Analyzer

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The ABC's of Overcurrent Coordination

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ABOUT THE AUTHOR

THOMAS P. SMITH, P.E. received his B.S. in Electrical Engineering in 1982, and his B.S. in Education in 1981 from the University of Nebraska. Mr. Smith has over 20 years of electric power systems design, analysis and training experience. He began his career in 1983 at the U.S. Army Corps of Engineers – Omaha District as a design engineer. In 1988 Mr. Smith joined Gilbert/Commonwealth where he performed a wide variety of power system studies for industrial and utility clients. In 1995 he began work as a private consultant. He has designed electrical distribution systems for air separation plants built throughout the world for Air Products and Chemicals. He annually prepares and teaches several seminars in power systems design and analysis. Mr. Smith is a Registered Professional Engineer in the states of Nebraska and Pennsylvania. He is a member of the IEEE.

The material in this guide was initially developed by Mr. Smith for his power system seminars. His design experiences were used as a foundation. He has been fortunate to work with, and is grateful to, the many fine engineers that have shared their knowledge and experiences with him over the years. Much of this material is not original, it can be found in old engineering references no longer in print, rules of thumb passed down from one engineer to another, or in various standards.

DISCLAIMER

Table of Contents

SECTION 1
INTRODUCTON

The proper selection and coordination of protective devices is mandated in article 110.10 of the National Electrical Code.

> *"The overcurrent protective devices, the total impedance, the component short-circuit current ratings, and other characteristics of the circuit to be protected shall be selected and coordinated to permit the circuit-protective devices used to clear a fault to do so without extensive damage to the electrical components of the circuit. This fault shall be assumed to be either between two or more of the circuit conductors or between any circuit conductor and the grounding conductor or enclosing metal raceway. Listed products applied in accordance with their listing shall be considered to meet the requirements of this section."*

To fulfill this mandate an overcurrent coordination study is required. The electrical engineer is always responsible for this analysis. It is an unfortunate fact of life that many times the engineer who specified and purchased the equipment will not set the protective devices. Therefore, compromises are inevitable.

There are three fundamental aspects to overcurrent coordination that engineers should keep in mind while selecting and setting protective devices.

- **Life Safety Requirements**

  Life safety requirements are met if protective device pickup settings are within distribution equipment continuous current ratings and rated short circuit test duration times. Life safety requirements are never compromised.

- **Equipment Protection Requirements**

  Equipment protection goals are met if overcurrent devices are set above load operating levels and below equipment damage curves. Conductor, cable, transformer and distribution equipment damage information is defined in applicable equipment standards. Capacitor, motor and generator damage information is component specific, and is normally provided by the manufacturer. Based on system operating and equipment sizing practices equipment protection is not always possible.

- **Selectivity Requirements**

  Selectivity goals are met if in response to a system fault or overload, the minimum area of the distribution system is removed from service. Again, based on system operating and equipment selection practices selectivity is not always possible.

Performing overcurrent coordination studies is a skill required of every electric power system engineer. This document is intended as a basic guide to overcurrent coordination. There is no substitute for experience.

It is strongly recommended that the design engineer objectively review the results of the overcurrent coordination study. If life safety, equipment protection, or selectivity goals have not been met, determine what could have been done differently. For instance, using switchgear equipped with power circuit breakers instead of switchboards equipped with molded case circuit breakers. Keep in mind there are inherent advantages and disadvantages between distribution systems and equipment. Engineers must know and understand these differences before equipment is purchased.

SECTION 2
LIFE SAFETY REQUIREMENTS

The results of the load flow study are used to confirm minimum equipment continuous current ratings. The results of the short circuit study are used to confirm minimum equipment interrupting and withstand ratings. To meet life safety requirements, the results of the overcurrent coordination study must confirm that protective device pickups are within equipment continuous current ratings, and that protective device clearing times are within distribution equipment rated short circuit duration times, Table 1.

Table 1 – SC Duration Limits

Distribution Equipment	Industry Standard	Short Circuit Test Duration Time
Panelboard	UL67	3 cycles
MCC	UL 845	3 cycles
Switchboard	UL 891	3 cycles
LV Switchgear	ANSI C37.50	30 cycles
MV Switchgear	ANSI C37.010	2 seconds

Consider the distribution system shown in Fig. 1. It is common in industry to find a MV main circuit breaker relay pickup set above the continuous current rating of the breaker, or to find a fuse sized above the switch amp rating. This practice is commonly done for selectivity reasons. However, this practice is misguided. It introduces a life safety problem in situations where the continuous load current is below the protective device trip setting, but above the equipment amp rating. Even though the equipment short circuit interrupting and withstand ratings are above fault duties, the distribution equipment is not rated to safely operate under these conditions.

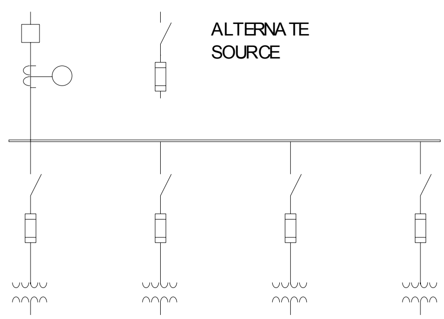


Fig. 1 – MV One Line Diagram

A second example of a life safety problem occurs when a main lug only panelboard, motor control center or switchboard is fed from a power circuit breaker, Fig. 2. In these situations it is common practice in industry to remove the instantaneous function from the power circuit breaker, again for selectivity reasons. In these situations, the downstream distribution equipment is required to endure a fault for much longer than the equipment rated short circuit duration time of 3 cycles.

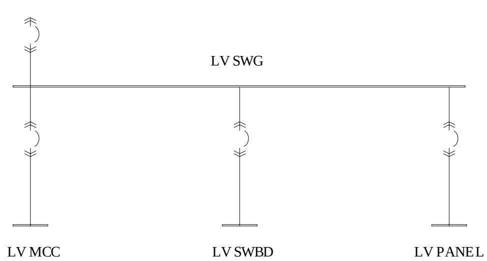


Fig. 2 – LV One Line Diagram

SECTION 3
EQUIPMENT PROTECTION REQUIREMENTS

A background in equipment damage characteristics is required to understand the basic principles of equipment protection. Time-current curve (TCC) landmarks and protection philosophies will be explored for feeders, capacitors, transformers, motors, generators, panelboards, motor control centers, LV switchgear and MV switchgear.

FEEDERS INCLUDING CABLES, CONDUCTORS & BUS DUCT

FEEDER TCC LANDMARKS

Feeder Ampacity (> 1-6 hours)

The ampacity is the rated continuous current carrying capacity of a conductor at a referenced ambient temperature and allowable temperature rise.

If a cable is loaded continuously above its rated ampacity the insulation temperature design limits will be exceeded. This will lead to loss of life not instantaneous failure. Table 2 summarizes cable temperature limits under short circuit, intermediate (emergency) overload, and normal operating conditions.

Table 2 – Operating Temperature Limits

Type	Voltage	Short Circuit	Emergency Overload	Normal
		0.01 < t < 10 sec.	10 sec. < t < 1-6 hrs	t > 1-6 hrs
TW	600V	150ºC	85ºC	60ºC
THWN	600V	150ºC	90ºC	75ºC
THHN	600V	150ºC	105ºC	90ºC
XLP	5-15kV	250ºC	130ºC	90ºC
EPR	5-15kV	250ºC	130ºC	90ºC

If a bare aerial conductor is loaded continuously above its rated ampacity the mechanical strength of the conductor is reduced. This will lead to loss of mechanical life and may result in instantaneous failure.

The ampacity landmark is located in the top decade of a TCC at 1000 seconds.

Feeder Intermediate Overload Limit Curve (from 10 seconds to 1-6 hours)

Conductor overcurrent (emergency) operating limit that if exceeded will damage the insulation of an insulated power conductor. This will lead to loss of life not instantaneous failure. Limit curves are based on the thermal inertia of the conductor, insulation and surrounding material, Tables 3 and 4. As a result, it can take from 1 to 6 hours for the temperature of a cable to stabilize after a change in load current, therefore, currents much greater than the rated ampacity of the cable can be supported for these time frames, see IEEE 242-2001 for more information.

Table 3 – Conductor K Factors

Cable Size	K Factors			
	Air		UG Duct	Direct Buried
	No Conduit	Conduit		
< #2 AWG	0.33	0.67	1.00	1.25
#2 - 4/0 AWG	1.00	1.50	2.50	3.00
> 4/0 AWG	1.50	2.50	4.00	6.00

Table 4 – Emergency Overload Current at 40°C Ambient

Time	Percent Overload					
Seconds	K=0.5	K=1	K=1.5	K=2.5	K=4	K=6
	EPR-XLP	T_N = 90°C		T_E = 130°C		
10	1136	1602	1963	2533	3200	3916
100	374	518	629	807	1018	1244
1000	160	195	226	277	339	407
10000	126	128	132	140	152	168
18000	126	127	128	131	137	147
	THH	T_N = 90°C		T_E = 105°C		
10	725	1020	1248	1610	2033	2487
100	250	338	407	518	651	794
1000	127	146	163	192	229	270
10000	111	112	114	118	124	131
18000	111	111	112	113	116	121
	THW	T_N = 75°C		T_E = 95°C		
10	987	1390	1703	2197	2275	3396
100	329	452	548	702	884	1080
1000	148	117	202	245	298	357
10000	121	123	125	132	142	154
18000	121	121	122	125	130	137

Feeder SC Damage Curve (0.01 to 10 seconds)

Ampere limit that if exceeded will damage the bare aerial conductor or the insulation of an insulated power conductor. Damage curves are plotted in the lower 3 decades of a TCC.

Bare Aerial Conductors

ACSR with an upper temperature limit of 645°C

$$t = (0.862 * A / I)^2 \quad (1)$$

where,

A = conductor area - cmils
I = short circuit current - RMS amps
t = time of short circuit – 0.01 to 20 seconds

Cables

Equations for cables consider all heat absorbed in the conductor metal with no heat transmitted from the conductor to the insulation. The temperature rise is a function of the size of the conductor, the magnitude of fault current and the duration of the fault.

Copper Cables

$$t = 0.0297 \log_{10}[(T_2+234)/(T_1+234)] (A/I)^2 \quad (2)$$

Aluminum Cables

$$t = 0.0125 \log_{10}[(T_2+228)/(T_1+228)] (A/I)^2 \quad (3)$$

where,

A = conductor area – cmils
I = short circuit current – RMS amps
t = time of short circuit – 0.01 to 10 seconds
T_1 = operating temperature, THWN-75°C
T_2 = maximum short circuit temperature, THWN-150°C

Feeder Damage Points

Segregated and Non-segregated Phase Bus Duct

Short circuit limit points for metal-enclosed non-segregated phase bus duct are defined at 10 cycles and 2 seconds, Table 5. The 10 cycle limit is expressed in RMS asymmetrical amperes. The 2 second limit is expressed in RMS symmetrical amperes, see ANSI C37.23.

Feeder & Plug-In Bus Duct

Short circuit limit points for feeder and plug-in duct are defined at 3 cycles, Table 6. The 3 cycle limit is expressed in RMS asymmetrical amperes, see UL 857.

Table 5 – Segregated and Non-segregated Phase Bus Duct Ratings

Voltage (kV)	2 Second Rating (kA – RMS Sym)	10 Cycle Rating (kA – RMS Asym)	0 Cycle Rating (kA – Peak)
0.625	22	28	51
	42	53	97
	65	81	150
	85	106	196
4.76	36	56	94
	49	76	128
8.25	41	64	107
15	23	36	60
	36	56	94
27	16	25	42
	25	39	65
38	16	25	42
	25	39	65
	31.5	49	83
	40	62	104

Table 6 – Feeder & Plug-In Bus Duct Ratings

Voltage (V)	3 Cycle Rating (kA – RMS Sym)	3 Cycle Rating (kA – Peak)
600	5	8.5
	7.5	13
	10	17
	14	28
	22	48
	25	55
	30	66
	35	76
	42	92
	50	110
	65	142
	75	160
	85	180
	100	220
	125	270
	150	330

FEEDER PROTECTION PHILOSOPHY

Step 1 – Identify TCC Landmarks

- Ampacity – located in the upper decade
- Intermediate Overload Curve – located in the upper 2 decades (typically not shown)
- Short Circuit Damage Curve – located in the bottom 3 decades

Step 2 – Identify TCC Areas

- Equipment Operating Area – located to the left and below the ampacity
- Equipment Damage Area – located to the right and above the intermediate overload and short circuit damage curves

Step 3 – Size and Set the Protective Device

- Set the protection device pickup at or below the ampacity
- Set the protection device characteristic curve below the intermediate overload and short circuit damage curves

Additional Comments

- If the maximum thru fault current penetrates the limits of the cable short circuit damage curve, insulation damage will occur.
- If the maximum thru fault current penetrates the limits of the conductor short circuit damage curve, conductor damage will occur.
- The thru fault current is defined as the maximum current that can flow for a short circuit located on or beyond the load-side feeder terminals.

Feeder Sample Problem

Calculate and plot the TCC landmarks for 3-1/C, 500MCM, THWN copper conductors installed in 2-1/2" conduit on a 480V distribution system. Then set a LV MCCB to protect the cable. The feeder breaker is a GE SG Spectra Series MCCB with a MVT Plus trip unit equipped with LSI adjustable functions. The maximum available through fault current is 21.5kA.

Solution

Step 1 – Identify TCC Landmarks

Ampacity – from NEC table 310.16 the ampacity = 380 A

Intermediate Overload Curve – from Tables 3 and 4

Time (sec.)	Current (%)	Current (A)
10	2197	380 x 21.71 = 8,348
100	702	380 x 7.02 = 2,667
1,000	245	380 x 2.45 = 931
10,000	132	380 x 1.32 = 501
18,000	125	380 x 1.25 = 475

Short Circuit Damage Curve - Damage points calculated from equation (2)

where,

A = 500,000 cmils
I = short circuit current – RMS amps
t = time of short circuit – 0.01 to 10 seconds
T_1 = 75°C (Table 2)
T_2 = 150°C (Table 2)

Time (sec.)	Current (A)
10.00	8,371
1.00	26,471
0.10	83,709
0.01	264,711

The cable TCC landmarks are plotted in Fig. 3.

Step 2 – Identify TCC Areas

The Equipment Operating Area is located to the left and below the ampacity as shown in Fig. 4.

The Equipment Damage Area is located to the right and above the intermediate overload and short circuit damage curves as shown in Fig. 4.

Step 3 – Size and Set the Protective Device

Set the breaker trip at or below the ampacity.

Set the breaker characteristic curve below the intermediate overload and short circuit damage curves as shown in Fig. 4.

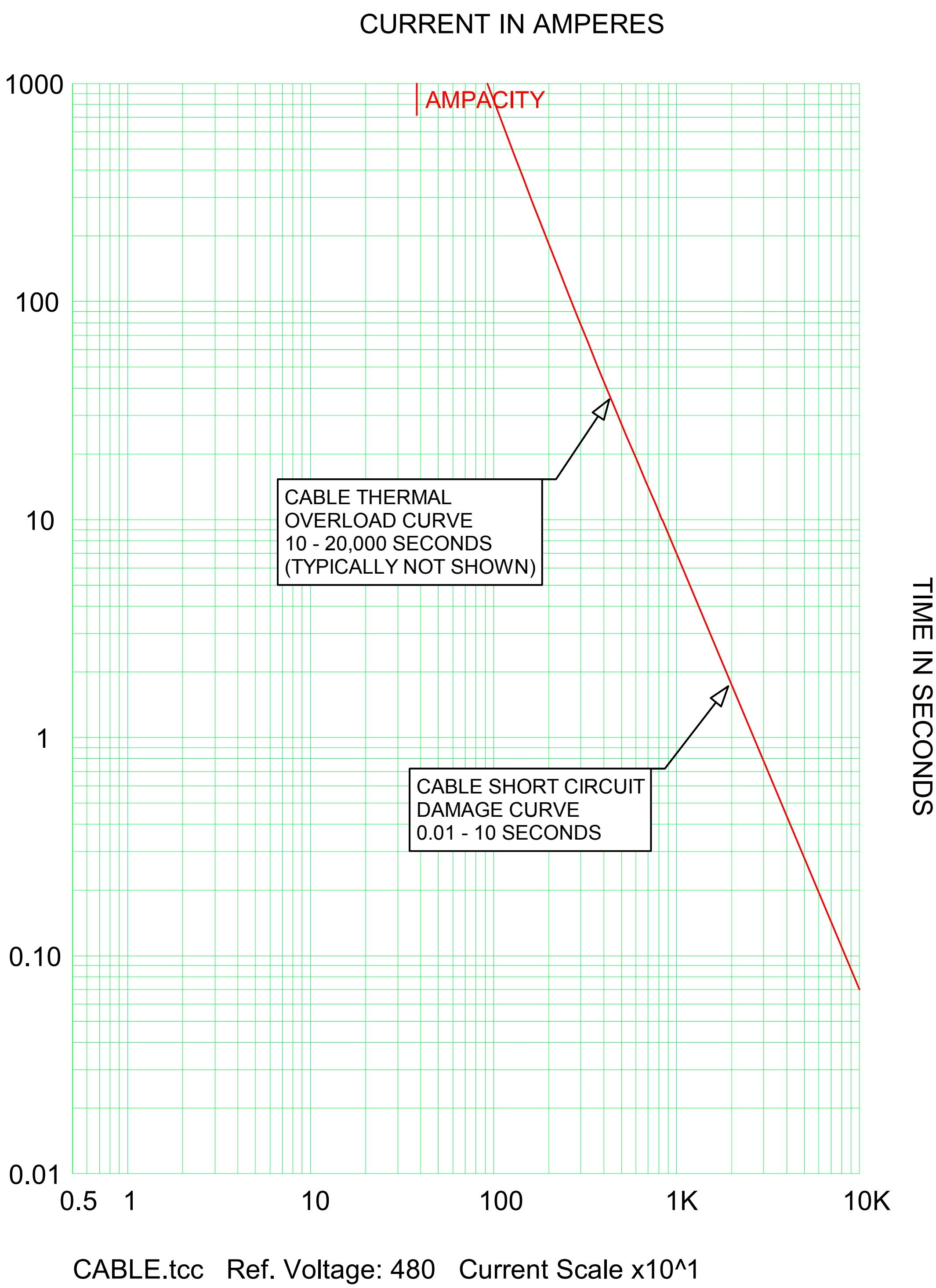


Fig. 3 – Cable TCC Landmarks

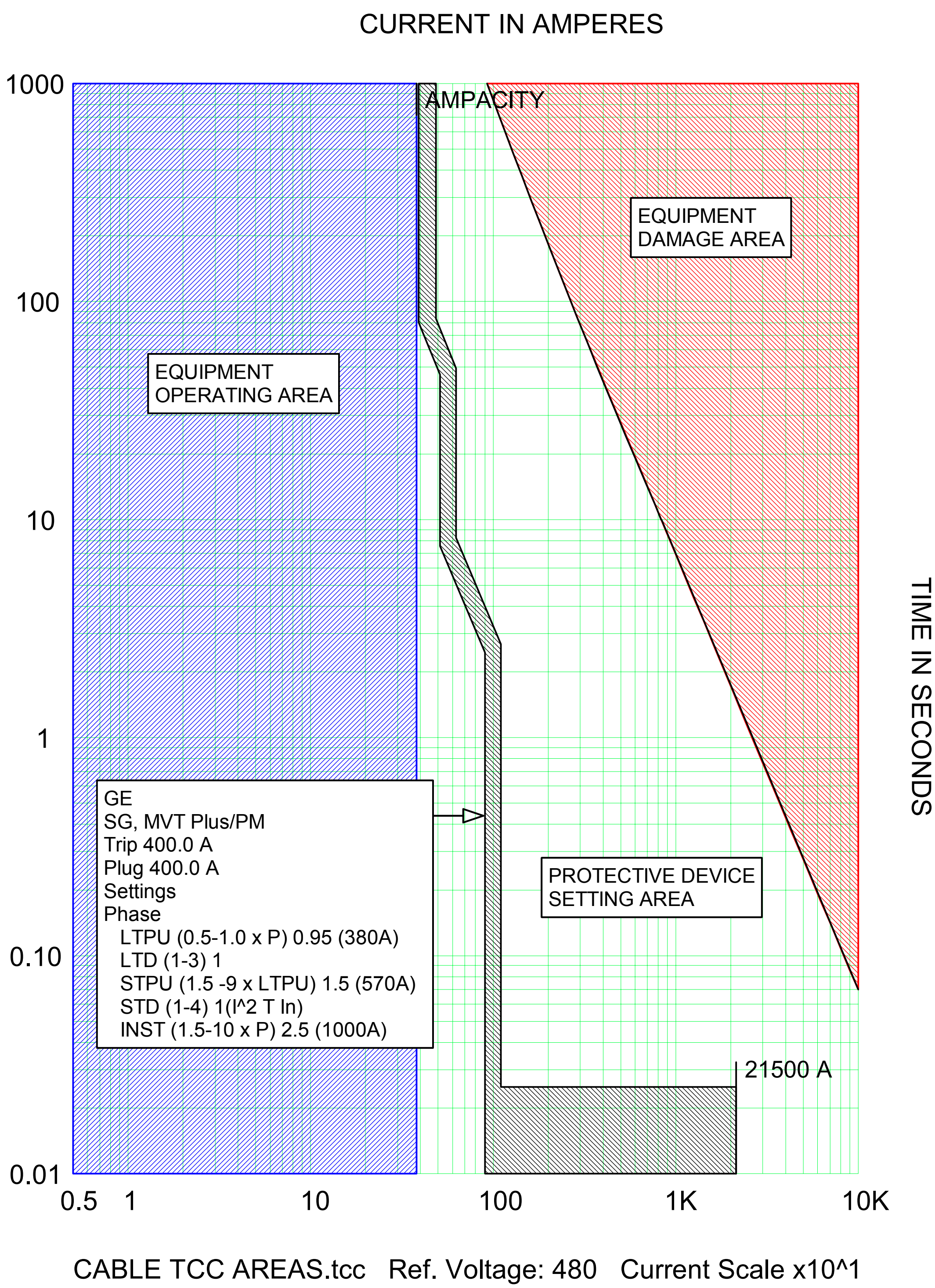


Fig. 4 – Cable TCC Areas

CAPACITORS

CAPACITOR TCC LANDMARKS

Capacitor Rated Current

The capacitor rated current represents the continuous current draw of the capacitor bank at rated power and voltage. The rated current landmark is located in the top decade of the TCC at 1000 seconds.

Capacitor Case Rupture Curve

The capacitor case rupture curve is a representation of the gas pressure limit from an internal arcing fault. If this limit is exceeded the enclosure will rupture. Protecting against case rupture will not save the capacitor bank from damage. The capacitor will need to be replaced. The purpose of protecting against a case rupture is to prevent spillage of insulating liquid and damage to adjacent equipment. Case rupture curves are plotted in all 5 decades of the TCC

CAPACITOR PROTECTION PHILOSOPHY

Step 1 – Identify TCC Landmarks

- Rated Current – located in the upper decade
- Case Rupture Curve – located in all 5 decades

Step 2 – Identify TCC Areas

- Equipment Operating Area – located to the left and below the full load amps
- Equipment Damage Area – located to the right and above the case rupture curve

Step 3 – Size and Set the Protective Device

- Size the protection above the rated current
- Set the protective device characteristic curve below the case rupture curve

Additional Comments

- If current from an internal arcing fault is allowed to penetrate the limits of the case rupture curve the capacitor enclosure will be damaged.

Capacitor Sample Problem

Plot the TCC landmarks for a 300kVAR, 4160V, 3-Ø capacitor bank. Then set a fuse to protect the capacitor.

Solution

Step 1 – Identify TCC Landmarks

Rated Current = 300kVAR / (√ 3 x 4.16kV) = 41.6A

Case Rupture Curve data points provided by the manufacturer.

Time (sec.)	Current (A)
2000	250
150	300
50	350
9	600
0.4	2,500
0.2	3,500
0.02	10,000

The capacitor TCC landmarks are plotted in Fig. 5.

Step 2 – Identify TCC Areas

The Equipment Operating Area is located to the left and below the full load amps as shown in Fig. 6.

The Equipment Damage Area is located to the right and above the rupture curve as shown in Fig. 6.

Step 3 – Size and Set the Protective Device

Size the fuse above the rated current.

The characteristic curve of the fuse must be below the rupture curve as shown in Fig. 6.

Fig. 5 – Capacitor TCC Landmarks

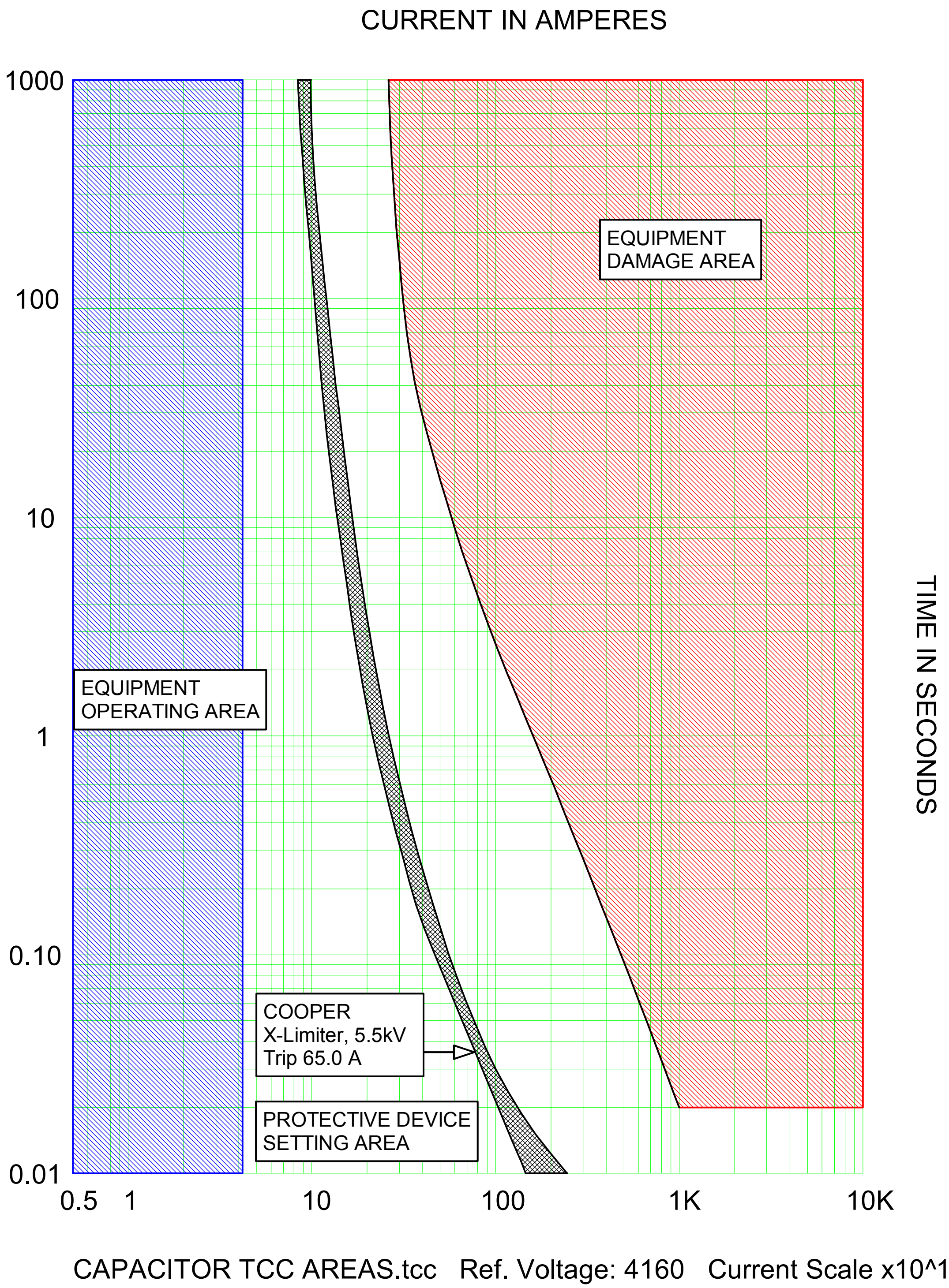


Fig. 6 – Capacitor TCC Areas

TRANSFORMERS

TRANSFORMER TCC LANDMARKS

Transformer Full Load Amps (FLA)

The FLA is the rated continuous current carrying capacity of a transformer at a referenced ambient temperature and allowable temperature rise, Table 7. Insulating materials are listed in Table 8 for information.

