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Selective Coordination for Emergency and Legally-Required Standby Power Distribution Systems

Presented for the

IEEE Central TN Section / Music City Power Quality Group

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Topics

- 2005 NEC Requirements
- What is selective coordination?
- Issues with the 2005 NEC Requirements
- Overcurrent Protective Device Characteristics
- Specific Guidelines for Achieving Selectivity

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2005 NEC Requirements

- Definition of Emergency System per NEC 700.1:

  Emergency Systems are those systems legally required and classed as emergency by municipal, state, federal, or other codes, or by any governmental agency having jurisdiction. These systems are intended to automatically supply illumination, power, or both, to designated areas and equipment in the event of failure of the normal supply or in the event of accident to elements intended to supply, distribute, and control power and illumination essential to human life.

2005 NEC Requirements

- Definition of Legally Required Standby System per NEC 701.2:

  Those systems required and so classified as legally required standby by municipal, state, federal, or other codes or by any governmental agency having jurisdiction. These systems are intended to automatically supply power to selected loads (other than those classed as emergency systems) in the event of failure of the normal source.

2005 NEC Requirements

NEC 700 – Emergency Systems

700.27 Coordination. *Emergency system(s) overcurrent devices shall be selectively coordinated with all supply side protective devices.*

NEC 701 – Legally Required Standby Systems

701.18 Coordination. *Legally required standby system(s) overcurrent devices shall be selectively coordinated with all supply side protective devices.*

2005 NEC Requirements

- Contrast these with the definition of selectivity per NEC 100:

  Coordination (Selective). *Location of an overcurrent condition to restrict outages to the circuit or equipment affected, accomplished by the choice of overcurrent protective devices and their ratings or settings.*

- The result: NEC 700.27 and 701.18 require "device-to-device" coordination, whereas NEC 100 implies system coordination.

2005 NEC Requirements

- Also contrast NEC 700.27 and 701.18 with NFPA 110-6.5.1:

  6.5.1* General *The overcurrent protective devices in the EPSS shall be coordinated to optimize selective tripping of the circuit overcurrent protective devices when a short circuit occurs.*

* Explanation in NFPA 110 Annex A: "A.6.5.1: It is important that the various overcurrent devices be coordinated, so far as practicable, to isolate faulted circuits and to protect against cascading operation on short circuit faults. In many systems, however, full coordination is not practicable without using equipment that could be prohibitively costly or undesirable for other reasons…"

2005 NEC Requirements

- Article 517 Health Care Facilities now requires that the essential electrical system also meet the requirements of Article 700

  517.26 Application of Other Articles. The essential electrical system shall meet the requirements of Article 700, except as amended by Article 517.

Topics

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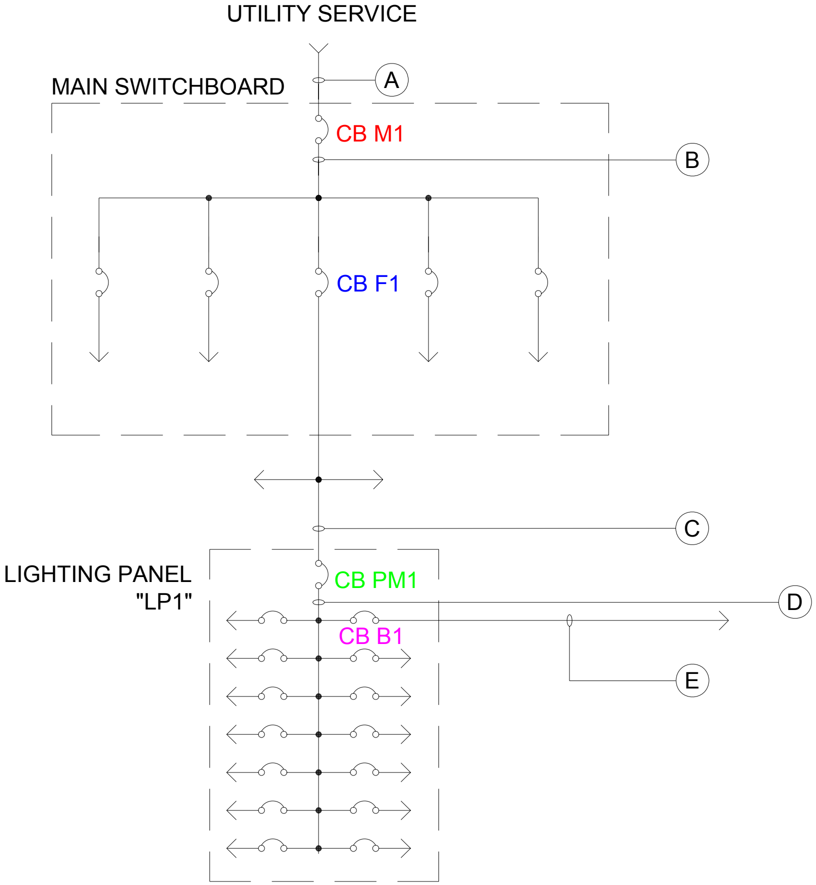
- What is selective coordination?
- Issues with the 2005 NEC Requirements
- Overcurrent Protective Device Characteristics
- Specific Guidelines for Achieving Selectivity

What is Selective Coordination?

- Selective coordination exists when the smallest possible portion of the system experiences an outage due to an overcurrent condition.



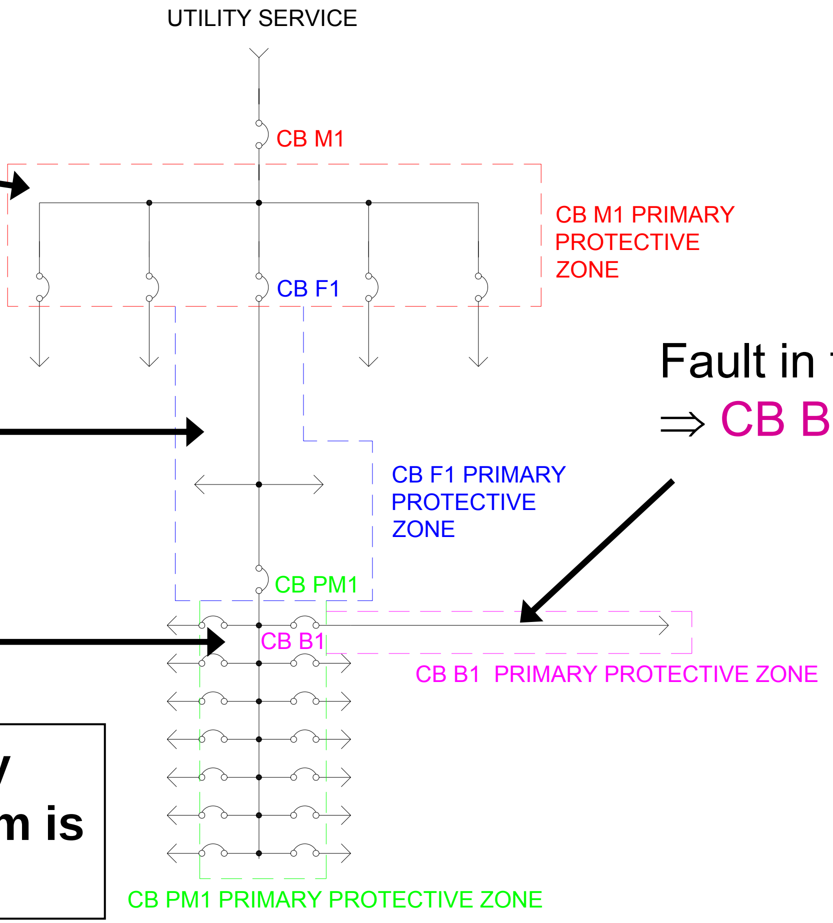
FAULT LOCATION	DEVICE THAT SHOULD OPERATE FOR SELECTIVE COORDINATION
A	UTILITY PROTECTIVE DEVICE
B	CB M1
C	CB F1
D	CB PM1
E	CB B1

What is Selective Coordination?

- The goal of selective coordination: Confine system outages due to overcurrents to the smallest possible number of loads
- The concept of <u>protective zones</u> is a useful tool to visualize this

What is Selective Coordination?

- Primary protective zones for the previous example:



Fault in this zone ⇒ CB M1 Trips

Fault in this zone ⇒ CB F1 Trips

Fault in this zone ⇒ CB PM1 Trips

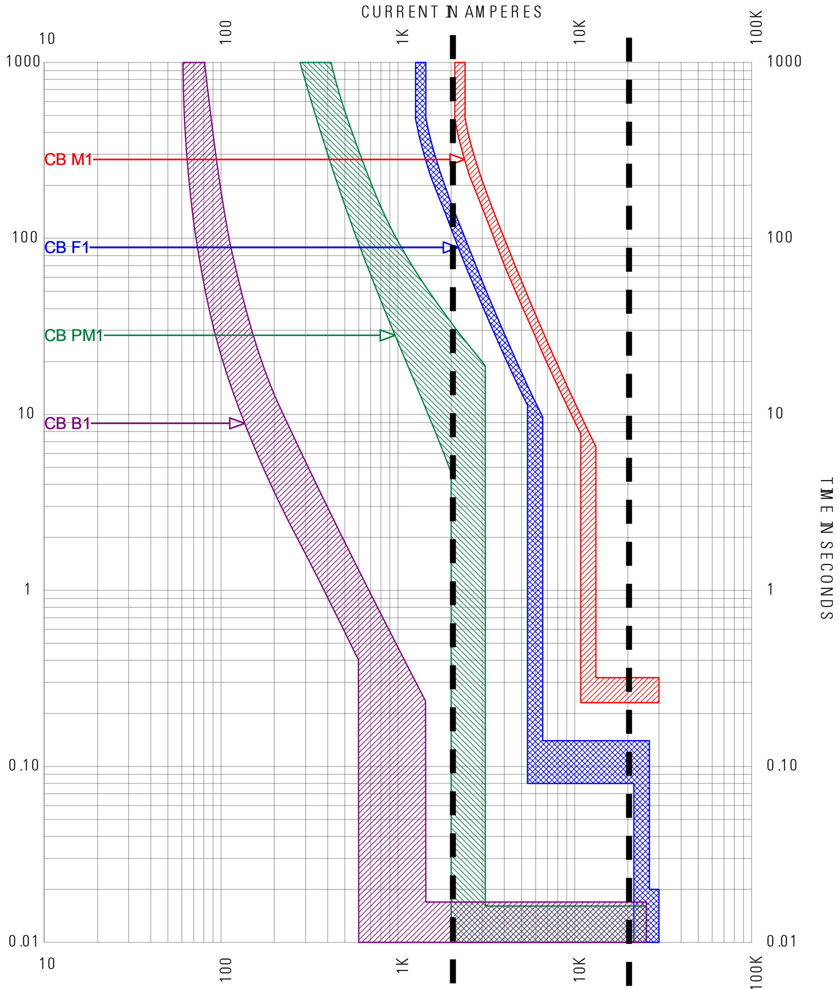
Fault in this zone ⇒ CB B1 Trips

No overlapping of primary protective zones ⇒ system is selectively coordinated

How is selective coordination achieved?

- Selective coordination is achieved by coordinating the time-current characteristics of overcurrent protective devices
- Device closest to fault trips first because it is selected or set to respond faster than upstream devices
- If the device closest to the fault fails to trip, the next upstream device will trip

How is selective coordination achieved?

