WHITE
PAPER

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TRANSFORMER PROTECTION

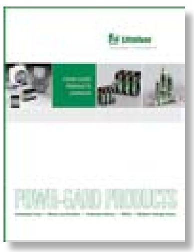
The Importance of Effective Transformer and Control Transformer Protection

OVERVIEW

Introduction

The importance of effective transformer and control transformer protection cannot be over emphasized. After motors, transformers are typically the second most common application where proper overcurrent protection is required and utilized to provide the necessary protection to facilities, electrical systems, equipment, and most importantly electrical workers and other involved personnel.

As a result, it is vitally important that there is at least a basic understanding of how transformers and their related electrical systems can be properly protected. The purpose of this white paper is to provide a more detailed discussion of the factors which must be considered when properly selecting and applying low voltage fuses and medium voltage fuses in electrical systems.



Descriptions, ratings, and application data for Littelfuse POWR-GARD® low voltage and medium voltage fuses are located in the corresponding sections of the Littelfuse POWR-GARD Catalog. To download a copy visit **www.littelfuse.com/catalogs**.

For questions, contact our Technical Support and Engineering Services Group at **800-TEC-FUSE (800-832-3873).** Definitions of terms used in this white paper can be found in the Technical Application Guide section of the POWR-GARD Catalog.

Overcurrent Protection Fundamentals

Before we go further, let's briefly review some overcurrent protection basics and touch on the types of fuses typically used to protect the transformers and control transformers installed within electrical systems.

Overcurrent Types and Effects

An overcurrent is any current that exceeds the ampere rating of conductors, equipment, or devices under conditions of use. The term "overcurrent" includes both overloads and short-circuits. For transformer protection, we'll just discuss overloads.

Overloads

An overload is an overcurrent confined to normal current paths in which there is no insulation breakdown.

Sustained overloads are commonly caused by installing excessive equipment such as additional lighting fixtures or too many motors. Sustained overloads are also caused by overloading mechanical equipment and by equipment breakdown such as failed bearings. If not disconnected within established time limits, sustained overloads eventually overheat circuit components, causing thermal damage to insulation and other system components.

Overcurrent protective devices must disconnect circuits and equipment experiencing continuous or sustained overloads before overheating occurs. Even moderate insulation overheating can seriously reduce the life of the components and/or equipment involved. For example in the case of motors, a single motor overloaded by just 15% may experience less than 50% of its normal insulation life.

Temporary overloads occur frequently. Common causes include temporary equipment overloads such as a machine tool taking too deep of a cut, or simply the starting of an inductive load such as a motor or transformer. Since temporary overloads are by definition harmless, overcurrent protective devices should not open or clear the circuit.

It is important to realize that fuses selected must have sufficient time-delay to allow transformers to start and temporary overloads to subside. However, should the overcurrent continue, fuses must then open before system components on the primary or secondary sides of the transformer are damaged. Littelfuse POWR-PRO® and POWR-GARD™ time-delay fuses are designed to meet these types of protective needs. In general, time-delay fuses hold 500% of the rated current for a minimum of ten seconds, yet will still provide short-circuit protection by opening quickly on higher values of current.

POWR-PRO time-delay fuses such as the FLSR_ID, LLSRK_ID, IDSR, or JTD_ID series have sufficient time-delay to permit transformers to perform when the fuses are properly selected in accordance with the NEC®.

Fusing Control Transformers

With one exception, control transformers are protected the same as regular transformers as discussed below. Control transformers with primary current less than 2 amperes and that are part of a UL Listed motor controller may have primary fusing not greater than 500% of rated primary current.

Transformer Protection for Low Voltage Applications (600 Volts and below)

Generally speaking, it is helpful to look at the different types of applications and corresponding requirements where low voltage fuses are used to protect the primary and/or secondary sides of transformers and control transformers. Note that in all of the below Transformer Protection Tables, the percentages indicated represent the *maximum* fuse rating recommended.

Transformers Over 600 Volts

The basic rule for transformers rated over 600 volts requires them to have primary and secondary protection in accordance with **Table 1**.