Table 7 – Transformer Temperature Ratings

Cooling Method	Ave/Max Amb. Temp.	Hot Spot Temp.	Temp. Rise	Total Temp. Rise	Insul. Temp.	Max. Winding SC Temp.
AA	30°C/40°C	15°C	75°C	120°C/130°C	130°C	300°C
		20°C	90°C	140°C/150°C	150°C	350°C
		25°C	115°C	170°C/180°C	180°C	400°C
		30°C	130°C	190°C/200°C	200°C	425°C
		30°C	150°C	210°C/220°C	220°C	450°C
OA	30°C/40°C	10°C	55°C	95°C/105°C	105°C	200°C-AL 250°C-CU
		15°C	65°C	110°C/120°C		

Note, the total temperature rise of an OA 65°C transformer, at a maximum ambient temperature of 40°C, is 120°C. This does exceed the transformer insulation rating of 105°C, and is allowed by ANSI.

The FLA label is located on the TCC in top decade at 1000 seconds. The FLA label is shown on the base (lowest kVA) rating of the transformer.

Table 8 – Insulating Materials

Insulation Class	Maximum Temperature	Insulating Materials
Y	90°C	Cotton, silk, paper, wood, cellulose, fibre without impregnation or oil-immersion
A	105°C	Class Y impregnated with natural resins, cellulose esters, insulating oils, etc., also laminated wood, varnished paper
Hybrid A	110°C	Insuldur® Insulation, Kraft paper with epoxy binders activated under pressure
E	120°C	Synthetic-resin enamels, cotton and paper Laminates with formaldehyde bonding
B	130°C	Mica, glass fibre, asbestos, etc., with suitable bonding substance; built-up mica, glass-fibre and asbestos laminates
F	155°C	The materials of Class B with more thermally-resistant bonding materials
H	180°C	Glass-fibre and asbestos materials, and built-up mica, with appropriate Silicone resins
C	>180°C	Mica, ceramics, glass, quartz, and asbestos without binders or with silicone resins of superior thermal stability
Hybrid H	220°C	NOMEX® insulation, varnish dipped and vacuum pressure impregnated (VPI)

Transformer Through-Fault Damage Curve

Liquid-Immersed Transformers

IEEE C57.109-1993 defines thermal and mechanical through-fault damage curves for liquid-immersed transformers, Tables 9-12. The standard states,

> *"if fault current penetrates the limits of the thermal damage curve transformer insulation may be damaged. If fault current penetrates the limits of the mechanical damage curve cumulative mechanical damage may occur. The validity of these damage limit curves cannot be demonstrated by test, since the effects are progressive over the transformer lifetime. They are based principally on informed engineering judgment and favorable, historical field experience."*

Through-fault damage curves are plotted in the top 3 decades of a TCC from 2 to 1000 seconds.

Table 9 – Category I Transformers
5 to 500 kVA single-phase
15 to 500 three-phase

Frequent or Infrequent Faults		
Time (sec.)	Current (A p.u.)	I^2T
1800	2	7200
300	3	2700
60	4.75	1354
30	6.3	1192
10	11.3	1277
2	25	1250
1.02	35 (1, 2)	1250
0.78	40 (2)	1250

1. Applies only to 37.5-100 kVA 1Ø and 112.5-300 kVA 3Ø transformers.
2. Applies only to 37.5-100 kVA 1Ø and 112.5-300 kVA 3Ø transformers.

Table 10 – Category II Transformers
501 to 1667 kVA single-phase
501 to 5000 three-phase

Frequent or Infrequent Faults		
Time (sec.)	Current (A p.u.)	I^2T
1800	2	7200
300	3	2700
60	4.75	1354
30	6.3	1192
10	11.3	1277
2	25	1250
Points for Frequent Fault Curve (Dog leg)		
$2551\ Z(p.u.)^2$	$0.7 / Z(p.u.)$	1250
4.08	$0.7 / Z(p.u.)$	$2 / Z(p.u.)^2$
2	$1 / Z(p.u.)$	$2 / Z(p.u.)^2$

Table 11 – Category III Transformers
1668 to 10 000 kVA single-phase
5001to 30 000 three-phase

Frequent or Infrequent Faults		
Time (sec.)	Current (A p.u.)	I^2T
1800	2	7200
300	3	2700
60	4.75	1354
30	6.3	1192
10	11.3	1277
2	25	1250
Points for Frequent Fault Curve (Dog leg)		
5000 $Z(p.u.)^2$	0.5 / Z(p.u.)	1250
8	0.5 / Z(p.u.)	2 / $Z(p.u.)^2$
2	1 / Z(p.u.)	2 / $Z(p.u.)^2$

Table 12 – Category IV Transformers
Above 10 000 kVA single-phase
Above 30 000 three-phase

Frequent or Infrequent Faults		
Time (sec.)	Current (A p.u.)	I^2T
1800	2	7200
300	3	2700
60	4.75	1354
30	6.3	1192
10	11.3	1277
2	25	1250
Frequent or Infrequent Fault Curve (Dog leg)		
5000 $Z(p.u.)^2$	0.5 / Z(p.u.)	1250
8	0.5 / Z(p.u.)	2 / $Z(p.u.)^2$
2	1 / Z(p.u.)	2 / $Z(p.u.)^2$

Dry-Type Transformers

IEEE C57.12.59-2001 defines thermal and mechanical through-fault damage curves for dry-type transformers, Tables 13 and 14.

Table 13 – Category I Transformers
1 to 500 kVA single-phase
15 to 500 three-phase

Frequent or Infrequent Faults		
Time (sec.)	Current (A p.u.)	I^2T
100	3.5	1250
10	11.2	1250
2	25	1250

Table 14 – Category II Transformers
501 to 1667 kVA single-phase
501 to 5000 three-phase

Frequent or Infrequent Faults		
Time (sec.)	Current (A p.u.)	I^2T
100	3.5	1250
10	11.2	1250
2	25	1250
Points for Frequent Fault Curve (Dog leg)		
$2551\ Z(p.u.)^2$	$0.7 / Z(p.u.)$	1250
4.08	$0.7 / Z(p.u.)$	$2 / Z(p.u.)^2$
2	$1 / Z(p.u.)$	$2 / Z(p.u.)^2$

Magnetizing Inrush Current Point(s)

One or more inrush current points may be plotted on a TCC. Inrush currents are expressed in peak amperes. The most common point is 12 times rated FLA at 0.1 seconds.

Another less common point is 25 times rated FLA at 0.01 seconds. This point is commonly used when applying fuses.

TRANSFORMER PROTECTION PHILOSOPHY

Step 1 – Identify TCC Landmarks (all based on the nominal kVA rating)

- Full Load Amps – located in the upper decade
- Thermal Damage Curve – located in the upper 3 decades
- Mechanical Damage Curve – located in the middle decade
- Inrush point defined @ 12 x FLA and 0.1 seconds
- Inrush point defined @ 25 x FLA and 0.01 seconds (Fuse applications only)

Step 2 – Identify TCC Areas

- Equipment Operating Area – located to the left and below the full load amps and inrush points
- Equipment Damage Area – located to the right and above the through-fault damage curves

Step 3 – Size and Set Protective Device

- Set the protection above the full load amps and inrush point(s)
- Set protection below the through-fault damage curves

Additional Comments

- If current penetrates the limits of the thermal damage curve, insulation damage may occur.
- If current penetrates the limits of the mechanical damage curve, cumulative mechanical damage may occur.

Transformer Sample Problem

Plot the TCC landmarks for a 1000kVA, OA, 4160-480V, Δ-YG, 5% impedance, substation type transformer. Then set a relay to protect the transformer.

Solution

Step 1 – Identify the TCC Landmarks

FLA = 1000kVA / (√ 3 4.16kV) = 139A

Through-fault damage curve data points calculated from Table 10. These points apply to the low-voltage, wye-connected winding.

Time (sec.)	Current (A p.u.)	Current (A)
1800	2	278
300	3	417
60	4.75	660
30	6.3	876
10	11.3	1571
2	25	3475
Points for Frequent Fault Curve (Dog leg)		
6.4	14	1946
4.08	14	1946
2	20	2780

A second set of data points is required because a fuse or relay on the delta-side of a Δ-YG connected transformer, will only detect 58% of a line-to-ground fault located on the wye-side. To account for this the current data points calculated above are adjusted by 0.58 for the delta winding.

Time (sec.)	Current (A p.u.)	Current (A)
1800	2 x 0.58 = 1.16	278 x 0.58 = 161
300	3 x 0.58 = 1.74	417 x 0.58 = 242
60	4.75 x 0.58 = 2.755	660 x 0.58 = 383
30	6.3 x 0.58 = 3.654	876 x 0.58 = 508
10	11.3 x 0.58 = 6.554	1571 x 0.58 = 911
2	25 x 0.58 = 14.5	3475 x 0.58 = 2016
Points for Frequent Fault Curve (Dog leg)		
6.4	14 x 0.58 = 8.12	1946 x 0.58 = 1129
4.08	14 x 0.58 = 8.12	1946 x 0.58 = 1129
2	20 x 0.58 = 11.6	2780 x 0.58 = 1612

Magnetizing Inrush Current Points

12 x FLA = 12 x 139A = 1668A @ 0.1 seconds

25 x FLA = 25 x 139A = 3475A @ 0.1 seconds

The TCC landmarks are plotted in Fig. 7.

Step 2 – Identify TCC Areas

The Equipment Operating Area is located to the left and below the FLA and inrush points, Fig. 8.

The Equipment Damage Area is located to the right and above the through-fault damage curves, Fig. 8.

Step 3 – Size and Set the Protective Device

Set the relay pickup above the FLA.

Set the relay characteristic curve above the inrush points and below the through-fault damage curves as shown in Fig. 8.

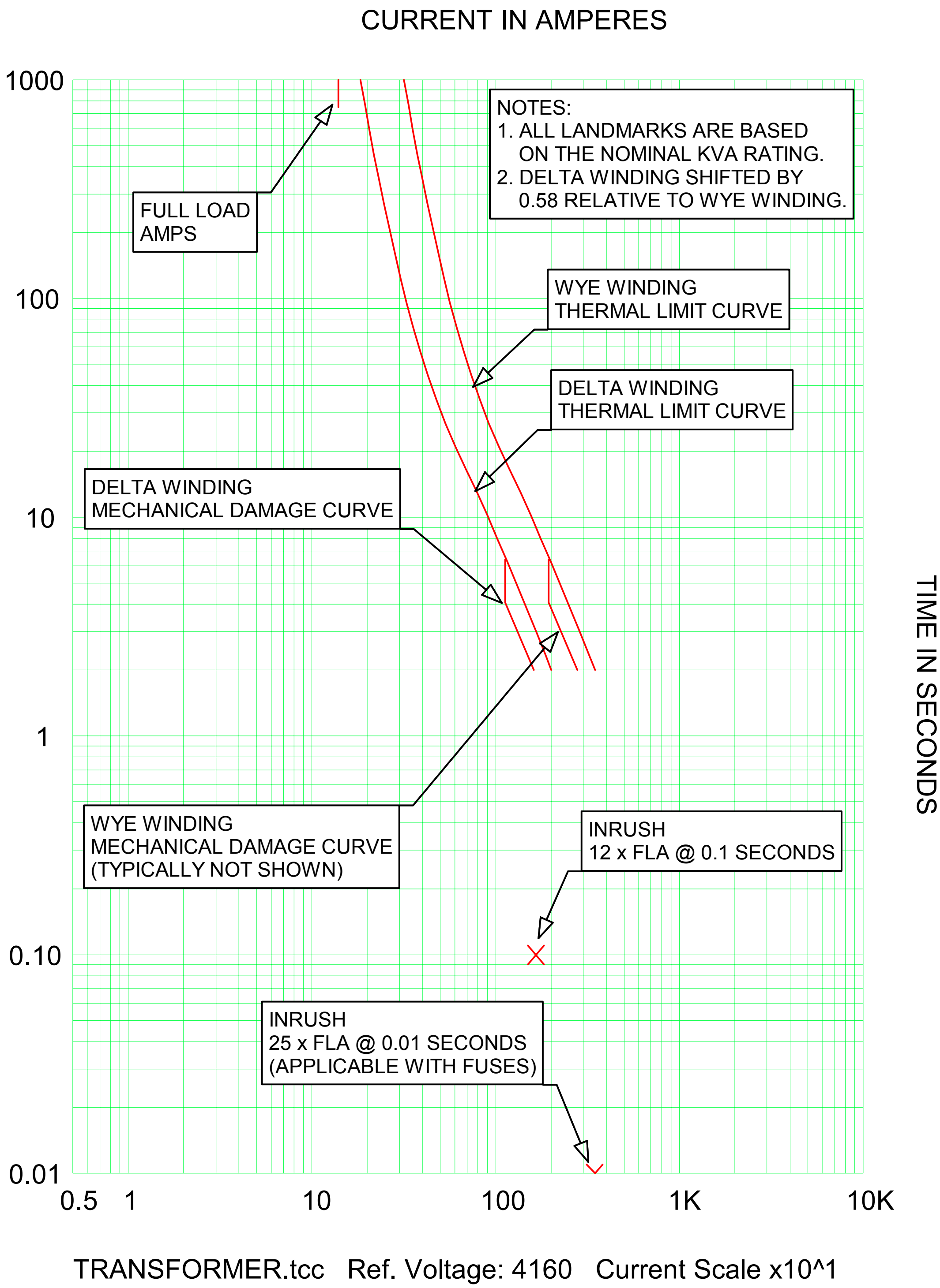


Fig. 7 – Transformer TCC Landmarks

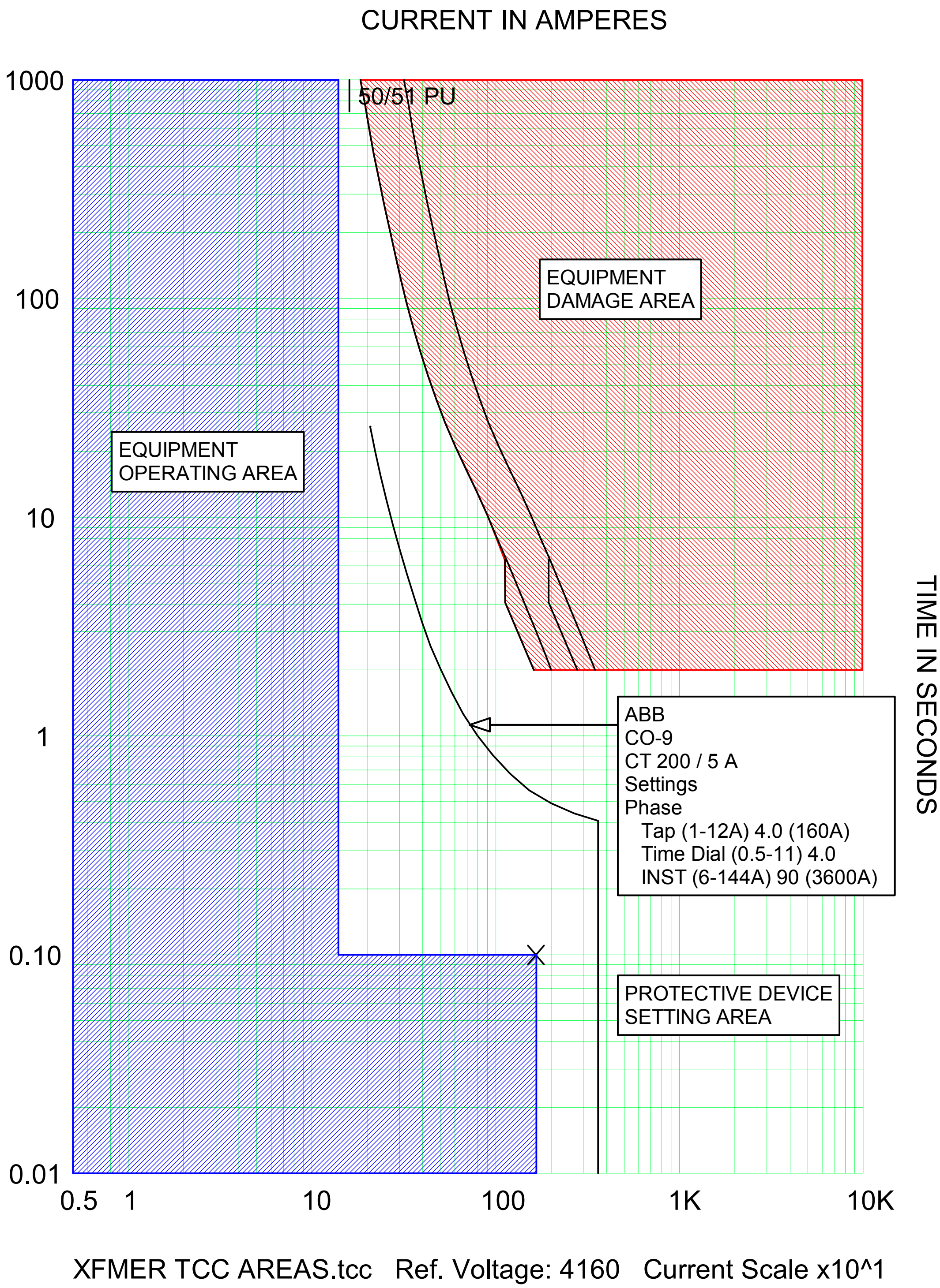


Fig. 8 – Transformer TCC Areas

MOTORS

MOTOR TCC LANDMARKS

Motor FLA

The motor FLA is the rated continuous current carrying capacity of a motor at a referenced ambient temperature and allowable temperature rise, Table 15.

Table 15 – Motor Temperature Ratings

Max Amb. Temp.	Hot Spot Temp.	Temp. Rise	Temp. Rise	Total Temp. Rise	Insul. System	Insul. Temp. Rating
40°C	5°C	Class A	60°C	105°C	Class A	105°C
40°C	10°C	Class B	80°C	130°C	Class B	130°C
40°C	10°C	Class B	80°C	130°C	Class F	155°C (1)
40°C	10°C	Class F	105°C	155°C	Class F	155°C
40°C	15°C	Class F	105°C	160°C	Class H	180°C (2)
40°C	15°C	Class H	125°C	180°C	Class H	180°C

1. Many existing machines are built with Class F insulation systems with nameplates based on Class B temperature rises.
2. Newer machines are trending towards Class H insulation systems with nameplates based on Class F temperature rises.

Motor Starting Curve

The motor starting curve represents the machine accelerating characteristic for a specific starting condition defined by the motor, driven equipment, starter and power source characteristics.

Motor Running Overload Thermal Limit Curve (Typical of MV Motors)

The running overload curve represents the stator thermal capability from rated full load current back to the current drawn at breakdown torque while the motor is running. This curve should never be used to approximate the continuous overload capability of a motor. Operation up to and beyond the limits of this overload curve will reduce insulation life.

Motor Accelerating Thermal Limit Curve (Typical of MV Motors)

The accelerating thermal limit curve represents the rotor thermal capability during acceleration from locked rotor up to the breakdown torque for a specified terminal voltage. These curves are typically not provided since they reside above the locked rotor thermal limit curve.

Motor Safe Stall Point (Typical of LV Motors)

The safe stall point represents the maximum time a motor can sustain a locked rotor condition without damage at a specified terminal voltage. NEMA MG-1 requires safe stall times not less than 12 seconds for motors less than 500HP and 1000V.

Motor Locked Rotor Thermal Limit Curve (Typical of MV Motors)

The locked rotor thermal limit curve represents the maximum time a motor can sustain a locked rotor condition without damage for a given set of terminal voltages.

MOTOR PROTECTION PHILOSOPHY

Step 1 – Identify TCC Landmarks

- Full Load Amps – located in the upper decade
- Motor Starting Curve – located in all 5 decades
- Rotor Safe Stall Point – located in the upper middle decades (Typical of LV motors)
- Stator Damage Curve – located in the upper decade (Typical of MV motors)
- Rotor Damage Curve – located in the middle decades (Typical of MV motors)

Step 2 – Identify TCC Areas

- Equipment Operating Area – located to the left and below the motor starting curve
- Equipment Damage Area – located to the right and above the safe stall point for LV motors, or the running overload and locked rotor thermal limit curves for MV motors

Step 3 – Size and Set Protective Devices

- Set protection above the full load amps and motor starting curve
- Set protection below the hot stall point for LV motors, or the running overload and locked rotor thermal limit curve for MV motors

Additional Comments

- If a motor operates above the limits of the running overload thermal limit curve, stator insulation life is reduced.
- If a LV motor is allowed to operate at locked rotor for a time above the hot stall point, rotor damage will occur.
- If a MV motor is allowed to operate at locked rotor for a time above the locked rotor thermal limit curve, rotor damage will occur.

LV Motor Sample Problem

Plot the TCC landmarks for a NEMA 100HP, 460V, 124A, 1800rpm, 1.15 SF induction motor with a safe stall time of 32 seconds. Then set an overload-MCP FVNR combination starter unit to protect the motor. The maximum available fault duty at the motor terminal box is 25kA.

Solution

Step 1 – Identify the TCC Landmarks

FLA = 124A

Motor starting curve was assumed. The starting time was set to 6 seconds and the LRA to 6 x FLA.

The safe stall time is 32 seconds.

The TCC landmarks are plotted in Fig. 9.

Step 2 – Identify TCC Areas

The Equipment Operating Area is located to the left and below the motor starting curve, Fig. 10.

The Equipment Damage Area is located to the right and above the safe stall point, Fig. 10.

Step 3 – Size and Set the Protective Device

Size the overload pickup above the motor FLA and below the rotor safe stall point.

Set the MCP characteristic curve above the motor starting curve, Fig. 10.

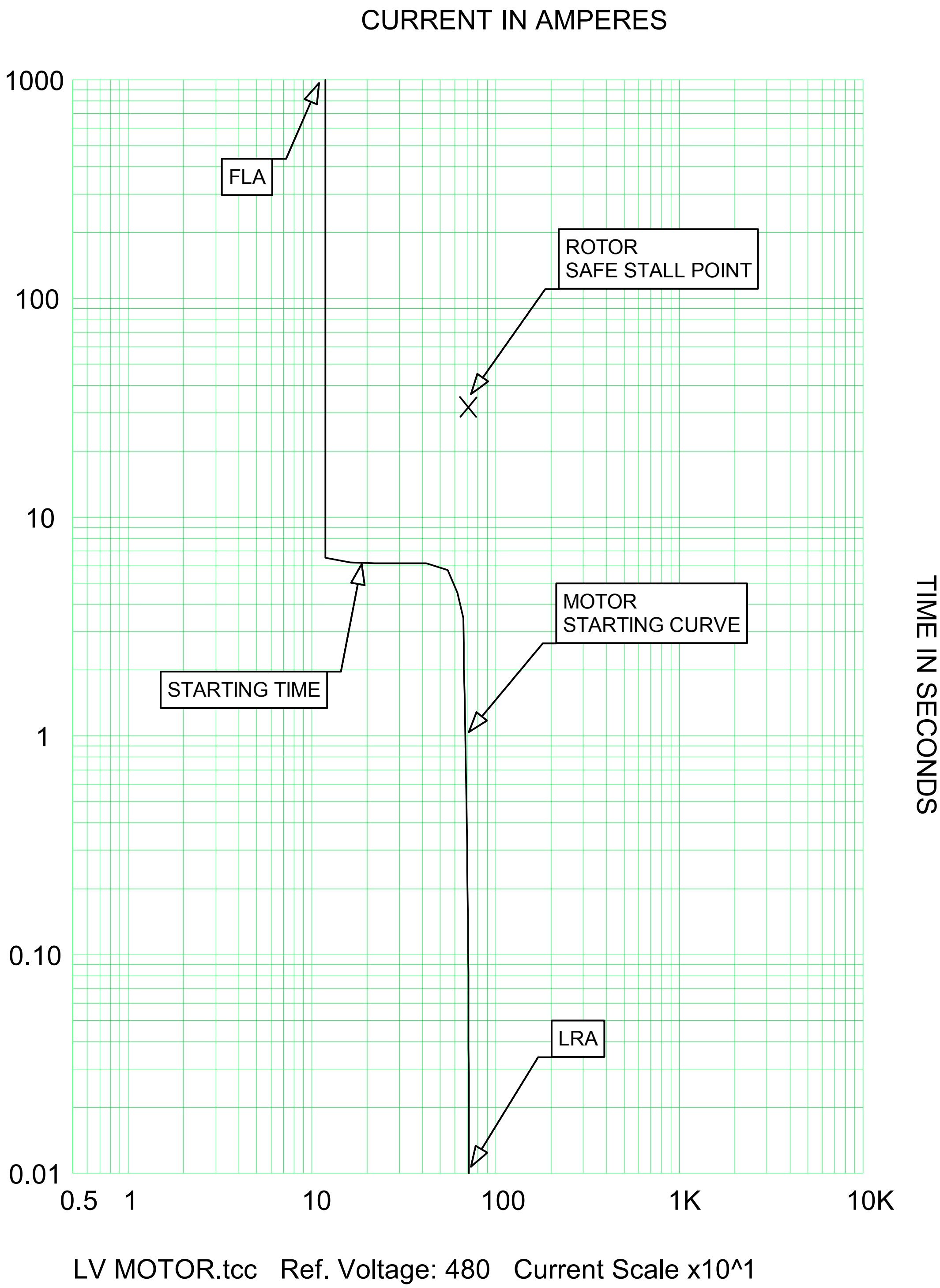


Fig. 9 – LV Motor TCC Landmarks

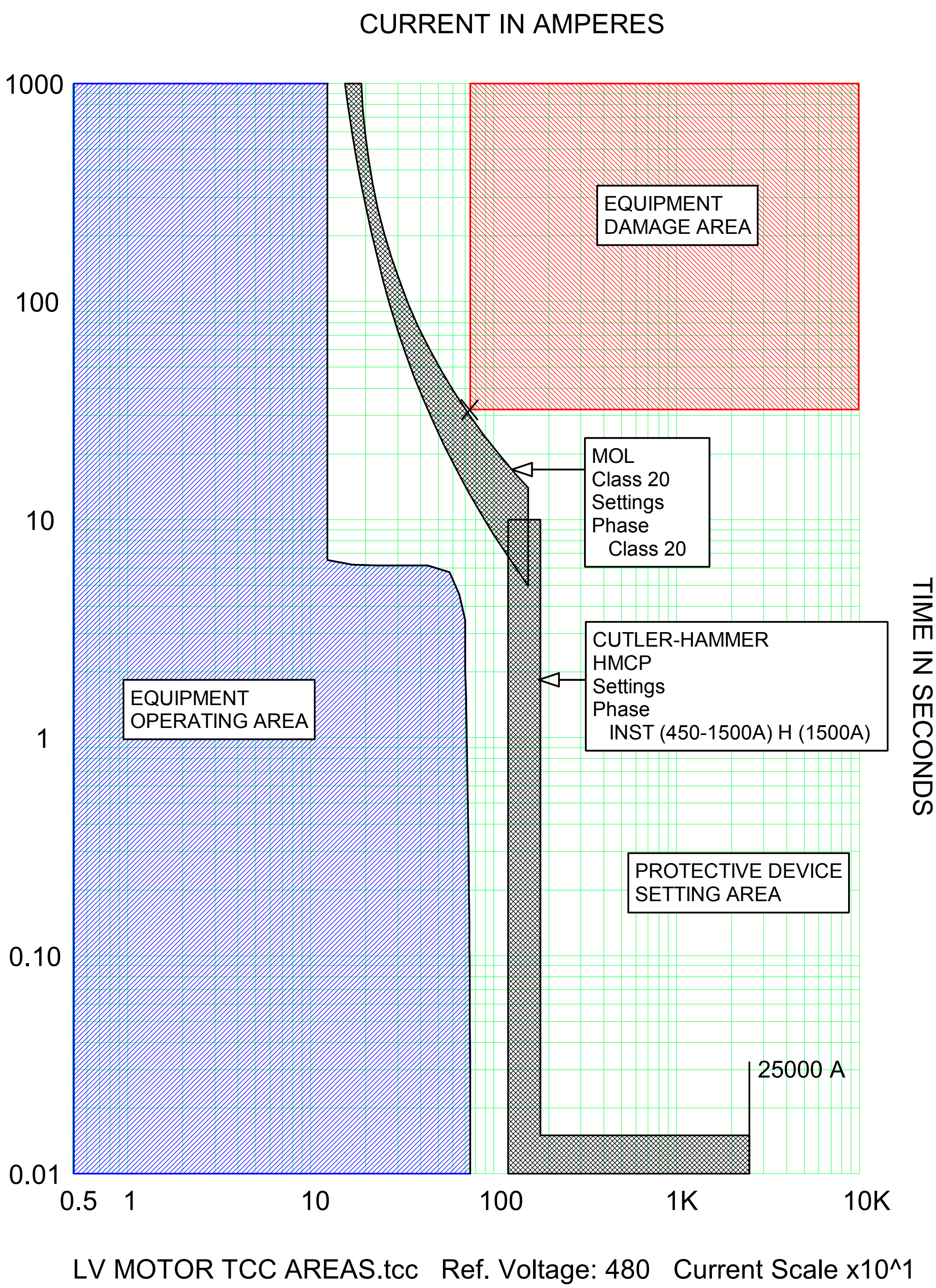


Fig. 10 – LV Motor TCC Areas

MV Motor Sample Problem

Plot the TCC landmarks for a NEMA 1500HP, 4000V, 187A, 1800rpm, 1.0 SF induction motor. Then set a relay to protect the motor. The maximum available fault duty at the motor terminal box is 18kA.

