Selection Guide
For Transformer-Primary Fuses in Medium- and High-Voltage Utility and Industrial Substations

S&C Power Fuses — Types SMD-1A, SMD-2B, SMD-2C, SMD-3, and SMD-50
Outdoor Transmission (34.5 kV through 138 kV)

S&C ELECTRIC COMPANY
Excellence Through Innovation
Selection Guide for Transformer-Primary Fuses in Medium- and High-Voltage Utility and Industrial Substations

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Monster Fuses Suggested Fuse Current Ratings for Power Transformer Applications

S&C Type SMD 1A, 2B & 2C Fuse Selection: monsterfuses.com

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Transformer Fuses in Medium- and High-Voltage Utility and Industrial Substations
This data bulletin is a guide for the selection, application, and coordination of S&C Type SMD Power Fuses when applied on the primary side of small-to-medium-sized transformers installed in utility and industrial substations. For the purpose of this guide, transformers having primary voltage ratings between 34.5 kV and 138 kV, with medium-voltage (4.16 kV through 34.5 kV) secondaries will be covered.

High-voltage power fuses provide a reliable and economical means of protecting small-to-medium-sized transformers installed in utility and industrial substations. The considerable economies inherent in power-fuse protection are possible, first, because the fuse itself is much less costly than other types of protective equipment and, second, because there is no need for auxiliary equipment such as station batteries, motor-driven switch operators, and protective relays. Further benefits of a compact fuse-protection package are low installation cost and a space-saving design that will accommodate almost any structure. In addition, unlike relay-actuated protective devices such as circuit breakers and reclosers, power fuses have maintenance-free time-current characteristics. They require only minimal physical maintenance — such as the periodic checking of the condition of the fuse-unit bore and occasional refinishing of fuse tubes exposed to severe weathering.

The transformer-primary fuse should be selected to provide system protection as well as transformer protection. With respect to system protection, the primary fuse should detect a potentially damaging overcurrent condition and operate promptly to isolate only the faulted segment, thereby minimizing short-circuit stresses on the remainder of the system and limiting the extent of the service interruption to the smallest possible portion of the system. For transformer protection, the primary fuse should operate promptly in response to a bus or cable fault located between the transformer and the nearest secondary-side overcurrent protective device. It should further provide backup protection for the transformer in the event the secondary-side overcurrent protective device either fails to operate due to a malfunction, or operates too slowly due to incorrect (higher) ratings or settings.

To best achieve these objectives, group protection of transformers is not generally recommended — each transformer should be individually protected. The ampere rating of a primary fuse selected to accommodate the total loading requirements of two or more transformers would typically be so large that only a small degree of secondary fault protection — and almost no backup protection — would be provided for each individual transformer. In addition, with group protection of transformers, the degree of service continuity is significantly reduced since a fault associated with any one transformer will result in the loss of service to all transformers protected by the fuse.

S&C Type SMD Power Fuses provide full-fault-spectrum protection for transformers: that is, these fuses will detect and interrupt all faults — large, medium, and small (even down to their minimum melting currents); whether the fault is on the primary or secondary side of the transformer; with line-to-line or line-to-ground voltage across the fuse; whether the transformer is adjacent to the fuse, or cable-connected to it from a remote location; and regardless of transformer winding connection. SMD Power Fuses are capable of handling the full range of transient recovery voltages associated with these conditions. They develop a positive internal gap of high dielectric strength after circuit interruption, thereby preventing destructive re-ignitions when exposed to full system voltage. The “dropout” action of these power fuses provides the additional benefit of visible air-gap isolation for the transformer after fuse operation.

The close fusing necessary to provide superior protection for secondary-side faults is possible with S&C Type SMD Power Fuses because: (1) they utilize silver or pretensioned nickel-chrome fusible elements that are not damaged by surges that may heat the element nearly to the severing point; (2) they are available in a wide variety of ampere ratings and speed characteristics especially suited to protecting transformers against very-low-magnitude fault currents; and (3) because they possess substantial peak-load capabilities and surge capacities more than adequate to withstand transformer magnetizing inrush currents as well as severe hot-load and cold-load pickup currents.

Close fusing with SMD Power Fuses, coupled with their exceptional low-current fault interrupting performance, assures maximum protection for the transformer against a broad range of secondary-side fault currents, thus minimizing the life-shortening thermal and mechanical stresses associated with prolonged transformer through-faults. In addition, the ability to fuse close to the full-load current of the transformer facilitates coordination with source-side protective devices by permitting the use of lower ratings or settings for faster response.
Application Principles

The selection of transformer primary-side protective devices and their ratings and settings has been a matter of considerable complexity. This publication provides complete, simplified procedures for selecting the optimal transformer-primary fuse, taking into consideration all of the following factors associated with the application:

1. System voltage;
2. Available fault current;
3. Anticipated normal transformer loading schedule, including daily or repetitive peak loads, and emergency peak loads;
4. Inrush currents, including the combined effects of transformer magnetizing-inrush current and the energizing-inrush currents associated with connected loads — particularly following a loss-of-source voltage (momentary or extended);
5. The degree of protection provided to the transformer against damaging overcurrents;
6. Coordination with secondary-side as well as other primary-side overcurrent protective devices; and
7. Protection of the downstream conductors against damaging overcurrents.

These factors are discussed in detail in the next section, entitled “Application Principles.” This discussion refers to selection tables located on the S&C Electric Company website


designed specifically to simplify the selection of the optimal transformer-primary fuse for your particular application.

The fuse selection tables list, for each transformer, a variety of fuse-unit ampere ratings and speed characteristics, along with the information necessary to confirm coordination of a given fuse with a variety of secondary-side protective devices. The tables also feature a specially designed “Transformer Protection Index” which indicates the degree of transformer protection provided by the primary fuse, as well as listings of the loading capabilities of the fuses when used with each of the transformers shown. You need only refer to these tables to obtain the information required to make your selection.

Select the Primary Fuse Rating . . .

A transformer-primary fuse must be selected for the voltage rating, the available fault current, and the continuous current-carrying requirement of the transformer on which it is to be applied. Since there are a multitude of voltage, short-circuit interrupting, and maximum ampere ratings available, you should choose the most economical primary fuse that will meet both your present and future requirements. In addition, from the wide variety of ampere ratings and speeds available, you should select the primary fuse providing the optimum protection for the transformer against secondary-side faults.

Voltage rating. The maximum voltage rating of the transformer-primary fuse should equal or exceed the maximum phase-to-phase operating voltage level of the system. S&C Type SMD Power Fuses are not “voltage critical” and, therefore, may be applied at any system operating voltage equal to or less than the maximum voltage rating of the fuse. Moreover, these fuses operate without producing overvoltages that can cause spurious operation of surge arresters or damage transformer insulation.

Short-circuit interrupting rating. The symmetrical short-circuit interrupting rating of the transformer-primary fuse should equal or exceed the maximum available fault current at the fuse location. When determining the interrupting rating of the primary fuse, you should consider the X/R ratio of the system at the fuse location, since power fuses may have higher-than-nominal symmetrical interrupting ratings for those applications where the X/R ratio is less than the value of 15 specified by IEEE Standard.\(^1\) You may, as a result, be able to use a less expensive primary fuse having a lower nominal symmetrical interrupting rating. Refer to your local S&C Sales Office for these higher symmetrical short-circuit interrupting ratings.

The interrupting rating of the transformer-primary fuse should be chosen with sufficient margin to accommodate anticipated increases in the interrupting duty due to system growth. Again, since fuses are available with a wide variety of interrupting ratings, you should choose a primary fuse having an interrupting rating only as large as necessary to meet your present and future requirements.

\(^1\) IEEE Standard C37.46, “Specifications for Power Fuses and Fuse Disconnecting Switches.”
**Application Principles**

**Ampere rating and speed characteristic.** The ampere rating and speed characteristic of the transformer-primary fuse should be selected to (1) accommodate the anticipated normal transformer loading schedule, including daily or repetitive peak loads, and emergency peak loads; (2) withstand the magnetizing-inrush current associated with the energizing of an unloaded transformer, as well as the combined magnetizing- and load-inrush currents associated with the re-energization of a loaded transformer following either a momentary or extended loss of source voltage; (3) protect the transformer against damaging overcurrents; (4) coordinate with secondary-side as well as other primary-side overcurrent protective devices; and (5) protect downstream conductors against damaging overcurrents. These principles, which are examined in greater detail in the following sections, provide the basic foundation of transformer-primary fuse selection.

**Accommodate Expected Loading Levels . . .**

In general, the transformer-primary fuse should be selected based on the anticipated normal transformer loading schedule, including daily or repetitive peak loads. The primary fuse ultimately selected should have a continuous loading capability, as differentiated from its ampere rating, equal to or greater than this highest anticipated loading level. Typical transformer loading levels for a number of conditions (i.e., self-cooled, forced-air-cooled) are shown in Table I. Loadability recommendations for various S&C Type SMD Power Fuses protecting specific transformers are included in the selection tables referenced by this guide, located on the S&C Electric Company website [www.sandc.com/edocs_pdfs/EDOC_025854.pdf](http://www.sandc.com/edocs_pdfs/EDOC_025854.pdf).

**Table I – Transformer Loading Levels**

<table>
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<tr>
<th>Temperature Capability</th>
<th>Transformer Type</th>
<th>kVA Three-Phase</th>
<th>Loading Level, Percent of OA Rating</th>
<th>OA</th>
<th>OA/FA</th>
<th>OA/FA/FA</th>
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<tbody>
<tr>
<td></td>
<td>OA①</td>
<td>OA②</td>
<td>OA/FA ③</td>
<td>55°C</td>
<td>65°C</td>
<td>55°C</td>
</tr>
<tr>
<td>&lt; 2,500</td>
<td>100</td>
<td>100</td>
<td>115</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>2,500 – 10,000</td>
<td>100</td>
<td>100</td>
<td>125</td>
<td>NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>&gt; 10,000</td>
<td>100</td>
<td>100</td>
<td>133</td>
<td>167</td>
<td>167</td>
<td></td>
</tr>
</tbody>
</table>

NA Not available.
① Base rating (self-cooled).
② Fan cooled (first stage). Also applicable to OA/FOA rating.
③ Fan cooled (second stage). Also applicable to OA/FA/FOA or OA/FOA/FOA ratings.
Application Principles

Conditions may occur during which the transformer will be loaded far in excess of the normal loading schedule. Such emergency peak loading typically occurs when one of two transformers (in a duplex substation, for example) is compelled under emergency conditions to carry the load of both transformers for a short period of time. Where emergency peak loads are contemplated, the transformer-primary fuse ultimately selected should have an emergency peak-load capability at least equal to the magnitude and duration of the emergency peak load. Refer to S&C Data Bulletin 210-190 for emergency peak-load capability values.

It is important to remember that a transformer-primary fuse should be selected to accommodate—not to interrupt—emergency peak loads. This requirement may result in the selection of a primary fuse ampere rating larger than would be required for a similarly rated single transformer installed alone, and therefore the degree of transformer protection provided by the primary fuse may be reduced.

