withstand this peak, the higher rated fuse may be used.

Probably the most common problem created by high arc voltages is the sparking over of lightning arresters. As this is a common problem, it is discussed in detail in the section 'Fuses and Lightning Arresters'.

It should be remembered that in most cases the fuse voltage rating should not exceed the system voltage by more than 40% and under no circumstances may the system voltage exceed the maximum design voltage rating of the fuse.

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 ½ cycle after fault initiation are a function of the circuit X/R ratio and this relationship is shown in Figure (2). 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 ½ cycle. Fuse standards, ANSI C 37.46-2.5, Table 1, call for asymmetry factors of 1.56 to 1.6. The minimum 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 current limiting power fuses.

When current limiting fuses are subjected to a severe fault they interrupt the circuit before the fault current reaches its first half cycle peak. Thus, the current which the fuse actually interrupts is considerably less than that which would flow if the fuse were replaced by a zero impedance conductor. All references made to the interrupting rating of current limiting fuses refer to the available fault current and not that which the fuse actually lets through.

The numerous fuse styles with different interrupting ratings offered by Westinghouse makes it impractical to tabulate them in this publication. All the interrupting ratings along with the voltage and continuous current rating for each fuse style may be found in price list 36-621 for CLE and CLO fuses, 36-622 for CLS fuses, 36-627 for CX fuses and 36-623 for CLT, CLTB, CLTO, CLTX and FDL fuses. Interrupting ratings are given in both symmetrical and asymmetrical amperes. Nominal three-phase KVA ratings may be quickly calculated using the previously mentioned relationship. All the interrupting ratings listed in the price lists or calculated using the given relationship are valid for both 50 and 60 hertz systems. For application on 25 hertz systems the interrupting ratings valid for 50 and 60 hertz systems must be multiplied by .74.

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 3000 feet. Table (1) 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 and not overload protective. No 'E' or 'C' rated fuse necessarily provides protection for all values of overload current between the range of one to two times its continuous current rating. In addition to this there are two types of current limiting fuses, the general purpose and the back-up. As mentioned in the 'General Information', general purpose fuses protect against both high and low values of fault current while back-up fuses only protect against high values of fault current. It must be kept in mind that the back-up fuse will not interrupt against low values of fault current and must be used in series with another protection device.

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

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 (2). These current ratings usually carry an 'E' or 'C' designation defined in ANSI C37.40 to C37.47 of 1969 and NEMA SG2 of 1969 as:

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 shall melt in 600 seconds at an rms current within the range of 220 to 264 percent of the continous current rating.

C) The current-responsive element of a 'C' rated power fuse shall melt in 1000 seconds at an rms current within the range of 170 to 240 percent of the continuous current rating.

Points (A) and (B) define the 'E' rating which is used for general purpose fuses and point (C) defines the 'C' rating which is used for distribution class general purpose fuses. Although the rating of a fuse as 'E' or 'C' does not make time-current curves identical, it does produce a similarity among different manufacturer's fuses as they all must meet the

Figure 2: Asymmetry Factor

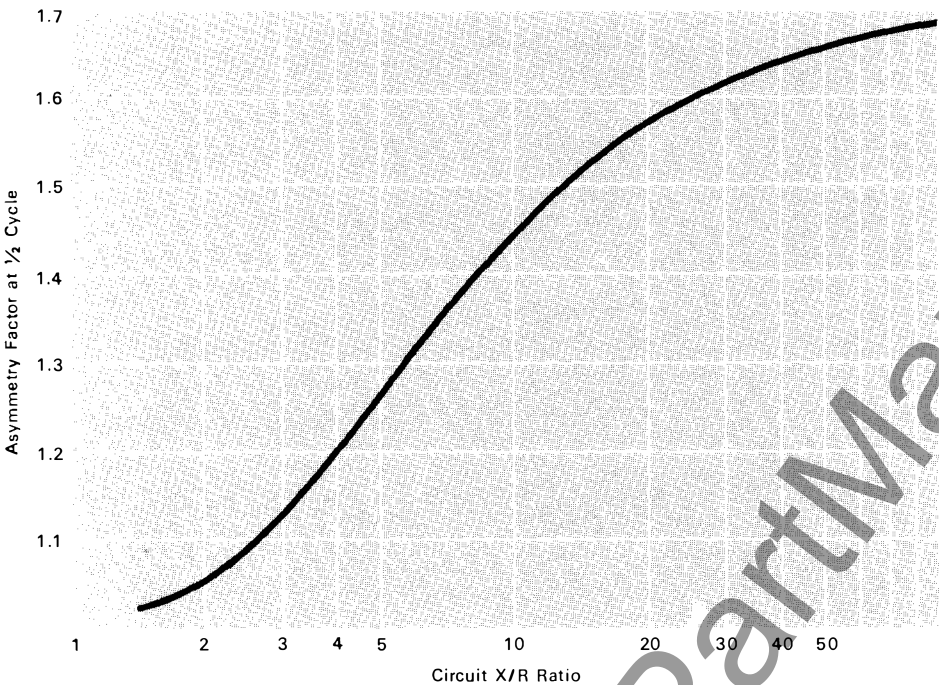


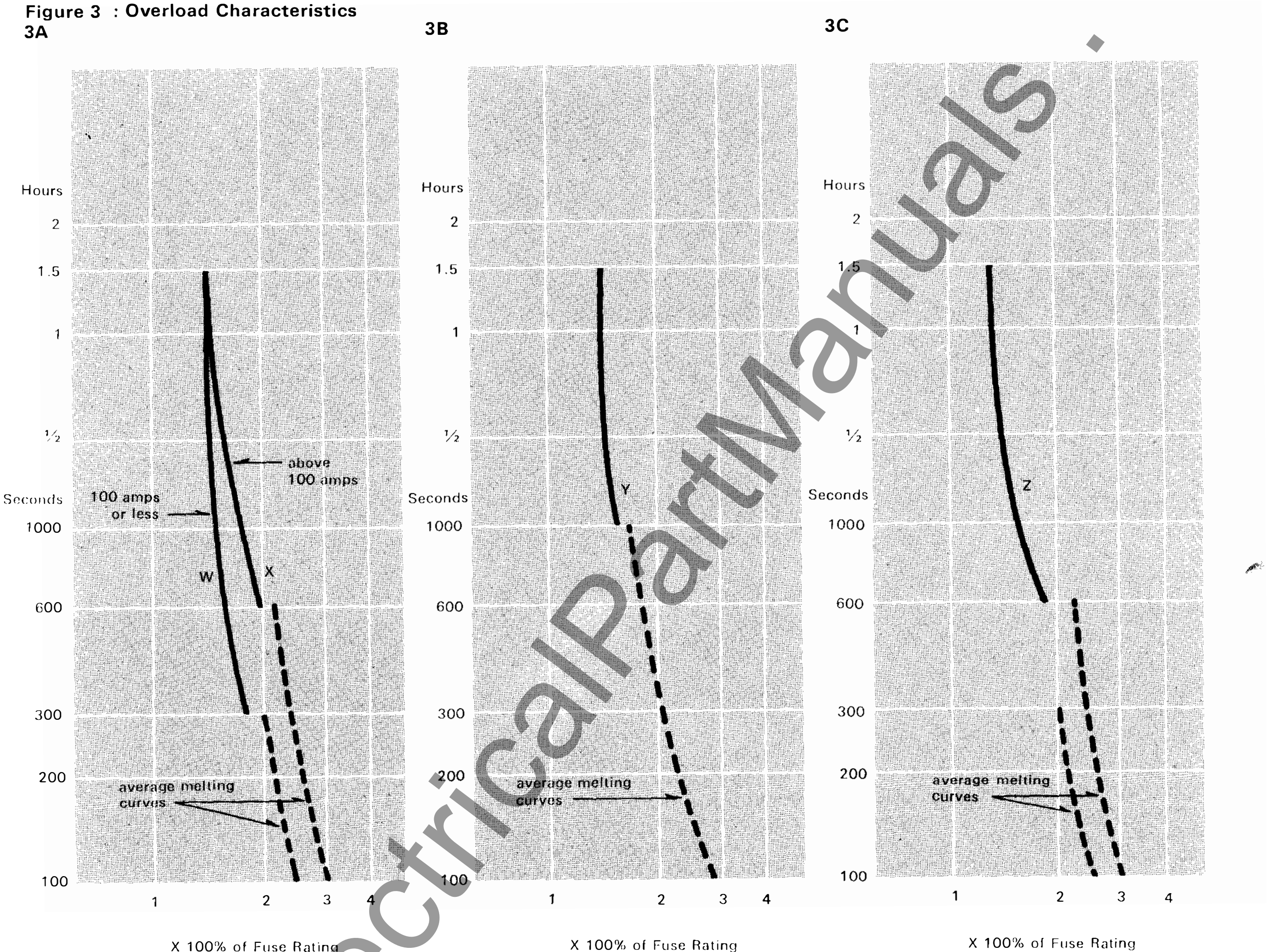
Table 1 - Altitude Corrections From ANSI C37.40-2.3

