Integrating Arc Flash Analysis with Protective Device Coordination

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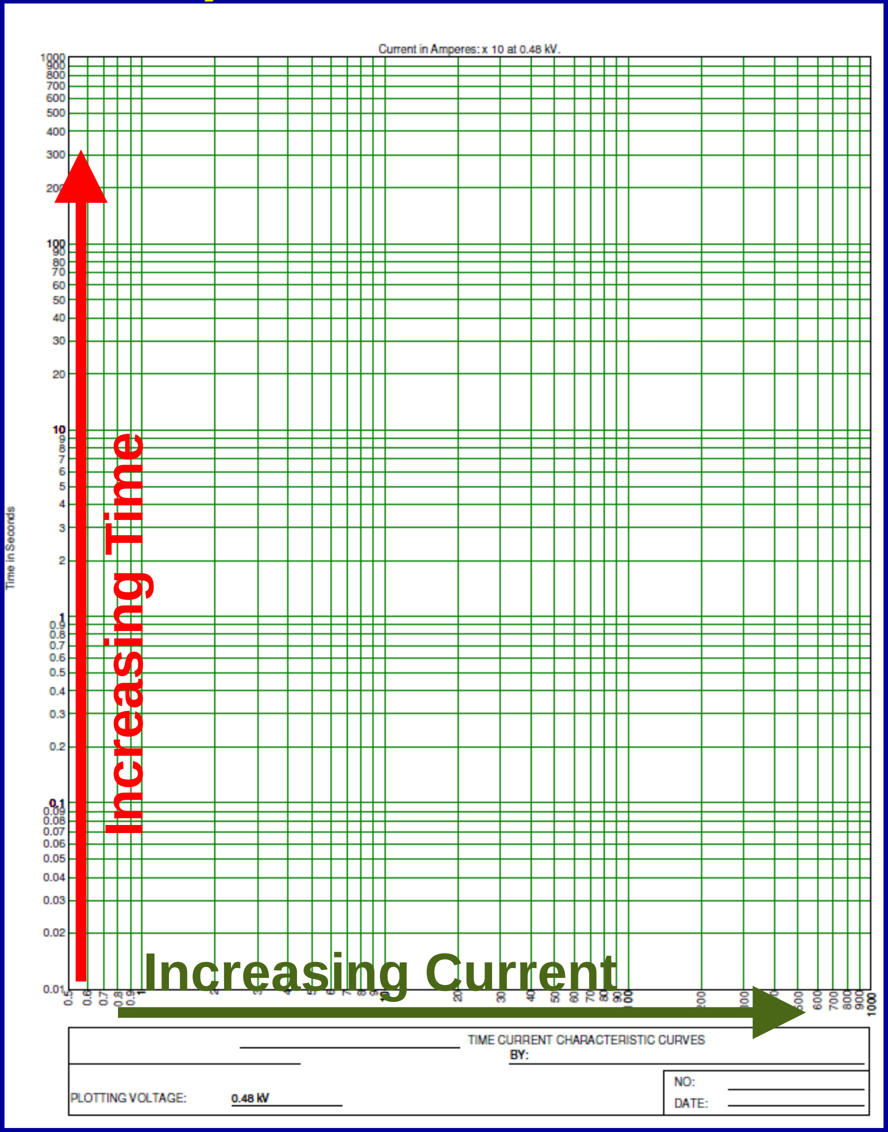
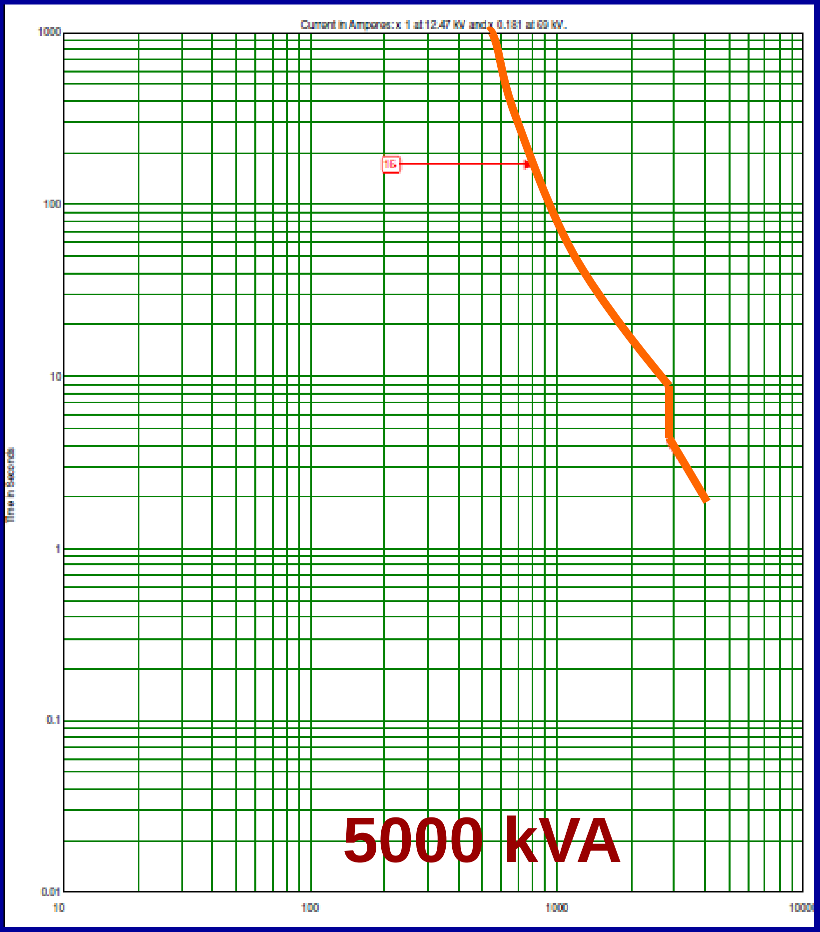
What is TCC (Time-Current Coordination)?

- TCC plots use a log-log template
- What are the axis' on a TCC?
  - Current on the **Horizontal**
  - Time on the **Vertical**
- Electrical power devices are modeled on TCCs and then they are combined with protective device models to determine how well the power devices are protected from overcurrent conditions.