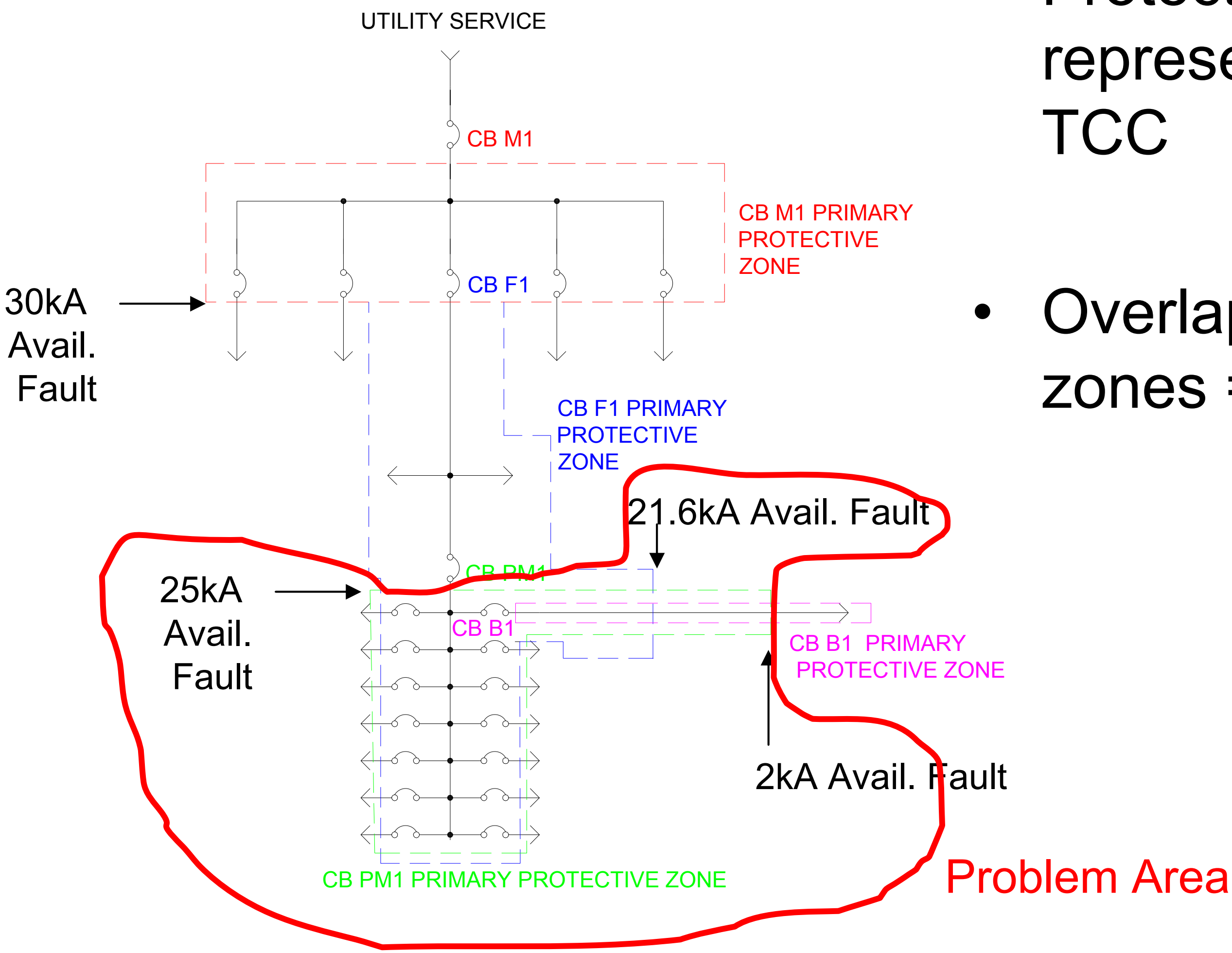


CB PM1, CB B1 Coordinate Through 2kA

CB F1, CB PM1 Coordinate Through 21.6kA

- Time-Current Characteristic (TCC) plot of previous example
- No overlap for devices with time-current band-type characteristics up to the available fault at the downstream device =>selectivity

How is selective coordination achieved?



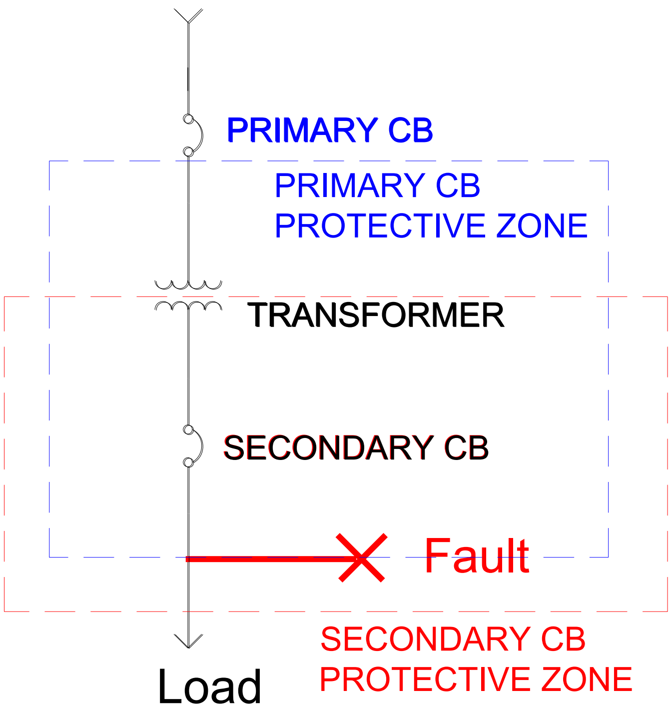
- Protective zone representation of previous TCC
- Overlapping protective zones => problem areas

How is selective coordination achieved?

- But, be wary:
  - Just because one overcurrent protective device is upstream from another does not mean they must selectively coordinate with each other in order for the system to be selectively coordinated
  - This statement is true in several commonly-encountered scenarios

What is Selective Coordination?

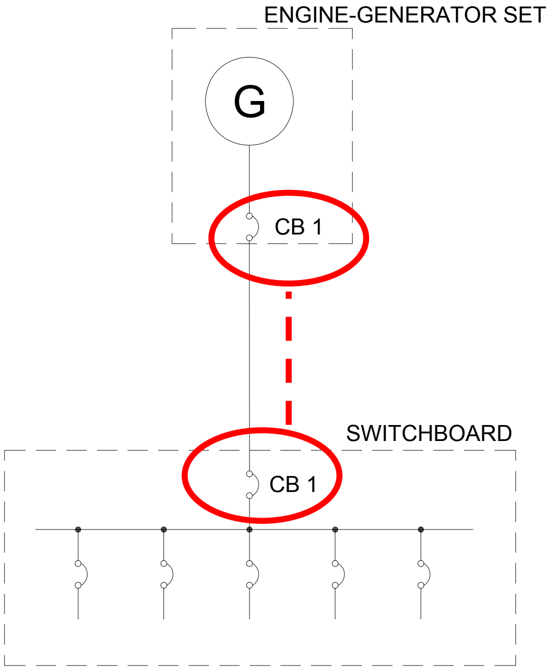
- One example of where selective coordination between two devices is not required for system selectivity to exist:



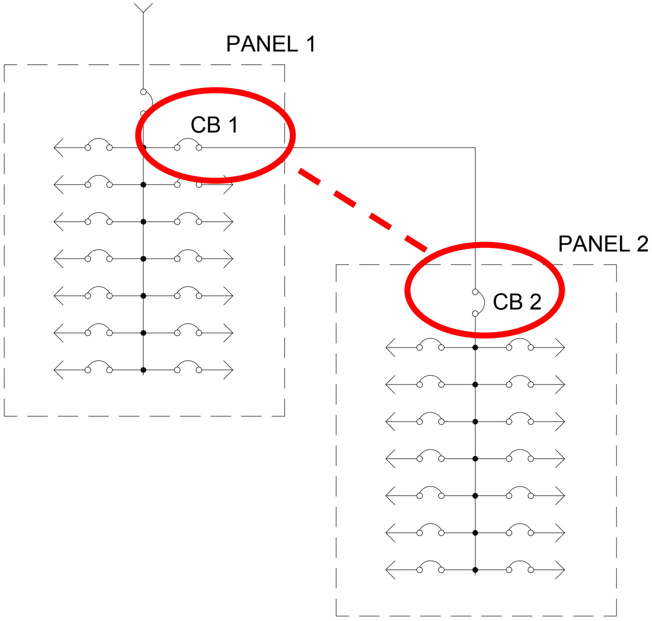
- A fault in the location shown can cause either the Primary CB or Secondary CB, or both, to trip with no difference in the number of loads affected.
- In other words, for purposes of coordination, the Primary CB and Secondary CB can be considered as one device, which in this case serves to protect the transformer.

What is Selective Coordination?

- Other examples of where device selectivity is not required for system selectivity:



a.)



b.)

Topics

- 2005 NEC Requirements
- What is selective coordination?
- Issues with the 2005 NEC Requirements
- Overcurrent Protective Device Characteristics
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Issues with the 2005 NEC Requirements

- Clear conflict between the definition of "selective coordination" in NEC 100 vs. requirements of 700.27 and 701.18, as well as the requirements of 700.27 and 701.18 vs. NFPA 110-6.5.1!
- Wording of NEC 700.27 and 701.18 are in terms of <u>device</u> coordination, not <u>system</u> coordination
- So far, most reasonable Authorities Having Jurisdiction (AHJ's) have allowed interpretation of NEC 700.27 and 701.18 in terms of <u>system</u> coordination
- However, this is <u>not</u> guaranteed going forward
- With one exception, all proposals to date to change wording of, or remove, the selectivity requirements in the 2008 NEC have been rejected

Issues with the 2005 NEC Requirements

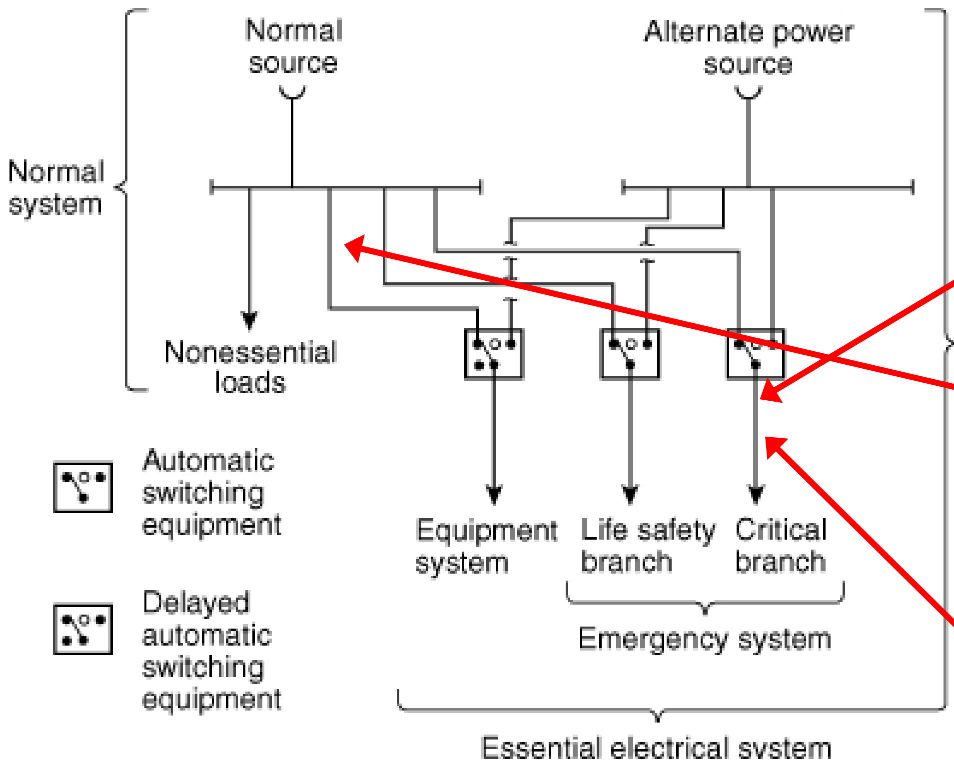
- Another issue: Ground-Fault Protection
  - Not addressed in NEC 700.27, 701.18
  - ~95% of all system faults are ground faults
  - If ground-fault protection is not considered: Can cause "practical" lack of selectivity even though NEC 700.27 and 701.18 are complied with

Issues with the 2005 NEC Requirements

- One scenario for a health-care facility:
  - If utility service is ≥ 1000A and 150V < Service Voltage to Ground ≤ 600V, ground-fault protection, set to no more than 1200A pickup and no more than 1s time delay at 3000A, is required per NEC 230.95
  - NEC 517.17 (B) requires an additional level of ground-fault protection in health-care facilities if service ground fault is provided per NEC 230.95 or NEC 215.10
  - For the service and additional level of ground-fault protection in this scenario to coordinate with the essential electrical system devices, additional levels of ground-fault protection would typically be required
  - But NEC 517.17(B) prohibits additional levels of ground-fault protection on the load side of essential electrical system transfer switches
  - All proposals to amend NEC 517.17(B) for the 2008 NEC have been rejected

Issues with the 2005 NEC Requirements

- In other words, NEC 700.27 and 701.18 could be satisfied and the following scenario could still exist:



With system supplied from normal source:

A ground fault here

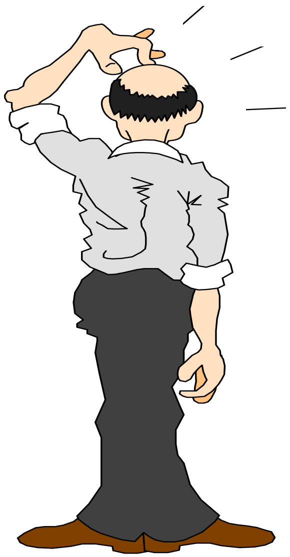
Could force the normal source overcurrent protective device ground-fault protection to trip

And force transfer to generators

ATS will close into a ground fault!

