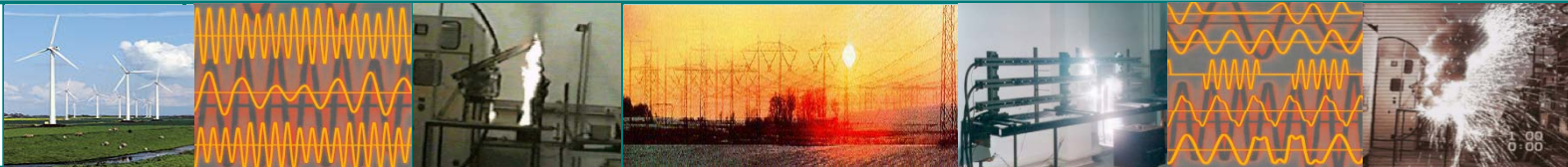


Co-ordination of LV Fuses and PPE for Personal Protection against the Thermal Hazards of Electric Fault Arcs

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and their Applications**

Road map

- Arc flash hazards
- Personal protection against thermal risks
- Laboratory measurements
- Effect of fuse links cutting-off
- Remaining arc energy and incident energy
- User guidelines for PPE and fuse selection, coordination
- Summary



One ma

while working
with
ARCS

Factor time

Effects of arcing - hazards

Y3 Camera 03.04.2013 12:06:38 001050 1050 ms 1000 fps 498 µs

Pressure wave

shrapnel

Sound emission

**radiation: heat and
intense light**

**Heat flux
convective heat
(plasma, hot gases)**

**Hot metal particles,
splash and vapour**

Toxic gases

Direct exposure

short-term exposures