**Withstand Inrush Currents . . .**

**Magnetizing-inrush current.** When an unloaded distribution or power transformer is energized, there occurs a short-duration inrush of magnetizing current which the transformer-primary fuse must be capable of withstanding without operating. A conservative estimate of the integrated heating effect on the primary fuse as a result of this inrush current is roughly equivalent to a current having a magnitude of 12 times the primary full-load current of the transformer for a duration of 0.1 second. A current having a magnitude of 25 times the primary full-load current of the transformer for 0.01 second is also frequently used.

The magnetizing inrush current for a 25-kVA, 7.62-kV, single-phase, pole-top-style distribution transformer is shown in Figure 1 (dotted line). This example is from a laboratory test, and is the highest inrush obtained for this transformer. For purposes of comparison, the magnetizing inrush current for a 10-MVA, 115-kV, three-phase, substation-class power transformer is also shown (solid line). Note that the first peak of the inrush current for the 10-MVA substation transformer is significantly less, on a per-unit basis, than that of the 25-kVA distribution transformer. Note also that the inrush current for the 10-MVA transformer decays more slowly.

The inrush that occurs on any particular energization will depend on, among other things, the residual magnetism in the transformer core as well as the instantaneous value of the voltage when the transformer is energized. Since these two parameters are unknown and uncontrollable, the fuse must be sized to withstand the maximum inrush that can occur under the worst-case energization. The minimum melting time-current characteristic of the primary fuse should be such that the fuse will not operate as a result of this magnetizing-inrush current.

![Figure 1. Magnetizing inrush currents for a 25-kVA single-phase distribution transformer (dotted line) and for a 10-MVA three-phase substation transformer (solid line). Note: 1 per-unit current is equal to transformer rated full-load current.](image-url)
The integrated RMS equivalent of the inrush current for the 10-MVA substation transformer (from Figure 1) is shown in Figure 2, along with the "rule-of-thumb" inrush points previously mentioned. Observe that the inrush points are higher than the actual RMS equivalent of the inrush current and are thus a conservative estimate of the inrush current. Sizing the transformer-primary fuse such that its minimum melting curve is above these "rule-of-thumb" inrush points will avoid unnecessary fuse operation, but can occasionally cause coordination problems with source-side protective devices, or it may result in compromising the degree of protection for the transformer because of the large rating selected. On these occasions, the use of a smaller fuse rating is desirable, and can be justified by using a better estimate of the heating equivalent of the magnetizing inrush current.

Figure 2. True RMS equivalent of the magnetizing inrush current for the 10-MVA transformer, from Figure 1, shown with "rule-of-thumb" inrush points and an 80E-ampere Standard Speed S&C Power Fuse minimum melting curve.
Application Principles

Magnetizing inrush currents also depend on the transformer rating and the available fault current. Because of the voltage drop across the source impedance during the inrush period, the inrush current will be less when the transformer is supplied from a weak source as compared to a strong source. Also, for small overhead-distribution transformers, the peak inrush current can be as high as 30 times the rated RMS current; for larger substation-class power transformers, the inrush peak will be lower, but the inrush duration will be longer. Figure 3 illustrates the maximum RMS equivalent magnetizing inrush currents as a function of transformer size. Note that the per-unit inrush current is lower for larger transformer sizes (actual amperes of inrush current are, of course, higher for the larger transformers). The strength of the source relative to the transformer full-load current is indicated by the ratio of the transformer full-load current to the system available fault current; a strong source will be able to supply a high fault current and will result in a lower ratio of full-load current to fault current.

“Hot-load” pickup. The transformer-primary fuse must also be capable of withstanding the inrush current that occurs when a transformer that is carrying load experiences a momentary loss of source voltage, followed by re-energization (such as occurs when a source-side circuit breaker operates to clear a temporary upstream fault and then automatically recloses). In this case, the inrush current is made up of two components: the magnetizing-inrush current of the transformer, and the inrush current associated with the connected loads. The ability of the primary fuse to withstand combined magnetizing- and load-inrush current is referred to as hot-load pickup capability.

[Image of Figure 3: RMS equivalent magnetizing inrush currents at 0.1 second (left) and at 0.01 second (right), in per unit of transformer rated full-load current, shown as a function of transformer size (kVA rating) with source strength indicated as a parameter. A strong source will have a lower ratio of rated load current to available fault current.]
The integrated heating effect on the transformer-primary fuse as a result of the combined magnetizing- and load-inrush current is equivalent to a current having a magnitude of between 12 and 15 times the primary full-load current of the transformer for a duration of 0.1 second. The specific multiple of primary full-load current is a function of several factors, including the transformer load immediately preceding the momentary loss of source voltage, the number of reclose operations attempted, and the available fault current. The hot-load pickup inrush current for a single reclose operation of the line-terminal circuit breakers serving the transformer is illustrated in Figure 4. The minimum melting time-current characteristic curve of the primary fuse, adjusted to reflect the pre-outage load current and elevated (or reduced) ambient temperatures, if applicable, should exceed the magnitude and duration of the combined inrush current.

**Preload and ambient-temperature adjustments.** Minimum melting time-current characteristic curves for medium- and high-voltage power fuses are determined in accordance with an IEEE Standard,\(^\text{▼}\) which specifies testing of fuses at an ambient temperature of 25ºC, and with no initial load. In practice, every fuse is carrying a load, which raises the temperature of the fusible element and thus reduces its melting time for a given value of current. To ensure that the transformer-primary fuse can withstand hot-load pickup current, (and to provide precise coordination between the primary fuse and load-side circuit breakers and reclosers), it is necessary to adjust the published minimum melting time-current characteristic curve of the primary fuse to reflect the reduced melting time for each specific level of fuse loading.

\(^\text{▼}\) IEEE Standard C37.46, “Specifications for Power Fuses and Fuse Disconnecting Switches.”

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**Figure 4.** Curve for determining magnitude of combined magnetizing- and load-inrush current for a single reclose operation.
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Figure 5 illustrates a typical curve used for making such an adjustment. Figure 6 illustrates a similar curve used to adjust the minimum melting time-current characteristic curve of the primary fuse for ambient temperatures above or below 25°C. Figure 7 illustrates the minimum melting time-current curve of a primary fuse so adjusted. As a point of information, the fact that the primary fuse will operate more quickly when preloaded as described in Figure 7 does not mean that the fuse will clear the fault more quickly. No adjustments need be made to the published total clearing time-current characteristic curve of the primary fuse.

![Figure 5. Curve for determining TCC adjustment factor due to preloading.](image)

![Figure 6. Curve for determining TCC adjustment factor for ambient temperatures above or below 25°C.](image)
Figure 7. Minimum melting and total clearing curves for a 100E-ampere Very-Slow Speed fuse, with the minimum melting curve adjusted to reflect the reduced melting time resulting from an assumed pre-fault load current of approximately 80 amperes.
Application Principles

“Cold-load” pickup. The final type of “inrush” current to which the transformer-primary fuse will be exposed is the long-duration overcurrent that occurs due to the loss of load diversity following an extended outage (30 minutes or more). These long-duration overcurrents are referred to as cold-load pickup. The cold-load pickup phenomenon is typically associated with utility distribution loading practices where the transformers are sized for the average peak load rather than the maximum expected peak load, thereby exposing the transformers to overcurrents of up to 30 minutes duration following re-energization. This phenomenon occurs since many electrical loads such as air conditioners, refrigerators, and electric space heaters are thermostatically controlled; they cycle on and off at random times relative to each other such that only a fraction of the total possible load is connected to the system at any given time. After an extended loss of power, however, many of these thermostatically controlled devices will be outside of their respective set-point limits so that, when power is restored, all of the thermostats will simultaneously demand power for their controlled equipment.

Typical cold-load inrush current profiles from a number of utilities are shown in Figure 8. These curves are typical of distribution transformers serving residential-type loads. Most peak loads seen by these transformers are associated with central- or large-room-type air conditioners or electric heating equipment having cyclical characteristics. As can be seen in this figure, the feeder current can remain significantly higher than the nominal current, calculated based on the total kVA rating of connected transformers, for quite a long time.

![Figure 8. Cold-load pickup current profiles.](image-url)
The integrated heating effect of the cold-load current profiles shown in Figure 8, for thermally responsive devices such as fuses, is illustrated in Figure 9 on page 14. For simplicity, cold-load inrush currents are usually represented by the following equivalent multiples of transformer nominal full-load current:

- $6 \times$ nominal load current for one second;
- $3 \times$ nominal load current for up to 10 seconds; and
- $2 \times$ nominal load current for up to 15 minutes.

The ability of the transformer-primary fuse to withstand the combined magnetizing- and load-inrush current associated with an extended outage is referred to as its cold-load pickup capability. Here again, the cold-load inrush will be affected by the source impedance and, if the source is weak, the use of a smaller fuse rating may often be justified.

In contrast to transformers serving primarily residential-type loads, transformers serving industrial, commercial, or institutional type loads are frequently sized to accommodate the maximum peak demand load without being overloaded. As a result, these transformers are actually loaded to only a small fraction of their rated power — perhaps only one-half or less. For this reason, and for the requirement for an orderly re-starting of equipment, the combined magnetizing- and load-inrush currents associated with the energizing of these transformers following an extended outage is no more severe than the inrush currents encountered under hot-load pickup conditions. Accordingly, cold-load pickup need not be considered when selecting the ratings of primary fuses for transformers applied on industrial, commercial, and institutional power systems.

**Protect Transformer Against Damaging Overcurrents . . .**

The most important application principle to be considered when selecting a transformer-primary fuse is that it must protect the transformer against damage from mechanical and thermal stresses resulting from a secondary-side fault that is not promptly interrupted. A properly selected primary fuse will operate to clear such a fault before the magnitude and duration of the overcurrent exceed the through-fault current duration limits recommended by the transformer manufacturer, or published in the standards. In the absence of specific information applicable to an individual transformer, the primary fuse should be selected in accordance with recognized guidelines for maximum permissible through-fault duration limits. Curves representing these limits can be found in IEEE Standard C37.91, “IEEE Guide for Protective Relay Applications to Power Transformers,” and IEEE C57.109, “IEEE Guide for Liquid-Immersed Transformer Through-Fault Current Duration.”
Figure 9. Integrated equivalent-current curves for some of the cold-load pickup current profiles shown in Figure 8. Industry “rule-of-thumb” points are also shown.
It is widely recognized that damage to transformers from through faults is the result of thermal as well as mechanical effects. The latter has gained increased recognition as a major cause of transformer failure. Though the temperature rise associated with high-magnitude through faults is typically quite acceptable, the mechanical effects are intolerable if such faults are permitted to occur with any regularity. Of special concern is the cumulative nature of certain mechanical effects such as insulation compression, insulation wear, and friction-induced displacement. The damage that occurs as a result of these cumulative effects is thus a function of not only the magnitude and duration of through faults, but also the total number of such faults.

The through-fault protection curves found in the aforementioned standards take into consideration the fact that transformer damage is cumulative, and the fact that the number of through faults to which a transformer can be exposed is inherently different for different transformer applications. For example, transformers with secondary-side conductors enclosed in conduit or isolated in some other fashion, such as those typically found in industrial, commercial, and institutional power systems, experience an extremely low incidence of through faults. In contrast, transformers with secondary-side overhead lines, such as those found in utility distribution substations, experience a relatively high incidence of through faults. The use of reclosers may subject the transformer to repeated current surges from each fault-clearing operation. Thus, for a given transformer in these two different applications, a different through-fault protection curve applies, depending on the type of application. For applications in which faults occur infrequently, the through-fault protection curve should reflect the fact that the transformer will be subjected to both thermal and cumulative-mechanical damage effects of through faults.