Solution

Step 1 – Identify the TCC Landmarks

FLA = 187A

The motor starting curve was determined from a motor starting study. The results are listed below.

Current (A p.u.)	Time (sec.)
3.0	11.7
4.1	11.3
4.5	7.6
4.6	4.6
4.7	2.2
4.8	0.0

The running overload thermal limit curve was provided by the manufacturer.

Current (A p.u.)	Time (sec.)
1.4	510.0
2.0	180.0
3.3	53.0

The locked rotor thermal limit curve was also provided by the manufacturer.

Current (A p.u.)	Time (sec.)
4.4	16.0
5.0	12.5
5.6	10.0

The TCC landmarks are plotted in Fig. 11.

Step 2 – Identify TCC Areas

The Equipment Operating Area is located to the left and below the motor starting curve, Fig. 12.

The Equipment Damage Area is located to the right and above the running overload and locked rotor thermal limit curves, Fig. 12.

Step 3 – Size and Set the Protective Device

Set the relay pickup above the motor FLA.

Set the relay characteristic curve above the motor starting curve and below the running overload and locked rotor thermal limit curves, Fig. 12.

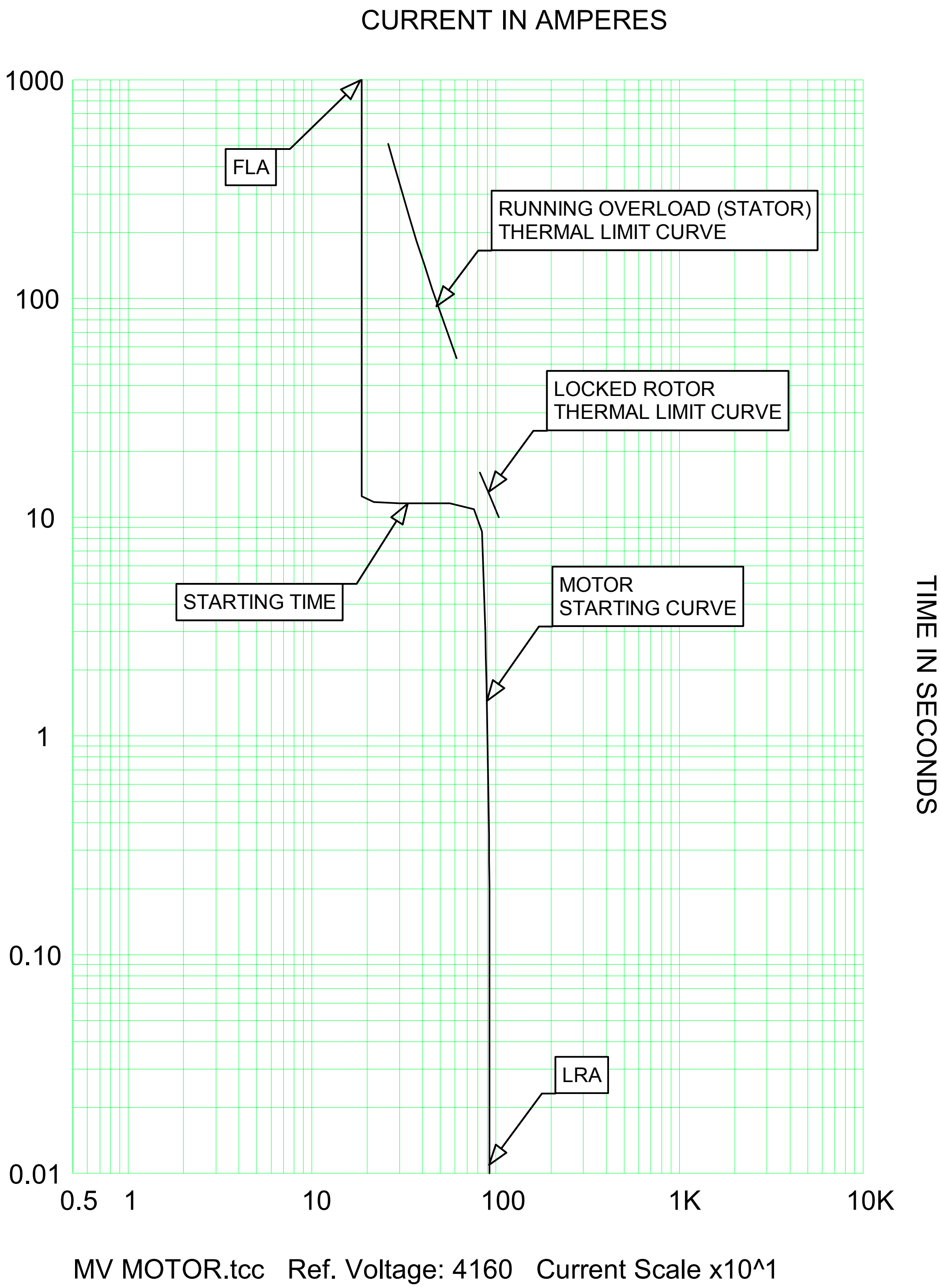


Fig. 11 – MV Motor TCC Landmarks

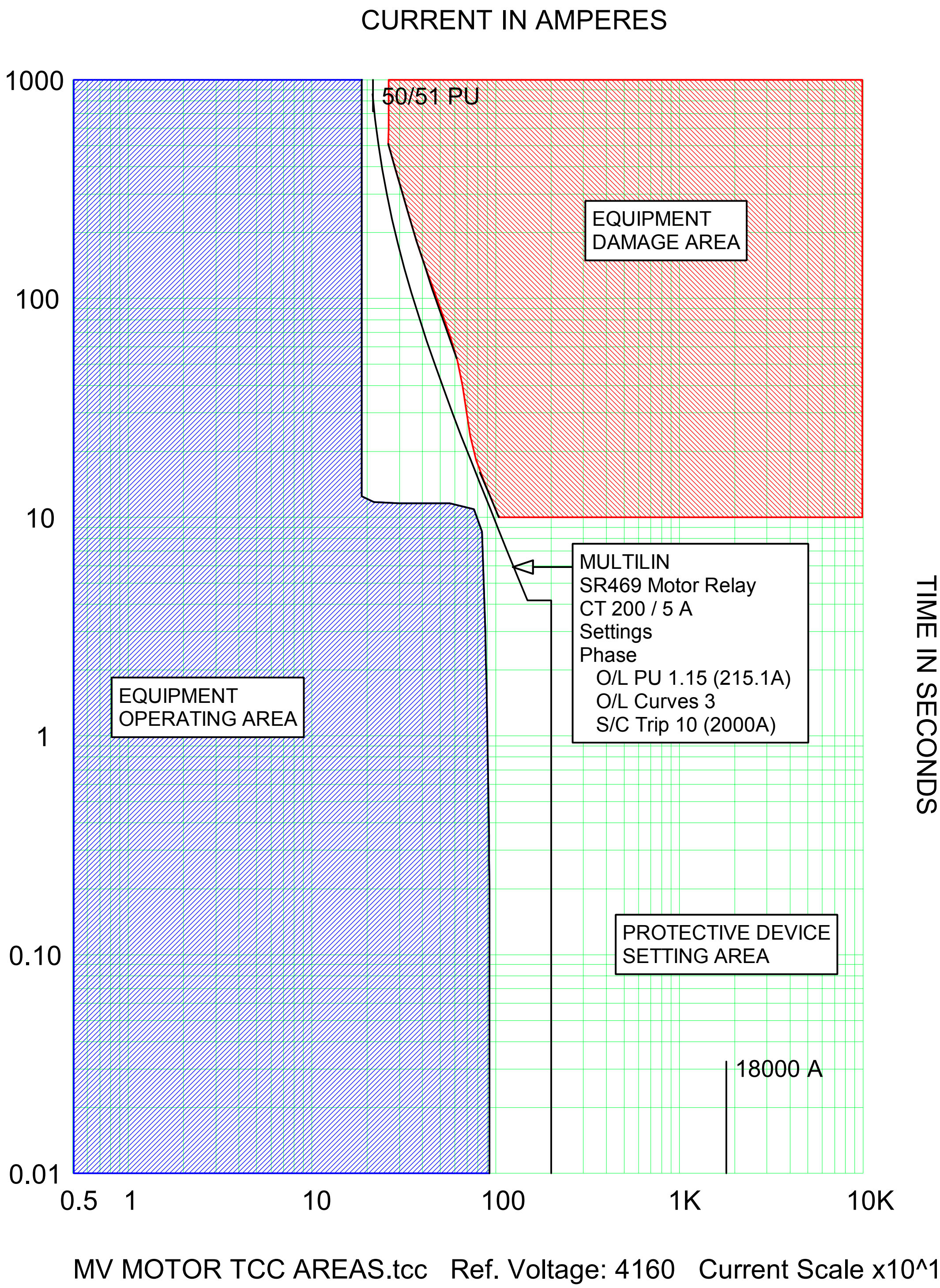


Fig. 12 – MV Motor TCC Areas

GENERATORS

GENERATOR TCC LANDMARKS

Generator FLA

The FLA is the rated continuous current carrying capacity of a generator at a referenced ambient temperature and allowable temperature rise, Table 16.

Table 16 – Generator Temperature Ratings

Max Amb. Temp.	Hot Spot Temp.	Temp. Rise	Temp. Rise	Total Temp. Rise	Insul. Temp.	Insul. Temp.
40°C	5°C	Class A	60°C	105°C	Class A	105°C
40°C	10°C	Class B	80°C	130°C	Class B	130°C
40°C	10°C	Class B	80°C	130°C	Class F	155°C
40°C	10°C	Class F	105°C	155°C	Class F	155°C
40°C	15°C	Class F	105°C	160°C	Class H	180°C
40°C	15°C	Class H	125°C	180°C	Class H	180°C

Generator Overload Curve

The overload curve is the rated continuous output capability of a generator at a specified frequency, voltage, power factor and cooling basis temperature, i.e., hydrogen-cooled machine rating based on a referenced hydrogen pressure, or a combustion-turbine machine rating based on a referenced inlet air temperature.

Under emergency conditions it is permissible to exceed the continuous rating of a generator. The overload capability of the armature winding of cylindrical-rotor, synchronous generator as defined in ANSI C50.13-1989 is listed in Table 17.

Table 17 – Generator Overload Capability

% Current	Time (sec.)
116	120
130	60
154	30
226	10

Generator Decrement Curve

The current response of a generator with a fault at its terminals is described using equations (4) through (9).

$$i_{ac} = (i_d'' - i_d')\, e^{-t/T_d''} + (i_d' - i_d)\, e^{-t/T_d'} + i_d \quad (4)$$

$$i_{dc} = \sqrt{2}\, i_d''\, e^{-t/T_A''} \quad (5)$$

$$i_{total} = (i_{ac}^2 + i_{dc}^2)^{0.5} \quad (6)$$

assuming the machine is at no load:

$$i_d'' = e_t / X_d'' \quad (7)$$

$$i_d' = e_t / X_d' \quad (8)$$

$$i_d = e_t / X_d\, (I_f / I_{fg}) \quad (9)$$

Generator Short Circuit Capability

ANSI C50.13-1989 states a generator shall be capable of withstanding any type of fault at its terminals without damage for times not exceeding the short-time limits when operated at rated KVA and power factor and at 5 percent overvoltage. Provided that the maximum phase current is limited by external means to a value that does not exceed the maximum phase current of a three-phase fault.

ANSI C50.12-1982 states a generator shall be capable of withstanding a three-phase terminal fault without damage for 30-seconds when operated at rated KVA and power factor and at 5 percent overvoltage, with fixed excitation. Again, provided that the maximum phase current is limited by external means to a value that does not exceed the maximum phase current of a three-phase fault, and provided that the I_2^2t limit $\leq$ 40.

LV GENERATOR PROTECTION PHILOSOPHY

Step 1 – Identify TCC Landmarks

- Full Load Amps – located in the upper decade
- Overload Curve – located in the upper 1 or 2 decades
- Decrement Curve – located in the bottom 3 decades

Step 2 – Identify TCC Areas

- Equipment Operating Area – located to the left and below the full load amps and to the left and below the decrement curve in the instantaneous region
- Equipment Damage Area – located to the right and above the overload curve

Step 3 – Size and Set Protection Devices

- Set protection above the full load amps and above the decrement curve in the lowest decade.
- Set protection below the overload curve.
- Set protection to intersect with the decrement curve in the second lowest decade.

Additional Comments

- If current penetrates the limits of the overload curve, stator insulation life is reduced.
- If protection is set above the decrement curve, the device will never trip.

LV Generator Sample Problem

Plot the TCC landmarks for a 750kVA, 480V, 902A, 0.8 pf lag diesel engine-generator with $X_d'' = 0.107$, $X_d' = 0.154$, $X_d = 1.54$, $T_d'' = 0.015$, $T_d' = 0.417$ and $T_A = 0.189$. The generator is capable of sustaining a three-phase short circuit at 3 times rated current for 5 seconds. Then set a circuit breaker to protect the generator.

Solution

Step 1 – Identify the TCC Landmarks

FLA = 902A

The overload curve was provided by the manufacturer.

Time (sec.)	Current (A p.u.)
1000	1.4
600	1.5
420	1.6
180	2.0

The decrement curve was calculated using equation (4).

t (sec.)	i_{dc} (A p.u.)	i_{ac} (A p.u.)	i_{total} (A p.u.)
0.01	13.5	7.5	15.4
0.02	12.8	6.6	14.4
0.03	12.2	6.2	13.7
0.04	11.6	6.0	13.0
0.05	11.0	5.9	12.5
0.10	8.6	5.5	10.2
0.30	3.2	4.5	5.5
0.50	1.2	3.9	4.1
0.70	0.4	3.6	3.6
0.90	0.2	3.3	3.3
1.00	0.1	3.3	3.3
1.50	0.0	3.1	3.1
2.00	0.0	3.0	3.0
2.50	0.0	3.0	3.0
3.00	0.0	3.0	3.0
3.50	0.0	3.0	3.0
4.00	0.0	3.0	3.0
4.50	0.0	3.0	3.0
5.00	0.0	3.0	3.0

The TCC landmarks are plotted in Fig. 13.

Step 2 – Identify TCC Areas

The Equipment Operating Area is located to the left and below the FLA and the decrement curve in the lowest decade, Fig. 14.

The Equipment Damage Area is located to the right and above the overload curve, Fig. 14.

Step 3 – Size and Set the Protective Device

Set the overload pickup above the generator FLA.

Set the breaker characteristic curve below the overload curve and above the decrement curve in the lowest decade, Fig. 14.

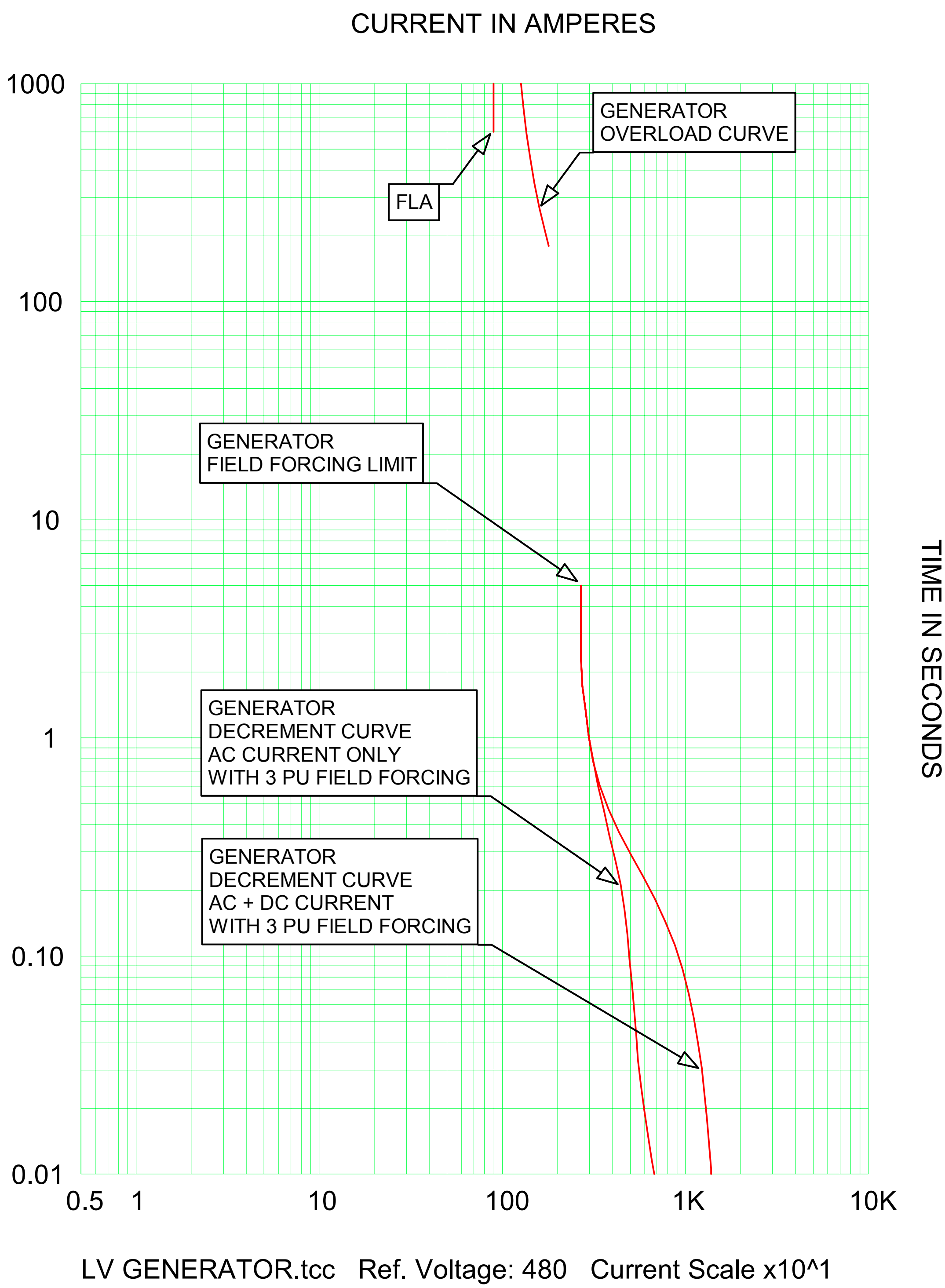


Fig. 13 – LV Generator TCC Landmarks

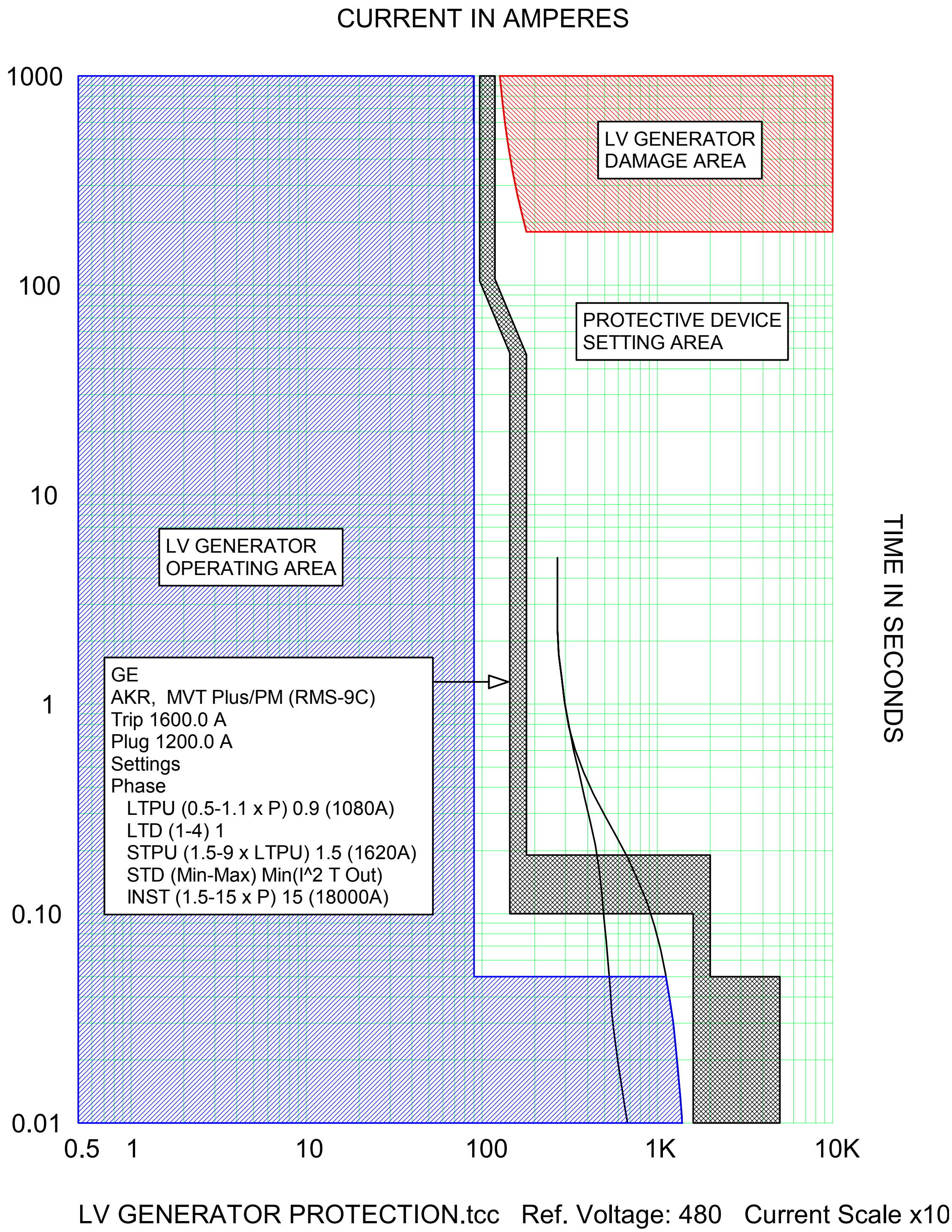


Fig. 14 – LV Generator TCC Areas

LV EQUIPMENT INCLUDING PANELBOARDS, MCCS, SWITCHBOARDS & SWITCHGEAR

LV EQUIPMENT TCC LANDMARKS

Ampacity

The ampacity is the rated continuous current carrying capacity of the equipment at a referenced ambient temperature.

Short Circuit Withstand Capability

Panelboards, MCCs and switchboards are tested to withstand their short circuit current rating for 3 cycles per UL 67, UL 845 and UL 891.

However UL 489, the LV molded-case circuit breaker standard, does not require breakers installed in this type of equipment to clear faults within 3 cycles! This represents a hole in the UL standards. Therefore, it is the specifying engineer's responsibility to confirm that breakers protecting panelboards, MCCs or switchboards have maximum instantaneous clearing times of 3 cycles or less.

LV switchgear and power circuit breakers are tested to withstand their short circuit current rating for 30 cycles.

LV EQUIPMENT PROTECTION PHILOSOPHY

Step 1 – Identify TCC Landmarks

- Ampacity – located in the upper decade
- SC Withstand Point – located in the bottom two decades

Step 2 – Identify TCC Areas

- Equipment Operating Area – located to the left and below the ampacity
- Equipment Damage Area – located to the right and above the withstand point

Step 3 – Size and Set Protection Devices

- Set protection at or below the ampacity.
- Set protection below the short circuit withstand point.

Additional Comments

- If current penetrates the limits of the short circuit withstand point the mechanical integrity of the equipment may be compromised.

LV Equipment Sample Problem

Plot the TCC landmarks for a 400A, 208V, 3-Ø panelboard rated 30kA. Then set a circuit breaker to protect the panelboard. 25kA is available at the panelboard.

Solution

Step 1 – Identify the TCC Landmarks

Ampacity = 400A

SC Withstand Point = 30kA @ 3 cycles

The TCC landmarks are plotted in Fig. 15.

Step 2 – Identify TCC Areas

The Equipment Operating Area is located to the left and below the ampacity, Fig. 16.

The Equipment Damage Area is located to the right and above the SC withstand point, Fig. 16.

Step 3 – Size and Set the Protective Device

Set the breaker pickup at or below the ampacity.

Set the breaker characteristic curve below the SC withstand point, Fig. 16.

