Protective Relay Basics

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Speaker Bio

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Licensed professional engineer for 15 years. 25 years in the electrical industry including 10 years as a MEP consulting engineer.

Experienced in medium voltage and low voltage design and construction. Specialized in healthcare and industrial facilities. Provided electrical power system consulting and studies while working for major electrical equipment manufacturers.

Currently resides in Orlando, FL and provides application consulting for engineers throughout the state. Proficient in all ABB/GE medium and low voltage distribution products. Also proficient in system modeling and studies with EasyPower and EMTP.

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Speaker Bio

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Overview

- The objective of this presentation is to convey a basic understanding of protective relays to an audience of engineers already familiar with low voltage protective device coordination.

- Fundamental concepts and terminology will be taught using the electromechanical overcurrent relay as a foundation and then these concepts will be expanded to modern numerical relays.

Introduction

Relay Vs Low Voltage Circuit Breaker

Relay

ABB Numerical Relay
Type REF-615

- Medium & High Voltage Protection (≥ 1000VAC)
- Single component in a larger assembly. Provides protection, logic, and metering
- Requires current transformers, control power, and the circuit breaker itself
- Uses induction and electromagnetic elements (historically)
- Complex application engineering
- Higher Accuracy (historically)

Low Voltage Circuit Breaker

- Low Voltage Protection (≤ 600VAC)
- All-in-one solution. Combines protection, sensors, control power, and circuit breaker in a single package
- Uses thermal, electromagnetic, and hydraulic elements (historically)
- Simplified application engineering
- Lower accuracy (historically)

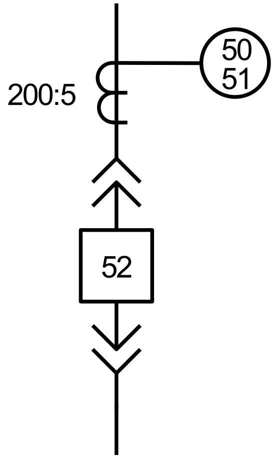
ABB LV Circuit Breaker
Tmax XT7

Relay vs Low Voltage Circuit Breaker

Symbols and Terminology

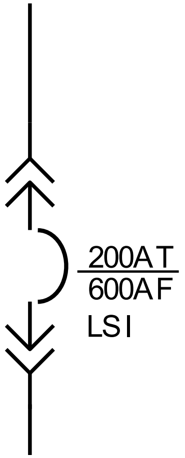
Relay

- Individual symbols for each element
- ANSI / IEEE device numbers to define protective functions
- Tap, Time Dial, Range, Curve Type, Inverse(ness) of Curve, CT Ratio



Low Voltage Circuit Breaker

- Single symbol
- Defined by trip type: Thermal Magnetic, Electronic, LSI
- Frame Size (amps), Sensor Rating (amps), Trip Rating
- Pickup, Delay, Long Time, Short Time, Instantaneous, Ground



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ANSI / IEEE Electrical Power System Device Numbers

Commonly used devices per IEEE Std C37.2 - 2008

Device Number	Function	Notes
27	Undervoltage Relay	
37	Undercurrent Relay	Also used for underpower
46	Phase Balance Current Relay	Also used for reverse phase
47	Phase Balance Voltage Relay	Also used for phase sequence
49	Thermal Relay	Motor (49M), Generator (49G), Transformer (49T)
50	Instantaneous Overcurrent Relay	Phase (50P), Neutral (50N), Ground (50G)
51	AC Time Overcurrent Relay	Phase (51P), Neutral (51N), Ground (51G)
52	AC Circuit Breaker	Type not specified, can be air, oil, vacuum, or SF6
59	Overvoltage Relay	
81	Frequency Relay	
86	Lockout Relay	Typically added to a breaker close circuit to prevent accidental reclosure after a trip.
87	Differential Protective Relay	Bus (87B) or Transformer (87T)

ANSI / IEEE Electrical Power System Device Numbers

Commonly used device number suffixes

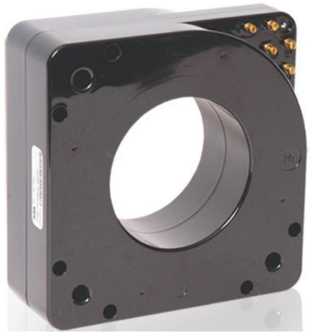
Suffix	Definition	Example
P	Phase	51P (Phase Time Overcurrent)
N	Neutral	51N (Neutral Time Overcurrent)
G	Ground	51N (Ground Time Overcurrent)
B	Bus	87D (Bus Differential)
T	Transformer	87T (Transformer Differential)
BF	Breaker Failure	50BF (Breaker Failure, zero or short time delay)

Principle Components

Three fundamental components required for each circuit breaker.

Protective Relay

+



Current Transformer

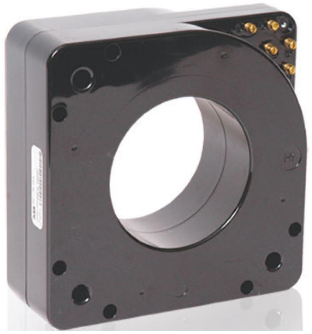
+

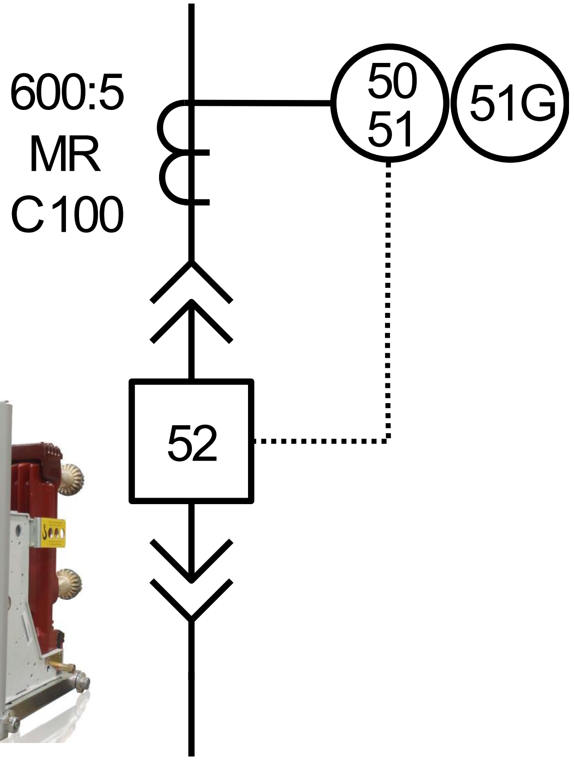
Circuit Breaker

Principle Components

Schematic Symbols

CT



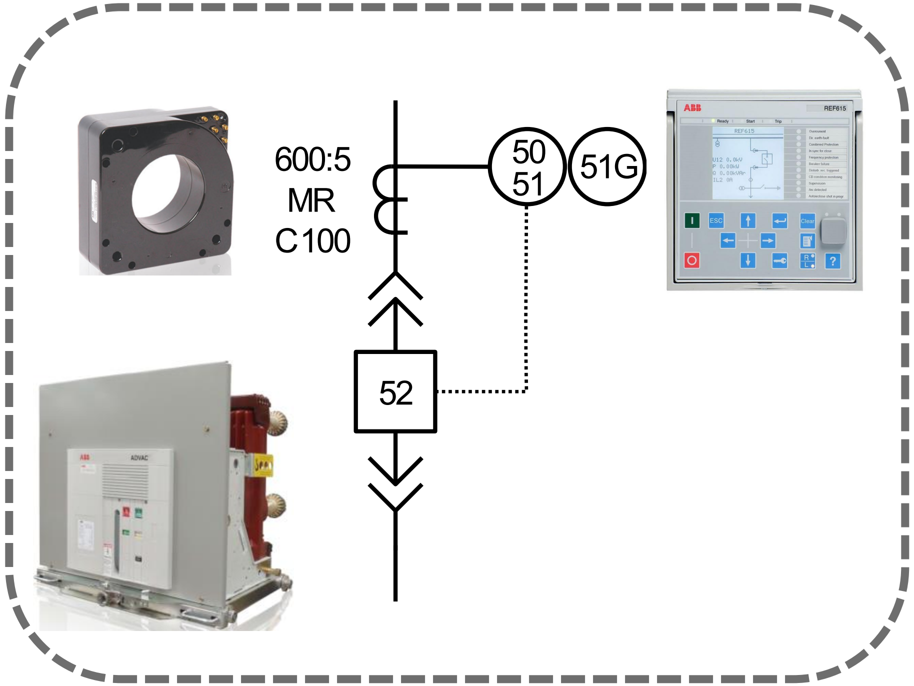


Protective Relay

Circuit Breaker

Principle Components

Components as integrated into switchgear



Components for each breaker

ABB Advance MV Metal Clad Switchgear

Current Transformer "CT"

Basic Concepts

- CT's transform line current down to a signal level that is acceptable to the relay. This signal level is typically 5A nominal.
- Primary side is the line current and secondary side is connected to the relay.
- Multiple relays can use the same CT. The limit is defined by the electrical load (burden) of the relays in relation to the maximum terminal voltage.
- Ratios are stated as "X" primary current to 5A i.e., 600:5 means that 600A of line current produces 5A of secondary current.
- There are two basic classes of current transformers: metering and relaying. Metering class relays should not be used for relay applications however relaying class CT's can be used for metering when high accuracy is not required.
- For a protection engineer, the most important CT characteristics are:
    - Ratio
    - Accuracy Class

ABB Type SAB Current Transformer

Current Transformer “CT”

What the protection engineer needs to know

- Ratio
  - Typically, 5A secondary although 1A secondary is available.
  - Can be single or multi ratio (MR).
  - Rule of thumb, select a ratio slightly larger than the rating of the circuit to be protected.
  - Numerical relays have more forgiveness than induction disk.

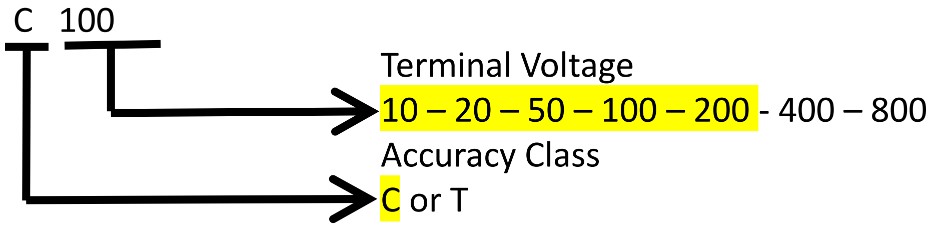
- Accuracy Class
  - Class C is the most common.
  - The number after the letter designates approximately how much voltage can be developed across the CT secondary prior to saturation. Larger numbers correspond to more core steel (more power output) for a given CT ratio.
  - Accuracy class is less critical to numerical relays due to their inherently low burden.

- Saturation Curve (optional)
  - Supplemental to accuracy class.
  - Can be very critical in specific relay applications such as differential.
  - Less critical for low burden relays where the short circuit ratio is less than 20.

IEEE C57.13 Table 8 - Standard multi-ratio current transformer taps*

Ratio	Tap	Ratio	Tap	Ratio	Tap
600:5 MR		1200:5 MR		2000:5 MR	
50:5	X2-X3	100:5	X2-X3	300:5	X3-X4
100:5	X1-X2	200:5	X1-X2	400:5	X1-X2
150:5	X1-X3	300:5	X1-X3	500:5	X4-X5
200:5	X4-X5	400:5	X4-X5	800:5	X2-X3
250:5	X3-X4	500:5	X3-X4	1100:5	X2-X4
300:5	X2-X4	600:5	X2-X4	1200:5	X1-X3
400:5	X1-X4	800:5	X1-X4	1500:5	X1-X4
450:5	X3-X5	900:5	X3-X5	1600:5	X2-X5
500:5	X2-X5	1000:5	X2-X5	2000:5	X1-X5
600:5	X1-X5	1200:5	X1-X5		

IEEE Relaying Class



- C class is considered a low leakage design and errors may be **C**alculated from excitation curve.
- T class are high leakage and must be verified by **T**est.