In using the through-fault protection curves to select the time-current characteristics of primary-side protective devices, you should take into account not only the inherent level of through-fault incidence, as described above, but also the location of each protective device and its role in providing transformer protection. As just noted, substation transformers with secondary-side overhead feeders have a relatively high incidence of through faults. The secondary-side feeder protective devices are the first line of defense against such faults, and thus their time-current characteristics should be selected by reference to the frequent-fault-incidence protection curve. More specifically, the time-current characteristics of feeder protective devices should be completely below and to the left of the appropriate frequent-fault-incidence protection curve.

Main secondary-side protective devices (if applicable) and transformer-primary fuses typically operate to protect against through faults only in the rare event of a fault between the transformer and the feeder protective devices, or in the equally rare event that a feeder protective device fails to operate or operates too slowly due to an incorrect (higher) rating or setting. The time-current characteristics of these devices, therefore, should be selected by reference to the infrequent-fault-incidence protection curve. In addition, these time-current characteristics should be selected to achieve the desired levels of coordination with other source-side and load-side protective devices.

Transformers with protected secondary conductors (for example, cable, bus duct, or switchgear) will likely experience an extremely low incidence of through faults. In this instance, the feeder protective devices may be selected
Application Principles

by reference to the infrequent-fault-incidence protection curve. The main secondary-side protective device (if applicable) and the transformer-primary fuse should also be selected by reference to the infrequent-fault-incidence protection curve. Again, these time-current characteristics should be selected to achieve the desired levels of coordination with other protective devices.

Most utility substation transformers protected by power fuses fall within two of the four size categories defined in IEEE Standard C57.12.00, “IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers”: Category II transformers (501-1667 kVA single-phase, 501-5000 kVA three-phase); and Category III transformers (1668-10,000 kVA single-phase, 5001-30,000 kVA three-phase). The applicable through-fault protection curves for these two transformer categories are shown in Figures 10 and 11.

In each case, the left-hand curve reflects both thermal and mechanical damage considerations and should be used for selecting feeder protective device time-current characteristics for frequent-fault-incidence applications. It is dependent upon the impedance of the transformer for fault currents above a fixed percentage of the maximum possible (70% for Category II transformers, 50% for Category III transformers) and is keyed to the \( \frac{I^2t}{t} \) of the worst-case mechanical duty (maximum fault current for two

**Figure 10.** Through-fault protection curves for liquid-immersed Category II transformers (501 kVA to 1667 kVA single-phase, 501 kVA to 5000 kVA three-phase.) Note: For fault currents from 70% to 100% of maximum possible, \( \frac{I^2t}{t} = K \) where \( I \) is the symmetrical fault current in per-unit of normal base current, and \( K \) is a constant determined at maximum \( I \) with \( t = 2 \) seconds. Sample \( \frac{I^2t}{t} = K \) curves have been plotted for the transformer impedances noted.
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The right-hand curve reflects primarily thermal damage considerations, and should be used for selecting feeder protective device time-current characteristics for infrequent-fault-incidence applications. This curve should also be used for selecting a main secondary-side protective device (if applicable) and primary-fuse time-current characteristics for all applications — regardless of the anticipated level of fault incidence.

The degree of transformer protection provided by the primary fuse should be checked for the level of fault current and type of fault (i.e., three-phase, phase-to-phase, or phase-to-ground) producing the most demanding conditions possible for each particular application; i.e., those for which the ratio of the primary-side line current to transformer winding current is the lowest. For these situations, one or more primary fuses will be exposed to a proportionately lower level of current than the windings and, as a consequence, the primary fuse must be carefully selected to operate fast enough to avoid damage to the transformer windings. Table II on page 19 lists the ratio of per-unit primary-side line currents to the per-unit transformer winding currents for three common transformer connections under a variety of secondary-fault conditions.

Figure 11. Through-fault protection curves for liquid-immersed Category III transformers (1668 kVA to 10000 kVA single-phase, 5001 kVA to 30000 kVA three-phase.) Note: For fault currents from 50% to 100% of maximum possible, \( I^2 t = K \) where \( I \) is the symmetrical fault current in per-unit of normal base current, and \( K \) is a constant determined at maximum \( I \) with \( t = 2 \) seconds. Sample \( I^2 t = K \) curves have been plotted for the transformer impedances noted.
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The relationship between the per-unit primary-side and secondary-side line currents and the associated per-unit transformer winding currents for (a) grounded-wye grounded-wye, (b) delta delta, and (c) delta grounded-wye connected transformers for various types of secondary faults. (Line current and winding current values are expressed in per unit of their respective values for a “bolted” three-phase secondary fault.)
From Table II, it is clear that a phase-to-phase secondary fault on a delta delta connected transformer and a phase-to-ground secondary fault on a delta grounded-wye connected transformer produce the most demanding conditions possible for those particular transformer connections, since the per-unit primary-side line currents are less than the per-unit transformer winding currents. Accordingly, to ensure proper transformer protection for these two situations, it is necessary to “shift” the base transformer through-fault protection curve to the left (in terms of current) by the ratio of the per-unit primary-side line current to the per-unit transformer winding current listed in Table II. The shifted transformer through-fault protection curve will then be in terms of the primary-side line current and, as such, will be directly comparable with the total clearing time-current characteristic curve of the transformer-primary fuse. For the grounded-wye grounded-wye connected transformer, the per-unit primary-side line currents and the per-unit transformer winding currents are the same, hence the base through-fault protection curve applies.

<table>
<thead>
<tr>
<th>Transformer Connection</th>
<th>Ratio of Per-Unit Primary-Side Line Current to Per-Unit Transformer Winding Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Fault</td>
<td>Three-Phase</td>
</tr>
<tr>
<td>Δ - Δ</td>
<td>1.0</td>
</tr>
<tr>
<td>Δ - Y</td>
<td>1.0</td>
</tr>
<tr>
<td>Δ - Δ</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table II—Relationship Between Per-Unit Primary-Side Line Current and Per-Unit Transformer Winding Current for Various Types of Secondary Faults

¹ Line current and winding current values are expressed in per unit of their respective values for a “bolted” three-phase secondary fault.
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Application Principles

- **Current, Percent of Transformer Self-Cooled Full-Load Current**
- **Time, Seconds**

The current value for the ANSI Point is determined using the following formula:

\[
\text{Current (in percent of transformer full-load current)} = \frac{1}{\%Z} \times \left(1 - \frac{1}{2.065 \times 0.58}ight)
\]

For example, for a 6.5% impedance delta grounded-wye connected transformer, the current value for ANSI Point is:

\[
\left(\frac{1}{0.055}\right)^{0.58}
\]

or 888% of the transformer full-load current.

Figure 13. Infrequent-fault incidence through-fault protection curves for various transformers.
Figure 13 illustrates the base transformer through-fault protection curve, applicable to a grounded-wye grounded-wye connected transformer (Curve A), as well as through-fault protection curves adjusted to reflect the two situations discussed previously. Curve B represents Curve A adjusted to reflect the reduced level of current (0.87 per unit) seen by two primary fuses during a phase-to-phase secondary fault on a delta delta connected transformer. Similarly, Curve C represents Curve A adjusted to reflect the reduced level of current (0.58 per unit) seen by two primary fuses during a phase-to-ground secondary fault on a delta grounded-wye connected transformer.

Although the transformer through-fault protection curves are only a guide, they are recommended as a criterion against which to measure the degree of transformer protection provided by the transformer-primary fuse. To meet this criterion for high-magnitude secondary-side faults, the total clearing time-current characteristic curve of the primary fuse should pass below the point (historically called the “ANSI” Point) on the appropriate through-fault protection curve at the current level corresponding to the maximum three-phase secondary-fault current as determined solely by the transformer impedance (i.e., an infinite source is assumed). Based on the design and application of the primary fuse, as described below, the total clearing time-current characteristic curve of the primary fuse will typically cross the transformer through-fault protection curve at some low level of current.

Another aspect of transformer protection involves low-current overloads. Medium- and high-voltage transformer-primary fuses are not intended to provide overload protection. For this reason, the minimum operating current of medium- and high-voltage power fuses is required by IEEE Standard® to be significantly greater than the ampere rating. For example, the “E”-rated power fuses discussed in this selection guide are required to operate at not less than 200 or 220% of the ampere rating. Accordingly, the total-clearing time-current characteristic curve of the primary fuse will cross the transformer through-fault protection curve at some low level of current. Because the primary fuse does not provide overload protection for the transformer, this should not be a concern; however, efforts should be made to keep the current value at which the two curves intersect as low as possible to maximize protection for the transformer against secondary-side faults.

The through-fault protection curve for a delta grounded-wye connected transformer can be used to illustrate these principles for primary-side fuses. See Figure 14 on page 22. The total clearing curves for primary fuses with a fusing ratio of 1.0, 1.5, or 2.0 all pass below the “ANSI” Point of the delta grounded-wye connected transformer’s through-fault protection curve. The total clearing curve for primary fuses with a fusing ratio of 2.5 or 3.0 pass completely above and to the right of the transformer through-fault protection curve and thus would not provide any protection for the transformer for a phase-to-ground secondary fault. Since the object of transformer-primary fusing is to provide protection for the transformer for all types of secondary faults, primary fuses having total clearing curves that pass above the “ANSI” Point (such as a primary fuse with a fusing ratio of 2.5 or 3.0 in Figure 14) would be considered unacceptable.

The transformer-primary fuse having the lowest fusing ratio of the three fuses that pass beneath the “ANSI” Point would provide the maximum protection for the transformer against secondary faults located between the transformer and the secondary-side circuit breakers or reclosers — as well as maximum backup protection for the transformer in the event the secondary-side breakers or reclosers fail to operate, or operate too slowly due to incorrect (higher) ratings or settings. From Figure 14, it may be seen that a primary fuse with a fusing ratio of 1.0 will provide protection for a delta grounded-wye connected transformer against phase-to-ground secondary faults producing currents as low as 235% of the full-load current of the transformer as reflected to the primary side. When the fusing ratio is 2.0, however, protection for the transformer is provided only when secondary faults produce primary-side currents exceeding 700% of the transformer full-load current.

▲ Fusing ratio is defined as the ratio of the transformer-primary fuse ampere rating to the transformer self-cooled full-load region.
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Figure 14. The effect of fusing ratios on the degree of protection provided a delta grounded-wye connected transformer against a phase-to-ground secondary fault.
As mentioned before, an effort should be made to select a transformer-primary fuse that will protect the transformer against all types of secondary-side faults. The primary-side line-current values for various types of secondary-side faults and for various transformer connections and impedances, expressed in percent of the transformer full-load current, are listed in Table III, below. The desired protection is obtained if the current value at which the total clearing time-current curve of the primary fuse and the transformer through-fault protection curve intersect is less than the applicable values as shown in Table III.

