DGUV
Deutsche Gesetzliche
Unfallversicherung
Spitzenverband

5188 E

BGI/GUV-I 5188 E

Information

Thermal hazards from electric fault arc

Guide to the selection of personal protective equipment for electrical work

October 2012

Imprint

About us Publisher:
German Social Accident
Insurance e.V. (DGUV)

Mittelstraße 51
10117 Berlin
Tel.: 030 288763800
Fax: 030 288763808
E-Mail: info@dguv.de
Website: www.dguv.de

Subcommittee „Electrical and precision engineering“, Expert Committee „Energy, textile electrical and media products sectors“ the DGUV.

Design
German Social Accident Insurance e.V. (DGUV), Media Production

English translation of the German edition from October 2012

BGI/GUV-I 5188 E available from the competent German social accident insurance institution
or on www.dguv.de/publikationen

Information

Thermal hazards from electric fault arc

Guide to the selection of personal protective equipment for electrical work

BGI/GUV-I 5188 E October 2012

Table of Contents

Preliminary remarks

Persons working on or in the vicinity of live electrical equipment are, in principle, exposed to hazards associated with electric fault arc. While an electric arc flash is rare in the normal working environment, its occurrence cannot be ruled out completely. For this reason, persons working in this environment will require reliable protection, especially because incorrectly performed work tasks can cause such arcing. Electric arcs are not only induced by short circuiting, but can also occur between two current-carrying components, when they are separated from each other (e. g. installation/removal of circuit protectors while under load).

The information contained herein is intended to support employers in their selection of suitable equipment (e. g. protective clothing or face shields for electrical work, etc.) for protection against the thermal effects of electric fault arcs. In so doing, a methodology has been adopted based on standardised Box test procedures according to VDE 0682-306-1-2 (see Annex 1).

Depending on the electrical network and equipment configuration, electric arcing can be extremely hazardous:

- High levels of thermal energy.
- Shockwaves and associated fragments released by the explosive propagation of an arc flash.
- High intensity electromagnetic radiation, particularly in the ultraviolet (UV) and infrared (IR) radiation bands, but also in the visible light band, which can lead to irreversible damage to the eyes and skin.
- High levels of acoustic shock (bang).
- Toxic gases and particles produced by melting and vaporised materials in the vicinity of the arc flash (including electrodes).

Each consequence, in itself, can endanger the health and even the life of a person in proximity of the occurrence. The most serious personal risks are associated with the thermal effects of electric fault arcs.

NOTE:
Methodologies based on a selection criteria where PPE is tested according to VDE 0682-306-1-1 (see Annex 1) are already described in NFPA 70e (Standard for Electrical Safety in the Workplace) and IEEE 1584-2002 (Guide for performing arc-flash hazard calculations), among others, and, for this reason, are not presented directly in this guide.

NOTE:
Moreover, an overview of PPE selection is included in the ISSA (International Social Security Association) Guideline for the selection of personal protective equipment when exposed to the thermal effects of an electric fault arc (2nd edition 2011).

1 Scope

This information provides guidance for action in the appraisal of potential thermal hazards due to electric fault arcs associated with electrotechnical work on electrical equipment. Accordingly, this document affords employers an element of support in the selection of essential PPE.

This information is applicable for work performed on or in the vicinity of electrical equipment > 50 V AC.

Examples:

- Household installations,
- Power distribution circuits,
- Industrial power systems.

The information contained herein does not address potential hazards associated with the side-effects of electric arcing, such as impact and acoustic shock or gases.

Neither does it apply to the use of electrical equipment conforming to pertinent guidelines or standards and having been designed or installed for use by unskilled persons.

NOTE:
The determinations made herein also apply to work performed on or in the vicinity of d. c. electrical equipment. Examination of the likely resulting energy and calculation formulas should be continued within the framework of continuing scientific research (see Section 3).

2 Definitions

Personal protective equipment against the thermal effects of an electric fault arc (PPEgS)
Personal protective equipment against the thermal effects of an electric fault arc applies to any medium meant to be worn or held by a person for protection against the thermal hazards associated with electric fault arcs.

Work
Any form of electrotechnical or non-electrotechnical activity where the potential for electrical hazard exists.

Live working
Any activity, by which a person, either physically or through the use tooling, equipment or devices, knowingly comes in contact with or enters a danger zone associated with live components. (from DIN VDE 0105-100, 3.4.4)

Work performed in the vicinity of live components
Any activity, by which a person, either physically or through the use of tooling, equipment or devices, knowingly enters a vicinity zone without entering the danger zone
(from DIN VDE 0105-100, 3.4.5).

Working distance a
The distance between the electric arc and a person's body (torso), that is effective during activity in the working environment being considered.

NOTE:
Working distance is expressed in mm.

Equivalent arc energy $W_{LBä}$
Equivalent arc energy $W_{LBä}$ resulting from the test level W_{LBP} at a precise working distance a and transmission factor k_T.

NOTE:
PPE protection level is expressed in kJ or kWs.

Normalised arc power k_P
Relationship of electric arc power to the short-circuit power in the electrical network at the fault location.

Direct exposure incident energy E_{i0}
Heat energy emanating directly from the electric fault arc per unit of affected area.

NOTE:
Direct incident energy is expressed in kJ/m^2 or kWs/m^2 (cal/cm^2)[1].

Transmitted incident energy E_{it}
Incident energy that penetrates PPE when exposed to electric arcing; a portion of the released incident energy.

NOTE:
Transmitted incident energy is expressed in kJ/m^2 or kWs/m^2 (cal/cm^2)[1].

Incident energy E_i
Heat energy (total heat) affecting a unit of area as a result of an electric arc.

NOTE:
Incident energy is expressed in kJ/m^2 or kWs/m^2 (cal/cm^2)[1].

Electrical system
Overall electric installations and equipment for producing, transmitting, converting, distributing and utilizing electrical energy.

Electrode gap d
Distance between the arc electrodes

NOTE:
Electrode gap is expressed in mm.

Duration of exposure
Period of exposure to electric fault arc energy in time.

NOTE 1:
Duration of exposure is expressed in s.

NOTE 2:
Exposure duration is normally significantly longer than arc duration.

1) Correlation:
$1\ cal/cm^2 = 41{,}868\ kJ/m^2$, $1\ kJ/m^2 = 0{,}023\ 885\ cal/cm^2$.

Short-circuit duration
Period of the short-circuit in time.

NOTE:
Duration of short-circuiting is expressed in s.

Arc duration
Period of the arc flash in time

NOTE:
Duration of arcing is expressed in s.

Arc energy W_{arc}
Electrical energy that causes and is converted into an arc flash; the sum (integral) of the product of the instantaneous values of arc voltage and arc current, as well as the time differential, determine the duration of arcing.

NOTE:
Electric arc energy is expressed in kJ or kWs.

Arc short-circuit current I_{kLB}
Current actually flowing at the fault location throughout the duration of arcing (due to the arc flash); determined as the average effective value over the duration of the short-circuit.

NOTE:
Electric arc short-circuit current is expressed in kA.

Arc current I_{arc}
Current actually flowing in the test circuit during the arc duration (through the arc flash); determined as the average effective value over the duration of arcing. [VDE 0682-306-1-2]

NOTE 1:
Electric arc current is expressed in kA.

NOTE 2:
Electric arc current flowing throughout the duration of arcing is subject to stochastic time variations due to nonlinear arc impedance.

Material
Textile fabrics or other materials used to produce single or multilayer PPE.

Prospective short-circuit current
Anticipated current that flows when the impedance at the fault location is negligible (electrical supply short-circuit). [VDE 0682-306-1-2]

NOTE 1:
Prospective short-circuit current is expressed in kA.

NOTE 2:
There is a general difference between the actual electric arc current and the prospective short-circuit current. The actual electric arc current flowing throughout the duration of arcing is lower and fluctuates due to the nonlinear arc impedance that varies stochastically over time.

Test level W_{LBP}
Electric arc energy set as part of the Box test (according to VDE 0682-306-1-2) for either of the two electric fault arc test categories and leading to a direct incident energy E_{i0P}.

NOTE:
Electric arc energy is expressed in kJ or kWs.

Test current $I_{arc, class}$
Prospective short-circuit current in the electrical test current circuit (anticipated current) used for setting a test category in the Box test method; effective value (symmetrical a. c. component).

NOTE:
Test current is expressed in kA.

R/X ratio
Relationship of the resistance to the inductive reactance of a short-circuited electrical circuit.

PPE protection level
Protection level of the PPE resulting from the test level W_{LBP} at a fixed working distance a and transmission factor k_T.

NOTE:
Equivalent arc energy is expressed in kJ or kWs.

Stoll curve
Correlation between thermal incident energy and exposure time derived from data related to the tolerance behaviour of human skin when exposed to heat; specifies the limits for the occurrence of second-degree skin burns.

Current limiting factor k_B
Relationship between the actual electric arc short-circuit current and the prospective short-circuit current.

Fault arc
An independent electric discharge due to a faulty connection between components of different potential in electric power equipment.

NOTE:
Electric fault arcing in the context of the information herein is considered to be an undesirable faulty occurrence caused by short-circuiting.

Fault arc protection classes
Categories of protective properties of the PPE against the thermal effects of an electric fault arc as tested through Box test procedures (according to VDE 0682-306-1-2). The classes are distinguished by test energy levels.

Transmission factor k_T
Factor describing the spatial propagation of the thermal impact of an electric arc on the working environment. It is determined by the geometric relationships between the equipment at the workplace.

Transmission and exposure conditions
Totality of the influences on the heat transfer associated with an electric fault arc.

Symbols and units

a	Working distance	mm
d	Electrode gap	mm
E_i	Incident energy	kJ/m^2 or $kW\,s/m^2$
E_{i0}	Direct exposure incident energy	kJ/m^2 or $kW\,s/m^2$ (cal/cm^2)
I_{arc}	Electric arc current	kA
$I_{arc,\ class}$	Test current	kA
I_{kLB}	Electric arc short-circuit current	kA
k_B	Current limiting factor	
k_P	Normalised arc power	
k_T	Transmission factor	
t	Time	s
W_{arc}	Arc energy	kJ, kWs
$W_{LBä}$	Equivalent arc energy, protection level	kJ or kWs
W_{LBP}	Test level	kJ or kWs

3 Procedures for selecting PPEgS

3.1 Overview of the evaluation process

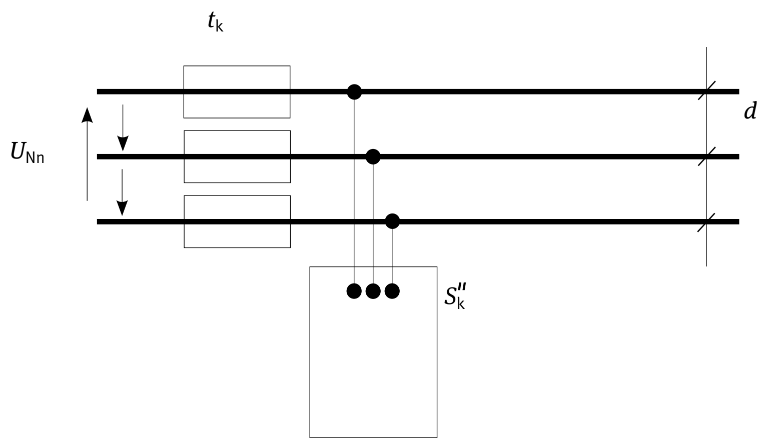
The first step entails an estimation of the arc energy W_{LB} that is converted in the event of a fault at the workplace. This is then compared to the equivalent arc energy $W_{LBä}$ with consideration given to the transmission characteristics and working distance, up to the level where protection is provided by the PPE.

3.2 Work environment parameters

The electrical system working environment is characterised by the following parameters:

Work environment		
Protection device	Electrical network	Electrical system
t_k	U_{Nn} S_k'' R/X	d

Fig. 1 Work environment parameters



Legend:

t_k [s]: Protection device trip time

U_{Nn} [V]: Rated network voltage

R/X: Resistive/reactive relationship related to network impedance

S_k'' [kVA]: 3-phase short-circuit capacity

d [mm]: Distance between two live components at the workplace

Fig. 2 Electrical equipment parameters

3.3 Determination of system electric arc energy in the event of a fault

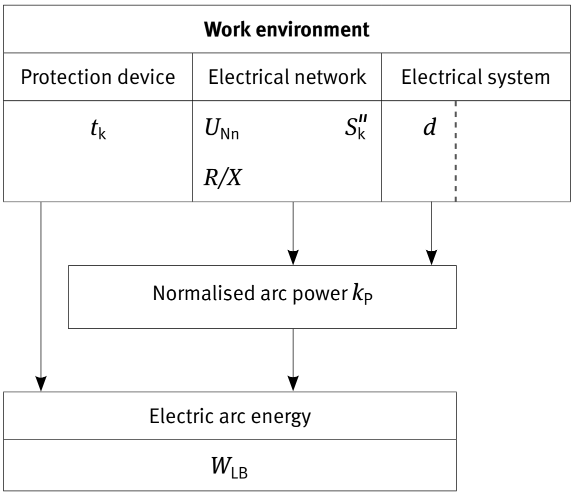


Fig. 3 Determination of electric arc energy

Electric arc energy W_{LB} is determined by the electric arc power P_{LB} and the duration of arcing, meaning the time t_k until tripping by the protection device:

$$W_{LB} = P_{LB} \cdot t_k$$

Electric arc power P_{LB} is dependent upon the type of arc formation and the geometry of the live components at the fault location. It is determined with the help of the normalised arc power k_P from the short-circuit power S''_k.

Normalised arc power k_P can be determined with consideration given to the effective electrode gap d (distance between system conductors), (e.g. according to the text in German, "Schau, H.; Halinka. A.; Winkler, W.: Elektrische Schutzeinrichtungen in Industrienetzen und -anlagen"). Reference values are specified in Annex A.3.3.4.

Worst-case examinations can be calculated using the maximum value k_{Pmax}:

$$k_{Pmax} = \frac{0{,}29}{(R/X)^{0{,}17}}$$

Consequently, the following correlations can be drawn with respect to electric arc energy in the event of a fault:

$$\begin{aligned} W_{LB} &= P_{LB} \cdot t_k \\ &= k_P \cdot S''_k \cdot t_k \\ &= k_P \cdot \sqrt{3} \cdot U_{Nn} \cdot I''_{k3} \cdot t_k \end{aligned}$$

The decisive short-circuit current I''_{k3} is the prospective 3-pole short-circuit current at the workplace (fault location). It is the outcome of a short-circuit current calculation (see Annex A.3.3.2.).