Medium and High Voltage Circuit Breaker

Basic Concepts

- Generally, MV and HV circuit breakers do not contain relays, trip units, or any element that will automatically cause the breaker to operate. They require relays and sensors to complete the system.
- Virtually any manufacturer / model relay can be used with any manufacturer / model circuit breaker. It is the responsibility of the application engineer to ensure that the relay and circuit breaker correctly specified and integrated.
- Interrupting technology can vary considerably and includes air, oil, vacuum or gas (SF6).
- Style can vary considerably and includes air-insulated metal clad switchgear, air-insulated metal enclosed switchgear, solid dielectric, gas insulated switchgear, dead tank outdoor, live tank outdoor, pad mount, pole mount.
- Relays can also be applied to non-beaker applications such as load interrupting switches both fused and non-fused.

ABB ADVAC 15kV Vacuum Breaker

Medium and High Voltage Circuit Breaker

What the protection engineer needs to know

- Frame size
  - For 15kV switchgear this is typically 600A, 1200A, 2000A, 3000A
- Interrupting rating in kA symmetrical RMS
  - Typical values @15kV are 25kA, 31.5kA, 40kA, 50kA, 63kA
- Interrupting time
  - Typical 3 or 5 cycles @60hz
- Short time withstand
  - Typically, 2 seconds for ANSI switchgear
- Various Ratio and class of current transformers available
- Trip coil voltage
  - DC – 24V, 48V, 125V, 250V
  - AC – 120V, 240V (needs capacitor trip)
  - Note trip coil voltage and circuit breaker control voltage may not be the same
- Control schematic

ABB ADVAC 15kV Vacuum Breaker

Overcurrent Relay

Basic Concepts

- There are many types of protective relay functions, but this presentation will focus on the most common type, basic overcurrent device 50/51 (instantaneous and time overcurrent).

- Traditionally, protective relays were electromechanical devices utilizing induction disk, coils, contacts, and solenoid elements to determine protective characteristics.

- Traditional overcurrent relays (50/51) used an induction disk for the time delayed element (51) and a solenoid for the instantaneous element (50).

- Modern multifunction relays combine basic overcurrent protection with many additional relay elements into a single compact unit.

ABB Numerical Relay
Type REF-615

Overcurrent Relay

Electromechanical Type

- Traditionally, protective relays were electromechanical devices that utilized induction disk, coils, contacts, and solenoid elements to determine protective characteristics.

- Electromechanical relays:
    - Very accurate relative to the simpler trip units used in early low voltage circuit breakers.
    - Low sensitivity to changes in ambient temperature
    - Allowed for advanced protective functions by virtue of their inherent ability to sum voltage and current phasors.
    - Very reliable when properly maintained and tested.

- Fundamental technology used from the beginning of the 20th century until the 1990's

- Required complex wiring and multiple devices for each breaker. A typical 3 phase breaker would require a minimum of 3 relays, one for each phase. Each protective function typically required its own discrete relay.

- Largely replaced by multifunction numerical relays.

- Many remain in service and are also used in new systems as backup to numerical relays.

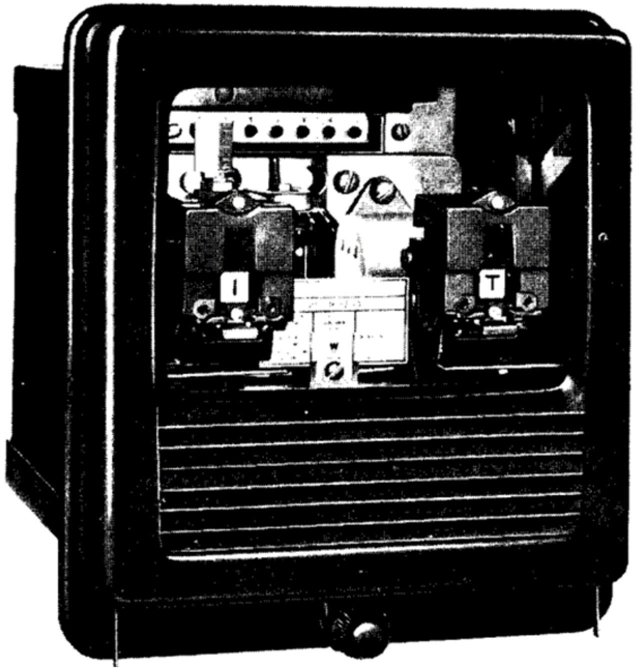


ABB Induction Disk
Overcurrent Relay
Type CO-9

Electromechanical Relay

Physical and form factor

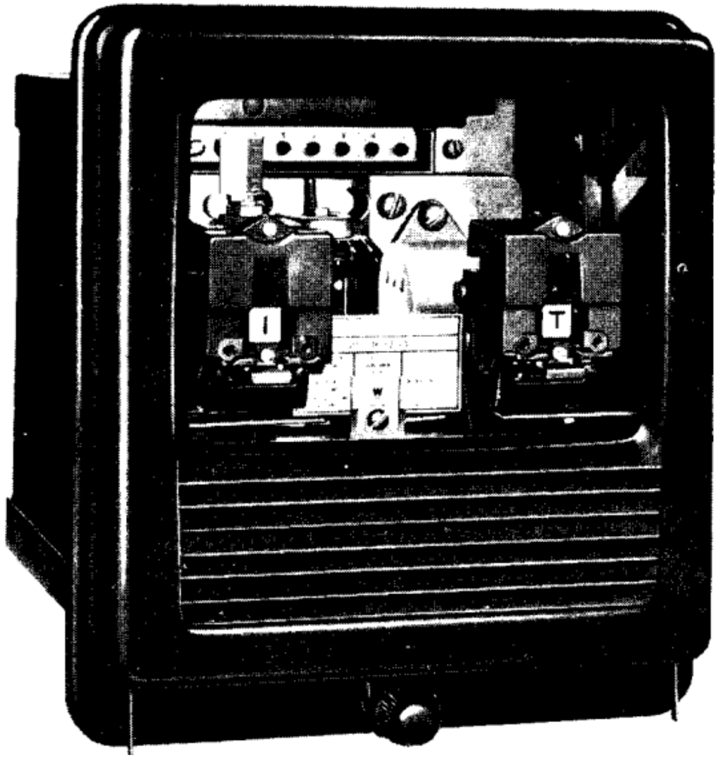
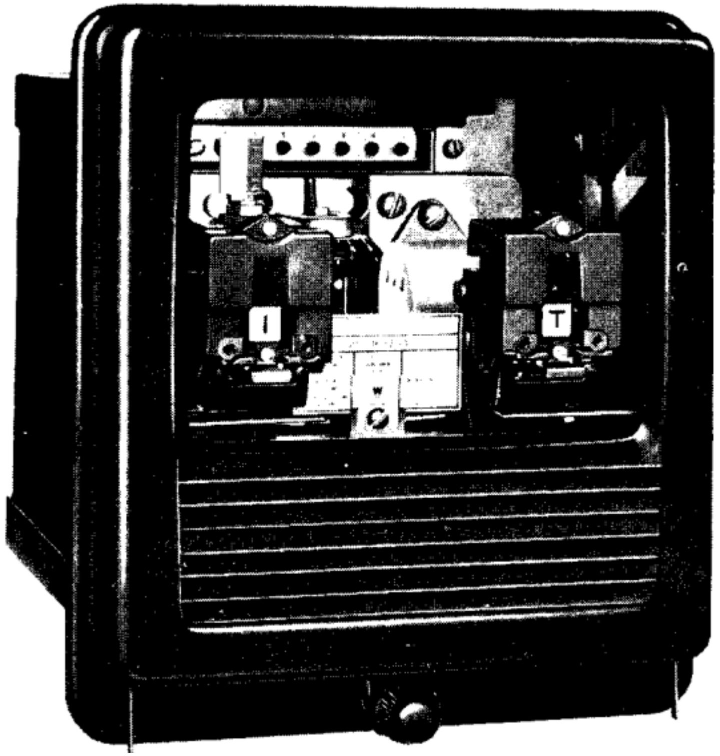