Table III—Secondary Fault Currents Reflected to Primary Lines

<table>
<thead>
<tr>
<th>Transformer Connection</th>
<th>Impedance</th>
<th>Maximum Primary-Side Line Current for Various Types of Secondary Faults, Percent of Transformer Full-Load Current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Phase-to-Ground</td>
</tr>
<tr>
<td></td>
<td>4%</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td>6%</td>
<td>1670</td>
</tr>
<tr>
<td></td>
<td>7%</td>
<td>1430</td>
</tr>
<tr>
<td></td>
<td>8%</td>
<td>1250</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>12%</td>
<td>830</td>
</tr>
<tr>
<td>– –</td>
<td>4%</td>
<td>2165</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>1730</td>
</tr>
<tr>
<td></td>
<td>6%</td>
<td>1445</td>
</tr>
<tr>
<td></td>
<td>7%</td>
<td>NOT APPLICABLE</td>
</tr>
<tr>
<td></td>
<td>8%</td>
<td>1085</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>865</td>
</tr>
<tr>
<td></td>
<td>12%</td>
<td>720</td>
</tr>
<tr>
<td>∆ – ∆</td>
<td>4%</td>
<td>1445</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>1155</td>
</tr>
<tr>
<td></td>
<td>6%</td>
<td>965</td>
</tr>
<tr>
<td></td>
<td>7%</td>
<td>825</td>
</tr>
<tr>
<td></td>
<td>8%</td>
<td>720</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>575</td>
</tr>
<tr>
<td></td>
<td>12%</td>
<td>480</td>
</tr>
</tbody>
</table>
Application Principles

Coordinate with Other Protective Devices . . .

General. The most important aspect of transformer-primary fusing is the provision of maximum protection for the transformer. It is also important, however, for the time-current characteristics of the primary fuse to be coordinated with the time-current characteristics of certain other overcurrent protective devices on both the secondary side and the primary side of the transformer.

 Coordination is defined as the selective operation of various overcurrent protective devices, and, if properly executed, will result in removal of the least-possible amount of load by the device clearing the fault, while normal service is maintained on the remainder of the circuit. The following sections describe how proper coordination is achieved both between the transformer-primary fuse and secondary-side protective devices, and between the transformer-primary fuse and source-side protective devices.

Figure 15 represents a portion of a simple radial circuit that serves to illustrate the principles of coordination just described. A secondary fault at Point C on the feeder should be cleared by feeder protective device 2 before the transformer-primary fuse 1 operates. In the same manner, a secondary fault at Point B, or a primary fault at Point A, should be cleared by the transformer-primary fuse 1 before another protective device even farther upstream begins to operate.

For most applications, a main secondary-side protective device is considered economically unjustifiable, since a properly selected primary fuse will provide the same degree of secondary-fault protection for the transformer as would a main secondary-side circuit breaker or recloser.

There are applications, however, where a main secondary protective device is commonly used for reasons other than secondary-side fault protection, such as: (1) in circuits with a large number of feeders, where the main secondary device serves as a “master” disconnect to permit rapid shutdown of all feeders in an emergency; (2) in circuits where overload protection is desired because the combined load capability of the feeders exceeds the overload capability of the transformer; and (3) in situations where the secondaries of two supply transformers are connected through a bus-tie circuit breaker in order to isolate a faulted transformer from the secondary-side bus.

The use of a main secondary-side circuit breaker or recloser does not alter the desirability of providing the maximum degree of protection for the transformer, while obtaining coordination with secondary-side devices such that the least-possible amount of load is removed in the event of a fault. This is best achieved by coordinating the transformer-primary fuse with the feeder circuit breaker or recloser having the highest ampere rating or setting (or, in the case of a duplex substation, with the bus-tie circuit breaker). A primary fuse so selected will have a smaller ampere rating than would be possible if the primary fuse were coordinated with the main secondary-side protective device, thereby providing a higher degree of protection for the transformer against secondary-side faults, as well as superior backup protection for the transformer in the event a secondary-side circuit breaker or recloser fails to operate correctly.

Lack of coordination between the transformer-primary fuse and the main secondary-side device is no problem, since the current range over which the two devices do not coordinate is very narrow, and even then it only occurs.

Figure 15. Coordination between a transformer-primary fuse and a feeder protective device. Refer to text.
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Coordinating with non-reclosing secondary-side protective devices

To establish coordination between the transformer-primary fuse and a non-reclosing feeder protective device, it is necessary to examine the relationship between the minimum melting time-current characteristic curve of the primary fuse and the total clearing time-current characteristic curve of the feeder circuit breaker (assumed). In so doing, however, the time-current characteristic curves for both devices must be converted to equivalent currents applicable to a common voltage (either primary side or secondary side). For this publication, the primary-side voltage has been used.

Complete coordination between the two devices is obtained when the total clearing time-current characteristic curve of the feeder circuit breaker lies below and to the left of the minimum melting time-current characteristic curve of the transformer-primary fuse for all current levels — from overload current up to the maximum three-phase secondary fault-current level — with proper allowances made for the transformer connection (discussed later), for the prefault load current, and for elevated (or reduced) ambient temperatures (if applicable).

Proper coordination between a transformer-primary fuse and a secondary-side circuit breaker is illustrated in Figure 16 on page 26. In this example, the transformer has a base (OA) rating of 7500 kVA three phase, 69 kV primary, 12.47 kV secondary. The transformer has a forced air (FA) rating of 9375 kVA (125%). The transformer impedance is 7%, and the maximum three-phase secondary fault current is 810 amperes (1000 MVA), as seen on the primary side of the transformer. The transformer is connected delta grounded-wye.

The transformer-primary fuse is a 100E-ampere Slow Speed SMD-1A Power Fuse rated 69 kV. The full-load current of the transformer, based on the forced-air (FA) rating, is 78.4 amperes. At this level of transformer loading, the primary fuse will be loaded to 78.4% of rating (78.4 ÷ 100 = 0.784). The preload adjustment factor, which can be determined from Figure 5 on page 10, is 0.85.

The secondary-side protective device is a Square D Type FVR circuit breaker controlled by Westinghouse CO-9 (very inverse) induction-disk overcurrent relays. The phase relay has a 360-ampere minimum pickup setting, and a time-dial of 3.0. The ground relay has a 240-ampere minimum pickup current, and a time-dial setting of 2.5. The coordinating time interval (CTI) for both relays is 0.15 second, consisting of 0.10 second for overtravel, and 0.05 second for tolerance. (It is assumed that the relays have been carefully field calibrated.) The circuit breaker total clearing time is 0.05 second (3 cycles).
Figure 16. Coordination between a transformer-primary fuse and a medium-voltage non-reclosing feeder circuit breaker.
A check of coordination indicates that a 100E Standard Speed SMD-1A Power Fuse will not coordinate with the phase relay described above at the available three-phase secondary-side fault current level of 810 amperes. Simply put, the total clearing time of the secondary-side circuit breaker is greater than the preload-adjusted minimum melting time of the primary fuse. However, a Slow Speed SMD-1A Power Fuse will coordinate with the phase relay. Refer to Figure 16. A 100E Very Slow Speed SMD-1A Power Fuse will also coordinate with the phase relay, although the degree of transformer protection will be reduced slightly.

If the fuse initially selected does not coordinate with the load-side protective device, then coordination should be rechecked, using a slower-speed fuse of the same ampere rating. If coordination still cannot be obtained — even with the slowest available fuse (i.e., Very Slow Speed) — then the alternatives listed below should be considered before resorting to a fuse with a larger ampere rating, which would reduce the degree of protection afforded the transformer:

a) Use more circuit breakers (feeders) on the secondary side of the transformer, thereby permitting the phase and ground relays to have lower minimum pickup currents;

b) Eliminate the main-secondary circuit breaker if present and if used solely for overcurrent protection;

c) Lower the time-dial settings of the load-side phase or ground relays;

d) Use a transformer with a higher impedance rating to reduce the level of fault current seen by the primary fuse; or

e) Accept incomplete coordination under certain infrequent conditions on a calculated-risk basis.

Coordinating with reclosing secondary-side protective devices

A circuit breaker with a reclosing relay or an automatic circuit recloser has the intelligence necessary to sense overcurrents, to interrupt those overcurrents, and to re-close automatically to reenergize the feeder. If the fault is permanent rather than temporary, the recloser will “lock out” after a preset number of reclosing operations (usually three or four), thus isolating the faulted feeder from the system. Most faults on overhead distribution feeders — perhaps as many as 80% — are temporary in nature and last only a few cycles to a few seconds at most. Automatic circuit reclosers, with their “trip-and-reclose” capability, eliminate prolonged outages on distribution systems due to these temporary faults.

Automatic circuit reclosers have dual timing capabilities that serve an important function in establishing coordination with other protective devices, and in helping to limit areas affected by permanent faults. A typical recloser operating sequence to “lockout” is shown in Figure 17. As illustrated, the first two fault-clearing operations are performed in accordance with the “fast” timing characteristic in order to clear temporary faults before any load-side protective devices operate. The remaining operations to lock-out incorporate a predetermined time delay, which allows protective devices nearer the fault to interrupt permanent faults, thereby limiting the extent of the outage to the smallest possible portion of the system. This scheme is often referred to as a “fuse saving” scheme, since fuses only respond to permanent faults within their zones of protection.
The fast timing characteristic is generally identified as the “A” curve on the recloser’s published time-current characteristic curves. Time-delayed operations, which are usually referred to as “slow” or “delayed” operations, are given curve designations “B,” “C,” “D,” etc. Time-current curves for a typical recloser are shown in Figure 18. Note that the fast (A) curve specifies the maximum clearing time for a single operation, with all variations negative. By contrast, the slow or delayed curves specify average clearing times for a single operation, variations are typically ±10% in terms of time, or ±0.01 second, whichever is greater.

Operating sequences for reclosers are selected primarily on the basis of providing protection against temporary faults and coordination with other protective devices. Typical sequences are: two fast / two delayed (2A / 2B), one fast / three delayed (1A / 3B), one fast / two delayed (1A / 2B), and two fast / one delayed (2A / 1B). Although it is possible to select recloser operating sequences that are either all fast or all delayed, this is generally not done except in unusual situations because of difficulties that will be encountered in coordinating the recloser with other protective devices.

Proper selection of the operating sequence and reclosing time intervals is vital to ensure that all outages due to faults are restricted to the smallest possible section of the feeder or lateral. Generally, the time-current characteristics and operating sequence of a recloser are selected to coordinate with source-side protective devices. Then, after a specific recloser size and operating sequence has been determined, protective equipment further out on the feeder are selected to coordinate with it.

Figure 18. Typical recloser curves.
When coordinating a transformer-primary fuse with a load-side circuit breaker with a reclosing relay, or with a load-side automatic-circuit recloser, the fault current flowing through the fuse will be interrupted by the breaker or recloser and then restored as the breaker or recloser goes through its operating sequence. Initially, the temperature of the fusible element in the primary fuse is determined by the pre-fault load current and by elevated (or reduced) ambient temperatures (if applicable). When a fault is initiated, the temperature of the fusible element increases towards its melting point. If the breaker or recloser opens before the fusible element reaches its melting point, the fuse will cool during the reclosing time interval (i.e., the breaker or recloser contacts are open). This current cycling will continue until: a) the fault is cleared by a fast operation of the circuit breaker or recloser, followed by a successful reclose; b) a load-side fuse clears the fault during the recloser’s delayed operation; or c) the recloser operates to lockout. Clearly, you would like the recloser to operate to lockout before the transformer primary-fuse operates. Figure 19 illustrates the heating and cooling of a primary fuse subjected to multiple reclose operations.