Table 1:
Fuses for Transformers over 600 volts

Transformer Rated Impedance	Maximum Fuse Rating in Percent of Transformer Rated Current			
	Primary Fuse Rating Over 600 Volts	Secondary Fuse Rating		
		Over 600 volts in all locations	600 volts or less in unsupervised locations	600 volts or less in supervised locations
Not more than 6%	300%	250%	125%	250%
More than 6% and not more than 10%	300%	225%	125%	250%

1. Littelfuse IDSR, LLNRK/LLSRK/LLSRK_ID, FLNR_ID/FLSR_ID, and JTD_ID series time-delay fuses may be rated at 125% of transformer secondary current.
2. Where the required fuse rating does not correspond to a standard fuse rating, the next higher standard rating is permitted.
3. An individual primary fuse is not required if the primary circuit fuse is not greater than 300% of transformer primary current.

Transformers Rated 600 Volts and Less

UL Industrial Control Standards (No. 508) and Motor Control Center Standards (No. 845) specify control power transformer protection corresponding to NEC Article 430.72(C). In addition, UL requires the primary of control power transformers used in controllers having short-circuit ratings in excess of 10,000 amperes to be protected by UL Class CC, J, R, or T fuses. For maximum fuse ratings permitted by the NEC, refer to **Table 2** for sizing of primary fusing and **Table 3** for sizing of secondary fusing.

Table 2:
Maximum Acceptable Rating of Primary Overcurrent Device

Rated Primary Current Amperes	Maximum Rating of Overcurrent Protective Device % of Transformer Primary Current Rating	
	No secondary fusing provided	Secondary fusing provided in accordance with Table 7
Less than 2	300[1]	250[1]
2 to less than 9	167	250
9 or more	125[2]	250

Table 3:
Maximum Acceptable Rating of Secondary Overcurrent Device

Rated Secondary Current Amperes	Maximum Rating of Overcurrent Protective Device % of Transformer Secondary Current Rating
Less than 9	167
9 or more	125[2]

1. 500% for Motor Circuit Control Power Transformers.

2. If 125% does not correspond to a standard fuse rating, the next higher standard rating may be used.

Reference NEC 430.72 (c) Exception No. 2: 450.3 (b) 1 and 2 UL 508 32.7: 845 11.16 and 11.17.

For more specific sizing recommendations, refer to **Tables 4 and 5** for Class J fuse protection and **Tables 6 and 7** for Class CC fuse protection.

Table 4 shows recommended Class J fuse ratings for standard transformers below 600 Volts *without* secondary protection, while **Table 5** shows the similar recommendations in applications *with* secondary protection.

Table 4:
Class J Fuse Protection Of Standard Transformers *Without* Secondary Protection—230, 460, 575 Volts Single-Phase

NEC® and UL Maximum Allowable Fusing (amps) With Only Primary Protection

Transformer kVA	230 Volts Single-Phase		460 Volts Single-Phase		575 Volts Single-Phase	
	Primary Current (A)	JTD or JTD_ID Series	Primary Current (A)	JTD or JTD_ID Series	Primary Current (A)	JTD or JTD_ID Series
0.15	0.65	1-1/2	0.33	8/10	0.26	KLDR 3/4*
0.35	1.52	4	0.76	2	0.61	1-1/2
0.50	2.17	3	1.09	3	0.87	2-1/2
0.75	3.26	5	1.63	4	1.30	3
1.00	4.35	6	2.17	3	1.74	5
1.50	6.52	10	3.26	5	2.61	4
2.00	8.70	12	4.35	6	3.48	5
2.50	10.87	15	5.43	8	4.35	6
3.00	13.04	17-1/2	6.52	10	5.22	8
3.50	15.22	20	7.61	12	6.09	10
5.00	21.74	30	10.87	15	8.70	12
8.00	34.78	45	17.39	25	13.91	17-1/2
8.25	35.87	45	17.93	25	14.35	20
10.00	43.48	60	21.74	30	17.39	25

Fuse recommendations are based on maximum acceptable rating of primary fuse as per NEC® 450.3(b), UL 508 32.7, and UL 845 11.16 and 11.17, as summarized in Table 4A below:

Table 4A

Rated Primary Current Amperes	Maximum Rating of Fuse % of Transformer Primary Current Rating (No Secondary Fusing Provided)
Less than 2	300
2 to less than 9	167
9 or more	125[2]

2. If 125% does not correspond to a standard fuse rating, the next higher standard rating may be used.
*KLDR= Littelfuse UL Class CC time-delay series.

