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APPENDIX VIII

Protective Device Coordination Analysis Procedure

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VIII. Protective Device Coordination Analysis Procedure

A. SYSTEM (RELAY) COORDINATION STUDY PROCEDURES

1. Protective Devices

The primary function of protective devices in a power system is to detect short circuits and isolate the fault by activating the appropriate circuit interrupting devices. A protective device coordination study is required to properly select the protective devices and, in the case of adjustable devices, to properly select the necessary settings so that the intended goal will be achieved.

By industry standard definition (ANSI C37.100 1972) there is general agreement on the meaning of the term SELECTIVITY:

“Selectivity for a protective system, a general term describing the interrelated performance of relays, and other protective devices, whereby a minimum amount of equipment is removed from service for isolation of a fault or other abnormality.”

Obviously, selectivity is a desirable characteristic in a protective scheme. However, it is not always possible to obtain the desired degree of system and equipment protection in a selective fashion. The term COORDINATION is sometimes used to describe a reasonable compromise, based on a thorough engineering evaluation, between the mutually desirable but competing objectives of maximum protection and maximum availability. The protective device ratings and settings recommended in this study result from an exercise of judgment as to the best balance between these factors.

2. General Discussion

The following is a tested, generally accepted philosophy for selecting and setting protective devices:

- a) A feeder "first line" or "primary" protective device will remove a faulty circuit as quickly as possible.
- b) If the feeder primary protection fails a "back-up" protective device will remove the fault. The back-up function is usually provided by an upstream device, which acts as the primary device in its zone. Therefore, time-current coordination is required between the feeder primary and back-up protective devices.

The protective-device settings are individually chosen to accommodate circuit parameters. The criteria commonly used in determining the recommended feeder protective-device settings are:

- a) Full-load current.

- b) Allowance for selectivity with downstream protective devices set to the highest pickup and time delay.
- c) Compliance with American National Standards Institute (ANSI) and National Electrical Code (NEC) requirements.
- d) Avoidance of nuisance tripping due to transformer magnetizing inrush currents, motor starting currents, or load current peaks.
- e) Short-circuit current for faults occurring in the protected zone of the system.

3. The Mechanics of Coordination

The method for deriving the settings for the various overcurrent protective devices will be by plotting the time-current characteristic curves of these devices on a single overlay sheet of log-log coordination paper. The time-current curve is a graphical illustration of the protection and coordination. The characteristic curves for the protective devices are prepared by the various equipment manufacturers, based on testing to determine the time response of the device.

After the one-line diagram has been completed and the necessary short-circuit calculations made, the next step is to examine the system for the device or devices, which are most important in the protective arrangement of the system. In general, the analysis starts at the extremities of the system and works back toward the power source.

Usually the load, which will be the one of prime interest, will be the largest single device having the highest normal current. Motors, because of their overcurrent condition during the starting period will, in most cases, be the critical branch circuit for coordination. However, other special loads may have higher settings, and all the various branch circuits are surveyed to insure that the highest one is selected.

The next step is to prepare a simple one-line diagram of the circuit and protective devices to be studied. The bus numbers used on these diagrams and curves correspond to those on the system one-line diagram and in the Short Circuit Study. The short circuit currents, indicated by the numbered triangle, are then located on the curve. It should be noted that currents at different voltage levels, and consequently protective devices which operate at different voltages, can be illustrated on a single curve by adjusting the current to the voltage level indicated, based on equivalent MVA. If the one-line diagram, as determined from the data and drawings obtained at the time of this study, is changed to a new system configuration, or a higher utility short circuit is available, or new loads added to the electrical system, the change in short circuit current may affect how well a particular plot of time-current curves predicts the coordination of the system. For this reason, coordination studies should be based on up-to-date short circuit calculations and system configuration.

The full load current and inrush over currents are identified for each load on load center to be studied. Protection limits for significant elements, such as cable, transformers or motors, are drawn on the curve as "landmarks" for determining the degree of protection/coordination achieved. These protection limits are derived from

the latest edition of the National Electrical Code (NEC), American National Standards Institute (ANSI), or generally accepted engineering practice and published data.

The next step is to determine the device type, rating or settings, which, in the judgment of the Power Systems Engineer, offers protection and selectivity with the other protective devices considered in this analysis, and to plot the resulting characteristic on the curve. The emphasis on choices and compromises are included to point out that there seldom is one "right" answer. A number of constraints will affect the final selection. Compromises are continually made between protection and service continuity. Knowledge of the process will also play a large part in making many of the decisions about device settings.

4. Time Margin and Other Considerations for Selective Coordination

Selective coordination is usually obtained when a definite time separation exists between the operating characteristics of series connected protective devices.

The required time separation or "coordination margin" between relay time current characteristics is determined by the sum of three (3) items: (1) relay over travel, (2) breaker total clearing time, and (3) safety margin. Many engineers assume that 0.1 second is a conservative over travel estimate for electromechanical relays. Solid-state relays have no over travel. Breaker total clearing time varies from three (3) to twelve (12) cycles. The safety margin takes into consideration the manufacturing and calibration tolerances of the relay are a function of the conservatism of the engineer. Times from 0.1 to 0.2 seconds are used for the safety margin. The coordination margin must exist between the relay curves at the highest pickup of the two (2) relays, at the instantaneous setting of the downstream (i.e., load-side feeder) breaker relay, and at the maximum short circuit current which can flow through both devices simultaneously. Typically, this coordination margin is 0.2 to 0.4 seconds.