The actual short-circuit current I_{kLB} in the low voltage range is significantly lower than the calculated system short-circuit current I''_{k3} (current limiting factor k_B) due to the attenuating properties of the electric arc and cannot be determined in certainty. In principle, the applicable correlation is:

$$I_{kLB} = 0{,}5 \cdot I''_{k3min} \qquad \text{(see Annex A.3.3.2)}$$

In the > 1 kV range, the limiting properties of the electric arc can be disregarded. The following applies: $k_B = 1$.

The duration of arc combustion is determined by the protection device and generally can be taken from the protective equipment manufacturer's selectivity calculations and/or the trip characteristic curves (current-time curves).

The low voltage range is generally considered to be safe if one assumes a current limitation of 50 % and uses this reduced current to ascertain the trip time from the protection characteristic curve. The current limiting factor then equates to $k_B = 0.5$; it follows that

$$I_{kLB} = 0{,}5 \cdot I''_{k3min}$$

The overcurrent protection device trip time should now be determined with the help of the characteristic curve and the ascertained electric arc short-circuit current I_{kLB} (see A 2.3.3).

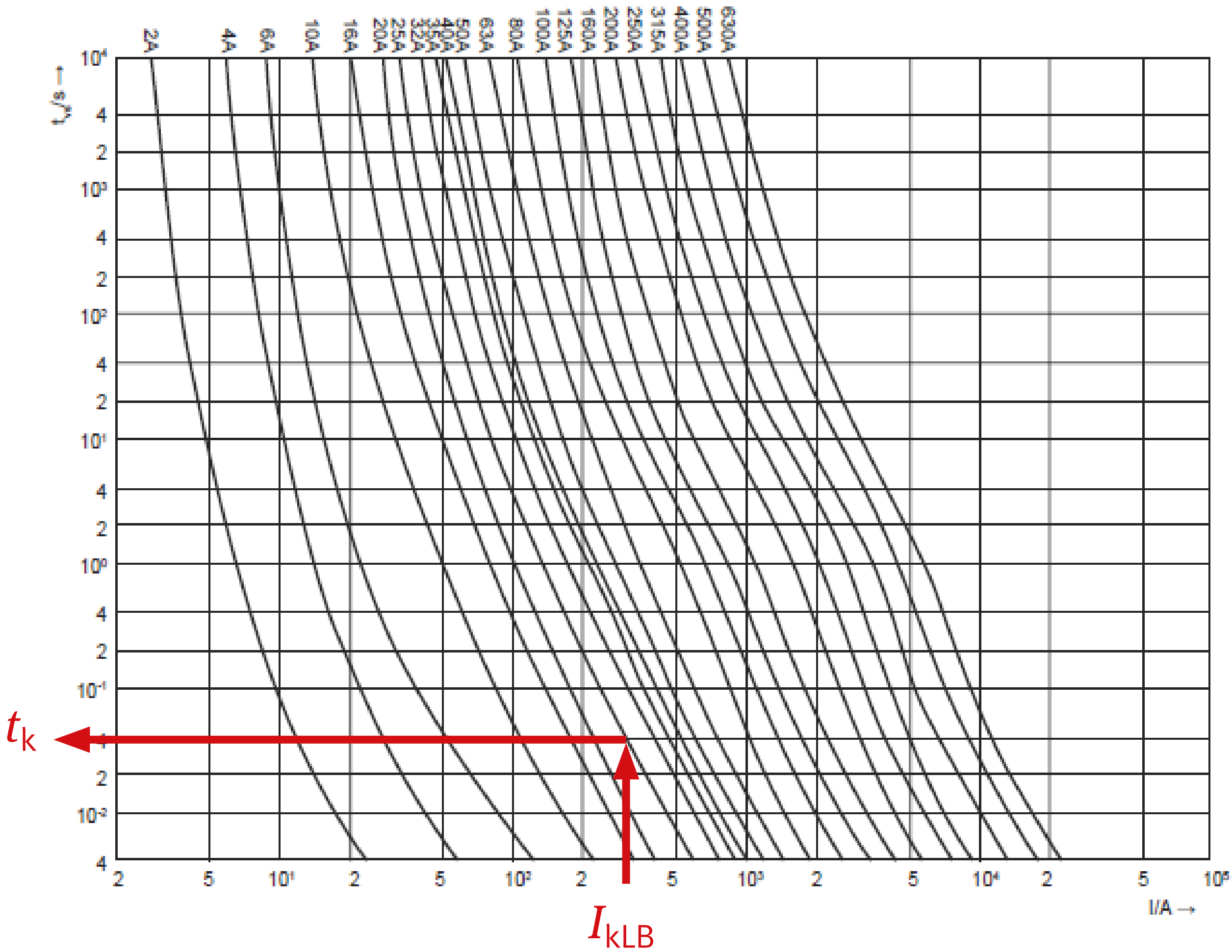


Fig. 4 Example for determining the overcurrent protection device trip time

NOTE:
At short-circuit durations longer than 1 s, it can be assumed that the person will be able to withdraw from the immediate danger area, if applicable. For this reason, longer periods will not need to be considered. This does not apply, however, if withdrawal of the person from the working environment is precluded or restricted (e. g. work in tight cable trenches or canals, narrow work corridors, work from ladders or lifting mechanisms).

3.4 Determination of equivalent arc energy

The equivalent arc energy is the protection level afforded by the PPE. It is determined by the test level for the PPE, working distance a and the equipment geometry (Factor k_T).

Working distance a is the distance between the electric arc and the person's body (torso) that is effective during the work activity or must be maintained in the working environment being considered. Where different tasks are being carried out in the working environment, the shortest distance emerging should be applied. (see Annex A 3.3.5)

It can generally be assumed that the distance to the person's torso when working will not fall short of a = 300 mm and that, particularly in the low voltage range, this can be applied as a reference value.

The transmission factor k_T takes into account the electrical system's geometric configuration and describes the spatial propagation of the electric arc thermal impact in space.

In a small-scale system, a directional propagation of the electric arc thermal impact occurs. The more open or large-scale the system, the more omnidirectional the electric arc thermal impact propagation will be.

Exemplary pictures of real system configurations are depicted in Section 4.3.

The test method used to verify the thermal impact of an electric fault arc is described in detail in Annex A 3.1.

The test method differentiates between two classes, which define the protective properties of the PPE against the thermal effects of an electric fault arc (test level). Both classes are verified through electric arcing with subsequent electric arc energies, as well as through the use of the test setups described in the test method.

Class 1 $W_{LBP1} = 158$ kJ
Class 2 $W_{LBP2} = 318$ kJ

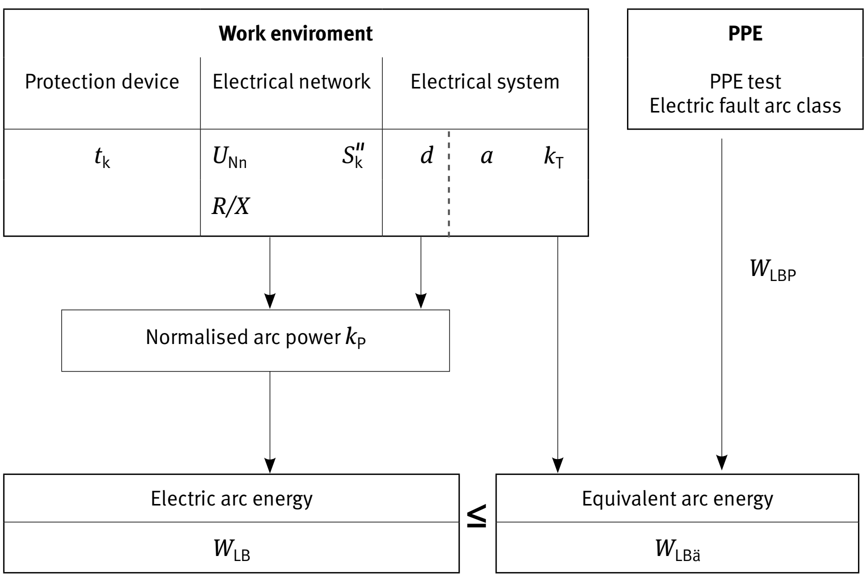


Fig. 5 Determination of equivalent arc energy with consideration given to working distance and geometry

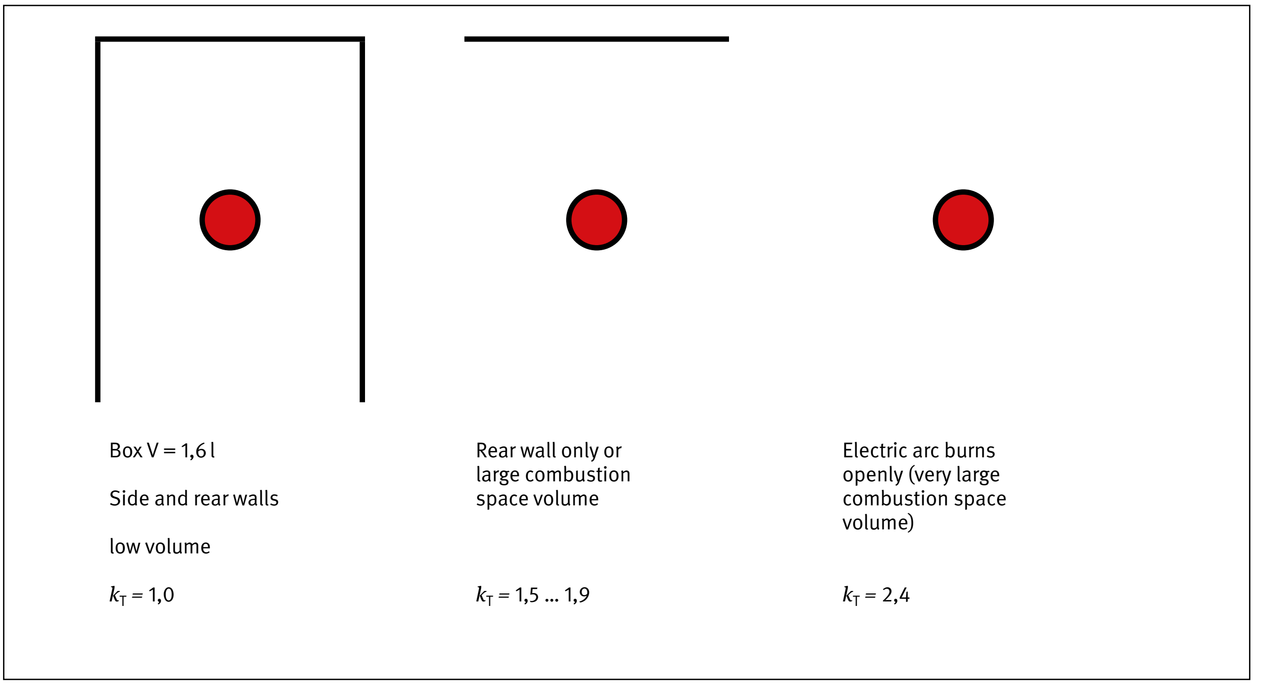


Fig. 6 Transmission factor reference values for different equipment relationships

An equivalent arc energy $W_{LBä}$, at which level protection is still afforded by the PPE for the respective distance a, can be determined for any working distance a over the experimentally verified reverse squared distance proportionality, using the electric arc energy of the test category W_{LBP}[2]. In addition, the system configuration can be taken into consideration using factor k_T. Generally valid for the Box test

$$W_{LBä} = k_T \cdot \left(\frac{a}{300\,\text{mm}}\right)^2 \cdot W_{LBP}$$

3.5 Selection of PPE

In the risk assessment or when selecting the PPE test category or protection class (Box test), the relation to the expected value for electric arc energy is to be considered based on the equivalent arc energy. The thermal hazards associated with electric arching are deemed covered if

$$W_{LB} \leq W_{LBä}$$

applies.

The limits for PPE use in a chosen test category or protection class with respect to the short-circuit current range, the permissible short-circuit duration or protection device trip time (and therewith the protective system itself), as well as the permissible working distance, can also be determined based on this relationship using the above mentioned determinant values and equations.

2) Feasibility study related to the testing and evaluation of protective gloves against the thermal hazards of electric fault arcing (AG: BGFE; AN: STFI/TU Ilmenau), STFI final report from 30 May 2005.

4 Instructions for practical application with practical examples

4.1 Instructions for practical application

A worksheet (Excel) has been developed to support use of the methodology, which can be downloaded from the Internet at the BG ETEM homepage (www.dguv.de; Webcode: d138299).

The following basic conditions should be considered when implementing the evaluation process in practice:

- The requirements set forth in BGV/GUV-V A3 „Electrical Systems and Equipment“ should be taken into account, particularly with respect to the use of additional PPE for work on live equipment or in the vicinity of live system components.
- The methodology only covers that protection afforded against the thermal effects of an electric fault arc. Experience has shown these effects have the most severe consequences. Electric fault arcs in high-energy systems can lead to further hazards caused by shockwaves, noise, optical radiation or escaping electric arc gases.
- If use of the selection algorithm determines that the protective properties of the PPE selected for the work process being considered are not adequate, the following exemplary measures could be considered in more detail:
    - The protection device's characteristics and corresponding trip time have a significant influence on the potential electric arc energy in the event of a fault. Replacement of the upstream protection device with a fast-acting industrial protection device or adjustment of the circuit breaker tripping characteristics during the work period might be considered in this context[3].
    - A separate protection device for electric fault arcs detects the electric arc by means of a sensor system, immediately initiates a bolted short-circuit and triggers the upstream protection device. The duration of arc combustion is reduced in this manner to just a few milliseconds.

      These devices can be foreseen for permanent installation during the system planning stage or can be used for mobile applications[4].
    - If the working distance can be increased, this will greatly influence the equivalent arc energy. Thus, it may well make sense to consider whether an increase in the working distance could be realised with the aid of additional auxiliary devices.
    - Short-circuit power at the workplace can be reduced by means of a modified circuit variant depending on the system configuration (e.g. disconnection of a machine network connection, removal of a parallel connection). Subsequent to these measures, the calculation process should be applied again for the modified network parameters.
- If the maximum value k_{Pmax} was used to determine normalised arc power k_P in the initial analysis, the calculation will be on the safe side, but it may also result in exceeding the target in practice. In this case, it is worthwhile calculating using a typical reference value or with consideration given to the practical system configuration.
- The geometry of the real system is entered into the calculation. The transmission factor k_T, which is normally established at the start during the initial approximation, can then be adapted based on the actual geometric system conditions and the working environment. If a deviation from transmission factor $k_T = 1$ is intended, this determination must be justified.