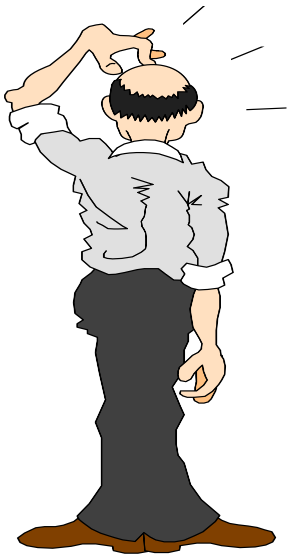
Issues with the 2005 NEC Requirements

- Why is selectivity in the NEC?
  - NEC is a fire and electrical safety document, not a performance standard
  - Why isn't this left to the discretion of the engineering community?
  - NEC is not a "design manual" – and following the requirements of the NEC, as they are currently written, will <u>not</u>, in and of itself, create a totally selectively-coordinated system.
  - What about other systems that could take the normal source off-line, such as fire pumps in multi-building campus-style complexes?
  - What about arc-flash hazards?



Issues with the 2005 NEC Requirements

- What were they thinking?
  - Requirements of 700.27 and 701.18 are generally well-intentioned – intended to increase system reliability
  - Unfortunately, they were written into the NEC in a way that was confusing.
  - Only one manufacturer took a stand in the code-making process against the impracticality of the requirements as written – and received no backing



Issues with the 2005 NEC Requirements

- What to do?
- Long-term actions:
  - Submit proposals for change through the code-making process
- Short-term actions:
  - Get with your local AHJ and be sure you understand his/her interpretation of NEC 700.27, 701.18 requirements
  - Understand overcurrent protective device characteristics and how to best apply these devices to achieve selectivity

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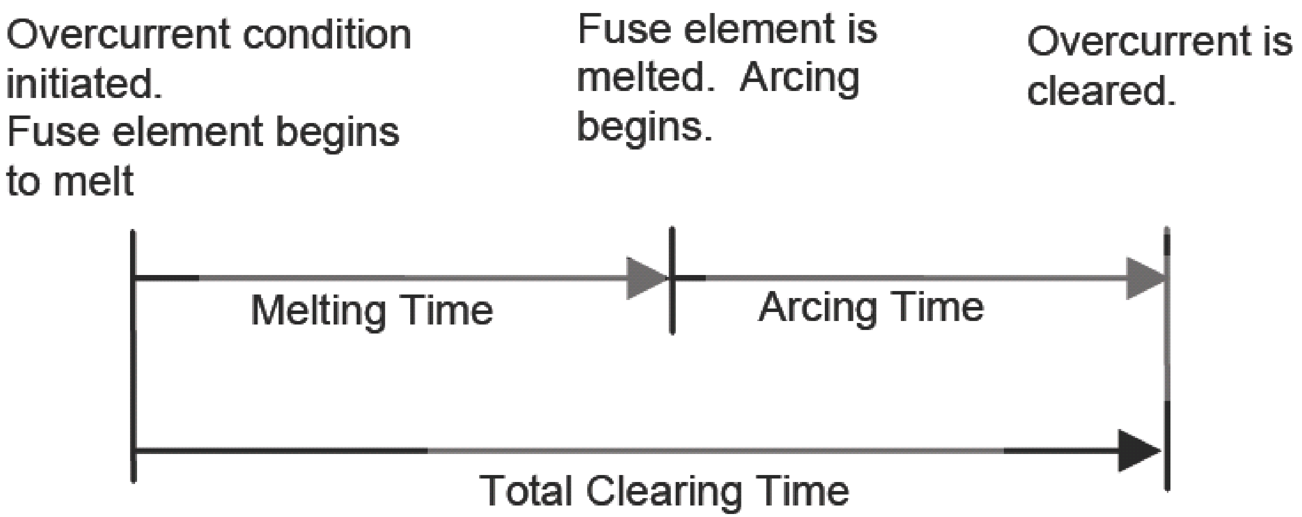
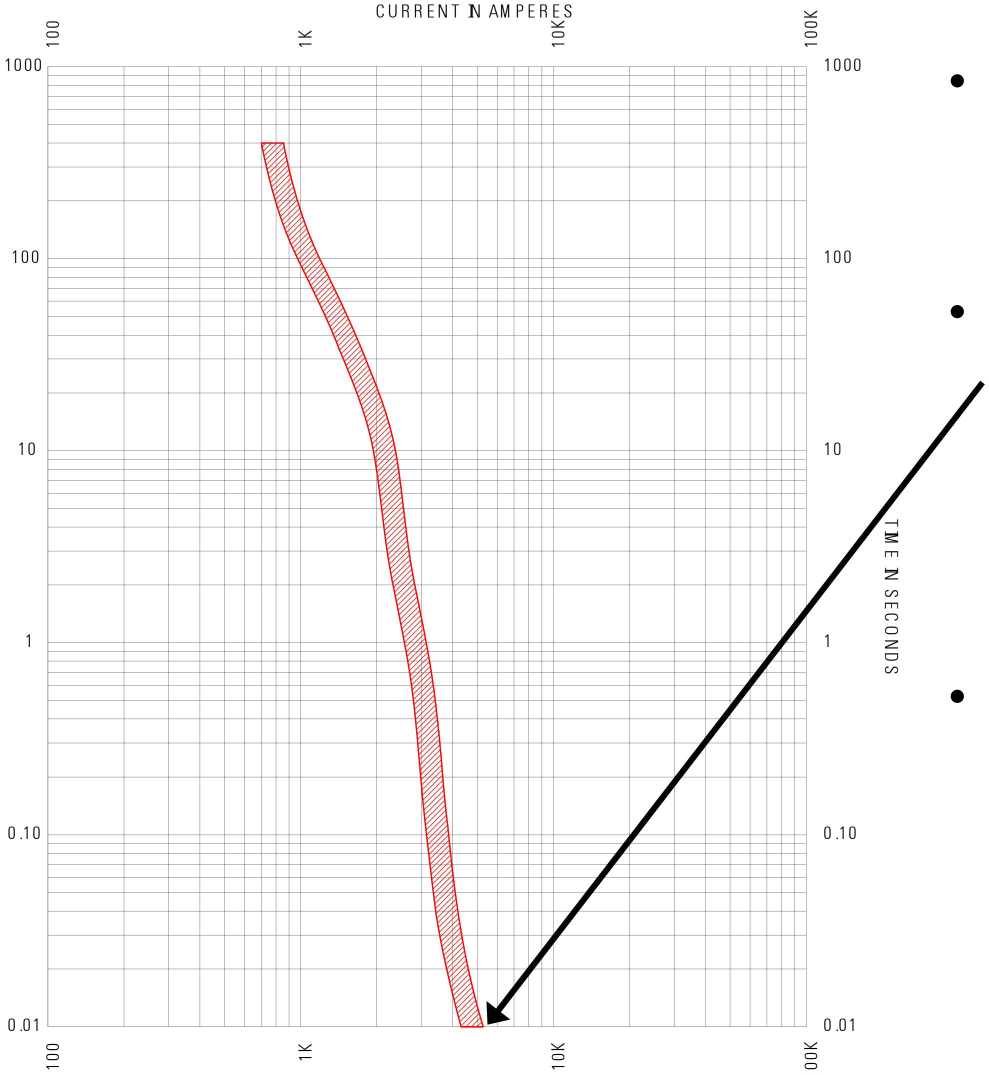
Overcurrent Protective Device Characteristics

- Fuses
  - Simplest overcurrent protective device
  - Timing characteristics depend upon the design of the fuse

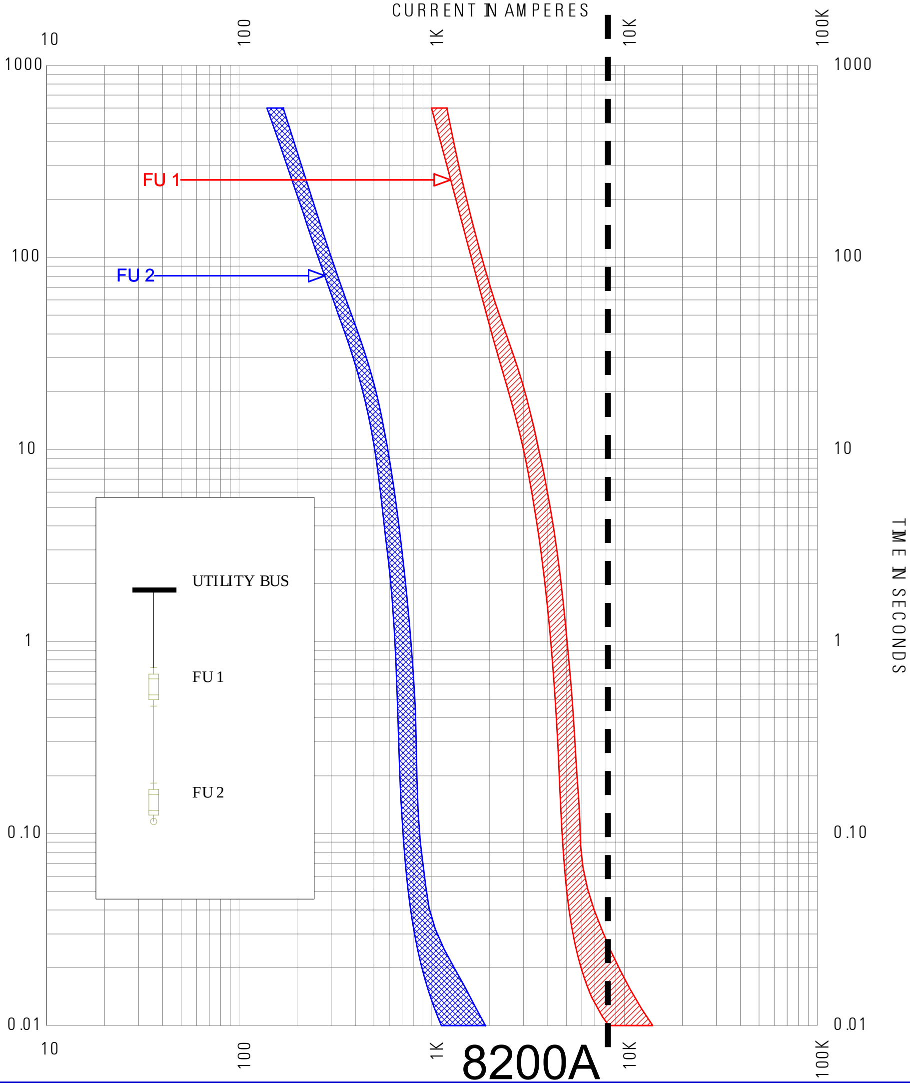


Overcurrent Protective Device Characteristics



- Fuse displays an extremely inverse time current characteristic
- Below 0.01 second: current-limiting fuses are operating in their current limiting region – simple TCC comparisons are not enough determine coordination
- Coordination below 0.01s requires a comparison between the minimum melting energy of the upstream fuse and the total clearing energy of the downstream fuse.