Table 5

Class J Fuse Protection Of Standard Transformers *With* Secondary Protection— 230, 460, 575 Volts Single-Phase

NEC® and UL Maximum Allowable Fusing (amps) With Secondary Protection

Transformer kVA	230 Volts Single Phase		460 Volts Single-Phase		575 Volts Single-Phase	
	Primary Current (A)	JTD or JTD_ID Series	Primary Current (A)	JTD or JTD_ID Series	Primary Current (A)	JTD or JTD_ID Series
0.15	0.65	1-1/2	0.33	8/10	0.26	KLDR 3/4*
0.35	1.52	4	0.76	2	0.61	1-1/2
0.50	2.17	5	1.09	3	0.87	2-1/2
0.75	3.26	8	1.63	4	1.30	3
1.00	4.35	10	2.17	5	1.74	5
1.50	6.52	15	3.26	8	2.61	6
2.00	8.70	20	4.35	10	3.48	8
2.50	10.87	25	5.43	12	4.35	10
3.00	13.04	30	6.52	15	5.22	12
3.50	15.22	35	7.61	17-1/2	6.09	15
5.00	21.74	50	10.87	25	8.70	20
8.00	34.78	80	17.39	40	13.91	30
8.25	35.87	80	17.93	40	14.35	35
10.00	43.48	100	21.74	50	17.39	40

*KLDR= Littelfuse UL Class CC time-delay series.
Fuse recommendations are based on maximum acceptable rating of primary fuse as per NEC® 450.3(b), UL 508 32.7, and UL 845 11.16 and 11.17, as summarized in Table 5B below:

Table 5B

Rated Primary Current Amperes	Maximum Rating of Fuse % of Transformer Primary Current Rating (Secondary Fusing Provided)
Less than 2	250†
2 or more	250

†Secondary fusing provided in accordance with Table 5C shown below:
See NEC Table 450.3(B) for exceptions.

Table 5C

Rated Secondary Current Amperes	Maximum Rating of Fuse % of Transformer Secondary Current Rating
Less than 9	167
9 or more	125[2]

If 125% does not correspond to a standard fuse rating, the next higher standard rating may be used.

Table 6 shows recommended Class CC fuse ratings for transformers with single-winding *240 Volt* primaries while **Table 7** shows similar recommendations for transformers with single-winding *480 Volt* primaries.

Table 6

Class CC Fuse Protection Of Transformers With Single-Winding Primaries— *240 Volt* Primary

Transformer VA	Primary Current (A)	NEC® and UL Maximum Allowable Fusing (amps) With Only Primary Protection		Littelfuse Recommended Fuse
		Control Power Transformer	Standard Transformer[1]	Time Delay KLDR Series
25	0.10	1/2	3/10	15/100
50	0.21	1	6/10	1/4
75	0.31	1-1/2	8/10	1/2
100	0.42	2	1-1/4	1/2
130	0.54	2-1/2	1-6/10	8/10
150	0.63	3	1-8/10	1
200	0.83	4	2-1/2	1-1/2
250	1.04	5	3	2
300	1.25	6-1/4	3-1/2	2-1/2
350	1.46	7	4-1/2	3
500	2.08	3-1/2	3-1/2	3-1/2
750	3.13	5-2/10	5-2/10	5
1000	4.17	7	7	9§
1500	6.25	10	10	10

§These fuse ratings permissible only when secondary protection is provided in accordance with Table 6B. (See reverse side).
[1] Based on NEC 430.73(C).

Table 7

Class CC Fuse Protection Of Transformers With Single-Winding Primaries *480 Volt* Primary

Transformer VA	Primary Current (amps)	NEC® and UL Maximum Allowable Fusing (amps) With Only Primary Protection		Littelfuse Recommended Fuse
		Control Power Transformer[1]	Standard Transformer	Time Delay KLDR Series
25	0.05	1/4	15/100	1/10
50	0.10	1/2	3/10	3/16
75	0.16	8/10	1/2	3/10
100	0.21	1	6/10	4/10
130	0.27	1-1/4	8/10	1/2
150	0.31	1-1/2	8/10	1/2
200	0.42	2	1-1/4	6/10
250	0.52	2-1/2	1-1/2	1-1/8
300	0.63	3	1-8/10	1-1/2
350	0.73	3-1/2	2	2
500	1.04	5	3	2-1/4
750	1.56	7-1/2	4-1/2	3
1000	2.08	3-1/2	3-1/2	3-1/2
1500	3.13	5	5	5
2000	4.17	7	7	9*
2500	5.21	8	8	10*
3000	6.25	10	10	10

*These fuse ratings permissible only when secondary protection is provided in accordance with Table B.