often directed exposures

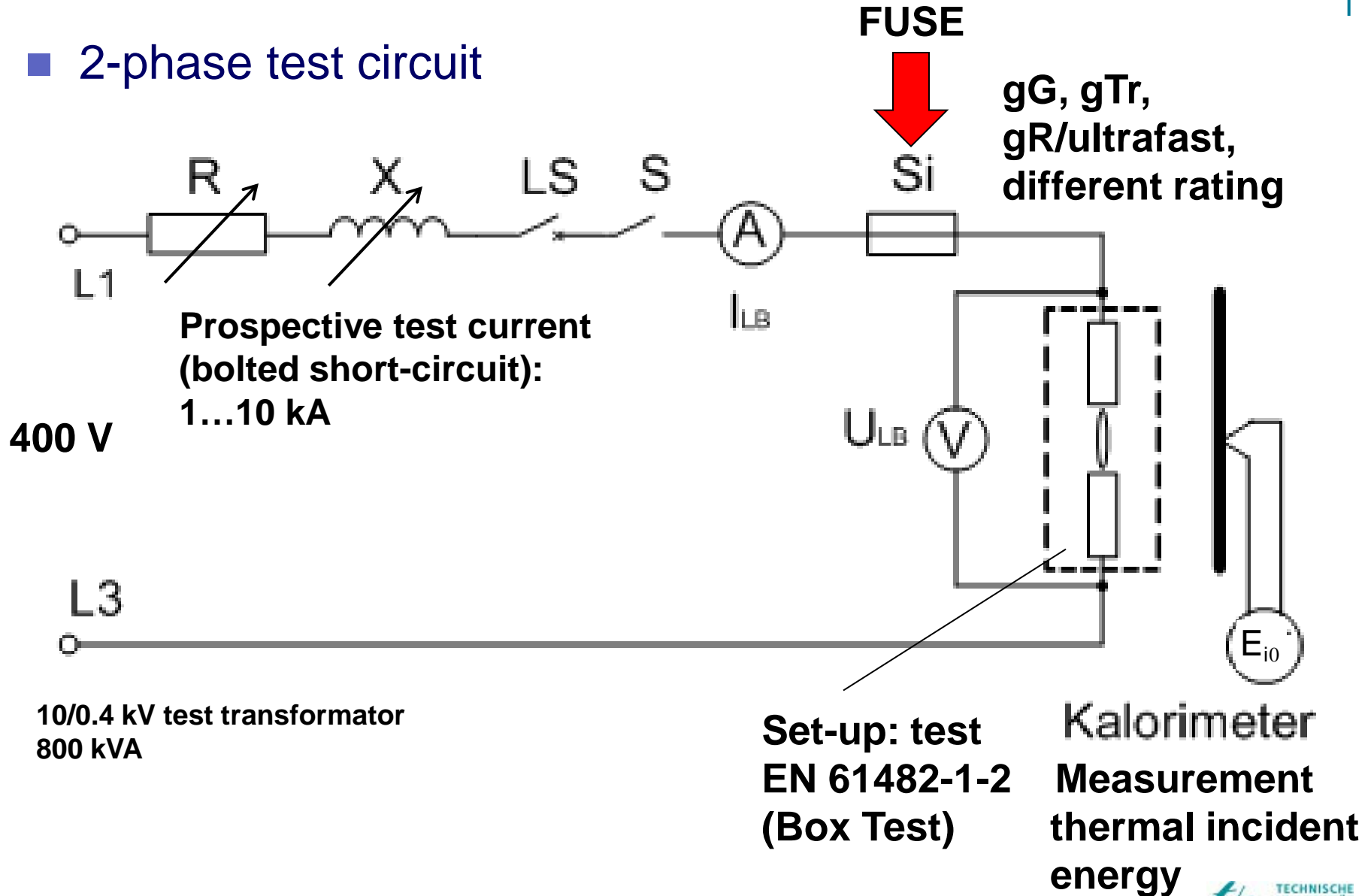
Personal protection while working

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

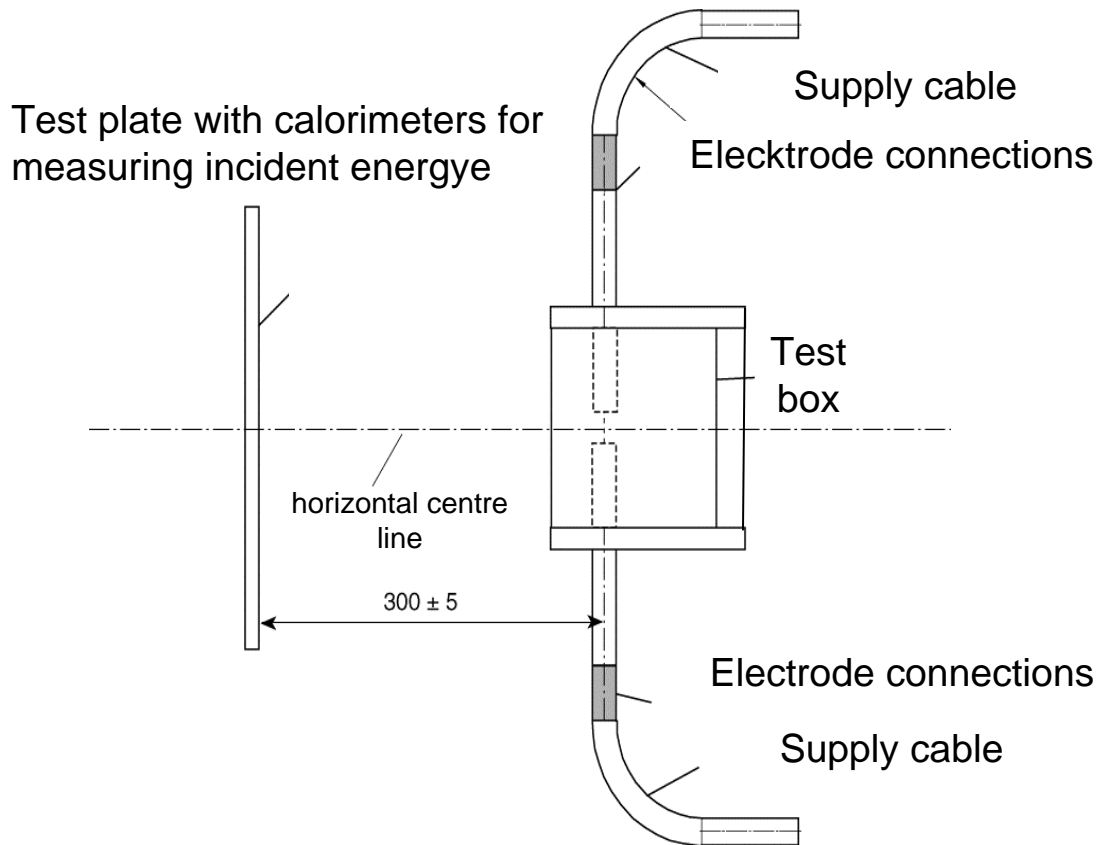


Laboratory measurements with LV fuse links

■ 2-phase test circuit



Test set-up



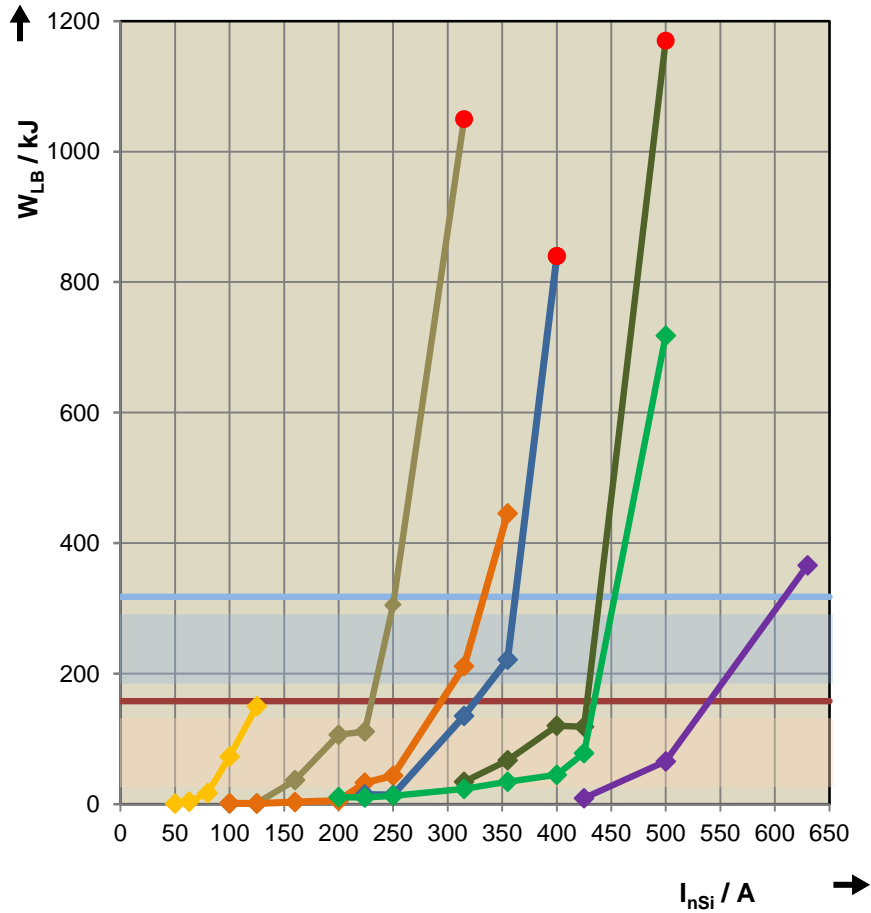
**Variation of prospective test currents (bolted short-circuit):
1 ... 10 kA**