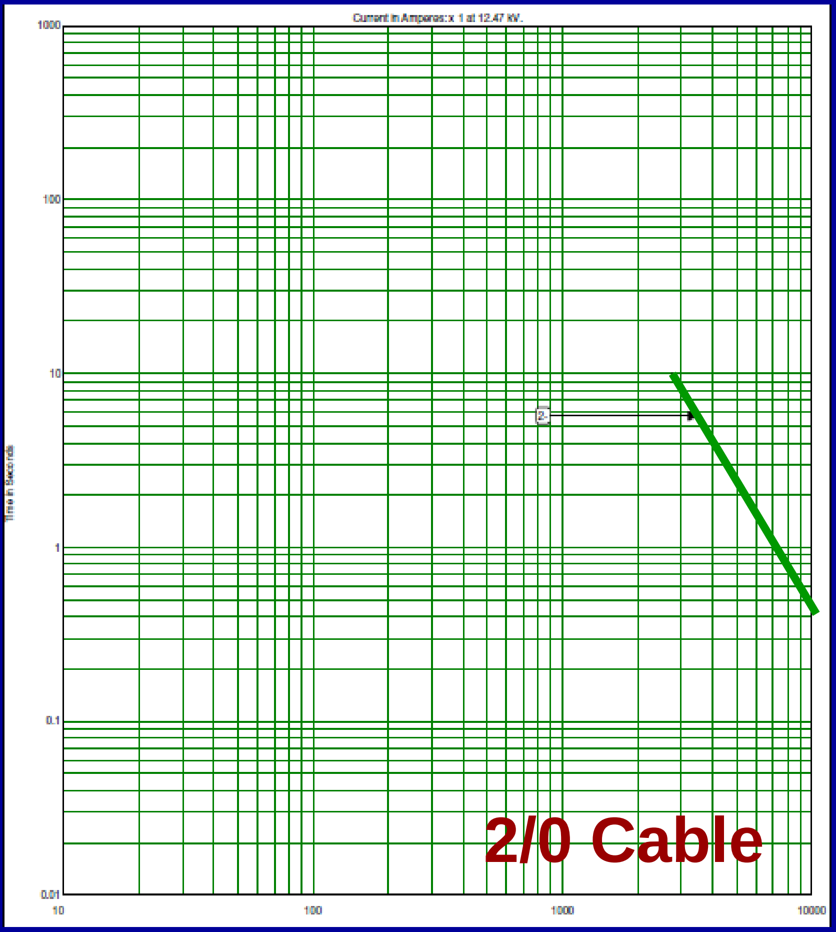


Some Electrical Power Device Models on a TCC Plot

Damage Curve Transformers



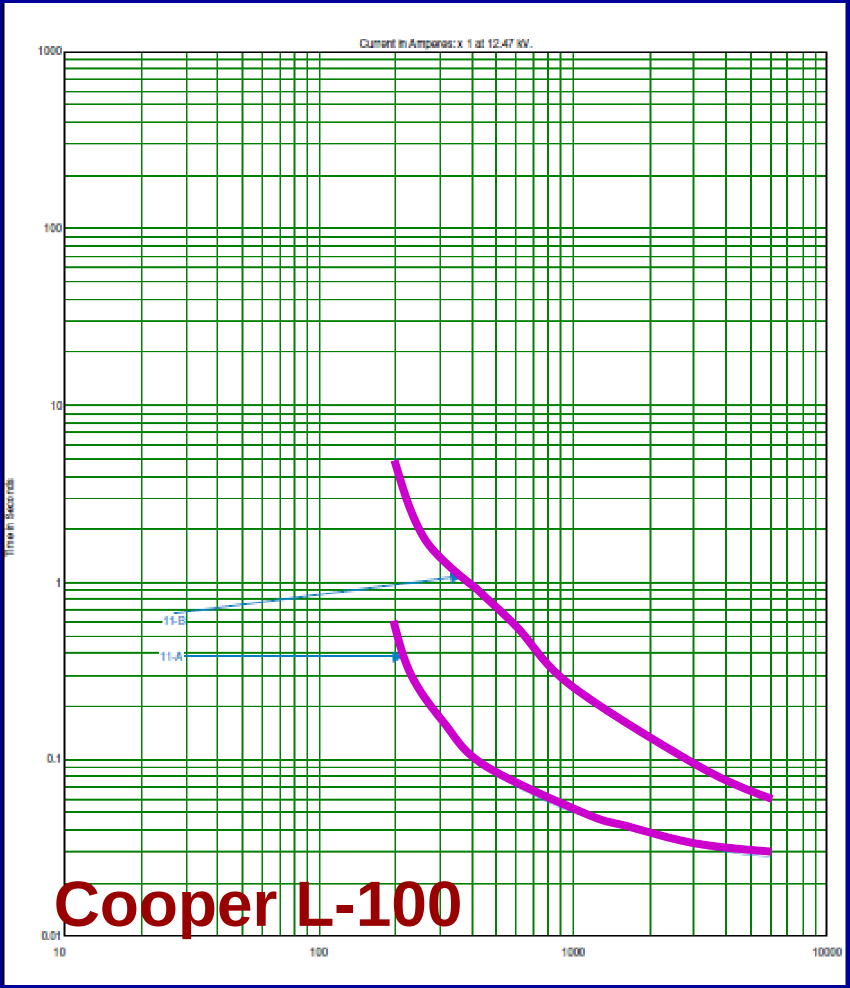
Damage Curve Lines



Some Electrical Protective Device Models on a TCC Plot

Relays w/Breakers Protection

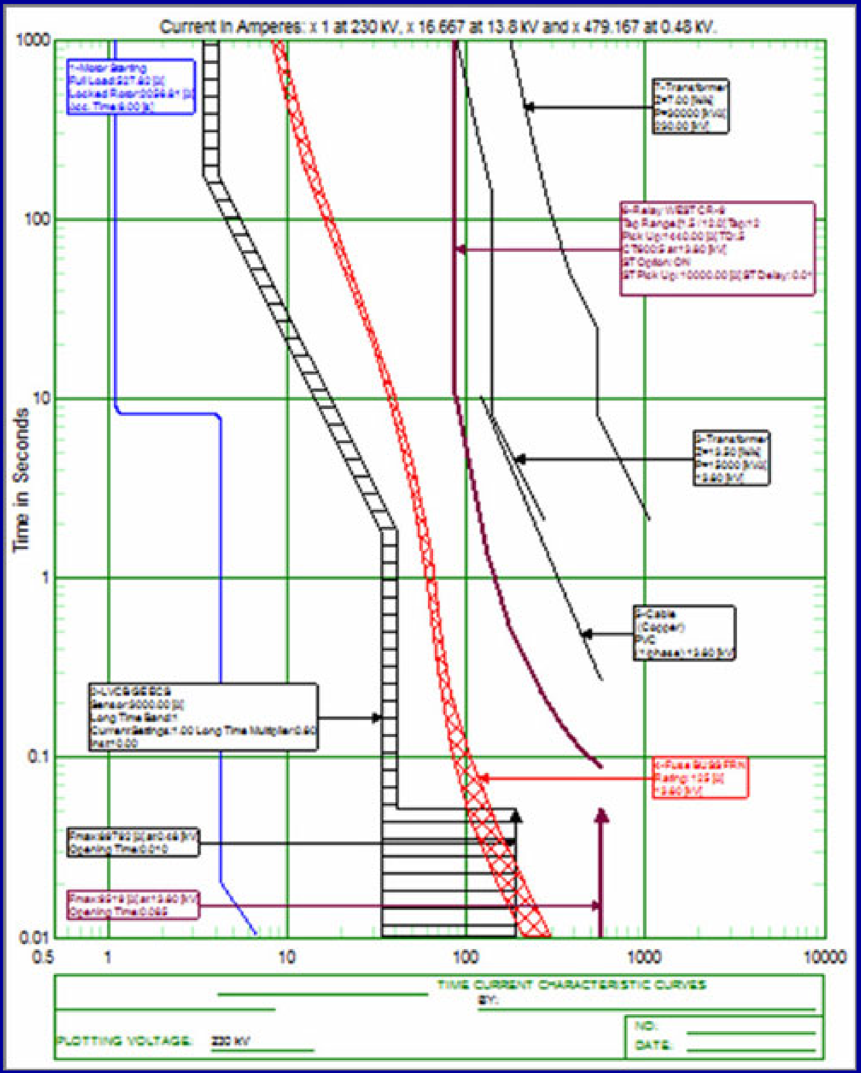
Reclosers Protection



Put them All Together

To check that the electrical devices are adequately protected from experiencing excessive current.

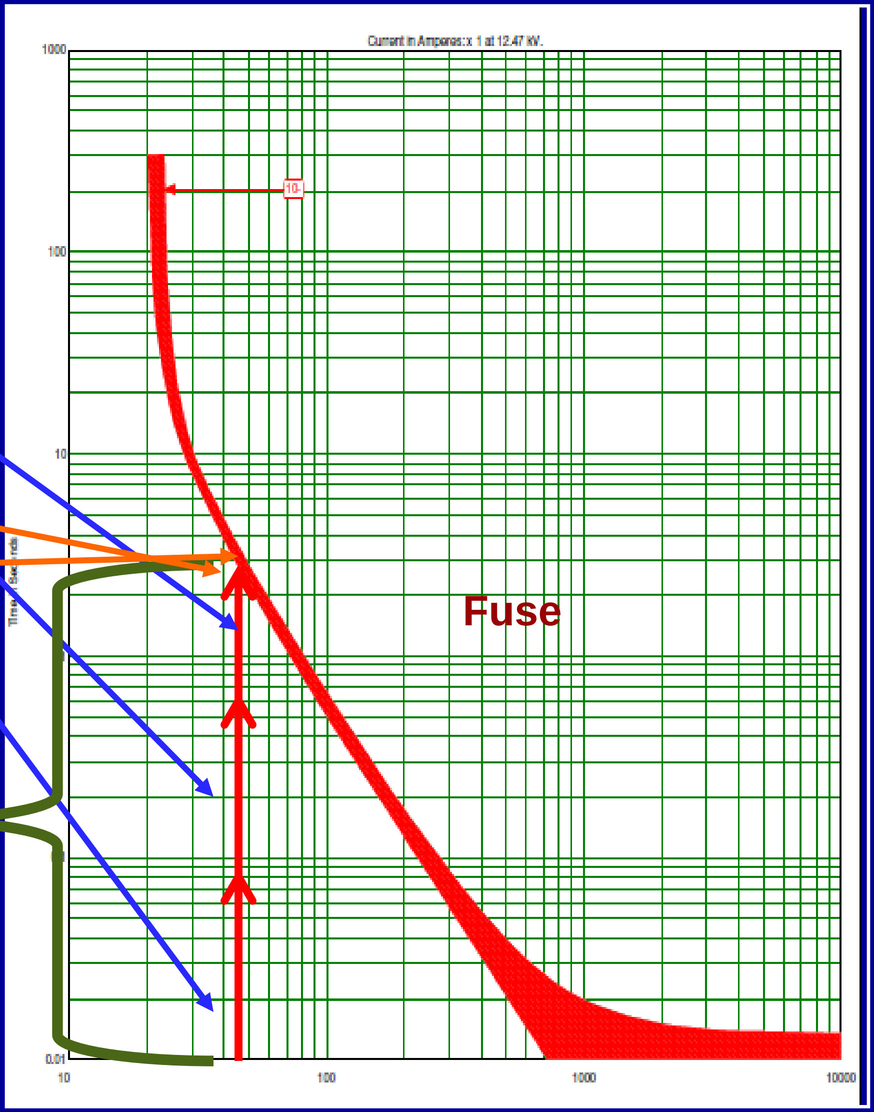
Where is the electrical worker in this protection scheme?



Source: www.cooperindustries.com

What does a fault look like on a TCC

- What does a fault look like on a TCC
- Fuse starts to melt
  (Minimum Melt)
- Fuse opens
  (Total Clear)
- The duration of a fault is this total length of time until cleared



2012 NESC Table 410-2
Arc Flash Protection Table

Fault Current (kA)

Time (cycles)

Phase-to-phase voltage (kV)	Fault current (kA)	4-cal system	8-cal system	12-cal system
		Maximum clearing time (cycles)	Maximum clearing time (cycles)	Maximum clearing time (cycles)
1 to 15	5	46.5	93.0	139.5
	10	18.0	36.1	54.1
	15	10.0	20.1	30.1
	20	6.5	13.0	19.5
15.1 to 25	5	27.6	55.2	82.8
	10	11.4	22.7	34.1
	15	6.6	13.2	19.8
	20	4.4	8.8	13.2
25.1 to 36	5	20.9	41.7	62.6
	10	8.8	17.6	26.5
	15	5.2	10.4	15.7
	20	3.5	7.1	10.6