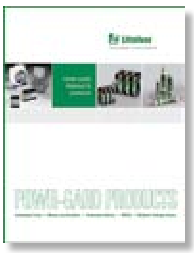
For Maximum Acceptable Rating of Primary Overcurrent Device refer to Table 2.

For Maximum Acceptable Rating of Secondary Overcurrent Device refer to Table 5c.

Transformer Protection for Medium Voltage Applications (above 600 Volts)

Introduction

Medium voltage fuses are applied quite differently than fuses rated 600 volts and less. The biggest difference is that medium voltage fuses are not intended to provide overload protection. They should only be applied in situations where it will not be required to open small overcurrents. Medium voltage fuses offer a much wider range of system voltages, thereby resulting in a correspondingly large number of fuse voltage ratings.



Descriptions and ratings of Littelfuse medium voltage fuses, along with some application data, are located in the Medium Voltage Fuse section of the Littelfuse POWR-GARD® Catalog. To download a copy visit **www.littelfuse.com/catalogs**.

For questions, contact our Technical Support and Engineering Services Group at **800-TEC-FUSE (800-832-3873)**. Definitions of terms used in this white paper can be found in the Technical Application Guide section of the POWR-GARD Catalog.

The following is a more detailed discussion of factors which must be considered when properly selecting and applying medium voltage fuses in electrical systems.

What are Medium Voltage Fuses?

Littelfuse medium voltage fuses are silver-sand, non-expulsion design, current-limiting type devices. When properly applied, they are designed to carry their nominal current rating continuously without "fatigue failure." This means that the fuse will not age, become brittle, or deteriorate under the most severe duty cycling.

When talking current-limiting medium voltage fuses, there are two basic types: general purpose and back-up. General purpose fuses have the ability to interrupt both large and small short-circuits down to currents that would cause the fuse to open within one hour. They are used to provide short-circuit protection for transformers, switchgear, and similar equipment.

Back-up fuses are designed to protect only against high fault currents, and must be used in series with equipment that provides the circuit's required overload and low value short-circuit protection.

While "R-Rated" medium voltage (MV) fuses are specifically designed to provide short-circuit protection for medium voltage motor controllers and associated equipment, "E-Rated" MV fuses are considered to be general purpose fuses. Their mounting dimensions permit them to be installed in a wide variety of medium voltage switches, in pad-mounted transformers, and at other similar locations. When properly applied, E-Rated fuses can protect against high and low value fault currents. A supplemental device is needed in series to remove currents below the minimum melting current rating of the fuse.

Guidelines for E-Rated Fuses

- Fuses with a rating of 100E or less will open (blow) within 300 seconds (5 minutes) at a current between 200% and 240% of the "E" rating.
- Fuses with a rating above 100E will open (blow) within 600 seconds (10 minutes) at a current between 220% and 264% of the "E" rating.
- Fuse Sizing:
  – Fuses are sized at a percentage of the full load current.
  – Generally, fuse size is based on 133% to 150% of full load current.
  – Always round up to the next standard fuse rating.

As an example…with a full load current of 104 amperes, the fuse size based on 133% of full load current would be a 138 ampere fuse. Such a fuse rating size does not exist, so it is permissible and recommended to round up to the next standard size which in this instance is 150 amperes (150E).

Be sure to note that nuisance fuse openings can occur if the fuse is sized too closely.

Table 8

Suggested Minimum current limiting medium voltage fuse current ratings for self-cooled 2.4-15.5 kV power transformer applications.