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

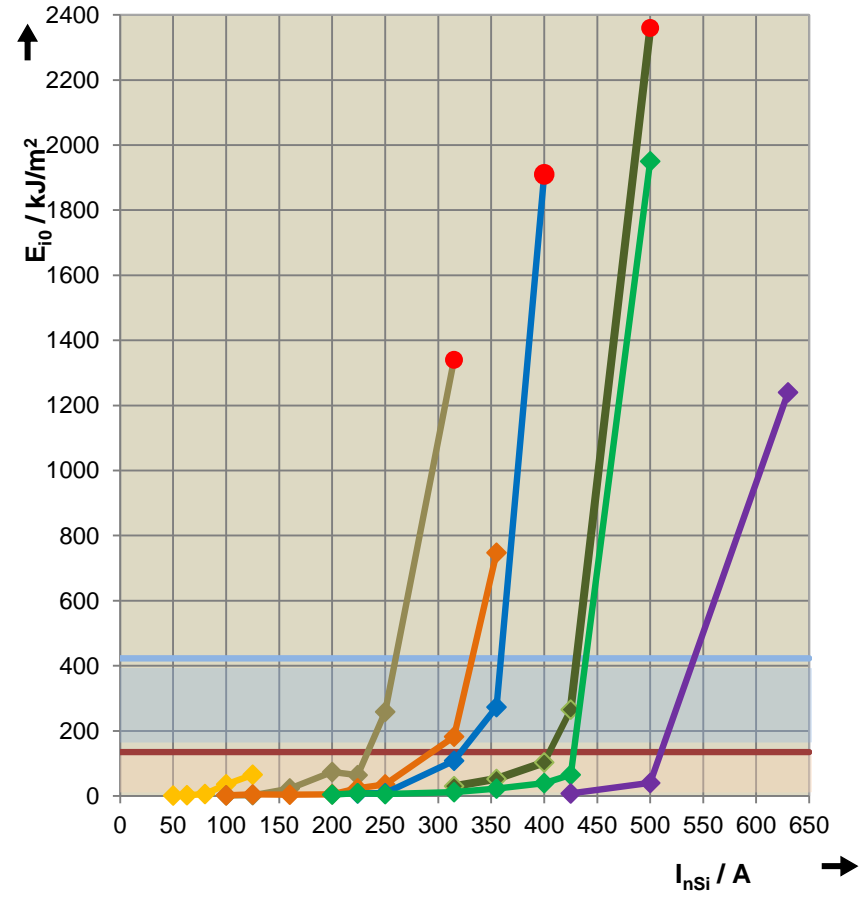
Arc energy

in dependency on fuse rated current



Incident energy

in dependency on fuse rated current



General fuse breaking behaviour

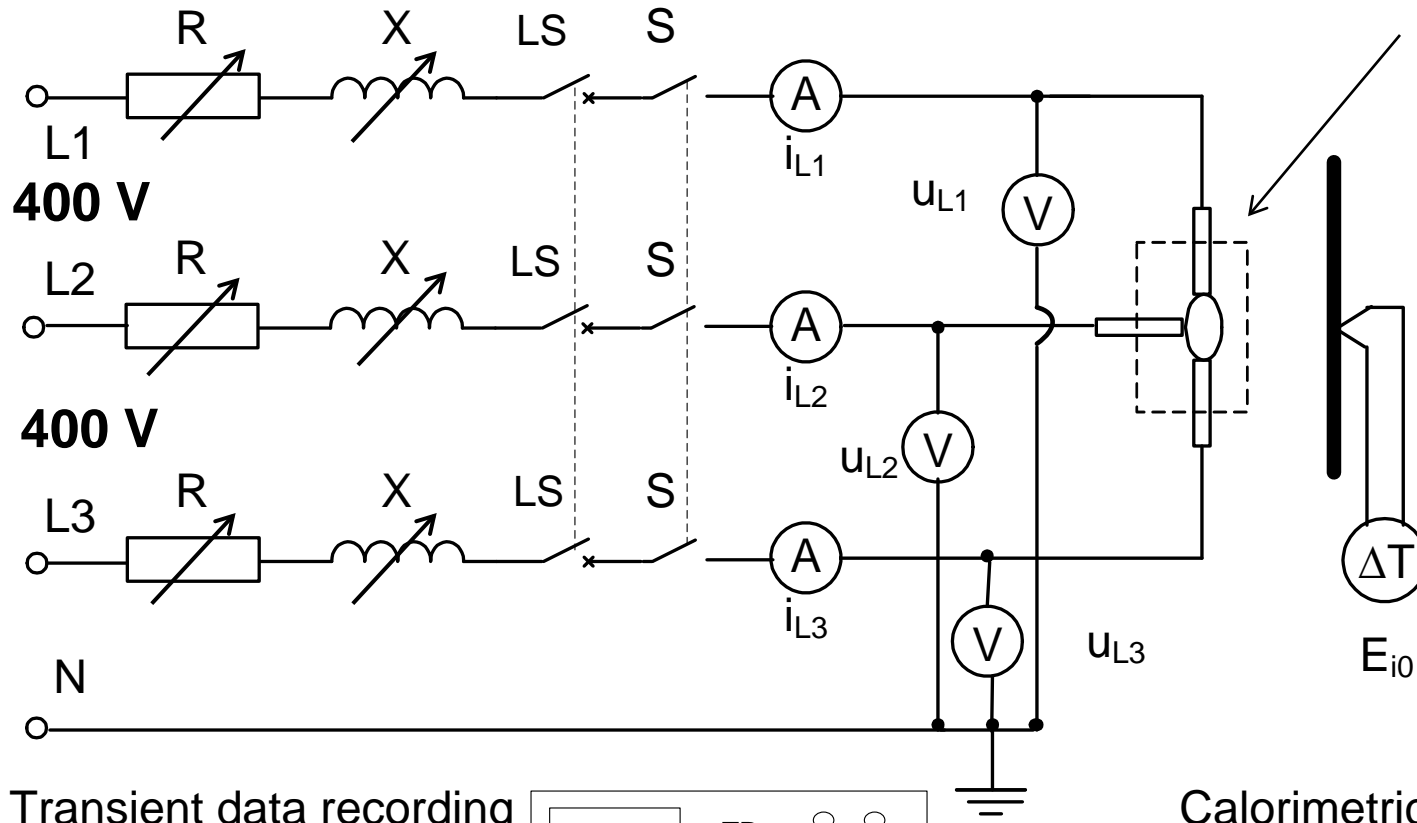
- Scattering; interactions between fuse arc and fault arc, fault current attenuation due to fault arc
- Fuse operation
 - Current limiting breaking $t_{op} < 10 \text{ ms}$
 - if $I''_k/I_{nSi} > 18...25$ general purpose fuses (gG)
 - $I''_k/I_{nSi} > 6...10$ very fast-acting fuses (aR), work-protecting 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