3) Strasse, U., Erfahrungen beim Einsatz von Arbeitssicherungen beim AuS im Kabelnetz von Vattenfall Europe Berlin; ETG Fachbericht Fachbereich 106 Arbeiten unter Spannung (AuS), Presentation for the ETG-Technical Meeting in Dresden from 19. to 20. September 2007.

4) Rotter, G., Bähnsch, R., Lichtbogenschutz-System DEHNarc – Geräte-System und Anwendung in der Praxis, 15 th BG ETEM Electrical Engineering Technical Meeting in Kassel, 2010.

If evaluation shows that the protective properties of the clothing made available are inadequate for the work process being considered and measures such as increasing the working distance, reducing the electric arc energy or introducing additional electric fault arc-resistant partition walls, can not be taken, then work must not be performed if the system has not been electrically isolated.

NOTE:
If observation reveals potential hazards associated with system operation, such as during system isolation, against which the available PPE does not offer adequate protection, then special consideration should be made in each individual case. Measures such as isolating the upstream network may be conceivable in this context.

- The manufacturer's instructions must be observed to ensure the PPE provides the appropriate protection in the event of a fault. In particular, it is essential to adhere to the instructions for proper usage, as well as those specified by the manufacturer for proper care. At the same time, it is recommended to wear cotton underwear.

4.2 Examples

The following examples depict work being carried out at different work locations in a typical municipal low voltage supply system.

4.2.1 Work location 1: Low voltage distribution in a transformer station

Work tasks are frequently carried on the low voltage distribution system in a transformer station.

Fig. 8 Work on a low voltage distribution system

An increased degree of risk exists when performing such work because, in the event of a fault at the workplace, significant short-circuit power is generated directly behind the transformer. The transformer output, as well as the transformer fuses or power supply branch circuit breaker trip times, are decisive for the energy released in an electric arc. One important factor is influenced by the structure or the switching status of the low voltage network with relationship to the type of energy supply to the low voltage stations (station meshing or per station low voltage network supply). The short-circuit power and the prospective short-circuit current at the workplace depend on whether a unilateral or a multilateral supply exists. It is often practical with meshed low voltage networks to neutralize the meshing prior to working on live components in the low voltage distribution system and to establish a unilateral energy supply, as is the case in the example considered.

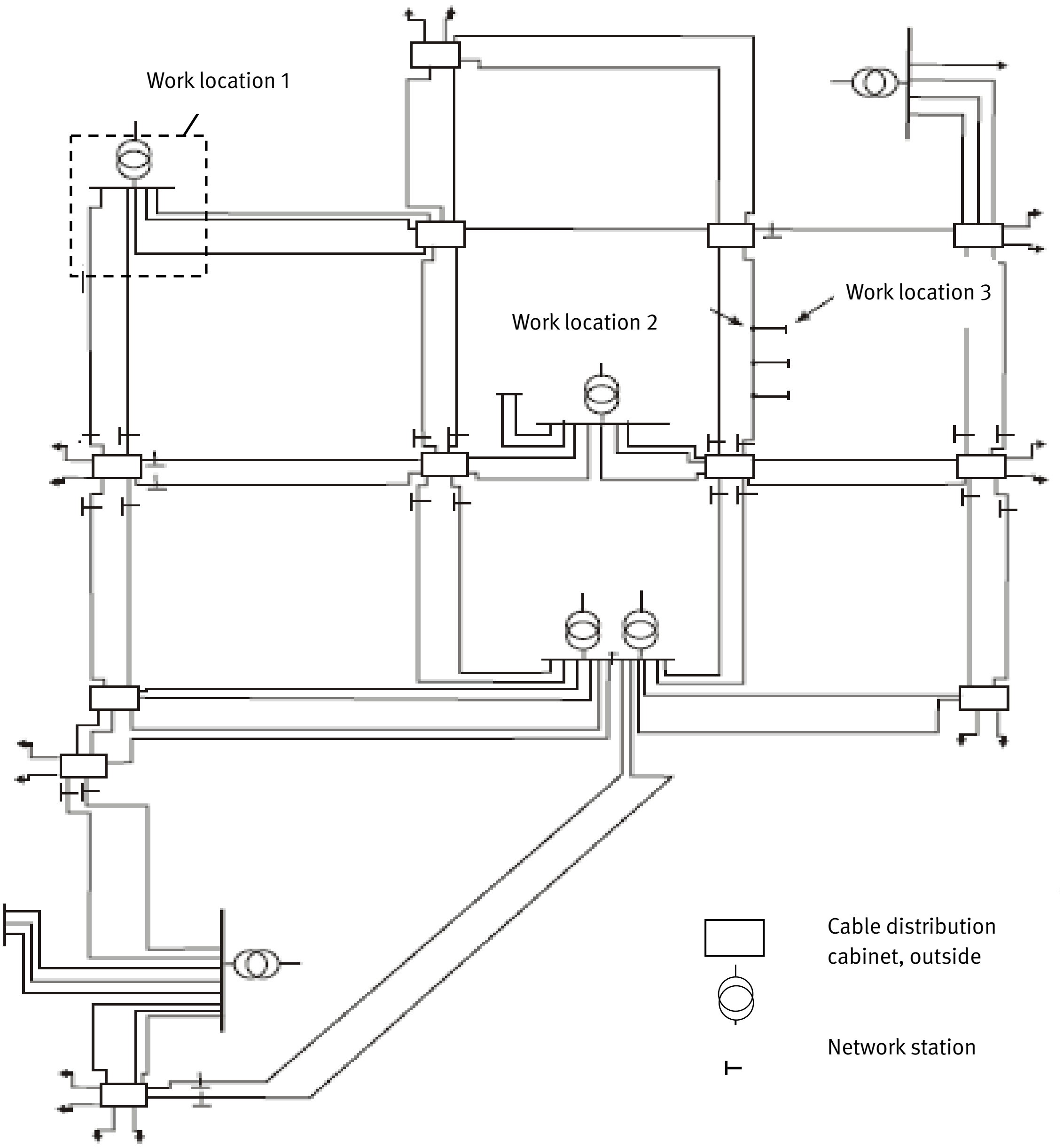


Fig. 7 Municipal low voltage supply system being considered

Step 1: Data for the workplace being considered
This example represents a municipal supply system (Fig. 8) where work location 1 is being considered. There are 20/0.4 kV transformers present at the network stations with rated capacities S_{rT} of 630 kVA or 400 kVA and short-circuit voltages u_K of 4 %. The standard 1-kV aluminium cable cross-sections are 150 mm^2 for the mains cables and 35 mm^2 for the house installation cables. The drawing in Fig. 7 depicts the network separation points, which can be opened during work on live components in order to establish a unilateral energy supply to the respective network areas in question. Work location 1 is supplied by a 630 kVA transformer over a 630 kVA NH (low voltage, high performance) transformer fuse with operating class gTr AC 400 V. The fuse current-time curve is depicted in Fig. 10.

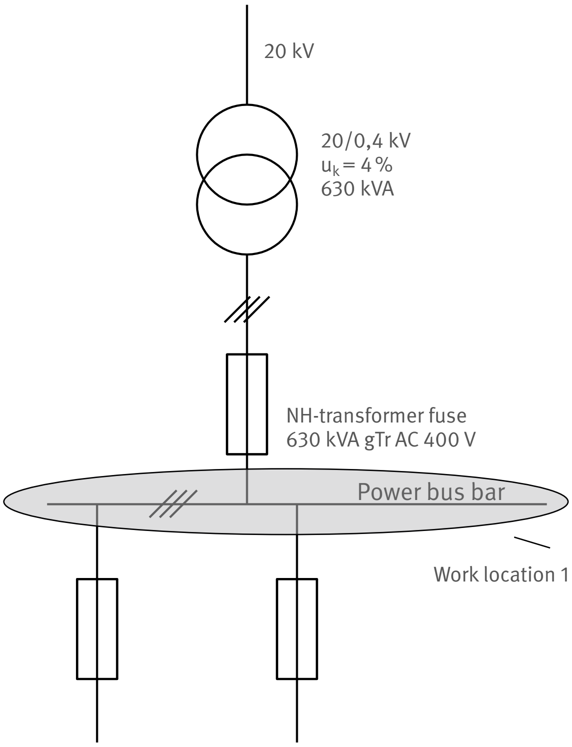


Fig. 9 Work location 1 equivalent circuit diagram

Step 2: Determination of I''_{k3}, R/X
Using the short-circuit current calculation according to VDE 0102 (Short-circuit currents in three-phase a.c. systems - Part 0: Calculation of currents), with a unilateral energy supply switching status for the work location results in a prospective short-circuit current (initial short-circuit alternating current) I''_{k3} of

I''_{k3max} = 23,1 kA (c = 1.05)
I''_{k3max} = 20,9 kA (c = 0.95)

The R/X ratio for network impedance in the fault circuit equates to 0.2.

Step 3: Determination of Electric arc current
The minimum fault current relevant for the NH fuse trip time with an electric arc short-circuit current results from the minimum prospective short-circuit current I''_{k3min} with the aid of limiting factor k_B, which characterizes the current-limiting effects of the electric arc in the fault circuit. Because a low voltage system and a worst-case examination are being dealt with in the initial ansatz, a current limiting factor of k_B = 0,5 will be assumed according to Section 3.3. For minimum fault current, it follows that

$$I_{kLB} = k_B \cdot I''_{k3min} = 0{,}5 \cdot 20{,}9 \text{ kA} = 10{,}45 \text{ kA}$$

The trip time for this current is taken from the protection characteristic curve in Fig. 10 is t = 0,1 s. This time equates to the short-circuit duration t_k.

NOTE:
In practice, the characteristic curve for the overcurrent protection device in use should be applied.

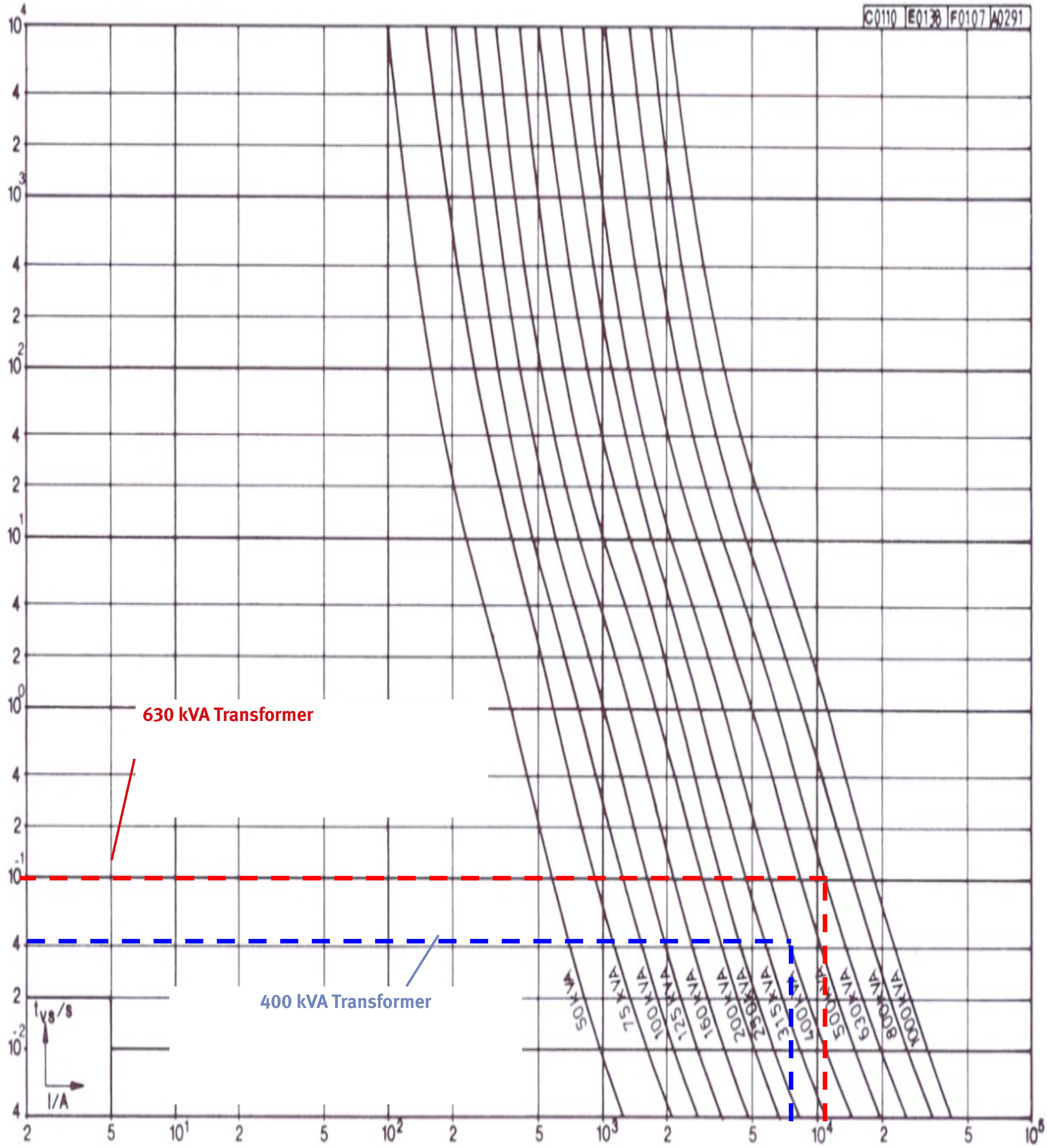


Fig. 10 Mean time/current characteristic curves for the fgTr AC 400 V fuse in use

Step 4: Electric arc power at the workplace
Using the maximum prospective short-circuit current I''_{k3max}, it follows for short-circuit power at the workplace that

$$S''_k = \sqrt{3} \cdot U_{Nn} = \sqrt{3} \cdot 400\,V \cdot 23{,}1\,kA = 16{,}004\,MVA$$

Under worst-case conditions, the maximum possible value for normalised arc power can be determined using the formula $k_{Pmax} = 0{,}29 / (R/X)^{0{,}17}$. This example results in the computation $k_{P,max} = 0{,}38$.