Altitude Above Sea Level Feet	Altitude Above Sea Level Meters	Interrupting Rating Times	Continuous Current Times
3000	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 2 : Available Continuous Current Ratings

Basic Fuse Type	Voltage KV	Current Range AMPS	General Purpose or Back-Up	Fuses In Parallel
CLE-PT NI	2.75	.25 to 5	General Purpose	1
CLE-PT NI	5 5 & 8.3	.25to 4	General Purpose	1
CLE-PT IND	5.5, 8.3 & 15.5	.5 to 10	General Purpose	1
CLE-PT IND	25.5	.5 to 1	General Purpose	1
CLE	2.75 & 5.5	15 to 225	General Purpose	1
CLE	8.3	15 to 125	General Purpose	1
CLE	15.5	15 to 65	General Purpose	1
CLE	2.75 & 5.5	250 to 750	General Purpose	2
CLE	8.3	150 to 200	General Purpose	2
CLE	15.5	80 to 125	General Purpose	2
CLE	15.5	150 to 200	General Purpose	3
CLO	15.5	30 to 65	General Purpose	1
CLO	15.5	80 to 125	General Purpose	2
CLS	2.75	25 to 225	Back-Up	1
CLS	5.5	30 to 225	Back-Up	1
CLS	2.75	300 to 700	Back-Up	2
CLS	5.5	300 to 700	Back-Up	2
CLT	2.75	5 to 150	General Purpose	1
CLT	5.5	8 to 60	General Purpose	1
CLT	8.3	5 to 250	General Purpose	1
CLT	15.5	4 to 100	General Purpose	1
CLTO	15.5	20 to 30	Back-Up	1
CLTB	8.3	18 to 20	Back-Up	1
CLTB	15.5	30	Back-Up	1
CLTB	22.0	18	Back-Up	1
FDL	8.3	15 to 40	Back-Up	1
FDL	17.1	15	Back-Up	1
CX	2.75 & 4.3	18 to 100	General Purpose	1
CX	5.5	10 to 60	General Purpose	1
CX	8.3	4.5 to 40	General Purpose	1
CX	15.5	6 to 18	General Purpose	1
CLTX	8.3/17.5	15K/10T & 30K/20T	Back-Up	1 & 2
CLTX	23.0	15K/10T & 30K/20T	Back-Up	1 & 2

Figure 3 : Overload Characteristics



W—Type E rated General Purpose fuse 100 amps or less except 15.5 Kv CLE - 1, 2, 3
X—Type E rated General Purpose fuse above 100 amps except 15.5 Kv CLE - 1, 2, 3
Y—Type C rated General Purpose fuse
Z—General Purpose fuse CLE - 1, 2, 3 15.5 KV only

aforementioned restrictions. Both ratings also reflect the approximate 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.

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, 600 or 1000 second melting current as stated in the 'E' and 'C' rated fuse definitions 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 by charring and weakening the fuse tube or changing the time-current characteristics of the fuse. Figures (3A) and (3C), which are also found as Curve 16 in application data 36-660-A, and Figure (3B) which is also found as Curve 9 in application data 36-661-C, give the overload characteristics of Westinghouse general purpose current limiting fuses. If back-up fuses are properly applied with a protection device to clear low fault currents, overloads should not present a problem. Do not exceed the overload curves given for general purpose fuses under any circumstances.

In the practical application of current limiting power fuses they are used to protect transformers, motors and other equipments where overloads and inrush currents are common. As mentioned above, current limiting fuses have a rather low thermal capacity and cannot carry overloads of the same magnitude and duration as transformers and motors 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 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.

In other specific applications a much higher ratio will be required to prevent the fuse from blowing on transformer inrush or motor starting current or from being damaged due to severe overloading. More specific application information can be found in the individual equipment application sections which follow.

It is quite common for distribution class fuses such as the CLT and the CX to be mounted in enclosures. These enclosures may be like the Westinghouse EFD switch which is an enclosure surrounded by air or the Westinghouse transformer drawout well which is mounted in the transformer and surrounded by hot oil. Due to the increased ambient temperature produced by these enclosures it is sometimes necessary to derate the continuous current rating of the fuse. When a Westinghouse fuse is to be used in an enclosure be sure to check with the manufacturer of that enclosure and use the current rating he suggests or apply his suggested derating factor if one is necessary.

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, however, as the total inductive energy stored in the circuit at the instant of interruption may not only be increased due to the paralleling of current limiting fuses, but it may also be unevenly distributed between the paralleled fuses due to impedance variations. It is possible, under such conditions, for one of the fuses to be confronted with an absorption of energy exceeding its design limits. The result may be failure to clear the circuit. Under no circumstances should fuses be paralleled unless the paralleling is one of the extensively tested Westinghouse designs or the specific application receives engineering approval from East Pittsburgh. If approval from East Pittsburgh is received for a particular style fuse, the following four points must be remembered: 1) only identical style fuse units may be paralleled; 2) the mounting must assure even current division; 3) the mounting or procedures should be such that fuses may not be energized individually; and 4) a derating factor of 90% should be applied to the full load rating of two paralleled fuses and 83.5% for three paralleled fuses (this derating factor does not apply to current ratings published for standard Westinghouse parallel designs).

Corrections for applying current limiting fuses above 3000 feet apply to the continuous current rating as well as the interrupting rating. Refer to Table (1) 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 current rating be less than the continuous load current and that 'E' and 'C' rated fuses may not provide protection for currents in the range of one to two times the continuous current rating.