For direct-acting and static trips, the coordination margin is, generally, a clear space (no overlap) between device characteristics. Series connected instantaneous trips will not be selective for fault current magnitudes above the higher set trip.

The characteristics for power fuses typically depict the minimum melt time and the total clearing time of the fuse. For some low-voltage fuses, the manufacturer will publish only one (1) curve representing an average clearing time. Generally, a clear space between fuse curves is an acceptable coordination margin; however, some fuse types require a safety margin or "setback allowance". The curves do not depict the characteristics for the fuse below .01 seconds. Selectivity for fuses, which would be operating in the half cycle region, depends on whether or not the let-through energy of the downstream fuse is less than the minimum energy required to start melting the upstream fuse. Fuse manufacturers usually provide a tabulation indicating the ratio of fuse sizes for various classes of fuses, which should result in selective coordination in the high fault current region.

To determine if the appropriate time separation exists between protective devices, the current each device "sees" must be considered. For instance, the transformer winding configuration affects the per-unit magnitudes of primary versus secondary fault

currents. A phase-to-phase fault on a delta-wye transformer (solidly grounded neutral) will result in a fault current flow of 87% of the three-phase fault current in both faulted lines and secondary windings; however, one of the primary lines will be carrying 100% of the three-phase fault current. In other words, the primary side protective device would see 16% more current than the secondary side device.

The time-variation or decrement of short circuit currents, as well as the relative magnitude of fault current, must be considered. For example, a main device may see less current than a feeder device, or, in the case of multiple sources, the incoming protective devices will operate on a different order of magnitude of fault current compared to that seen by the downstream device.

Some apparent compromises in selectivity (i.e. overlapping device characteristics) are not major concerns due to the fact that the current magnitude expected for any type of fault is beyond this operating region of the devices. In some instances, these compromises are acceptable from the standpoint that the tripping of both devices insures better protection without resulting in a more widespread outage.

Ground fault relays are insensitive to normal current flow; hence, they can be set to respond faster than the phase overcurrent devices. The time separation required between these relays is the same as their phase overcurrent counterparts for devices operating within the same ground fault zone. The delta connected winding of transformers do not pass zero-sequence fault currents; therefore, the ground fault devices at one (1) system voltage level need not coordinate with those on another voltage level.

5. NEC Requirements

Enactment of the Federal Occupational Safety and Health Act of 1970 (OSHA) has made strict compliance with the National Electrical Code (NFPA No. 70, ANSI No. C1) a legal requirement on all new construction after 15 March 1972. Prior to OSHA, industrial plants were generally exempt from NEC requirements. Today the Code has the effect of Federal Law although its provisions are generally not retroactively enforceable on equipment installed before 15 March 1972.

The NEC describes itself as containing "provisions considered necessary for safety." The NEC was prepared by a team of recognized authorities and is based on firm engineering principles. Thus, while the NEC may not be strictly enforceable in some of the older portions of a system, it is an excellent standard by which an entire system can be judged.

The Articles of the NEC which are most frequently referenced in this portion of the study include:

- 230 Services
- 240 Overcurrent Protection
- 430 Motors, Motor Circuits and Controllers
- 450 Transformers and Transformer Vaults

In addition, Article 310 Conductors for General Wiring is used as the source for cable ampacities. Conductor, motor and transformer protection is discussed in greater detail for each circuit analyzed by a time-current curve.

TRANSFORMER OVER CURRENT PROTECTION IN SUPERVISED LOCATIONS

(based on multiples of rated full load current)

IMPEDANCE	PRIMARY SIDE			SECONDARY SIDE		
	VOLTAGE	CIRCUIT BREAKER	FUSE	>600V		≤600V
				CIRCUIT BREAKER	FUSE	CB OR FUSE
≤ 6%	>600 V	6X	3X	3X	2.5X	2.5X
>6% ≤10%	>600 V	4X	3X	2.5X	2.25X	2.5X
ALL	<600 V	3X	2.5X	NONE	NONE	NONE
≤ 6%	<600 V	6X	3X	3X	2.5X	2.5X*
>6% ≤10%	<600 V		4X	2.5X	2.25X	2.5X*

* See Note 5

NOTES:

1. Where the required fuse rating or circuit breaker setting does not correspond to a standard rating or setting, a higher rating or setting that does not to exceed the next higher standard rating or setting shall be permitted.
2. Where secondary overcurrent protection is required, the secondary overcurrent device shall be permitted to consist of not more than six (6) circuit breakers or six (6) sets of fuses grouped in one (1) location. Where multiple overcurrent devices are utilized, the total of all the device ratings shall not exceed the allowed value of a single overcurrent device. If both circuit breakers and fuses are used as the overcurrent device, the total of the device ratings shall not exceed that allowed for fuses.
3. A supervised location is a location where conditions of maintenance and supervision ensure that only qualified persons monitor and service the transformer installations.
4. Electronically actuated fuses that may be set to open at a specific current shall be set in accordance with settings for circuit breakers.
5. A transformer equipped with a coordinated thermal overload protection by the manufacturer shall be permitted to have separate secondary protection omitted.

6. American National Standard for Transformers

The ANSI curve, which may be shown on the time-current curves, represents the amount of mechanical and thermal stresses a distribution or power transformer is required to withstand without injury, as specified by ANSI-C57.12-1973.