Overcurrent Protective Device Characteristics



- For selective coordination by TCC comparison, these two fuses will coordinate until both TCCs go below 0.01A
- In this case, the maximum fault current level for coordination is 8200A
- Above 8200A, coordination must be determined by energy comparison (minimum melting energy of upstream fuse vs. total clearing energy of downstream fuse) => fuse ratio tables

Overcurrent Protective Device Characteristics

- Circuit Breakers
  - Available in thermal-magnetic and electronic tripping types
  - Timing characteristics depend upon type of circuit breaker

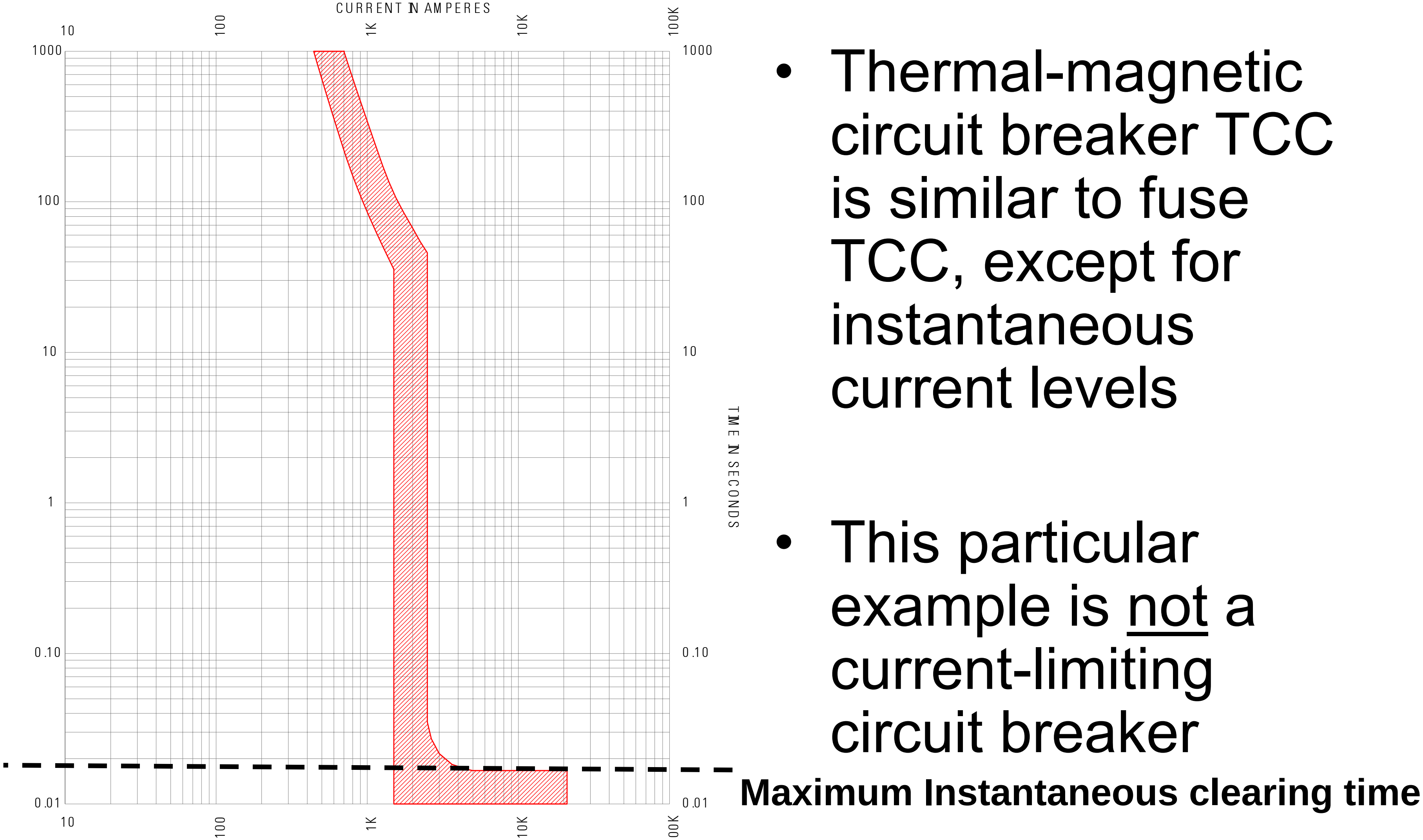
Circuit Breaker Type[1]	Standard	Tripping Type	Short-time Withstand Capability[2]
Molded-Case	UL 489	Thermal-magnetic	Typically much lower than interrupting rating
		Electronic	Typically lower than interrupting rating
		Electronic (insulated case)[3]	Often comparable to interrupting rating
Low-Voltage Power	ANSI C37.13 UL 1066	Electronic	Typically comparable to interrupting rating

1. Other circuit breaker types, such as molded-case circuit breakers with instantaneous-only trip units, are available for specific applications, such as short-circuit protection of motor circuits

2. Short-time current is defined by ANSI C37.13 as the designated limit of available (prospective) current at which the circuit breaker is required to perform a duty cycle consisting of two 0.5s periods of current flow separated by a 15s interval of zero current. For UL 489-rated circuit breakers short-time withstand is not defined and the duty cycle may vary.

3. Insulated-case circuit breakers exceed the UL 489 standard. The term “insulated case” is not a UL term.

Overcurrent Protective Device Characteristics

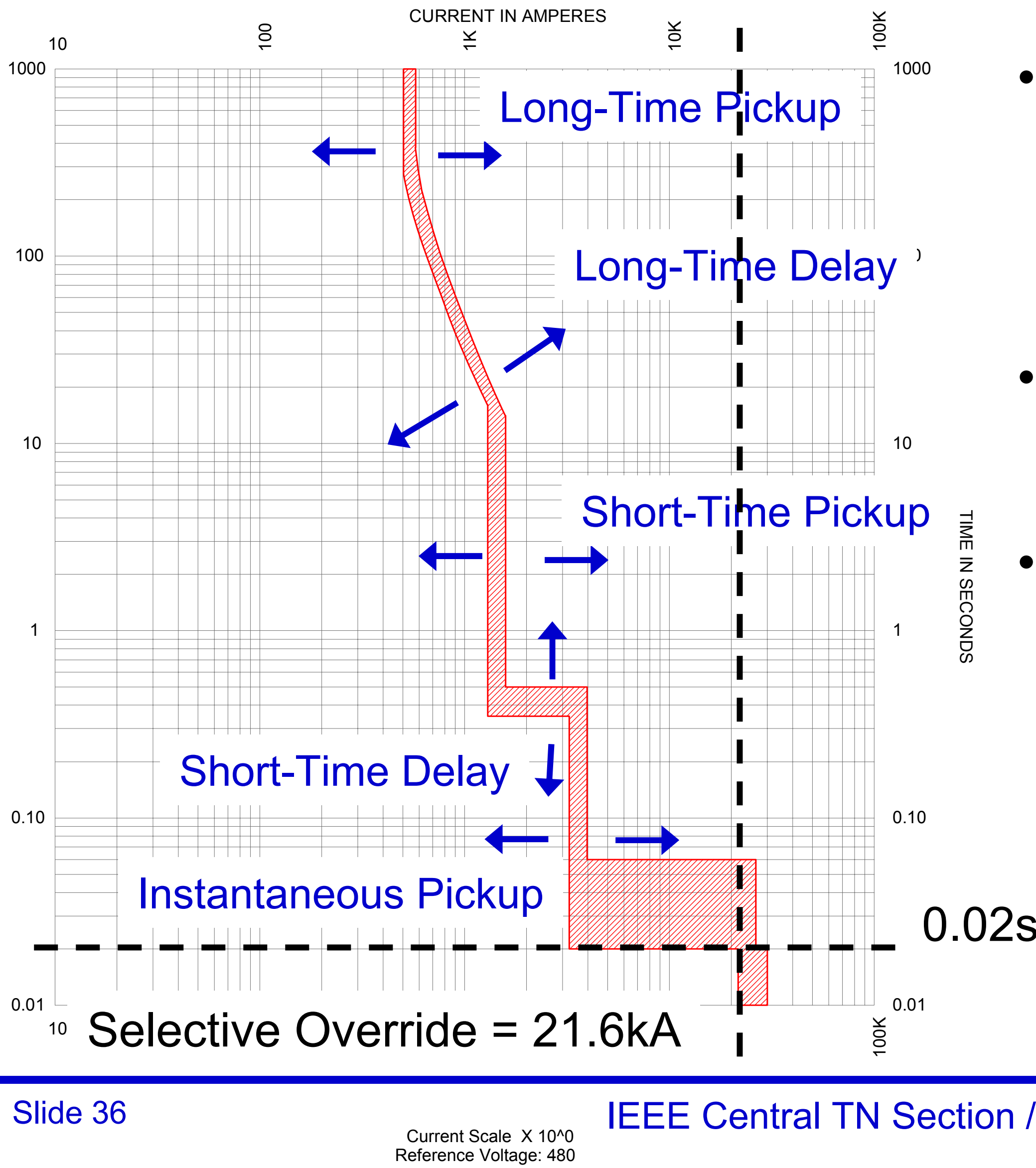


- Thermal-magnetic circuit breaker TCC is similar to fuse TCC, except for instantaneous current levels
- This particular example is not a current-limiting circuit breaker

Overcurrent Protective Device Characteristics

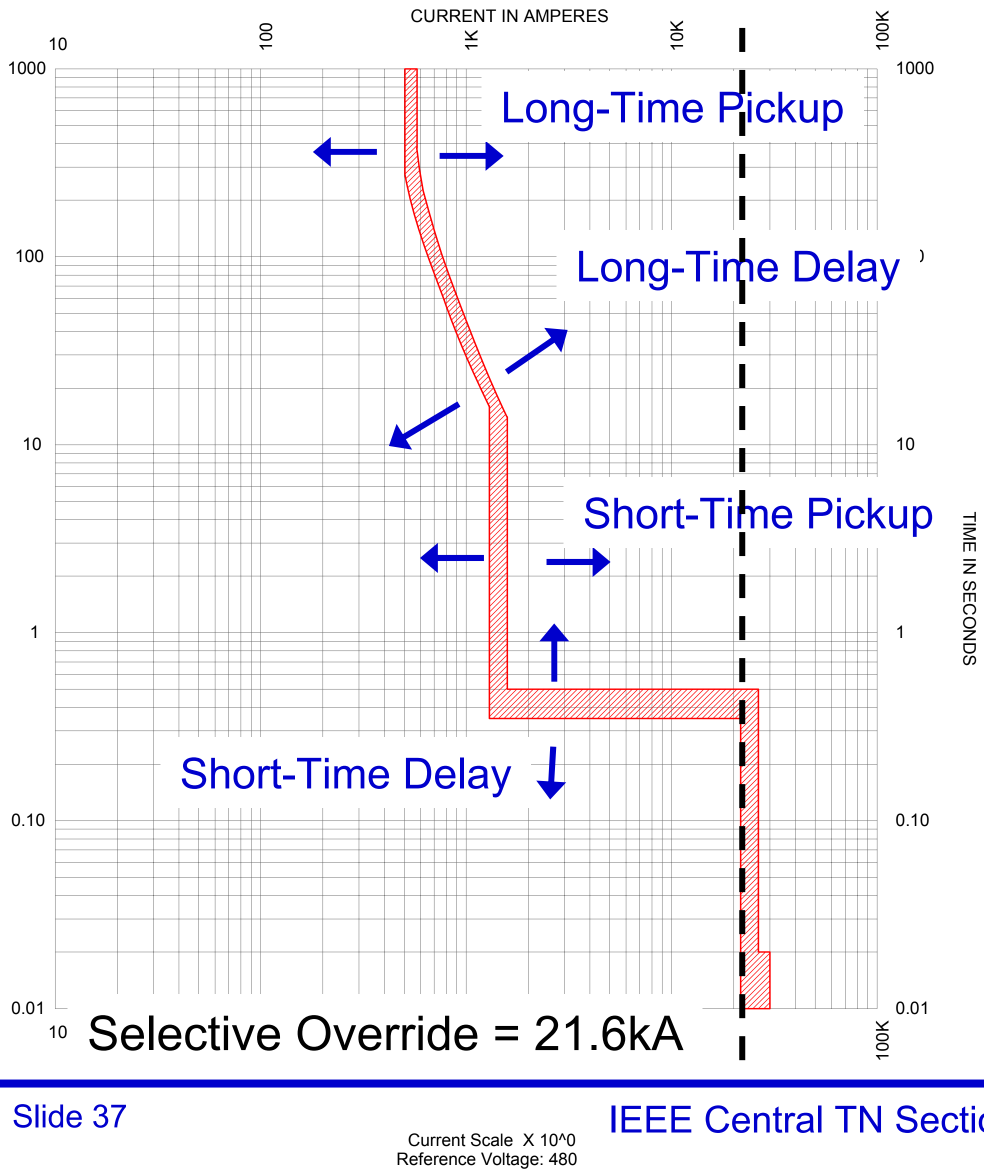
- Circuit Breakers
  - The available range of instantaneous pickups on any circuit breaker is always a function of the short-time withstand capabilities of the circuit breaker
  - A published short-time withstand capability is not required for molded-case circuit breakers per UL 489 (nor is the withstand time standardized), yet the capability still exists
  - The withstand capability will manifest itself in the TCC for the circuit breaker, typically the allowable range of instantaneous pickup settings