ABB Electromechanical Relay – Type CO-9

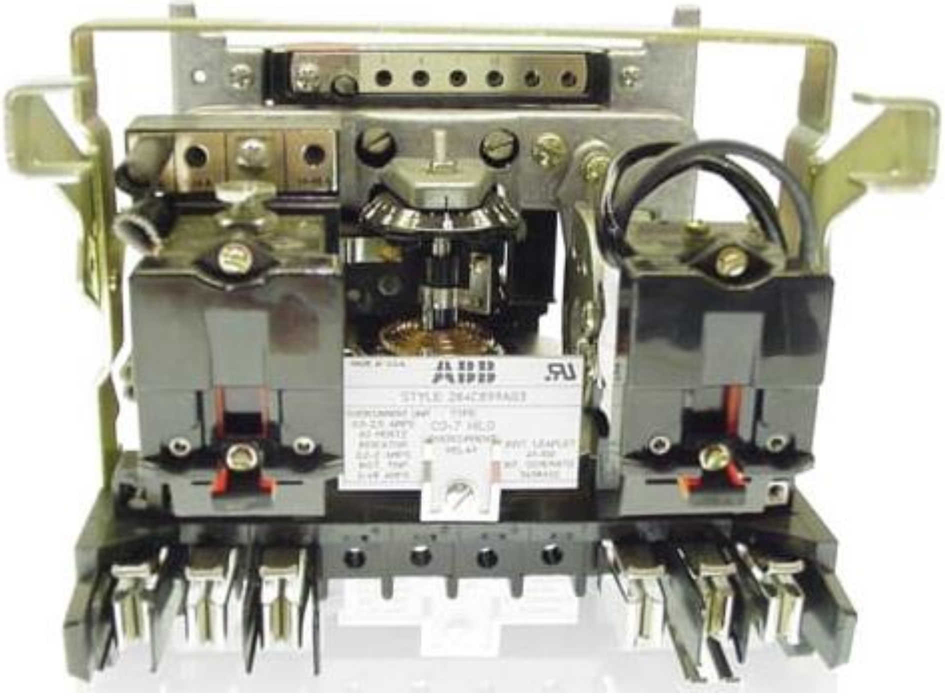
ABB Numerical Relay – Type REF-615

Electromechanical Relay

Draw-out element in protective case



Type CO-9 in standard case

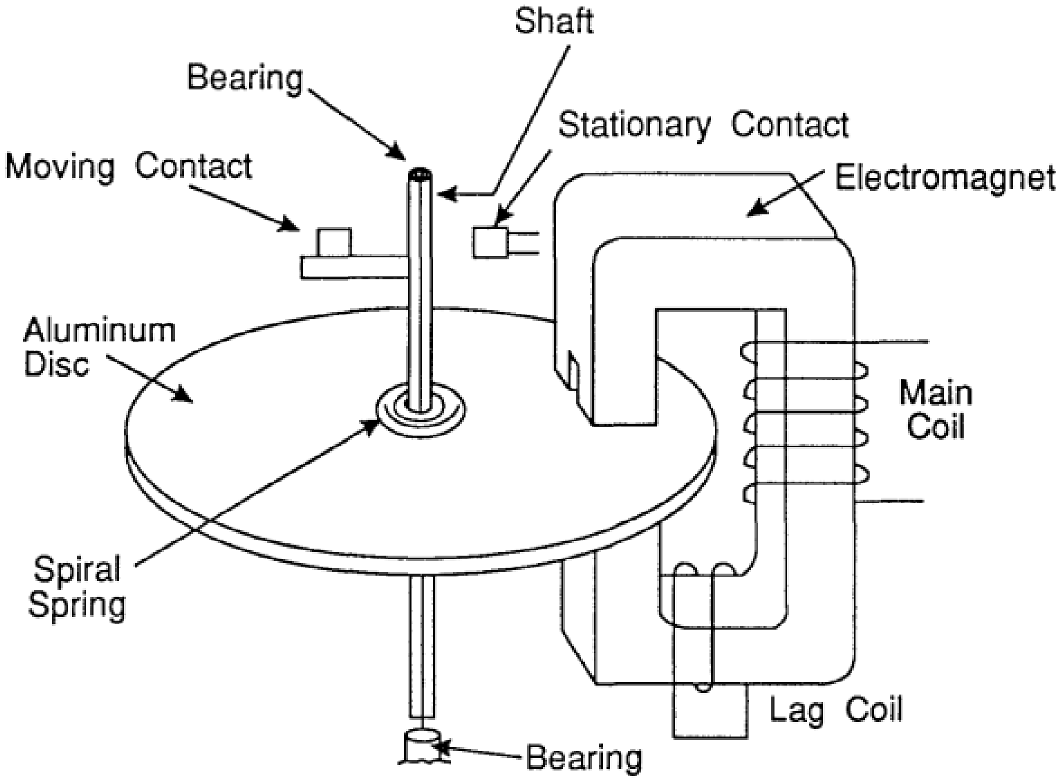


Internal draw-out element

Induction Disk

Principle of operation

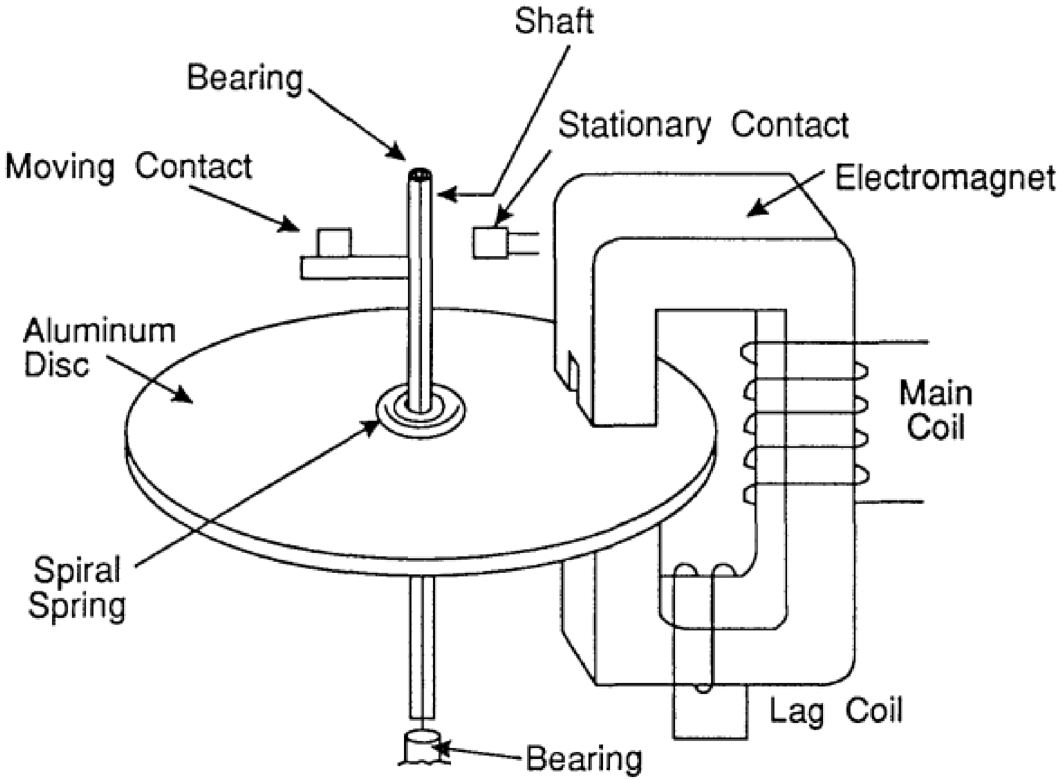
- Induction disks are used for time delayed elements.
- Moving contact connected to a rotating aluminum disk.
- Alternating current is induced into the disk causing it to rotate relative to two stationary but phase shifted magnetic fields.
- In a standard overcurrent relay, the phase shifted fields are created by a shaded pole structure.
- Restraining torque is created by a permanent magnet. Return torque is created by a spiral spring.
- Time Dial – Sets the starting distance between the moving and stationary contact. This determines the elapsed time to trip for a given current.
- Tap – Sets the current (field strength) in the main coil proportional to a given current.



Induction Disk

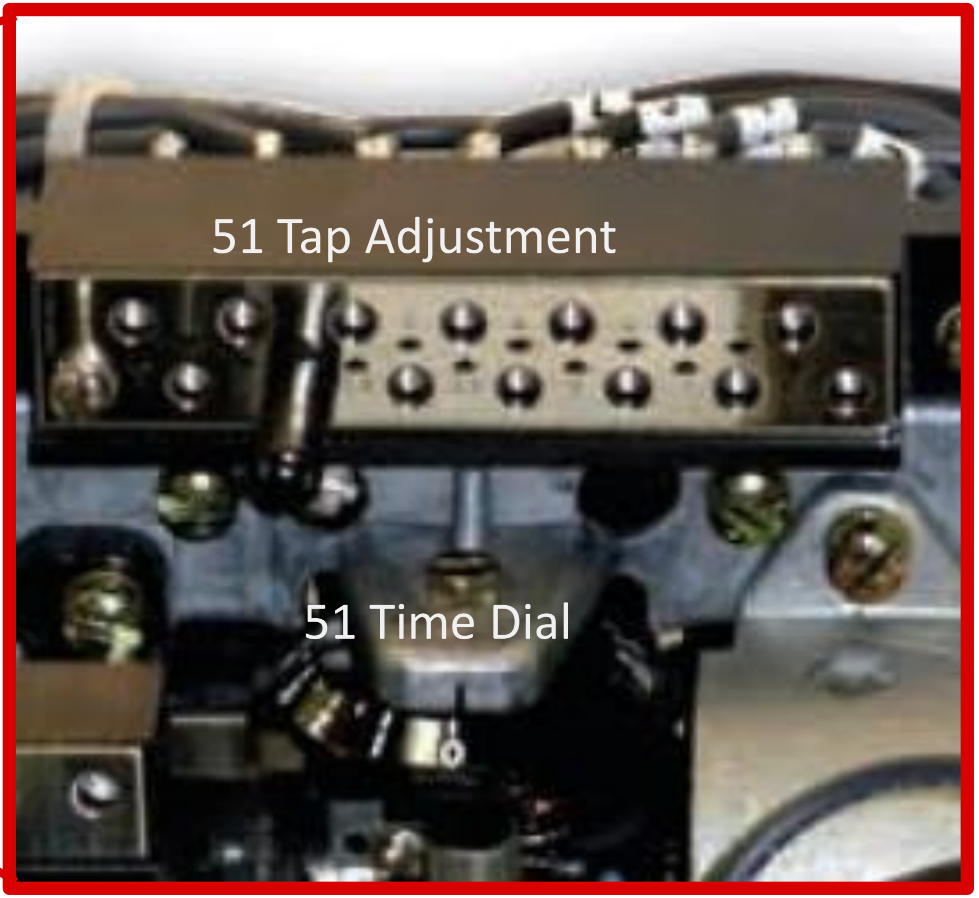
Principle of operation

- Accurate but very delicate mechanism. Not reliable in harsh atmospheres.
- Disk overtravel needs to be accounted for in coordination studies.
- The setting methods (particularly the time dial) are imprecise. Standard operating procedure was to set, test, adjust settings, retest, repeat.