ANSI Standard C57.12.00-b-1978 entitled "Thermal and Short-circuit Requirements Supplement to ANSI C57.12.00-1973 General Requirements for Distribution, Power and Regulating Transformers" defines short circuit current and time limits for four (4) categories of transformers.

TRANSFORMER CATEGORIES

CATEGORY	KVA		WITH STAND CAPABILITY	
	SINGLE-PHASE	THREE-PHASE	SECONDS	PER-UNIT BASE CURRENT
I	5 TO 25	15 TO 75	$1250/I^2$	40 OR $1/Z_t$
I	37 TO 100	112 TO 300	$1250/I^2$	35 OR $1/Z_t$
I	167 TO 500	500	$1250/I^2$	25 OR $1/Z_t$
				CHOOSE THE SMALLER VALUE
II	501 TO 1667	501 TO 5000	2*	$1/Z_t$ *
III	1668 TO 10000	5001 TO 30000	2*	$1/(Z_t + Z_s)$ *
IV	10000	30000	2*	$1/(Z_t + Z_s)$ *

I = Symmetrical short-circuit current in times normal base current
(transformer self-cooled rating)

Z_t = Transformer per-unit impedance

Z_s = System per-unit impedance on transformer base

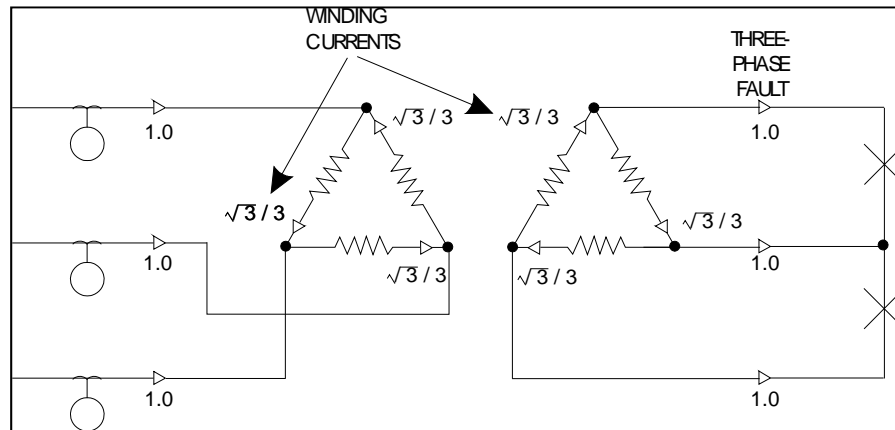
*These points define an I^2t curve in the short time region. This region is from 70% to 100% of maximum through-fault current for Category II and 50% to 100% for Category III.

The following pages show line and winding currents in delta-delta and delta-wye connected transformers for different fault conditions. Note that a line-to-ground fault on a solidly grounded system supplied from a delta-wye transformer produces a maximum winding current at only 58% of maximum line current in certain windings and lines. Similarly, a line-to-line fault on an ungrounded system supplied from a delta-delta transformer produces maximum winding currents at only 87% of maximum line current in certain windings and lines. These considerations dictate a lower rating or setting of primary protective devices based on either 58% or 87% of the maximum through-fault transformer withstand ability. To account for this, the withstand ability curve usually is shifted to lower current values prior to the selection of a protective device.

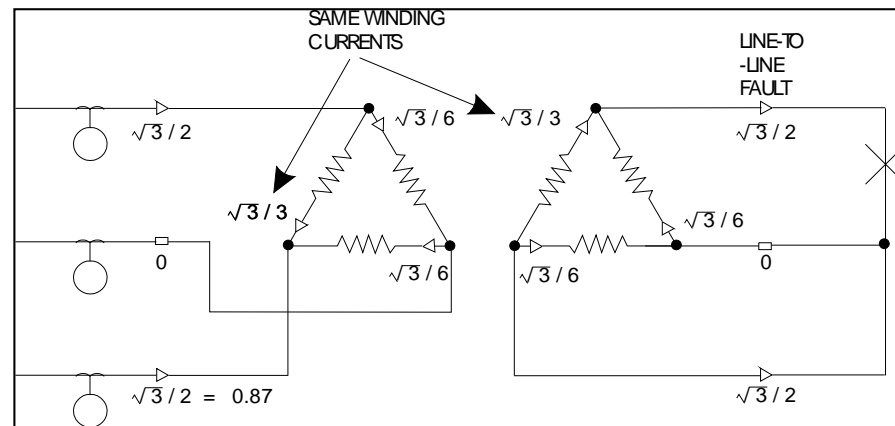
7. Setting Three-Phase Transformer Primary Protective Devices

The following diagrams illustrate connections requiring settings below 0.87 or 0.58 per-unit of the current to a three-phase secondary fault. All current magnitudes are in per-unit of the line current during a three-phase secondary bolted short circuit.

a) Delta-Delta Transformer:

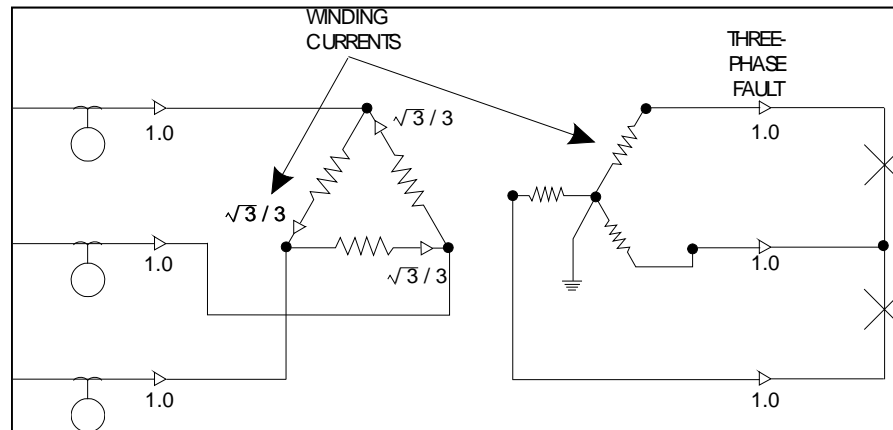


- i. Three-phase secondary short circuit. Maximum winding currents approach ANSI Standard withstands.

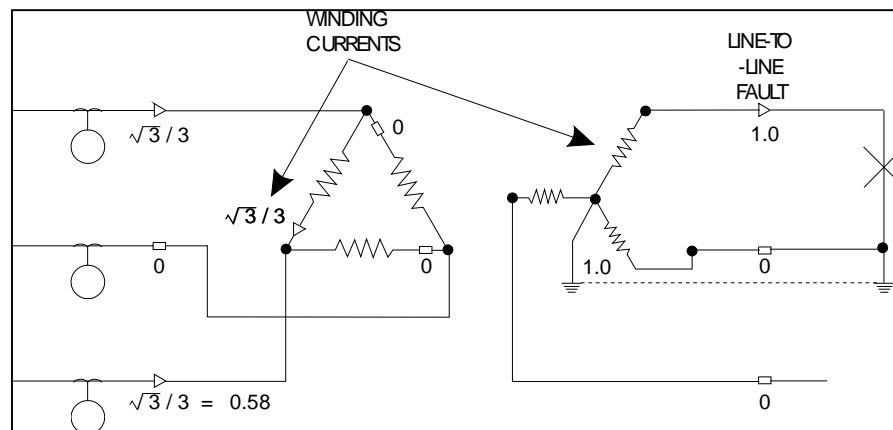


- ii. Fault with same current in windings of one core leg but less primary line current.

b) Delta Wye Transformer with secondary neutral solidly grounded:



- i. Three phase secondary short circuit. Maximum winding currents approach ANSI Standard withstands.



- ii. Fault with approximately the same current in windings of one core leg but less primary line current.

8. Calibration & Testing of Recommended Protective Relay Settings

Coordination established in this report required that the individual device operating characteristics do not depart appreciably from those shown on the coordination curves. The specified settings will provide operation of the devices essentially as shown. However, the device tolerance and the difficulty in exact field settings may result in deviations from the specified operating times. Therefore, it is recommended the settings be calibrated by field tests to obtain the desired response.

Coordination depends on operation of the protective devices as shown, though normally inactive for long periods. To assure continuing coordination, it is essential the protective devices be calibrated and checked at regular intervals by a qualified engineer using well-maintained test equipment appropriate for the device to be calibrated and tested.

9. Field Testing & Application of Recommended Protective Relay Settings

To accomplish the physical reality of a coordinated protective relay system, proper relay settings must be established by test in the field and all the physical devices must be in proper working condition.

- a) The protective relays must be checked for good operating conditions.
- b) CT and PT ratios and connections must be checked for correctness.
- c) Directional phase and ground relays must be checked for correct directional throw using system load currents and voltages.
- d) Relays must be calibrated, and settings must be applied BY TEST using proper test equipment. Relays should be left in their cases during calibration and test procedures.
- e) Differential relay circuits must be checked for correct balance with primary circuit under load.
- f) D C control relays, and control circuits for breaker tripping must be correct and in good operating condition.
- g) D C batteries, which supply d c control power, must be kept in good and reliable condition. Battery chargers must be kept in good condition.
- h) Breakers must be maintained in good operating condition.
- i) Pilot wire circuits must be checked for continuity.

All protective relays so tested should be sealed. This is very important to be sure that only knowledgeable, authorized personnel are permitted to work on protective relays. Future work on protective relay maintenance or relay setting changes should also require that whoever does it also seals the relays.

10. Fuse Coordination Considerations

- a) Fuse Types, Ratings and Application

Some of the more common fuses found in industrial use are as follows:

UL Class	Short Circuit Rating	Description
H	10000	General-Purpose Renewable.
J	200000	Below 600 amps, non-renewable, current-limiting.
L	200000	601-6000 amps, non-renewable, current-limiting, some time-delay.
R	200000	Rejection fuse holder accepts only Class R to assure short circuit rating.
K1	200000	Non-renewable, high degree of current limitation.
K5	200000	Non-renewable, dual-element, time-delay, some current limitation.
"R" Rated (Medium-Voltage)	Varies	Non-renewable current-limiting type generally used for medium-voltage motor circuits.
"E" Rated (Medium-Voltage)	Varies	Non-renewable current-limiting type general-purpose fuse used for transformer and feeder protection.

Class H: Class H fuses are single element, all purpose fuses which are generally used in low amperage circuits where the system capacity is low. Extreme care should be taken to insure that these fuses are not applied to parts of the system where the system fault capacity exceeds the short circuit interrupting rating of the fuse (10000 amps).

