Coordination of PPE and fuse links for personal protection against arc thermal hazards in LV systems

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Road map

- **Arc flash hazards, personal protection against thermal risks**
- **Laboratory measurements**
- **Effect of fuse links cutting-off, remaining arc energy and incident energy**
- **Coordination of PPE and fuse selection, user guidelines**
- **Summary**

One major electrical risk while working

Short-circuits with

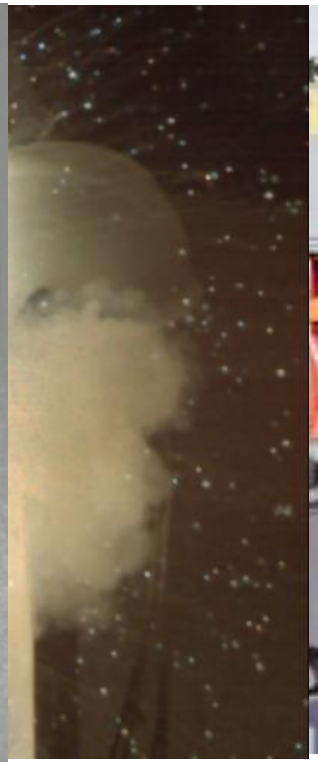
Electric FAULT ARCS

Protection:

Factor time important

Personal protection while working

- Arc flash → thermal risks → protection required:
  mitigation of arc energy and/or incident energy
- Protection: PPE + protective devices (e.g. fuses)
- coordination



Arc existence limits in LV systems (400 V)

Clearing time	Arc energy		Direct exposure incident energy	
t_{aus}	W_{LB}		E_{i0}	
	kJ		kJ/m²	
Prosp. short-circuit current	0,5 kA	1,0 kA	0,5 kA	1,0 kA
0,1 s	5	10	2	3
0,3 s	16	29	6	10
0,5 s	27	48	11	25

instable arc behavior (tendency to self-extinction) with short-circuit currents of 0,5 kA

Energy is below the threshold for the onset of 2nd degree skin burns (Stoll criterion)

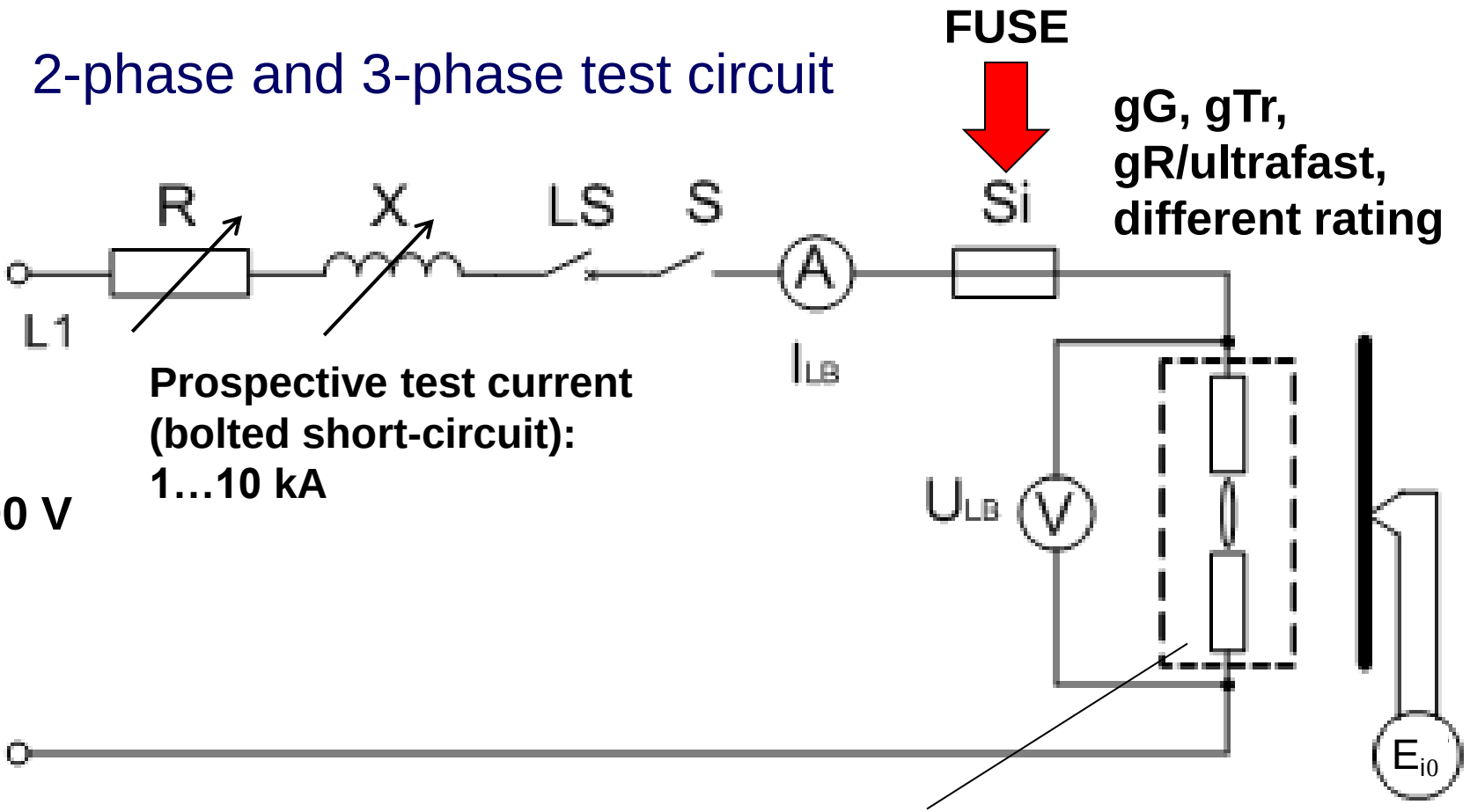
Protection needed for short-circiut currents of 1 kA and higher