From this results an electric arc energy W_{LB}:

$$W_{LB} = k_P \cdot S''_k \cdot t_k = 0{,}38 \cdot 16{,}004\,MVA \cdot 0{,}1\,s = 608{,}2\,kJ$$

This energy is the anticipated value for electric arc energy at workplace 1 in the event of a fault.

Step 5: Establish the working distance
A working distance of $a = 300\,mm$ is used for work on low voltage distribution systems. This corresponds to the minimum distance between a person's torso and the frontal area of the opened equipment.

Step 6: Test level for the PPE
The test levels for PPE under standardised Box test conditions according to VDE 0682-306-1-2 are

Electric fault arc protection class 1: $W_{LB\,P1} = 158\,kJ$
Electric fault arc protection class 2: $W_{LB\,P2} = 318\,kJ$

Step 7: Transmission factor, equivalent arc energy
When working on low voltage distribution systems in transformer stations, it should be assumed that large-scale installations will be used with spatial limitations primarily due to a rear wall structure. A transmission factor of $k_T = 1{,}5$ is assumed at this location. Using a working distance of $a = 300\,mm$, it follows for equivalent arc energy that

$$W_{LBä} = k_T \cdot \left(\frac{a}{300\,mm}\right)^2 \cdot W_{LBP} = 1{,}5 \cdot \left(\frac{300\,mm}{300\,mm}\right)^2 \cdot W_{LBP}$$

$W_{LBä} = 237$ kJ for Electric fault arc protection class 1
$W_{LBä} = 477$ kJ for Electric fault arc protection class 2

Step 8: Selection of protection class
$W_{LB} = 608{,}2\,kJ > W_{LBä,Kl2} = 477\,kJ$ applies. Consequently, the system must be shutdown or measures must be taken according to Section 4.1 and a new calculation must be made.

Execution of the required work steps will yield the results below.

Step	Determination	Parameter	Result for worst-case examination	Result for precise calculation according to[5]
1	Network parameter: Nominal network voltage	U_{Nn}	400 V	400 V
	Equipment geometry: Distance between conductors	d	60 mm	60 mm
2	Short-circuit current calculation	I''_{k3pmax}	23,1 kA	23,1 kA
		I''_{k3pmin}	20,9 kA	20,9 kA
		R/X	0,2	0,2
3	Current limitation	k_B	0,5	0,633
	Minimum fault current	I_{kLB}	10,45 kA	13,23 kA
	NH fuse characteristic curve (Fig. 10)	t_k	0,1 s	0,045 s
4	Short-circuit power	S''_k	16 MVA	16 MVA
	Normalised arc power	k_P	0,38	0,338
	Electric arc power	P_{LB}	6,1 MW	5,4 MW
	Electric arc energy (anticipated value)	W_{LB}	608,2 kJ	243,4 kJ
5	Working distance	a	300 mm	300 mm
6	Standardised PPE test level	W_{LBPKl1}	158 kJ	158 kJ
		W_{LBPKl2}	318 kJ	318 kJ
7	Transmission factor: small-scale system	k_T	1,5	1,5
	Equivalent arc energy (protection level)	$W_{LbäKl1}$	237 kJ	237 kJ
		$W_{LbäKl2}$	477 kJ	477 kJ
8	Comparison: $W_{LB} \leq W_{LBä}$?	608,2 kJ > 477 kJ		243,4 kJ < 477 kJ
	PPE Electric fault arc protection class	**Take other measures or isolate**		**Class 2**

Table 1 Example summary: Work on the low voltage distribution system of a (630 kVA) transformer station; Work location 1

In the case of a station with a 400 kVA transformer (short-circuit voltage 4 %; NH fuse 400 kVA gTr AC 400 V), the prospective short-circuit current - under otherwise similar conditions as above - will fall within the range I''_{k3} = 12,7 to 14,1 kA.

The R/X ratio equates to 0,2. The characteristic curve for the NH fuse (Fig. 10) for k_B = 0,5 and I_{kLB} = 6,4 kA reveals a short-circuit duration of t_k = 0,045 s. Short-circuit power equates to S''_k= 9,769 MVA.

A normalised arc power of k_P = 0,38 results in an electric arc power of P_{LB} = 37 MW and an anticipated electric arc energy value of W_{LB} = 167,6 kJ. The same working distance a = 300 mm and the same transmission relationships (k_T = 1,5) as before means that PPE protection class 1 will be required.

5) Schau, H.; Halinka. A.; Winkler, W.: Elektrische Schutzeinrichtungen in Industrienetzen und -anlagen.

Step	Determination	Parameter	Result	Result for precise calculation according to[5]
1	Network parameter: Nominal network voltage	U_{Nn}	400 V	400 V
	Equipment geometry: Distance between conductors	d	60 mm	60 mm
2	Short-circuit current calculation	I''_{k3pmax}	14,1 kA	14,1 kA
		I''_{k3pmin}	12,7 kA	12,7 kA
		R/X	0,2	0,2
3	Current limitation	k_B	0,5	0,633
	Minimum fault current	I_{kLB}	6,4 kA	8 kA
	NH fuse characteristic curve (Fig. 10)	t_k	0,045 s	0,04 s
4	Short-circuit power	S''_k	9,8 MVA	9,8 MVA
	Normalised arc power	k_P	0,38	0,338
	Electric arc power	P_{LB}	3,7 MW	3,3 MW
	Electric arc energy (anticipated value)	W_{LB}	167,6 kJ	132,1 kJ
5	Working distance	a	300 mm	300 mm
6	Standardised PPE test level	W_{LBPKl1}	158 kJ	158 kJ
		W_{LBPKl2}	318 kJ	318 kJ
7	Transmission factor: small-scale system	k_T	1,5	1,5
	Equivalent arc energy (protection level)	$W_{LbäKl1}$	237 kJ	237 kJ
		$W_{LbäKl2}$	477 kJ	477 kJ
8	Comparison: $W_{LB} \leq W_{LBä}$?	167,6 kJ < 237 kJ		132,1 kJ < 237 kJ
	PPE Electric fault arc protection class	**Class 1**		**Class 1**

Table 2 Example summary: Work on the low voltage distribution system of a (400 kVA) transformer station; Work location 1

5) Schau, H.; Halinka. A.; Winkler, W.: Elektrische Schutzeinrichtungen in Industrienetzen und -anlagen.

4.2.2 Work location 2: Low voltage cabling

Work is frequently carried out on cable joints in the cable network (see Fig. 11). Work location 2 in this example (T-joint at the end of approx. 100 m network cabling) is depicted in Fig. 7. The level of fault current and electric arc energy is greatly dependent on the distance between the work location and the network supply station (transformer) and, for this reason, on the length of the corresponding network cable.

Fig. 11 Work on a cable sleeve

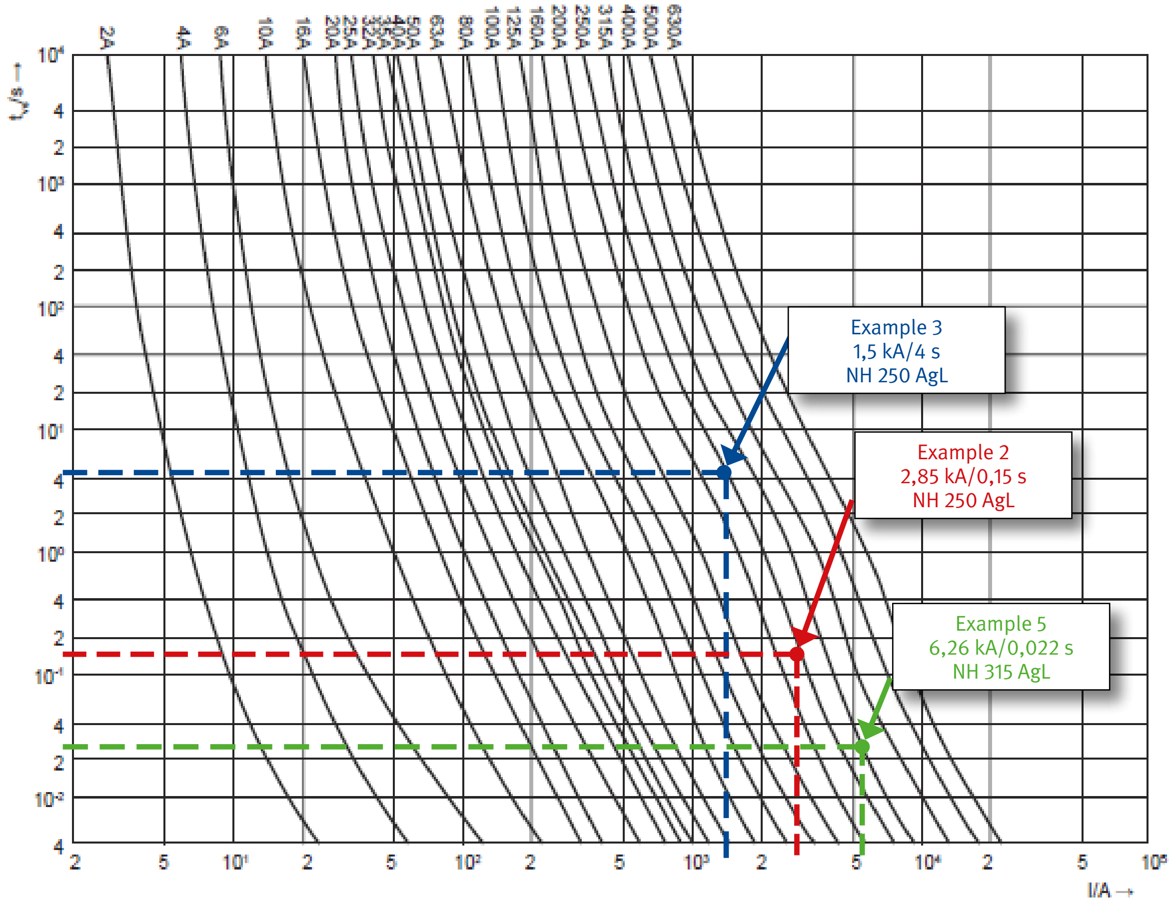


Fig. 12 Mean time/current characteristic curves for the NH gL/gG AC 400 V line fuse being considered

In this example, the work location is being fed through a network cable from a 630 kVA transformer station. The NH fuse in the supplying station's cable branch is decisive for breaking the electric fault arc. In this context, an NH 250 A full-range line fuse is used with operating class gG or gL AC 400 V. The characteristic curve is depicted in Fig. 12.

Execution of the required work steps will yield the results below.

Step	Determination	Parameter	Result	Result for precise calculation according to[5]
1	Network parameter: Nominal network voltage	U_{Nn}	400 V	400 V
	Equipment geometry: Distance between conductors	d	45 mm	45 mm
2	Short-circuit current calculation	I''_{k3pmax}	6,3 kA	6,3 kA
		I''_{k3pmin}	5,7 kA	5,7 kA
		R/X	1,0	1,0
3	Current limitation	k_B	0,5	0,59
	Minimum fault current	I_{kLB}	2,85 kA	4,25 kA
	NH fuse characteristic curve (Fig. 12)	t_k	0,15 s	0,09 s
4	Short-circuit power	S''_k	4,365 MVA	4,365 MVA
	Normalised arc power	k_P	0,29	0,24
	Electric arc power	P_{LB}	1,266 MW	1,047 MW
	Electric arc energy (anticipated value)	W_{LB}	189,9 kJ	94,2 kJ
5	Working distance	a	300 mm	300 mm
6	Standardised PPE test level	W_{LBPKl1}	158 kJ	158 kJ
		W_{LBPKl2}	318 kJ	318 kJ
7	Transmission factor: large-scale system	k_T	1,9	1,9
	Equivalent arc energy (protection level)	$W_{LbäKl1}$	300 kJ	300 kJ
		$W_{LbäKl2}$	604,2 kJ	604,2 kJ
8	Comparison: $W_{LB} \leq W_{LBä}$?	189,9 kJ < 300 kJ		94,2 kJ < 300 kJ
	PPE Electric fault arc protection class	**Class 1**		**Class 1**

Table 3 Example summary: Work on a cable network joint; Work location 2

The work being performed at Work location 2 (cable sleeves) under consideration requires PPE in the Electric fault arc protection class 1 according to the appraisal in Section 3 and with precise calculations.

5) Schau, H.; Halinka. A.; Winkler, W.: Elektrische Schutzeinrichtungen in Industrienetzen und -anlagen.

4.2.3 Work location 3: House junction box

The replacement of a house junction box is often associated with work on live equipment (Fig. 13 (inside/outside)). Such an example in Work location 3 is considered in Fig. 7. Energy is once again supplied to the work location from an upstream network station with a 630 kVA transformer. In contrast to Example 2, the short-circuit current is significantly less because the house connection cables have only comparatively small cross-sections. The house connection cable in the example has a length of approx. 15 m.

The branch fuse in the upstream cable distribution cabinet is decisive for breaking the short-circuit; in this case, an NH 250 A fuse is used with operating class gG AC 400 V.

Fig. 13 Work on a house junction box

Execution of the required work steps will yield the results below.

Step	Determination	Parameter	Result	Result for precise calculation according to[5]
1	Network parameter: Nominal network voltage	U_{Nn}	400 V	400 V
	Equipment geometry: Distance between conductors	d	45 mm	45 mm
2	Short-circuit current calculation	I''_{k3pmax}	6,3 kA	6,3 kA
		I''_{k3pmin}	5,7 kA	5,7 kA
		R/X	1,0	1,0
3	Current limitation	k_B	0,5	0,59
	Minimum fault current	I_{kLB}	2,85 kA	4,25 kA
	NH 250 A fuse characteristic curve (Fig. 12): t_k = 2,5 s*	t_k	0,15 s	0,09 s
4	Short-circuit power	S''_k	4,365 MVA	4,365 MVA
	Normalised arc power	k_P	0,29	0,24
	Electric arc power	P_{LB}	1,266 MW	1,047 MW
	Electric arc energy (anticipated value)	W_{LB}	189,9 kJ	94,2 kJ
5	Working distance	a	300 mm	300 mm
6	Standardised PPE test level	W_{LBPKl1}	158 kJ	158 kJ
		W_{LBPKl2}	318 kJ	318 kJ
7	Transmission factor: small-scale system	k_T	1,9	1,9
	Equivalent arc energy (protection level)	$W_{LbäKl1}$	300 kJ	300 kJ
		$W_{LbäKl2}$	604,2 kJ	604,2 kJ
8	Comparison: $W_{LB} \leq W_{LBä}$?	189,9 kJ < 300 kJ		94,2 kJ < 300 kJ
	PPE Electric fault arc protection class	**Take other measures or isolate**		

Table 4 Example summary: Work on a opened house junction box; Work location 3

Referencing the characteristic curve (Fig. 12), a trip time of t > 1 s results, so that it can be assumed that the maximum time relevant to the exposure equates to t_k = 1 s. (also refer to the note at the end of Section 3.3).