Class J: Class J fuses are normally applied to provide short circuit protection in lower amperage circuits. The high degree of current limitation and higher interrupting rating make these

fuses the choice over the Class H fuse in locations of higher system short circuit capacity.

Class L: Class L fuses are commonly used to protect service entrances and large feeders where system capacities are high. Rated from 601 to 6000 amperes, these fuses provide the current limitation and high capability necessary to give adequate short circuit protection to main feeders.

Class R: Class R fuses are used in places of high short circuit capacity. Their purpose is to insure that a fuse with a lower interrupting rating cannot be substituted; hence, the name "rejection" fuse. It should be noted that normally fused switch panels cannot obtain a UL rating above 10000 amps unless some type of "rejection" fuse clips are used to prevent the interchangeability of fuse classes.

Class K1: Class K1 fuses are similar to Class J fuses with a high degree of current limitation in the short circuit region. K1 fuses are most often applied to protect equipment which cannot withstand high short circuit currents, such as low interrupting capacity circuit breakers; RK1 fuses are most commonly used to insure replacement with the same class fuse, the R signifying the rejection feature.

Class K5: Class K5 fuses have a dual element construction giving them a long time delay characteristic in the overload region, combined with a degree of current limitation. These fuses are commonly used for motor and transformer protection where the time delay characteristic allows for inrush currents while providing close protection. K5 fuses can usually be sized closer to motor full load currents than most other types of low voltage fuses. As with the Class K1, the Class K5 fuse is commonly combined with the rejection feature.

Class R: Medium voltage fuses, current limiting, used for short circuit protection.

Class E: Medium voltage fuses, current limiting, used for short circuit and overcurrent protection.

b) Fuse Selection for Coordination

An important consideration in fuse selection is providing coordination with upstream and downstream fuses at the fault level. Selectivity between similar fuses is normally maintained if 2:1 ratio is observed. However, to gain selectivity between current limiting fuses of different downstream, dual element, time delay (or K5) fuse requires at least a 4:1 ratio. Published information tabulating fuse size ratios for coordination is readily available from the fuse manufacturer, as shown in the Blackout Prevention Table on the next page.

Coordination of a fuse with an upstream circuit breaker instantaneous characteristic is usually not possible. However, if the peak let through current of a current limiting fuse at the appropriate fault level is below the upstream breaker instantaneous setting, then selectivity could be achieved. It is only the exceptional circumstances where this is possible.

BLACKOUT PREVENTION SELECTIVITY GUIDE*		B. LOAD SIDE FUSE								
		KRP-C HI-CAP TIME-DELAY FUSE 601-6000A	KTU LIMITRON FAST-ACTING FUSE 601-600A	KTN, KTS, KTN-R, KTS-R, LIMITRON FAST-ACTING FUSE 0-600A	JJM, JJS, TRON FAST-ACTING FUSE (CLASS T) 0-600A	JKS LIMITRON QUICK-ACTING FUSE (CLASS J) 0-600A	FRN, FRS, FRN-R, FRS-R, FUSETRON DUAL-ELEMENT FUSE 0-600A	LPN, LPS, LPN-R, LPS-R, LOW PEAK DUAL-ELEMENT FUSE 0-600A	JMC HI CAP TIME-DELAY FUSE (CLASS J DIM.) 15-600A	SC TYPE FUSE (CLASS G) 0-600A
LINE SIDE FUSE	KRP-C HI-CAP TIME-DELAY FUSE 601-6000A	2:1	2:1	2:1	2:1	2:1	4:1	3:1	3:1	**
	KTU LIMITRON FAST-ACTING FUSE 601-6000A	2:1	2:1	2:1	2:1	2:1	6:1	5:1	5:1	**
	KTN, KTS, KTN-R, KTS-R, LIMITRON FAST-ACTING FUSE 0-600A	--	--	3:1	3:1	3:1	8:1	4:1	4:1	4:1
	JJM, JJS, TROM FAST-ACTING FUSE (CLASS T) 0-600A	--	--	3:1	3:1	3:1	8:1	4:1	4:1	4:1
	JKS LIMITRON QUICK-ACTING FUSE (CLASS J) 0-600A	--	--	3:1	3:1	3:1	8:1	4:1	4:1	4:1
	FRN, FRS, FRN-R, FRS-R, FUSETRON DUAL-ELEMENT FUSE 0-600A	--		1.5:1	1.5:1	1.5:1	2:1	1.5:1	1.5:1	1.5:1
	LPN, LPS, LPN-R, LPS-R, LOW PEAK DUAL-ELEMENT FUSE 0-600A	--	--	1.5:1	1.5:1	1.5:1	4:1	2:1	2:1	2:1
	JMC HI CAP TIME-DELAY FUSE (CLASS J DIM.) 15-600A	--	--	1.5:1	1.5:1	1.5:1	4:1	2:1	2:1	2:1
	SC TYPE FUSE (CLASS G) 0-600A	--	--	2:1	2:1	2:1	4:1	4:1	3:1	2:1

* Applies only to the indicated BUSS fuses.