Personal protection

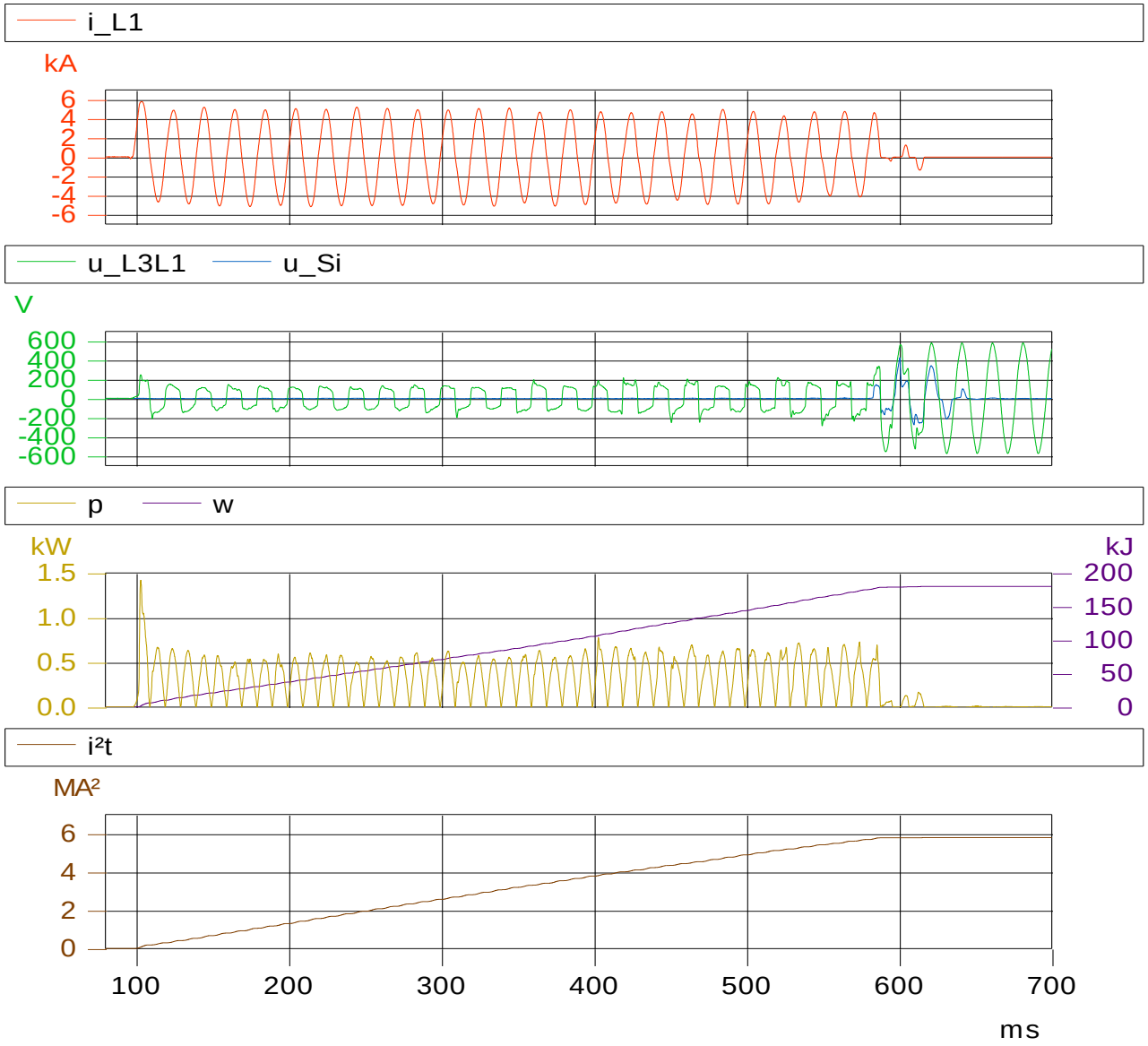
- Protection needed for short-circuit currents of 1 kA and higher
- Personal protective equipment (PPE) for prevention of 2nd degree skin burns
- PPE protection level: energy threshold
- Clearing time of protective devices determines the fault arc energy
- Devices for overcurrent and short-circuit selective protection: circuit breakers (release), fuse links
- problems:
  - Stochastic, non-linear arc behaviour
  - current-time characteristic: problem current attenuation
  - Difficult to determine or approach (calculate)
- Experimental verfication of fuse breaking times necessary