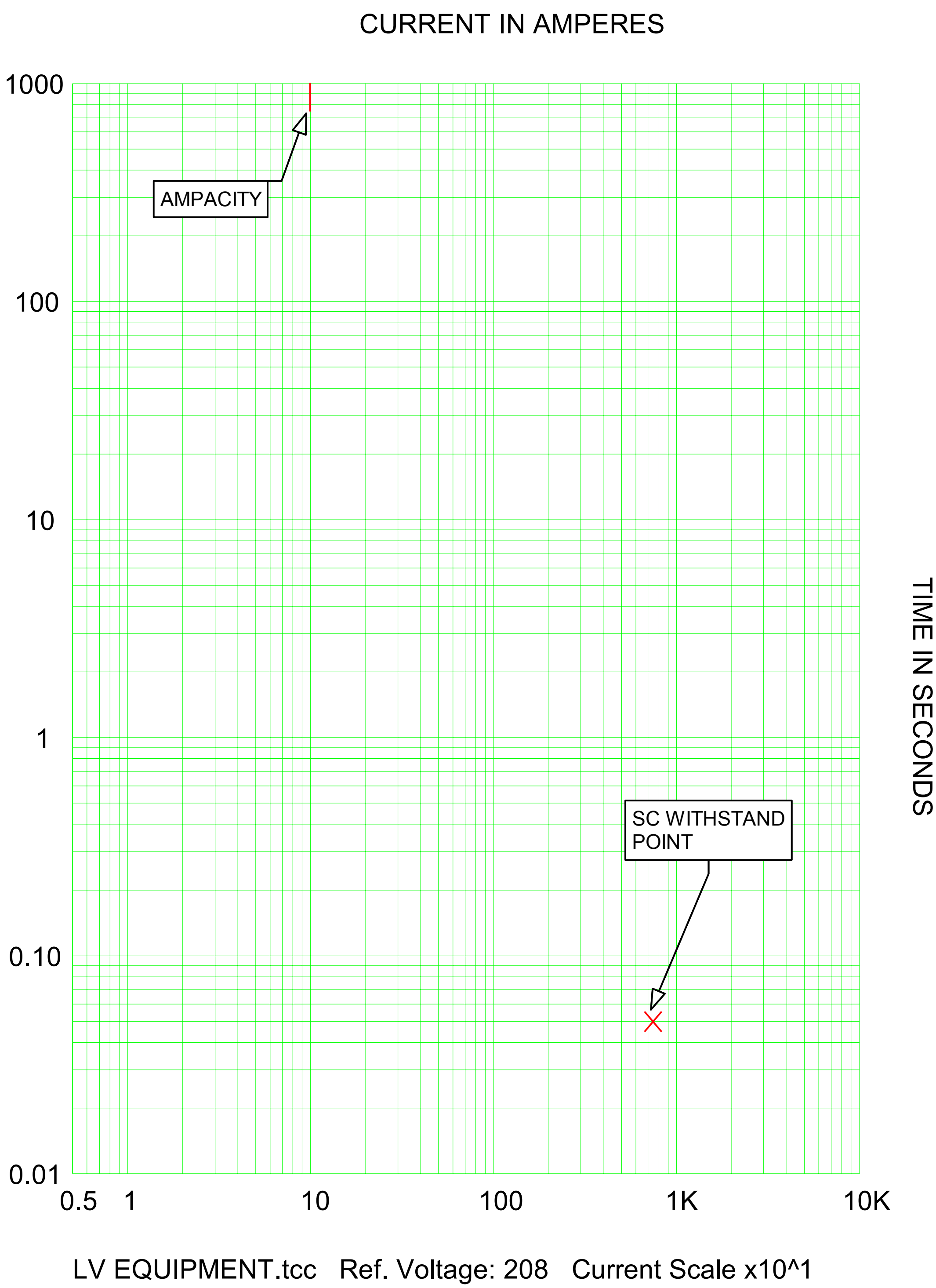


Fig. 15 – LV Equipment TCC Landmarks

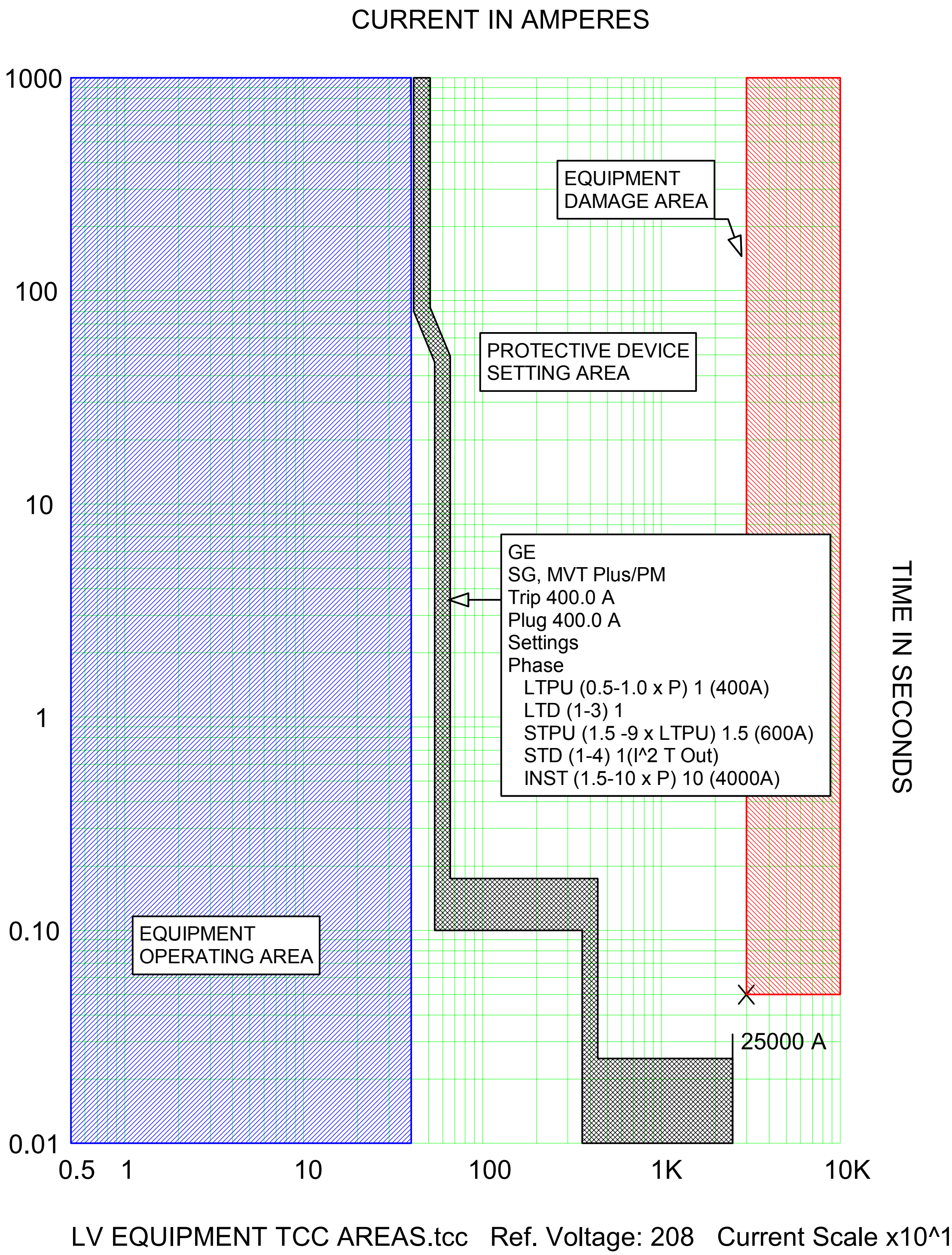


Fig. 16 – LV Equipment TCC Areas

MV EQUIPMENT INCLUDING SWITCHGEAR & CIRCUIT BREAKERS

MV EQUIPMENT TCC LANDMARKS

Ampacity

The ampacity is the rated continuous current carrying capacity of the equipment at a referenced ambient temperature.

Short Circuit Current Thermal Limit Curve

MV switchgear and circuit breaker short circuit thermal limit. The energy limit is defined by the symmetrical short circuit rating at 2 seconds per ANSI C37.010. The thermal limit curve is calculated using equation (10).

$$t_2 = t_1 (I_1 / I_2)^2 \qquad (10)$$

MV EQUIPMENT PROTECTION PHILOSOPHY

Step 1 – Identify TCC Landmarks

- Ampacity – located in the upper decade
- Shot Circuit Thermal Limit Curve – located in the top three decades

Step 2 – Identify TCC Areas

- Equipment Operating Area – located to the left and below the ampacity
- Equipment Damage Area – located to the right and above the short circuit thermal limit curve

Step 3 – Size and Set Protection Devices

- Set protection at or below the ampacity.
- Set protection below the short circuit thermal limit point.

Additional Comments

- If current penetrates the limits of the short circuit thermal limit curve the mechanical integrity of the equipment may be compromised.

MV Equipment Sample Problem

Plot the TCC landmarks for a 1200A, 4160V, 3-Ø circuit breaker rated 31.5kA. Then set a relay to protect the MV circuit breaker and switchgear. 25kA is available at the switchgear.

Solution

Step 1 – Identify the TCC Landmarks

Ampacity = 1200A

Rated short circuit current = 31.5kA

Rated permissible tripping delay time = 2 seconds

Short circuit thermal limit curve is calculated using equation (10).

Time (sec.)	Current (kA)
2	31.50
20	9.96
200	3.15
1378	1.2

The TCC landmarks are plotted in Fig. 17.

Step 2 – Identify TCC Areas

The Equipment Operating Area is located to the left and below the ampacity, Fig. 18.

The Equipment Damage Area is located to the right and above the SC thermal limit curve, Fig. 18.

Step 3 – Size and Set the Protective Device

Set the relay pickup at or below the ampacity.

Set the relay characteristic curve below the SC thermal limit curve, Fig. 18.

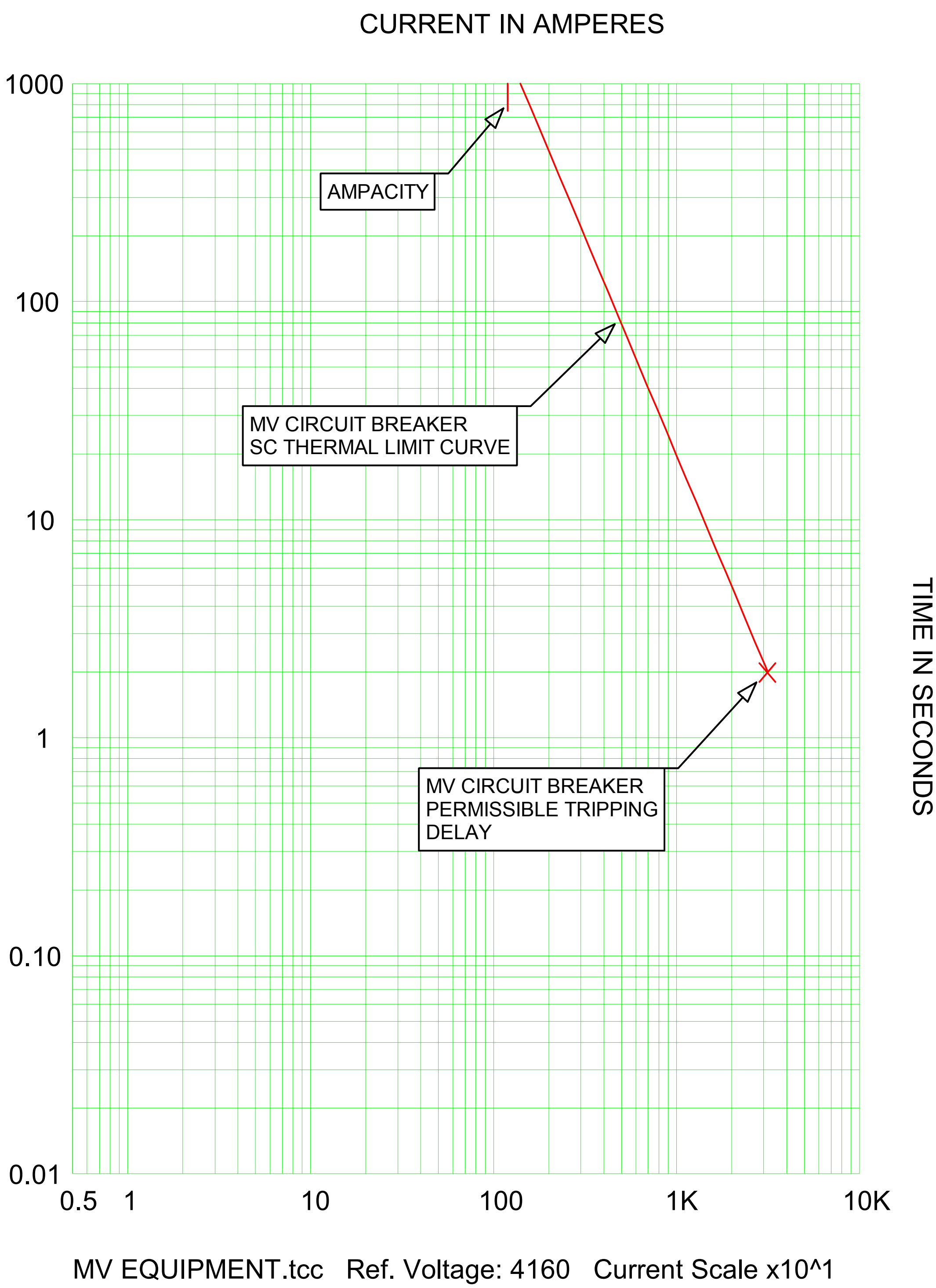


Fig. 17 – MV Circuit Breaker TCC Landmarks

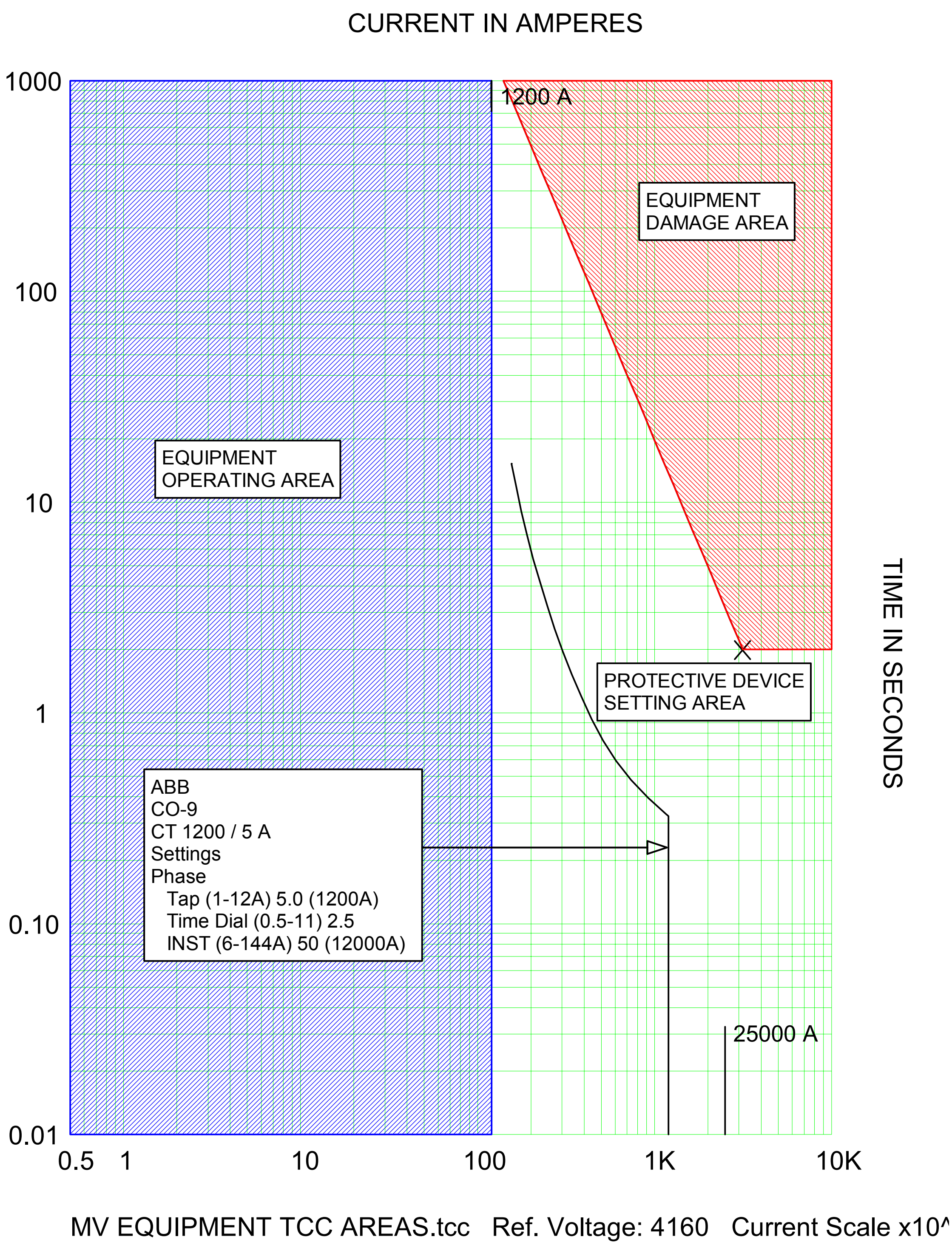


Fig. 18 – MV Circuit Breaker TCC Areas

SECTION 4
SELECTIVITY REQUIREMENTS

Selectivity between series protective devices is difficult to achieve unless the engineer responsible for specifying and purchasing the distribution equipment is familiar with available equipment features and functions. The engineer must also have a clear understanding of how sections of the distribution system should be removed from service during an overload or fault condition. Table 18 lists overcurrent relay curve types with associated applications, which are typically used in industry. Table 19 lists LV power circuit breaker trip functions with associated applications, which are again typically used in industry.

Table 18 – Relay Curve Selection Chart

Application	Functions	Relay Curve
Main Service	51	Extremely Inverse
Generator	51V	Very Inverse
Transformer	50/51	Very Inverse
Motor	50/51	Long Time
Capacitor	50/51	Short Time
Residual Neutral	51	Inverse
Neutral Ground	51	Inverse
Ground	50	Instantaneous

Table 19 – LV Power Circuit Breaker Trip Function Chart

Application	Long Time	Short Time	Instantaneous	Ground Fault
Main	Y	Y	N	Y
Tie	Y	Y	N	Y
Motor Feeder	Y	N	Y	Y
Transformer Feeder	Y	Y	Y	Y
Generator Feeder	Y	Y	Y	Y
MCC Feeder	Y	Y	N	Y
Switchboard Feeder	Y	Y	N	Y
Panelboard Feeder	Y	Y	N	Y

When evaluating the tripping characteristics for series protective devices on a TCC, coordinating time intervals must be maintained based on the equipment under consideration. Table 20 lists coordinating time intervals that have been successfully used throughout industry.

The primary reason for coordinating time intervals is that MV relays and breakers are provided as separate, discrete components. Characteristic curves are provided by the relay vendor, and rated interrupting times are provided by the breaker manufacturer. It is the responsibility of the engineer performing the coordination study to be aware of the overall relay-breaker TCC characteristics for the application under consideration.

There are two special cases concerning coordinating time intervals that warrant further discussion. The first considers series fuses. The proper approach recommended in the standards and by fuse vendors is to maintain fuse ratios, not time margins on the TCC, Table 21. For instance, consider the case of a 1600A Class L main fuse serving a 1000A Class L feeder fuse. When plotted on a TCC, the two curves will <u>not</u> touch. However, according to Table 21, a 2:1 ratio must be maintained. In this case, the ratio is 1.6:1, therefore selectivity is not achieved.

The second case considers series LV power or molded-case circuit breakers. No coordinating time interval between series devices is required. Breaker characteristic curves incorporate breaker sensing and operating times. The purpose of the breaker total clear curve is to indicate that all poles in the circuit have been cleared. Therefore, if the curves do not touch, selectivity is achieved.

Table 20 – Series Device Coordinating Time Intervals

Upstream Device	Downstream Device	Relay Disk Over-travel	Relay Tolerance	Operating Time (sec.) (note 4)	Total Time (sec.)	Typical Time (sec.)
51 Relay	51 Relay	0.1	0.07 (note2)	0.05	0.22	0.4
				0.08	0.25	
				0.13	0.30	
			0.17 (note 3)	0.05	0.32	
				0.08	0.35	
				0.13	0.40	
51 Relay	50 Relay	N/A	0.07 (note 2)	0.05	0.12	0.2
				0.08	0.15	
				0.13	0.20	
			0.17 (note 3)	0.05	0.22	
				0.08	0.25	
				0.13	0.30	
Static Relay	Static Relay	N/A	0.07 (note 2)	0.05	0.12	0.2
				0.08	0.15	
				0.13	0.20	
			0.17 (note 3)	0.05	0.22	
				0.08	0.25	
				0.13	0.30	
51 Relay	LV CB	N/A	0.07 (2)	N/A	0.07	0.2
			0.17 (3)		0.17	
51 Relay	Fuse	N/A	0.07 (2)	N/A	0.07	0.2
			0.17 (3)		0.17	
Fuse	50 Relay	N/A	0.07 (note 2)	0.05	0.12	0.2
				0.08	0.15	
				0.13	0.20	
			0.17 (note 3)	0.05	0.22	
				0.08	0.25	
				0.13	0.30	
Fuse	Fuse	N/A	N/A	N/A	(note 5)	(note 5)
LV CB (6)	LV CB (6)	N/A	N/A	N/A	(note 7)	(note 7)

Notes:
1. Total time at maximum current seen by both devices.
2. Recently tested and calibrated relay.
3. Not recently tested and calibrated relay.
4. Downstream breaker operating time, 3-cycle (0.05 sec.), 5-cycle (0.08 sec.) and 8-cycle (0.13 sec.).
5. Coordinating time interval is not applicable. Maintain published fuse ratios.
6. Low voltage molded case or power circuit breaker.
7. Coordinating time interval is not applicable. Published time-current curves should not overlap.

Table 21 – Typical Fuse Ratios

LINE-SIDE FUSE	LOAD-SIDE FUSE				
	Class L 601-6000A	Class K1 0-600A	Class J 0-600A	Class K5 Time Delay 0-600A	Class J Time Delay (0-600A)
Class L (601-6000A)	2:1	2:1	2:1	6:1	2:1
Class K1 (0-600A)	-	2:1	3:1	8:1	4:1
Class J (0-600A)	-	3:1	3:1	8:1	4:1
Class K5 Time Delay (0-600A)	-	1.5:1	1.5:1	2:1	1.5:1
Class J Time Delay (0-600A)	-	1.5:1	1.5:1	8:1	2:1

Note: For illustration only. Refer to manufacturer for specific data.

Relay – MV Breaker Characteristic Curve Sample Problem

Plot the nominal relay operating time versus relay tolerance, disk over-travel and breaker operating time. Consider an electro-mechanical (E-M) CO-11 relay that has not been recently tested and calibrated, controlling an 8-cycle circuit breaker.

Solution

Relay-Breaker Operation Limits	Nominal Band	Minimum	Maximum
Relay Tolerance	0.17 sec.	-0.085 sec.	+0.085 sec.
E-M Relay Disk Over-travel	0.10 sec.	-	+0.10 sec.
8 Cycle Breaker Operating Time	0.13 sec.	-	+0.13 sec.

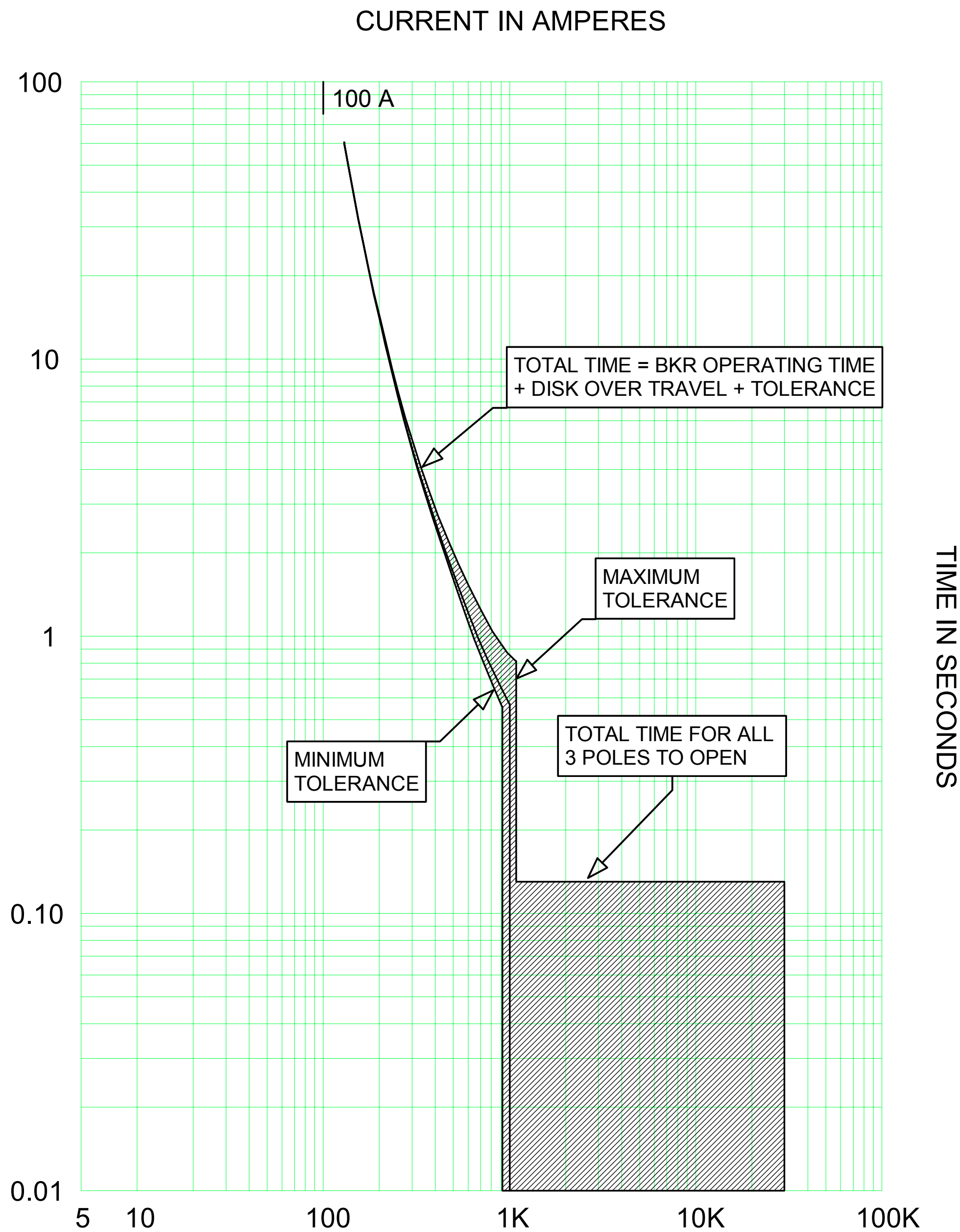
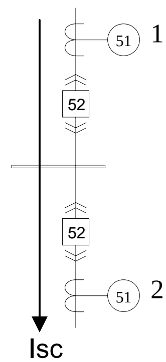


Fig. 19 – Relay Tolerance Bands

Selectivity Problem 1

Applicable combinations include:

Device	ANSI No.	Protection Device
Upstream	51	E-M Relay
Downstream	51	E-M Relay, Static Relay