When coordinating reclosers and fuses, the repeated heating and cooling of the fusible element must be considered. To achieve this end, adjustment factors are applied to the time-current characteristic curves of the circuit breaker or recloser — rather than the transformer-primary fuse — to generate an “equivalent” recloser lockout curve as “seen” by the primary fuse. A number of different techniques have been used over the years to develop recloser lockout curves, each providing differing levels of accuracy. One method, sometimes referred to as the “Conservative Method,” involves simply ignoring the cooling that occurs during the reclosing time intervals, and considering only the heating of the primary fuse. Such a method, as the name suggests, yields very conservative results. A more accurate method — sometimes referred to as the “Cooling-Factor Method” — precisely defines the recloser lockout curve by reflecting both the heating and the specific cooling characteristics of the primary fuse as a function of the duration of each reclosing time interval. Cooling factor curves for S&C Type SMD Power Fuses are shown in Figure 20 on page 30.

As shown in Figure 20, cooling factors for different fuses can vary substantially. For example, after a reclosing time interval of 2 seconds has elapsed, a Standard Speed SMD fuse unit rated less than 40E amperes has lost 60% of its heat input as compared to a Slow Speed SMD fuse unit (having the same ampere rating), which has lost only 20% of its heat input.
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Since the transformer-primary fuse is located on the source side of the feeder circuit breakers or reclosers, the goal is to have the primary fuse *not* melt before the breaker or recloser on the faulted feeder operates all the way to lockout. The maximum current value up to which the primary fuse and breaker or recloser will coordinate is generally the lower of:

a) The maximum interrupting capacity of circuit breaker, recloser, or fuse; or

b) The intersection of the minimum melting curve of the primary fuse and the maximum equivalent operating curve of breaker or recloser (i.e., the “lockout” curve).

**Example 1: Conservative Method.** Coordination between a transformer-primary fuse and a secondary-side recloser is illustrated in Figure 21. In this example, the transformer has a base (OA) rating of 7500 kVA three phase, 115 kV primary, 13.2 kV secondary. The transformer has a forced-air (FA) rating of 9375 kVA (125%). The transformer impedance is 7.5%, and the maximum three-phase secondary fault current is 478 amperes (2000 MVA), as seen on the primary side of the transformer. The transformer is connected delta grounded-wye.

The transformer-primary fuse is a 65E-ampere Standard Speed SMD-2B Power Fuse rated 115 kV. The full-load current of the transformer, based on its forced-air rating, is 47 amperes. At this level of transformer loading, the primary fuse will be loaded to 72% of rating (47 amperes ÷ 65 amperes = 0.72). The preload adjustment factor, which can be determined from Figure 5 on page 10, is 0.88.

The secondary-side recloser is a Cooper Type VSML electronically controlled vacuum recloser, rated 14.4 kV, 560 amperes continuous. The phase-trip pickup current is 280 amperes, and the operating sequence is one fast (A), three slow (C) operations. The reclosing time interval between the fast operation and the first delayed operation...
Application Principles

is 0.5 second (instantaneous). Between the delayed operations, the reclosing time interval is 5 seconds.

As noted earlier, the most conservative approach to establishing coordination between the transformer-primary fuse and a feeder recloser would be to ignore the cooling of the primary fuse during the reclosing time intervals, and simply sum the heating effect or heat input of each operation. That is, the recloser lockout curve would be created by adding the total clearing times of the proper number of fast and delayed operations, at various current levels. While the conservative method will ensure coordination, it may force the selection of a larger transformer-primary fuse than otherwise would be necessary. A larger fuse, in turn, will provide a reduced level of transformer protection, and it may create coordination problems with devices located even further to the source side of the fuse.

The maximum equivalent lockout curve for a reclosing circuit breaker or recloser can be obtained by use of the following equation:

\[
T_l = \frac{\sum_{j=1}^{n} T_{Rj}}{1 - P} \quad \text{(Equation 1)}
\]

\(T_l\) = Point on the maximum equivalent lockout curve of the recloser, at current \(I\).

\(P\) = Reduction in the melting time of the fuse due to preloading, expressed as a decimal part of its total melting time.

\(T_{Rj}\) = Maximum clearing time at current \(I\) for the \(j\)th operation of the recloser.

\(n\) = Number of operations of the recloser.

Since the fuse must allow the recloser to operate to lockout without melting, the recloser’s maximum equivalent lockout curve is calculated by adding up the individual operating times of the one fast \(A\) curve and three slow \(C\) curves at various current levels. As noted previously, the published fast \(A\) curve is based on maximum clearing time, but the delayed \(C\) curve is based on average clearing time and must be adjusted by its positive tolerance of 10%.

The recloser’s maximum’s equivalent lockout curve can be calculated by using Equation 1:

\[
T_l = \frac{T_A + 3(1.1T_C)}{1 - P}
\]

Where \(T_A\) and \(T_C\) are points from the published recloser \(A\) and \(C\) curves, respectively, at the selected current \(I\).

At the maximum three-phase secondary-side fault current value of 478 A:

\(T_A = 0.025\) second
\(T_C = 0.14\) second
\(P = 0.12\) (For 72% preload) (From Figure 5)

\[
T_l = \frac{0.025 + 3(1.1)(0.14)}{1 - 0.12} = 0.55\) second
\]

The minimum melting time of the 65E-ampere Standard Speed SMD-2B Power Fuse at 478 amperes (0.42 second) is less than the maximum equivalent lockout curve of the recloser at this same current level (0.55 second), so complete coordination between the primary fuse and the recloser is not obtained. Before considering a fuse with a slower speed characteristic, or one with a larger ampere rating having the same speed characteristic, coordination should be checked using the more precise Cooling-Factor Method.
Figure 21. Source-side fuse/load-side recloser coordination using Conservative Method. The primary fuse does not coordinate with the recloser.
Example 2: Cooling-Factor Method. In order to obtain precise coordination between the transformer-primary fuse and a secondary-side circuit breaker or recloser, it is necessary to compensate for the heat stored in the primary fuse when the recloser contacts are closed, and the heat that is lost when the contacts are open. The heat stored in the fuse (preheating) during the time the recloser contacts are closed is directly proportional to the recloser's total clearing times (for fast or delayed operations). As noted before, an adjustment can be made to the recloser's fast (A) and slow (B, C, etc.) curves by the application of a factor (C) to the clearing times. These cooling factors (C), for a specific reclosing time interval, or cooling time, reflect the heat remaining in the fuse after preheating and cooling, in percent of preheating. See Figure 20 on page 30.

Maximum equivalent lockout curves for the circuit breaker or recloser, for various operating sequences, are obtained by use of the following equations.

a. One operation of reclosing device:

\[
T_l = \frac{T_{R1}}{(1 - P)} \tag{Equation 2}
\]

b. Two operations of reclosing device:

\[
T_l = \frac{T_{R1} C_1 + T_{R2}}{(1 - PC_1)} \tag{Equation 3}
\]

c. Three operations of reclosing device:

\[
T_l = \frac{T_{R1} C_1 C_2 + T_{R2} C_2 + T_{R3}}{(1 - PC_1 C_2)} \tag{Equation 4}
\]

when the reclosing times are the same, this simplifies to:

\[
T_l = \frac{T_{R1} C^2 + T_{R2} C + T_{R3}}{(1 - PC^2)} \tag{Equation 4a}
\]

d. Four operations of reclosing device:

\[
T_l = \frac{T_{R1} C_1 C_2 C_3 + T_{R2} C_2 C_3 + T_{R3} C_3 + T_{R4}}{(1 - PC_1 C_2 C_3)} \tag{Equation 5}
\]

when the reclosing times are the same, this simplifies to:

\[
T_l = \frac{T_{R1} C^3 + T_{R2} C^2 + T_{R3} C + T_{R4}}{(1 - PC^3)} \tag{Equation 5a}
\]

Where:

- \(T_l\) = Point on the maximum equivalent lockout curve of the recloser at current (I).
- \(P\) = Reduction in the melting time of the fuse due to preloading, expressed as a decimal part of its total melting time.
- \(T_{Rj}\) = Maximum clearing time at current (I) for the \(j\)th operation of the recloser.
- \(C_k\) = Cooling factors from Figure 20 on page 30 for \(k\)th reclosing time interval of the recloser.
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As in the previous example, the goal is to have the recloser operate all the way to lockout before the transformer-primary fuse operates. The reclosing time interval between the fast operation and the first delayed operation is 0.5 second (instantaneous). Between the delayed operations, the reclosing time interval is 5 seconds. The equivalent recloser lockout curve is calculated using Equation 5:

\[ T_l = \frac{T_A C_1 C_2 C_3 + 1.1T_c C_2 C_3 + 1.1T_c}{(1 - PC_1 C_2 C_3)} \]

Where \( T_A \) and \( T_C \) are points from the published recloser A and C curves, respectively, at the current \( I \).

At the maximum three-phase secondary-side fault value of 478 A:

\( T_A = 0.025 \) second  
\( T_C = 0.14 \) second  
\( P = 0.12 \) (For 72% preload) (From Figure 5)

For a 0.5-second reclosing time interval: \( C_1 = 1.0 \)

For a 5-second reclosing time interval: \( C_2 = C_3 = 0.25 \) (From Figure 20)

\[ T_l = \frac{(0.025)(1.0)(0.25)(0.25)+(1.1)(0.14)(0.25)(0.25)+(1.1)(0.14)(0.25)+(1.1)(0.14)}{(1 - (0.12)(1.0)(0.25)(0.25))} = 0.21 \) second

As noted earlier, the minimum melting time of the 65E Standard Speed SMD-2B Power Fuse at 478 amperes is 0.42 second. In this example, complete coordination results because the equivalent lockout time of the recloser, at 478 amperes (0.21 second), is well below the minimum melting time of the primary fuse, thereby illustrating the advantages of the Cooling-Factor Method.

As the above example illustrates, including the effects of cooling of the transformer-primary fuse during the reclosing time intervals often times allows the selection of a smaller primary fuse ampere rating, or a primary fuse with the same rating but having a faster speed characteristic, for better transformer protection. The Cooling-Factor Method is particularly useful when the coordination with the secondary-side breaker or recloser is particularly tight.
Figure 22. Source-side fuse/load-side recloser coordination using Cooling-Factor Method. Complete coordination is achieved.
Additional coordination considerations for delta grounded-wye connected transformers

For a phase-to-phase secondary fault not involving ground on a delta grounded-wye connected transformer, the per-unit primary-side line current in one phase is greater than that resulting from a three-phase secondary fault, while the secondary-side line current is only 0.87 per unit of the three-phase secondary fault-current value (hence, the ratio, as listed in Table IV, is 1.0 ÷ 0.87, or 1.15). To compensate for the line-current differential inherent to the delta grounded-wye connected transformer, it is generally recommended that a 15% margin in terms of current (or an equivalent margin in terms of time) be maintained between the total clearing time-current characteristic curve of the feeder protective device and the minimum melting time-current characteristic curve of the transformer-primary fuse. Refer to Figure 23.