Laboratory measurements with LV NH fuse links

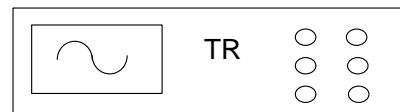
■ 3-phase test circuit

Different electrode materials, combinations, main series: Al-Cu-St

extended 3-phase electrode arrangement in box



Transient data recording system



Calorimetric measurement

Arc tests in 3-phase test circuit

- First analyses: tests without fuses (fix-adjusted arc duration)
Different types of arc formation
 - Ratio of arc energy 3p/2p:
 - arc power depending on electrode orientation
 - different number of partial arcs
 - opposing configurations (triangular) average: appr. 2
 - coplanar: may also become higher (long arcs)
 - Ratio of incident energy 3p/2p
 - depending on electrode materials
 - Average values for combination Al – Cu - St
 - Calculations of 3-phase energy conditions
on base of average arc energy ratio from 2-phase measurement results (assumption: continuous 3-phase arcing)

3-phase arcing tests with fuse links

- **Main test series:** with fuse links in test circuit supply (each line)
 - Opposing electrodes, electrode configuration symmetrical to calorimeter configuration
 - Electrode material combination: Al – Cu – Steel
(comparability to 2-phase testing)
 - Average 3-phase conditions, no worst case scenarios
- **Test results**
 - Arc duration according to fusing time of 3 fuse links
 - Simultaneous extinction of all 3 arcs is only exception
 - Mostly: one fuse first, then 2nd and 3rd one (also longer intervals)
 - 2-phase intervals: influence on total arc duration (final extinction), arc power, arc energy, incident energy)
 - Theoretically: higher energies compared to continuous 3-phase arcing (no practical cases in tests)
 - Calculated 3-phase energies additionally considered