Coordination

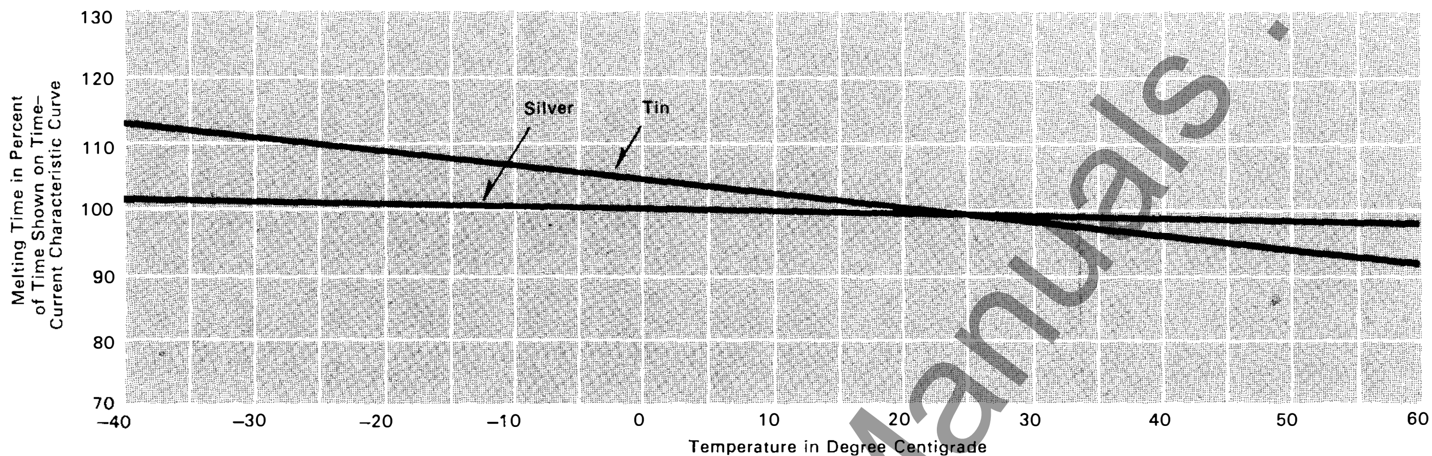
In addition to selecting a fuse which meets the voltage, interrupting and continuous current ratings, it is important to examine the melting and clearing characteristic of the fuse. These melting and clearing characteristics are expressed as time-current relationships and are designated as minimum melt curves, total clearing curves, damage i^2t values and total clearing i^2t values. The minimum melt curve gives the minimum amount of time in seconds required to melt the fusible elements at a particular value of symmetrical current under specified temperature and no load 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. The damage and total clearing i^2t values are energy representative values which indicate the minimum melt and total clearing coordinating values for currents which will melt the fuse element in less than .01 seconds. As the i^2t is an energy representative value, it represents a fixed value for melting times of .01 seconds and below but should be disregarded in lieu of the curves for melting times .01 seconds or greater. 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 overcurrent protective devices. These curves are located in application data 36-661-A for CLE and CLO fuses, 36-661-B for CLS fuses and 36-661-C for CLT, CLTO, CLTB, CX, CLTX, and FDL fuses. I^2t values are listed on the transparency which contains the respective melting and total clearing curves.

As previously mentioned, there are two basic types of current limiting fuses. The general purpose fuse which should clear any value of fault current which causes the element to melt and the back-up fuse which only protects against fault currents to a specified minimum value. When coordinating using a general purpose fuse be sure the current does not exceed the fuse overload characteristics which are given in Figures (3A), (3B) and (3C). If back-up fuses are used, see that another protection device is used which will clear fault currents below the minimum value specified for the back-up fuse.

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 fuse total clearing curve beneath the minimum operating curve of any upstream protective equipment. When coordinating to times less than .01 seconds simply use the i^2t values and keep the damage i^2t of the fuse above the total clearing i^2t of any downstream overcurrent protective device, and keep the total clearing i^2t of the fuse beneath the damage value of the upstream equipment. Coordinating with the current limiting fuses thus involves a comparison of melting and total clearing curves for those currents which would melt the fusible element in greater than .01 seconds and a comparison of i^2t energy representative values for the currents which would melt the fusible element in less than .01 seconds.

The time-current curves which are used when coordinating are published by the fuse manufacturers and are based on standard condi-

Figure 4 : Effect of Ambient Temperature On Melting Curve



tions which do not allow for such variables as preloading, ambient temperature and manufacturing tolerances. 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.

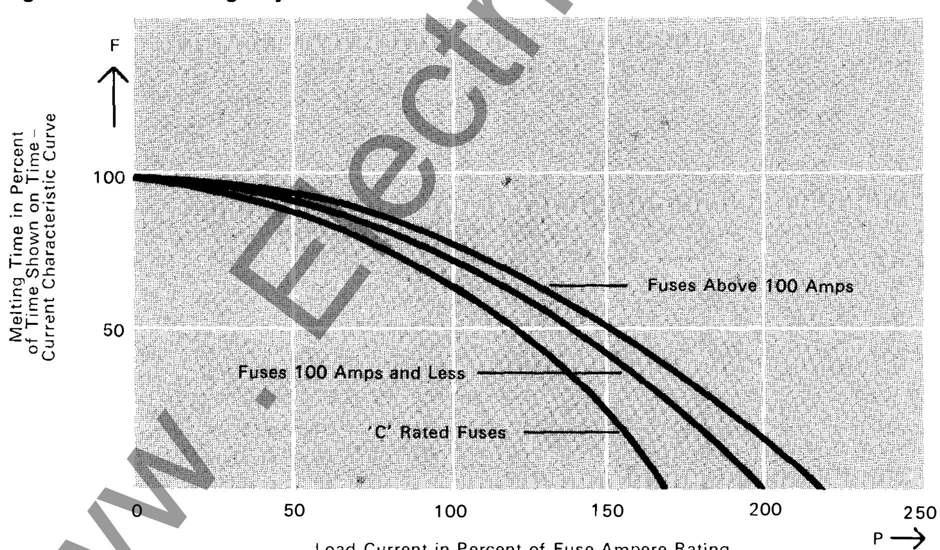
If desired or if unusual conditions exist, shifts in the time-current curve due to ambient temperature and preloading may be examined individually. Westinghouse time-current characteristics are derived from tests on fuses in an ambient temperature of 25 degrees C and no initial loading as specified in ANSI C37.46. Fuses subjected to conditions other than the above will experience shifts in the time-current curves. Figure (4) gives the adjusting factor for changes in ambient temperature and Figure (5) the adjusting factor for preloaded fuses. These adjusting factors are valid only for Westinghouse power fuses.

When a paralleled fuse combination is to be coordinated with other devices, the melting and clearing curves for the combination must be adjusted. The minimum melting and total clearing curves for the two fuses in parallel should be such that the combination curve, for a given time, has a current value of 180% of the current value of the single fuse. For currents which melt the fusible element in less than .01 seconds the two fuses in parallel would have a damage i^2t value four times that of the single fuse and a total clearing i^2t 2.5 times that of the single fuse.

Figure (6) gives an example of a properly coordinated fuse application. The figure shows a general purpose CLE fuse protecting the primary of a 1000 KVA transformer with Westinghouse type DS low voltage air circuit breakers protecting the secondary equipments.

Coordination with reclosing circuit breakers may be performed with the aid of the coordination chart found as Curve 23 in application data 36-660-A. This curve is explained in the repetitive faults section of this application data.

Figure 5 : 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 – 'E' Rated
220% for Fuses Above 100 Amps – 'E' Rated
170% for Fuses which are 'C' Rated

For permissible duration of Load Currents above 100% see Figure 3.

Application

When applying current limiting power fuses there are some points to be kept in mind in addition to the basics of voltage rating, interrupting rating, continuous current rating and coordination. One of these points concerns the two types of current limiting fuses, general purpose and back-up. A general purpose fuse is a complete protection device but the back-up fuse must be used in series with another protection device so it will not be called upon to interrupt currents that are below its specified minimum interrupting rating. Examples of a properly applied back-up current limiting fuse are the CLS where the fuse is used in series with a motor starter to protect it from fault currents which exceed the starter rating and the FDL which is used in series with a protective link to provide a much higher interrupting rating than the link alone could provide.

Other points to consider when applying current limiting fuses include those of let-through current and properly applying fuses on systems with lightning arresters. Each of these two points are discussed in detail in the following two sections. Following those sections specific applications of current limiting fuses to protect power transformers, potential transformers and motors will be discussed in detail due to their frequent application.