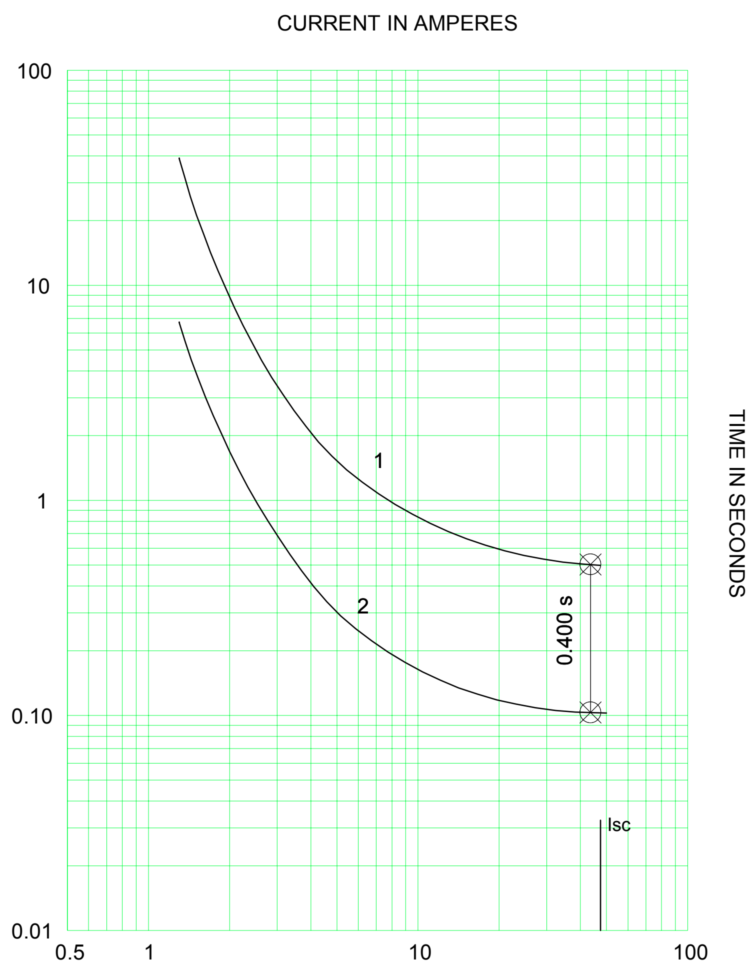
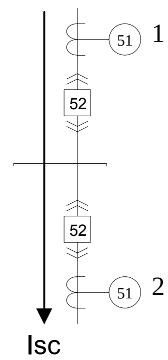


Fig. 20 – 51 Relay Upstream with 51 Relay Downstream

Selectivity Problem 2

Applicable combinations include:

Device	ANSI No.	Protection Device
Upstream	51	Static Relay
Downstream	51	E-M Relay, Static Relay



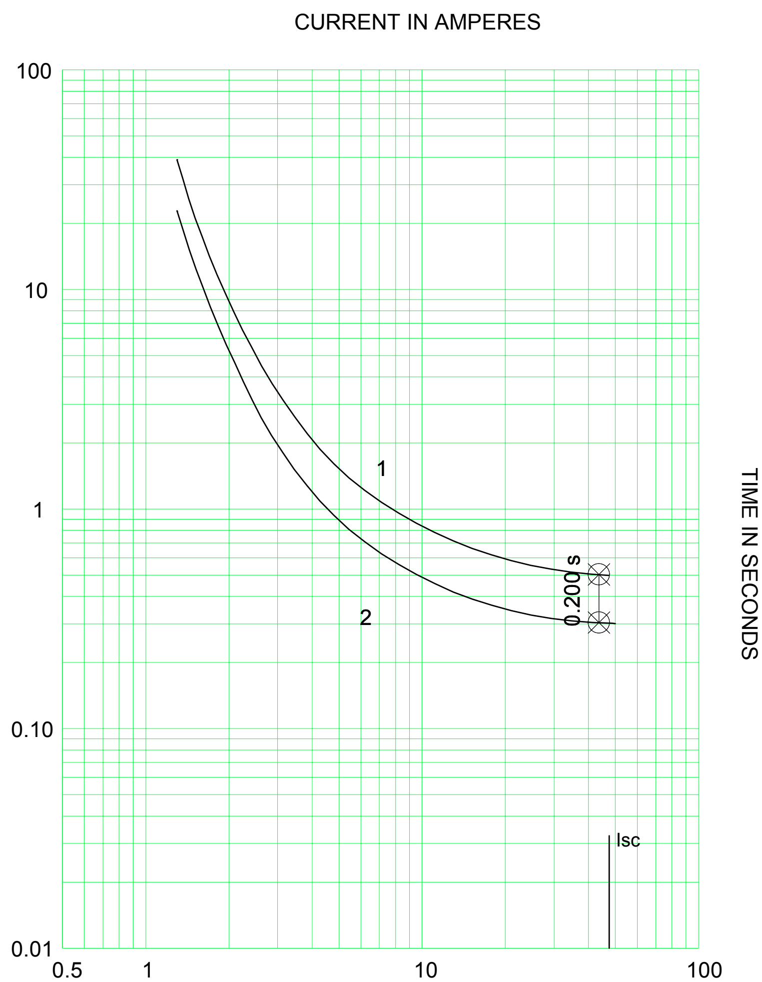
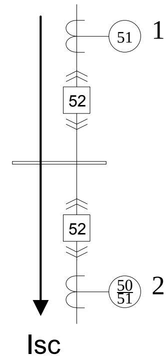


Fig. 21 – 51 Relay Upstream with 51 Relay Downstream

Selectivity Problem 3

Applicable combinations include:

Device	ANSI No.	Protection Device
Upstream	51	E-M Relay
Downstream	50/51	E-M Relay, Static Relay



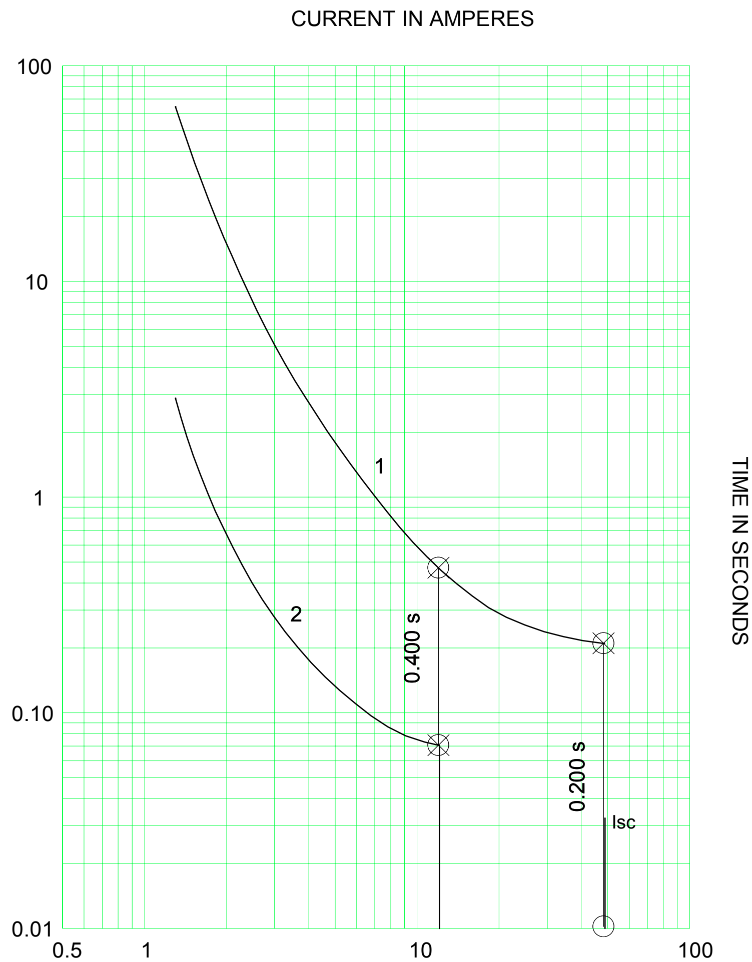


Fig. 22 – 51 Relay Upstream with 50/51 Relay Downstream

Selectivity Problem 4

Applicable combinations include:

Device	ANSI No.	Protection Device
Upstream	50/51	E-M Relay, Static Relay
Downstream	-	MCCB, ICCB, PCB

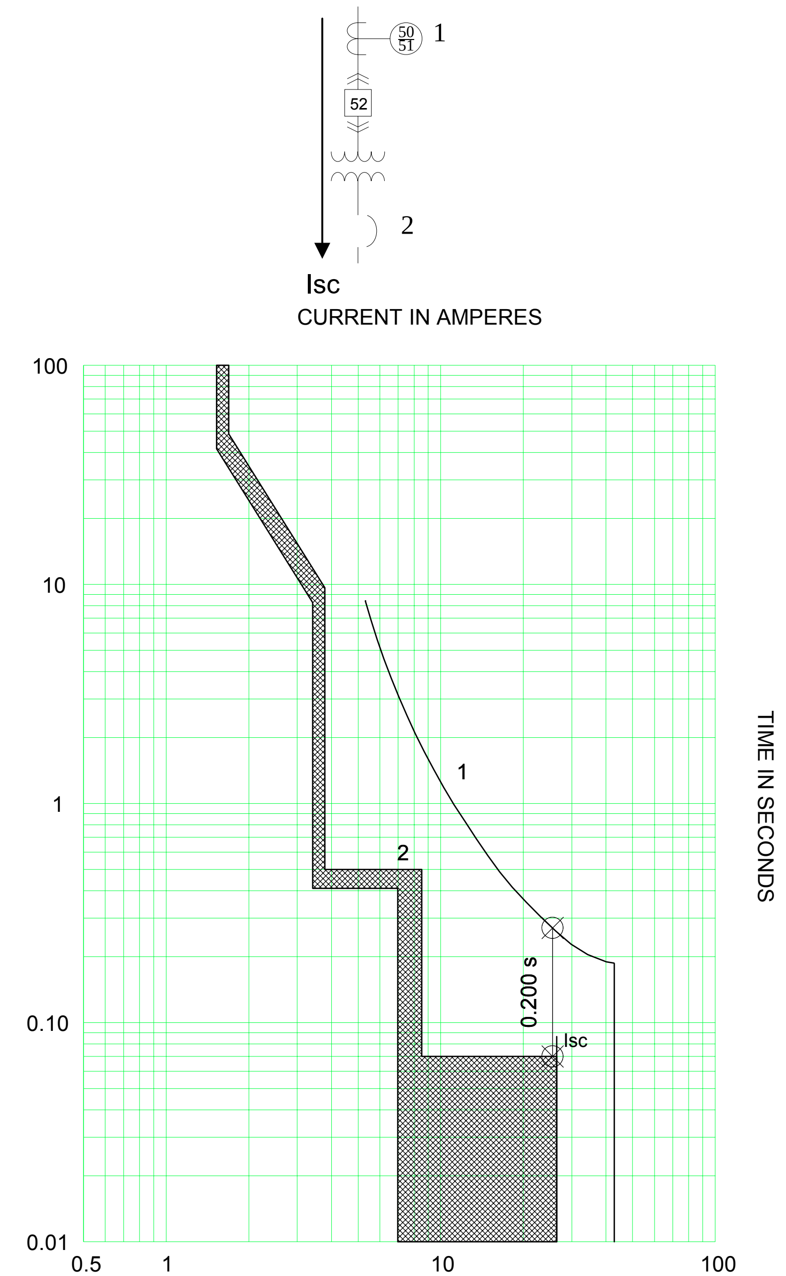
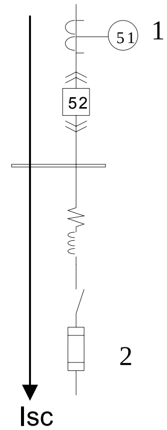


Fig. 23 – 50/51 Relay Upstream with LV CB Downstream

Selectivity Problem 5

Applicable combinations include:

Device	ANSI No.	Protection Device
Upstream	50/51	E-M Relay, Static Relay
Downstream	-	Fuse



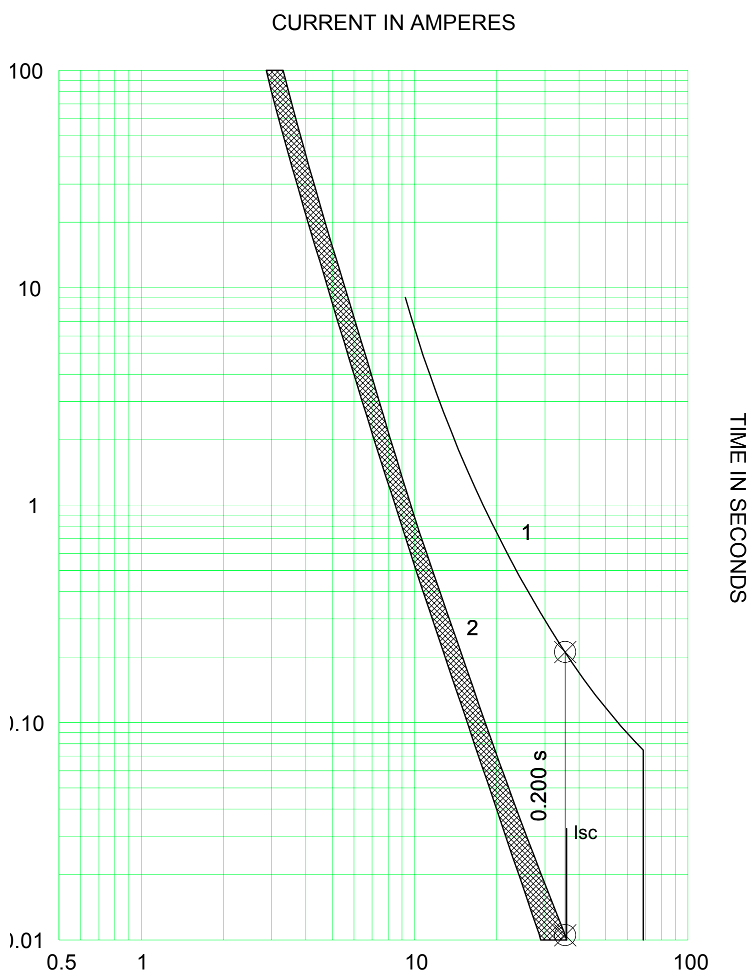


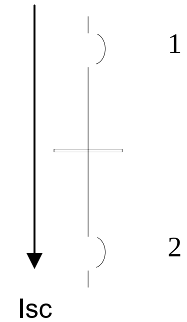
Fig. 24 – 51 Relay Upstream with Fuse Downstream

Selectivity Problem 6

Applicable combinations include:

<u>Device</u>	<u>Protection Device</u>
Upstream	LV PCB or MCCB
Downstream	LV PCB or MCCB

For selectivity between LV circuit breakers, no margins are required. As long as devices do not intersect, selectivity is achieved.



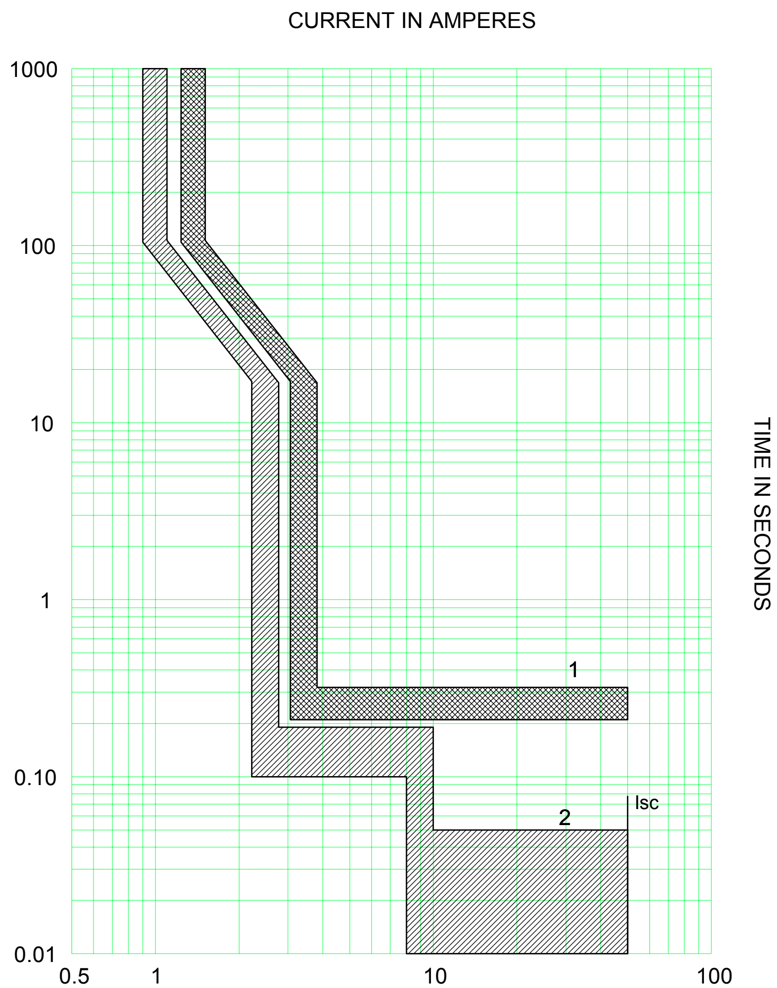


Fig. 25 – LV CB Upstream with LV CB Downstream

To coordinate fuses, maintain manufacturer published fuse ratios listed in selectivity tables. All fuse selectivity tables are manufacturer specific. To achieve fuse selectivity between different manufacturers, the clearing I^2T of the downstream fuse must be less than the minimum I^2T of the upstream fuse.

The minimum melt and total clear curves take into account fuses tolerances. However, to take into account ambient temperature, preloading and pre-damage, down stream devices should not come within 75% of the minimum melt curve. At a minimum, to avoid the effects of pre-damage, down stream devices should not come within 90% of the minimum melt curve, Fig. 26.

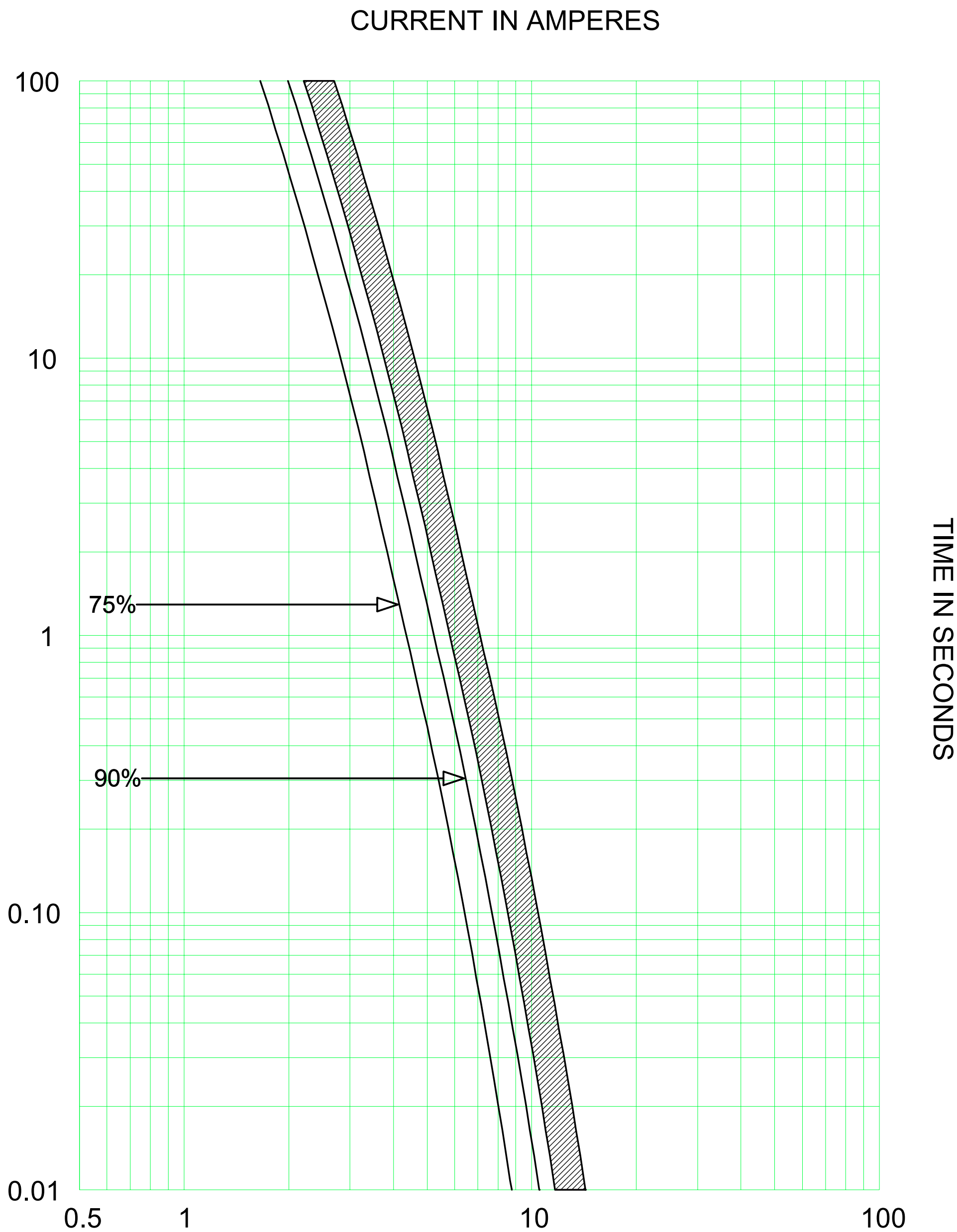


Fig. 26 – Fuse Boundary Limits

SECTION 5
SETTING GUIDELINES

MV Motor Switchgear Feeder Unit

Industry standard overcurrent protection schemes for MV induction and synchronous motors fed from switchgear circuit breakers include an instantaneous overcurrent relay (device 50/51). The 50/51 relay characteristics are plotted on a phase TCC along with the motor starting and damage curves, and the feeder damage curve.

The purpose of the 50/51 relay is to allow the motor to start and run, and to protect the motor and cable from overloads and faults. To accomplish this, the relay characteristics must be above and to the right of the motor starting curve, and to the left and below the rotor, stator and cable damage curves, and the amp rating of the cable.

Suggested margins are listed below that have historically allowed for safe operation of the motor and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
CT	Size	125-150% of FLA	
51	Pickup	115-125% of FLA	Set below motor stator damage curve.
			Set at or below cable ampacity.
51	Time Dial	2-10 seconds above knee of motor curve	Set below motor rotor damage curve.
			Set below cable damage curve.
50	Pickup	200% of LRA	Set below cable damage curve.
			Cable damage curve must be above the maximum fault current at 0.1 seconds.

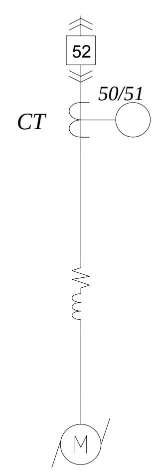


Fig. 27 – MV Motor Switchgear Feeder Unit

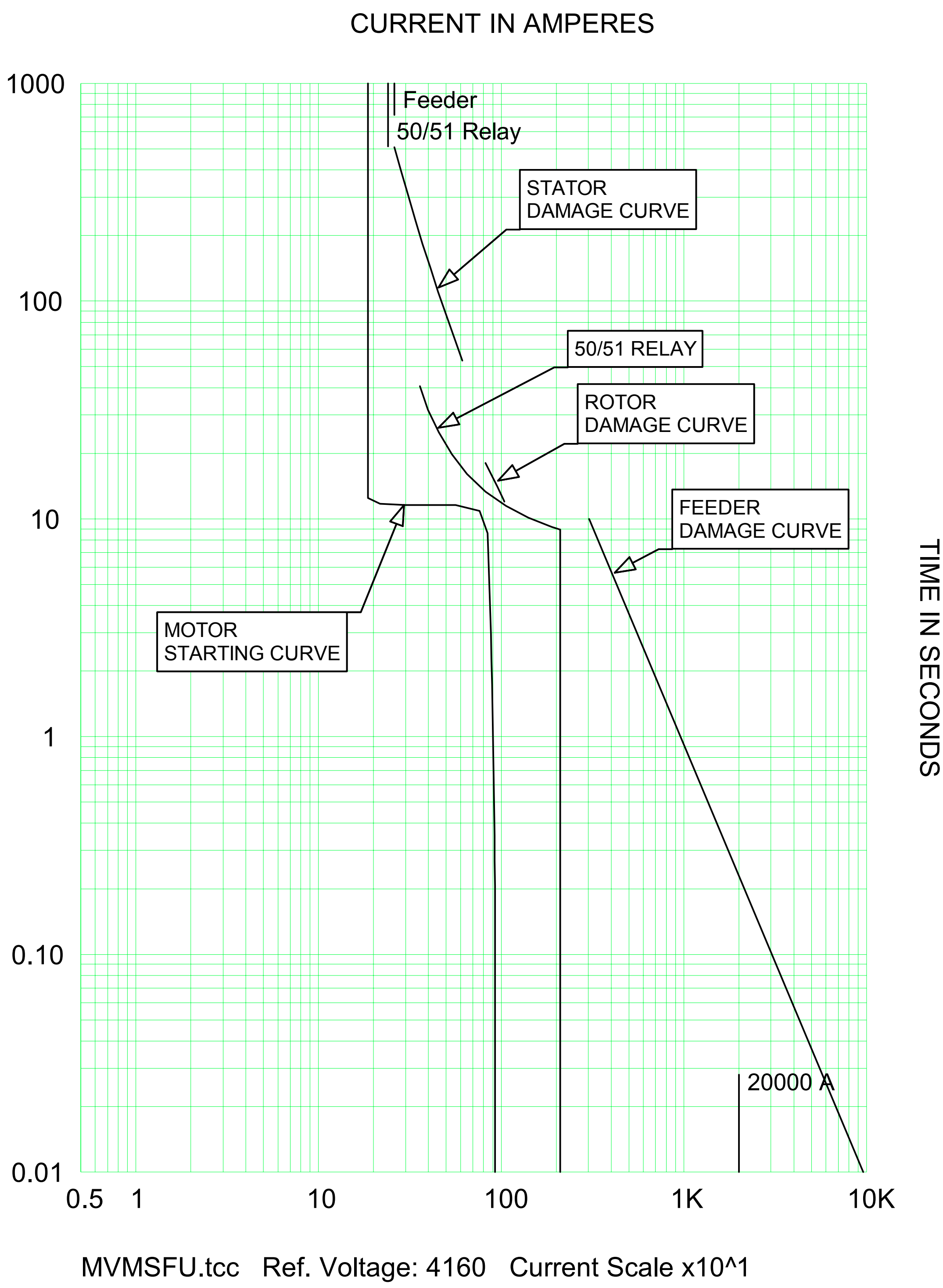


Fig. 28 – MV Motor Switchgear Feeder Unit

MV Motor Fused Starter Feeder Unit

Industry standard overcurrent protection schemes for MV induction and synchronous motors fed from fused starters include an overcurrent relay (device 51), and a set of R-rated fuses (device 50). R rated fuses melt at 100 times the R rating and 20 seconds. Both the fuse and relay characteristics are plotted on a phase TCC along with the motor starting and damage curves, and the feeder damage curve.

The purpose of the fuse-relay combination is to allow the motor to start and run, and to protect the motor and cable from overloads and faults. To accomplish this, the fuse-relay characteristics must be above and to the right of the motor starting curve, and to the left and below the rotor, stator and cable damage curves, and the amp rating of the cable.

Suggested margins are listed below that have historically allowed for safe operation of the motor and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
CT	Size	125-150% of FLA	
51	Pickup	115-125% of FLA	Set below motor stator damage curve.
			Set at or below cable ampacity.
51	Time Dial	2-10 seconds above knee of motor curve	Set below motor rotor damage curve.
			Set below cable damage curve.
50	Fuse Size	$R_{Rating} \geq 1.1*LRA/100$	Set below cable damage curve.
		$AMP_{Rating} > FLA$	Cable damage curve must be above the maximum fault current at 0.01 seconds.