Laboratory measurements with LV fuse links

- 2-phase and 3-phase test circuit



Recorded electrical arc data (example)



- Example:

2-phase arcing fault

switched-off by a fuse NH gG 315 A

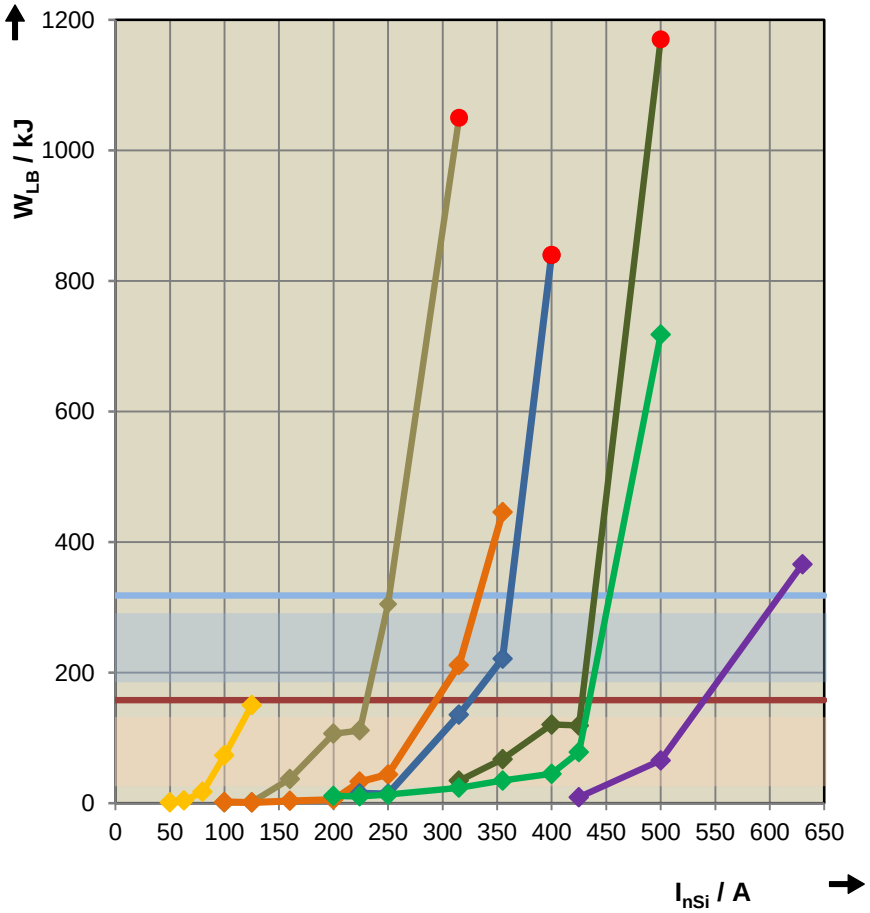
(bolted test current 4 kA)