Footnote: Working Distance = 15 inches

Working Distance

Points from 4 cal PPE Clothing System

12.47 kV
15-inch distance

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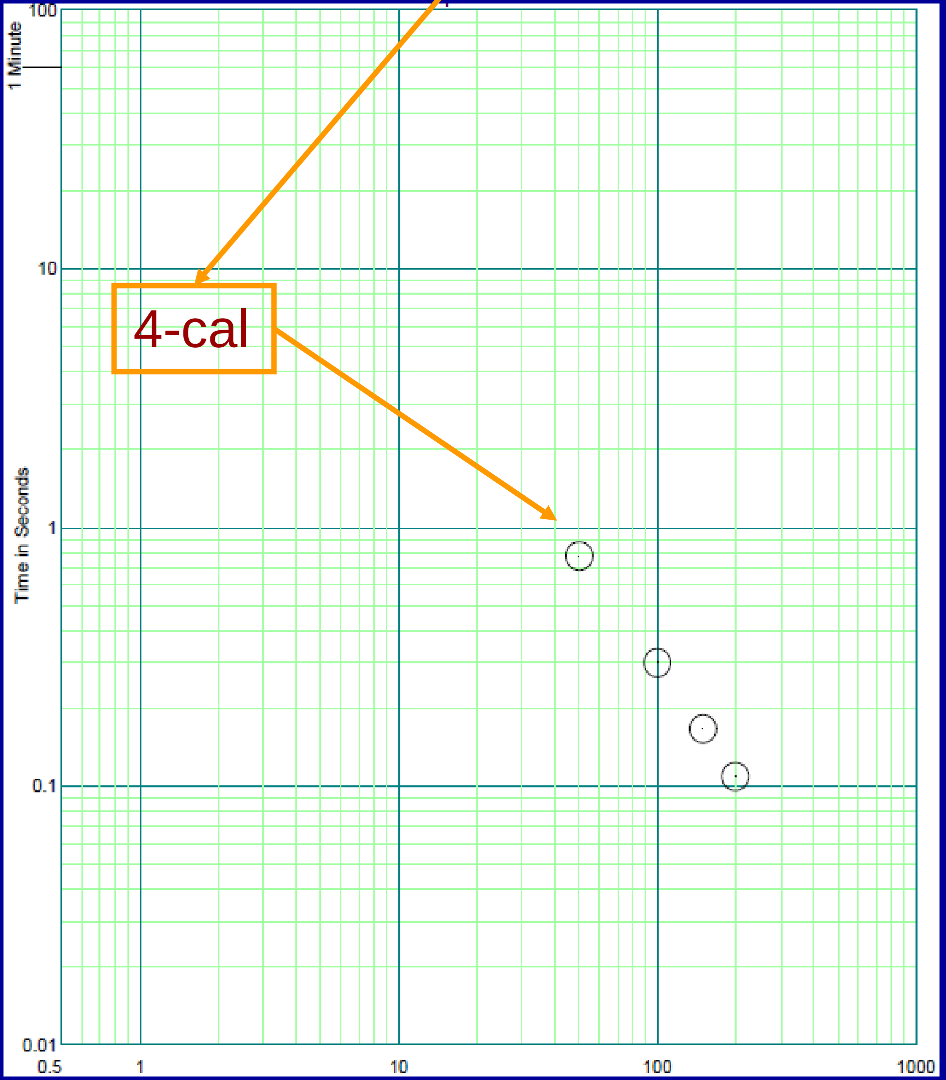

Points from 4, 8, 12 cal PPE Clothing Systems

Phase-to-phase voltage (kV)	Fault current (kA)	4-cal system Maximum clearing time (cycles)	8-cal system Maximum clearing time (cycles)	12-cal system Maximum clearing time (cycles)
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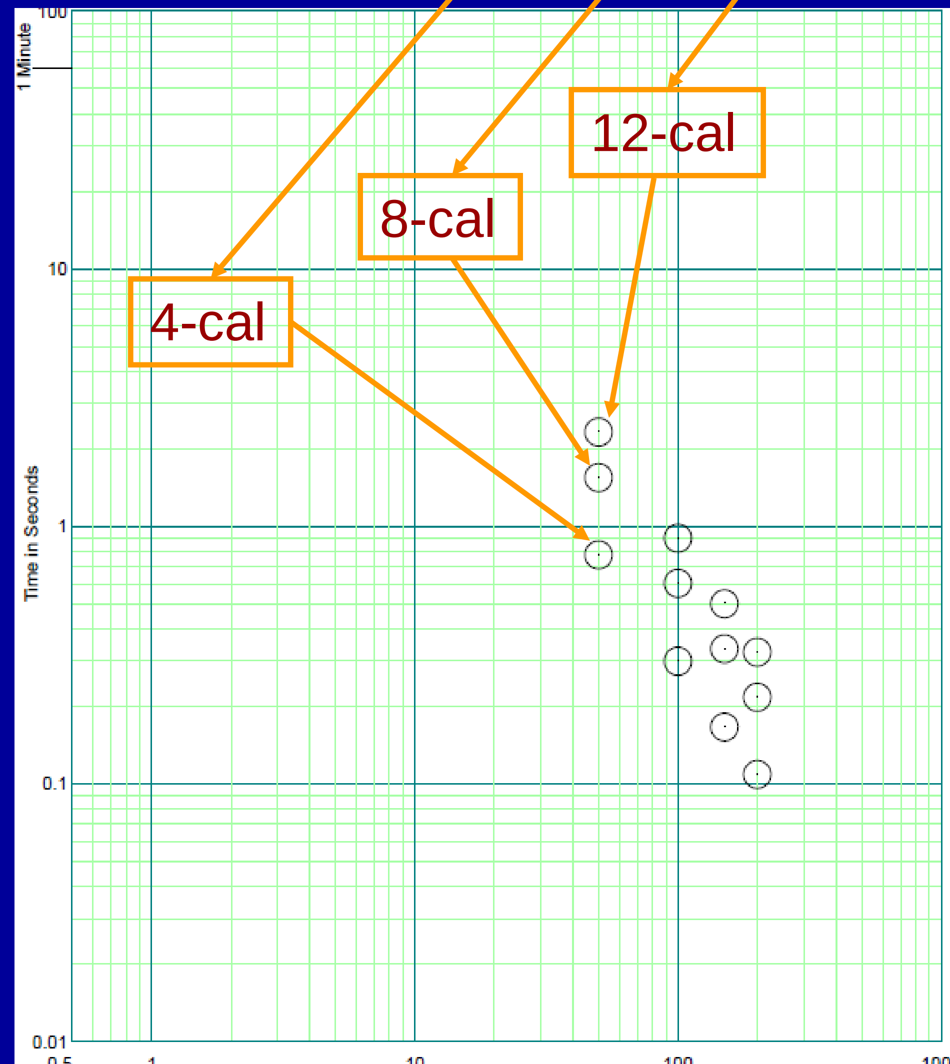
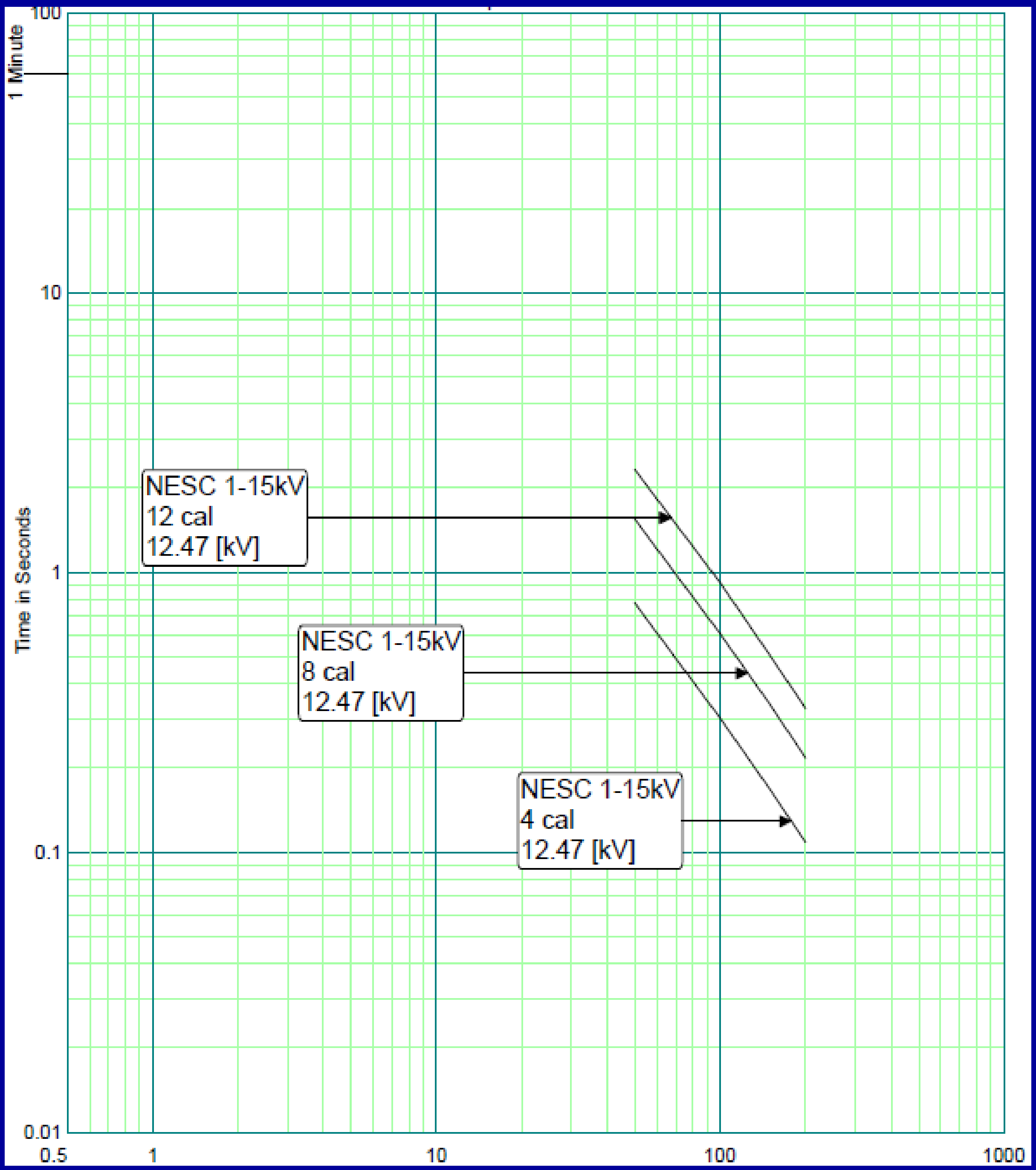
12.47 kV
15-inch distance