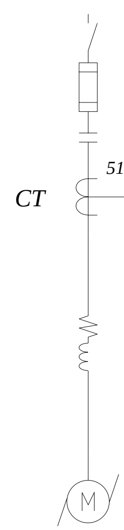


Fig. 29 – MV Motor Fused Starter Feeder Unit

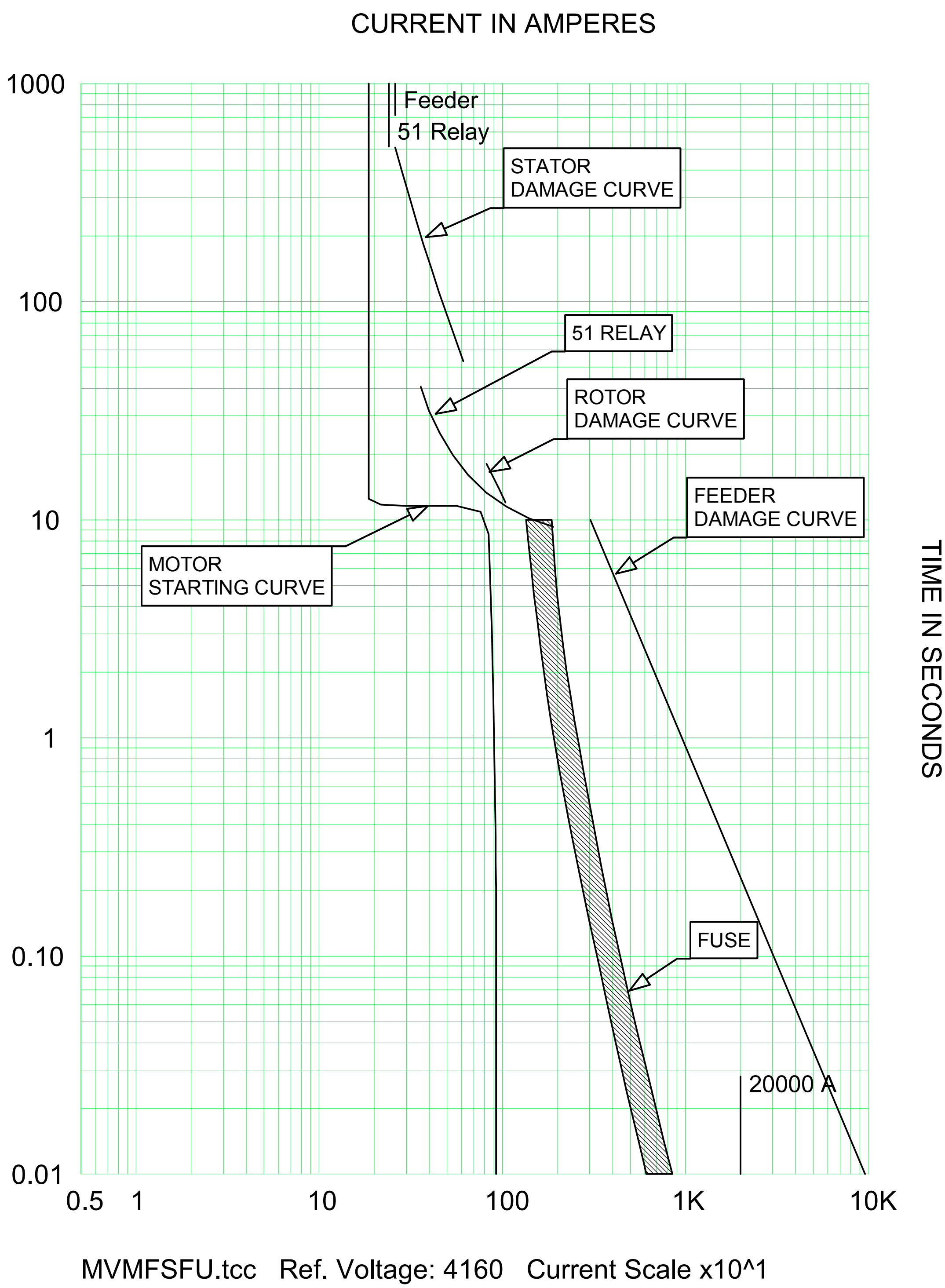


Fig. 30 – MV Motor Fused Starter Feeder Unit

LV Motor Power Circuit Breaker Feeder Unit

Industry standard phase overcurrent functions purchased with power circuit breakers (PCB) serving LV motors include long time pickup, long time delay and instantaneous pickup. Short time pickup and short time delay are not used. The PCB characteristics are plotted on a phase TCC along with the motor starting curve and safe stall point, and the feeder damage curve.

The purpose of the PCB is to allow the motor to start and run, and to protect the motor and cable from overloads and faults. To accomplish this, the PCB characteristics should be above and to the right of the motor starting curve, and to the left and below the motor safe stall point, cable damage curve and amp rating. Note it is not always possible to be below the cable amp rating due to breaker tolerances.

Suggested margins are listed below that have historically allowed for safe operation of the motor and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
PCB	LTPU	125% of FLA	Set at or below cable ampacity.
PCB	Time Dial	2-10 seconds above knee of motor curve	Set below motor safe stall point.
PCB	INST	200% of LRA	Set below cable damage curve. Cable damage curve must be above the point defined by the maximum fault current and the PCB instantaneous clear curve.

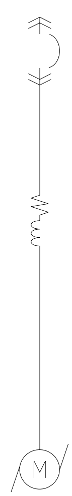


Fig. 31 – LV Motor Power Circuit Breaker Feeder Unit

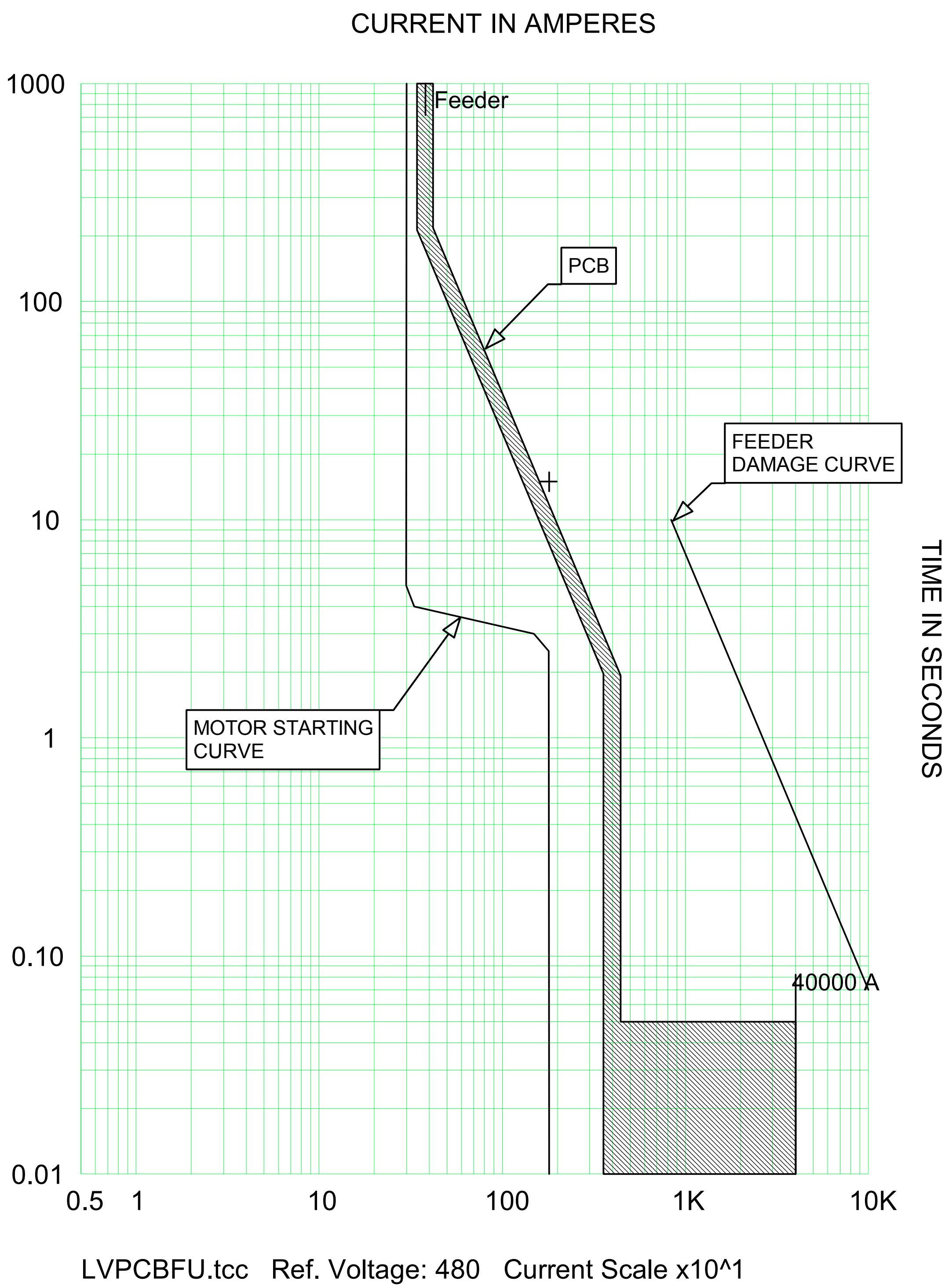


Fig. 32 – LV Motor Power Circuit Breaker Feeder Unit

LV Motor MCP Starter Feeder Unit

Industry standard phase overcurrent protection is provided in MCP starter units by two discrete components, an overload relay and an MCP. The MCP is a circuit breaker with the thermal element removed. The overload and MCP characteristics are plotted on a phase TCC along with the motor starting curve and safe stall point, and the feeder damage curve.

The purpose of the overload-MCP combination is to allow the motor to start and run, and to protect the motor and cable from overloads and faults. To accomplish this, the overload-MCP characteristics should be above and to the right of the motor starting curve, and to the left and below the motor safe stall point, the cable damage curve and amp rating. Note it is not always possible to be below the cable amp rating due to overload tolerances.

Suggested margins are listed below that have historically allowed for safe operation of the motor and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
OL	Pickup	125% of FLA if SF $\geq$ 1.15	Set at or below cable ampacity.
		115% of FLA if SF = 1.00	
OL	Time Dial	Fixed assume Class 20	Set below motor safe stall point.
MCP	Size	125-160% of FLA	Defer to recommended size by manufacturer.
MCP	Pickup	200% of LRA	Set below cable damage curve.
			Cable damage curve must be above the point defined by the maximum fault current and the MCP instantaneous clear curve.

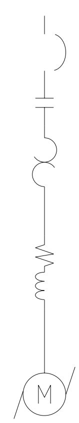


Fig. 33 – LV Motor MCP Starter Feeder Unit

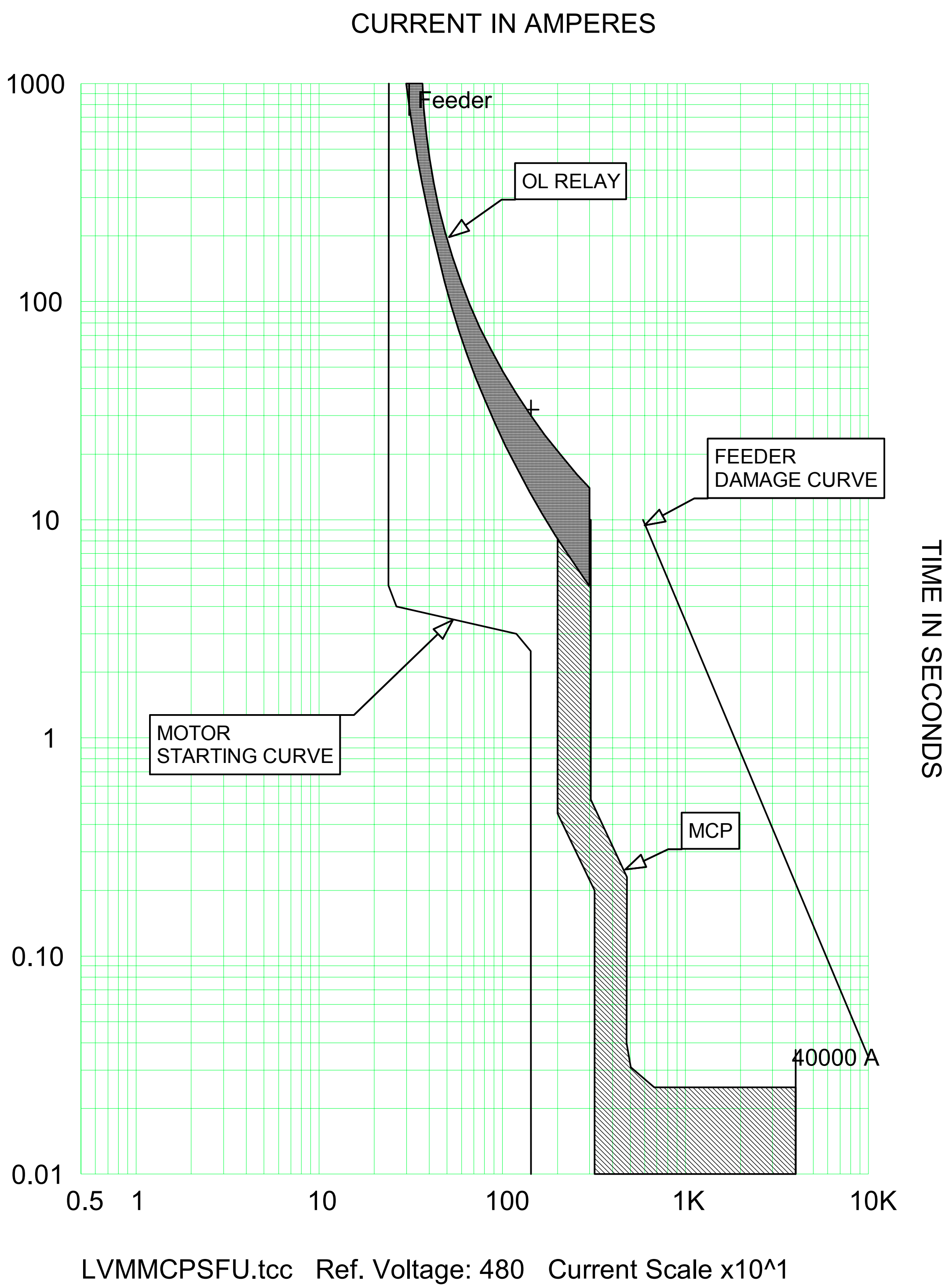


Fig. 34 – LV Motor MCP Starter Feeder Unit

LV Motor Fused Starter Feeder Unit

Industry standard phase overcurrent protection is provided in fused starter units by two discrete components, an overload relay and a fuse. Both the overload and fuse characteristics are plotted on a phase TCC along with the motor starting curve and safe stall point, and the feeder damage curve.

The purpose of the overload-fuse combination is to allow the motor to start and run, and to protect the motor and cable from overloads and faults. To accomplish this, the overload-fuse characteristics should be above and to the right of the motor starting curve, and to the left and below the motor safe stall point, the cable damage curve and amp rating. Note it is not always possible to be below the cable amp rating due to overload tolerances.

Suggested margins are listed below that have historically allowed for safe operation of the motor and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
OL	Pickup	125% of FLA if SF $\geq$ 1.15	Set at or below cable ampacity.
		115% of FLA if SF = 1.00	
OL	Time Dial	Fixed assume Class 20	Set below motor safe stall point.
Fuse	Size	175% of FLA	Set below cable damage curve.
			Cable damage curve must be above the point defined by the maximum fault current and 0.01 seconds

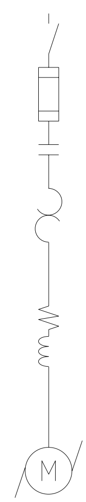


Fig. 35 – LV Motor Fused Starter Feeder Unit

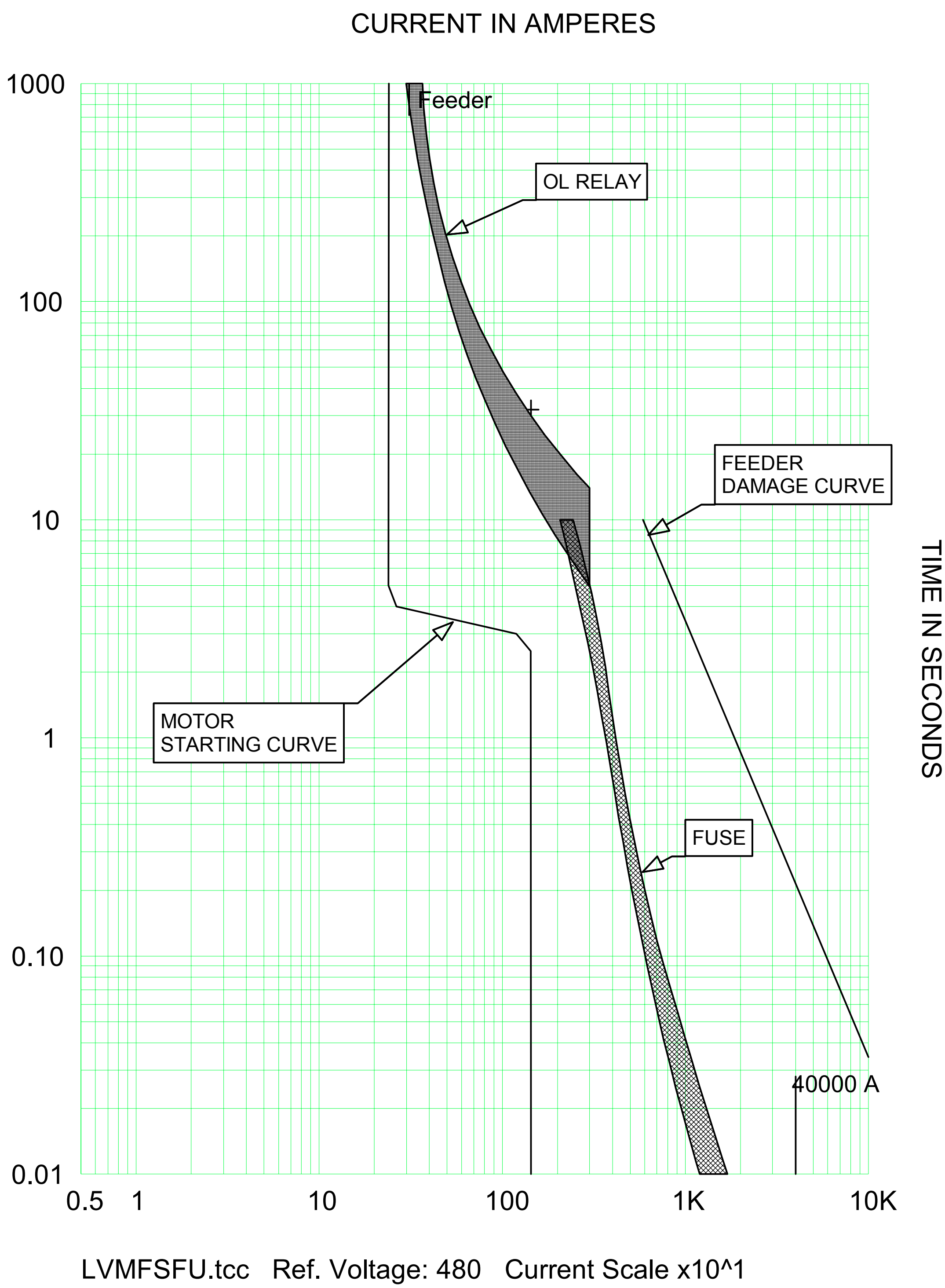


Fig. 36 – LV Motor Fused Starter Feeder Unit

MV Generator Switchgear Feeder Unit with Voltage Controlled 51V

Industry standard backup overcurrent protection schemes for MV generators fed from switchgear circuit breakers include either a voltage controlled or voltage restrained overcurrent relay (device 51V). The voltage controlled overcurrent relay will be covered in this section. The 51V relay characteristics are plotted on a phase TCC along with the generator decrement curve and damage point, and the feeder damage curve.

The purpose of the relay is to allow the generator to operate, and to provide backup fault protection for the generator and cable. To accomplish this, the relay pickup must be to the left of the generator armature steady state current. Also, the relay time delay characteristics must be above and to the right of the generator decrement curve with constant excitation, and to the left and below the generator damage point, cable damage curve and the amp rating of the cable. The time delay must also be set to be selective with downstream feeder relays.

Suggested margins are listed below that have historically allowed for safe operation of the generator and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
CT	Size	125-150% of FLA	
51V	Pickup	80-90% of $I_d = 1/X_d$	Assume $X_d = 1.5\ \Omega$ p.u. if X_d unknown.
51	Time Dial	Above knee of generator decrement curve with constant excitation	Set above downstream feeder relays.
			Set below cable damage curve.

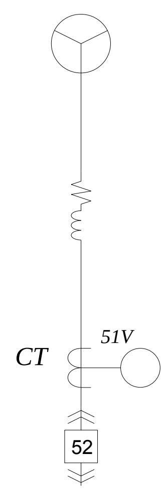


Fig. 37 – MV Generator Switchgear Feeder Unit w/VC 51V

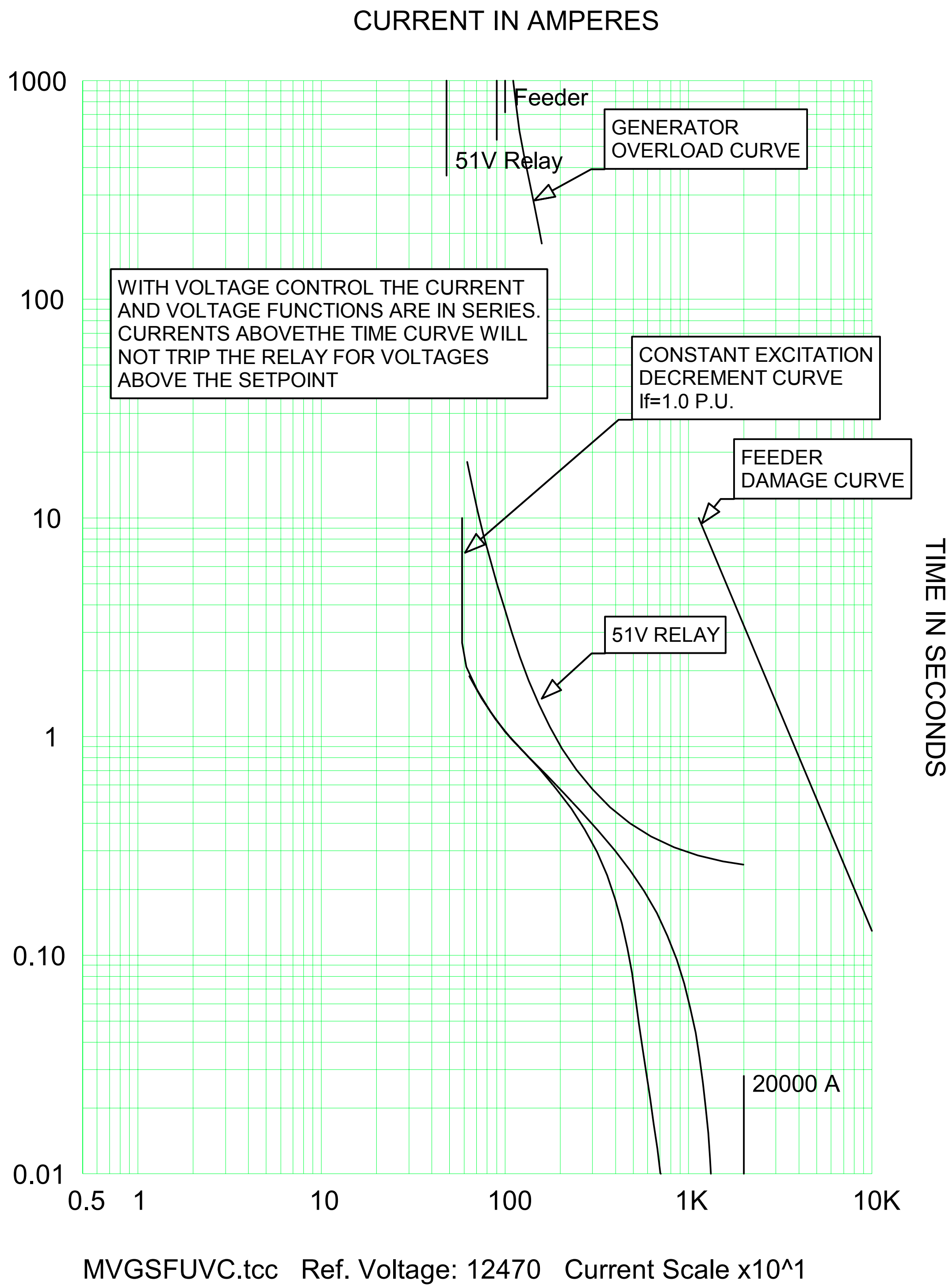


Fig. 38 – MV Generator Switchgear Feeder Unit w/VC 51V

MV Generator Switchgear Feeder Unit with Voltage Restrained 51V

Industry standard backup overcurrent protection schemes for MV generators fed from switchgear circuit breakers include either a voltage controlled or voltage restrained overcurrent relay (device 51V). The voltage restrained overcurrent relay will be covered in this section. The 51V relay characteristics are plotted on a phase TCC along with the generator decrement curve and damage point, and the feeder damage curve.

The purpose of the relay is to allow the generator to operate, and to provide backup fault protection for the generator and cable. To accomplish this, the relay pickup at 0% restraint must be to the left of the generator armature steady state current, and at 100% restraint must be to the right of the generator full load amps. Also, the relay time delay characteristics must be above and to the right of the generator decrement curve with constant excitation, and to the left and below the generator damage point, cable damage curve and the cable amp rating. The time delay must also be set to be selective with downstream feeder relays.

Suggested margins are listed below that have historically allowed for safe operation of the generator and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
CT	Size	125-150% of FLA	
51V	Pickup	125-150% of FLA	@ 100% Voltage Restraint
			Set below Overload Curve
51	Time Dial	Above knee of generator decrement curve with constant excitation	Set above downstream feeder relays.
			Set below cable damage curve.