5) Schau, H.; Halinka. A.; Winkler, W.: Elektrische Schutzeinrichtungen in Industrienetzen und -anlagen.

It can be seen from the results in the example that PPE in the Electric fault arc protection class 2 is **not adequate** for work on a house junction box. The high anticipated value of electric arc energy is brought about by a long short-circuit duration, from which a long exposure duration emerges.

In order to facilitate work in this case,

- protection devices guaranteeing defined and sufficiently rapid breaking characteristics must be used or
- compliance with an adequate minimum distance must be required or
- PPE tested for greater Incident energy levels must be used.

The option mentioned at first will be singled out for consideration below. For this, it must be ensured that the NH 250 A gG branch fuse present in the network supply station's cable branch is replaced with a safe-work fuse with a low rated current and/or with fast-acting or super-fast-acting operating characteristics for the duration of the work task. This means that prior to beginning and subsequent to completing the work task a fuse replacement will be necessary. If an NH 160 A safe-work fuse is used with an operating class aR (fast-acting: üf2, very-fast-acting: üf1, super-fast-acting: üf01, hyper-fast-acting: üf02) is used, a current-limiting break will occur in any case. Regarding the calculations in this context, a short-circuit duration of t_k = 0,01 s is to be applied.

An NH 160 A aR/690 V - üf01 fuse is used for this example, whereby a trip time of 6.87 ms results.

The performance of work tasks using PPE in the Electric fault arc protection class 1 is now made possible through the use of the safe-work fuse.

The use of this fuse will yield the following results:

Step	Determination	Parameter	Result	Result for precise calculation according to[5]
1	Network parameter: Nominal network voltage	U_{Nn}	400 V	400 V
	Equipment geometry: Distance between conductors	d	45 mm	45 mm
2	Short-circuit current calculation	I''_{k3pmax}	3,4 kA	3,4 kA
		I''_{k3pmin}	3,0 kA	3,0 kA
		R/X	2,0	2,0
3	Current limitation	k_B	0,5	0,554
	Minimum fault current	I_{kLB}	1,5 kA	1,66 kA
	NH fuse characteristic curve (Fig. 12)	t_k	0,01 s	0,01 s
4	Short-circuit power	S''_k	2,353 MVA	2,353 MVA
	Normalised arc power	k_P	0,26	0,222
	Electric arc power	P_{LB}	0,61 MW	0,5 MW
	Electric arc energy (anticipated value)	W_{LB}	6,1 kJ	5,2 kJ
5	Working distance	a	300 mm	300 mm
6	Standardised PPE test level	W_{LBPKl1}	158 kJ	158 kJ
		W_{LBPKl2}	318 kJ	318 kJ
7	Transmission factor: small-scale system	k_T	1	1
	Equivalent arc energy (protection level)	$W_{LbäKl1}$	158 kJ	158 kJ
		$W_{LbäKl2}$	318 kJ	318 kJ
8	Comparison: $W_{LB} \leq W_{LBä}$?	6,1 kJ < 158 kJ		5,2 kJ < 158 kJ
	PPE Electric fault arc protection class	**Class 1**		

Table 5 Example summary: Work on an opened house junction box while using a safe-work fuse; Work location 3

5) Schau, H.; Halinka. A.; Winkler, W.: Elektrische Schutzeinrichtungen in Industrienetzen und -anlagen.

4.2.4 Work location 4: Electrical installation behind a house junction box

As a rule, when working on live equipment or in the vicinity of live components in the house electrical installation, basic protection, meaning PPE in the Electric fault arc protection class 1, is sufficient. The following example depicts the calculation for a typical configuration behind an NH 63 A gL fuse.

Fig. 14 Work behind the house supply systemx

Step	Determination	Parameter	Result	Result for precise calculation according to[5]
1	Network parameter: Nominal network voltage	U_{Nn}	400 V	400 V
	Equipment geometry: Distance between conductors	d	25 mm	25 mm
2	Short-circuit current calculation	I''_{k3pmax}	3,4 kA	3,4 kA
		I''_{k3pmin}	3,0 kA	3,0 kA
		R/X	2,0	2,0
3	Current limitation	k_B	0,5	0,554
	Minimum fault current	I_{kLB}	1,5 kA	1,66 kA
	NH 63 AgLfuse characteristic curve (Fig. 12)	t_k	0,04 s	0,04 s
4	Short-circuit power	S''_k	2,353 MVA	2,353 MVA
	Normalised arc power	k_P	0,26	0,25
	Electric arc power	P_{LB}	0,61 MW	0,56 MW
	Electric arc energy (anticipated value)	W_{LB}	24,5 kJ	22,6 kJ
5	Working distance	a	300 mm	300 mm
6	Standardised PPE test level	W_{LBPKl1}	158 kJ	158 kJ
		W_{LBPKl2}	318 kJ	318 kJ
7	Transmission factor: small-scale system	k_T	1	1
	Equivalent arc energy (protection level)	$W_{LbäKl1}$	158 kJ	158 kJ
		$W_{LbäKl2}$	318 kJ	318 kJ
8	Comparison: $W_{LB} \leq W_{LBä}$?	24,5 kJ < 158 kJ		22,6 kJ < 158 kJ
	PPE Electric fault arc protection class	**Class 1**		

Table 6 Example summary: Work on an electrical installation behind a house junction box; Work location 4

5) Schau, H.; Halinka. A.; Winkler, W.: Elektrische Schutzeinrichtungen in Industrienetzen und -anlagen.

4.2.5 Work location 5: Low voltage distribution system for industry

The following example depicts the calculation for a typical configuration behind an NH 315 A gG fuse. Various tasks are carried out behind the NH fuse on the installation in this example. This ranges from simple adjustments on protection devices and equipment to replacement of the equipment itself.

The work location is on the electrotechnical equipment for a cooling unit.

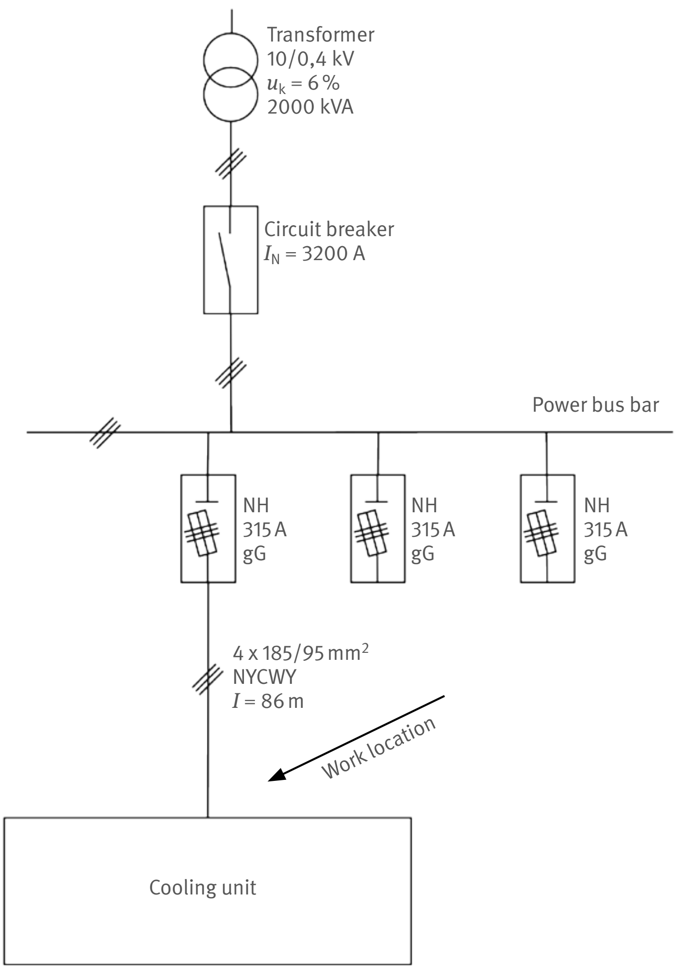


Fig. 15 Industrial plant system overview

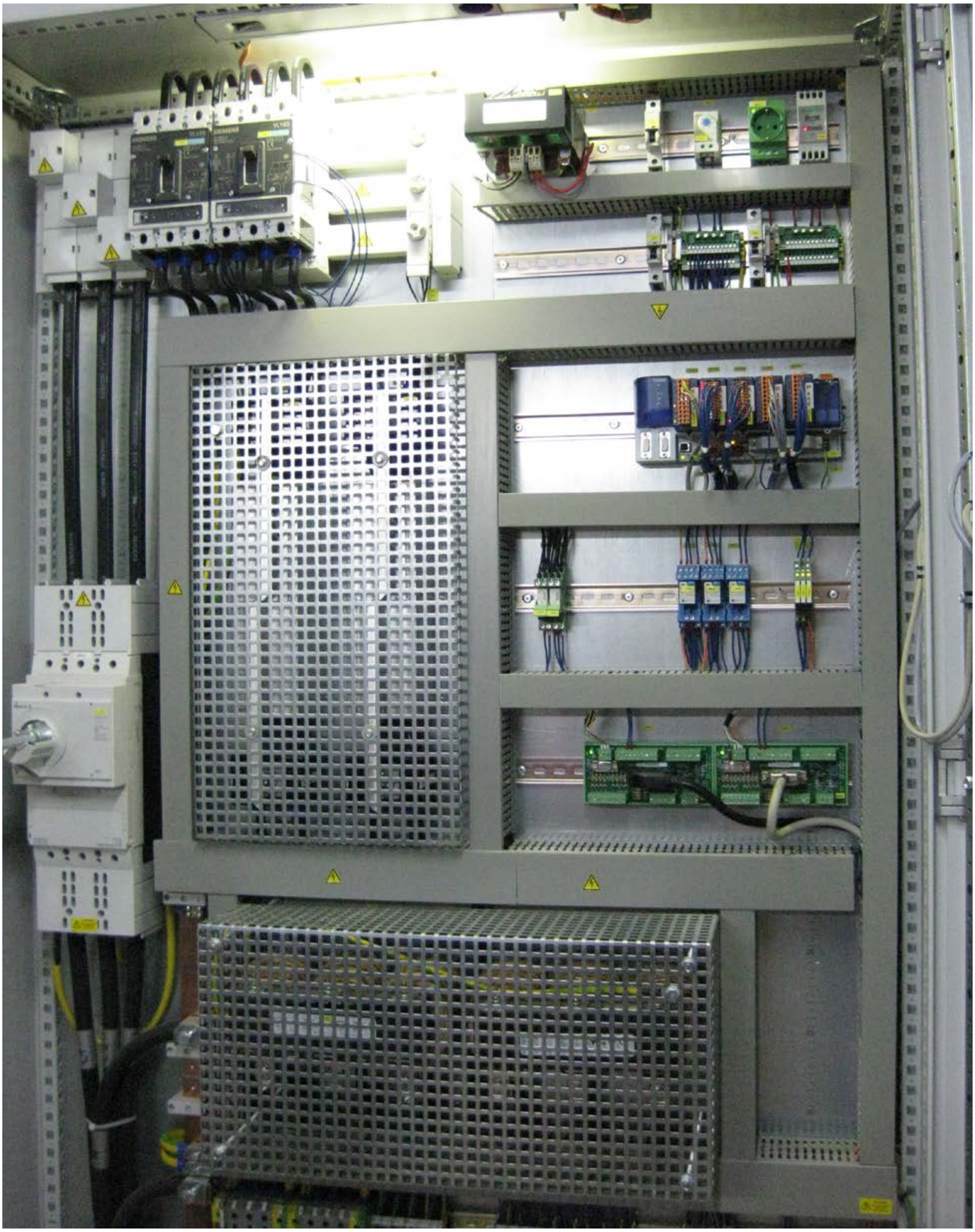


Fig. 16 Work on an industrial low voltage system (cooling unit control cabinet)

Step	Determination	Parameter	Result	Result for precise calculation according to[5]
1	Network parameter: Nominal network voltage	U_{Nn}	400 V	400 V
	Equipment geometry: Distance between conductors	d	20 mm	20 mm
2	Short-circuit current calculation	I''_{k3pmax}	15,34 kA	15,34 kA
		I''_{k3pmin}	12,52 kA	12,52 kA
		R/X	0,87	0,87
3	Current limitation	k_{B}	0,5	0,731
	Minimum fault current	I_{kLB}	6,26 kA	9,15 kA
	NH fuse characteristic curve (Fig. 12)	t_{k}	0,022 s	0,001 s
4	Short-circuit power	S''_{k}	10,63 MVA	10,63 MVA
	Normalised arc power	k_{P}	0,297	0,149
	Electric arc power	P_{LB}	3,16 MW	1,59 MW
	Electric arc energy (anticipated value)	W_{LB}	69,43 kJ	15,86 kJ
5	Working distance	a	300 mm	300 mm
6	Standardised PPE test level	W_{LBPKl1}	158 kJ	158 kJ
		W_{LBPKl2}	318 kJ	318 kJ
7	Transmission factor: small-scale system	k_{T}	1,5	1,5
	Equivalent arc energy (protection level)	$W_{\mathrm{Lb\ddot{a}Kl1}}$	237 kJ	237 kJ
		$W_{\mathrm{Lb\ddot{a}Kl2}}$	477 kJ	477 kJ
8	Comparison: $W_{\mathrm{LB}} \leq W_{\mathrm{LB\ddot{a}}}$?	69,43 kJ < 158 kJ		15,86 kJ < 158 kJ
	PPE Electric fault arc protection class	**Class 1**		

Table 7 Example summary: Work on an industrial low voltage system

As a rule, when working on live equipment or in the vicinity of live components in an Industrial plant electrical installation, basic protection, meaning PPE in the Electric fault arc protection class 1, is sufficient.

5) Schau, H.; Halinka. A.; Winkler, W.: Elektrische Schutzeinrichtungen in Industrienetzen und -anlagen.