Lines from
4, 8, 12 cal
PPE points

12.47 kV
15-inch distance



For Arc Flash Assessment Using NESC Tables vs. TCC's

Phase-to-phase voltage (kV)	Fault current (kA)	4-cal system Maximum clearing time (cycles)	8-cal system Maximum clearing time (cycles)	12-cal system Maximum clearing time (cycles)
1 to 15	5	46.5	93.0	139.5
	10	18.0	36.1	54.1
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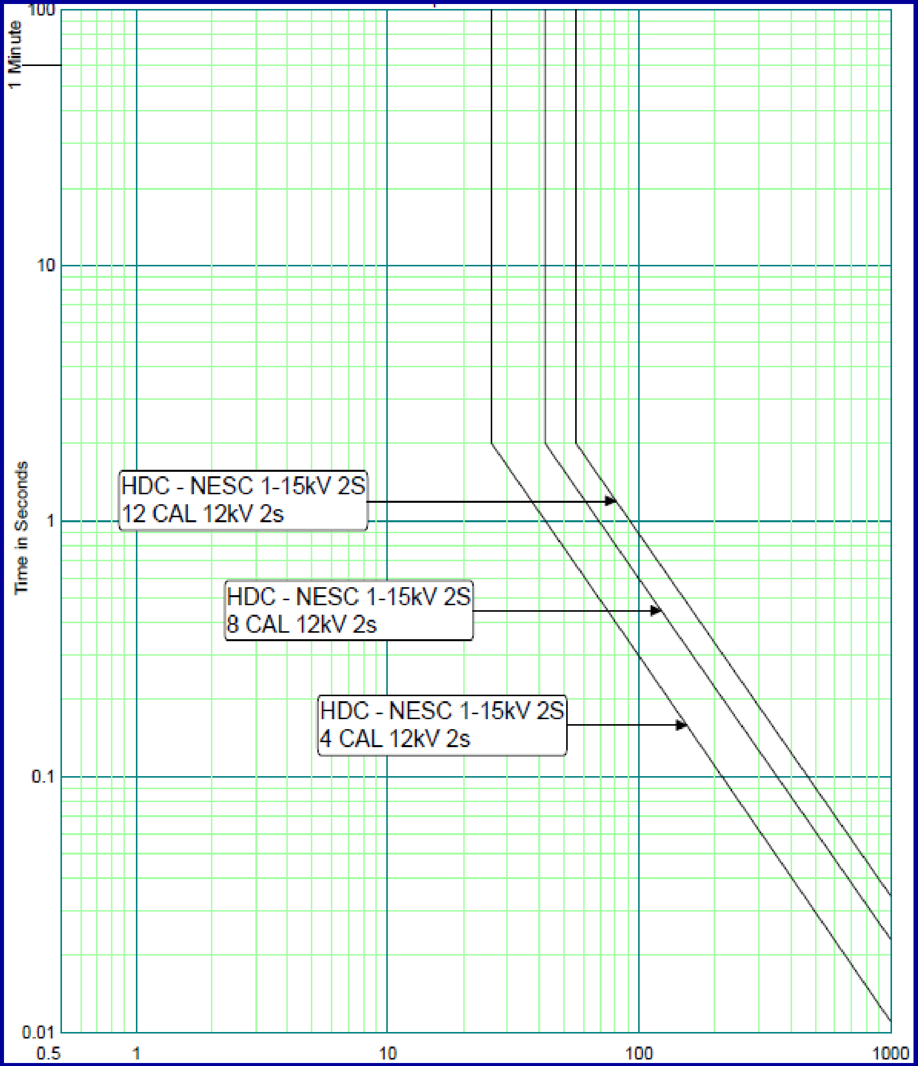
- So what are these?

  Conceptually these are

  Human Damage Curves (HDC)

  based on what is worn
- How can they be used when plotted with protection devices?
  - Particular levels of a PPE-cal system can be reviewed.
  - They are developed:

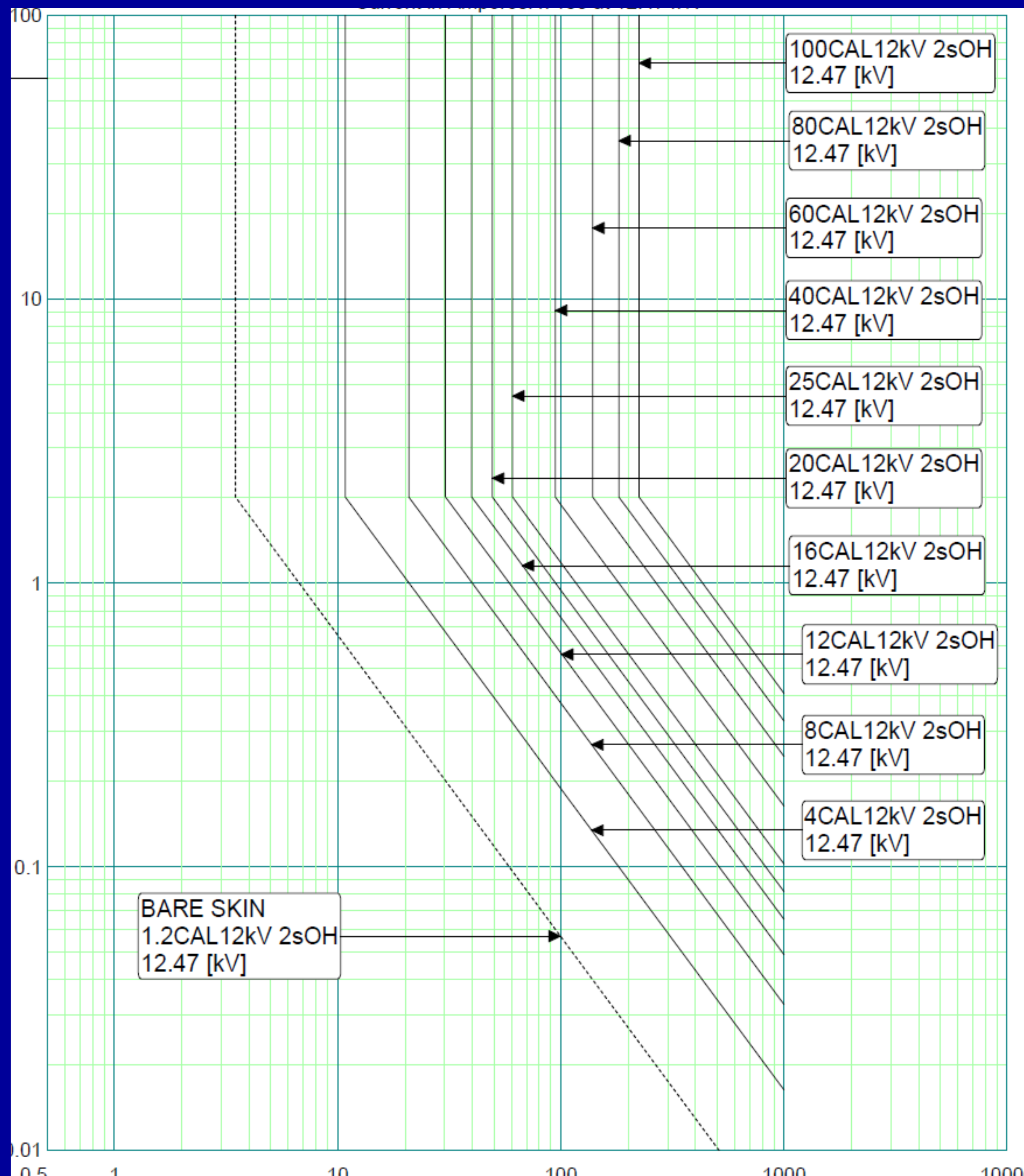
    - For a given voltage level
    - For a given condition (air and box)
    - For a given working distance



This is an Example of:
12.47kV PPE – using IEEE 1584, open air, and 15 in working distances

PPE HDC Family of Curves

12.47kV
15 in
Open Air
2 sec escape line
IEEE 1584

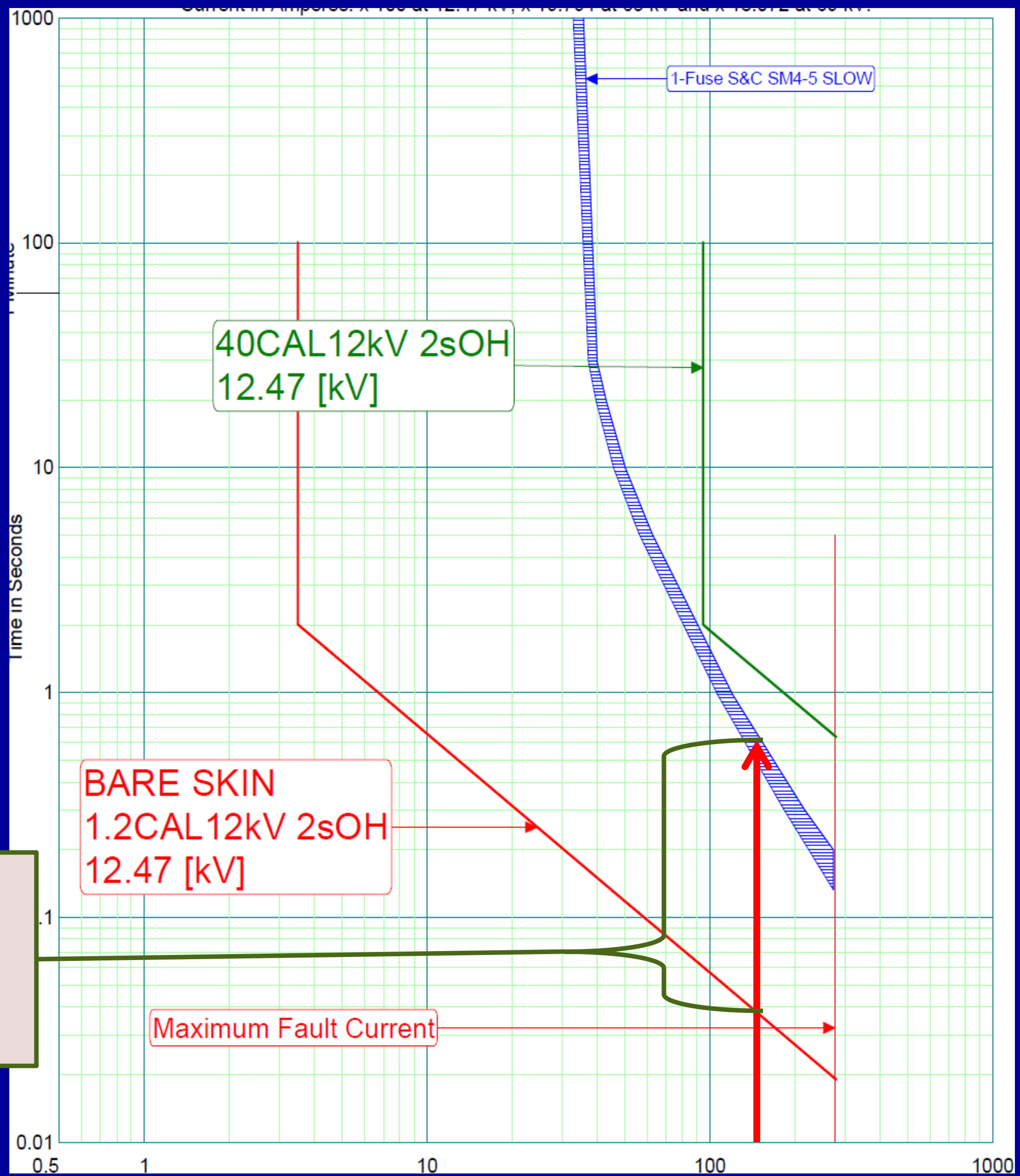


Alternate PPE Curves Based on Various Methodology

- Energy (cal/cm^2) curves vary based on methodology
  - NESC tables – used here
  - IEEE 1584 (empirical method)
  - ARCPRO
  - Lee Method – Not recommended
  - NFPA 70E – Not valid for electric utilities