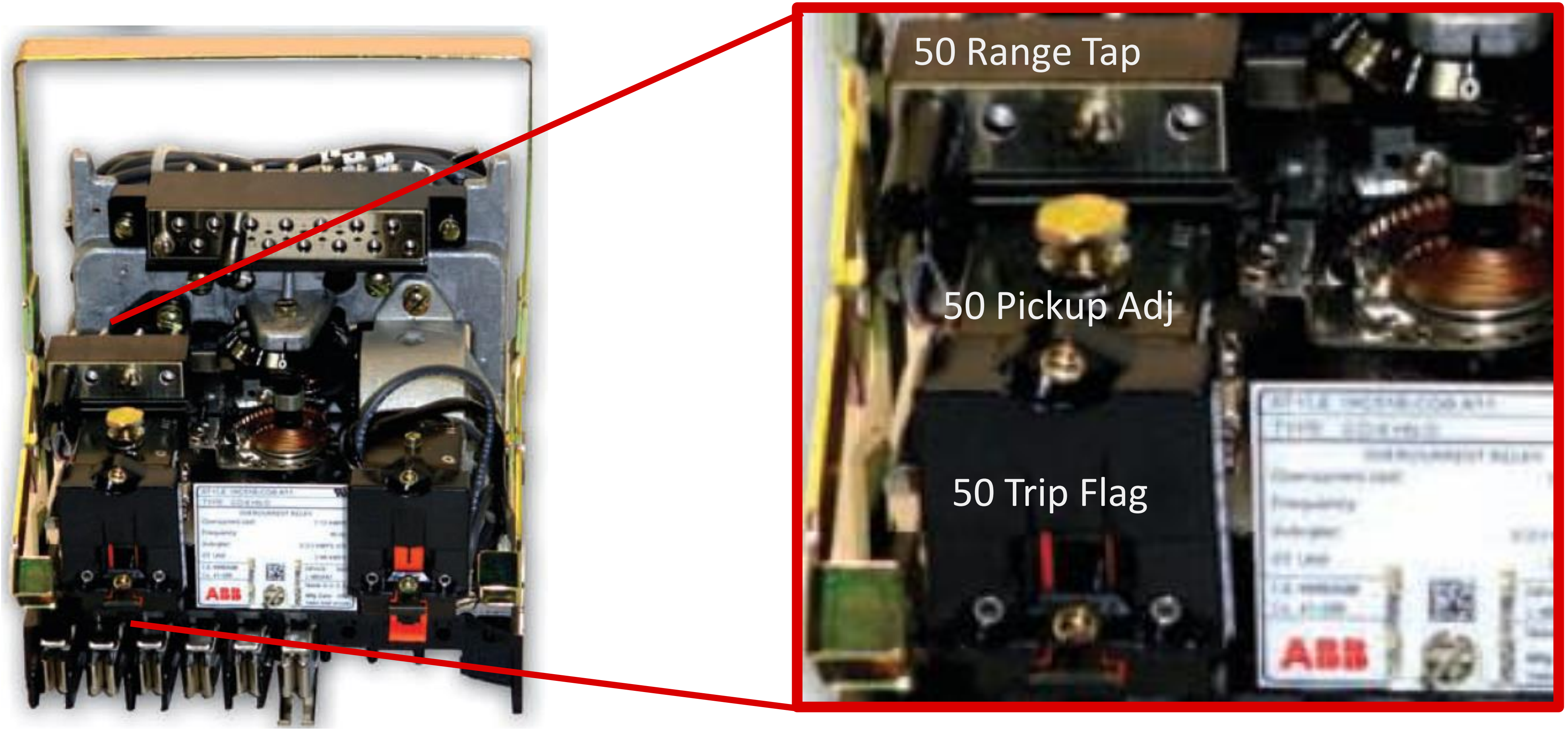
Type CO Overcurrent Relay

Time Overcurrent Unit Settings



Type CO Overcurrent Relay

Instantaneous Trip – IIT Unit Settings

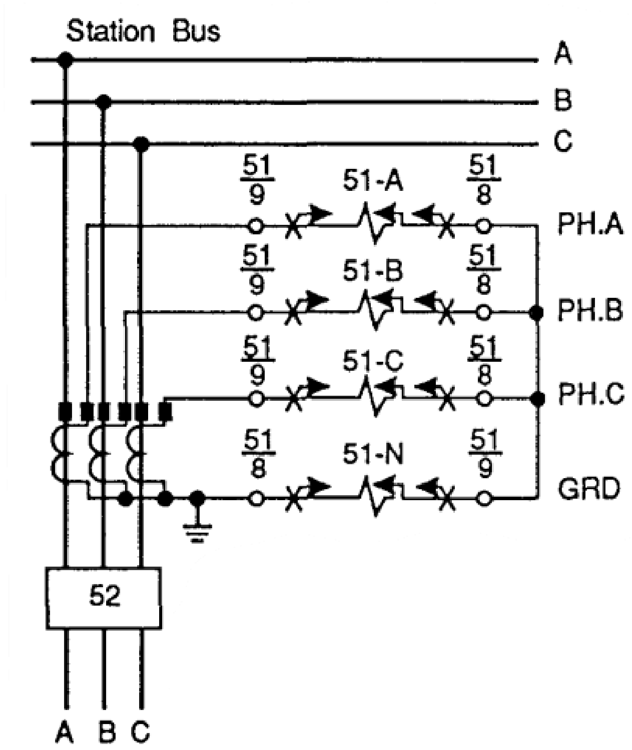


Type CO Overcurrent Relay

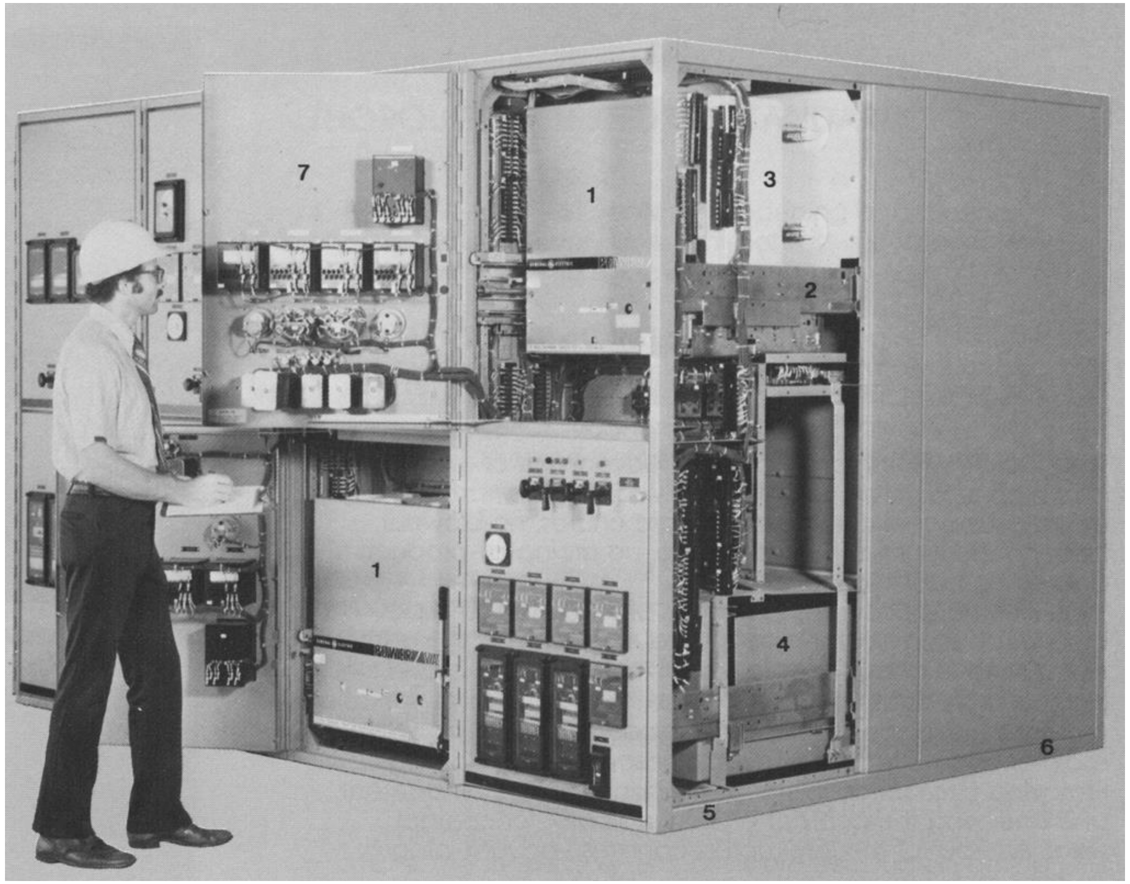
Time Overcurrent – ICS Unit. Provides seal-in around the induction disk contacts and Trip Flag (a.k.a indicating target)

Example Relay Installation in Switchgear

Minimum of 3 to 4 electromechanical relays per breaker



Example schematic – 3 phase plus ground

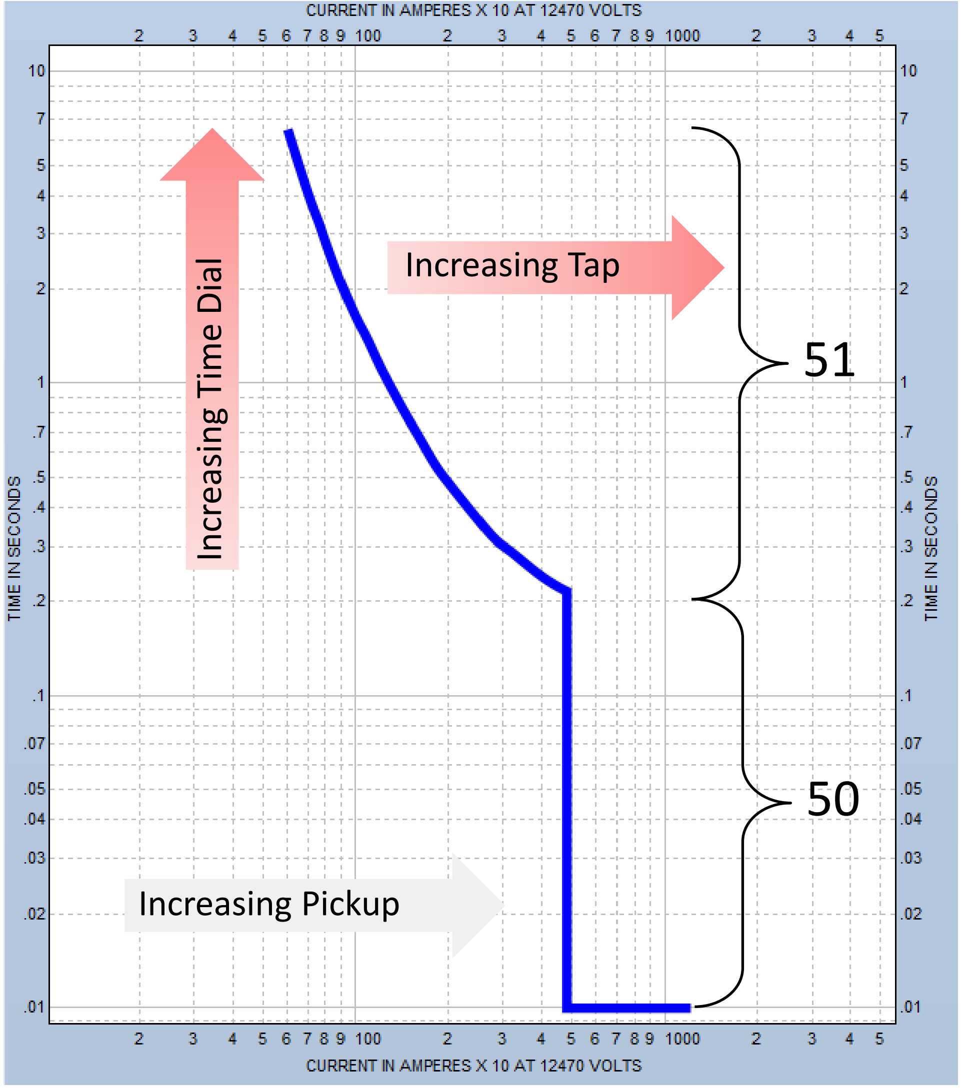


50/51 Time Current Curve

Fundamental settings & how they affect the curve

<u>51 – Time Overcurrent</u>

- **Curve**
  - <u>Electromechanical</u>: The curve is fixed and designated by relay model (i.e. CO-11 Very Inverse, CO-9 Very Inverse)
  - <u>Numerical</u>: Configurable to standard relay types
- **Tap**
  - Increasing tap values move the curve to the right.
  - Standard convention is tap setting is equal to the CT secondary current that will cause the relay to pickup**. (i.e. 200:5 CT with a tap setting of 3 will pickup at 120A line current)
  - <u>Electromechanical</u>: Ranges are by specific relay model, typically 6 taps available. (i.e. range = 2.0 to 6.6 with taps at 2.0, 2.5, 3.0, 3.5, 4.0, 5.0, 6.0)
  - <u>Numerical</u>: 0.25 to 25 in 0.05 steps for 5A secondary (0.05 to 5 times CT secondary current).
- **Time Dial**
  - Increasing time dial moves the curve up.
  - <u>Electromechanical</u>: 0.5 to 11
  - <u>Numerical</u>: 0.05 to 15 in 0.01 steps

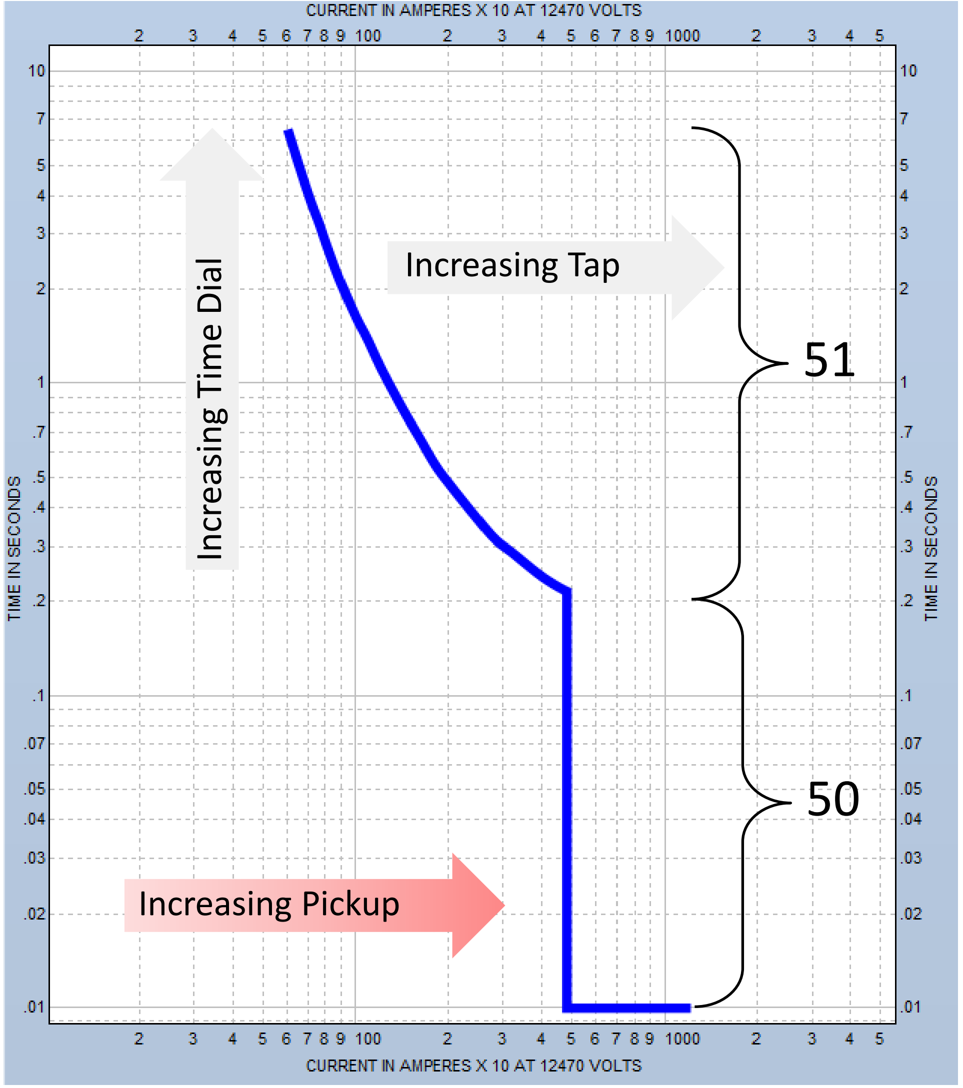


50/51 Time Current Curve

Fundamental settings & how they affect the curve

<u>**50 – Instantaneous Overcurrent**</u>

- **Pickup**
  - Increasing pickup moves the curve to the right.
  - Standard convention is tap setting is equal to the CT secondary current that will cause the relay to pickup**. (i.e. 200:5 CT with an instantaneous setting of 40 will pickup at 1600A line current)
  - <u>Electromechanical</u>: Ranges are set by tap plug. Typically, 3 ranges available such as 2-7, 7-14, 14-48. Adjustment screw then sets the specific tap within the range.
  - <u>Numerical</u>: 0.5 to 200 in 0.05 steps for 5A secondary (0.1x to 40x times CT secondary current).