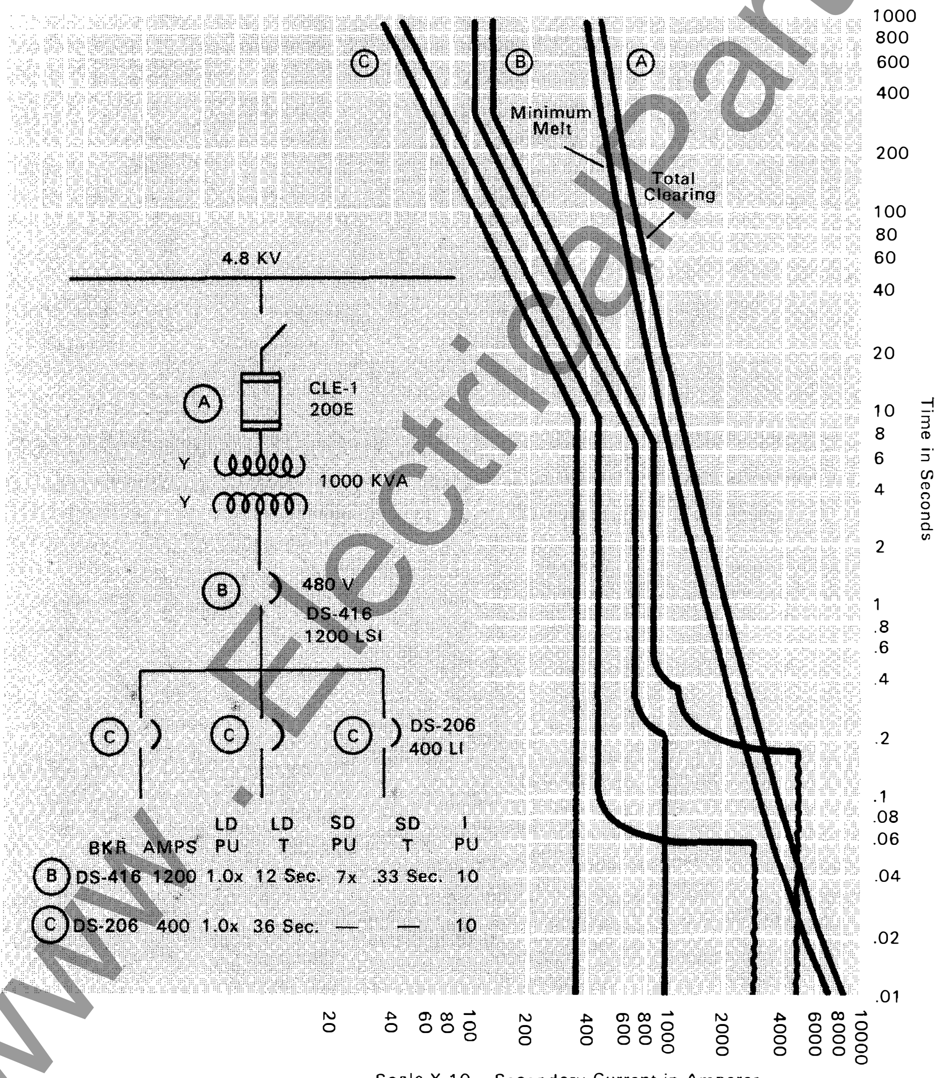
Let-Through Current

Probably the most important feature of current limiting fuses is the fact that the fuse limits the fault current and energy which is seen by the system being protected. This energy is termed let-through energy as it is that amount of the available fault energy which the fuse 'lets through'. A general purpose current limiting fuse is not current limiting for low values of fault current and the let-through current is the same as the fault current. Generally, these values of fault currents do not present problems due to their low magnitude. For currents equal to or greater than its threshold current, the fuse will limit the energy 'it lets through' to the system. This let-through current is dependent on the particular fuse type, the magnitude of the fault current and the timing of fault initiation.

As just stated, 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 cannot limit the peak current which has already passed. With a fully asymmetrical fault the current crests at about ½ cycle and with a symmetrical fault it crests in exactly ¼ cycle. Thus, the current limiting action changes with the degree of asymmetry of the fault.

Westinghouse publishes let-through curves which are based on power circuits with an inherent 7% power factor. Figure (7) shows a typical let-through curve. The horizontal axis gives the rms symmetrical available fault and the vertical axis the peak instantaneous let-through current. Let-through current for any particular fuse may be found by choosing the curve for the fuse in question and reading the let-through for any given value of available fault. The point where the curve intersects the asymmetrical available peak line is the threshold point or that point where the fuse first becomes current limiting. These curves, found in application data 36-661-A for the CLE and CLO, 36-661-B for the CLS and 36-661-C for the CLT, CLTB, CLTO, CLTX and CX, make it easy to check the fuses let-through against the withstand of the equipment it is protecting.

Figure 6: Fuse-Breaker Coordination



Fuses and Lightning Arresters

Current limiting fuses generate arc voltages which exceed system normal frequency recovery voltages. The magnitude of arc voltage generated is dependent on the element design, element length and type and size of filler. A strap type element, for example, generates arc voltages that are more dependent on the system voltage while a uniform cross section wire element produces arc voltages dependent on the fault current value. Users of current limiting fuses are not generally aware of the fuse design so a general estimation of generated arc voltage is needed. Westinghouse current limiting fuses perform their function by generating arc voltages which may peak as high as three times the nominal voltage rating of the fuse at its interrupting rating.

When applying current limiting fuses care should be taken to see that the arc voltages produced by the fuse do not exceed the basic insulation level of the system. An examination of the basic insulation level of the system will show that lightning arresters are the principal equipment to check. If arc voltages cause interconnected lightning arresters to operate a relatively high current would be shunted into the arresters which are not designed for such interrupting duty.

The easiest way to eliminate the problem of fuse generated arc voltages sparking over arresters is to locate the fuse on the line side of the arrester. Although this is a straight-forward approach to eliminating the problem, it is usually not practical. Many utilities prefer to apply the fuse on the load side of the arrester to eliminate possible fuse damage which might result from lightning. Other utilities employ CSP transformers with bushing mounted current limiting fuses where the fuse must be installed on the load side of the arrester.

For current limiting fuses applied on the load side of a distribution arrester, arc voltages usually do not affect the arrester if the fuse and arrester have the same voltage rating. If, however, the arrester is on the line side and has a voltage rating lower than that of the fuse, it may sparkover. Under this condition the arrester and the fuse will share the current. Distribution type arresters have higher impedances which keep them from experiencing excessive amounts of current and they are not usually damaged. Intermediate and station type arresters on the other hand have lower impedances which allow them to experience excessive currents and they may become damaged. Therefore, station and line type arresters should not be applied on the line side or in parallel with current limiting fuses unless their sparkover value is greater than the maximum arc voltage the fuse can produce.

Machine protection arresters are purposely designed to have low sparkover values. They should, however, be connected directly to the machine terminals and not on the line side of the fuse. If properly connected, the fuse arc voltage can have no effect on them.

Correctly applied Westinghouse distribution class lightning arresters found on the line side of the fuse have sparkover values sufficiently high to remain unaffected by fuse operations.

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 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 in general, except 1.5:1 for 15.5 KV CLE-1, CLE-2 and CLE-3 fuses.