Overcurrent Protective Device Characteristics



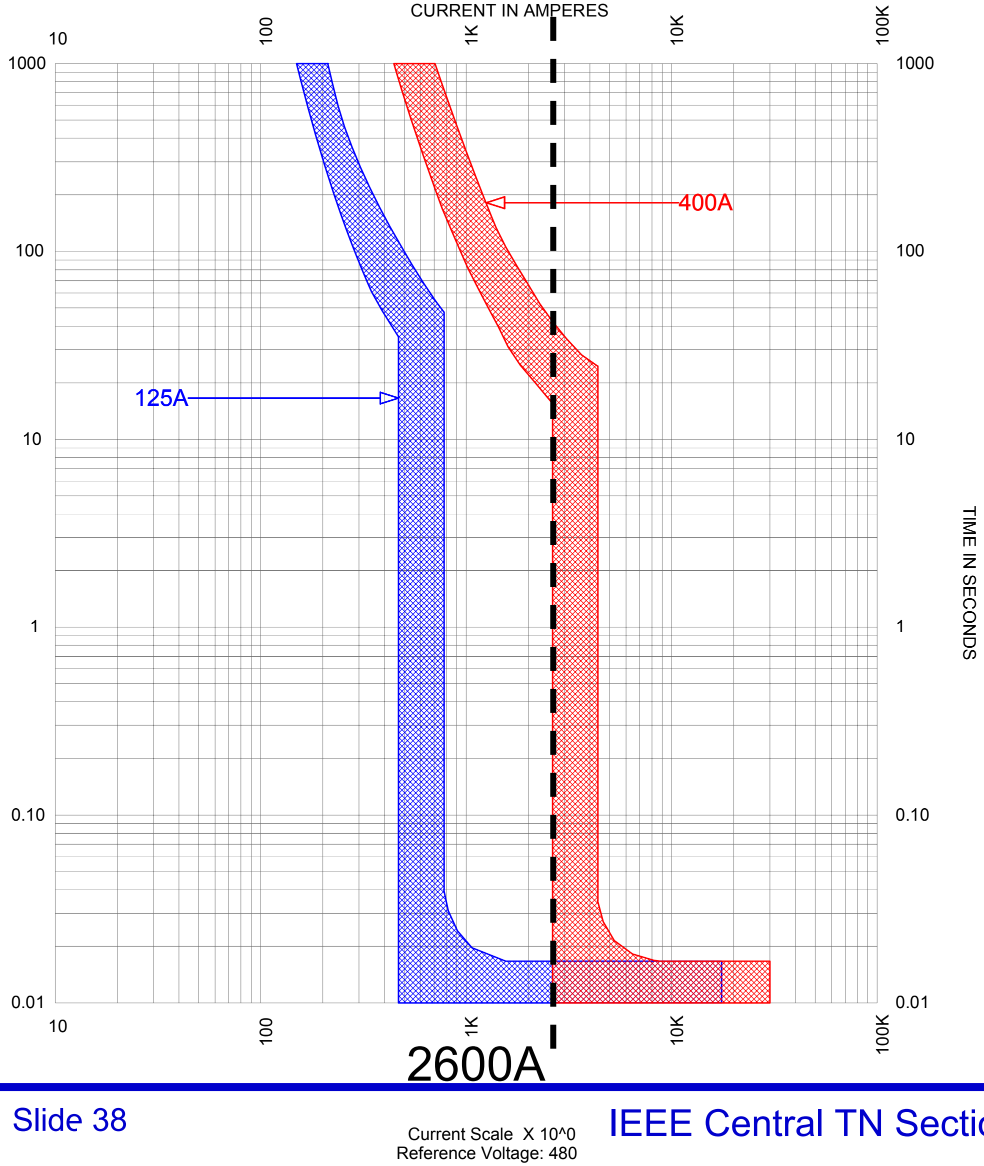
- Some electronic-trip circuit breakers have a minimum tripping time above 0.01s associated with the instantaneous function
- This time delay helps to coordinate with downstream circuit breakers
- However, there is typically also a selective instantaneous override, above which the instantaneous characteristic is always enabled and has a faster operating time than the standard instantaneous characteristic

Overcurrent Protective Device Characteristics



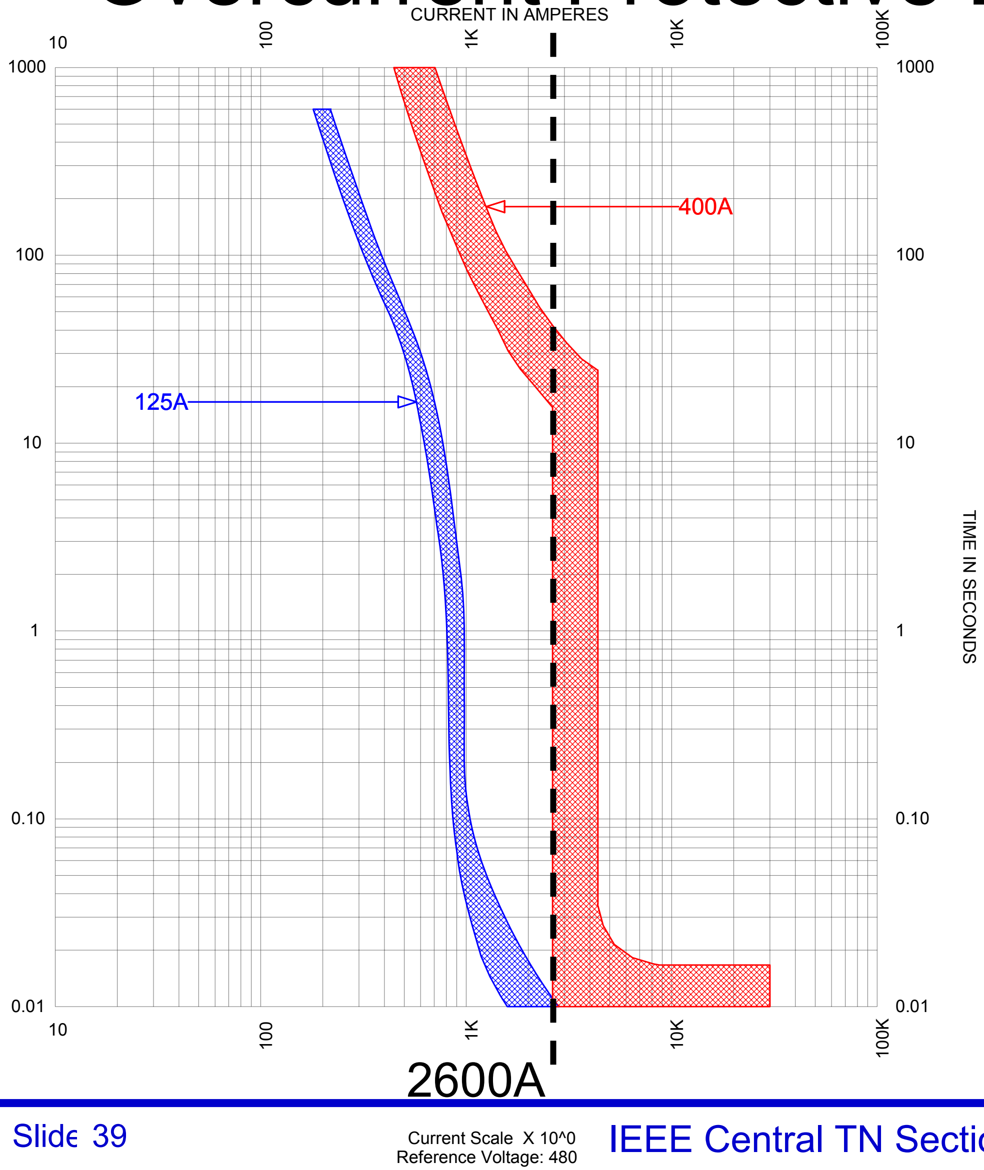
- If the instantaneous function is turned off, the instantaneous selective override remains
- Its purpose is to protect the circuit breaker when the instantaneous function is turned off
- The selective override level depends upon the circuit breaker design

Overcurrent Protective Device Characteristics



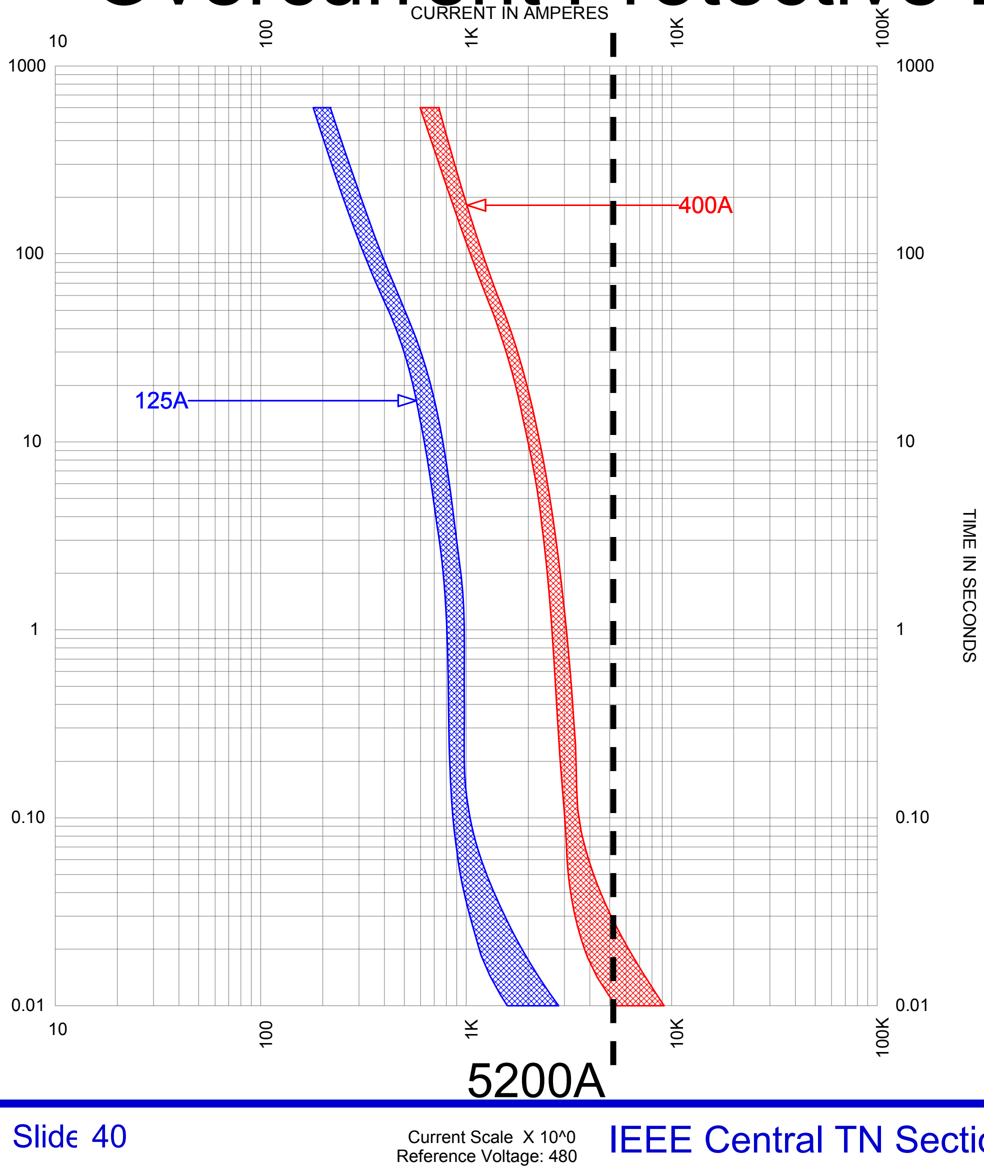
- Two thermal-magnetic circuit breakers coordinate up to the instantaneous pickup level of the upstream circuit breaker
- In this case, that level is 2600A