Laboratory measurements

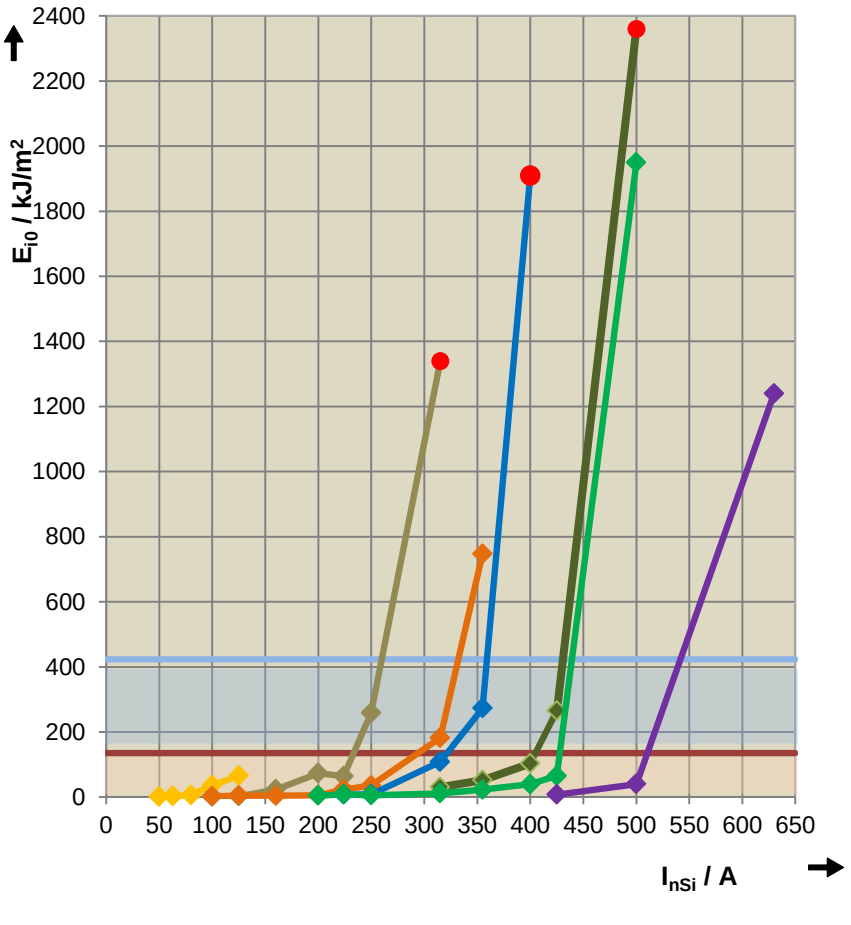
- LV fuse links (NH fuses) in test circuit supply
  - 400 V/500 V
  - operational classes gG, gTr and working-protection (aR, gR, …)
- Relevant fuse rating currents
- Fault current range (bolted short-circuit current): 1… 10 kA
- Tests: measurement of fusing time, electric arc energy and thermal incident energy
- Analyzing: remaining arc energy < PPE protection level
- Protection levels of box tested PPE (APC 1 and 2) under standard exposure conditions (box heat transfer, a = 300 mm)
- constraints:
  - Number of test shots (scattering, statistical safety)
  - Tolerances of currents and fusing time of fuse links
  - Characteristics of different manufacturers
  - no fuse I-t characteristics in digital form