4.3 Examples of work locations for determining transmission factor k_T

Fig. 17 Work on a house junction box: $k_T = 1{,}0$

Fig. 18 Replacement of a fuse panel in a control cabinet (close to the side wall): $k_T = 1{,}0$

Fig. 19 Work on a cable distribution cabinet: $k_T = 1{,}5$

Fig. 20 Work on a compact station: $k_T = 1{,}7$

Fig. 22 Work on an electricity pole: $k_T = 2{,}4$

Abb. 21 Muffenmontage: $k_T = 1{,}9$

Annex 1
Directives, regulations, literature

Below are listed the following sources:

1. Directives

Available from:
Bundesanzeiger Verlagsgesellschaft mbH,
Postfach 10 05 34
50445 Köln

Directives 89/686/EEC: Council Directive on the approximation of the laws of the Member States relating to personal protective equipment.

2. Regulations

Available from:
Your responsible accident insurance institution
or from www.dguv.de/publikationen.

Accident prevention regulations for "Electrical equipment and operating equipment" (BGV/GUV-V A3).

3. Standards/VDE provision

Available from:
Beuth-Verlag GmbH,
Burggrafenstraße 6, 10787 Berlin
or
VDE-Verlag,
Bismarckstraße 33, 10625 Berlin

DIN EN ISO 14116: Protective clothing - Protection against heat and flame - Limited flame spread materials, material assemblies and clothing (2008-08).

prENV 50354: Electrical arc test methods for material and garments, for use by workers at risk from exposure to an electrical arc (2000).

DIN EN 60909/VDE 0102: Short-circuit currents in three-phase a.c. systems - Part 0: Calculation of currents (2002-07).

DIN EN 61482-1-1/VDE 0682-306-1-1: Live working - Protective clothing against the thermal hazards of an electric arc - Part 1-1: Test methods - Method 1: Determination of the arc rating (ATPV or EBT50) of flame resistant materials for clothing (2010-03).

DIN EN 61482-1-2/VDE 0682-306-1-2: Live working - Protective clothing against the thermal hazards of an electric arc - Part 1-2: Test methods - Method 2: Determination of arc protection class of material and clothing by using a constrained and directed arc (Box test) (2007-12).

IEC 61482-2: Live working - Protective clothing against the thermal hazards of an electric arc - Part 2: Requirements (2009-04).

DIN EN 60903/VDE 0682-311: Live working - Electric insulating gloves (2004-07).

NFPA 70e: Standard for Electrical Safety in the Workplace (2009).

IEEE 1584: Guide for performing arc-flash hazard calculations (2002).

ASTM F2178-08: Standard Test Method for Determining the Arc Rating and Standard Specification for Face Protective Products.

Work Item ASTM/WK 14928: New Test Method for Test Method for Determining the Arc Rating of Gloves 1.

4. Literature

Schau, H.; Halinka. A.; Winkler, W.: Elektrische Schutzeinrichtungen in Industrienetzen und –anlagen Hüthig & Pflaum Verlag Munich/Heidelberg 2008.

GS-ET-29, Supplemental requirements for the testing and certification of electrician face shields, status as of 2010-02, Expert committee for electrical engineering testing and certification facility in DGUV Test, www.bgetem.de/pruefstelle-et/pruefgrundsaetze.

Strasse, U., Erfahrungen beim Einsatz von Arbeitssicherungen beim AuS im Kabelnetz von Vattenfall Europe Berlin; ETG Fachbericht Fachbereich 106 Arbeiten unter Spannung (AuS), Presentation for the ETG-Technical Meeting in Dresden from 19 to 20 September 2007.

Rotter, G., Bähnsch, R., Lichtbogenschutz-System DEHNarc – Geräte-System und Anwendung in der Praxis, 15th BG ETEM Electrical Engineering Technical Meeting in Kassel, 2010.

Machbarkeitsuntersuchung zur Prüfung und Bewertung von Schutzhandschuhen gegen thermische Gefahren von Störlichtbögen (Feasibility Study by AG: BGFE; AN: STFI/TU Ilmenau), STFI final report from 30 May 2005.

IVSS Guideline for the selection of personal protective equipment when exposed to the thermal effects of an electric fault arc; 2nd edition 2011.

Annex 2

Standardisation of PPE against the thermal effects of electric fault arcing

A 2.1 Standards for protective clothing in Europe

The testing of PPE in Europe with respect to electric fault arcing is a comparatively young field. Contrary to testing the effectiveness of protective clothing and head, face or hand protection against a variety of other risks, the detailed investigation into the options for protecting against the thermal effects of an electric fault arc first began in the 1990s.

Fig. 23 Test setup, Box test method

The standardisation process began with the initial desire to be able to safely and reproducibly test and evaluate that particular clothing used to protect against the effects of an electric fault arc. To this end, testing was begun in two classes based on the prENV 50354 draft standard existing at the time as to the protection provided by textile fabrics and products. This method already employed a box with one side open for generating a directed electric arc exposure at the textile fabric or product specimens positioned at a distance of 300 mm. This draft already defined the use of aluminium and copper electrodes, as well, in order to be as consistent as possible with real conditions.

Assessment criteria was comprised of:

- no specimen afterflame time > 5 s,
- no hole formation > 5 mm,
- no melting through to the inside,
- functionality of the garment closure system following exposure.

The method's greatest disadvantage, however, was its lack of goal orientation towards making a definitive statement as to the actual protective properties of PPE against the thermal effects of electric fault arcing. The method's intent was merely to confirm that, when tested clothing is in use used when a fault occurs, no clothing-related injurious effects (e. g. due to burnt clothing) are to be expected by the wearer. To that effect, the possibility for evaluating the risk of skin burn, as could be experienced if protective clothing with inadequate thermal insulation were used, was not included either.

These safety-relevant gaps in the testing and evaluation of protective clothing against the thermal hazards associated with electric fault arcing were subsequently closed, however, with the drafting of the internationally harmonised standard VDE 0682-306-1-2. Consistent with the advancement of the idea of directed electric arc testing by means of a test box opened only in the direction of the specimen, this standard comprises the testing of fabrics and garments over two protection classes distinguished by respective levels of electric arc energy and incident energy.

The table below provides an overview of the relevant parameters for each test category:

Test category	Mean value of electric arc energy W_{arc} [kJ]	Mean value of incident energy E_{io} [kJ/m²]	Test current [kA]	Arc time [ms]
Class 1	158	135	4	500
Class 2	318	423	7	500

Table 8 Box test method parameters

The basic philosophy of this methodology consists of objective testing and evaluation of the protection against electric fault arcs afforded by highly flame-resistant materials or material combinations, as well as testing of the protective properties of finished products. Both the fabrics specimens and garments are positioned at a distance of 300 mm to the electric arc axis, which corresponds to a conceivable working distance under realistic working conditions. The electric arc axis is defined by the two vertical electrodes positioned at a distance of 30 mm to each other. The electrode material is comprised of aluminium (upper) and copper (lower) in order to replicate system conditions as closely as possible in practice. The desired focusing of the extreme thermal effects associated with electric arc exposure is created with the parabolic form of the test box, which surrounds the electrode array on three sides. The upper and lower sections of the plaster box construction are sealed by means of insulating boards. In accordance with the testing current used for the respective test category, an arc flash is ignited in a 400 V AC test circuit and extinguished after a combustion duration of 500 ms.

A test plate with two integrated calorimeters for measuring transmitted incident energy is used to mount the textile specimens. This enables measurement of the heat transfer to the skin surface (rear side of sample) and, in so doing, allows for conclusions to be drawn as to the risk of second degree burning in comparison to the limit values associated with the Stoll/Chianta criteria. In addition, a visual assessment is made of each specimen based on afterflame time, hole formation and melting through to the inside.

Garments, such as jackets, overcoats, parkas, etc., are tested on a standardised mannequin. Besides the visual assessment criteria analogous to a surface inspection, an additional functional test is performed on the garment's closure system. This is required because only a functioning closure system enables the fastest possible removal of garments following an electric arc accident. Moreover, testing the finished product also serves as a test of other accessories, such as reflective strips, logos or emblems, with respect to their resistance to electric arcing.

This testing standard has been well-established for years and serves as the certification basis for numerous clothing articles used for protection against electric arcing within the territory covered by Europe's mandatory Directive 89/686/EEC relating to personal protective equipment.

A 2.2 Standards for protective clothing outside the EU

Outside Europe, evaluation of electric fault arc protection is based primarily on one other test method. Determination of the ATPV (Arc Thermal Performance Value) arc rating according to IEC 61482-1-1 dominates the field. This methodology, also published as VDE 0682-306-1-1, calls for a medium voltage source and is based on three circularly arranged material specimens (120 ° offset) being exposed to an open, non-directional arc flash. The textile specimens are affixed to panels, on which two calorimeters are installed for measuring transmitted incident energy. In addition, each panel is outfitted with two unprotected calorimeters mounted on the left and right sides of the specimen, which simultaneously register the direct incident energy. The centre of the circle is formed by 2 stainless steel electrodes at a distance of 300 mm to each panel (electrode gap 300 mm).

As opposed to the Box test method, VDE 0682-306-1-1 does not specify defined classes of protection. The method determines variations in the arc duration from at least 20 individual values as well as a mathematical regression algorithm for each highly flame-resistant material for the respective arc rating (ATPV or EBT50). At the same time, the rating represents an energy impacting the material, which, with 50 % probability, will not lead to second-degree skin burns (ATPV) or to a breaking up of the material down to the skin surface (EBT50).

Assessment criteria for each individual test sample are:

- Hole formation/breaking up of the material in all positions,
- Heat transfer exceeding the limit values for skin burn (Stoll curve).

After determining the rating for the material, product durability is tested using the same arc duration and mannequin mounting instead of panel mounting.

In order to make a decision appropriate for the ATPV arc rating regarding the use of the clothing, the user of this method must be able to safely and successfully apply the results of a hazard or risk assessment, such as described in NFPA 70e or IEEE 1584. Otherwise, the rated value will not suffice for making a selection recommendation for work on or in the vicinity of electrical equipment. Similarly, there are no sure options to date for assessing the comparability between the ATPV value and the primary method used in Europe for testing and certifying protective clothing according to VDE 0682-306-1-2.

A 2.3 Standards for other types of PPE

As opposed to protective clothing, there are neither precise internationally harmonised requirements nor testing or evaluation standards that address other means of effective bodily protection against electric fault arcing, such as face shields or gloves. Yet, a high burn risk still exists in the event of a fault, emphasizing all the more the necessity for appropriate personal protection. For this reason, efforts are being made to implement relevant procedures at both the national and the international levels.

The common element among these efforts is that they are based, to the greatest extent possible, on existing international standards for protective clothing. A largely complete selection of protective equipment is available to the user today, whose electric fault arc protection properties have been tested and evaluated to the same basic principles.

A.2.3.1 Standards for Europe

Electrician face shields are covered by the most comprehensive testing and evaluation procedures to date in the GS-ET-29 Principles of testing by the Electrical engineering testing and certification facility ETEM in DGUV Test. It defines supplemental requirements for the testing and certification of **face shields for electrical work** and has been in use since 2009 for all approved products in the Federal Republic of Germany.

The Principles of testing use directed exposure with the Box test method analogous to that of VDE 0682-306-1-2 in both test categories for evaluation of thermal protection with respect to the effects of an electric fault arc. In contrast to the test of clothing, however, one test head outfitted with four calorimeters is used for positioning test specimens (e. g. a helmet in combination with visor). This is centred opposite to the electric arc axis, so that the central calorimeter is located at a distance of 350 mm from the nose area. The vertical position of this calorimeter is also centred at the middle of the electric arc axis. This guarantees the central impact of the electric arc energy being at the centre of the visor while simultaneously measuring the transmitted incident energy at different positions around the head. Besides the calorimeter in the area of the nose, the test head is also outfitted with two additional calorimeters in the areas of the eyes and the chin. A 500 mm high and 600 mm wide torso plate is used to simulate the area of a human's upper body. By measuring the incident energy with calorimeters, an objective conclusion can be drawn as to the risk of facial skin burn associated with a frontal exposure, as well as with the suppression of flame and gas clouds. Electric arc testing of the face shield is considered to have been passed when four of the test specimens demonstrate an afterflame time ≤ 5 s, no melting through of the test objects and no appearance of hole formation. At the same time, the value pairs of all test head calorimeters must lie below the limit values according to the Stoll/Chianta criteria for the risk of skin burn. By testing electrician face shields in this manner, the user can assume to be in possession of a product proven to the current state of technology.

At the international level, the existing standard IEC 60903 for electrically insulating protective gloves, currently under revision, is being considered for expansion to include the testing and evaluation of resistance to electric arcing and related protection afforded by **gloves**. It uses the basic system conditions for directed exposure with the Box test method according to VDE 0682-306-1-2 while using specimen holders designed especially for gloves. Two side-by-side configured panels, each of which being outfitted with horizontally and vertically oriented calorimeters centred at the middle of the electric arc axis, enable testing of complete gloves. In addition to testing programs for Classes 1 and 2 related to clothing, a program for Class 3 is also possible. It serves the evaluation of products exposed to significantly higher direct incident energy (760 kJ/m²), which appears justifiable for gloves, if only because of their anticipated close proximity to a potential fault source. The additional class ratting is achieved by reducing the distance between the specimen and the electric arc by 50 % (150 instead of 300 mm) while using the respective Class 1 electric arc energy (158 kJ). This application is not limited to electrically insulating protective gloves but, for this reason, can also provide important safety-related information about other glove types, such as those made of leather. Procedures call for the testing of at least four gloves, none of which may exhibit an afterflame time > 5 s, hole formation, melting through to the inside or material shrinkage > 5 %, nor may they exceed the limit values for skin burn corresponding to Stoll/Chianta criteria. Under these conditions, the user can assume the protective gloves have been tested and evaluated according to latest and best knowledge available.

A.2.3.2 Standards outside the EU

Testing and evaluation options are also available for clothing articles used as supplemental protective equipment, which have been tested according to the ATPV arc rating described in IEC 61482-1-1.

Head and face protection can be tested according to the ASTM F2178-08 standard, which was published only in the USA. This methodology uses systems engineering for determining the ATPV for textiles, whereby the test specimens, including helmet and visor, are affixed to a head outfitted with four calorimeters. This is then attached to a mannequin, similar to those used for durability testing for clothing. The central calorimeter is horizontally and vertically centred opposite the electric arc axis in the facial area of the head, analogous to the Box test method. Direct incident energy and transmitted incident energy are determined for each test cycle by means of unprotected calorimeters positioned on the sides of the head, allowing for an incremental calculation of the ATPV arc rating.