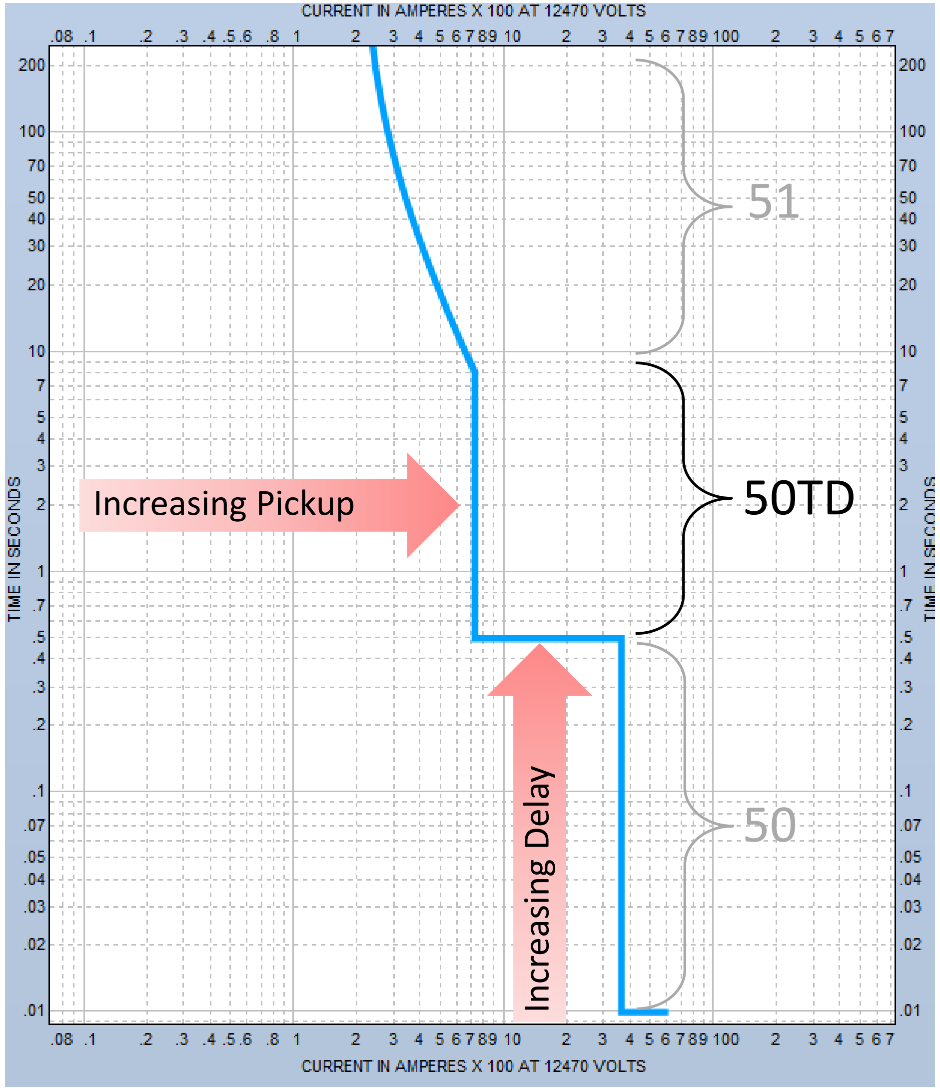
** Include note numerical relays, CT multiplier and the effect on settings table in Easypower.

50/50TD/51 Time Current Curve

Numerical Relay with delayed device 50 (50TD)

50TD – Delayed Instantaneous Overcurrent

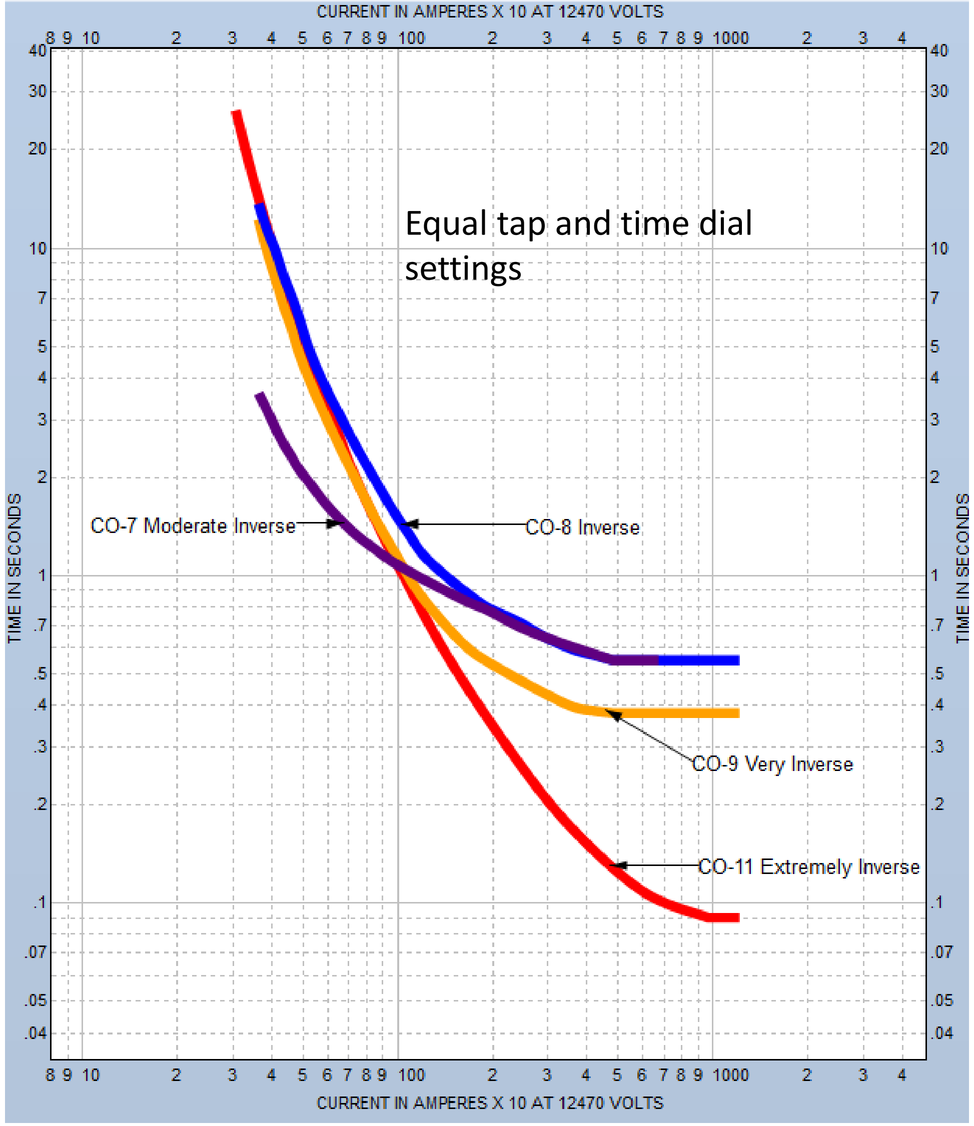
- Numerical Relays Only
- **Pickup**
    - Increasing pickup moves the curve to the right.
    - Numerical: 0.5 to 200 in 0.05 steps for 5A secondary (0.1x to 40x times CT secondary current).
- **Delay**
    - Increasing pickup move the curve to the right.
    - Numerical: 40ms to 200s in 10ms steps.



Inverse Time Curve Family

ABB CO Relay

Type	Curve Name	Typical Applications
CO-11	Extremely Inverse	• Cable protection • Transformer protection • Fuse coordination • LV Breaker coordination
CO-9	Very Inverse	• Motor protection • Similar applications to CO-11
CO-8	Inverse	• Coordination with legacy and special devices • Backup protection
CO-7	Moderately Inverse	
CO-6	Definite Time	• Delayed instantaneous (50TD). • Other protective functions where simple time delay is required such as overvoltage.
CO-5	Long	• Legacy device – similar applications to CO-11 or CO-9 or motors with long starting times
CO-2	Short	• Legacy device – similar applications to CO-6



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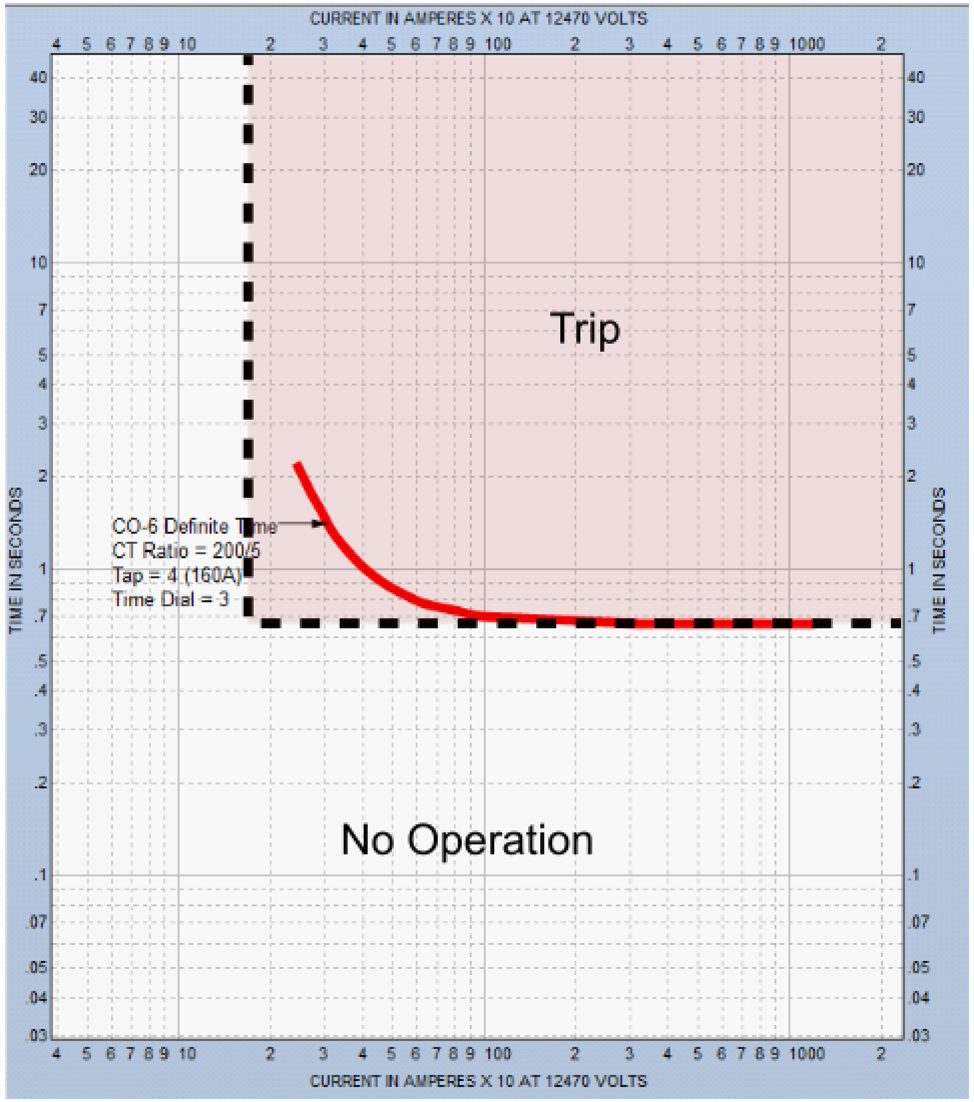
Definite Time Curve

ABB CO-6 Relay vs Ideal Definite Time

- The ideal definite time relay has binary response. It only operates (trip) when the current has exceeded the pickup level and the timer has reached limit. Current in excess of the pickup value does not affect the ideal response.