NH-gG-fuses – 2-phase short-circuits (arcing faults)

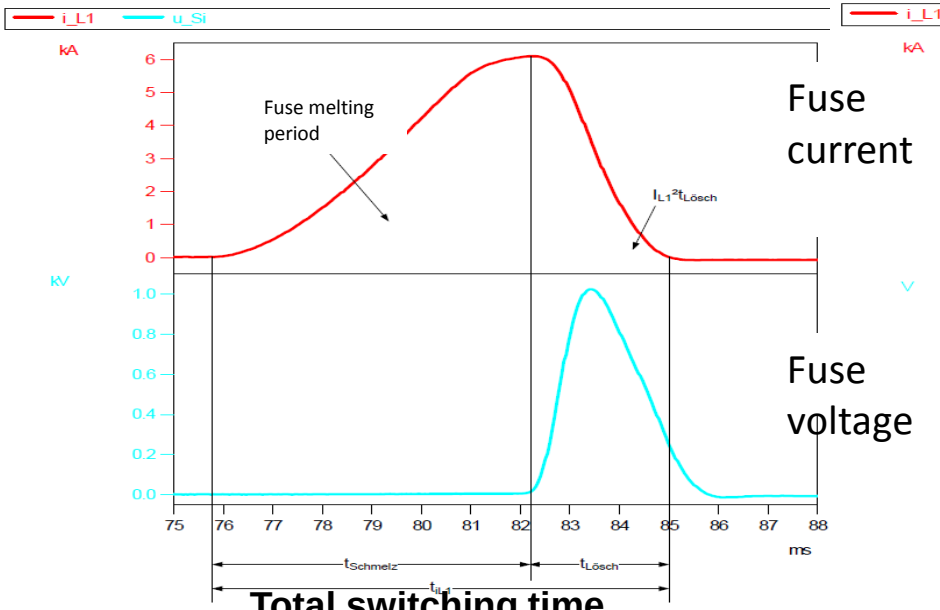
Arc energy
in dependency on fuse rated current



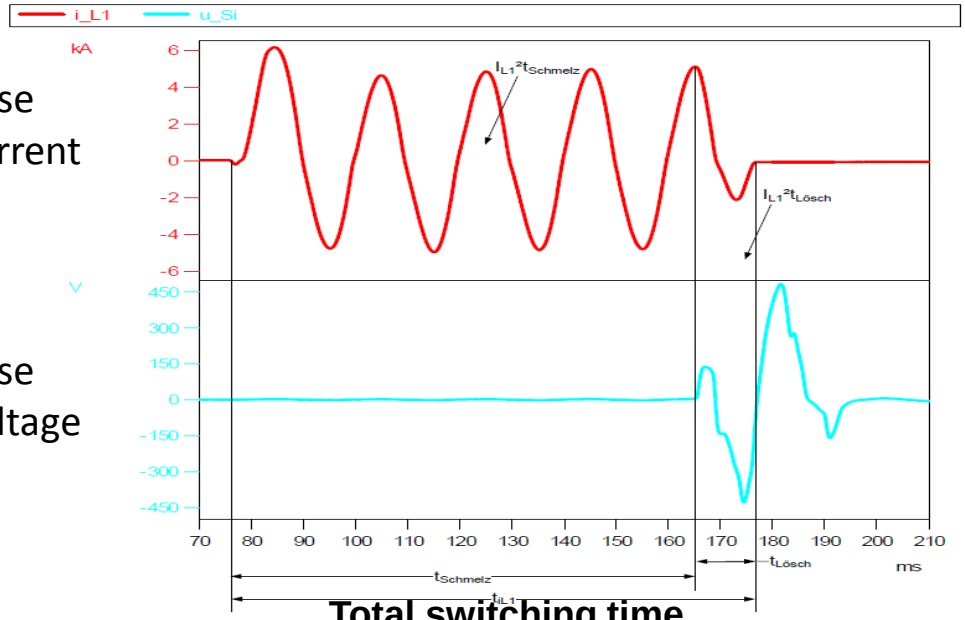
Incident energy
in dependency on fuse rated current