System Nom. kV	2.4		4.8		7.2		14.4	
Fuse Max. kV	2.75		5.5		8.3		15.5	
Trans-former kVA Rated Self-Cooled	Full Load Current Amps	Fuse Rating Amps (E)	Full Load Current Amps	Fuse Rating Amps (E)	Full Load Current Amps	Fuse Rating Amps (E)	Full Load Current Amps	Fuse Rating Amps (E)
Single Phase Transformers								
5	2.1	5	1	1.5	0.7	3	0.4	1
10	4.2	12	2.1	3	1.4	3	0.7	1
15	6.3	12	3.1	5	2.1	3	1.1	3
25	10.4	15	5.2	8	3.5	5	1.7	3
37.5	15.6	25	7.8	12	5.2	8	2.6	4
50	20.8	30	10.4	15	7	10	3.5	5
75	31.3	45	15.6	25	10.4	15	5.2	8
100	41.7	60	20.8	30	13.9	20	3.6	10
167	70	100	35	50	23.2	40	11.6	18
250	104	150	52.1	80	34.8	50	17.4	30
333	139	200	69.5	100	46.3	65	23.1	40
500	208	300	104	150	69.6	100	34.7	60
667	278	400	139	200	92.6	150	46.3	75
883	347	-	173	250	115.5	200	57.8	85
1250	521	-	260	400	174	250	86.8	125
Three Phase Transformers								
9	2.2	5	1.1	3	0.7	3	0.4	1
15	3.6	5	1.8	3	1.2	3	0.6	1
30	7.2	12	3.6	5	2.4	4.5	1.2	3
45	10.8	15	5.4	8	3.6	5	1.8	3
75	18	25	9	6	6	10	3	5
112.5	27	40	13.6	20	9	15	4.5	8
150	36	50	18	25	12	18	6	10
225	54	75	27.2	40	18	25	9	15
300	72	100	36	50	24	35	12	18
500	120	200	60	100	40	60	20	30
750	180	250	90	125	60	100	30.1	45
1000	241	350	120	200	80	125	40.1	60
2000	481	750	241	350	160	250	80.2	125
2500	600	-	301	450	200	-	100	150

Continuing with sizing of E-Rated fuses…the transformer sizing guide in **Table 8** shows the suggested *minimum* current limiting medium voltage fuse current ratings for self-cooled 2.4 – 15.5 kV power transformer applications.

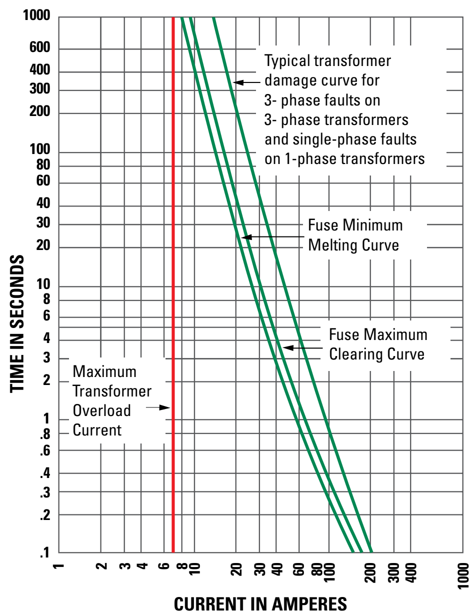
Transformer Protection

A principle use of medium voltage fuses is to provide primary short-circuit protection for transformers. When selecting MV fuses to protect transformers, the following factors must be considered in descending order of importance:

1. The fuse's voltage and interrupting ratings must equal or exceed system requirements at the point where the fuses will be applied.
2. The fuse's continuous current rating must be large enough to withstand transformer magnetizing (in-rush) current. (Minimum Fuse Rating).
3. The fuse's continuous current rating must be able to withstand transformer overloading and emergency operation, while meeting all NEC® requirements. (Maximum Fuse Rating).
4. Fuses must protect the system on the line side of the fuse from the effects of short circuits on the load side of the fuses. (Utility System Coordination).
5. Fuses must coordinate with the transformer secondary protection where and whenever possible. (Facility System Coordination).
6. Fuses must protect the transformer against secondary bolted faults.