Table IV—Relationship Between Per-Unit Primary-Side Line Current and Per-Unit Secondary-Side Line Current for Various Types of Secondary Faults

<table>
<thead>
<tr>
<th>Transformer Connection</th>
<th>Ratio of Per-Unit Primary-Side Line Current to Per-Unit Secondary-Side Line Current①</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type of Fault</td>
</tr>
<tr>
<td>∆ - ∆</td>
<td></td>
</tr>
<tr>
<td>∆ - Y</td>
<td></td>
</tr>
<tr>
<td>Y - Y</td>
<td></td>
</tr>
</tbody>
</table>

① Primary-side and secondary-side line current values are expressed in per unit of their respective values for a “bolted” three-phase secondary fault.
Figure 23. Application of minimum time margin (equivalent to 15% current margin) between the minimum melting curve of the transformer-primary fuse and a medium-voltage circuit breaker (feeder or main), for a delta grounded-wye connected transformer.

- \( I_1 \) – Maximum three-phase secondary-side fault.
- \( I_2 \) – 87% of \( I_1 \).
- \( T_1 \) – Minimum melting time of primary fuse at \( I_1 \).
- \( T_2 \) – Total operating time of circuit breaker at \( I_2 \).

Note: For coordination \( T_1 \) must be greater than \( T_2 \).
Application Principles

Coordination between the transformer-primary fuse and upstream protective devices

After the transformer-primary fuse has been selected to provide the maximum degree of protection for the transformer and to coordinate with secondary-side circuit breakers and reclosers, it is necessary to consider coordination with upstream protective devices. To achieve coordination with an upstream protective device, the total clearing time of the primary fuse must be less than the minimum melting time of a source-side fuse, or the minimum-operating time of the relay associated with a source-side circuit breaker, for all currents less than the maximum-available fault current at the location of the primary fuse. In establishing such coordination, no adjustment need be made to the total clearing time-current characteristic curve of the primary fuse.

Certain adjustments must be made to the minimum operating time-current curves of the source-side protective devices, however. Specifically, the minimum melting time-current characteristic curves for source-side power fuses must be adjusted to reflect the assumed prefault load current, as well as elevated (or reduced) ambient temperatures (if applicable). Similarly, the time-current characteristic curves for source-side relays must be adjusted for any overtravel and tolerance, as recommended by the manufacturer of the device. Refer to Figure 24.

Earlier in this guide, it was recommended that you select the smallest-practicable ampere rating of transformer-primary fuse in order to maximize transformer protection. Such a fuse selection will also greatly facilitate coordination with upstream protective devices since the lower total clearing time-current curve associated with this fuse will more easily fit below the time-current curve of the upstream protective device.

Protect Downstream Conductors Against Damaging Overcurrents . . .

The final application principle to be considered when selecting a transformer-primary fuse is that it must protect the conductors between the primary fuse and the transformer against damage from overheating due to excessive overcurrents. In general, the size of conductor to be used is determined by considering the conductor’s ampacity, as well as its behavior under short-circuit current conditions. Selection of the conductor size from the standpoint of its continuous current-carrying capability is easily done by reference to ampacity tables available in the industry literature, or published by the conductor manufacturer. Similarly, conductor sizes capable of withstanding available short-circuit currents can easily be selected from industry-accepted graphs, or those distributed by the conductor manufacturers. If the size of conductor to be used is selected in this manner, the primary fuses selected in accordance with the recommendations presented in this publication will easily protect the conductors against damage from overheating due to excessive overcurrents.
Figure 24. Coordination between a transformer-primary fuse and an upstream circuit breaker.
Introduction to Fuse Selection Tables . . .

As described previously, the selection of a transformer-primary fuse ampere rating and speed characteristic involves consideration of the following factors:

1. Anticipated normal transformer loading schedule, including daily or repetitive peak loads, and emergency peak loads;
2. Inrush currents, including the combined effects of transformer magnetizing-inrush current and the energizing-inrush currents associated with connected loads (i.e., hot-load pickup), and the long-term overcurrent that occurs upon re-energizing the transformer following an extended outage (i.e., cold-load pickup);
3. The degree of protection provided to the transformer against damaging overcurrents;
4. Coordination with secondary-side as well as other primary-side overcurrent protective devices; and
5. Protecting downstream conductors against damaging overcurrents.

In the past, the task of selecting a transformer-primary fuse ampere rating and speed involved complex graphical solutions using time-current characteristic curves published for the various overcurrent protective devices, taking into consideration the many adjustment factors required by the manufacturers of those devices and the particular transformer connection.

The fuse selection tables located on the S&C Electric Company website


are based on the consideration of the aforementioned factors, and permit the selection of the optimal transformer-primary fuse after just a few simple calculations. The need to perform graphical coordination studies has been eliminated. The tables list, for each transformer, primary-fuse ampere ratings and speeds that will accommodate the full range of loading levels normally encountered, and that will withstand the energizing-inrush currents associated with each transformer shown. In addition, for each such fuse, the degree of transformer protection provided by the primary fuse is quantified using S&C’s unique “Transformer Protection Index,” which indicates the level of secondary-fault current down to which the primary fuse will operate to protect the transformer in accordance with the appropriate transformer through-fault protection curve. Furthermore, each fuse ampere rating and speed listed in the tables has been “precoordinated” with medium-voltage secondary-side circuit breakers and reclosers. You need only refer to these tables to select the optimal fuse ampere rating and speed to protect your transformer and coordinate with the appropriate secondary-side overcurrent protective device.

S&C Type SMD Power Fuses possess the performance characteristics and quality that make them especially suited for the simultaneous satisfaction of all of the selection criteria. These time-tested fuses are available in a wide variety of ampere ratings and speeds, permitting close fusing for maximum protection and optimum coordination. And their time-current characteristics are precise, with only 10% total tolerance in melting current, compared to the 20% (or greater) tolerance of other fuses (20% and 40% respectively, in terms of time). Because of these narrow tolerances, S&C Power Fuses can be counted on to respond faster than other fuses of comparable ampere rating and speed, resulting in better and more reliable protection for the transformer. Furthermore, these narrow tolerances allow the upstream protective devices to be set to operate faster for better system protection while still retaining coordination.

Exceptional care in the design and manufacture of S&C Power Fuses guarantees that they are accurate with respect to their minimum melting time-current characteristics not only initially, but also on a sustained basis — neither age and vibration, nor surges that heat the element nearly to the severing point, will affect the characteristics of these fuses. S&C Power Fuses possess sufficient loading capability to easily accommodate daily or repetitive peak loads in excess of your normal transformer loading schedule. And they have surge capacities which are more than adequate to withstand any inrush currents they will likely experience. This provides operating economies because there is no need to replace unblown companion fuses on suspicion of damage following a fuse operation . . . a performance characteristic not generally found in other brands of power fuses.

As a consequence of these performance characteristics, S&C Power Fuses allow you to fuse closer to the transformer full-load current than is possible with other fuses, providing the maximum degree of protection against secondary faults. They are thus better able to protect the transformer against damage due to faults between the transformer and secondary-side circuit breakers or reclosers, and furthermore, supply backup protection in the event of the incorrect functioning of secondary-side devices. In addition, the ability to fuse closer to the transformer full-load current facilitates coordination with upstream protective devices, by allowing them to have lower ampere ratings and/or settings for faster response.

Once the transformer-primary fuse ampere rating and speed characteristic have been selected as outlined in the section entitled “How to Use the Fuse Selection Tables” on page 45, it is only necessary to determine the appropriate power fuse type based on the voltage rating, short-circuit interrupting rating (considering the maximum anticipated available fault current at the fuse location), and maximum
ampere rating required. As can be seen from Table VI on pages 48 and 49, S&C Type SMD Power Fuses are offered in a multitude of voltage, short-circuit interrupting, and maximum ampere ratings, allowing you to economically match the power fuse to the load- and fault-current levels of your particular applications. Moreover, S&C Type SMD Power Fuses are offered in a wide variety of mounting configurations designed to accommodate the space and bus configuration requirements of many different station layouts. Consult your nearest S&C Sales Office for help in making the most economical selection.

### Basis for Listings in the Fuse Selection Tables . . .

The fuse selection tables referenced in this publication were developed in accordance with the application principles previously discussed. In applying these principles as described, it was necessary to make certain decisions and assumptions, all of which are outlined in detail below. For easy access to this information, this discussion is arranged in the following sections in the same order as it appears in the fuse selection tables.

**Transformer self-cooled ratings.** Table VII on page 50 serves as an index to the fuse selection tables applicable to transformers having primary voltage ratings between 34.5 kV and 138 kV, with medium-voltage (2.4 kV through 34.5 kV) secondaries. The transformer ratings in Table VII are listed on a self-cooled basis. The fuse selection tables are applicable to all transformers with the listed ratings even if they are equipped with cooling fans, if they have increased temperature capability (e.g., 65°C temperature rise instead of 55°C temperature rise), or if they have both cooling fans and increased temperature capability.

The transformer impedances listed in Table VII were selected as being representative of transformers used in utility and large industrial substations, and were used in preparing the fuse selection tables. Transformers with special impedances are not within the scope of this publication, and thus have not been considered.

**Prefault load.** As mentioned previously, the time-current characteristic curves for medium-voltage power fuses are determined at 25°C and with no initial load. In practice, every fuse is carrying some load which, in addition to ambient temperatures in excess of 25°C, raises the temperature of the fusible element, and hence reduces the melting time for a given value of current. This adjustment must be considered when determining coordination between the transformer-primary fuse and secondary-side circuit breakers or reclosers as well as in calculating the hot-load pickup capability of the primary fuse.

**Coordination with secondary-side overcurrent protective devices.** In general, this section of the fuse selection tables was developed by examining the relationships that exist between the minimum melting time-current characteristic curve of the transformer-primary fuse and the total clearing time-current characteristic curves for medium-voltage secondary-side circuit breakers and reclosers. As explained previously, proper coordination between the primary fuse and the secondary-side overcurrent protective device requires the consideration of a number of factors. The assumptions made in considering these factors are outlined below.

The maximum three-phase secondary-fault current level used in determining coordination between the transformer-primary fuse and the secondary-side circuit breaker or recloser is based on consideration of the source impedance, as well as the more dominant transformer impedance. For the purpose of the fuse selection tables, the source impedance is based on a variety of short-circuit MVA levels up through: 2000 MVA at 34.5 kV; 2500 MVA at 46 kV; 3000 MVA at 69 kV; 2000 MVA at 115 kV; and 2000 MVA 138 kV. Additional fault-current contribution by motors or other secondary-side devices has not been considered, thus assuring that coordination between the transformer-primary fuse and the secondary-side protective device will be realized under all circumstances.