Fuse switching diagramms



Total switching time (operating time)



Total switching time (operating time)

- Current-limiting operation
  (example: NH gG 160 A with prospective test current 4 kA
- non-current-limiting operation
  (example NH gG 224 A with 4 kA)

General fuse breaking behaviour

- Scattering; interactions between fuse arc and fault arc, fault current attenuation due to fault arc
- Fuse operation
  - Current limiting breaking $t_{op} < 10$ ms

    if $I''_k/I_{nSi} > 18…25$ general purpose fuses (gG)

    $I''_k/I_{nSi} > 6…10$ very fast-acting fuses (aR), work-protecting fuses

    no risk of 2nd degree skin burns by remaining thermal arc hazards

    no further analyses necessary
  - Non-current-limiting breaking

    fusing time determines arc and incident energy

Preparation of results: Guidelines for users

- simplified tool for practical use (meeting of PPE protection levels)

  Selection matrix

  with correlation minimum short-circuit current (bolted) – fuse rating current

  good overview, easy to handle

  valid for for standard exposure conditions

  Base : PPE box test APC 1 and 2

Selection matrix NH gG line protection fuses

3-phase short-circuit							
Fuse rated current I_{nSi} / A	Fuse link NH gG						
50	Protection with PPE class1						
63							
80							
100							
125							
160	Protection with PPE class 2						
200							
224							
250							
315							
355							
400							
425							
500	no protection with PPE						
	1,0-2,5	2,2-4,5	4,5-5,5	5,5-6,5	6,5-7,5	7,5-10,5	>10,5
	Minimum bolted short-circuit current I''_{k3p} /kA						

2-phase short-circuit						
Fuse rating I_{nSi} / A	Fuse links NH gG					
50	Protection with PPE class 1					
63						
80						
100						
125						
160	Protection with PPE class 2					
200						
224						
250						
315						
355						
400						
425						
500	no protection with PPE					
	1,0-2,5	2,5 – 4,5	4,5 – 5,5	5,5 – 6,5	6,5 – 10,5	ab 10,5
	Minimum bolted short-circuit current I''_{k2p} / kA					

- Standard exposure conditions: a = 300 mm, k_T = 1

NH gTr fuses

2-phase short-circuit			
Fuse rating S_n / kVA (I_{nSi} / A)	Fuse link NH gTr		
250 (361)	**Protection with PPE class1**		**Protection with PPE class 2**
315 (455)	**no protection**		
400 (577)			
	4,5 – 7,5	7,5 - 10,5	ab 10,5
	Minimum bolted short-circuit current I''_{k2p} / kA		

3-phase short-circuit:

fuse ratings of 250 kVA or below: **protection is only achieved by PPE class 2 and when the short-circuit current is 7 kA or higher**

protection cannot be provided with NH gTr fuses of ratings > 250 kVA (neither with PPE class 1 nor class 2)

Selection matrix work-protection fuses

3-phase short-circuit and 2-phase short-circuit			
Fuse rated current I_{nSi} / A	Fuse link NH working protection		
160	**Protection with PPE class 1 (and class 2)**		
200			
250			
315	**No potection**		
355			
400			
500			
	1,0-2,5	2,5-4,5	>4,5
	Minimum bolted short-circuit current I''_{k3p} or I''_{k2p} / kA		

- Standard exposure conditions: a = 300 mm, k_T = 1

Summary and conclusions

- fuses are very efficient means for providing personal protection against thermal hazards of electric fault arcs
- interactions between fault arcs and fuse arcs, current attenuation effect due to fault arcs
- measurements in high-power test lab: 2-phase and 3-phase short-circuits (arcing faults) in 400 V systems
- fuse rating limits as protection ranges specified on base of arc energies measured
- Coordination with PPE is purposeful (base: PPE protection levels), personal protection can be provided for large number and variety of working places
- Results prepared in form of simplified user guidelines
- Guidelines are to supplement risk assessment procedures (e.g. DGUV-I 203-077)

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