** SC fuses available in sizes up to 60 amps. Selectivity is not an issue here.

II. RECOMMENDED TRANSFORMER FUSE SIZE

A. PRIMARY VOLTAGE

kVA	13.8 kV	4.16 kV	kVA	2.4 kV
500	25E, 30E, 40E, 50E, 65E	65E, 80E, 100E, 125E, 150E, 175E, 200E	105	25E, 30E, 40E, 50E, 65E
750	30E, 40E, 50E, 65E, 80E	100E, 125E, 150E, 175E, 200E, 250E, 300E	600	150E, 175E, 200E, 250E, 300E, 400E
1000	40E, 50E, 65E, 80E, 100E, 125E	125E, 150E, 175E, 200E, 250E, 300E, 400E	880	225E, 250E, 300E, 400E, 2-250E, 2-300E
1500	50E, 65E, 80E, 100E, 125E, 150E, 175E	200E, 250E, 300E, 400E, 2-250E, 2-300E		
2000	80E, 100E, 125E, 150E, 175E, 200E, 250E	250E, 300E, 400E, 2-250E, 2-300E, 2-400E		
2500	100E, 125E, 150E, 175E, 200E, 250E, 300E	N/A		
3750	175E, 200E, 225E, 2-225E, 250E, 300E, 400E	N/A		
10000	2-225E, 2-250E, 2-300E, 400E, 2-400E	N/A		

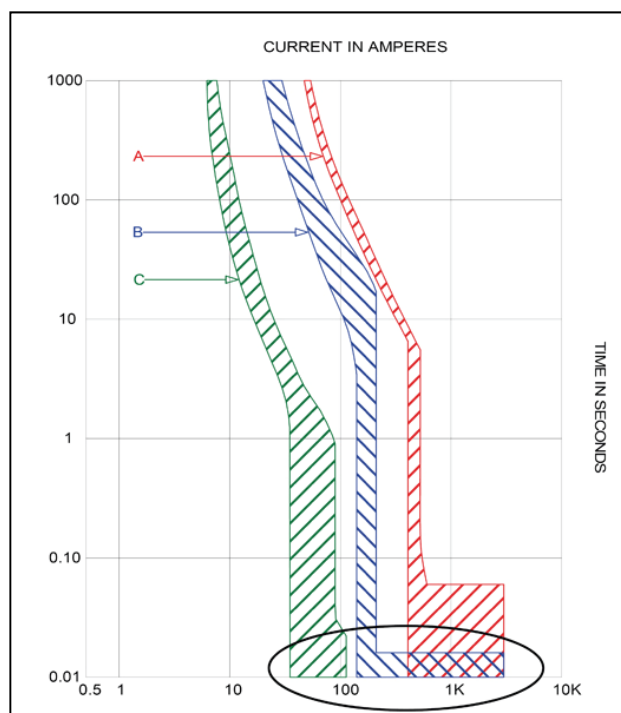
B. Considerations

1. Short-Circuit Current Considerations

All protective device characteristic curves shown on the time-current graphs end at the calculated maximum short-circuit current at that device.

2. Molded Case Breaker Coordination

A molded case circuit breaker will trip with no intentional time delay for short-circuit currents above its instantaneous trip setting. Because of this, molded case breakers in series can only be selectively coordinated with each other if there is sufficient impedance between them so that the maximum available short-circuit current at the downstream breaker is less than the instantaneous trip setting of the upstream breaker. In Figure 2, breaker “C” illustrates this principle.



There is enough cable impedance to limit the maximum available short-circuit current at “C” to less than the instantaneous trip setting of either “A” or “B”. When molded case breakers are in series without sufficient impedance between them to permit complete coordination, e.g., a panel main breaker and one of the branch devices in the panel, the time-current curves will overlap in the high-current instantaneous trip region. This is illustrated by the overlap between the curves for devices “A” and “B” in Figure 2. Most molded case breakers exhibit some degree of current limitation that will often result in selective operation in the overlap region. Time-current coordination curves included in this report do not match the results from Square D’s data bulletin (0100DB0501R3). The software used to generate the curves is incapable of accounting for the dynamic impedance the system has when two or more devices in series “see” a fault. The data bulletin takes the dynamic impedance introduced by the

downstream device into account. Greater separation between the instantaneous settings may increase the likelihood that the two devices will operate selectively. The potential lack of coordination is generally not considered critical and can be avoided only by adopting a different and, in general, less economically practical design especially when the following are considered:

- Most faults occur in equipment such as motors, lighting panels, and process control panels which typically are located at the end of branch circuits, significantly reducing fault level and thereby reducing or eliminating the possibility of non-selective operation.
- Lower magnitude arcing faults in rotating machinery and lighting panels are statistically more common than bolted three-phase faults.
- Ground faults are more common than three-phase faults.
- Maximum fault current is a random event depending on point-on-wave of the fault occurrence and other factors.
- The device cutoff points on time-current coordination graphs are based on bolted fault current levels which correspond to zero impedance. Typical fault current impedance is usually greater than zero so the actual fault current seen by overcurrent devices can be less than what is shown on the time-current coordination graphs.

Recommended breaker trip settings are given in the "OVERCURRENT DEVICE SETTING TABLE – LV CIRCUIT BREAKERS". In addition, an illustration of the actual magnetic trip adjustment dials for Square D circuit breakers is included in the REFERENCES section to aid the setting process.

3. Time-Overcurrent Relay Coordination

The overcurrent relays were examined and settings selected to provide the best possible coordination with the appropriate line and load side protective devices.