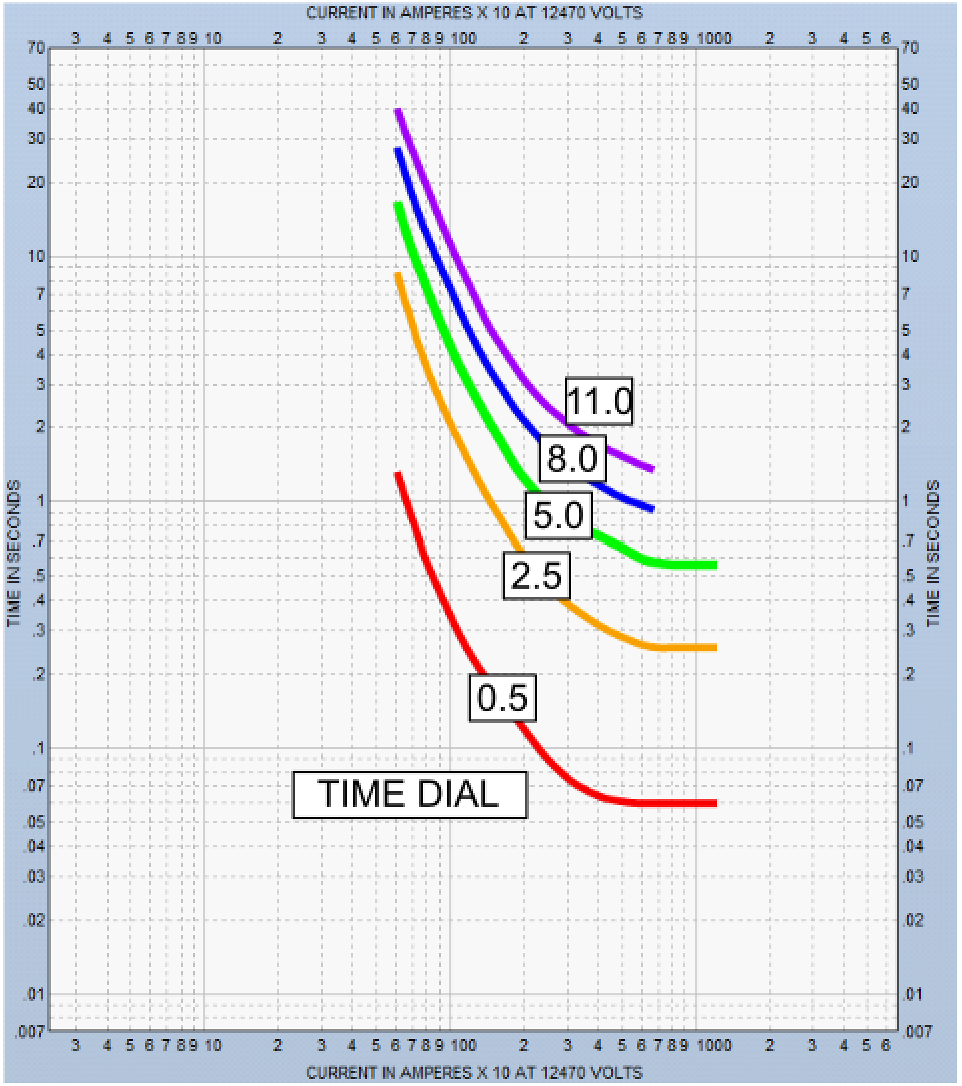
- The electromechanical implementation of definite time is far from ideal response. It's essentially an inverse time device with slight inverse characteristics.



Device 51-Time Dial

CO-9 Very Inverse Time Dial Range 0.5 to 11

- Example of how the time dial adjustments change the response of relay.
- The curve is not only shifts up and down (time) but also slightly left and right (amps).



Coordination Intervals

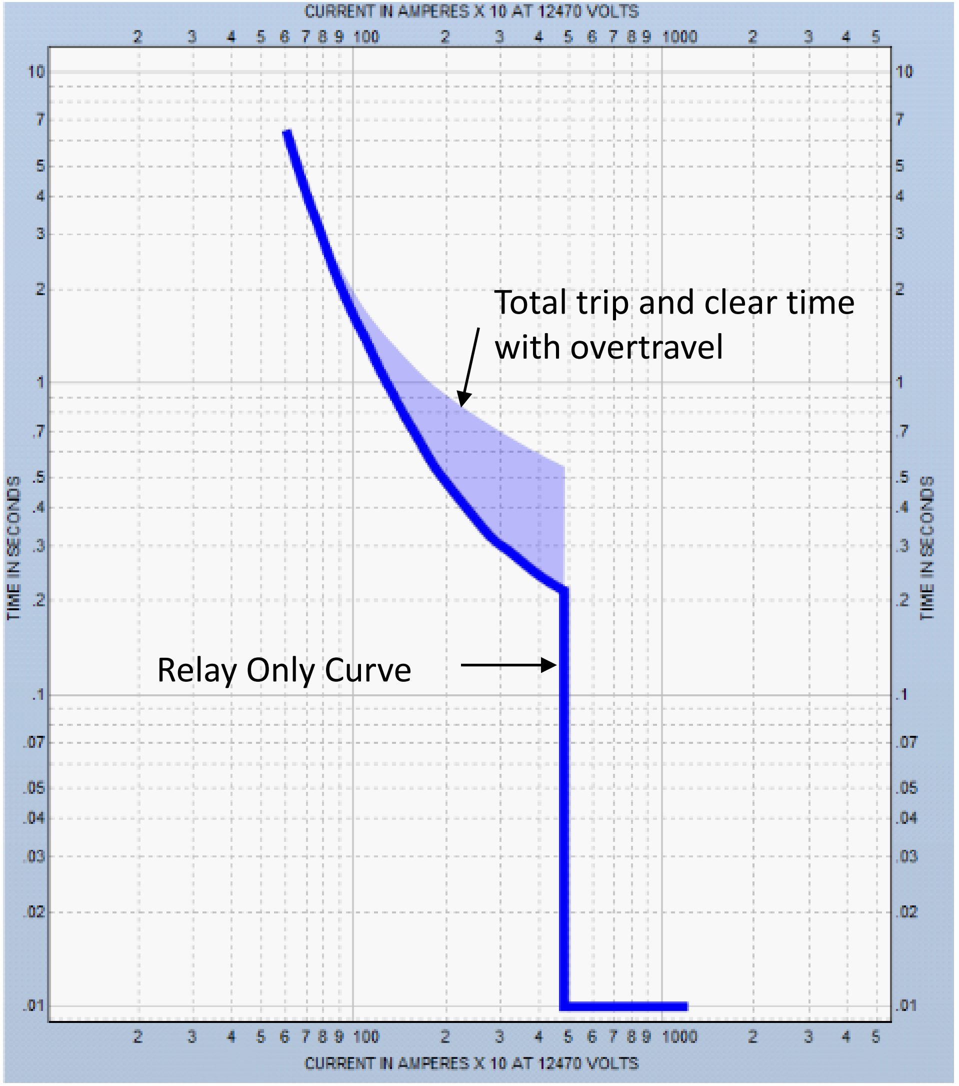
Total time to trip and clear

- Relay curves show only the time for the relay itself to operate and do not include additional time required to trip and clear the fault. The relay curve is shown as the dark blue line.

- Additional time must be added to the curve when coordinating to other protective devices. This additional time is shown in the light blue area.

- In addition to the relay curve, the following items must be accounted for to compute the total maximum time to trip and clear:
    - CT Accuracy - time varies but 12 cycles is a good safety factor barring detailed analysis.
    - Circuit Breaker Trip and Clear Time – 3 or 5 cycles
    - Interposing relay delays – 1 to 3 cycles
    - Relay Overtravel (Electromechanical Only) – Assume 6 cycles barring availability of detailed information.

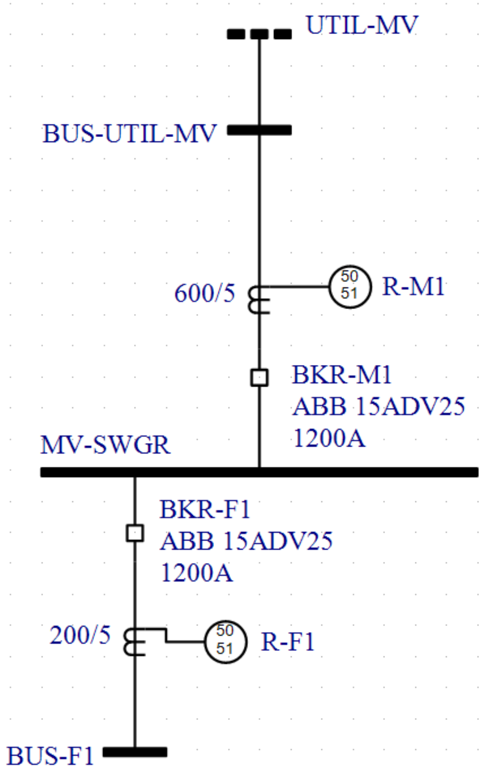
- Barring detailed information and analysis, recommended coordination intervals are:
    - 12 cycles (0.2 sec) for numerical relays
    - 24 cycles (0.4 sec) for electromechanical relays

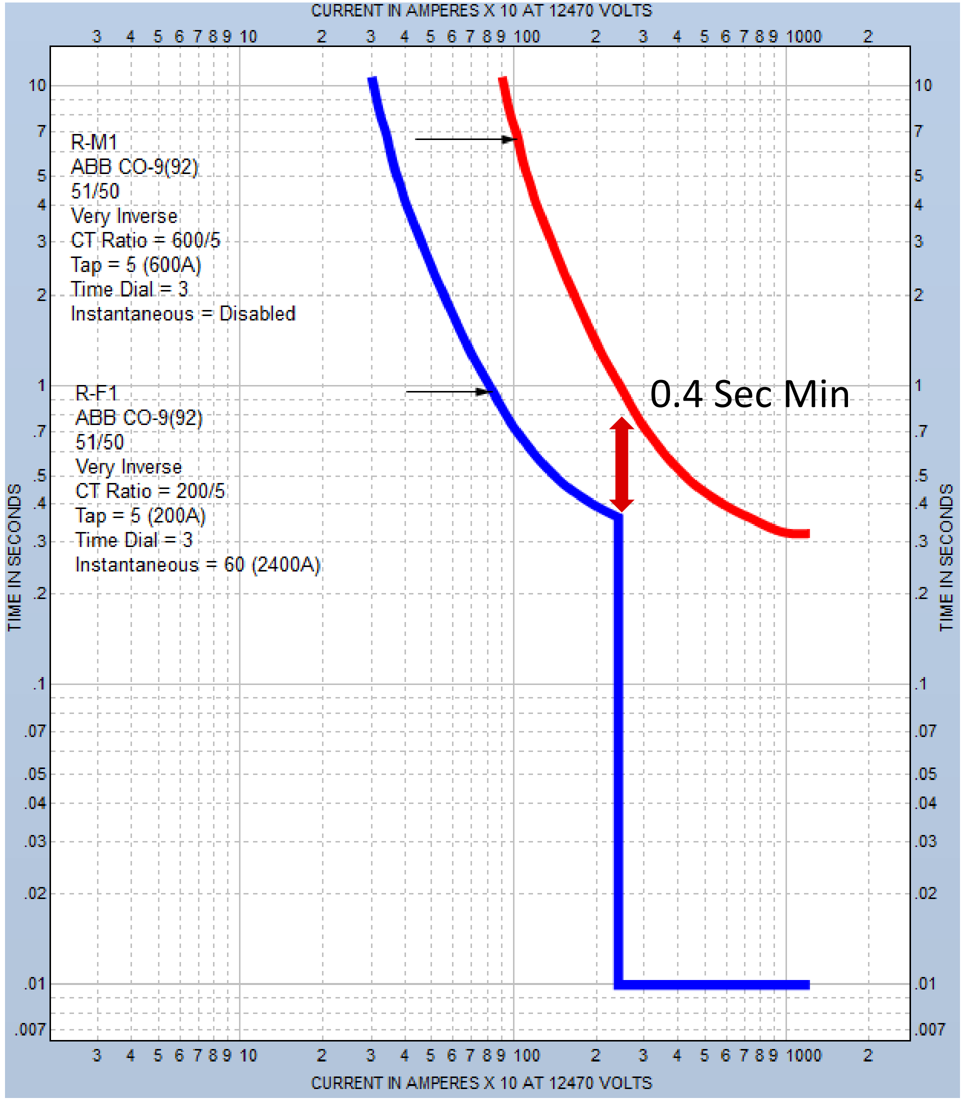


Relay to Relay Coordination

Electromechanical Type Relay

- The fault needs to be completely cleared before the upstream relay picks up (red curve)
- Electromechanical - Minimum time coordination interval between relays is 0.4 seconds (24 cycles).
- The spacing between numerical relays can be much shorter typically 0.3 seconds (12 cycles) but no less then 0.1 seconds (6 cycles).