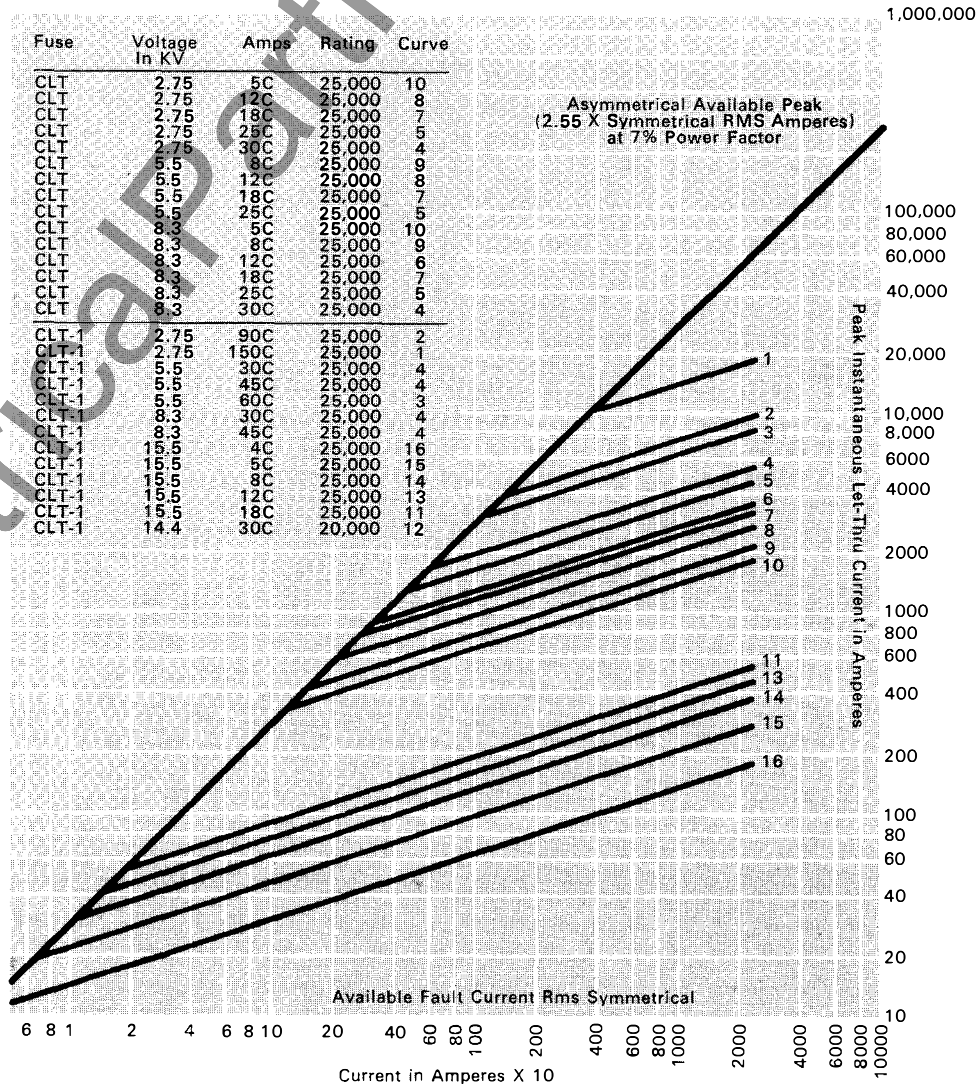
Thus, a fuse rating is chosen by multiplying the transformer full load rating by 1.4 or 1.5 and then selecting the fuse which has a continuous current rating of that value. If there is no fuse rated exactly 1.4 or 1.5 times the transformer full load rating, the next larger rated fuse should be selected.

Table (3) gives suggested fuse ratings for single phase and three-phase power transformers based on the 1.4:1 ratio given above. If 15.5 KV CLE-1, CLE-2 or CLE-3 fuses are to be used, be sure to check for the 1.5:1 ratio.

It should be remembered that the 1.4:1 and 1.5:1 ratios are general values 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

Figure 7: CLT Let-Through Curves

Fuse	Voltage In KV	Amps	Rating	Curve
CLT	2.75	5C	25,000	10
CLT	2.75	12C	25,000	8
CLT	2.75	18C	25,000	7
CLT	2.75	25C	25,000	5
CLT	2.75	30C	26,000	4
CLT	5.5	8C	25,000	9
CLT	5.5	12C	25,000	8
CLT	5.5	18C	25,000	7
CLT	5.5	25C	25,000	5
CLT	8.3	5C	25,000	10
CLT	8.3	8C	25,000	9
CLT	8.3	12C	25,000	6
CLT	8.3	18C	25,000	7
CLT	8.3	25C	25,000	5
CLT	8.3	30C	25,000	4
CLT-1	2.75	90C	25,000	2
CLT-1	2.75	150C	25,000	1
CLT-1	5.5	30C	25,000	4
CLT-1	5.5	45C	25,000	4
CLT-1	5.5	60C	25,000	3
CLT-1	8.3	30C	25,000	4
CLT-1	8.3	45C	25,000	4
CLT-1	15.5	4C	25,000	16
CLT-1	15.5	5C	25,000	15
CLT-1	15.5	8C	25,000	14
CLT-1	15.5	12C	25,000	13
CLT-1	15.5	18C	25,000	11
CLT-1	14.4	30C	20,000	12



cooling, then the application ratio for the fuse rating to the forced cooled rating should be 1.2:1 for fuses rated 8.3 KV and below and 1.3:1 for fuses rated 15.5 KV.

Magnetizing inrush is the other factor the fuse must be able to withstand without damage. The magnitude of inrush for power transformers may vary but, in general, is of magnitude 12 times the transformer full load rating for a 1/10 of a second duration. This magnitude of inrush versus full load current is usually much larger for distribution transformers, often getting as high as 25 to 40 times full load current. When the inrush does not exceed 12 times full load current it should not present a problem for any applications using a ratio as low as 1:1. If, however, there are any extenuating circumstances, questions, or the transformers have a greater inrush than the values just indicated, as is often found in distribution transformers, refer to the appropriate time-current curves and check to see that the inrush magnitude and duration never cross the fuses' minimum melting curve.

Applying back-up current limiting fuses in conjunction with a protective link is increasing in usage, especially for protection of pole type transformers. When applying a back-up fuse in this manner there are two points to keep in mind. First, the fuse rating must be high enough that the protective link will clear the circuit for all currents which would melt the back-up fuse in a time greater than that published for the fuse; and secondly, the back-up fuse rating must be low enough that the fault current never exceeds the rating of the protective link and the let-through does not exceed the withstand of the protected equipment. Typical misapplications can result from using a back-up fuse with an oversize link or with a CSP transformer where the link characteristics are not known. The use of an oversized link can result in the back-up fuse attempting to clear a fault current below its published value or the let-through of the back-up for high faults being insufficient to melt the link which results in the back-up fuse having to withstand full recovery voltage.

These two problems also exist when a back-up fuse is used with a CSP transformer with unknown link characteristics plus the possibility of the let-through of the back-up fuse being of sufficient magnitude to cause the link to explode and cause a catastrophic failure.

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 to two times the continuous current rating. Refer to the continuous current section or Appendix 1 for further information.

Potential Transformer Application

Type CLE-PT fuses provide protection for the systems to which potential transformers are connected. Like other fuses the CLE-PT must meet all of the basic selection requirements but there are a couple differences in the application which will be mentioned here.