- Fuse Response curve
- Maximum fault current

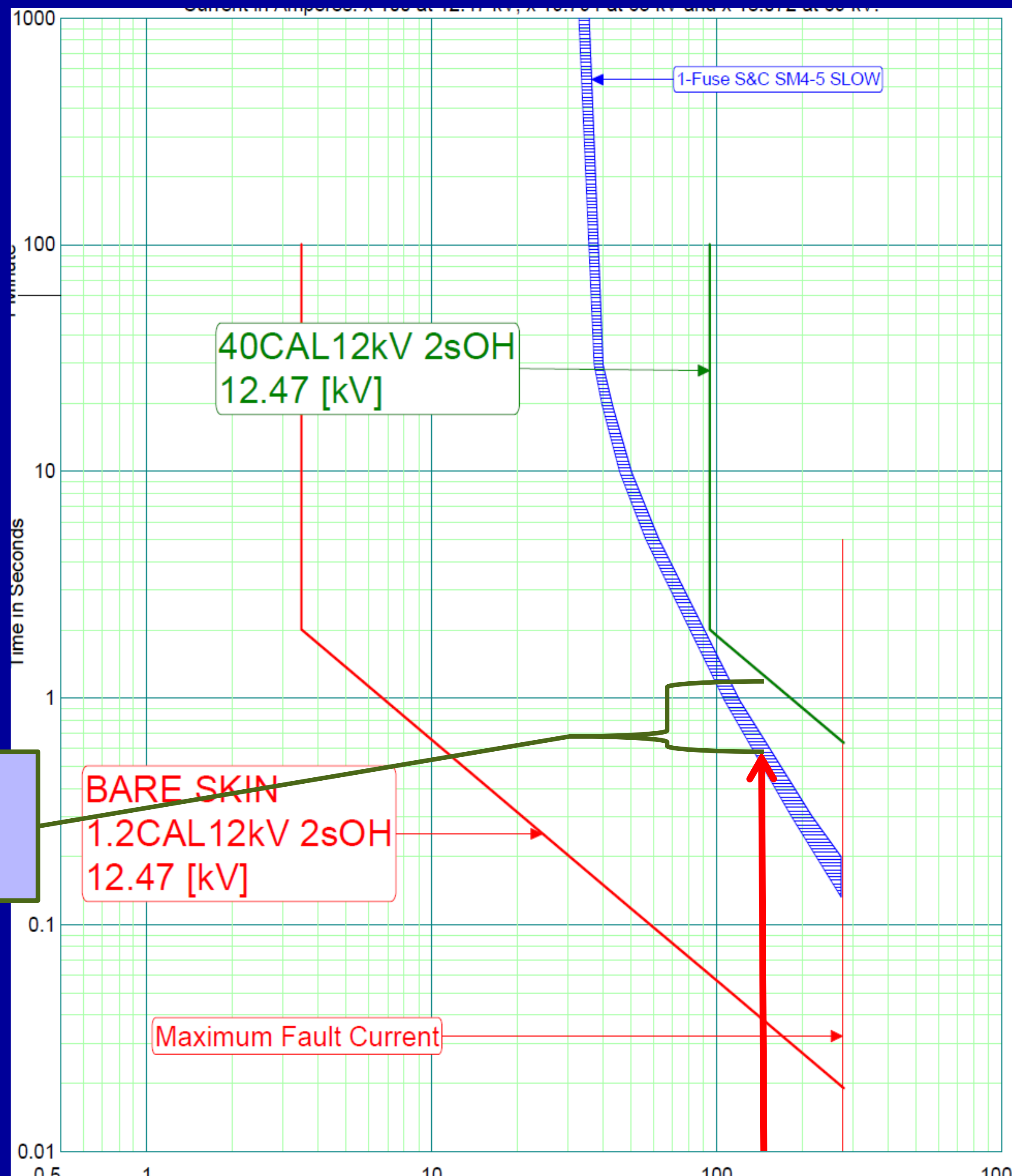
- HDC - 2-second
  1.2 cal bare skin
  40 cal PPE



Bare Skin is inadequate!
Burn injury!!!!
YOUR SKIN IS TOAST

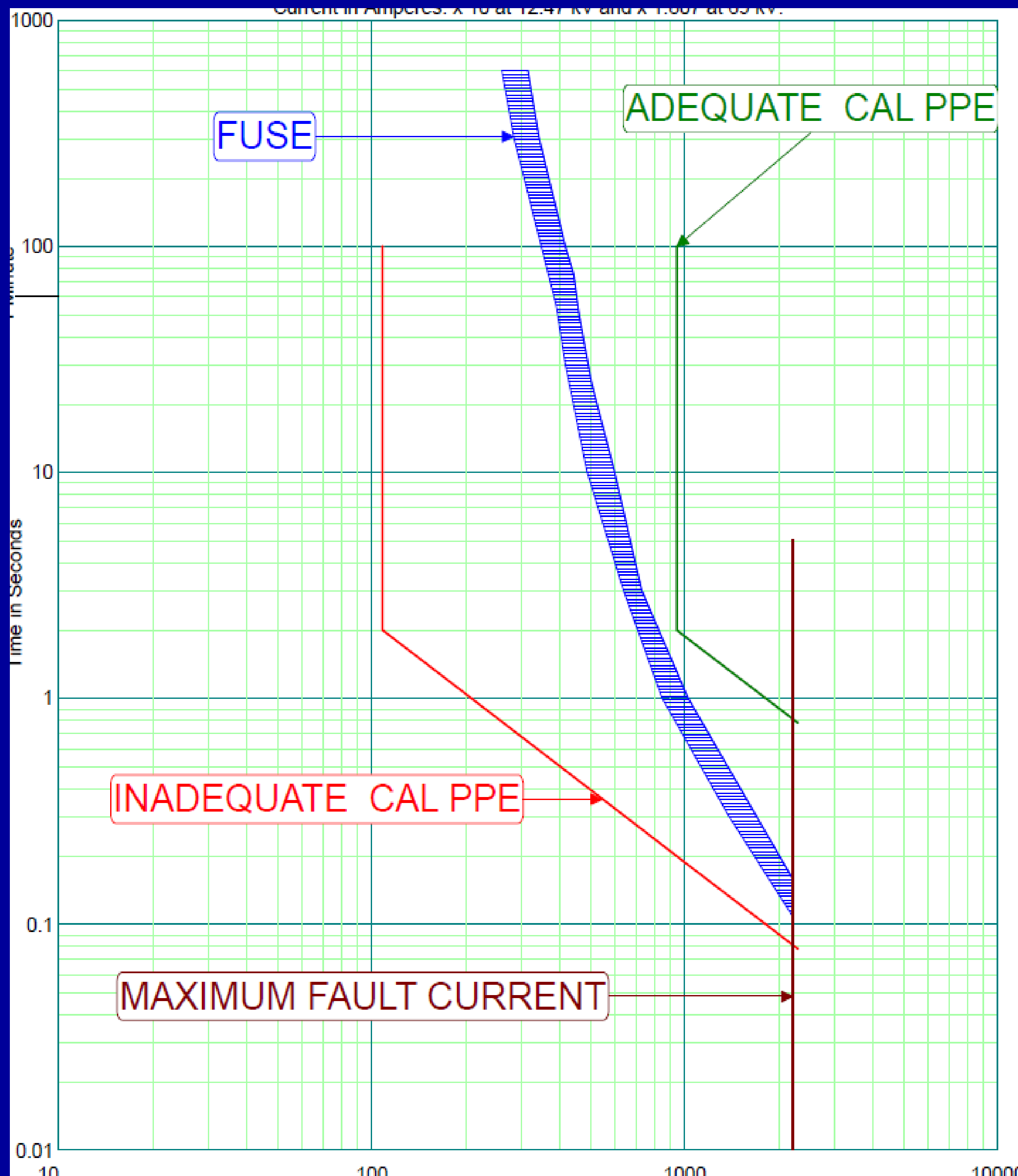
- Fuse Response curve
- Maximum fault current

- HDC - 2-second
 1.2 cal bare skin
 40 cal PPE



PPE is Adequate
NO Burn injury

Two PPE HDCs curves



How Do We Use This in an Arc Flash Analysis Study?