These relay time-current curves are plotted as single lines as opposed to the manufacturing tolerance band plotted for fuse and low-voltage circuit breakers. However, certain time margins have been considered when coordinating these relays. These time margins account for manufacturing tolerances, induction disk over-travel, circuit breaker opening time and a safety margin. The coordinating time margins consist of the downstream breaker clearing time plus the upstream relay disk overtravel time, plus a safety margin to account for relay and CT inaccuracies. For electromechanical relays, time margins of 0.3-0.4 seconds are desirable. For digital relays upstream, there is no significant allowance necessary for overtravel and a smaller interval such as 0.25-0.3 seconds can be used. For fuses upstream, a 10% margin in current for any time or a 25% margin in time for any current may be used to account for ambient temperature and preloading effects.

Only the protective settings shown in the study setting table are supplied. Other relay settings required for normal operation (i.e. general system, logic, control, LED read-out, etc) are not considered within the study scope and must be provided in the field by the test engineer/s responsible for initial relay programming and operation. Please refer to Square D's approval/record drawings for the Medium Voltage Switchgear equipment regarding required control and timing setpoints.

The recommended relay settings are given in the "PROTECTIVE DEVICE SETTING TABLE - RELAYS".

4. Low-Voltage Ground-Fault Relay Settings

The feeder ground fault time settings were chosen to selectively coordinate with the appropriate load side devices. Where possible, the ground fault current pickup settings on these feeders were chosen at maximum for best selective coordination.

Selective coordination with downstream breakers does not exist for any ground fault current exceeding this maximum pickup setting but less than the magnetic setting of the load side breaker. This is unavoidable because the load side protective devices are not equipped with ground fault protection. Figure 3 illustrates this

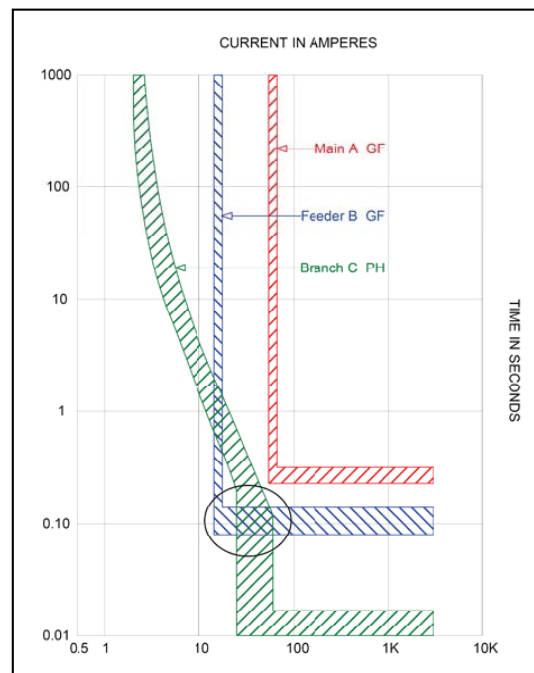


Figure 3: Example ground fault coordination (current scale X 10).

As shown in Figure 3, the feeder ground fault device B does not selectively coordinate with branch breaker C for ground fault currents in the range of 140A-600A as indicated. Main breaker A and feeder breaker B phase device time-current curves are omitted for clarity.

The main and tie ground fault time and pickup settings have been set just high enough to selectively coordinate with the settings chosen for the feeder ground fault relays.

All ground fault settings are tabulated in the appropriate overcurrent device setting tables.

For healthcare facilities, per NEC Section 517.17, wherever ground-fault protection of equipment is provided on the service disconnecting means, an additional level of ground-fault protection must be provided on the next downstream feeder disconnecting means. This requirement is intended to reduce the risk of a ground fault in the system causing nuisance tripping of the main service disconnect, which is more likely if only one level of ground fault protection is required. Note that this section does not require ground-fault protection in locations where it would otherwise not be required, e.g., on 208V systems. If multiple levels of ground-fault protection are required, then a minimum separation of six-cycles is to be provided between the service and feeder ground-fault protective devices to achieve selective coordination.

Low-voltage ground fault, required by NEC 230.95 for main overcurrent protective devices, presents a selectivity challenge. For improved selectivity, it is recommended all ties and feeder devices have ground fault protection. Ground fault protection on ties and feeder breakers, along with a modified differential ground fault scheme, provides selectivity within the applied equipment and immediately downstream; however, selectivity between the main ground fault devices and phase overcurrent protective devices downstream cannot be achieved.

5. Transformer Protective Devices

If in the project scope, medium- and/or low-voltage transformer primary overcurrent protective devices were checked for compliance with NEC Article 450. Also, medium voltage protective devices, primary, secondary and secondary feeder, were evaluated with respect to the applicable ANSI/IEEE Through Fault Guides (C57.12.59 for dry and cast resin type and C57.109 for liquid immersed type) and the Appendix for ANSI/IEEE C37.91. Transformer standards define low-voltage transformers as having a primary voltage less than or equal to 600V. Transformer full load currents and magnetizing inrush currents were also considered.

If a transformer is subject to a through fault, thermal damage occurs to conductors and insulation due to resistive heating. Mechanical damage occurs to windings and structural components due to large magnetic forces associated with the fault current. In general, smaller transformers are assigned a single damage characteristic that accounts for both thermal and mechanical damage. Larger transformers are assigned a two-part characteristic with a thermal characteristic and a more restrictive mechanical characteristic. For the most conservative protection, thermal-mechanical limits should be used. In many cases, it may be acceptable to use only the thermal characteristic, especially if the transformer is not subject to frequent through faults. Transformers connected to overhead secondary feeders should be considered to be subject to frequent through faults.