Instrument potential transformer fuses are selected on the basis of the transformer magnetizing inrush current instead of the

Table 3 : Suggested Minimum Current Limiting Fuse Current Ratings For Self-Cooled 2.4-15.5 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	2.75		5.5		5.5		8.3		15.5		15.5		15.5		15.5	
Transformer KVA Rating Self-Cooled	Full Load Current Amps	Fuse① Rating Amps E or C	Full Load Current Amps	Fuse① Rating Amps E or C	Full Load Current Amps	Fuse① Rating Amps E or C	Full Load Current Amps	Fuse① Rating Amps E or C	Full Load Current Amps	Fuse① Rating Amps E or C	Full Load Current Amps	Fuse① Rating Amps E or C	Full Load Current Amps	Fuse① Rating Amps E or C	Full Load Current Amps	Fuse① Rating Amps E or C
Three Phase Transformers																
9	2.2	5	1.3	3	1.1	3	0.7	3	0.4	1	0.4	1	0.4	1	0.4	1
15	3.6	5	2.1	3	1.8	3	1.2	3	0.7	1	0.7	1	0.6	1	0.6	1
30	7.2	12	4.2	8	3.6	5	2.4	4.5	1.4	3	1.3	3	1.3	3	1.2	3
45	10.8	15	6.2	10	5.4	8	3.6	5	2.2	4	2.0	3	1.9	3	1.8	3
75	18	25	10.4	15	9.0	15	6	10	3.6	6	3.3	5	3.1	5	3	5
112.5	27	40	15.6	25	13.6	20	9	15	5.4	8	5.0	8	4.7	8	4.5	8
150	36	50	20.8	30	18	25	12	18	7.2	10	6.6	10	6.2	10	6	10
225	54	75	31.3	45	27.2	40	18	25	10.8	15	9.9	15	9.4	15	9	15
300	72	100	41.6	60	36	50	24	35	14.4	25	13.1	20	12.5	18	12	18
500	120	200	69.4	100	60	100	40	60	24.1	40	21.9	30	21	30	20	30
750	180	250	104	150	90	125	60	100	36.1	60	32.8	45	31	45	30.1	45
1000	241	350X	140	200	120	200	80	125	48.1	75	43.7	65	42	60	40.1	60
1500	360	600	208	300	180	250	120	200	72.2	100	65.6	100	62	100	60.1	100
2000	481	750	278	400X	241	350X	160	250	96.2	150	87.5	150	84	125X	80.2	125X
2500	600	. . .	346	600	301	450X	200	. . .	120	200X	109	175	104	175	100	150
Single Phase Transformers																
5	2.1	5	1.2	3	1.0	1.5	0.7	3	0.4	1	0.4	1	0.4	1	0.4	1
10	4.2	12	2.4	5	2.1	3	1.4	3	0.8	1.5	0.8	1.5	0.7	1	0.7	1
15	6.3	12	3.6	5	3.1	5	2.1	3	1.3	3	1.1	3	1.1	3	1.1	3
25	10.4	15	6	10	5.2	8	3.5	5	2.1	3	1.9	3	1.8	3	1.7	3
37.5	15.6	25	9	15	7.8	12	5.2	8	3.1	5	2.8	4	2.7	4	2.6	4
50	20.8	30	12	20	10.4	15	7.0	10	4.2	8	3.8	8	3.6	8	3.5	5
75	31.3	45	18	25	15.6	25	10.4	15	6.3	10	5.7	8	5.4	8	5.2	8
100	41.7	60	24	40	20.8	30	13.9	20	8.3	12	7.6	12	7.2	12	6.9	10
167	70	100	40	50	35.0	50	23.2	40	13.9	20	12.7	18	12.1	18	11.6	18
250	104	150	60	100	52.1	80	34.8	50	20.8	30	19.0	30	18.1	30	17.4	30
333	139	200	80	125	69.5	100	46.3	65	27.7	40	25.2	40	24.1	40	23.1	40
500	208	300	120	200	104	150	69.6	100	41.6	60	38	60	36.2	60	34.7	60
667	278	400X	160	250	139	200	92.6	150	55.4	85	50.5	75	48.2	75	46.3	75
883	347	. . .	200	350X	173	250	115.5	200	69.4	100	63.5	100	60.4	85	57.8	85
1250	521	. . .	300	450X	260	400X	174	250	104	175	95	150	90.6	150	86.8	125X

① Fuse ratings are for the smallest fuse possible. Choose next largest rating if given rating is not available in selected fuse line. Be sure to check for 1.5:1 ratio for 15.5 KV CLE-1, CLE-2 and CLE-3.

full load current rating. To prevent unnecessary fuse operation, the fuses must have sufficient inrush capacity to pass safely the magnetizing current inrush of the transformer. Fuses should be selected on the basis of the smallest current rating whose minimum melting time-current relationship lies above and to the right of the inrush value.

In some applications transformers are operated in a wye connection at .557 times their normal rated voltage. The CLE-PT will usually protect the transformer when applied at this reduced voltage but if the short circuit is through long leads or if the primary voltage is materially decreased by the short circuit on the secondary, the short circuit current may not be sufficient to blow the fuses.

Motor Protection

High voltage motor starters are used to protect high voltage motor circuits. These starters utilize overload relays and back-up current limiting fuses to provide complete overcurrent protection. The fuses operate to interrupt high values of fault current which exceed the interrupting rating of the contactor and the overload relay operates to open the contactor before the fuse blows for lesser, yet abnormal, currents due to motor overloads, locked rotor, repeated starts, extended accelerating time or low value fault currents. To obtain this coordination the proper combination of fuse, contactor, current transformer and overload relay must be used to assure that the contactor operates within its ratings and the fuse operates for those values of fault current which exceed the contactor's rating. Responsibility for this coordination rests with the manufacturer of the motor starter. In choosing suitable components, the following four areas of protection must be considered:

1. Protection of the motor against sustained overloads and locked rotor conditions by means of the overload relays.
2. Protection of the fuses against sustained currents above their continuous current ratings and yet below their minimum interrupting value by means of the overload relays.
3. Protection of the circuit by means of the overload relays for currents within the interrupting limits of the contactor and below the operating time of the fuses.
4. Protection of the circuit, contactor, overload relays and current transformers from the damaging effects of maximum fault currents by means of properly sized back-up current limiting fuses which hold the let-through currents to tolerable levels.

When selecting a fuse for such a coordinated motor starter scheme, the basic requirements for the fuse in addition to those of adequate voltage and interrupting rating are:

1. The fuse continuous current rating must be equal to or greater than the full load current of the motor.
2. The fuse must have the capacity to carry, without damage, currents less than the pickup value of the overload relay but no less than 125% of motor full load current.
3. The fuse must have the capacity to carry, without damage, currents greater than the pickup value of the overload relay but less than the fuse melt and overload curve intersection for sufficient time to allow the overload relay to operate.