- Group the power system into areas:
  - Generation and generation plants – similar 70E approach
  - Transmission/Subtransmission – each line is evaluated
  - Substations and substation buses – grouped by voltage
  - Distribution feeders – each substation relays/fuses
  - Distribution transformers – use the standard fusing tables
  - Secondary drops – use NESC, except 480V
  - Secondary networks – use NESC 120/208V
  - Spot networks – use supplying source fuses or relays

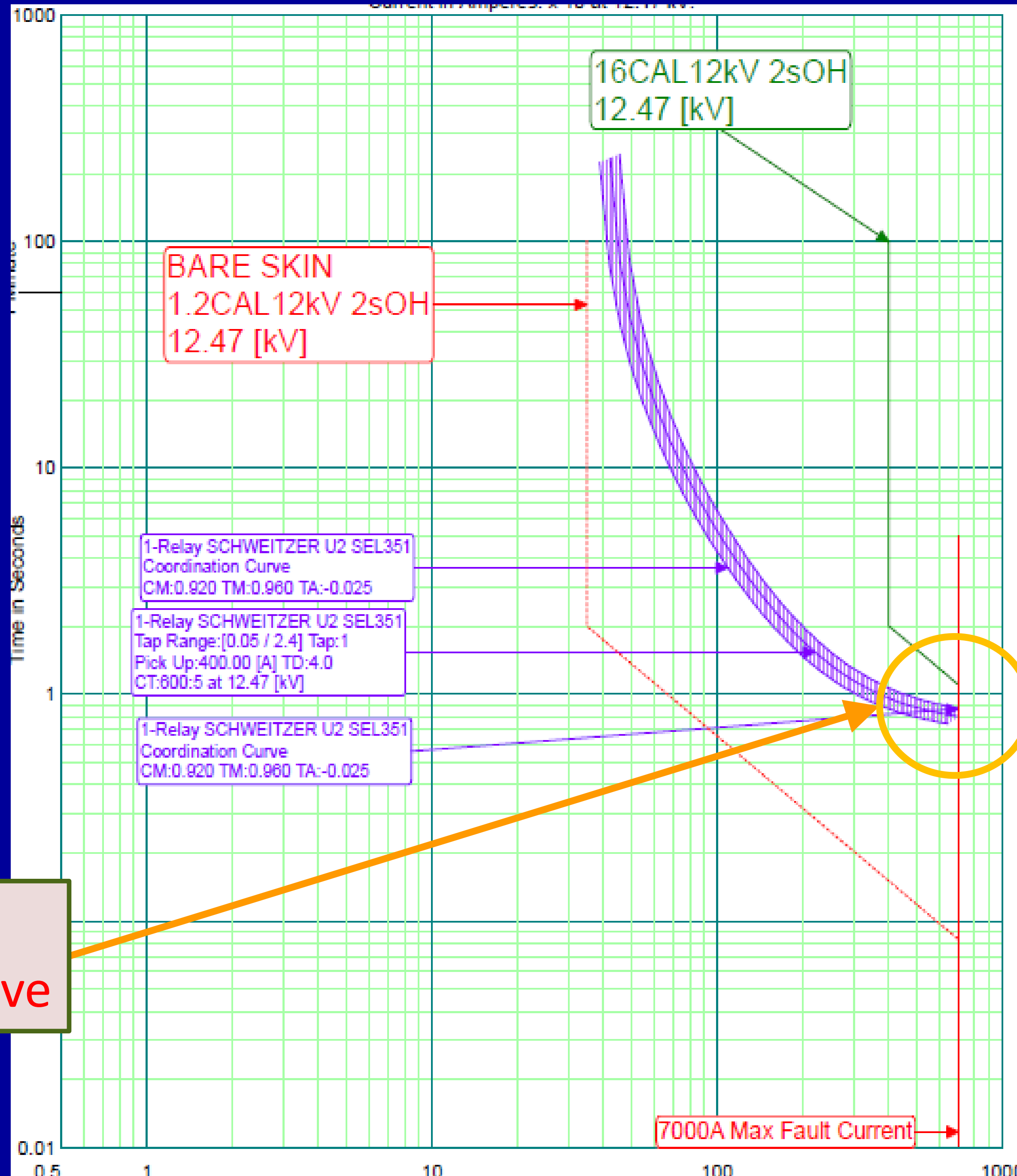
Three Basic Evaluation Approaches

- Overcurrent Curves
- Differential Curves
- Standard Service Equipment Protection Curves

Overcurrent Curves (Relay and Fuse) and the Human Damage Curve

- Overcurrent Curves
- These are used by
  - Relays (any voltage) and
  - Fuses to protect medium voltage (MV) and low voltage (LV) circuits

TCC plot example of an overcurrent relay response curve, maximum fault current, and resulting 2-sec 16 cal PPE HDC

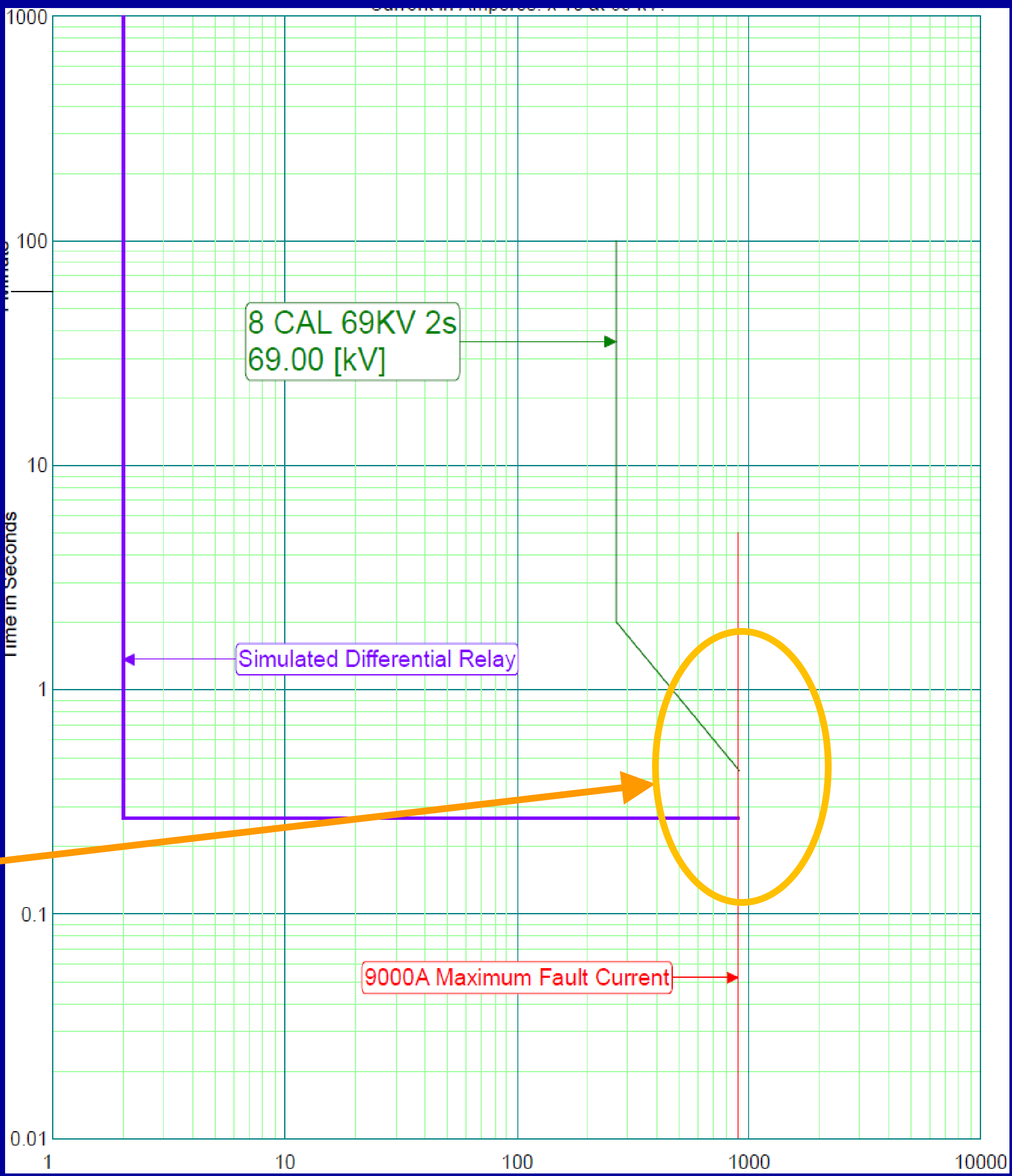


Keep PPE HDC curve above overcurrent curve

Differential Relay Curves and the Human Damage Curve

- Differential Curves
- These are used to protect
  - Buses,
  - Transformers, and
  - HV line sections

TCC plot example of a differential relay, maximum fault current between both directions, resulting 2-sec 8 cal PPE HDC