Overcurrent Protective Device Characteristics



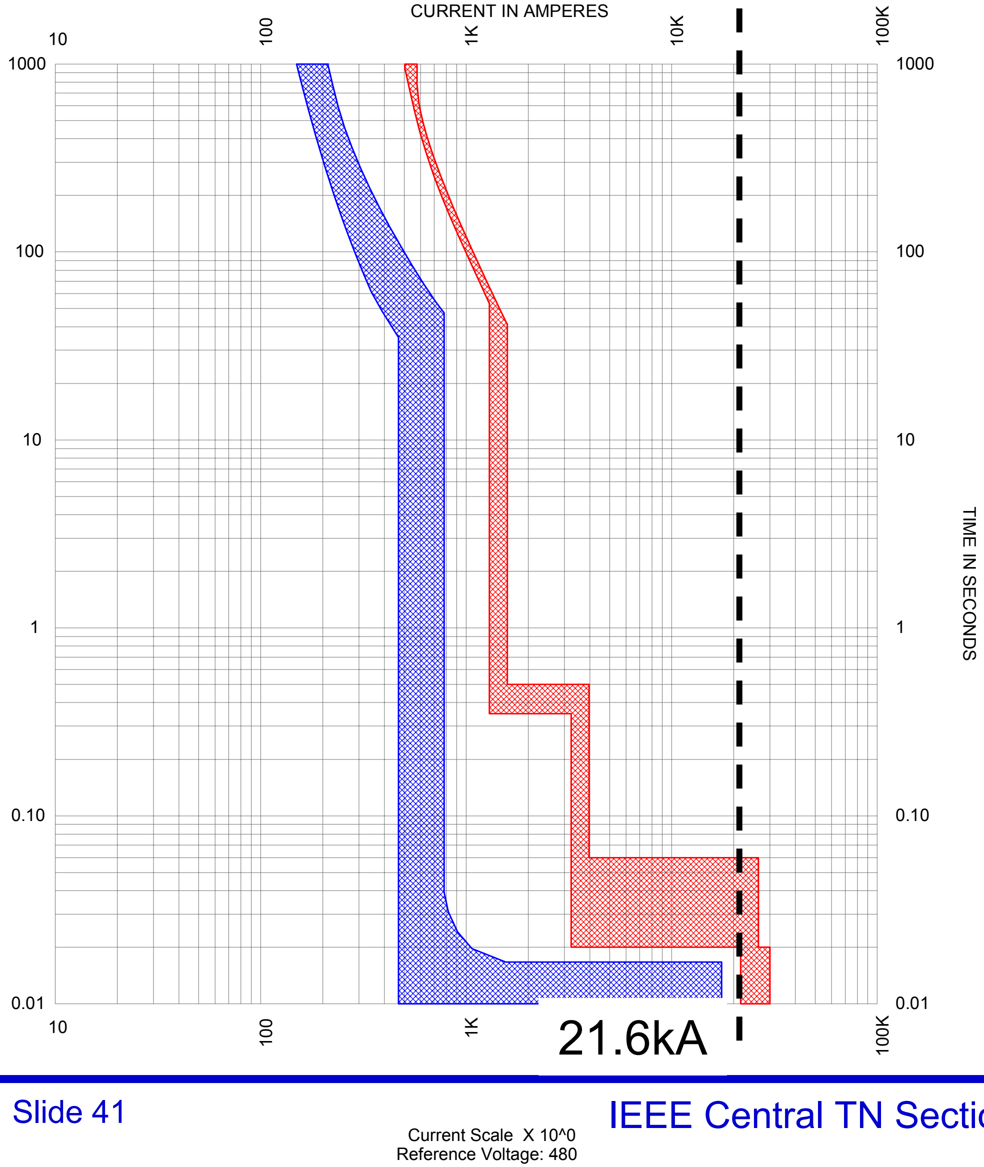
- Replace the 125A circuit breaker with fuses, and the coordination level is the same: 2600A

Overcurrent Protective Device Characteristics



- Replace the 125A circuit breaker with fuses, and the coordination level per the TCC is 5200A – still a low level
- Selectivity ratio tables are required above 5200A

Overcurrent Protective Device Characteristics



- Coordination between an electronic-trip circuit breaker with .02s-delayed instantaneous characteristic is even better – up to the selective override level of the circuit breaker
- In this case, that level is 21.6kA

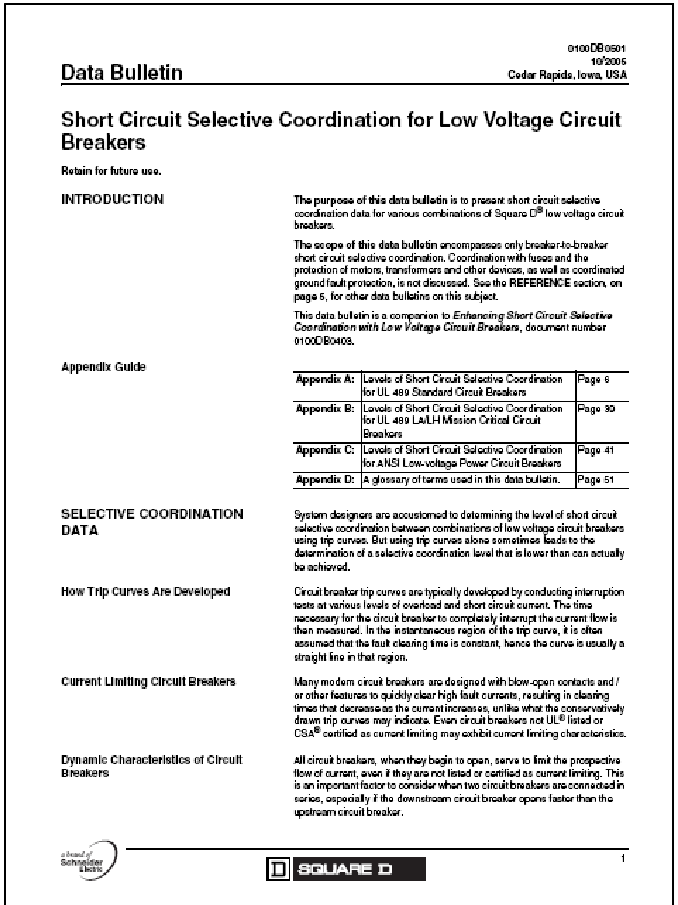
Overcurrent Protective Device Characteristics

- In the past, the major differentiator between circuit breaker and fuse coordination was the existence of fuse ratio tables
  - These allow comparison at fault currents that cannot be evaluated via TCC comparison
  - If a given ratio is kept between two fuses of given types, they will always selectively coordinate
  - This is based upon comparison between the minimum melting energy of the upstream fuses vs. the total clearing energy of the downstream fuses

Overcurrent Protective Device Characteristics

- Circuit breakers also exhibit characteristics which cause the TCC results for coordination to be inaccurate
  - Current-limiting effects: Even circuit breakers which are not UL listed as current-limiting can exhibit these effects for high fault currents
  - Dynamic impedance effects: The downstream circuit breaker exhibits a *dynamic impedance* when it begins to interrupt, which effectively lowers the current "seen" by the upstream breaker
- These characteristics cause the TCC results to be overly conservative regarding selective coordination for higher fault currents

Overcurrent Protective Device Characteristics



Data Bulletin

0100DB0601
10/2006
Cedar Rapids, Iowa, USA

Short Circuit Selective Coordination for Low Voltage Circuit Breakers

Retain for future use.

INTRODUCTION

The purpose of this data bulletin is to present short circuit selective coordination data for various combinations of Square D® low voltage circuit breakers.

The scope of this data bulletin encompasses only breaker-to-breaker short circuit selective coordination. Coordination with fuses and the protection of motors, transformers and other devices, as well as coordinated ground fault protection, is not discussed. See the REFERENCE section, on page 5, for other data bulletins on this subject.

This data bulletin is a companion to *Enhancing Short Circuit Selective Coordination with Low Voltage Circuit Breakers*, document number 0100DB0403.

Appendix Guide

Appendix A:	Levels of Short Circuit Selective Coordination for UL 489 Standard Circuit Breakers	Page 6
Appendix B:	Levels of Short Circuit Selective Coordination for UL 489 LA/LH Mission Critical Circuit Breakers	Page 30
Appendix C:	Levels of Short Circuit Selective Coordination for ANSI Low-voltage Power Circuit Breakers	Page 41
Appendix D:	A glossary of terms used in this data bulletin.	Page 51

SELECTIVE COORDINATION DATA

System designers are accustomed to determining the level of short circuit selective coordination between combinations of low voltage circuit breakers using trip curves. But using trip curves alone sometimes leads to the determination of a selective coordination level that is lower than can actually be achieved.

How Trip Curves Are Developed

Circuit breaker trip curves are typically developed by conducting interruption tests at various levels of overload and short circuit current. The time necessary for the circuit breaker to completely interrupt the current flow is then measured. In the instantaneous region of the trip curve, it is often assumed that the fault clearing time is constant, hence the curve is usually a straight line in that region.

Current Limiting Circuit Breakers

Many modern circuit breakers are designed with blow-open contacts and / or other features to quickly clear high fault currents, resulting in clearing times that decrease as the current increases, unlike what the conservatively drawn trip curves may indicate. Even circuit breakers not UL® listed or CSA® certified as current limiting may exhibit current limiting characteristics.

Dynamic Characteristics of Circuit Breakers

All circuit breakers, when they begin to open, serve to limit the prospective flow of current, even if they are not listed or certified as current limiting. This is an important factor to consider when two circuit breakers are connected in series, especially if the downstream circuit breaker opens faster than the upstream circuit breaker.

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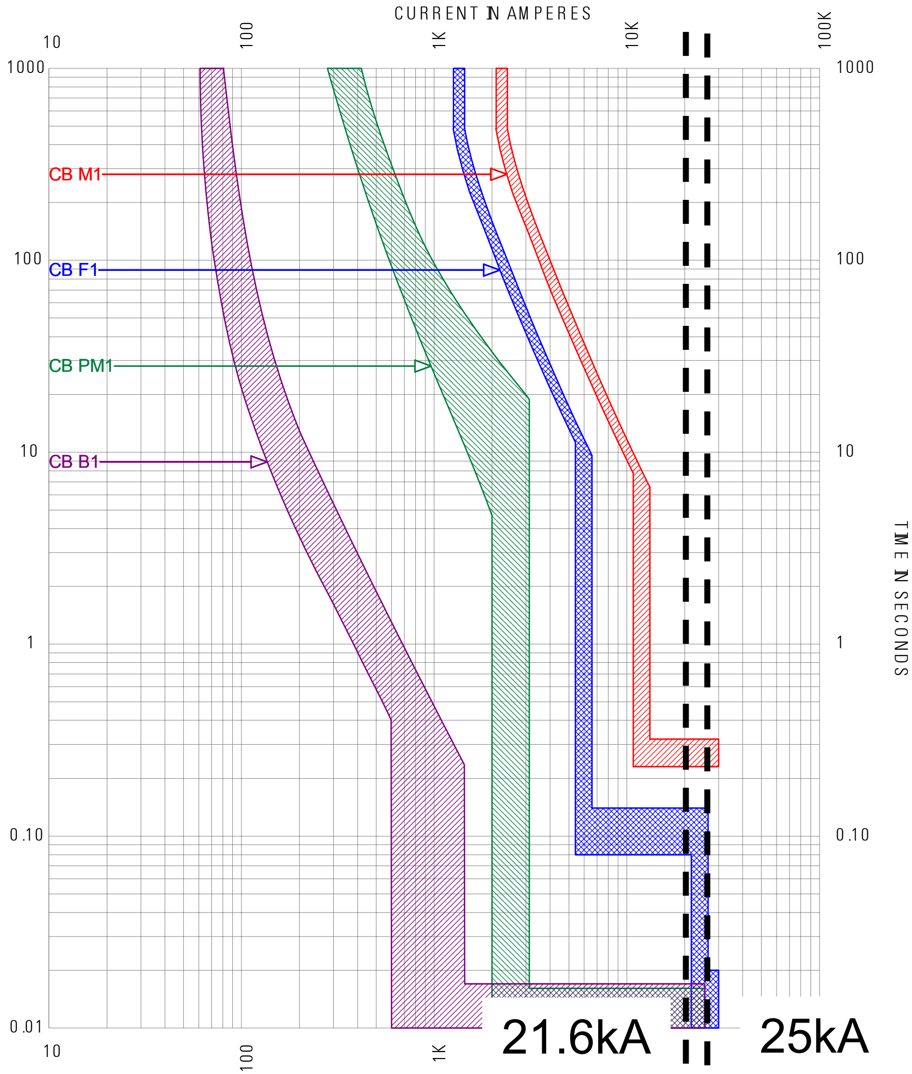
- One circuit breaker manufacturer has utilized these characteristics to produce short circuit selectivity tables for their circuit breakers
- These tables are based upon tested values and certified by the manufacturer
- These tables, in many cases, show coordination in the instantaneous region even where the CB TCCs overlap

Overcurrent Protective Device Characteristics



- In this example, CB F1 and CB PM1 coordinate up to 21.6kA per the TCC
- But, per the selectivity tables they coordinate up to the available fault current of 25kA at CB PM1

Overcurrent Protective Device Characteristics

- The existence of short-circuit selectivity tables makes the application of circuit breakers and fuses very similar
- In some cases, it actually gives an advantage to circuit breakers from a selectivity standpoint
- TCC comparisons are still required, however, to insure coordination down to 0.1s. However, TCC comparisons are required to insure adequate equipment protection in any case, with fuses or circuit breakers.