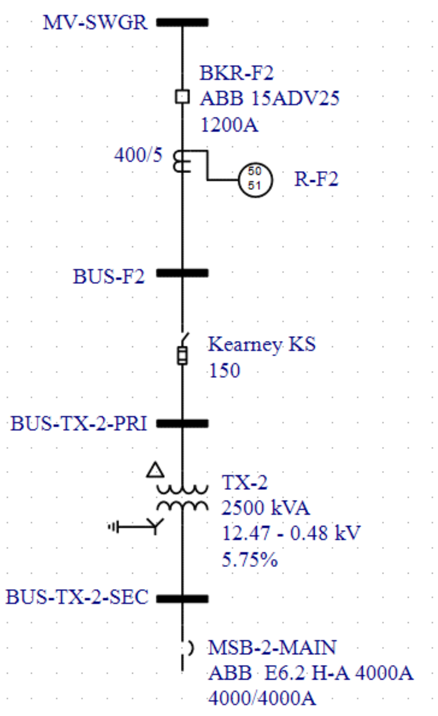


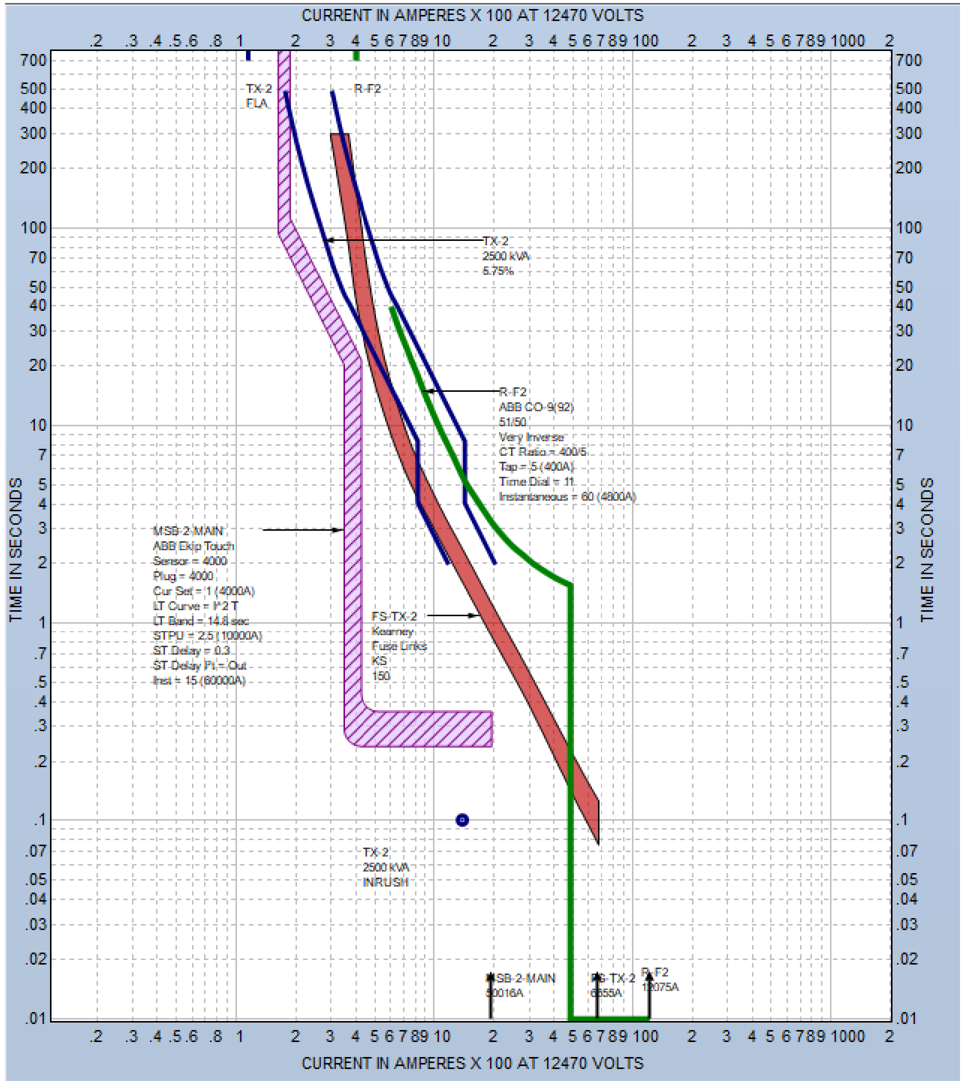


Transformer Protection

Electromechanical Type Relay

- This is an example of typical utility upstream transformer and feeder protection coordinated with a low voltage service main circuit breaker.
- Coordination between the customer and utility is often overlooked.
- The transformer's primary fuse (red curve) and the low voltage main (purple curve) do not have to coordinate as they are in series.
- Setting the low voltage main below the fuse can prevent unnecessary utility service calls.

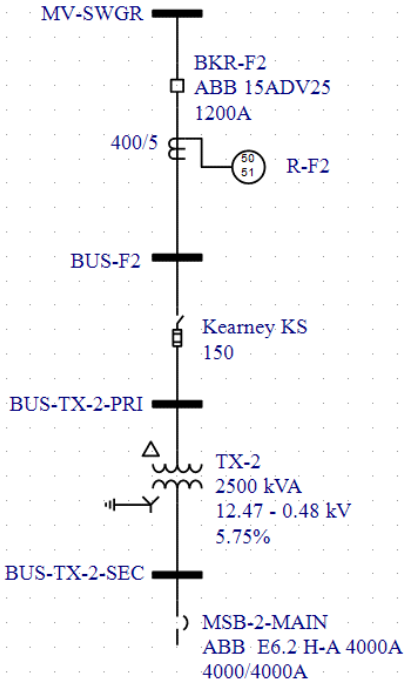


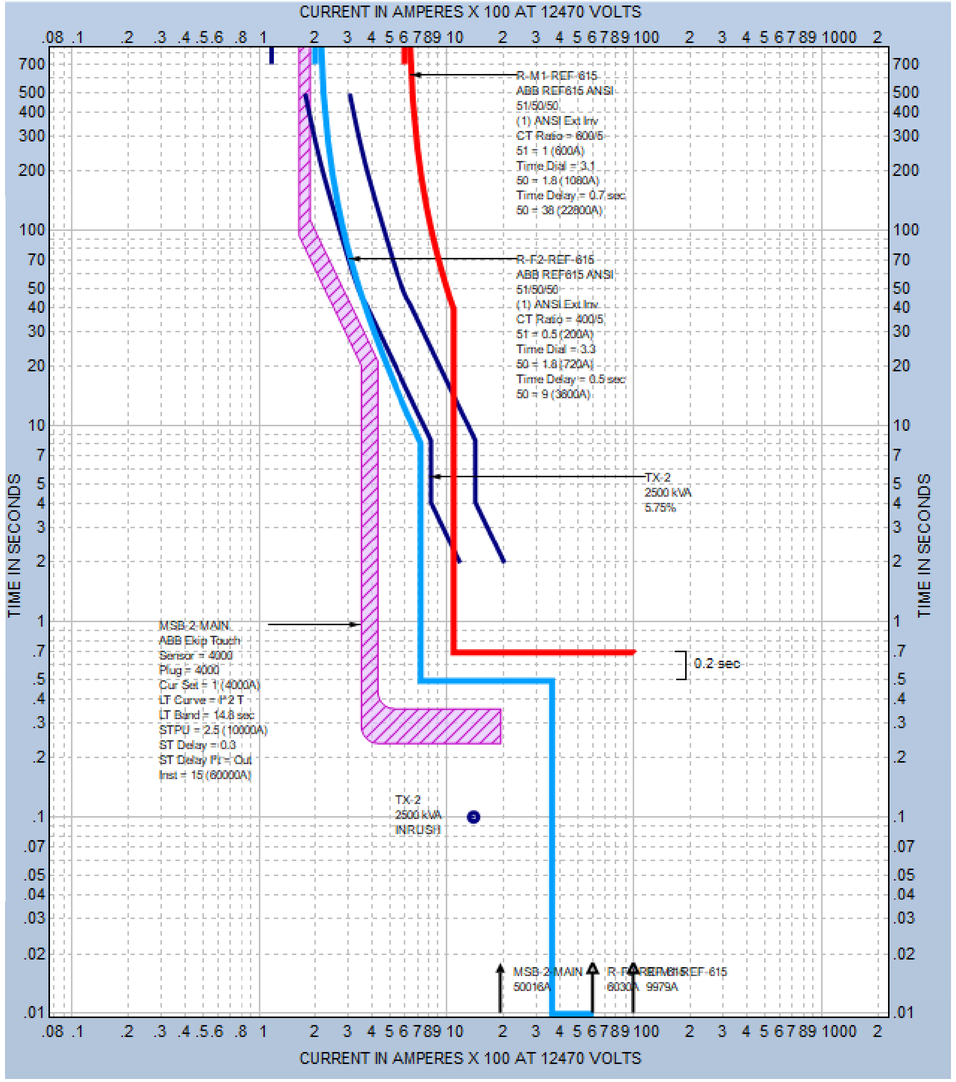


Transformer Protection

Numerical Type Relay – ABB REF-615

- This curve illustrates enhanced protection made possible by numerical relays.
- Coordination intervals can be cut in half.
- Adding the 50TD element to both relays reduces the fault clearing time while maintaining full selectivity.
- High precision settings allow the primary side relay to better protect the full damage curve of the transformer (both three phase and unbalanced damage curves).





Recommendations For Relay Coordination

Rules of thumb to be used only with engineering judgement.

1. For electromechanical relays: Avoid mixing different manufacturers and models of overcurrent relay in the same circuit. Curve names were not standardized across manufacturers. For example, an ABB CO-9 Very Inverse relay does not have the same curve as a GE IAC 53 Very Inverse curve.

2. For numerical relays: Mixing manufacturers is typically not an issue. Numerical relays offer a large selection of curve types. When possible, choose ANSI standard curves (applies to North America only).