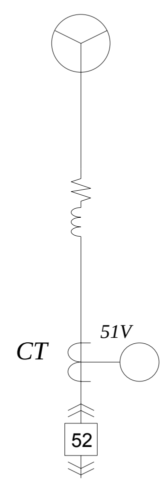


Fig. 39 – MV Generator Switchgear Feeder Unit w/VR 51V

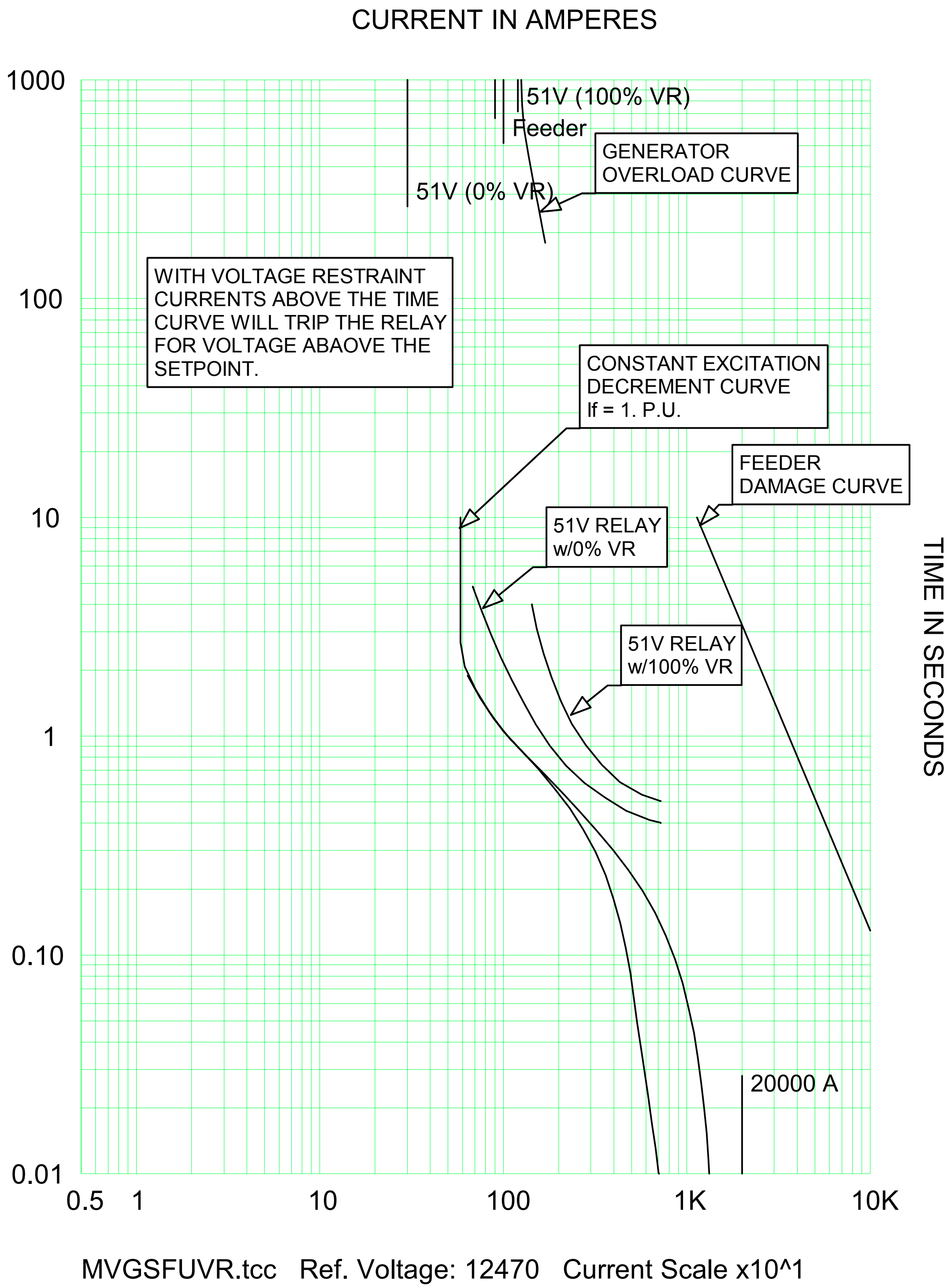


Fig. 40 – MV Generator Switchgear Feeder Unit w/VR 51V

LV Generator Molded-Case Circuit Breaker or Power Circuit Breaker Feeder Unit

Industry standard phase overcurrent functions purchased with molded case or power circuit breakers serving LV generators include long time, short time and instantaneous functions. The circuit breaker (CB) characteristics are plotted on a phase TCC along with the generator characteristics, and the feeder damage curve.

The purpose of the CB is to allow the generator to operate, and to protect the generator and cable from overloads and faults. To accomplish this, the CB characteristics should be above the generator FLA, intersect the generator decrement curve in the short time region, fall to the left and below the generator damage point, the cable damage curve and amp rating, and be above the generator decrement curve in the instantaneous region.

Suggested margins are listed below that have historically allowed for safe operation of the generator and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
CB	LTPU	115-125% of FLA	Set at or below cable ampacity.
CB	LTD, STPU & STD	Minimum	Set to intersect with generator decrement curve.
CB	I^2T	Out	If I^2T in the breaker may never trip.
CB	INST	Above total decrement curve	Set below cable damage curve.
			Cable damage curve must be above the point defined by the maximum fault current and the CB instantaneous clear curve.

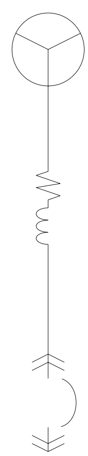


Fig. 41 – LV Generator Molded Case or Power Circuit Breaker Feeder Unit

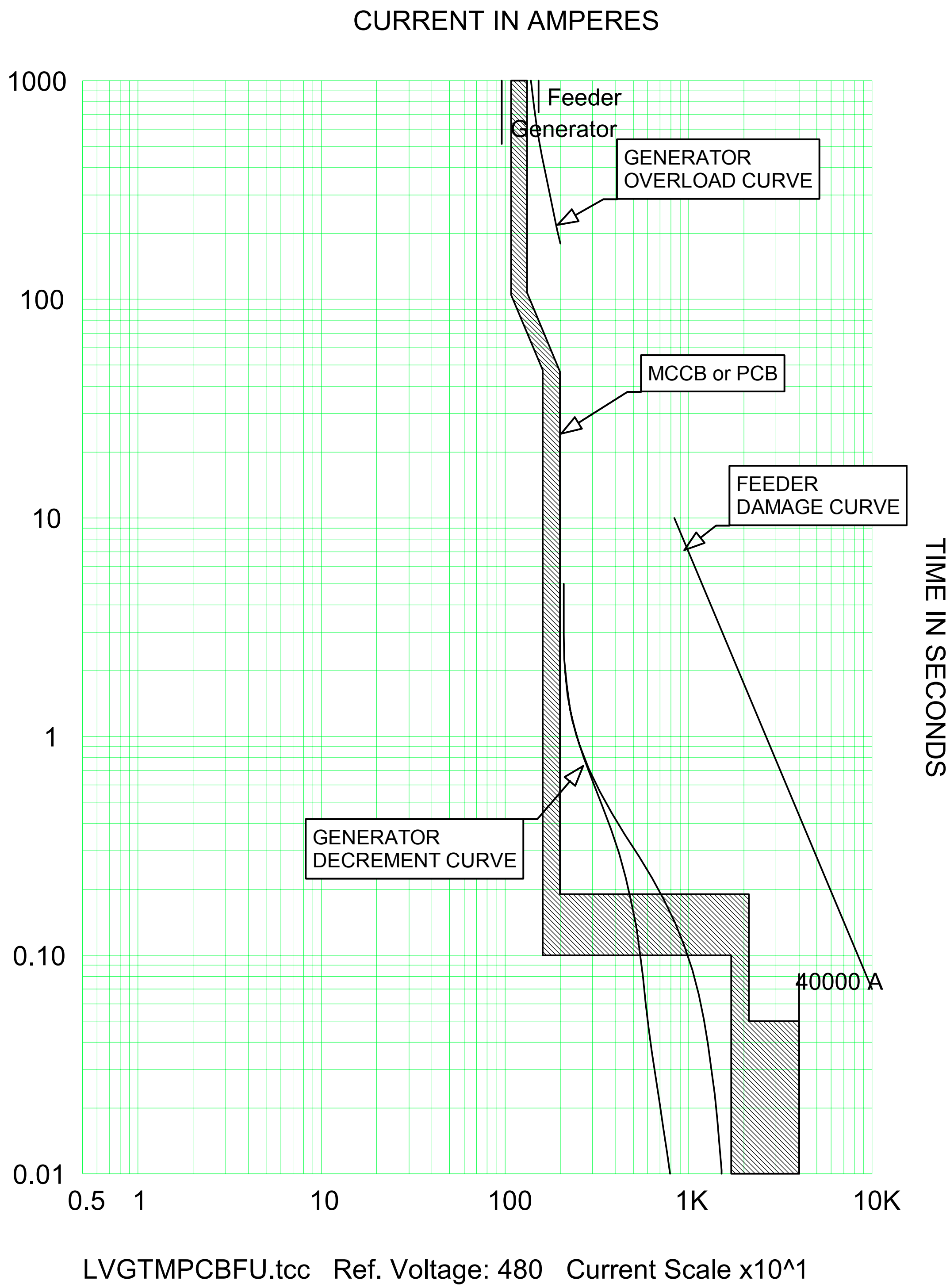


Fig. 42 – LV Generator Molded-Case or Power Circuit Breaker Feeder Unit

MV Transformer Switchgear Feeder Unit

Industry standard overcurrent protection schemes for MV transformers fed from switchgear circuit breakers include an instantaneous overcurrent relay (device 50/51). The 50/51 relay characteristics are plotted on a phase TCC along with the transformer and feeder damage curves.

The purpose of the phase overcurrent relay is to allow for full use of the transformer, and to protect the transformer and cable from overloads and faults. To accomplish this, the relay characteristic should be to the right of the transformer FLA rating and inrush point, and to the left of the transformer and cable damage curves and the cable amp rating.

Suggested margins are listed below that have historically allowed for safe operation of the transformer and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
CT	Size	200% of FLA	FLA on base rating.
51	Pickup	110-140% of FLA	Set below the transformer damage curve.
			Set at or below cable ampacity.
51	Time Dial	let-thru current @ 1.0 second	Set below the transformer damage curve.
			Set at or above low voltage main device.
50	Pickup	200% of let-thru current or inrush	Set below cable damage curve.
			Set above transformer inrush point.
			Cable damage curve must be above the maximum fault current at 0.1 seconds.

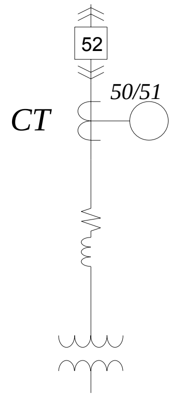


Fig. 43 – MV Transformer Switchgear Feeder Unit

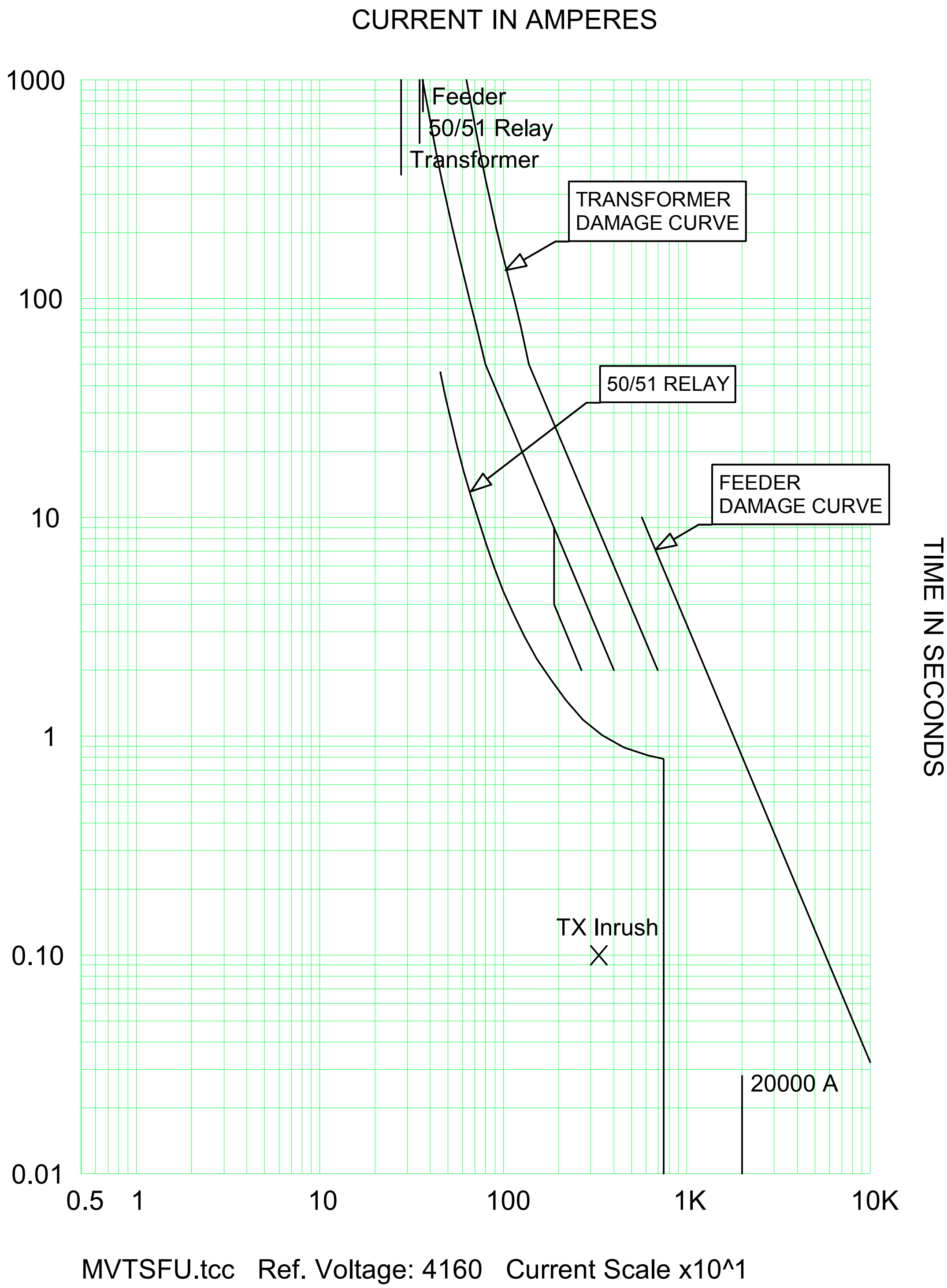


Fig. 44 – MV Transformer Switchgear Feeder Unit

MV Transformer Fused Switch Feeder Unit

E-rated power fuses are typically used in fused switches serving MV transformers. Fuses rated 100E or less must trip in 300 seconds at currents between 200 and 240% of their E ratings. Fuses above 100E must trip in 600 seconds at currents between 220 and 264% of their E ratings. The fuse characteristics are plotted on a phase TCC along with the transformer and feeder damage curves.

The purpose of the fuse is to allow for full use of the transformer, and to protect the transformer and cable from faults. To accomplish this, the fuse characteristic should be to the right of the transformer inrush point and to the left of the cable damage curve. The fuse will always cross the transformer damage curve. The LV main device provides overcurrent protection for the circuit.

Suggested margins are listed below that have historically allowed for safe operation of the transformer and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
50	Fuse Size	E-rating > FLA	FLA at top rating.
			Set at or below cable ampacity.
			Set above transformer inrush 12 x 0.1 seconds.
			Set above transformer inrush 25 x 0.01 seconds.
			Cable damage curve must be above the maximum fault current at 0.01 seconds.

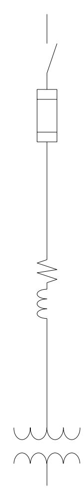


Fig. 45 – MV Transformer Fused Switch Feeder Unit

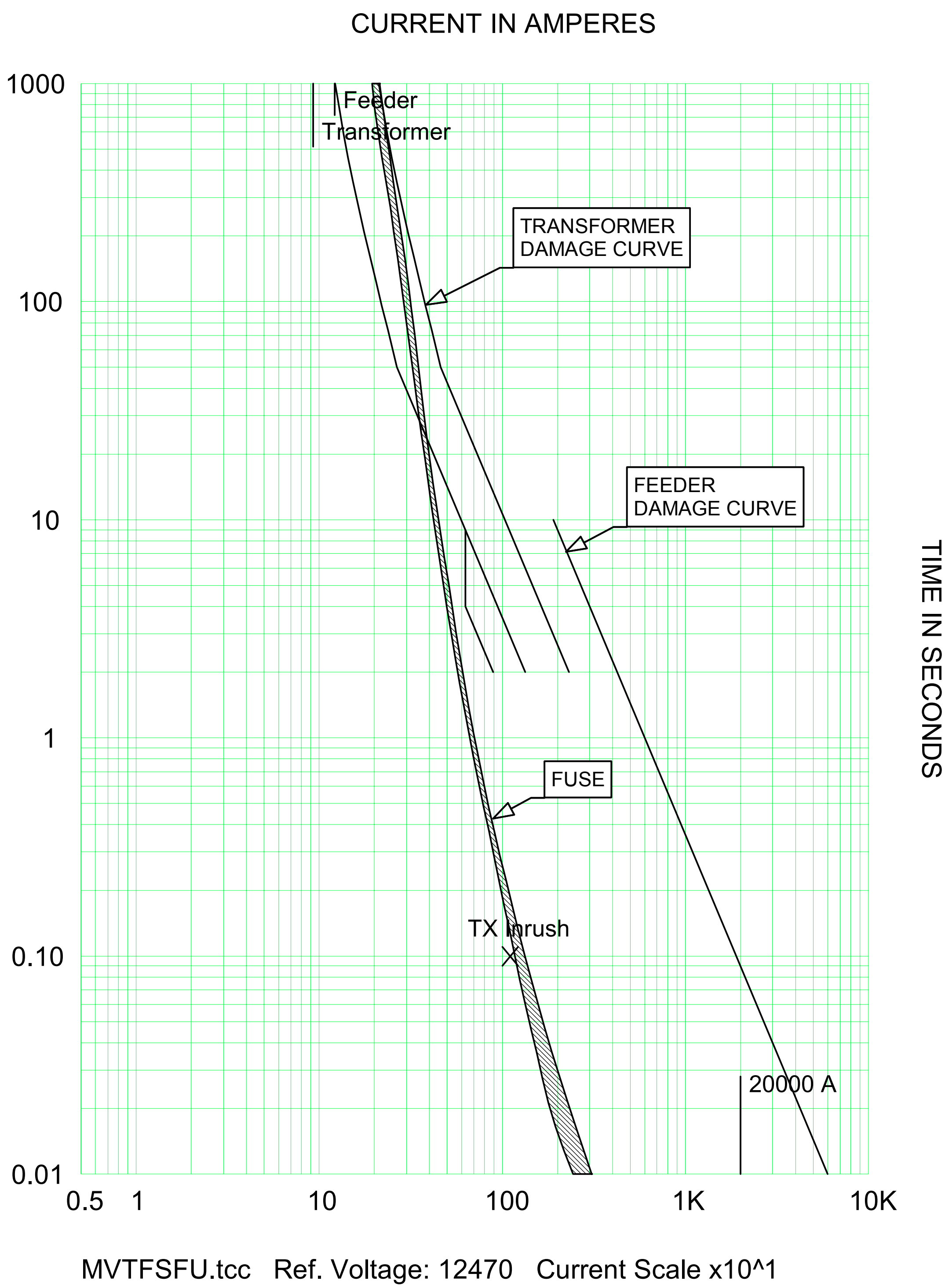


Fig. 46 – MV Transformer Fused Switch Feeder Unit

MV Capacitor Switchgear Feeder Unit

Industry standard overcurrent protection schemes for MV fused capacitor banks fed from switchgear circuit breakers include an instantaneous overcurrent relay (device 50/51). The 50/51 relay characteristics are plotted on a phase TCC along with the feeder damage curve.

The purpose of the phase overcurrent relay is to allow for full use of the capacitor, and to protect the capacitor and cable from overloads, and the cable from faults. The purpose of the fuse is to prevent a case rupture due to a fault within the capacitor tank. To accomplish this, the relay and fuse characteristics should be to the right of the capacitor amp rating, and to the left of the capacitor case rupture curve, cable damage curve and cable amp rating. Note, the phase relay is not fast enough to protect the capacitor bank from damage.

Suggested margins are listed below that have historically allowed for safe operation of the transformer and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
CT	Size	150% of $I_{Capacitor}$	
51	Pickup	130-155% of $I_{Capacitor}$	Set at or below cable ampacity.
51	Time Dial	Time Dial 1 for E-M relay	
50	Pickup	200-450% of $I_{Capacitor}$	Set below cable damage curve.
			Cable damage curve must be above the maximum fault current at 0.1 seconds.
Fuse	Fuse Size	200% of $I_{Capacitor}$	Defer to manufacturer recommendations.
			Set below capacitor case rupture curve.

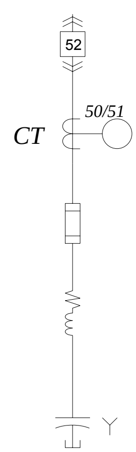


Fig. 47 – MV Capacitor Switchgear Feeder Unit

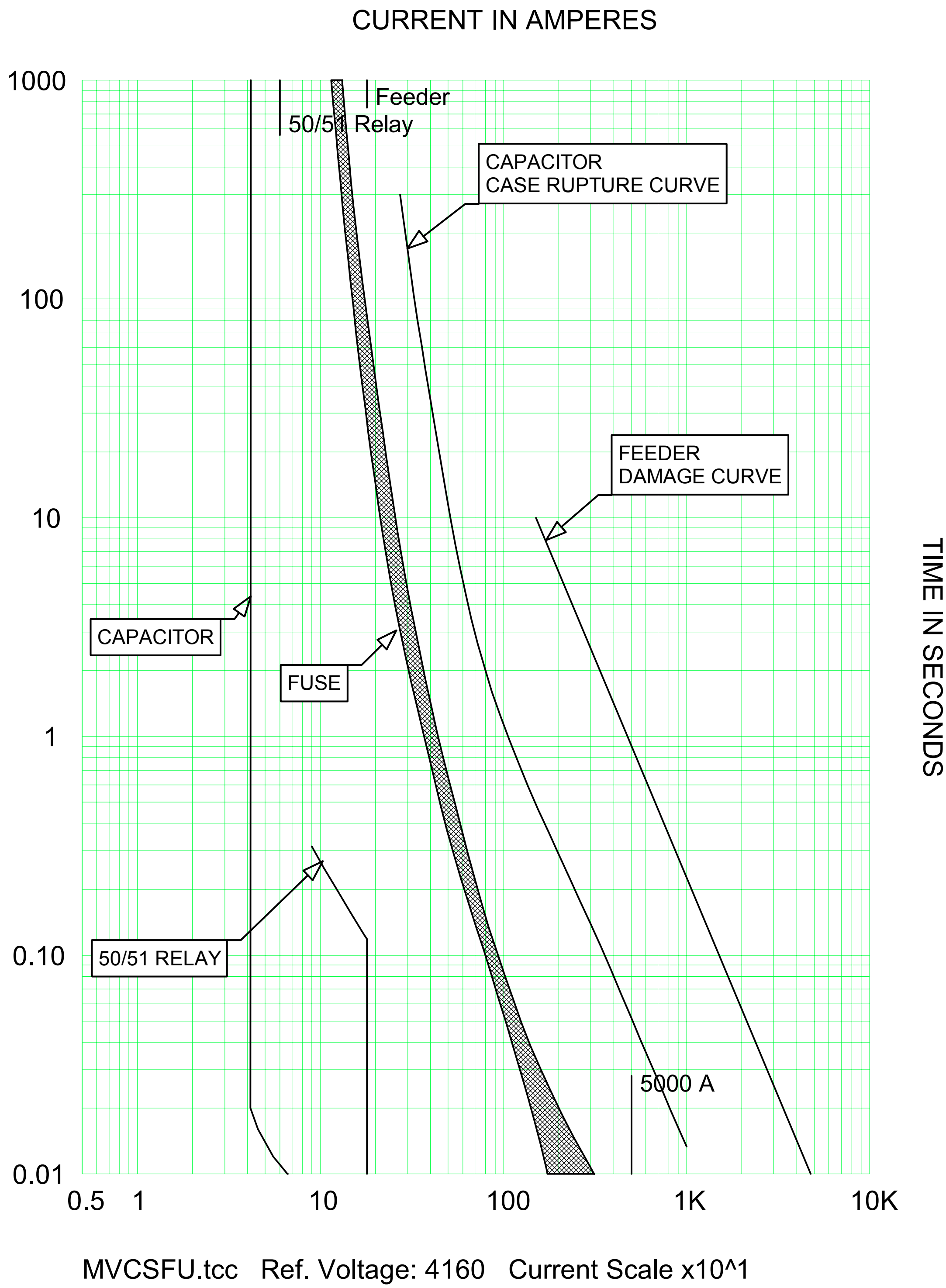


Fig. 48 – MV Capacitor Switchgear Feeder Unit

MV Main Service Switchgear Feeder Unit

Industry standard overcurrent protection schemes for switchgear main circuit breakers include an overcurrent relay (device 51). However, there are those who believe in adding an instantaneous function (device 50). The problem with adding this function is that the main and feeder instantaneous functions will never be selective. Those who do this, accept the risk of nuisance tripping in order to reduce tripping times for a fault on the main bus. The relay characteristics are plotted on a phase TCC along with upstream and downstream protective device characteristics.

The purpose of the 51 relay is to provide overcurrent protection for the main service bus and feeder. The 51 relay must be selective with downstream feeder relays.

Suggested margins are listed below that have historically allowed for safe operation of the main bus and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
CT	Size	$\geq$ 100% Bus Rating	
51	Pickup	$\leq$ 100% Bus Rating	Do not set pickup according to load.
			Set above the transformer FLA.
			Set below the transformer damage curve.
			Set at or below feeder ampacity.
			Set below the feeder damage curve.
			Do not set above main bus ampacity
51	Time Dial	No Specific Rule	Set above feeder relays.
			Set below transformer primary relay if possible. Not necessary to coordinate since devices are in series.

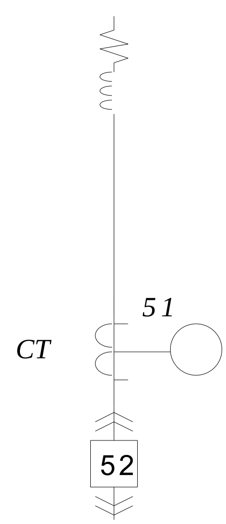


Fig. 49 – MV Main Service Switchgear Feeder Unit

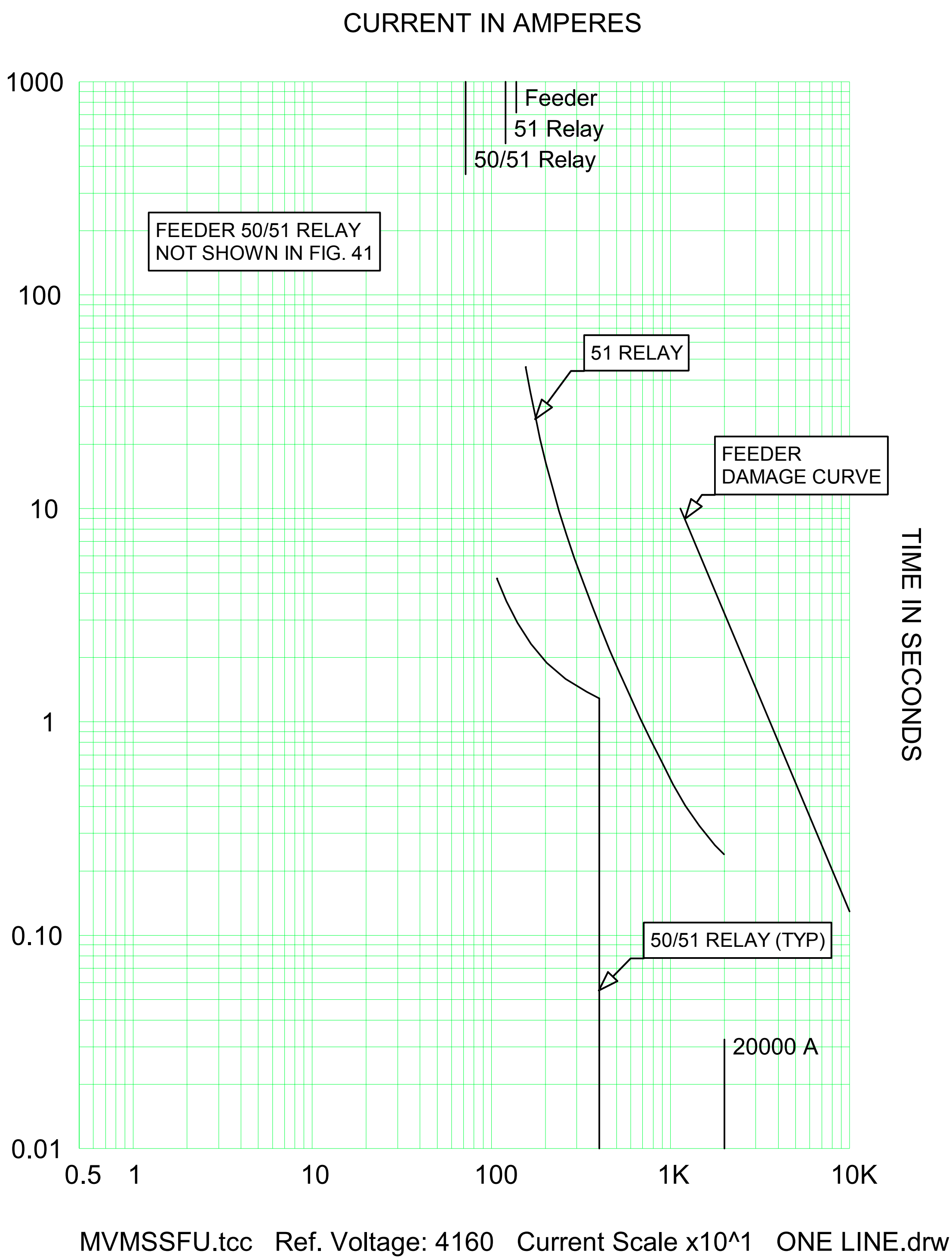


Fig. 50 – MV Main Service Switchgear Feeder Unit

LV Main Service Power Circuit Breaker Feeder Unit

Industry standard phase overcurrent functions purchased with main service PCB include long time and short time functions. Do not purchase main PCBs with an instantaneous function. Main PCBs purchased with instantaneous functions will not be selective with feeder PCBs and defeat one of the purposes of purchasing switchgear over switchboard. The PCB characteristics are plotted on a phase TCC along with the upstream and downstream protective devices, and the primary feeder damage curve.