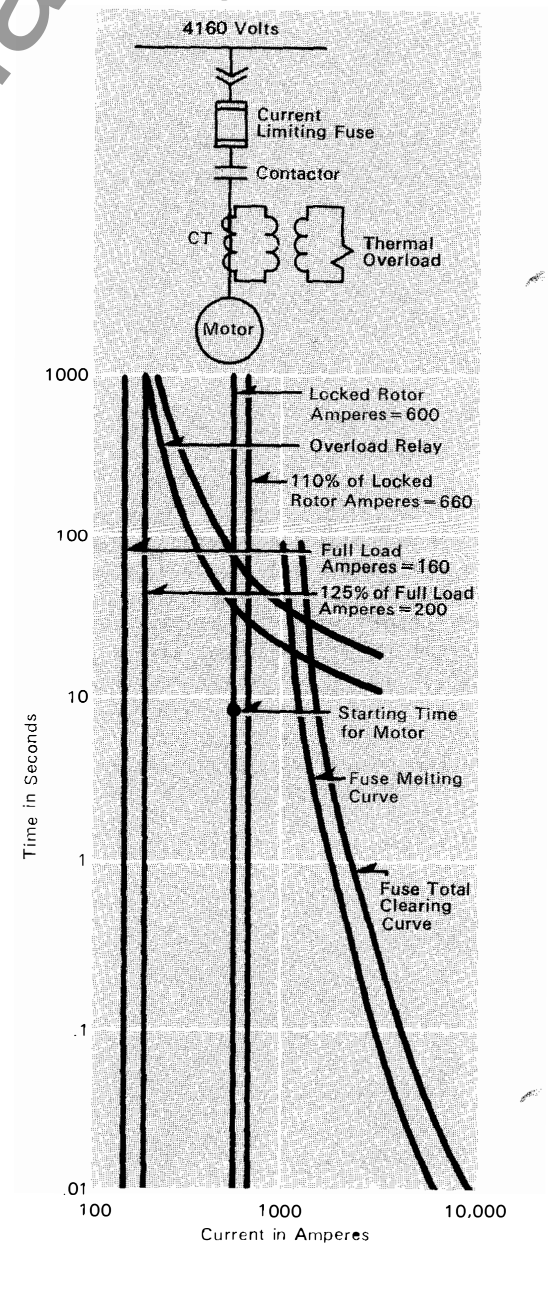
As has been implied up to now, full range motor protection can be provided only by a combination of fuses and other sensing devices. In the case of most motor starters, relays are used to cover the range up to and somewhat beyond the maximum possible load current of the equipment, while the fuses furnished only short circuit protection. Thus, the fuses are not protecting the motor itself; they are protecting the circuit up to the motor terminals, particularly the starting equipment. This is the reason for emphasizing the need to avoid damage to the fuse from long duration overloads such as caused by locked rotor conditions. Damage can generally be avoided by keeping the melting curve of the fuse above the locked rotor current by a safe margin until it is intersected by the relay curve. A reasonable margin is ten percent but knowledge of the manufacturer's application instructions will state just how close an application is permissible.

Although it is possible to protect a motor with a general purpose fuse, it is not a common application for two reasons. First, the melting current of the fuse is approximately twice its rated current. This means that the fuse does not provide protection against anything less than a 100% overload, and usually this range is even larger. Secondly, the damage characteristics of the apparatus and the total clearing time-current characteristic of the fuse hardly ever coincide. Thus, a motor protected only by a full range fuse may be exposed to overloads of somewhat longer duration than desirable or the fuse may limit the equipment's overload capacity.

Figure (8) shows the coordination for a current limiting fuse and motor starter combination. The motor is rated 1500 HP, 4160 volts, 3 phase. This coordination shows how the fuse meets all the aforementioned requirements.

As should be obvious, the duty of fuses in motor starter circuits is characterized by the frequent application of high overloads such as motor starting currents and cooling periods when the motor is off. To assure the performance of the Westinghouse CLS fuse in withstanding these frequent and severe heating and cooling cycles the fuse has been thoroughly tested. The test consisted of running 2000 amps through a fuse for 10 seconds, then 400 amps for 5 minutes and finally cooling the fuse with no current for 5 minutes. This three-step cycle was repeated 3000 times with the fuse showing no deterioration as measured by change in resistance at the conclusion.

Figure 8: Fuse and Motor Starter Coordination Diagram



To aid in selecting a fuse for motor starter application, the following may prove helpful: Full Load Current =

$$\frac{(\text{Horse Power})\ (746)}{(\text{Voltage})\ (\sqrt{3})\ (\text{Efficiency})\ (\text{Power Factor})}$$

For general use a .9 for efficiency and a .8 for power factor yield the following simple relationship between full load current and horsepower.

$$\text{Full Load Current} = \frac{(\text{Horse Power})\ (.701)}{(\text{Kilo-volts})}$$

Again on a general basis, inrush current may be assumed to be six times the full load current for a duration of 15 seconds.

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 becoming of increasing interest as a result of the increased application of current limiting fuses on pole type transformers. The 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' and 'C' 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 (9). 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 θ which can be calculated with sufficient accuracy by the formula $\theta = .1\ S^2$ where S is the melting current at .1 seconds divided by the melting current at 300, 600, or 1000 seconds. The 300 seconds applies for fuses rated 100E amperes or less, the 600 seconds for fuses rated above 100E amperes, and the 1000 seconds for 'C' rated fuses.

The time constant of a specific fuse, having been obtained in terms of seconds, gives to the general heating and cooling curves of Figure (9) 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' and 'C' rated fuses are defined.

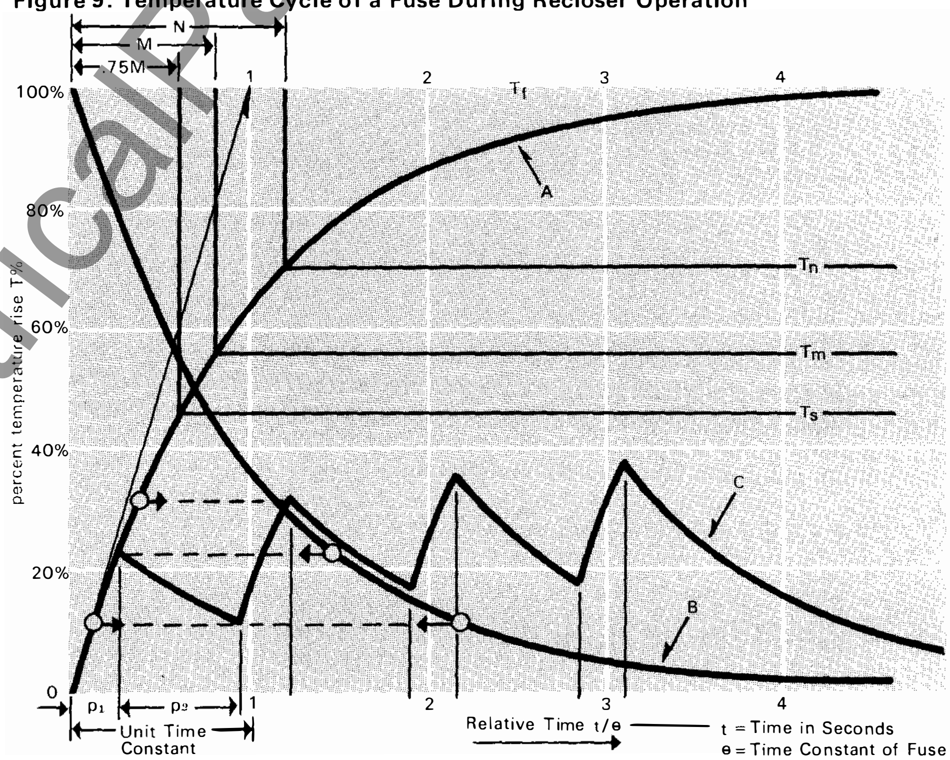
If the fuse is not to blow, Curve C must remain below the level T_m by a safe margin. It is common practice to provide such a safety margin by coordinating the breaker with a fuse curve whose time ordinates are 75 percent of those of the melting curve. Line T_s represents this temperature on Figure (9).

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 (10). On these coordinates the cooling Curve B becomes a straight line. Curves as shown in Figure (10) may be found as Curve 23 in application data 36-660-A.

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. As mentioned in that section, transformers may be protected by either a general purpose fuse or a back-up fuse in series with a protective link. The following discussion pertains to the general purpose characteristics and the resultant characteristics produced by using a back-up fuse in series with a protective link.

Figure 9: 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 are different if measured by the final temperature level T_f reached at a given current.

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.