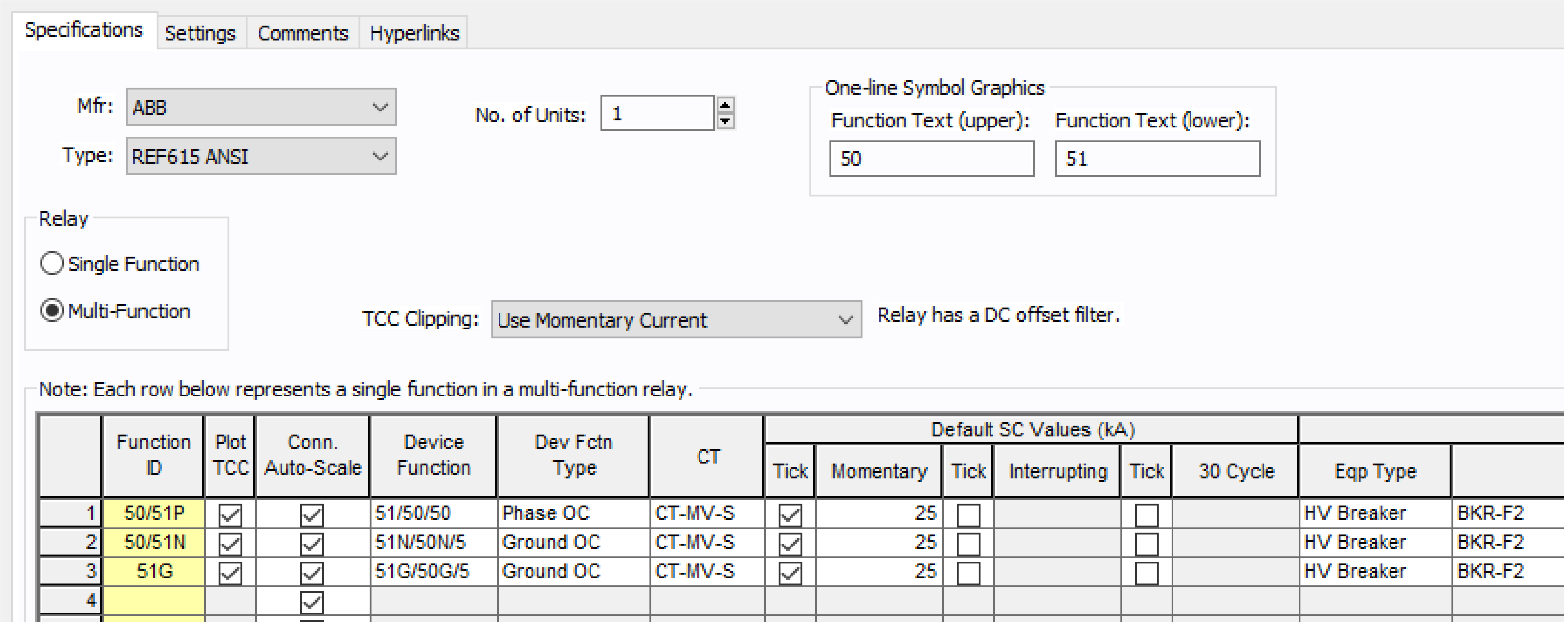
3. The upstream relay should use an equal or less inverse curve type then the downstream relay. For example, an upstream Very Inverse relay will coordinate with a downstream Extremely Inverse, but an upstream Extremely Inverse relay will not (necessarily) coordinate with a downstream Very Inverse relay.

4. When coordinating with expulsion type fuses (non-current limiting) use delayed instantaneous trip (50TD) to maintain full selectivity.

5. When coordinating with current limiting type fuses, set the instantaneous trip (50) to 1.1x the current limiting value of the fuse.

EasyPower Examples

Numerical Multifunction Relay – Specifications Tab


Specifications | Settings | Comments | Hyperlinks

Mfr: ABB

Type: REF615 ANSI

No. of Units: 1

One-line Symbol Graphics

Function Text (upper): 50

Function Text (lower): 51

Relay

○ Single Function

◉ Multi-Function

TCC Clipping: Use Momentary Current

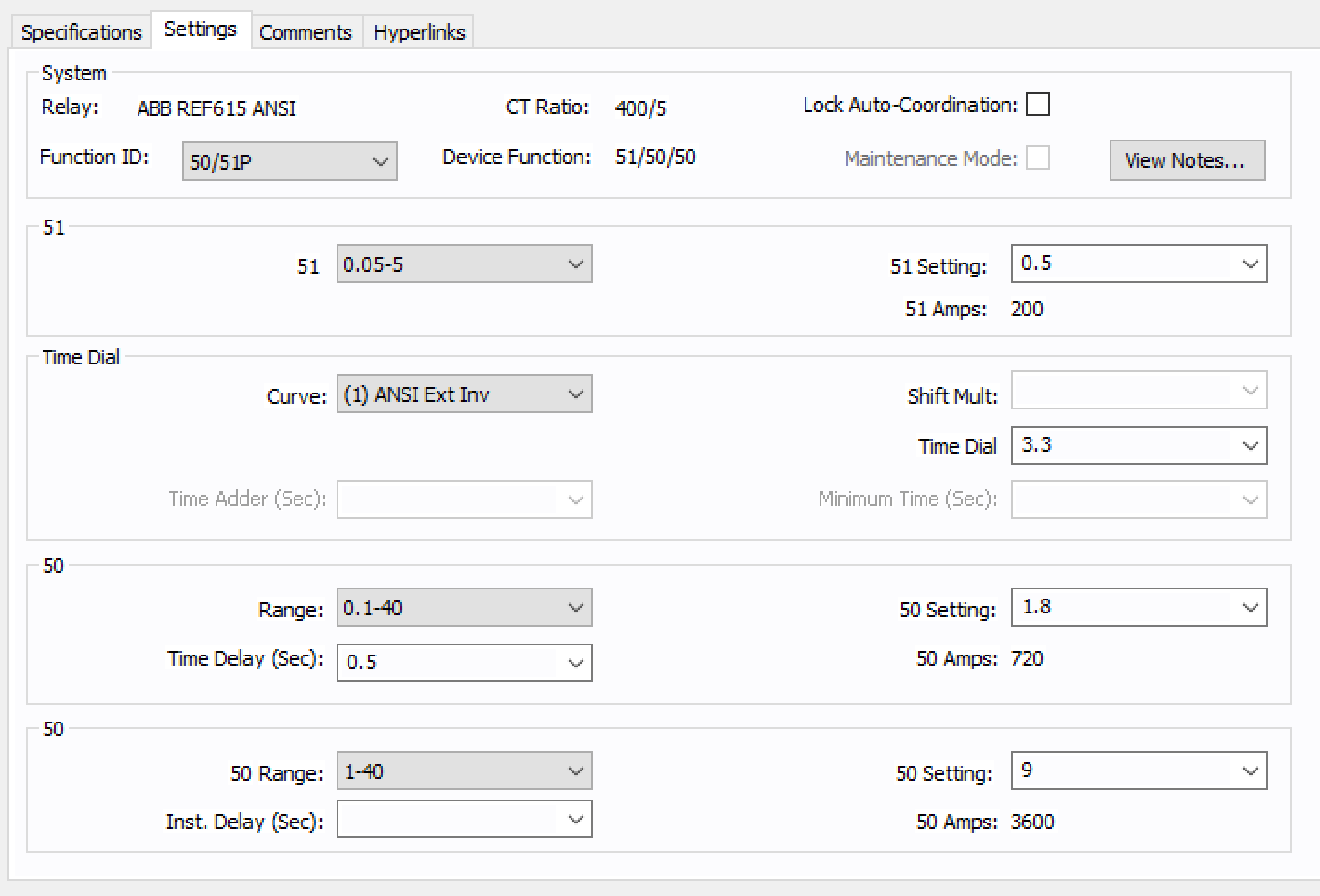
Relay has a DC offset filter.

Note: Each row below represents a single function in a multi-function relay.

	Function ID	Plot TCC	Conn. Auto-Scale	Device Function	Dev Fctn Type	CT	Default SC Values (kA)							
							Tick	Momentary	Tick	Interrupting	Tick	30 Cycle	Eqp Type	
1	50/51P	☑	☑	51/50/50	Phase OC	CT-MV-S	☑	25	☐		☐		HV Breaker	BKR-F2
2	50/51N	☑	☑	51N/50N/5	Ground OC	CT-MV-S	☑	25	☐		☐		HV Breaker	BKR-F2
3	51G	☑	☑	51G/50G/5	Ground OC	CT-MV-S	☑	25	☐		☐		HV Breaker	BKR-F2
4			☑											

EasyPower Examples

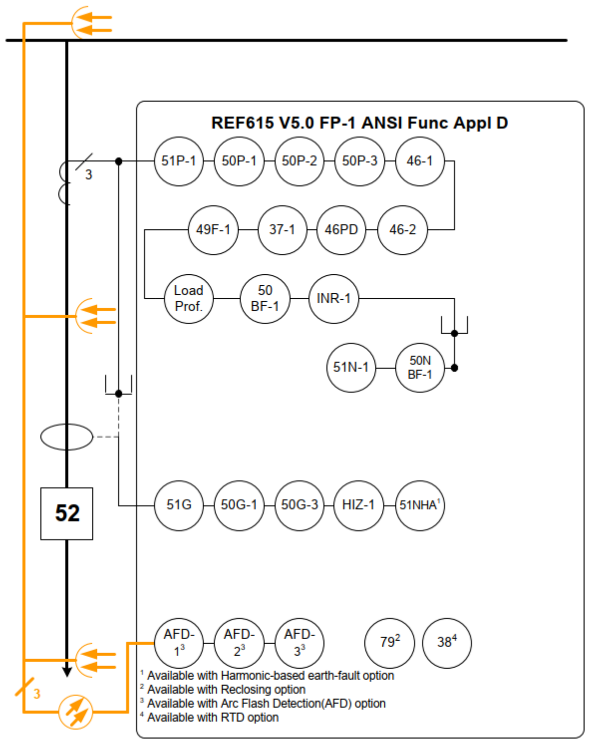
Numerical Multifunction Relay – Settings Tab



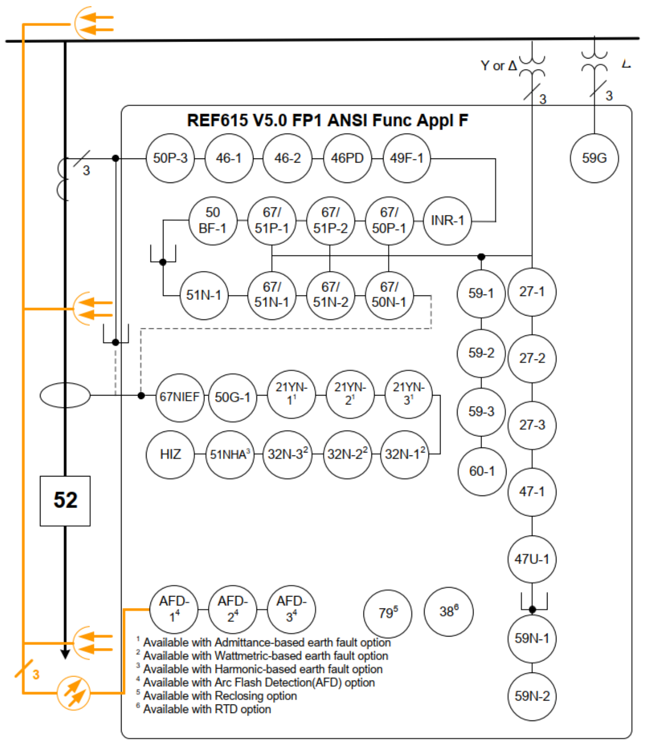
Numerical Relay

Multiple protection elements in a single device

Basic Feeder Protection – Current Only



Advanced Feeder Protection – Current and Voltage



Numerical Relay

REF-615 Device 51 Trip Curves Available

Table 85. Operation characteristics

Characteristic	Value (range)
Operating curve type	1 = ANSI Ext. inv. 2 = ANSI Very. inv. 3 = ANSI Norm. inv. 4 = ANSI Mod inv. 5 = ANSI Def. Time 6 = L.T.E. inv. 7 = L.T.V. inv. 8 = L.T. inv. 9 = IEC Norm. inv. 10 = IEC Very inv. 11 = IEC inv. 12 = IEC Ext. inv. 13 = IEC S.T. inv. 14 = IEC L.T. inv 15 = IEC Def. Time 17 = Programmable 18 = RI type 19 = RD type

Thank You

Questions?

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