Topics

- 2005 NEC Requirements
- What is selective coordination?
- Issues with the 2005 NEC Requirements
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- Specific Guidelines for Achieving Selectivity

Specific Techniques for Achieving Selectivity

- Recognize that fuses and circuit breakers can both be used to achieve “total” selective coordination
  - CBs give performance advantages over fuses in other areas beyond selective coordination – these will not be elaborated upon here, but be aware that the advantages do exist

Specific Techniques for Achieving Selectivity

- Recognize that ~ 95% of system faults are ground-faults
  - Defeats the purpose of the NEC 700.27 and 701.18 requirements in health-care facilities in light of NEC 517.17(B) unless a specific waiver for 517.17(B) from the AHJ can be obtained
  - For other types of facilities: Give due consideration to ground-fault protection

Specific Techniques for Achieving Selectivity

- Recognize that true “short-circuit” conditions are most likely to occur during commissioning of a new system, rather than during normal operation
  - Due to nicks in cable insulation during cable pulling and errors in equipment installation
  - Makes an argument against the requirement for “total” selective coordination – if the AHJ is receptive
  - Can certainly be the subject of proposals to change future editions of the NEC to modify selectivity requirements

Specific Techniques for Achieving Selectivity

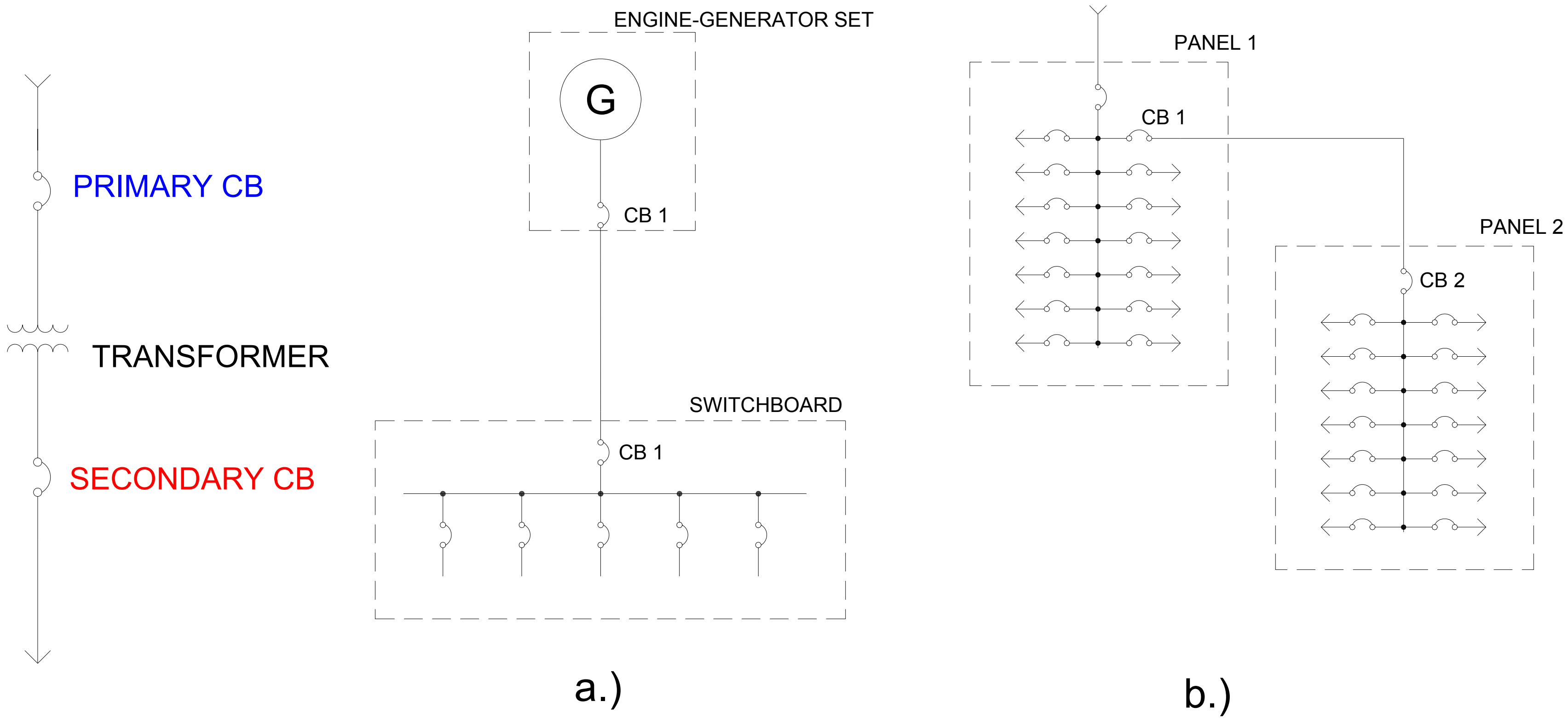
- Recognize that a time-current coordination study is required for successful system protection and coordination
  - Claims to the contrary, regardless of the source – simply not true!
  - Implementation is very similar for both fuses and circuit breakers
  - Consider selective coordination early in the design process

Specific Techniques for Achieving Selectivity

- Understand the difference between system selectivity and device-to-device selectivity
  - NEC requirements for selectivity are in conflict in this matter, and with the requirements of NFPA 110
  - Only system selectivity makes a practical difference in system reliability
  - Where AHJ will accept system selectivity, so much the better

Specific Techniques for Achieving Selectivity

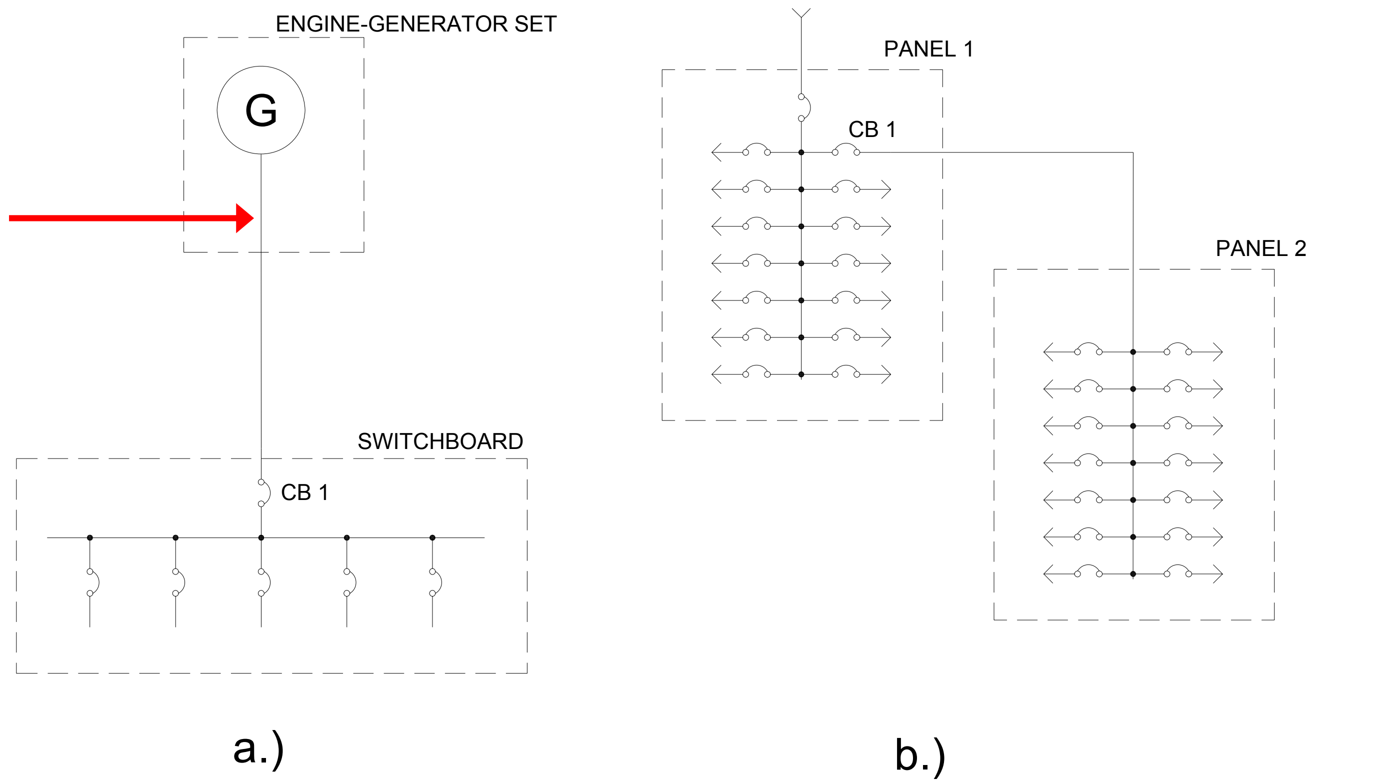
- Typical examples



Specific Techniques for Achieving Selectivity

- Examples re-designed to eliminate series devices, if necessary:

Be careful in this situation: Some AHJ's may not allow due to interpretation of NEC 445.18

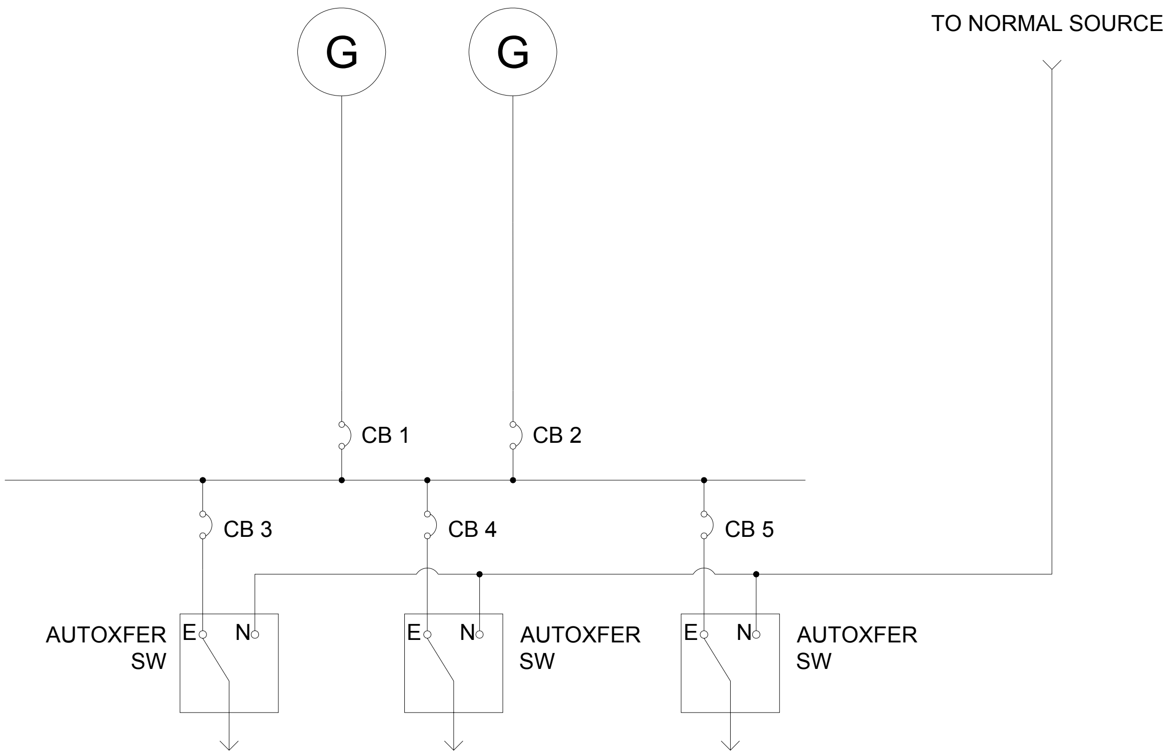


Specific Techniques for Achieving Selectivity

- Recognize the pitfalls of generator protection
  - Selective coordination often is difficult or impossible while maintaining adequate generator protection
  - Trade-offs often must be made
  - Be wary of circuit breakers supplied with engine-generator sets – these may need to be LS w/electronic trip and high withstand (possibly ANSI LV power circuit breakers)
  - Care must be taken with protective functions built into generator controllers as well