The purpose of the main PCB is to provide overcurrent protection for the main service bus. The main PCB must be selective with downstream feeder devices. Note it is not always possible to be below the cable amp rating due to beaker trip unit tolerances and feeder sizing practices.

Suggested margins are listed below that have historically allowed for safe operation of the main bus and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
PCB	LTPU	100% of Bus Rating	Set at or below cable ampacity.
PCB	LTD, STPU & STD	Minimum	Selective with downstream devices.
			Cable damage curve must be above the point defined by the maximum fault current and the STD clear curve.
PCB	I^2T	In or Out	Selective with downstream devices.
PCB	INST	Out	Do not purchase instantaneous function.

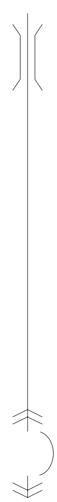


Fig. 51 – LV Main Service Power Circuit Breaker Feeder Unit

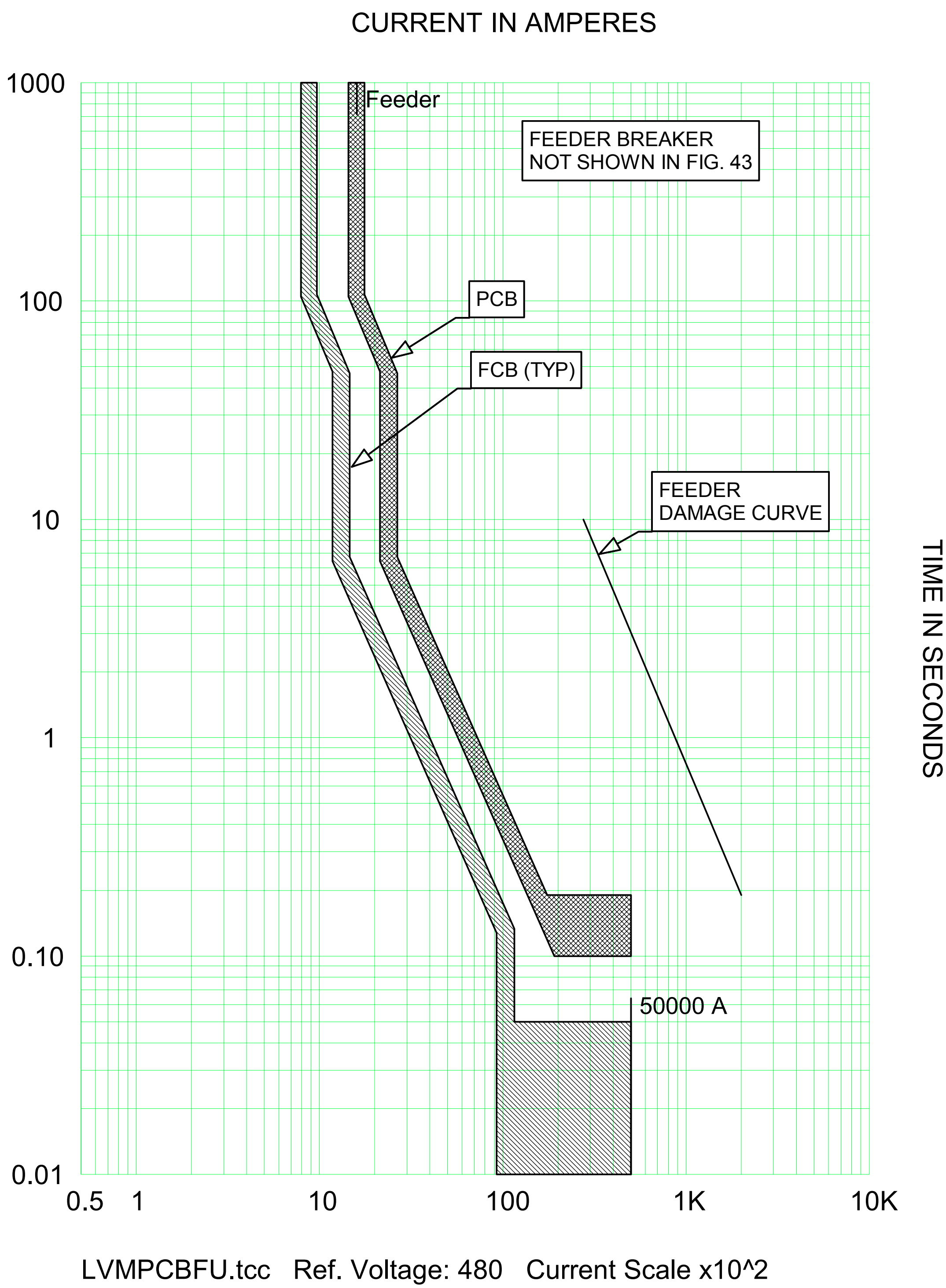


Fig. 52 – LV Main Service Power Circuit Breaker Feeder Unit

LV Main Service Molded-Case Circuit Breaker Feeder Unit

Industry standard phase overcurrent functions purchased with main service molded case CBs include long time, short time and instantaneous functions. Main CBs with instantaneous functions will not be selective with downstream feeder CBs. This is an unfortunate fact of life with molded case breakers. The CB characteristics are plotted on a phase TCC along with the upstream and downstream protective devices, and the primary feeder damage curve.

The purpose of the CB is to provide overcurrent protection for the main service bus and feeder. The CB must be selective with downstream feeder devices in the long time and short time regions. Note it is not always possible to be below the cable amp rating due to overload tolerances and feeder sizing practices.

Suggested margins are listed below that have historically allowed for safe operation of the main bus and cable while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
CB	LTPU	100% of Bus Rating	Set at or below cable ampacity.
CB	LTD, STPU & STD	Minimum	Selective with downstream devices.
CB	I^2T	In or Out	Selective with downstream devices.
CB	INST	Maximum	Cable damage curve must be above the point defined by the maximum fault current and the CB instantaneous clear curve.

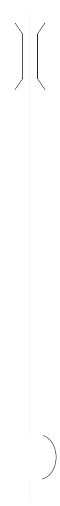


Fig. 53 – LV Main Service Molded-Case Circuit Breaker Feeder Unit

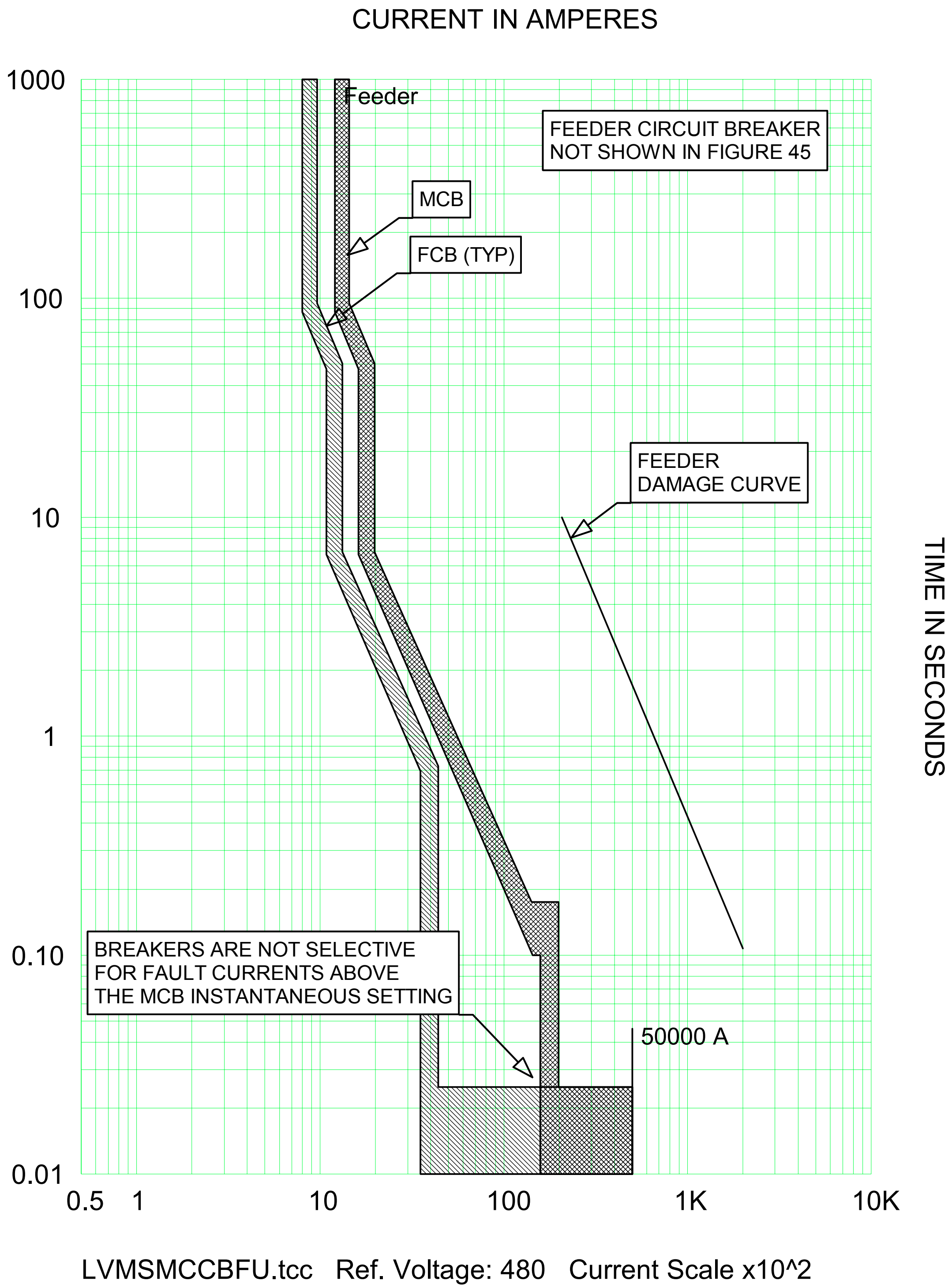


Fig. 54 – LV Main Service Molded-Case Circuit Breaker Feeder Unit

MV Resistor Grounded Systems

Industry standard ground overcurrent protection schemes for switchgear or fused starter distribution equipment include; residual neutral overcurrent relays (device 51N) on main breakers, instantaneous ground relays (device 50G) on feeders, and transformer neutral overcurrent relays (device 51G) monitoring ground resistors. All relay characteristics are plotted on a ground TCC along with the resistor damage point.

The 50G feeder ground relays are the first level of ground fault protection. The second level is the 51N relay on the main breaker. The 51G relay is the last level of ground fault protection. The 51N and 51G relays would trip the main switchgear breaker. The 51G relay would also trip the transformer HV feeder breaker.

Suggested margins are listed below that have historically allowed for safe operation of equipment while reducing instances of nuisance trips.

Device	Function	Recommendations	Comments
CT	Size	50% of $NGR_{Amp\ Rating}$	Typical NGR amp ratings are 200, 400, 1000 and 1200 amperes
51G	Pickup	25% of $NGR_{Amp\ Rating}$	Set below NRG amp rating
51G	Time Dial	Time Dial 2 for E-M relay	Set above 51N
51N	Pickup	25% of $NGR_{Amp\ Rating}$	Set at or below 51G
51N	Time Dial	Time Dial 1 for E-M relay	Set above feeder relays.
BYZ CT	Size	50/5	Typical all feeders.
50G	Pickup	5 amps primary	Typical all feeders.

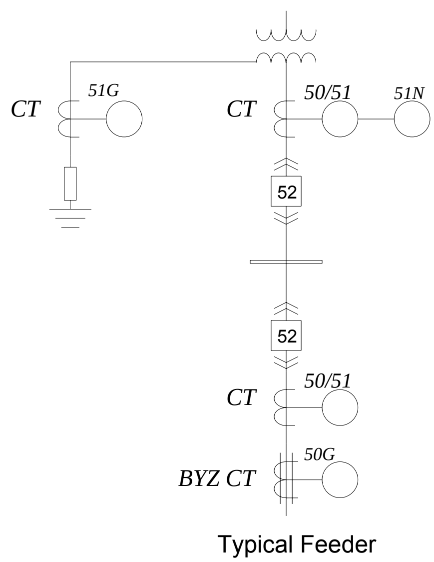


Fig. 55 – MV Resistor Grounded Systems

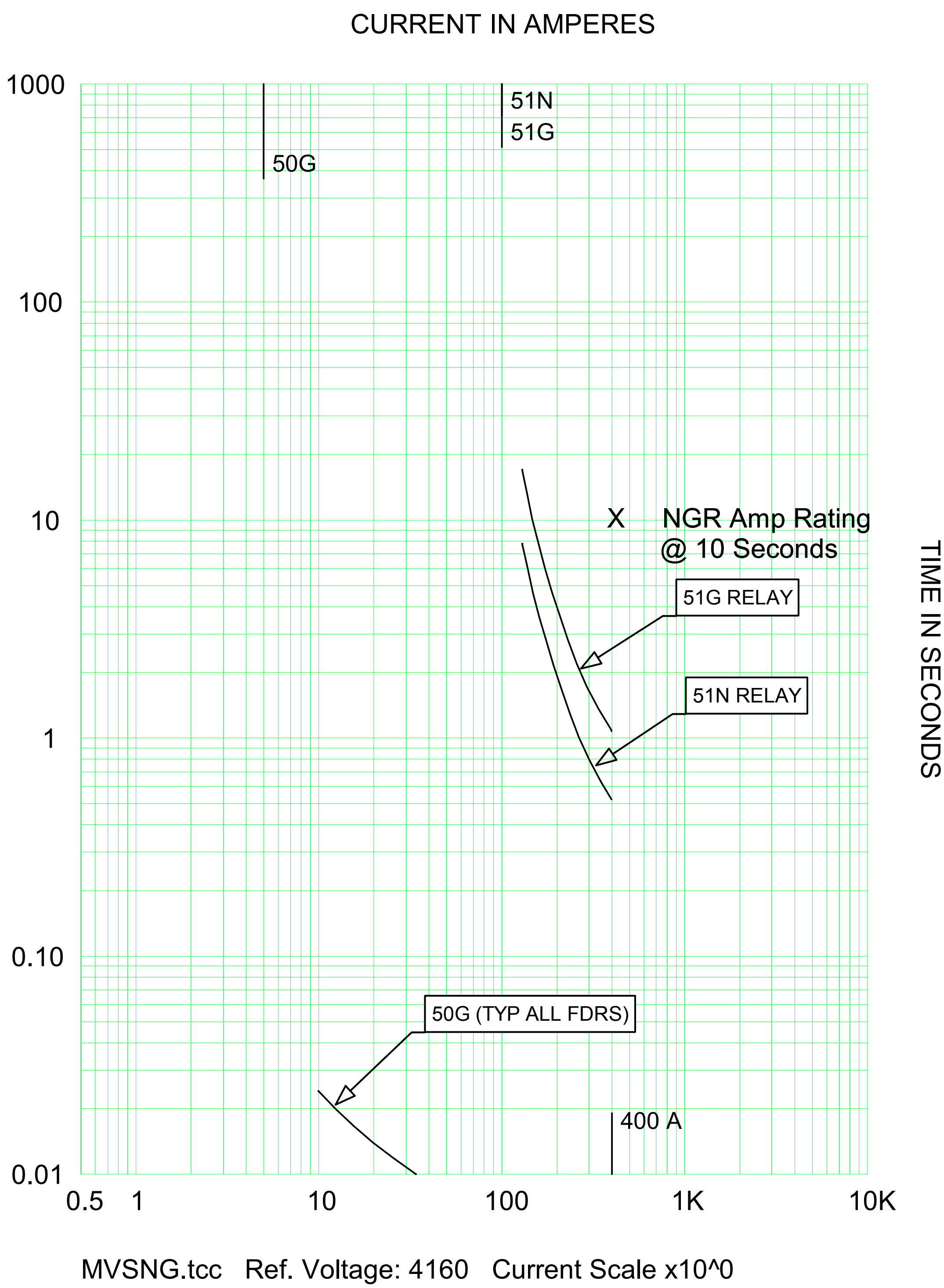


Fig. 56 – MV Resistor Grounded Systems

LV Solidly Grounded Systems

Ground fault protection is required on LV main services rated 1000 amps or more per the National Electrical Code. The main CB ground characteristics are plotted on a ground TCC along with feeder breaker and fuse characteristics.

Feeder breakers with integral or shunt trip ground fault protection are first level ground fault devices. These devices are never a problem to coordinate with. Other feeder breakers and fuses are also first level ground fault devices. These devices are a problem to coordinate with. Fuses greater than 100A, and thermal magnetic circuit breakers greater than 50A, will not be selective with main ground fault devices set at maximum pickup (1200 amps) and maximum time delay (0.5 seconds)!

This problem is compounded by the fact that, on many manufacturer's breakers, the ground fault pickup is a function of sensor rating with a setting range of 0.2 – 0.6. Therefore, a minimum sensor rating of 2000 amps is required to derive a maximum ground fault pickup setting of 1200 amps. Sensors less than 2000 amps have maximum ground fault pickups less than 1200 amps. Sensors greater than 2000 amps will have maximum ground fault pickup settings limited to 1200 amps.

Device	Function	Recommendations	Comments
51G	GFPU	$\leq$ 1200 amps	Selective with downstream devices.
51G	I^2T	In or Out	"In" if coordinating with fuses.
51G	GFD	Minimum	Selective with downstream devices.

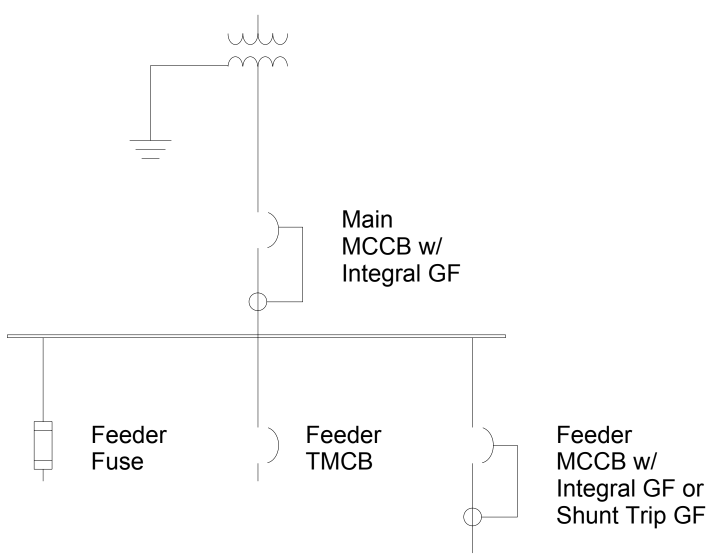


Fig. 57 – LV Solidly Grounded Systems

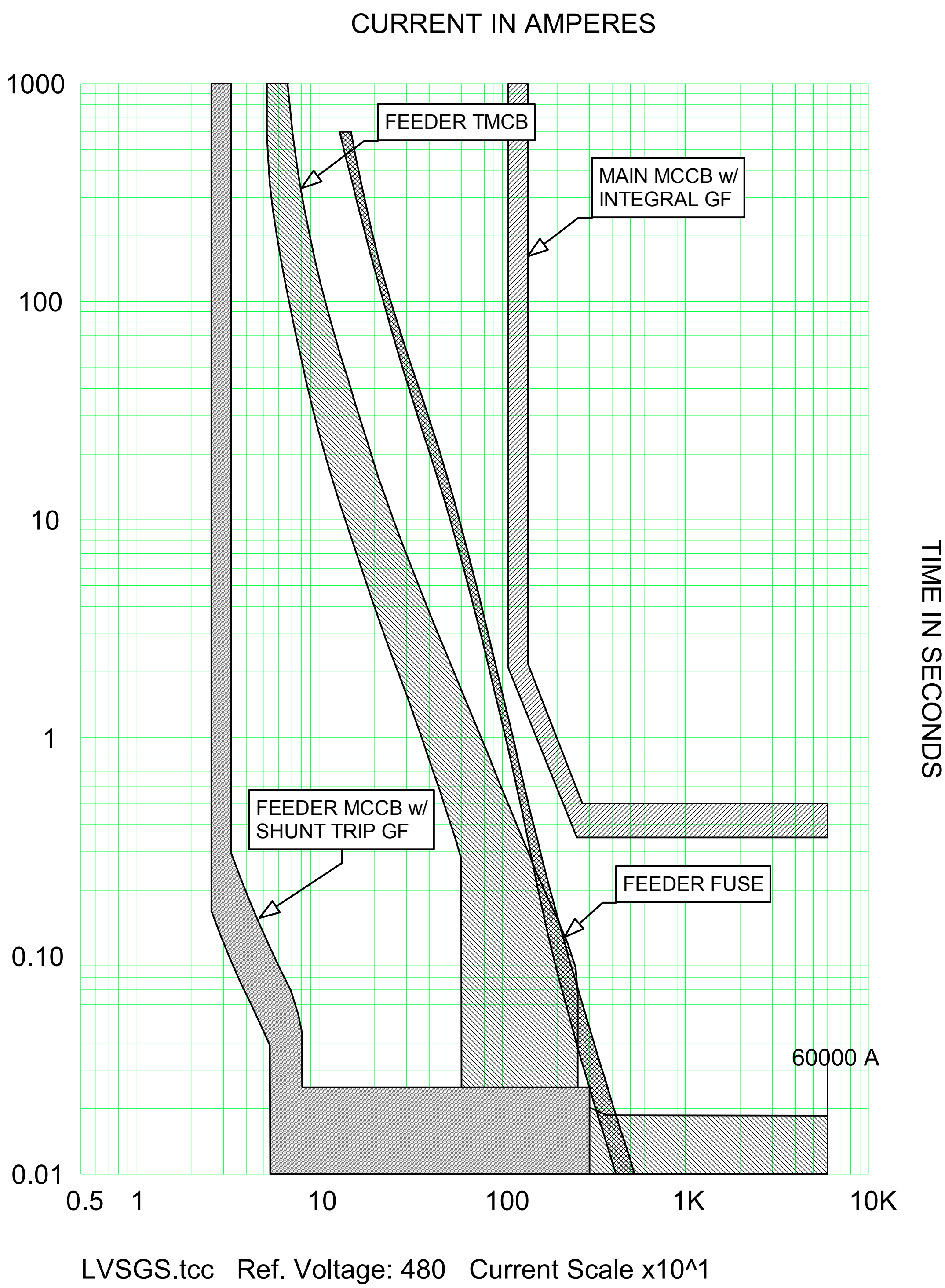


Fig. 58 – LV Solidly Grounded Systems

SECTION 6
STUDY PROCEDURE

The overcurrent coordination study procedure consists of six steps, Table 22.

Table 22 – Study Procedure

Step	Description	Zone Type
1	Break the Power System into Zones of Protection	-
2	Set the Protective Devices Serving All Directly Connected Loads	1
3	Set the Lowest Level Bus Main and Tie Protective Devices	2
4	Set the Bus Feeder Protective Device	3
5	Repeat Steps 3 and 4 Until Finished	-
6	Develop Protective Device Setting Summary Tables	-

The first step is to break the power system into zones of protection as shown in Fig. 59. The boundary for each zone is established by a protective device. Each protective device is included in two zones.

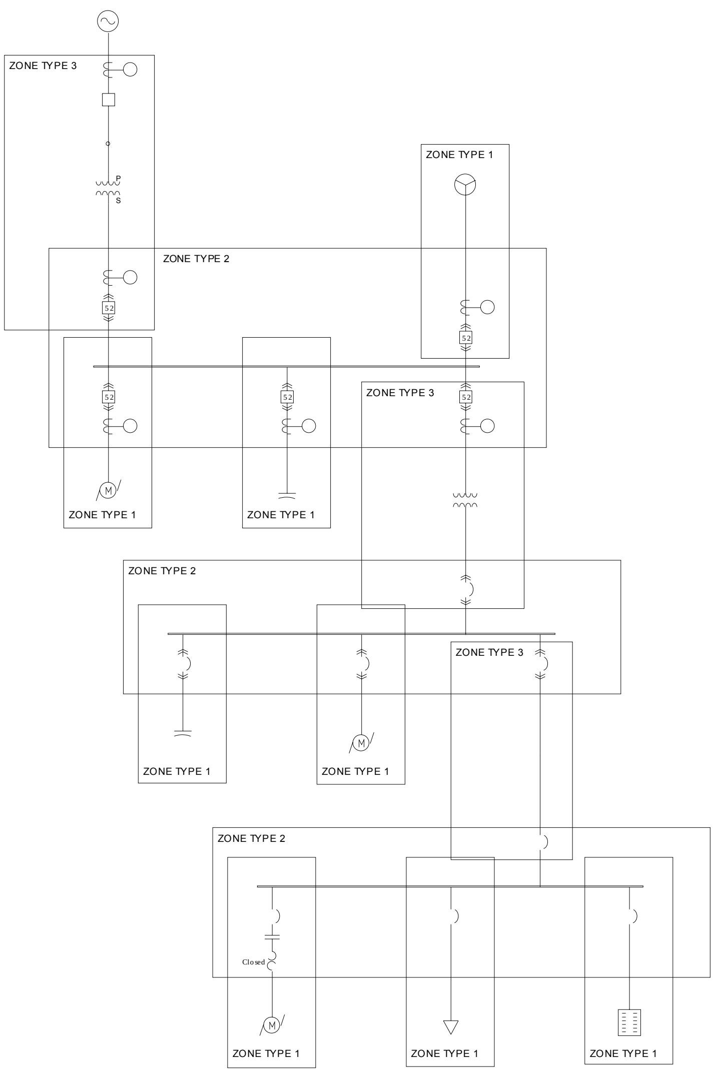


Fig. 59 – Zones of Protection

The second step is to set all the protective devices in Zone Type 1. Zone Type 1 includes all directly connected loads at each voltage level in the distribution system. This includes lighting panelboards, receptacle panelboards, motor starters, capacitors, heaters and generators. The third step is to set the main protective device at the lowest distribution board. The distribution board can be a panelboard, motor control center, switchboard or switchgear. The fourth step is to set the feeder protective device serving the distribution board in step 3. The distribution board service could be from a different voltage level through a step-down transformer, or at the same voltage level through a cable. The fifth step is to repeat steps 3 and 4 until the coordination is finished. The sixth and final step is to summarize protective device settings in summary tables.

This guide covered overcurrent coordination. However, when engineers are performing comprehensive protective device coordination studies other devices such as timers, metering interfaces, DCS interfaces and other protective devices need settings specified. An improper timer setting like an improper relay setting can have catastrophic consequences. Finally, when composing study reports, always categorize the results and recommendations in terms of life safety, equipment protection and selectivity.

SECTION 7
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24. UL 891 – December 23, 1998, *Dead-Front Switchboards*
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