Figure 1

Time - current Curves for Transformer Protection Application

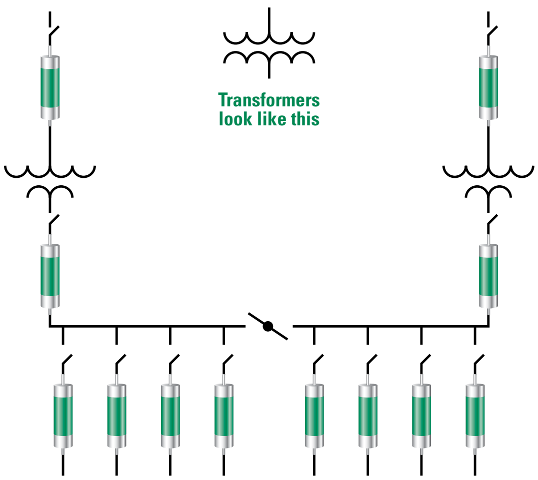


7. And where and whenever possible, fuses should protect the transformer against higher impedance secondary faults.

Transformer magnetizing or inrush current depends on several factors including the transformer's design, the amount of residual flux in the transformer core at the instant the transformer is energized, the point on the voltage wave at which the switch is closed, and the characteristics of the electrical system powering the transformer. A power transformer's in-rush current approximates 12 times the transformer full load current, while a distribution transformer's in-rush current can exceed 25 to 40 times of the full load current. The current generally lasts less than one-tenth of a second.

Figure 2

Typical Example of Double-ended Loadcenter Operated with Normally Open Bus tie



To determine the minimum size fuse that will withstand the in-rush current, it is recommended that the in-rush current be obtained from the transformer manufacturer. Then, note the current on the fuse's minimum melting time-current curves at 0.10 second. This is illustrated in more detail in **Figure 1.** The fuse whose minimum melting curve is just to the right and above the transformer inrush point becomes the minimum fuse rating to use for properly protecting the system.

Medium voltage fuses with current ratings that equal or exceed a transformer's self-cooled, full load current will usually meet such a requirement when the in-rush current does not exceed 12 times transformer full load current. However, transformers are generally operated at close to full load current on a continuous basis and are often overloaded under emergency conditions. A typical example is a double-ended loadcenter operated with a normally open bus tie. See **Figure 2**.

Each transformer is rated to carry 150% of the load on its half of the loadcenter. With loss of service to one transformer, the main switch for that line is opened and the bus tie switch is closed. This shifts all load to the remaining transformer. The system is operated in an overloaded state until the other line is back in service. If the outage continues for a long period of time, manual load shedding can be used to control transformer overloading.

Other similar operating schemes also result in transformer overloading. As a result, medium voltage fuses usually have continuous current ratings larger than required to withstand transformer in-rush current.

NEC® Article 450 covers transformer installations and establishes the maximum ratings of transformer overcurrent protective devices. Regarding medium voltage fuses, NEC Article 450.3 states, in part:

> Overcurrent Protection of transformers shall comply with NEC Article 450.3(A) – Transformers Over 600 Volts, Nominal, and shall be provided in accordance with **Table 9.**

NOTE: In this section, the word "transformer" shall mean a transformer or polyphase bank of two or more single-phase transformers operating as a single unit.

Table 9

Based on NEC® Table 450.3(A) Maximum Rating or Setting of Overcurrent Protection for Transformers Over 600 Volts (as a Percentage of Transformer-Rated Current)

		Primary Protection Over 600 Volts		Secondary Protection (See Note 2)		
				Over 600 Volts		600 Volts or Less
Location Limitations	**Transformer Rated Impedance**	**Circuit Breaker (see Note 4)**	**Fuse Rating**	**Circuit Breaker (see Note 4)**	**Fuse Rating**	**Circuit Breaker or Fuse Rating**
Any Location	Not more than 6% (see Note 1)	600%	300%	300%	250%	125%
	More than 6% but not more than 10% (see Note 1)	400%	300%	250%	225%	125%
Supervised Locations Only (see Note 3)	Any (see Note 1)	300%	250%	Not Required	Not Required	Not Required
	Not more than 6% (see Note 5 for Secondary Protection)	600%	300%	300%	250%	250%
	More than 6% but not more than 10% (see Note 5 for Secondary Protection)	400%	300%	250%	225%	250%

Note 1 – If the required fuse rating or breaker setting does not correspond to standard ratings/settings, the next higher rating/setting may be used.

Note 2 – If secondary overcurrent protection is required, no more than six breakers or sets of fuses may be grouped in any one location. When multiple overcurrent devices are used, the sum of all device ratings shall not exceed the allowed value of any single device. If both breakers and fuses are used, the total of device ratings shall not exceed that if using only fuses.

Note 3 – A "supervised location" is one where maintenance and supervision conditions ensure that only qualified persons are allowed to monitor and perform installation service on the transformer.

Note 4 – Electronically actuated fuses set to open at a specific current shall be set and calibrated in accordance with the corresponding settings of the circuit breakers involved.

Note 5 – Separate secondary protection is not necessary if the transformer is equipped with a coordinated thermal overload protection provided by the manufacturer.