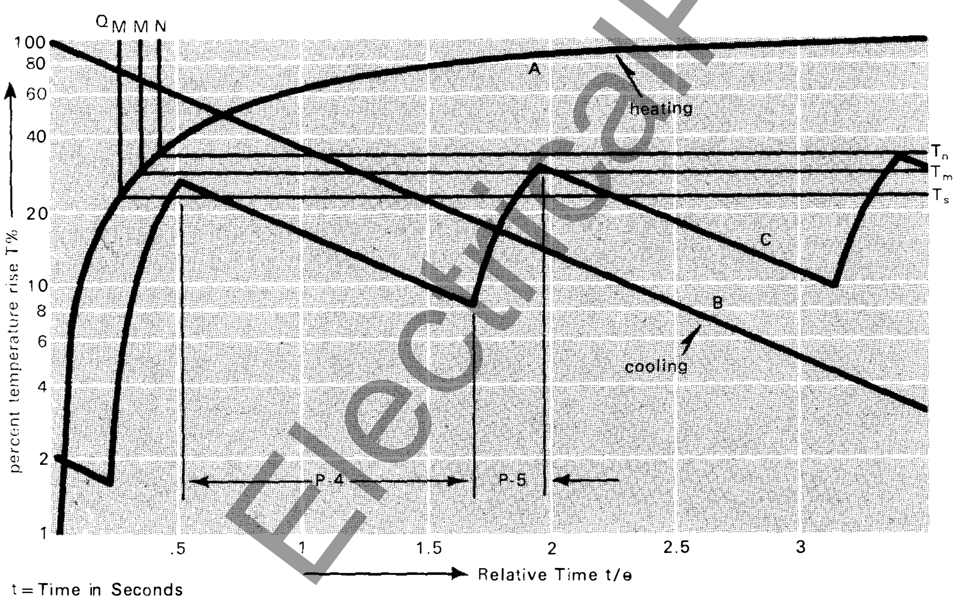
There are two major areas of concern when selecting a continuous current rating for the fuse which is to protect a transformer. The rating must be large enough to prevent false or premature fuse interruption from magnetizing or inrush currents and it must also be large enough to prevent fuse damage or 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 power transformers, the heating effect of the inrush current in a current limiting fuse can generally 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. Distribution transformers may have inrush currents as high as 25 to 40 times full load current. Thus, the general 12 times value must be replaced by the applicable multiple. The fuse whose minimum melting curve lies just above and to the right of the inrush point is the lowest rated fuse which can be used at the primary terminals. When the inrush does not exceed 12 times full load current, this criterion is usually satisfied for all Westinghouse current limiting 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 (Figures (3A) and (3C) which are also found as Curve 16 in application data 36-660-A and Figure (3B) which is also found as Curve 9 in application data 36-661-C) 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 Figures (3A), (3B) and (3C).

Suggested minimum fuse sizes for protection of self-cooled transformers are given in Table (3) which is found in this application data. These tables were based on the premise that the maximum 1.5 hour overload on the trans-

Figure 10: Reclosing Circuit Breaker-Fuse Coordination Chart



t = Time in Seconds
θ = Time Constant of Fuse

Recloser data: 400 PR (cycling code A1-3CH3)
Fuse type and rating: CLT (draw-out) 8.3 KV 150 C.
Fuse speed ratio, S-2150/420 = 5.11.
Thermal time constant, $\theta = .10\ S^2$, 2.61 seconds.
Fault current 1350 amps.

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. 9 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.

Period No.	Recloser Timing T Seconds Closed	Recloser Timing T Seconds Open	Total Time T	Relative Time T/θ	Resulting % Temperature
1①	0.054		0.054	0.021	2.0 ①
2		0.5	0.554	0.212	
3	0.8		1.354	0.519	
4		3.0	4.354	1.668	
5	0.8		5.154	1.975	
6		3.0	8.154	3.124	
7	0.8		8.954	3.430	32.0

Normal melting time 0.913 M = 0.35 $T_m = 30.0$
q② x M 0.2625 $T_s = 24.5$
Total clearing time 2.0 N = 0.42 $T_n = 35.0$

former 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 Table (3) are those which are higher than 1.4 times the transformer full load current. Remember that the ratio must be checked if 15.5 KV CLE-1, CLE-2 or CLE-3 fuses are to be used as they must employ a 1.5:1 ratio. 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.

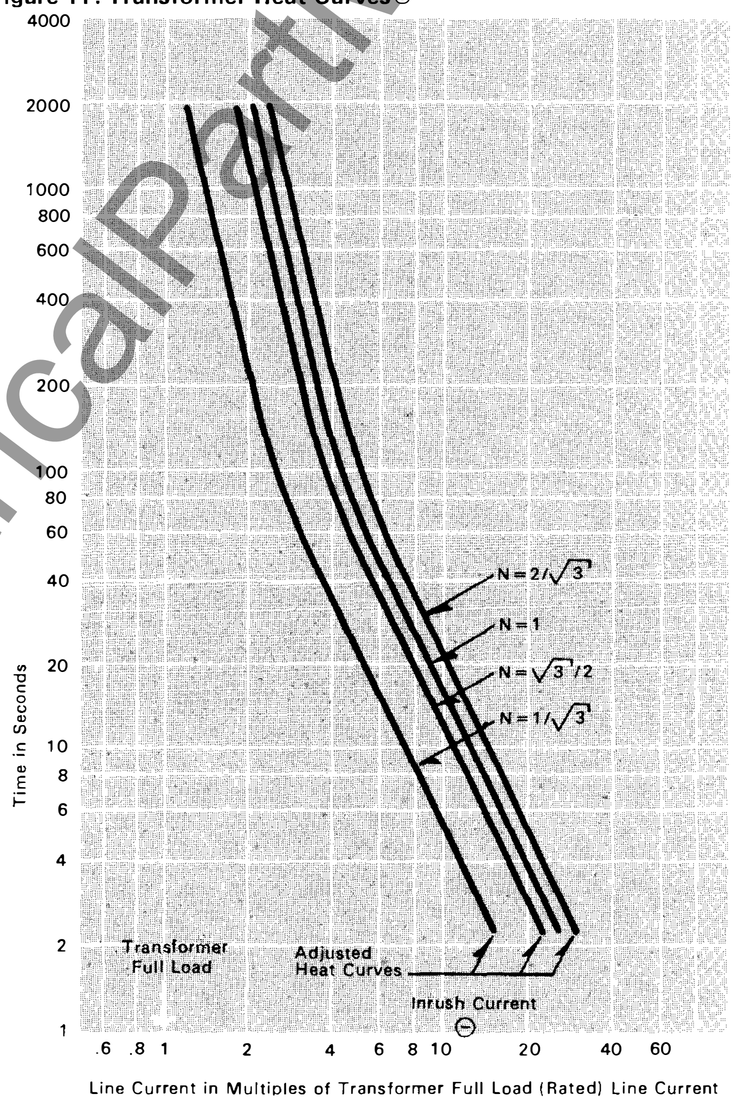
When the transformer has forced cooling, the minimum fuse size which can be applied should be based on the transformer top rating and the extent to which the transformer will be overloaded beyond the top rating.

It should be remembered that 'E' and 'C' rated current limiting fuses 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 Figures (3A), (3B) and (3C) 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 current limiting fuses generally are fast enough to prevent catastrophic failure of the transformer but not fast enough to prevent extensive damage.

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 (11) and on curve 22 of Application Data 36-660-A 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 times 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

Figure 11: 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 Application to Power Transformers.

Table 4: 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	....	$\sqrt{3}/2$

time overloads impressed on the transformer and the fact that 'E' and 'C' rated current limiting 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 (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. Subsequently, 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 - 1965) is 1 for wye connected primaries and $\sqrt{3}$ for delta connected primaries. ANSI C57.12.00 - 1965 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 (4) 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 (11) 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 (4).

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 connected primary windings. Table (4) 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 (4) 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 (4) 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 (4) 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 lies below the fuse 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 (4). 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.

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