Preparation of results: Guidelines for users

- simplified tools for practical use (meeting of PPE protection levels)
- Forms:
 1. **Minimum over-current factor**
(Base: prospective [bolted] short-circuit current; very rough estimation, very safe) – valid for standard exposure conditions
 2. **Selection matrix**
with correlation minimum short-circuit current (bolted) – fuse rating current – good overview, valid for for standard exposure conditions
 3. **Permissible clearing time**
(normalized characteristic with curve factor, on base of prospective [bolted] short-circuit current – allows also consideration of any exposure conditions (a, kT)

1. Minimum over-current factor

- Direct determination of maximum fuse rating current
- by means of minimum over-current factor $k_{\ddot{U} \text{ min}}$ and bolted short-circuit current $I_{k \text{ xp}}''$

$$I_{n \text{ Si max}} = \frac{I_{k \text{ xp}}''}{k_{\ddot{U} \text{ min}}}$$

NH fuse link	PPE class	Minimum over-current factor $k_{\ddot{U} \text{ min}}$	
		2p short-circuit (xp = 2p)	3p short-circuit (xp = 3p)
gG	1	20	20
	2	18	19
gTr	1	28	28
	2	25	25
Work-protection	1	6	8
	2	6	8

Values valid for standard exposure conditions: $a = 300 \text{ mm}$, $k_T = 1$

Selection matrix NH gG fuses – 3-phase faults

3-phase short-circuit															
Fuse rated current I_{nSi} / A	Fuse link NH gG														
50	<div style="text-align: center;"> <p>Protection</p> <p>with PPE class 1</p> </div>														
63															
80															
100															
125															
160															
200															
224															
250															
315															
355															
400															
425															
500															
		<div style="text-align: center;"> <p>no protection</p> </div>													
		<div style="text-align: center;"> <p>Protection with PPE class 2</p> </div>													
	<table border="1" style="width: 100%; text-align: center;"> <tr> <td>1,0-2,5</td> <td>2,2-4,5</td> <td>4,5-5,5</td> <td>5,5-6,5</td> <td>6,5-7,5</td> <td>7,5-10,5</td> <td>>10,5</td> </tr> <tr> <td colspan="7">Minimum bolted short-circuit current I''_{k3p} /kA</td> </tr> </table>	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						
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															

Selection matrix NH gG line protection fuses

3-phase short-circuit								2-phase short-circuit																						
Fuse rated current I_{nSi} / A	Fuse link NH gG							Fuse rating I_{nSi} / A	Fuse links NH gG																					
50	Protection with PPE class 1							50	Protection with PPE class 1																					
63																														
80																														
100																														
125																														
160	Protection with PPE class 2							160	Protection with PPE class 2																					
200																														
224	no protection with PPE							224	no protection with PPE																					
250																														
315																														
355																														
400																														
425																														
500																														
																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		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''_{k3p} / kA								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 $S_n / \text{kVA} (I_{nSi} / \text{A})$	Fuse link NH gTr		
250 (361)	Protection with PPE class1		
315 (455)	no		Protection with PPE class 2
400 (577)	protection		
	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	<div style="background-color: #00FF00; padding: 10px; text-align: center;"> Protection with PPE class 1 (and class 2) </div>		
200			
250			
315			
355			
400			
500			
	<div style="background-color: #FF0000; padding: 10px; text-align: center;"> No protection </div>		
	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, $k_T = 1$

3. Maximum permissible clearing time

- for permissible cut-off time of the upstream fuse link
 - **normalized PPE current-time characteristic**
 - a diagram (graphical)
 - b mathematical function (equation)
 - c digitized curves for numerical calculation
-
- Determination of (maximum) permissible clearing time
 - Determination of fuse rating from fuse operating characteristic (fuse manufacturer data) with the actual arcing fault current $I_{kLB, xp}$ for $t_{kaus, KLHerst} < t_{kzul}$
 - for any exposure conditions

Permissible clearing time – normalized PPE I-t characteristic

- equation

$$t_{k\ zul} = t_{aus\ max} = \frac{KL}{I_{k\ xp}''}$$

PPE	KL	
	x = 2	x = 3
class 1	1000	500
class 2	2000	1000

- Numerical value pairs of the linear curve

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. BGI/GUV-I 203-077)

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NH/HH-Recycling



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(club for promoting environment-equitable recycling of used NH/HH fuses) - Germany

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