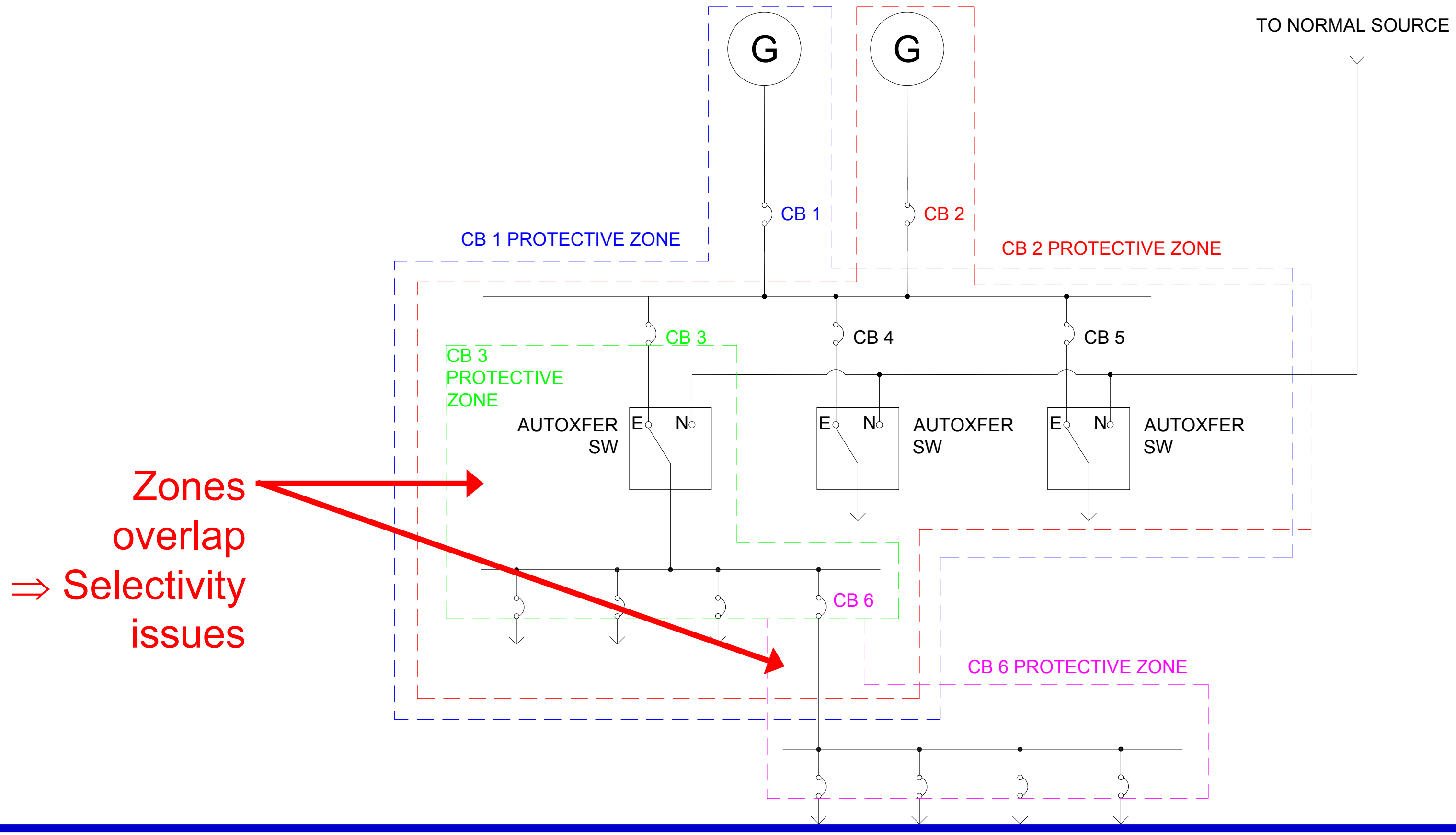
Specific Techniques for Achieving Selectivity

- Typical application with paralleled generators:



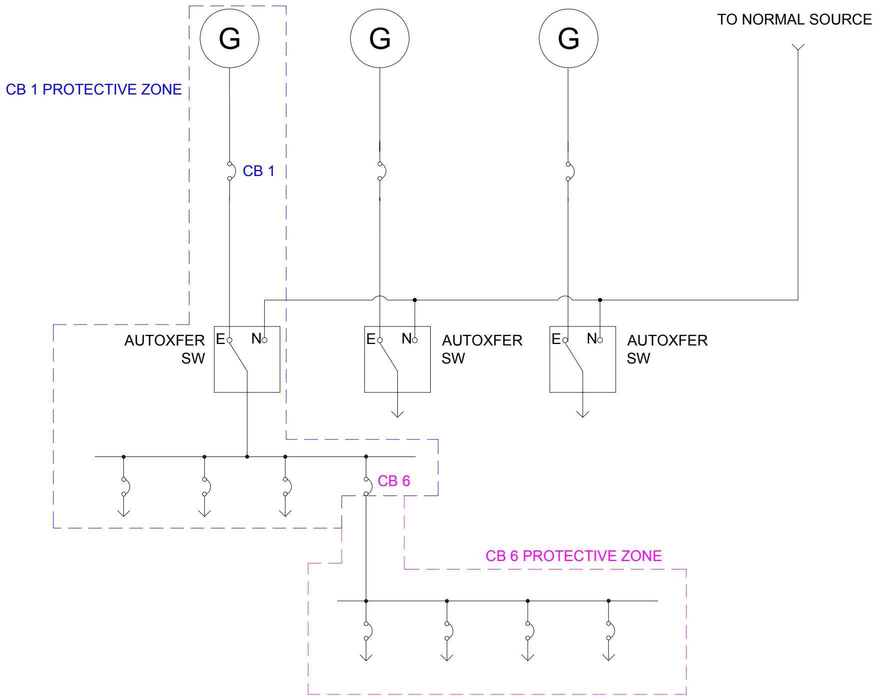
Specific Techniques for Achieving Selectivity

- Typical primary protective zones if CB1 and CB2 provide both generator overload and short-circuit protection:



Specific Techniques for Achieving Selectivity

- One solution: More, smaller generators w/o paralleling



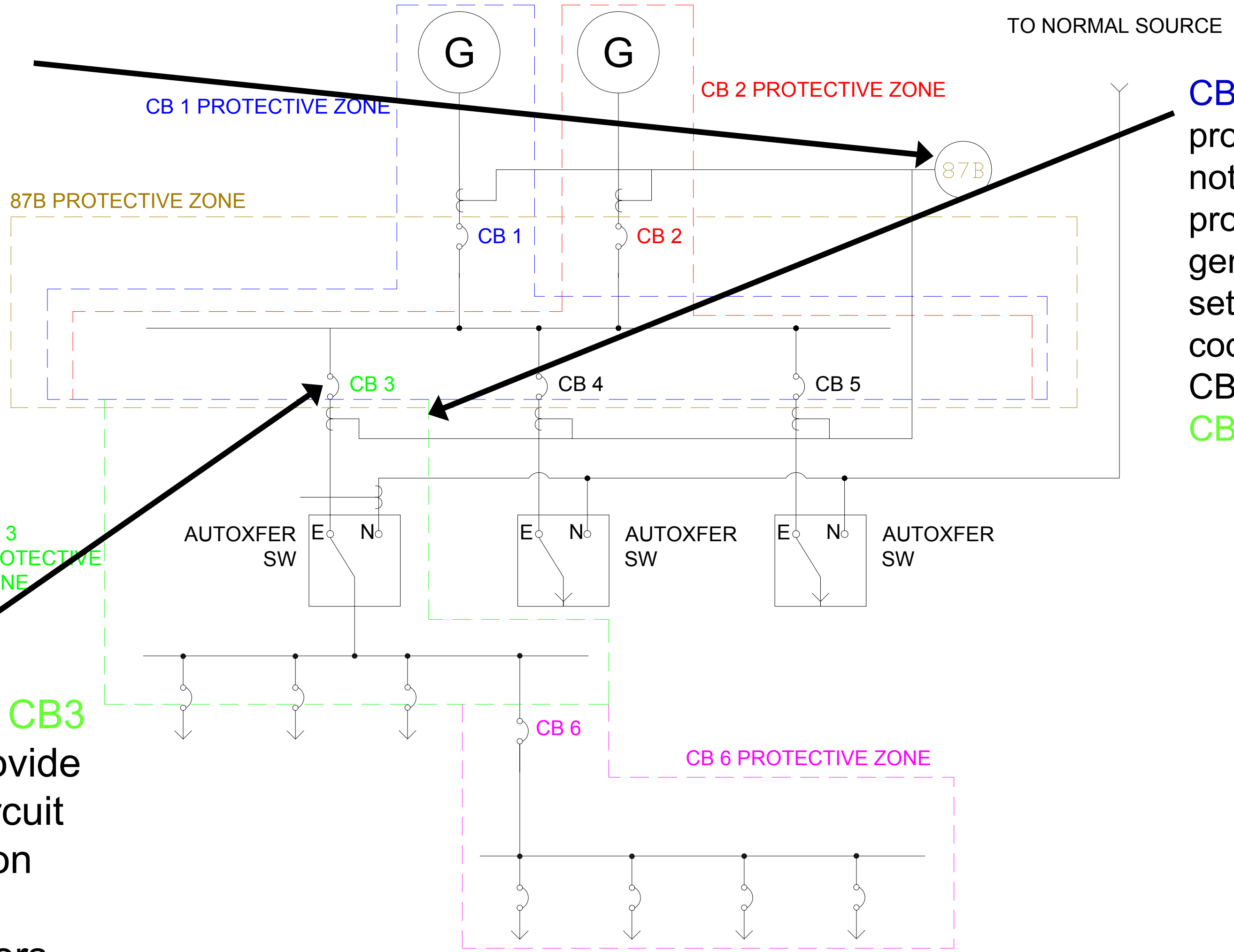
- Expensive!
- Reliability issues
- Not always practical

Specific Techniques for Achieving Selectivity

- Better solution: Allow paralleling swgr feeders to provide short-circuit protection, supplemented by bus-differential protection for the generator paralleling bus
- Not a "cure-all" but does often help

Specific Techniques for Achieving Selectivity

Bus differential protection provides short-circuit protection for generators for faults on generator paralleling bus



CB1 and CB2 set to provide overload, but not short-circuit, protection for generators. These settings allow coordination with CBs on the level of CB3.

CB's on CB3 level provide short-circuit protection for generators

Specific Techniques for Achieving Selectivity

- When using circuit breakers: Specify circuit breakers with high withstand capabilities
  - Not always published for UL 489 molded-case circuit breakers – but will be borne out in TCCs
  - Consider ANSI power circuit breakers at higher levels in the system, such as the service and generator paralleling switchgear

Specific Techniques for Achieving Selectivity

- Utilize step-down transformers to lower fault current
  - If loads can be converted from 480Y/277V to 208Y/120V
  - Method of last resort in some cases

Specific Techniques for Achieving Selectivity

- Increase circuit breaker frame size
  - May require larger feeder size but larger frame sizes are more likely to be able to coordinate

Specific Techniques for Achieving Selectivity

- Utilize the tools at your disposal
  - Circuit breaker short-circuit selectivity tables
  - Local mfr. technical support – they can work with you to achieve selectivity for a given system design

Specific Techniques for Achieving Selectivity

- For particularly difficult low-voltage transformer protection/selectivity problems, increase transformer size
  - 30kVA to 45kVA, 45kVA to 75kVA, etc.
  - Allows larger size overcurrent protective devices, which are more likely to coordinate

Specific Techniques for Achieving Selectivity

- Zone-Selective Interlocking (ZSI) – know the facts vs. the myths
  - Available only between electronic-trip circuit breakers
  - Used to decrease fault energy (and arc flash hazard) by allowing faults between two circuit breakers to be cleared in the minimum time
  - But, <u>ZSI cannot be used to force selectivity</u>: In fact, selectivity must exist before ZSI can be implemented

Specific Techniques for Achieving Selectivity

- Don’t forget on-site adjustment requirements when circuit breakers are used
  - Most manufacturers set circuit breakers at minimum settings except for long-time trip adjustments, if applicable
  - Must be based upon time-current coordination study

Summary

- 2005 NEC Selectivity Requirements
  - 700.27 requires emergency systems to be selectively coordinated
  - 701.18 requires legally required standby systems to be selectively coordinated
  - 700.27 and 701.18 imply "device-to-device" coordination, whereas the definition in Article 100 implies system coordination

Summary

- Issues With 2005 NEC Selectivity Requirements
  - Don't always make sense
  - Don't necessarily belong in the NEC
  - Conflicts are present
  - Requirements in conflict with NFPA 110

Summary

- Overcurrent Protective Device Characteristics
  - Simple TCC comparisons are not always enough to judge selectivity
  - Fuses – ratio tables are required to judge selectivity between two fuses operating in current-limiting range
  - Circuit breakers – short-circuit selectivity tables may be used to judge selectivity between circuit breakers in instantaneous region – may be better than shown on TCC

Summary

- Specific Guidelines for Achieving Selectivity
  - A coordination study is always required, regardless of the protective device type used
  - True short-circuits are rare, ground-faults are common
  - Best approach is system rather than device-to-device selectivity

Summary

- Specific Guidelines for Achieving Selectivity (cont'd)
  - Recognize the pitfalls of generator protection
  - Specify circuit breakers with high withstand capabilities
  - Use step-down transformers to lower fault current
  - Use larger circuit breaker frame sizes
  - Increase transformer sizes

Summary

- Specific Guidelines for Achieving Selectivity (cont'd)
  - Know the realities vs. the myths regarding ZSI
  - Don't forget on-site adjustment requirements
- Long-Term
  - Change the NEC to put this issue back into the hands of the engineering community
- Both fuses <u>and</u> circuit breakers may be used to achieve selective coordination!

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