To evaluate through fault protection according to the ANSI Guides, the applicable curve was plotted representing a transformer's projected damage threshold for the cumulative effects of through faults. However, this ANSI through fault curve must be reduced for certain unbalanced secondary faults, because even though full short-circuit current is flowing in one or more secondary windings, the primary overcurrent device experiences less current.

Secondary line-to-neutral faults on delta-wye connected transformers produce only 0.577 of the maximum 3-phase fault current in the primary overcurrent device while one secondary winding experiences the full short-circuit current as illustrated in Figure 4 below. Therefore, to account for this fault condition, the ANSI through fault curve has been adjusted by a factor of 0.577. Both curves (three phase line-to-line and single phase line-to-neutral) are plotted on the time-current graphs.

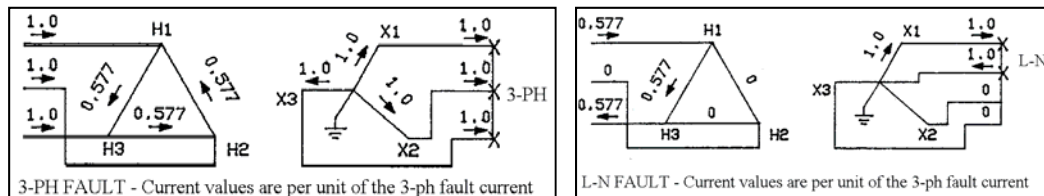


Figure 4: Delta-Wye 3-PH and L-N fault current per unit values.

Since the through fault curves represent a transformer's projected damage threshold for the cumulative mechanical and thermal effects of through faults, all applicable primary and secondary overcurrent devices were checked to ensure interruption before these through fault curves were reached.

Further, to avoid nuisance interruptions, the primary overcurrent devices were also checked to ensure they will carry the transformers rated full load and equivalent magnetic inrush currents which are plotted on the time-current graphs.

Because of the restrictions mentioned above, complete selective coordination between the transformer primary and secondary main devices may not exist for any transformers examined as shown by the overlapping of their characteristics on the time-current graphs. However, this is judged acceptable, because the opening of either device results in the same extent of service interruption.

6. Cable Protection

Feeder overcurrent protective devices were reviewed to verify the protection of their load side cables as shown on the one-line diagrams in accordance with NEC Article 240. If the adjustable low-voltage protective devices are set as suggested in this report, then the cables reviewed will be properly protected.

It should be noted that if a low-voltage phase conductor is properly sized per NEC 240, then it is not possible to damage the phase conductor during short-circuits below the AIC rating of the breaker protecting the phase conductor. UL tests to verify the short-circuit rating of a circuit breaker are performed considering 75°C cable. The corresponding phase conductor is sized according to the NEC and must pass the fault tests without compromising its integrity. Therefore, the ICEA cable withstand curves have not been included on the time-current coordination graphs

7. Selective Coordination and the NEC

Selective coordination, while always desirable, is not required by the NEC except in certain situations:

- In health-care facilities, per NEC 517.17(C): “Ground-fault protection for operation of the service and feeder disconnecting means shall be fully selective such that the feeder device, but not the service device, shall open on ground faults on the load side of the feeder device.”
- In elevator circuits when more than one elevator motor is fed by a single feeder. See NEC 620.62.
- In emergency and legally-required standby power systems (including those in hospitals and other health-care facilities where so required), per NEC 700.27 and NEC 701.18.

For this analysis, selective coordination was reviewed based on pre-2005 NEC rules concerning emergency and elevator circuits. This study represents additions to a pre-existing normal distribution system. Only one emergency circuit is included within the study scope (ATS-1, panel DP-BP-2 and loads downstream) and no generator source for that circuit is included. In general, 2005 and later Code rules require a stricter interpretation of selective coordination that requires oversized panels, breakers or electrical design changes to the cable and conduit layout that may have an impact on the architectural design. If selective coordination according to 2005 NEC or later is required then further analysis beyond the scope of this study will be necessary.

The NEC requirement for selective coordination in emergency and legally-required standby systems, call for each overcurrent device to be “selectively coordinated with all supply side overcurrent protective devices.” This requirement can be problematic for system designers because it recognizes only device coordination and not system coordination. Special consideration of selective coordination (beyond the traditional coordination study) must be given when the system is initially designed, since for both fusible and circuit-breaker based systems, designs that are otherwise NEC compliant may not meet the selective coordination requirements of the latest NEC interpretation.

How selective coordination is defined also presents an issue for the study engineer. Existing study software cannot accurately represent the interrupting characteristics of multiple breakers when opening on a fault. In reality, as confirmed by testing, some breakers will always trip before another even if the study graph shows overlapping trip curves. This is due to the differing masses of breaker parts, spring action and the dynamic impedance of the fault through two devices. Therefore, in some cases, a higher level of selective coordination is available compared to what is shown on the graphs. When current NEC rules for selective coordination are specified, Square D data bulletin 0100DB0501R3 is used in conjunction with the study graphs to provide a more accurate view of the level of selective coordination provided.

Compliance with NEC articles 517.17 (Health Care Facilities), 700.27 (Emergency Systems), and 701.18 (Legally Required Standby Systems) may require interpretation and approval by the local authority having jurisdiction.