A U.S. draft standard[6] for **gloves** is under discussion, whereby systems engineering for clothing would be used to enable a determination of the ATPV arc rating for protective gloves. For this purpose, a ring-shaped structure with a quarter-circle opening has been designed on which four panels are located for affixing the test specimen. Each glove panel is outfitted with a calorimeter, whose alignment is horizontally and vertically centred at the middle of the electric arc axis and is used for measuring the transmitted incident energy. Two each unprotected calorimeters arranged on the sides of the panels serve to determine direct incident energy for each individual test cycle, as is done with textile testing. Determination of the ATPV arc rating then takes place analogous to the methodology already described.

Nevertheless, the same restrictions apply to the ATPV arc rating determined for face shields or gloves as for clothing. Its use requires experience in the application of U.S. directives related to the assessment of electric fault arc risks at the workplace.

A 2.4 Specification standards for product approval and selection

Garments used for protection against electric arcing are high-tech textile products, often offering multifunctional protection. For this reason, the execution of a suitable electric fault arc durability test when selecting such clothing is not only sufficient in itself. Much more, it must be recognised and kept in mind that not one of the methods described to date is capable of reproducing the demands to which such PPE would be subjected.

All of the standards mentioned to this point are merely test standards, which may confirm the most essential, but still not all characteristics related to safe clothing. In an emergency situation, for example, an inner lining made of non-flame-resistant material or a seam made of 100 % polyester thread can cause significant serious injury to the wearer. Likewise, when too little current flow resistance is present, such as when surface conducting fibres are used to enhance clothing electrostatic dissipation capabilities, the protection against contact with live parts under certain circumstances may be lacking and further secondary hazards may ensue.

Moreover, the classic textile requirements, such as dimensional stability when washing, maximum firmness and resistance to tear propagation, are, of course, not only quality-relevant to the user, but safety-relevant as well. Ultimately, only the use of suitable and appropriately tested accessories, such as flame-resistant reflective strips, logos or emblems, will avoid negatively influencing a clothing article's protective function. In order to achieve a degree of safety for the potential clothing user, both the manufacturer and the responsible certification body must have considered these risks and, by requiring suitable materials and appropriate design, eliminated them to the greatest extent possible.

The international standard, IEC 61482-2, is presently regarded to be the best method for comprehensively testing and evaluating clothing used for protection against electric arcing. Even though a presumption of conformity to the PPE Directive 89/686/EEC does not exist yet for this standard, it provides the most extensive assessment options at the present time.

6) Work Item ASTM WK14928 - New Test Method for Test Method for Determining the Arc Rating of Gloves 1.

An essential component of this product standard is the verification of electric fault arc protection properties through use of textile materials, as could be provided for according to VDE 0682-306-1-2. A decisive basic requirement is the exclusive use of flame-resistant raw materials (Index 3 according to DIN EN ISO 14116) for the outer and, if applicable, for the inner clothing layers. Typical demands for protective clothing placed on dimensional stability and mechanical wear durability, as well as on minimum requirements for maximum tensile strength and tear propagation resistance, supplement the material-specific requirement profile.

IEC 61482-2 also regulates important safety-relevant requirements related to the clothing design itself. The subject of different protection classes for the front and back sides, perhaps selected for wear comfort, is also clearly regulated along with the exclusive use of flame-resistant sewing thread for all main seams. If special design requirements have been considered in addition to the standard, such as sealable pockets to protect against extensive molten metal splatter in case of fault, the user is assured of comprehensively tested and proved clothing to protect against the thermal risks of an electric arc accident. This also applies for the respective trousers or overalls as part of a complete protective suit. Even though none of the methods presented provides for the testing of products as assembled parts, the certification body will subject these products to an intensive assessment as to their protective properties. For this, the use of identical raw materials for pants and jackets, as well as the implementation of the design stipulations adopted in IEC 61482-2 will be decisive. If, in the results of a risk assessment, the use of a complete protective suit or overalls has been dispensed with, then the acceptability of pants selected separately from the arc rated jacket must be tested by the user himself. In order to avoid related uncertainties and perhaps risks, as the case may be, it is recommended to choose a complete suit made up of a jacket and pants.

A European-wide, uniform methodology for the approval of clothing used for protection against electric arcing can not yet be expected because of the still outstanding, partial or complete conveyance of IEC 61482-2 into a generally compulsory harmonised EN standard (meaning an EN standard with presumption of conformity to the PPE directives), as well as the different potential experience levels of the certifying bodies. For this reason, employers should ensure that the requirements of this product standard have been taken into account and implemented into the product, accordingly, through an inspection of the certificate (EC type examination certificate), a thorough examination of the clothing, as well as a direct enquiry by the manufacturer or dealer.

Annex 3
Parameters and risk analysis of thermal hazards to persons related to electric arcing

A 3.1 Energy parameters for thermal hazards to persons related to electric arcing

The electrical energy fed into an electric fault arc is almost completely converted therein and emitted or released back in various forms. The impact of electric fault arcing is, for this reason, determined primarily by the electric arc energy W_{LB}. Electric arc energy clearly identifies the relationships associated with system short-circuit-related arcing. Different network and system conditions will result in different electric arc energies.

The significant level of exposure or risk a person is subjected to due to the direct thermal impact of an electric arc is the energy density impacting the exposed surface of the skin. This is the incident energy E_i that is present as direct incident energy E_{i0} with the thermal impact of a proximate electric arc. If the person is wearing PPE, then the incident energy should be considered as transmitted incident energy E_{iT}. In the testing of PPE, a determination is made as to whether the transmitted incident energy will exceed the limits for the onset of a second-degree skin burn. A successful test will verify that the PPE is arc-resistant and provides protection up to the level of direct incident energy, as per the test settings.

There is a complicated non-linear correlation between electric arc energy and direct incident energy, which is determined through the specific transmission and exposure relationships, including system configuration and the effective distance between the arc flash and the person (transfer relations). The transmission and exposure conditions related to the thermal effects can be very diverse. A risk analysis must include or cover all related cases and require a „worst-case“ examination.

The correlation between electric arc energy and direct incident energy is known for both protection classes for the PPE Box test (protective textile and clothing) according to VDE 0682-306-1-2. These are control parameters for the test settings and characterize the transfer relations for the test setup.

The effects of radiation (including reflections) exist during the Box test, particularly as a result of arc flash directivity (gas flow) resulting from the small-scale box structure and through „worst-case“ transfer conditions due to the influence of electrode materials. Comparable examinations using other configurations show that, with the same electric arc energy being fed into the Box test structure, the highest level of thermal incident energy results.

A 3.2 Process of risk analysis

The electric arc energy W_{LB} that is to be expected within the scope of application must be determined in the risk analysis. The maximum value of anticipated electric arc energy will be ascertained and is measured in kJ. Based on this, it must then be verified that the maximum occurrence of exposure (thermal impact) will not exceed the level of protection and strength afforded by the PPE. The related parameter is then the electric arc energy for the test category being examined in the Box test. The level of equivalent arc energy for the PPE test must cover this level. For specific applications, existing deviations from the distance, geometry and test transmission relationships can be taken into account when determining equivalent arc energy $W_{LBä}$.

When selecting the PPE test or protection class, the relation to the anticipated electric arc energy value must be considered on the basis of the equivalent arc energy. The thermal hazards associated with electric arching are deemed covered if

$$W_{LB} \leq W_{LBä}$$

applies.

It should be explicitly pointed out that the test currents used for the Box test categories do not correspond to the usage limits of PPE with respect to the level of short-circuit current!

The risk analysis is comprised of the following work steps:

- Determination of the anticipated electric arc energy value,
- Examination of the PPE electric arc protection level,
- Consideration of divergent exposure conditions.

The determinations below will be comprised in the work steps for the workstation or area being analysed:

- Nominal or stipulated network voltage.
- Prospective (metallic) short-circuit current.
- R/X ratio for network or short-circuited electrical circuit impedance.

- System geometry (electrode gaps and volume relationships at potential fault locations).
- Working distance (potential electric fault arc onset and combustive locations, minimal effective distances to arc flashing).
- Type, model, settings and characteristics of the protection device(s) (circuit breakers, fuses or other special protection devices upstream from the work area).
- Protection level for the PPE test category.

NOTE:
It should be pointed out that the different switching states of the distribution network or energy supply system can lead to different short-circuit power readings and energy levels. For this reason, it may be necessary to analyse a number of such cases in a system.

Analysis of the energy supply system must take place for all work areas, generally meaning from the feed point of the affected network up to the user outlet.

A 3.3 Work steps

A.3.3.1 Ascertaining the general operating conditions
The starting point is to consider the general operating conditions. A list should first be compiled, including network voltage levels, network equipment types and locations, as well as work tasks.

NOTE:
In so doing, it must be considered that, for different network switching states and upstream supply systems, different prospective short-circuit current readings can result. Short-circuit current is greatest when the network junction (switchgear bus bar or distributor) is supplied through multiple feeders or transformers. Differing short-circuit current values under different switching states in the same system must nevertheless be taken into account, because electric arc energy at lower short-circuit current levels due to the longer protection device trip times may by all means be greater than that at the higher current levels.

With respect to (electrotechnical) work activities, all tasks performed on open electrical equipment or where a system must be opened (work in the vicinity of live components, live working) play a role.

NOTE:
In the case of type tested switchgear for which the test validation of arc resistance is available (medium voltage: electric arc testing according to VDE 0671-200, low voltage: electric arc testing criteria 1-5 according to EN 60439-1, Supplemental sheet 2), personal protection can always be assumed when operating or performing work tasks on a closed system; this does not need to be incorporated into the further analysis. On non-tested systems, it must not be assumed that the system will remain closed in the event of an electric arc fault and/or that the effects of inadmissible electric arcing will not occur outside the system (e. g. due to escaping hot gases, bursting parts, etc.); this situation must be treated as in the case of an opened system.

A.3.3.2 Calculation of short-circuit current at the workstations being considered
A prerequisite for the risk analysis and the selection of PPE is to be knowledgeable about the prospective short-circuit currents or short-circuit powers associated with the equipment (or network junction) potentially being worked on.

NOTE:
As a rule, the risk analysis should be undertaken for different workstations in a network or supply system. In larger systems, it is often advisable to develop and observe identical structures and parameters or similar basic electrical configurations (circuitry).

Short-circuit current calculations are to be performed according to standardised procedures (VDE 0102). Calculation software is usually available for this process. Maximum and minimum prospective 3-phase initial short-circuit AC currents

$$I''_{\mathrm{k3max}}$$

and

$$I''_{\mathrm{k3min}}$$

are to be determined for each workstation/system area for the possible/relevant network switching states. Standard determinations of these currents are made for metallic, zero impedance short-circuits (impedance at the fault location is zero).

Information regarding short-circuit current or short-circuit power can also be obtained through the power supply network operator. It is important to ensure that the fault location short-circuit currents apply to the work location being considered.

NOTE:
If the power supply network operator can only provide short-circuit current (or short-circuit power) at the supplying step down transformer for the low voltage network, then a calculation must be made of the short-circuit current for work locations (fault locations) located remotely from the low voltage network transformer, based on the technical data of the supplying medium voltage to low voltage transformer with consideration given to the type and length of low voltage cable used. If applicable, a multi-source feed to the fault location should be taken into consideration.

In the event of an actual short-circuit (with arc flashing), a reduced current, the electric arc short-circuit current or fault current with an electric arc short-circuit, will flow as a result of the electric fault arc (fault location impedances). If software is available that can be used for determining the short-circuit current associated with an electric arc short-circuit I_{kLB}, then this current should also be determined for the relevant switching states.

Electric arc short-circuit current can be calculated based on I''_{k3min} as well as with the help of a current limiting factor k_B[5]. The following applies

$$I_{kLB} = k_B I''_{k3pmin}$$

Factor k_B is determined on the basis of the arc voltage U_B dependent on the network nominal voltage, the R/X ratio of the short-circuited electrical circuit impedance and the electrode gap d (distance between neighboring conductors in the electrical system)[5].

NOTE:
The reduction or limitation of the fault current resulting from an electric arc at the fault location plays a practical role only in low voltage systems. In practice, current limitations for medium or low voltage networks can be ignored ($k_B = 1$).

A.3.3.3 Determination of short-circuit duration (duration of arcing)

The arc flash or short-circuit duration t_k is a significant parameter and will be required for the risk analysis. It is determined by the protection device and generally can be taken from the protective equipment manufacturer's selectivity calculations and/or trip characteristic curves (current-time curves).

It must be considered that, in current-time dependent protection devices, the trip time will be influenced by the level of the actual short-circuit current and, thereby, from the current limitation through the electric fault arc, itself. The actual short-circuit current in the low voltage range does not correspond to the prospective short-circuit current, but to the electric arc short-circuit current I_{kLB} and can be significantly limited. Determination of the actual short-circuit current I_{kLB}, with consideration given to a number of influencing variables, can only be done by approximation[5] and is subject to a degree of uncertainty (see A.3.3.4).

One is generally considered to be in a safe zone if a current limitation of 50 % is assumed and this reduced current is used to establish the trip time as taken from the protection characteristic curve. The current limiting factor then equates to $k_B = 0{,}5$; it follows that

$$I_{kLB} = 0{,}5\, I''_{k3pmin}$$

When using scatter range information for the current-time curve for a protection device (e. g. fuse), the value from the upper range limit should be used for short-circuit duration.

NOTE:
A protection device is considered to be a device positioned upstream from the respective work area, or a separate protection device installed or activated especially in connection with a work task. With a multi-source feed to a fault location, the protection device with the longest trip time should be used to determine short-circuit duration.

NOTE:
When using software tools (selectivity calculations), it must be ensured that the calculation is made based on the limited electric arc short-circuit current I_{kLB}.

Regarding protection devices, their protection boundaries and selectivity levels should be taken into account. With non-current-limiting fuses and circuit breakers with direct actuation, the short-circuit duration can be taken directly from the current-time curve or the selective tripping schedule. With circuit breakers, the setting of time delay levels or selective tripping times must be taken into account where applicable. The following reference values are considered to be typical for circuit breakers trip times without a time delay:

Circuit breaker	Undelayed trip time
Low voltage (< 1000 V)	60 ms
Medium voltage (1 to 35 kV)	100 ms
High voltage (> 35 kV)	150 ms

Table 9 Typical circuit breaker trip times

Information provided by the manufacturer will provide more specific related data.