**The Transformer Protection Index.** The Transformer Protection Index is provided in the fuse selection tables to allow you to evaluate the degree of transformer protection provided by the transformer-primary fuse ampere rating selected. As explained in the section entitled, “Protect Transformer Against Damaging Overcurrents . . .” beginning on page 13, there are two objectives that must be achieved in order to obtain a comprehensive level of protection for the transformer. First, the total-clearing time-current characteristic curve of the primary fuse should pass below and to the left of the ANSI Point of the appropriate transformer through-fault protection curve, and second, the point at which the two curves intersect should be at as low a multiple of the transformer primary full-load current as possible. The Transformer Protection Index indicates how well these two objectives are achieved. The presence of an index indicates that the first objective was achieved, whereas the absence of an index signifies that the primary fuse does not provide protection for the transformer, since the total clearing time-current curve of the primary fuse passes above and to the right of the ANSI Point. Accordingly, a smaller primary fuse ampere rating should be selected. The indexes indicate the percentage of the transformer primary full-load current down to which the primary fuse will operate to protect the transformer in accordance with the appropriate transformer through-fault protection curve.
The Fuse Selection Tables

The indexes are listed in the fuse selection tables for commonly used transformer connections. For delta grounded-wye connected transformers, the indexes are based on a phase-to-ground secondary fault, which is the most demanding type of fault for this transformer connection from a protection standpoint. For delta delta connected transformers, the indexes are based on a phase-to-phase secondary fault, which is the most demanding type of fault for this transformer connection from a protection standpoint. Similarly, for grounded-wye grounded-wye connected transformers, and for delta wye connected transformers with the secondary-neutral side grounded through an impedance, the indexes should be based on a three-phase secondary fault. However, since the indexes for these transformer connections (based on a three-phase secondary fault) are only slightly smaller (better) than the indexes determined for delta delta connected transformers, for simplicity, indexes for the delta delta connected transformer have been listed in the fuse selection tables.

Loading capability. In general, loading capability refers to the amount of load the transformer-primary fuse can pick up (even after a momentary or extended loss of source voltage) without operating, and carry on a continuous basis. Two loadability values are listed in the fuse selection tables for each fuse ampere rating: the minimum of the continuous peak-load capability and the hot-load pickup capability, and the cold-load pickup capability. These two capabilities are discussed below:

1. Continuous peak-load capability . . . ability of the transformer-primary fuse to carry on a continuous basis, daily, or repetitive peak loads regardless of duration. Continuous peak-load values for S&C Type SMD Power Fuses can be determined by referring to S&C Data Bulletin 210-190.
2. Hot-load pickup capability . . . ability of the transformer-primary fuse that is carrying load to withstand the combined magnetizing- and load-inrush currents associated with the re-energizing of the transformer following a momentary loss of source voltage. Specifically, hot-load pickup capability is the maximum transformer load current which, when used as the pre-outage load current in adjusting the minimum melting time-current characteristic curve of the primary fuse, results in a fuse curve that passes above and to the right of the point representing the magnitude and duration of the combined magnetizing- and load-inrush currents.
3. Cold-load pickup capability . . . ability of the transformer-primary fuse to withstand the combined magnetizing- and load-inrush currents associated with the re-energizing of the transformer following an extended outage (30 minutes or more). Cold-load pickup capability is typically associated with utility distribution transformer loading practices, where the transformers are often sized for the average peak load rather than the maximum-expected peak load, thereby exposing the transformers to overcurrent of up to 30 minutes duration following re-energization. In contrast, transformers applied in industrial, commercial, and institutional power systems are usually sized to accommodate maximum peak-load conditions without being overloaded. For this reason, the combined magnetizing- and load-inrush current associated with the energizing of a transformer following an extended outage is no more severe than the inrush current encountered under hot-load pickup conditions — where the primary fuse is loaded to the peak-load capability listed in the fuse selection tables. As a consequence, cold-load pickup capability need not be considered when protecting transformers serving industrial, commercial, and institutional power systems.

Ampere ratings. For each transformer kVA rating, the fuse selection tables list a choice of fuse ampere ratings in all of three speed characteristics: S&C Standard Speed, TCC No. 153; S&C Slow Speed, TCC No. 119; and S&C Very Slow Speed, TCC No. 176. The smallest ampere rating listed for each transformer kVA rating and for each speed characteristic provides a minimum loading capability, for any of the three conditions evaluated, of at least 80% of the full-load current of the transformer.

Elevated ambient temperature. An ambient operating temperature not exceeding 40°C is considered to be typical for medium-voltage power fuse installations. The required adjustment (reduction) in melting time for an ambient temperature of 40°C would be very small—on the order of 2% in terms of time, or 1% in terms of current—and thus can be ignored.
Example 1 — Non-reclosing Secondary-Side Protective Device (Circuit Breaker)

Steps

1. The index on page 50 lists Table XI as applying to transformers rated 115 kV three-phase, 12 MVA (base), 8% impedance.

2. The maximum total clearing time (TE) for the phase relay for a maximum three-phase secondary-side fault (701 amperes at 115 kV) is 0.42 second.

3. The appropriate entry in the column corresponding to a 2000-MVA system available fault-current level is 0.54 second.

4. The Transformer Protection Index (TPI) for the transformer in this example is 335%. A comparison of this value with the values listed in Table V on page 47 indicates that the primary fuse will protect the transformer in accordance with the through-fault protection curve against all types of secondary faults.

5. The primary fuse has a continuous and hot-load pickup capability of 220% of the transformer full-load current, which is greater than the OA/FA/FAA rating of the transformer (157%). The primary fuse has a cold-load pickup capability of 110% of the transformer full-load current.

6. A primary-fuse rating of 80E amperes, Slow Speed, TCC No. 119 is conditionally recommended.

7. Confirm that coordination is achieved based on pre-loading the primary fuse under the assumption that the transformer is operating at its top (20-MVA) rating. The preload adjustment factor (see Figure 5 on page 10) is 0.64. The adjusted minimum melting time of the 80E-ampere Slow Speed fuse is 0.35 second [0.54 second (from Step 3) × 0.64 = 0.35 second]. Since this value is less than T_E for the phase relay determined earlier (0.42 second), the 80E ampere Slow Speed fuse will not coordinate with the phase relay after all. An 80E-ampere Very Slow Speed primary fuse (TCC No. 176) will coordinate with the phase relay, even when preloaded to a current level equal to the top rating of the transformer. The adjusted minimum melting time for the 80E-ampere Very Slow Speed fuse is 0.79 second (from the table) × 0.64 = 0.51 second.

8. The recommended primary-fuse ampere rating (80E amperes, Very Slow Speed, TCC No. 176) coordinates with source-side overcurrent protective devices (not considered in this example).

9. From Table VI on pages 48 and 49, an S&C Power Fuse Type SMD-2B is available in the voltage rating (115 kV), maximum ampere rating (250E), and interrupting rating (10,500 amperes symmetrical) sufficient for the application in this example.
Example 2 — Reclosing Secondary-Side Protective Device (Recloser)

Steps

1. The index on page 50 lists Table VIII as applying to transformers rated 34.5 kV three-phase, 5,000 kVA (base), 6.5% impedance.

2a. The published maximum total clearing time for the recloser fast (A) curve for a maximum three-phase secondary-side fault (1195 amperes at 34.5 kV) is 0.05 second. The published nominal total clearing time for the recloser slow (B) curve is 0.14 second.

2b. Cooling factors (C1, C2, etc.) for the various available fuse speeds, for an instantaneous and a 2-second reclosing time interval, are:
   - Standard Speed: 1.0 (Instantaneous) 0.58 (2 second)
   - Slow Speed: 1.0 (Instantaneous) 0.80 (2 second)
   - Very Slow Speed: 1.0 (Instantaneous) 0.95 (2 second)

2c. The preload adjustment factor is 0.90 (from Figure 5). The factor “P” is 0.10 (1.0 - 0.90 = 0.10).

3. The calculated values for TE for the various fuse speeds using Equation 5 (two fast, two slow sequence) are:
   - Standard Speed: \( T_E = 0.28 \) second
   - Slow Speed: \( T_E = 0.35 \) second
   - Very Slow Speed: \( T_E = 0.42 \) second

4. The appropriate entries in the column corresponding to a 1000-MVA system available fault-current level, and conditionally recommended fuse ratings are:

   - Standard Speed: \( T_E = 0.30 \) sec. 125E Standard Speed
   - Slow Speed: \( T_E = 0.53 \) sec. 125E Slow Speed
   - Very Slow Speed: \( T_E = 0.53 \) sec. 100E Very Slow Speed

5. The Transformer Protection Indices (TPIs) for the fuses selected above are 375%, 405%, and 310%, respectively. A comparison of these values with the values listed in Table V indicates that the primary fuse will protect the transformer in accordance with the through-fault protection curve against all types of secondary faults.

6. The primary fuses selected above have a continuous and hot-load pickup capability of at least 175% of the full-load current of the transformer, which is more than sufficient for the application given that the transformer is not equipped with fans. The 100E-ampere Very Slow Speed fuse has a somewhat limited cold-load pickup capability of 105% of the transformer full-load current. If cold-load pickup is a concern, the 125E-ampere Standard Speed fuse or the 125E-ampere Slow Speed fuse should be used.

7. All of the recommended primary-fuse ampere ratings coordinate with source-side overcurrent protective devices (not considered in this example).

8. From Table VI on pages 48 and 49, an S&C Power Fuse, Type SMD-1A is available in the voltage rating (34.5 kV), maximum ampere rating (200E), and interrupting rating (17,500 amperes symmetrical) sufficient for the application in this example.
How to Use The Fuse Selection Tables . . .

In using these tables, it is recommended that the transformer-primary fuse be coordinated with the largest feeder circuit breaker or recloser, rather than a main secondary-side protective device (if any). This will provide superior protection for the transformer while maintaining the same degree of service continuity. Accordingly, you should follow the steps below as they apply to your largest feeder protective device. The examples on pages 43 and 44 illustrate the use of these steps in selecting a primary fuse.

Non-Reclosing secondary-side protective device (circuit breaker)

1. Locate the appropriate selection table based on the applicable transformer kV rating. Refer to page 50 for index to selection tables.

2. Determine, from published operating characteristics, the maximum total clearing time of the feeder circuit breaker having the largest (highest) ratings or settings [i.e., the total operating time of the phase or ground relay (which ever is longer) plus the interrupting time of the circuit breaker] at the maximum three-phase secondary-side fault current level. In this publication, the primary-side system voltage is used.

3. Enter the table in the column entitled, “Secondary-side Circuit Breaker or Recloser — Upper Limit for TE . . . ,” in the specific column corresponding to the maximum three-phase secondary fault-current level. Select the first line containing a “TE” entry equal to or larger than the value determined in Step 2.

4. In the line selected in Step 3, and in the “Transformer Protection Index . . . ” column corresponding to the transformer connection, determine the Transformer Protection Index (TPI). If there is no TPI in this line, choose a smaller transformer-primary fuse ampere rating as described below. Compare the TPI to the entries listed in Table V, on page 47, corresponding to the transformer connection and impedance. Entries greater than or equal to the TPI indicate the fault types for which transformer protection is provided in accordance with the appropriate through-fault protection curve. If protection is not provided for the fault types listed, you may wish to select a smaller primary-fuse ampere rating to obtain a smaller TPI by adjusting the settings of the phase and/or ground relay, as follows:
   - Lower the time-dial setting.
   - Lower the minimum pickup current.
   - Use a different (faster) relay time-current characteristic.

Return to Step 2.