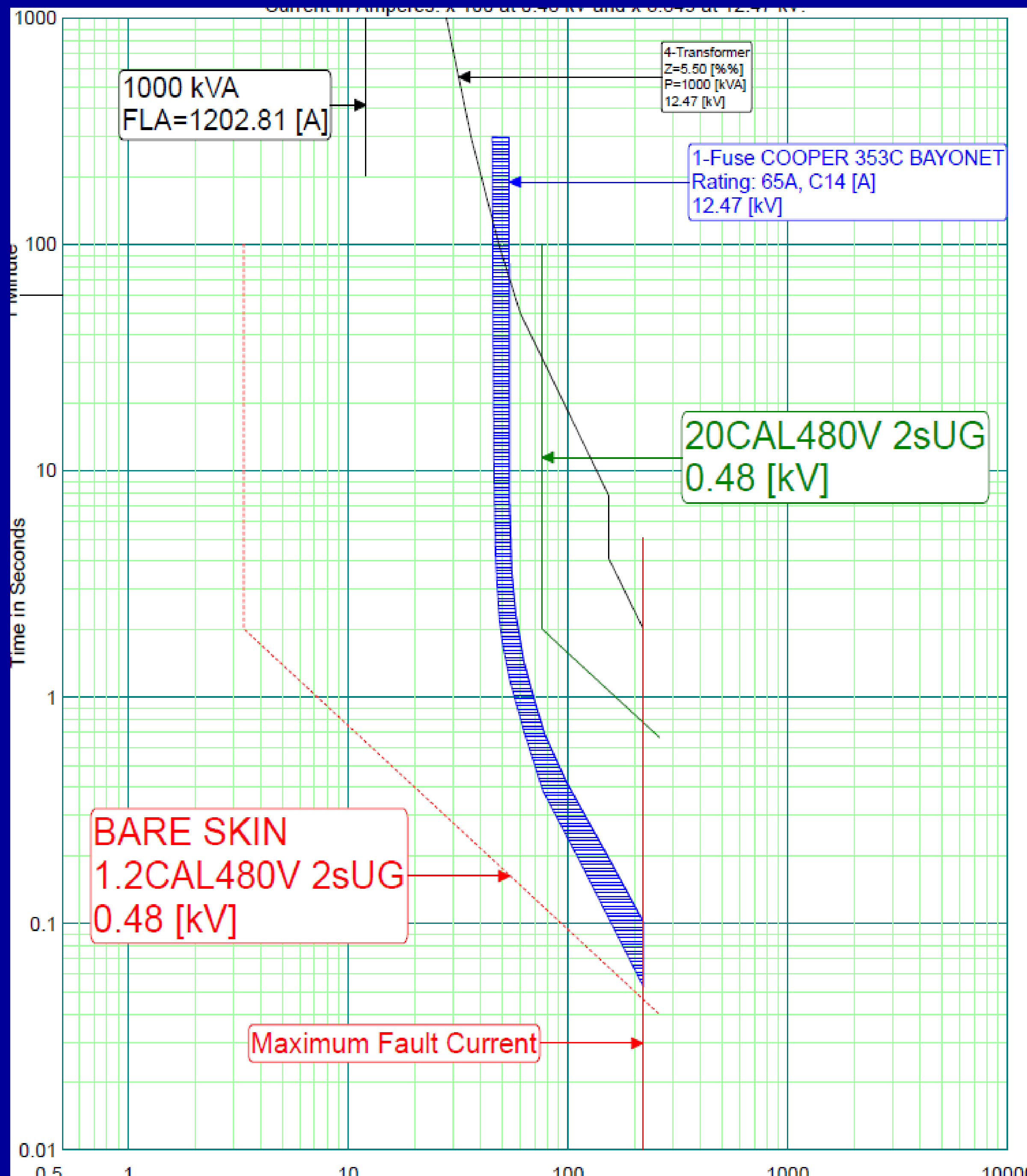
Fast differential

Standard Service Equipment Protection and the Human Damage Curve

- Standard Service Equipment Protection Curves

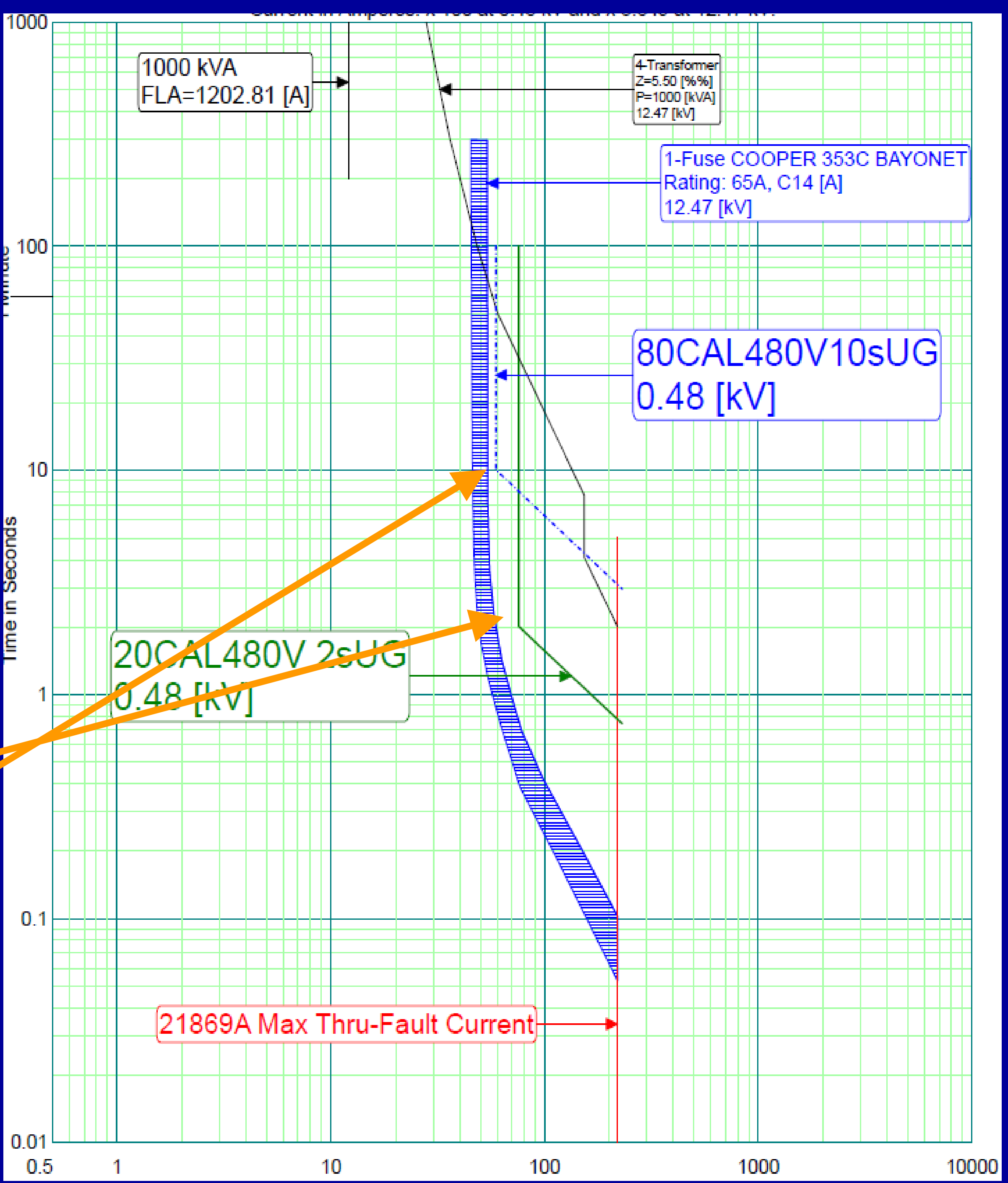
- These are mainly fuses that protect the same size equipment or equipment arrangements throughout a power system, but the concern here is at secondary or low voltage (LV) level.

TCC example of a 12.47kV/480V three-phase 1000kVA transformer with its standard bay-o-net expulsion fuse, maximum through fault current, and resulting 2-second 20 cal PPE HDC



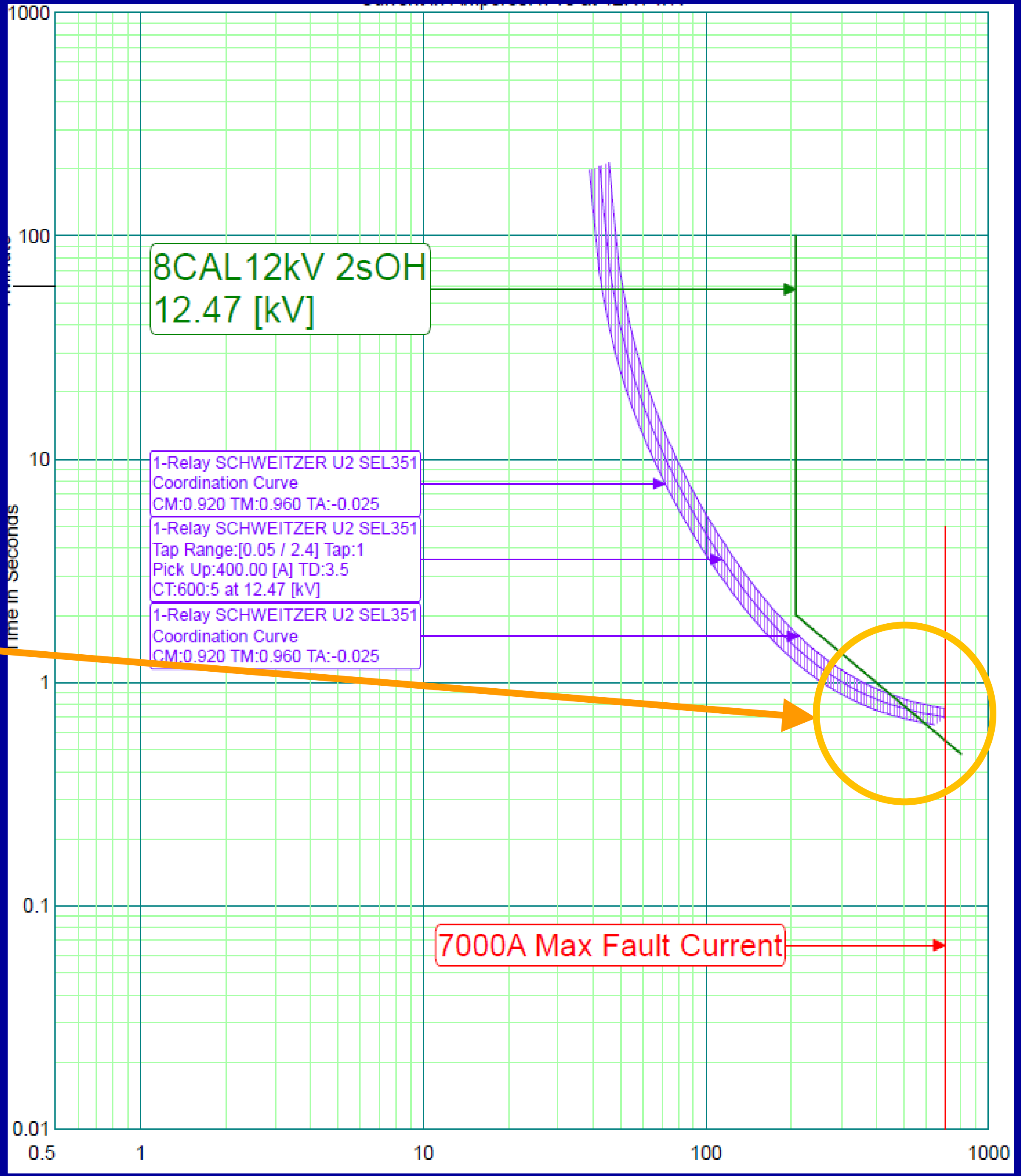
Confine Space for a 1000kVA Transformer

TCC example of a 12.47kV/480V three-phase 1000kVA transformer with its standard bay-o-net expulsion fuse, maximum through fault current, and resulting 2-sec and 10-sec PPE HDC