Current limiting fuses feature a short-circuit duration of less than 10 ms. The fuse current-time curves exhibit the virtual melting times, meaning the actual trip times will not necessarily coincide. For safety reasons, fuses used in current limiting situations should feature a short-circuit duration of t_k = 10 ms. This value is considered to be on the safe side.

NOTE:
At short-circuit durations longer than 1 s, it can be assumed that the person will be able to withdraw from the immediate danger area, if applicable. For this reason, longer periods will not need to be considered. This does not apply, however, if withdrawal of the person from the working environment is precluded or restricted (e. g. work in tight cable trenches or canals, narrow work corridors, work from ladders or lifting mechanisms).

A.3.3.4 Determination of the anticipated electric arc energy value

The determination to be made is the maximum value of electric arc energy that can be anticipated at the respective fault location or within the scope of application being considered.

Electric arc energy is dependent on network conditions, meaning from the network short-circuit power S''_k at the potential fault location and the short-circuit duration t_k, as determined by the electric protection devices (trip times for circuit breakers and fuses, as well as separate protection devices if applicable) as taken from the protection characteristic curves:

$$\begin{aligned} W_{LB} &= P_{LB} \cdot t_{LB} = k_P \cdot S''_k \cdot t_k \\ &= k_P \cdot \sqrt{3} \cdot U_{Nn} \cdot I''_{k3pmax} \cdot t_k \end{aligned}$$

Network short-circuit power at the fault location is the result of the nominal or stipulated network voltage U_n and the maximum prospective 3-phase short-circuit current I''_{k3max} for the relevant network switching states.

NOTE:
With a multi-source feed to a fault location, overall short-circuit current I''_{k3max} will be composed of the respective partial currents. That share of the short-circuit current emanating from motors that could be fed back to the fault location must be taken into account, if applicable.

In the case of a fault located within the switchgear or distribution system, the line impedance between the energy supply source (usually a transformer) and the system must generally be taken into account.

Furthermore, electric arc energy is dependent on system conditions characterised by factor k_P, which accounts for the type of arc formation and the electrode geometry at the fault location. This factor can be determined by approximation with the aid of arc voltage[5]. For arc voltages, there are empirical conditional equations, which - aside from electrical circuit parameters - require knowledge of system conductor wire spacing. The 50 % arc voltage value determination can be assumed.

For a very rough estimation without considering the system geometry, the theoretical maxima of the parameter k_P can be used, which can be determined according to

$$k_{Pmax} = \frac{0{,}29}{(R/X)^{0{,}17}}$$

this equation. R is the active component thereby, while X is the reactive component of impedance in the short-circuited electrical circuit[5].

Furthermore, it was determined that the following specified range of values k_P are typical for conventional system configurations, in practice, and can be used as reference values:

U_n	d	R/X	k_P
400 V	30 mm	0,2	0,229
		0,5	0,215
		1,0	0,199
		> = 2,0	0,181
	45 mm	0,2	0,289
		0,5	0,263
		1,0	0,240
		> = 2,0	0,222
	60 mm	0,2	0,338
		0,5	0,299
		1,0	0,270
		> = 2,0	0,253
10 to 20 kV	120 to 240	0,1	0,04 to 0,08

Table 10 Reference values for normalised arc power

NOTE:
When using the maximum value or the reference value, the determination of geometric parameters is circumvented at the cost of precision. Particularly with the ansatz for maximum value, a significant safe distance can emerge under certain circumstances.

A.3.3.5 Determination of working distance

Working distance a is the distance between the electric arc and the person's body (torso) that is effective during the work activity or must be maintained in the working environment being considered. Where different tasks are being carried out in the working environment, the shortest distance emerging should be applied. The configuration of the potential electric arc-related electrodes in the system (conductor arrangement) is decisive in determining the fault location (location of the electric arc flash).

Those electrical systems at which persons perform work tasks (repairs, service, maintenance, assembly, inspection, measurement, etc.) are considered integral to the working environment and workstations. A work task is considered to be any activity performed in the vicinity of live components or live working.

Typical working distances resulting from the work positions and the characteristic design or geometry and dimensions of the electrical equipment are:

Equipment type	Typical working distances
Low voltage distribution/house junction box, main control cabinet	300 to 450 mm
Low voltage switchgear	300 to 600 mm
> 1 kV	according to DIN VDE 0105-100

Table 11 Typical working distances

Distance relationships should be determined as accurately as possible so that a determination of the working distance can be established. Yet, it can generally be assumed that the distance to the person's torso will not fall short of a = 300 mm while working and, particularly in the low voltage range, that this can be applied as a reference value.

NOTE:
Personal protection can always be assumed when working on closed systems that have passed a type test for arc resistance; consequently, a working distance does not need to be determined (see 4.3.1). In the case of non-tested systems, however, the potential for electric arcing and related effects outside the system must be expected (e. g. when opening doors). The working distance that must then be provided for will be composed of the distance to the system encasement and the typical working distances referenced above (values taken from the lower limits).

Establishing a working distance that the worker must not fall short of represents a possible measure for facilitating work activities with PPE at a specific level of protection (test category or protection class).

A.3.3.6 PPE electric arc protection level

It must be ensured during test setup for the Box test that the thermal transfer relations (including the effectiveness of the electrode material) correspond with „worst case" conditions according to VDE 0682-306-1-2. The electric arc energies W_{LBP} in the test setup corresponding to the respective incident energies E_{i0P} in the test can be used to establish utilisation limits for PPE:

Box test	Statistical mean value	
VDE 0682-306-1-2	Electric arc energy W_{LBP}	Direct incident energy E_{i0P}[1]
Class 1	158 kJ	135 kJ/m^2
Class 2	318 kJ	423 kJ/m^2

Table 12 Box test parameters

NOTE:
The specified direct incident energy values E_{i0}, which identify the Box test categories, do not correspond to the ATPV values, which are determined in tests according to VDE 0682-306-1-1 or in their subsequent procedures according to NFPA 70E and IEEE 1584; neither do they compare with the established transmission and exposure conditions, nor are analytical conversions or mathematical transfers possible in these values.

At an effective distance of a = 300 mm (corresponding to the test setup), the electric arc energy values W_{LBP} lead to the applicable incident energies. Electric arc energy W_{LBP}, which identifies the test category in the Box test, is used as a comparative parameter $W_{LBä}$ for the ascertained electric arc energy W_{LB} within the scope of application.

At the same time, it is presupposed that the use of PPE is foreseen for working distances of a = 300 mm and for systems that are small-scale and limited by side, rear and partition walls, analogous to the Box test setup (with a volume of around V = 1,6 10^{-3} m^3). Corrections are possible with divergent conditions.

A.3.3.7 Consideration of divergent exposure relationships
Equivalent arc energy $W_{LBä}$ can be determined for any working distance a by using an experimentally verified reverse squared distance proportionality from the electric arc energy of the test category W_{LBP}. It represents that level where protection provided by the PPE for a respective distance a is still maintained. Moreover, the system configuration can be taken into consideration. The following is generally valid for the Box test

$$W_{LBä} = k_T \cdot \left(\frac{a}{300\,\text{mm}} \right)^2 \cdot W_{LBP}.$$

The transmission factor for electric arc energy k_T for Box test conditions equals k_T = 1. For divergent combustion and transmission conditions, a coefficient can also be used with the following values:

Type of system	Transmission factor for electric arc energy k_T
(Very) small-scale systems with side, rear and partition walls	1
Large-scale systems, spatial limitations primarily due to rear wall structure	1,5 to 1,9
Open systems without significant limitations in the electrode chamber	2,4

Table 13 Transmission factor

A.3.3.8 Using the analysis results for risk assessment
In the risk assessment or when selecting the PPE test category or protection class (Box test), the relation to the expected value for electric arc energy is to be considered based on the equivalent arc energy. The thermal hazards associated with electric arching are deemed covered if

$$W_{LB} \leq W_{LBä}$$

applies.

Starting with this relation together with the above mentioned determinant parameters and equations, the limits for PPE applicability in a chosen test category or protection class can be determined with respect to short-circuit current range, permissible short-circuit duration or protection device trip time (and therewith the protective system itself) and permissible working distance.

A 3.4 Alternative test methods

The procedures described herein are not applicable for alternative test methods to the Box test method. It is then necessary to determine the correlation between electric energy and direct incident energy (transmission function) generally valid for the affected test setup or to ascertain the direct incident energy that can be expected in the event of a fault, and then to compare these with the incident energy level from the PPE test.

In addition to the Box test, one test method is also used in accordance with VDE 0682-306-1-1 (ATPV test or Arc-Man test). As opposed to the Box test method, in which a directed test arc is generated, similar to an arc that might be expected in an accident when working on a control cabinet or distribution system, the electric arc generated in the Arc-Man method is open and non-directional, meaning it is generated in a quasi free field. The two methods can not be compared directly and are not transferrable or convertible among themselves. On the one hand, this is due to the type of electric fault arc, whose length and propagation are predetermined by the test setup, the electrode materials used and many other physical-technical differences. The heat transfer that takes place in the Arc-Man test is primarily due to radiation.

On the other hand, Arc-Man test results lead to the so-called „Arc Thermal Performance Value", or ATPV. In this context, the incident energy is determined according to a statistical methodology, by which a 50 % probability exists of suffering second-degree skin burns behind the PPE. Even if an electric fault accident is relatively improbable, the EU directive regarding PPE allows no interpretation of PPE that would tolerate such injury. For this reason, as a matter of principle, such test methods should not be used within the EU.

ATPV is the direct incident energy that emerges with the special transfer relations existing in the test. It should be noted that ATPV does not correspond to the levels of direct incident energy associated with the test categories. The incident energy levels generated in the Box test method are not ATPV values or limits of the ATPV range.

Products available on the international marketplace have been tested under certain circumstances according to both methods, meaning the Box test and Arc-Man test methods. Even if the test results are not directly comparable, they can nevertheless help in the selection of suitable PPE, particularly when the maximum anticipated electric arc energy lies above the electric arc energy for the electric fault arc protection class WLBP or the equivalent arc energy WLBä described in A.4.3.

For this reason, a manufacturer who tests its products according to both methods can specify the ATPV realised, even in the EU marketplace, in order to provide the user with further selection criterion to help the selection of suitable PPE.

When using ATPV for selection of PPE, however, a risk analysis must be undertaken in which the anticipated incident energy is ascertained. For this, NFPA 70E (Standard for Electrical Safety in the Workplace) and IEEE 1584 (Guide for performing arc-flash hazard calculations), among others, provide relevant algorithms.

It must be noted, however, that ATPV-based testing and PPE selection are bound by the limitations of the methodology.

Annex 4

PPE selection support form

PPE Electric ARC Protection Class Calculation Form

Work order:	Replace NH fuse	Responsible person:	M. Mustermann
Work location:	Transformer station 2 Main low voltage distribution system	Date:	12.04.2012
Network voltage:	400 V		
Max. short-circuit current:	23,10 kA		
Min. short-circuit current:	20,90 kA		
Distance between conductors:	60,0 mm		
R/X ratio: (Section 3.2)	0,2	Rationale:	none
Current limiting factor k_B: (Section 3.3)	0,38	Rationale:	none
Protection device:	315 A gTr AC 400 V fuse (... manufacturer ...)		
Tripping time of the protection device:	0,100 s	Note:	Circuit breaker set value / trip time taken from protection characteristiv curve
Transmission factor k_T: (Abschnitt 3.4)	1,50	Rationale:	none
Distance of person from electric arc source location a:	300 mm		
Results:	**Isolate or take othe measures**		

The following measures would make work possible:

Shortening the upstream protection device trip time to < 0,039 s for PPE in Class 1 or to < 0,078 s for PPE in Class 2.

Increasing the working distance to > 481 mm for PPE in Class 1 ot to > 339 mm for PPE in Class 2.

Work order:	Replace NH fuse	Responsible person:	John Doe
Work location:	Transformer station 2 Main low voltage distribution system	Date:	12.04.2012

Calculation		**Parameter**	**Result**
Network parameter	Network voltage	U_{Nn}	400,0 V
Equipment geometry	Distance between conductors	d	60 mm
Short-circuit current calculation	max. short-circuit current	I''_{k3pmax}	23,10 kA
	min. short-circuit current	I''_{k3pmin}	20,90 kA
	R/X ratio	R/X	0,20
Current limitation		k_B	0,380 s
Minimum fault current	$I_{kLB} = k_B \cdot I''_{k3pmin}$	$I_{kLB} =$	7,94 kA
Overcurrent protection device trip time (circuit breaker/trip time set value taken from the protection device characteristic curve)		t_k	0,100 s
Short-circuit power	$S''_k = \sqrt{3} \cdot U_{Nn} \cdot I''_{k3pmax}$	$S''_k =$	16,00 MVA
Normalized arc power	$k_P = 0{,}29 \ / \ (R/X)^{0{,}17}$	$k_P =$	0,381
Electric arc power	$P_{LB} = k_P \cdot S''_k$	$P_{LB} =$	6,10 MW
Electric arc energy (anticipated)	$W_{LB} = k_P \cdot S''_k \cdot t_k$ (Annahme: $k_P = k_{Pmax}$)	$W_{LB} =$	610,18 kJ
Working distance		a	300 mm
Standardized PPE test level		$W_{LBPKl2} =$	318,0 kJ
		$W_{LBPKl1} =$	158,0 kJ
Transmission factor		k_T	1,50
Protection level of clothing at the electric arc location (projection of Bo test parameters to the electric arc location)	$W_{LBä} = k_T \cdot (a/300\,mm)2 \cdot W_{LBP}$	$W_{LBäKl2} =$	477,0 kJ
		$W_{LBäKl1} =$	237,0 kJ
Comparison		$W_{LB} < W_{LBäKl1}$	nein
		$W_{LB} < W_{LBäKl2}$	nein
Results:	**Isolate or take othe measures**		
Rationale for R/X ratio: none			
Rationale for currentlimiting factor: none			
Ratioale for transmission factor: none			
Protection device: 315 A gTr AC 400 V fuse (... manufacturer ...)			

Deutsche Gesetzliche Unfallversicherung e.V. (DGUV)

Mittelstraße 51
10117 Berlin
Tel.: 030 288763800
Fax: 030 288763808
E-Mail: info@dguv.de
Internet: www.dguv.de