5. In the line selected in Step 4, and in the column headed “Loading Capability . . .,” verify that the listed value is sufficient to meet your hot-load or cold-load pickup requirements. If not, read down the table in this column, stopping in the first line containing an adequate loading capability value. Verify that the entries in the secondary-side protective device ratings or settings columns and the “Transformer Protection Index . . .” columns are still acceptable. If not, you may wish to consider reducing your loading requirements.

6. The primary-fuse ampere rating and time-current characteristic shown in the line selected above are those recommended for your application. Note: The TE values listed in the tables assume no preloading of the primary fuse. Verify that coordination still exists by adjusting the TE value using the graph in Figure 5 on page 10.

7. Verify that the primary fuse selected in Step 6 coordinates with the upstream protective device. See page 38.

8. To select the type of primary fuse (i.e., SMD-1A, SMD-2B, SMD-2C, SMD-3, or SMD-50), refer to Table VI on pages 48 and 49. Based on the system voltage, interrupting duty, and maximum continuous current, note the power fuse types that can be used. Your local S&C Sales Office will help you make the most economical selection.
Reclosing secondary-side protective device (recloser)

1. Locate the appropriate selection table based on the applicable transformer kV rating. Refer to page 50 for index to selection tables.
2. Collect data.
   2a. Determine, from published operating characteristics, the maximum total clearing time of the feeder recloser having the largest (highest) ratings or settings for the fast (A) operation(s) at the maximum three-phase secondary-side fault current level. Next, for this same recloser, determine the nominal clearing time for the delayed (B, C, or D, etc.) operations at the maximum three-phase secondary-side fault current level. For this publication, the primary-side system voltage is used.
   2b. Determine the cooling factors for the various available fuse unit speeds (e.g., Standard, Slow, Very Slow), and for the reclosing time intervals being used. See Figure 20 on page 30.
   2c. Using the Preload Adjustment Curve shown in Figure 5 on page 10, determine preload factor “P.” This is the reduction in the melting time of the fuse due to preloading, expressed as a decimal part of the melting time (i.e., 1.0 – the preload adjustment factor).
3. Based on the information determined above, calculate $T_E$ for the various fuse unit speeds using Equations 2 through 5a, depending on the specific reclosing sequence being used. See page 33.
4. Enter the table in the column entitled, “Secondary-side Circuit Breaker or Recloser — Upper Limit for $T_E$ . . . ,” in the specific column corresponding to the maximum three-phase secondary fault current level. Select the first line containing a “$T_E$” entry equal to or larger than the values determined in Step 2 for the various fuse speeds under consideration.
5. In the lines selected in Step 3, and in the “Transformer Protection Index . . .” column corresponding to the transformer connection, determine the Transformer Protection Indices (TPIs). If there is no TPI in these lines, choose a smaller transformer-primary fuse ampere rating as described below. Compare the TPI to the entries listed in Table V, on page 47, corresponding to the transformer connection and impedance. Entries greater than or equal to the TPIs indicate the fault types for which transformer protection is provided in accordance with the appropriate through-fault protection curve. If protection is not provided for one or more of the fault types listed, you may wish to select a smaller primary fuse ampere rating to obtain a smaller TPI by adjusting the settings of the recloser, as follows:
   a. Lower the recloser’s minimum pickup current.
   b. Use a different (faster) time-current characteristic curve for the delayed operation (e.g., a “C” curve instead of a “D” curve, or a “B” curve instead of a “C” curve).

   Return to Step 2.
6. In the line selected in Step 4, and in the column headed “Loading Capability . . .,” verify that the listed value is sufficient to meet your hot-load or cold-load pickup requirements. If not, read down the table in this column, stopping in the first line containing an adequate loading capability value. Verify that the entries in the secondary-side protective device ratings or settings columns and the “Transformer Protection Index . . .” columns are still acceptable. If not, you may wish to consider reducing your loading requirement.
7. The primary fuse ampere rating and time-current characteristic shown in the line selected above are those recommended for your application.
8. Verify that the primary fuse selected in Step 7 coordinates with the upstream protective device. See page 38.
9. To select the type of primary fuse (i.e., SMD-1A, SMD-2B, SMD-2C, SMD-3, or SMD-50), refer to Table VI on pages 48 and 49. Based on the system voltage, interrupting duty, and maximum continuous current, note the power fuse types that can be used. Your local S&C Sales Office will help you make the most economical selection.
### Table V—Secondary Fault Currents Reflected to Primary Lines

<table>
<thead>
<tr>
<th>Transformer Connection</th>
<th>Impedance</th>
<th>Phase-to-Ground</th>
<th>Phase-to-Phase</th>
<th>Three-Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4%</td>
<td>2500</td>
<td>2165</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>2000</td>
<td>1730</td>
<td>2000</td>
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<td></td>
<td>6%</td>
<td>1670</td>
<td>1445</td>
<td>1670</td>
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<td></td>
<td>7%</td>
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<td>1240</td>
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<td></td>
<td>12%</td>
<td>830</td>
<td>720</td>
<td>830</td>
</tr>
<tr>
<td>△ - △</td>
<td>4%</td>
<td>NOT APPLICABLE</td>
<td>2165</td>
<td>2500</td>
</tr>
<tr>
<td>△ - △</td>
<td>5%</td>
<td>1730</td>
<td>2000</td>
<td>1670</td>
</tr>
<tr>
<td>△ - △</td>
<td>6%</td>
<td>1445</td>
<td>1670</td>
<td>1250</td>
</tr>
<tr>
<td>△ - △</td>
<td>7%</td>
<td>1240</td>
<td>1430</td>
<td>1000</td>
</tr>
<tr>
<td>△ - △</td>
<td>8%</td>
<td>1085</td>
<td>1250</td>
<td>830</td>
</tr>
<tr>
<td>△ - △</td>
<td>10%</td>
<td>865</td>
<td>1000</td>
<td>720</td>
</tr>
<tr>
<td>△ - △</td>
<td>12%</td>
<td>720</td>
<td>830</td>
<td>830</td>
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## Table VI — SMD Power Fuses (with SMD Fuse Units)

<table>
<thead>
<tr>
<th>kV, Nominal</th>
<th>SMD-50</th>
<th>SMD-1A</th>
<th>SMD-2B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuse Type</td>
<td>Amperes, RMS</td>
<td>Amperes, RMS</td>
<td>Amperes, RMS</td>
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<tr>
<td></td>
<td>Max</td>
<td>Interrupting</td>
<td>Max</td>
</tr>
<tr>
<td></td>
<td>SYM</td>
<td>ASYM</td>
<td>SYM</td>
</tr>
<tr>
<td>34.5</td>
<td>23</td>
<td>6 700</td>
<td>10 600</td>
</tr>
<tr>
<td></td>
<td>27.6</td>
<td>6 700</td>
<td>10 600</td>
</tr>
<tr>
<td></td>
<td>34.5</td>
<td>6 700</td>
<td>10 600</td>
</tr>
<tr>
<td>46</td>
<td>23</td>
<td>6 000</td>
<td>9 600</td>
</tr>
<tr>
<td></td>
<td>27.6</td>
<td>6 000</td>
<td>9 600</td>
</tr>
<tr>
<td></td>
<td>34.5</td>
<td>5 000</td>
<td>8 000</td>
</tr>
<tr>
<td>69</td>
<td>23</td>
<td>4 000</td>
<td>6 400</td>
</tr>
<tr>
<td></td>
<td>27.6</td>
<td>4 000</td>
<td>6 400</td>
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<tr>
<td></td>
<td>34.5</td>
<td>3 350</td>
<td>5 300</td>
</tr>
<tr>
<td></td>
<td>46</td>
<td>3 350</td>
<td>5 300</td>
</tr>
<tr>
<td>115</td>
<td>69</td>
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<td>8 000</td>
</tr>
<tr>
<td></td>
<td>115</td>
<td>5 000</td>
<td>8 000</td>
</tr>
<tr>
<td>138</td>
<td>115</td>
<td>5 000</td>
<td>8 000</td>
</tr>
<tr>
<td></td>
<td>138</td>
<td>4 200</td>
<td>6 700</td>
</tr>
</tbody>
</table>

① Where no interrupting rating is listed, or when higher interrupting capacity is needed, refer to your nearest S&C Sales Office.

② The listed ratings apply only to SMD-2B and SMD-2C Fuse Units used with mountings that are of the latest design (i.e., incorporating upper end fittings having four attachment bolts for 69 kV and below, or three attachment bolts for 115 and 138 kV), or that have been modernized with new end fittings.

③ Symmetrical ratings assigned are based on available symmetrical short-circuit current at locations where the X/R ratio is 15.

● Nominal rating.
### The Fuse Selection Tables

#### SMD-2C

<table>
<thead>
<tr>
<th>Amperes, RMS</th>
<th>Interrupting</th>
<th>MVA③</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>SYM</td>
<td>ASYM</td>
</tr>
<tr>
<td>300E</td>
<td>33 500</td>
<td>53 500</td>
</tr>
<tr>
<td></td>
<td>33 500</td>
<td>53 500</td>
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<td>33 500</td>
<td>53 500</td>
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</tbody>
</table>

#### SMD-3

<table>
<thead>
<tr>
<th>Amperes, RMS</th>
<th>Interrupting</th>
<th>MVA③</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>SYM</td>
<td>ASYM</td>
</tr>
<tr>
<td>300E</td>
<td>25 000</td>
<td>…</td>
</tr>
<tr>
<td></td>
<td>25 000</td>
<td>…</td>
</tr>
<tr>
<td></td>
<td>25 000</td>
<td>…</td>
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<td>…</td>
</tr>
<tr>
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<td>25 000</td>
<td>40 000</td>
</tr>
</tbody>
</table>

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① Where no interrupting rating is listed, or when higher interrupting capacity is needed, refer to your nearest S&C Sales Office.

② The listed ratings apply only to SMD-2B and SMD-2C Fuse Units used with mountings that are of the latest design (i.e., incorporating upper end fittings having four attachment bolts for 69 kV and below, or three attachment bolts for 115 and 138 kV), or that have been modernized with new end fittings.

③ Symmetrical ratings assigned are based on available symmetrical short-circuit current at locations where the X/R ratio is 15.

● Nominal rating.
### The Fuse Selection Tables

#### Table VII — Index to Selection Tables

<table>
<thead>
<tr>
<th>Transformer Rating (Self Cooled)</th>
<th>Table Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>kV</td>
<td>kVA</td>
</tr>
<tr>
<td>34.5</td>
<td>300</td>
</tr>
<tr>
<td>46</td>
<td>300</td>
</tr>
<tr>
<td>69</td>
<td>1 500</td>
</tr>
</tbody>
</table>

#### Transformer Rating (Self Cooled)

| kV  | kVA       | Impedance, Percent | Table Number |
| 115 | 5 000     | 7 500              | 10 000 | 12 000 | 15 000 | 18 000 | 20 000 | 24 000 | 25 000 | 30 000 | 7.5%, 8.0%, 8.5% | XI |
| 138 | 5 000     | 7 500              | 10 000 | 12 000 | 15 000 | 18 000 | 20 000 | 24 000 | 25 000 | 30 000 | 9.0%, 9.5%, 10.0% | XII |

Fuse selection tables are located on the S&C Electric Company website:

S&C Power Fuses
SMD-1A, SMD-2B, SMD-2C, SMD-3, and SMD-50