Relay and a Fixes PPE of 8 cal

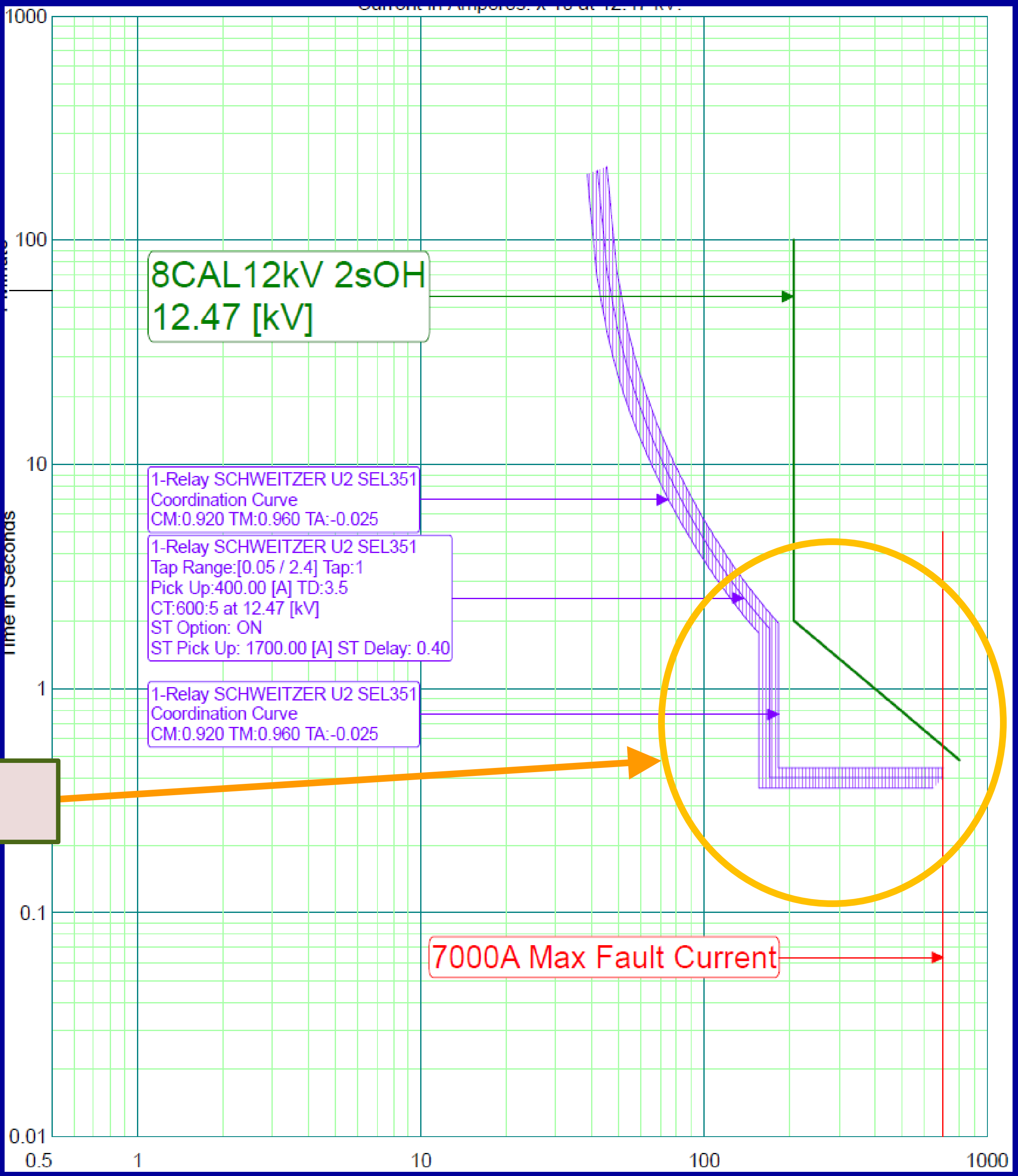
TCC plot example of an overcurrent relay response curve with a fixed 8 cal PPE HDC and the indication that the PPE will likely fail at high fault currents



Relay Adjustment to Accommodate an 8 cal PPE

TCC plot of an overcurrent relay response curve with a short time setting changed to make the 8 cal PPE work

Settings Change

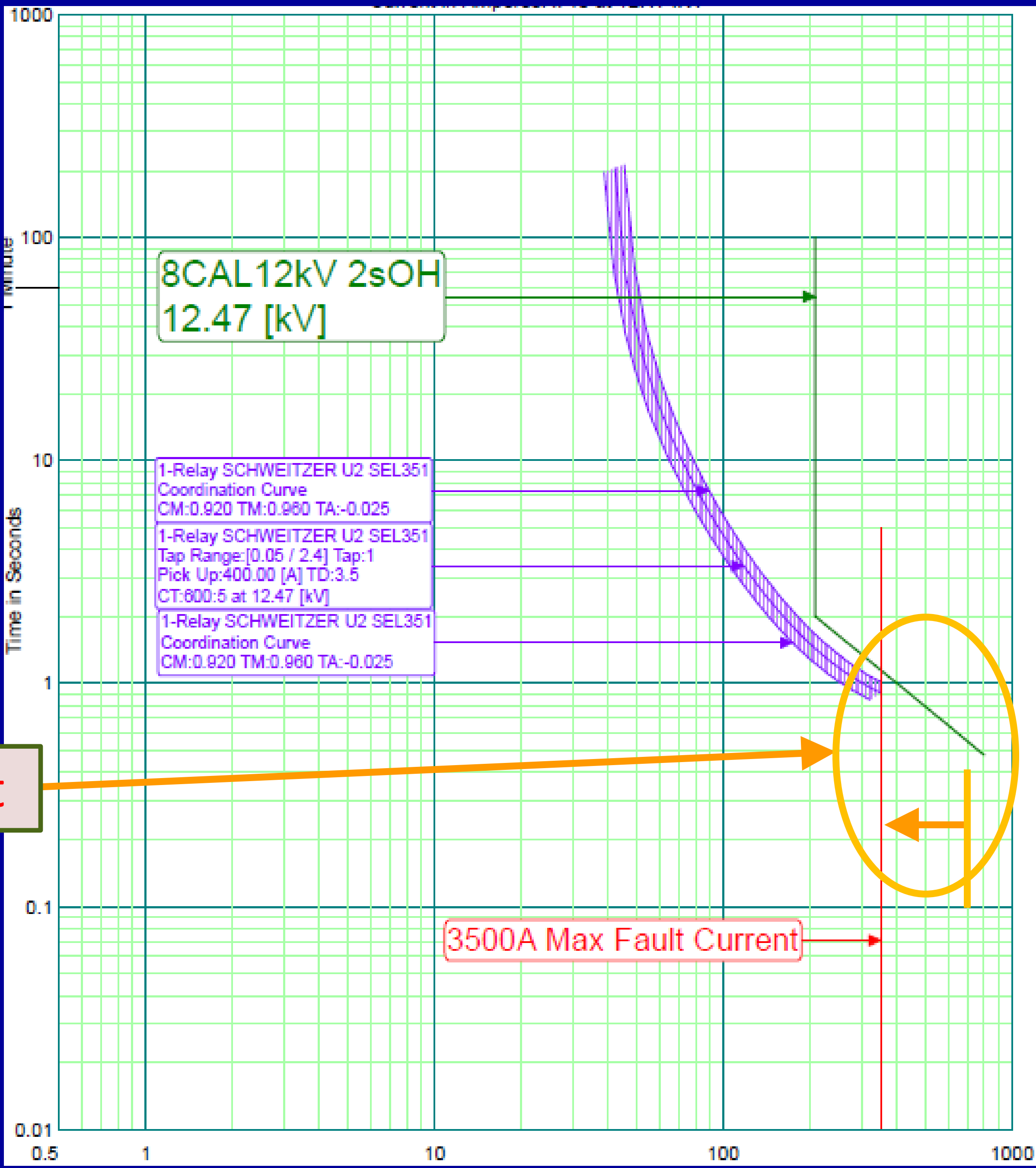


System Adjustment to Accommodate an 8 cal PPE

- **Adjust the system available fault current to one half that would then allow the 8 cal PPE to work**

TCC plot of an overcurrent relay response curve with the fault reduced to one half that would then allow the 8 cal PPE to work

Reduced fault current



Features and Benefits of Using TCC Method for Arc Flash Studies

- Can review the full range of faults currents for a circuit
- Better able to see what to change and its impact
  - Upgrade breaker/relays
  - Change Fusing
  - Relocating protection devices
- Use of alternate settings
- Use of Instantaneous
- Use of differential schemes
- Change working distance
- Change PPE
- Examine the extraction times

Conclusions-1

- Term Human Damage Curve (HDC) was intentional
  - Avoidance of harm is always a top priority in the design, construction, operation and maintenance of an electric power system
  - HDC term sharpened the need to mitigate the hazard
- HDC method is not an ideal solution that will insure safety for electrical workers, but it is a quantitative and qualitative framework tool
  - For evaluating an arc flash hazard
  - For mitigating to a solution to protect workers

Conclusions-2

- This method is currently the most informative method available to model, evaluate, and mitigate an arc flash for meeting compliance requirements of both the NESC and NFPA 70E

- However there are management challenges to implement this
  - For coordination engineers - it is a minor culture shock
  - For safety managers - it is added responsibility and new tool
  - For Utility management - will have to be involved in a greater way

Conclusions-3

- However, it does not replace the NESC or its tables or create a new calculation method, but enhances all the current knowledge of an arc flash
- It provides a method that addresses two problems at once:
  - Safety of workers and
  - Protection of utility equipment
- Complete three major studies with the method and currently finishing up a fourth study with great customer understanding and enthusiasm.
  - >200 substations – 12kV, 35kV, 69kV, 138kV, 345kV – 120/208V and 480V net
  - >50 substations – 4kV, 35kV and 69kV – 120/208V and 480V net
  - >20 substation – 4kV, 12kV and 35kV
  - >10 substations – cooperative with 12 kV, 25 kV, and 69kV

Thank You and Questions

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