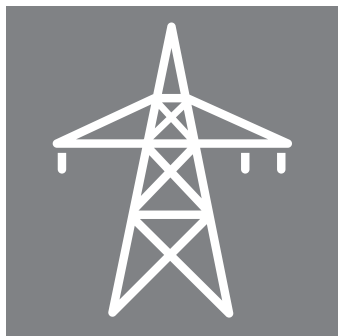
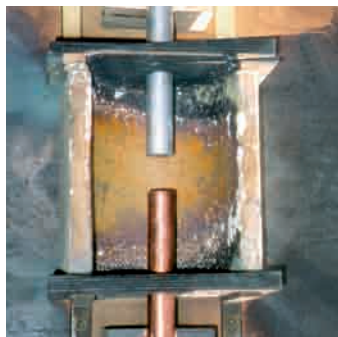
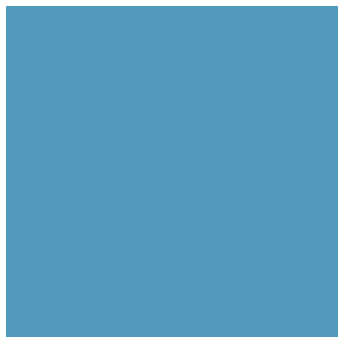


Guideline for the selection of personal protective equipment when exposed to the thermal effects of an electric fault arc



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INTERNATIONAL SOCIAL SECURITY ASSOCIATION

Section for Electricity

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**Guideline
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1 Scope – Introduction

Each and every day electro-technical work is carried out world-wide at the risk of the occurrence of an electric fault arc either by failure or due to a technical reason. There are different ways to protect people against the arc risks. At first the fault arc shall be prevented by technical measures such as constructions and electrical protective devices, and creating electrically safe working conditions (de-energized installations, working rules etc.). Training and competence policy procedures have to be applied. In many case it is not possible to totally eliminate the risk that nevertheless a fault arc can occur and Personal Protective Equipment (PPE) must be selected for protecting people.

Since the first publication of these guidelines in 2001 great advances have been made. The effects when an electric arc occurs can now be specified with more precision. We are now able to predict what arc energies have to be expected in the events of arcing faults. Moreover it is difficult in an electric installation to predict the direction of the arc due to the magnetic field caused by the short circuit current, and the resulting movements of the arc plasma and the arc roots at different elevations of the electric arc. But there is now an improved knowledge on these processes.

However there are different consequences of electric fault arcs: thermal effects, electric shock, noise, UV emissions, pressure, shrapnel, the consequences of physical and mental shock and toxic influences. Standards and test methods deal only with the thermal effects. This guideline focus also only on these aspects representing the most serious risks for persons.

Thus PPE that works one hundred per cent against an electric fault arc is not possible. Rather, the consequences of an electric arc can be reduced and many times eliminated.

In the case that any work in the vicinity of an electrical installation or under live conditions is necessary, the person is generally in an area that is not approachable for the normal population. In those cases the general technical preventive measures, e.g. plates and doors, have to be opened or even to be removed for a certain period of time, as long as any sort of aforesaid work has to be done. As these actions are part of maintenance and repair work, hazards due to electric arcs cannot be completely eliminated for the fore-seeable future.

Additionally other workers such as operators may be in proximity with the equipment or interact in such a way which could be exposed to an electrical arc. These risks should be included in the risk assessment, too.

In the frame of the International Section of the ISSA on Prevention of Occupational Risks due to Electricity an international working group analyzed the situation and

1 Scope – Introduction

provides new information. This revised guideline reflects the improved knowledge since the first edition. A complete revision was made.

As major improvement the guideline gives information for risk assessment and how to apply the standardized procedures to the real work environment. The working group referred to experiences and the improved situation of the standardization of electric arc test methods. Today considerations may be based on well-established testing methods for PPE for arc flash exposures that are internationally standardized and harmonized.

This guideline follows the requirements of the European Directive for Personal Protective Equipment (89/686/EEC) [1]. In the following according PPE are considered exclusively; all items of this guideline are PPE in the sense of the directive.

The document is intend to help employers to fulfil the obligations according to the Council Directive 89/391/EEC on the introduction of measures to encourage improvements in the safety and health of workers at work.

2 What is an fault arc – types of exposure

An electric arc is a self-maintaining discharge in gases. It originates from gas ionization and is a conductive electrical interconnection between electrodes of different potentials, different phase relationship or one of these and earth. An electric fault arc in electrical power equipment is an unintended event. It can be caused by a technical fault or – as it is documented in most cases – by mistake of the operator. Fault arcs accompany almost all short-circuits in electric power equipment with releasing huge amounts of energy.

Electric arcs do not only occur with short-circuits but also in case of switching-off or breaking electrical circuits under load (fuses, disconnectors, cables, cable lugs, terminal ends) if there are no special precautions. These switching arcs may also be of risk for persons and cause electric fault arcs. But the highest energies are released in case of short-circuit fault arcs.

While in the low voltage range a galvanic contact is necessary to ignite an electric fault arc, in high voltage systems only a non-compliance with a relevant distance to live parts may be sufficient for triggering (electric breakdown or flashover).

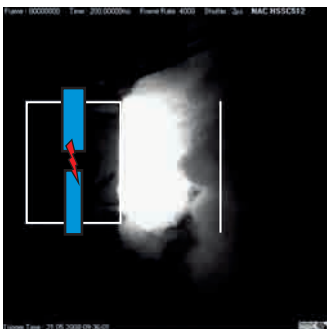


Fig. 2.1:
Hot plasma and gas cloud escaping in case of an arc in a box (enclosure), (source: Schau)

In dependency of the system voltage level, power equipment construction and working activity, different types of arcs and exposure modes may exist:

- open arc – arc in open installations, risk of mainly radiation if a certain distance to the arc exists
- box arc – arc in a limited volume, focused and amplified effects resulting from radiation, convection heat and metal splash (see Fig. 2.1)
- ejected arc – plasma jets are ejected and affect persons
- tracking arc – arcs formed at the body surface in connection with electrocution (current flow through human body) in HV systems.

Due to extremely high energies occurring with fault arcs in case of short-circuits there are high risks for personal injury, damages of the equipment and interruptions in the electric power supply.

3 Hazards of fault arcs

3.1 Physical and technical effects

Depending on power and duration of an electric arc quite different physical effects can arise which result from the extremely high temperature in the arc column. Temperatures of more than 5.000° C are possible within an electric arc. In the arc development metal of the arc electrodes is vaporized and ionized. It is formed into a conductive connection between the electrodes. Due to the intensified current flow the temperature rises and a plasma develops between the electrodes. Radiation is emitted by the arc plasma.

A plasma is distinguished by the fact that all the chemical compounds in it have been broken up and are ionized. Thus this plasma cloud has got a very high chemical aggression. Due to the vaporization of metal and the following immense heating up, a mass and gas expansion takes place which rapidly transports metallic vapor and splash away from the arc roots. As a result of cooling down and reacting with atmospheric oxygen, metal oxides can be found which, in the course of further cooling, appear as black or grey smoke. As long as vapor and smoke have got sufficient temperature they deposit a quite sticky sort of contamination (see Figure 3.1).

An immediately physical reaction during the development of the arc is the huge pressure rise which in 5–15 ms can reach its first peak of up to 0,3 MPa. This corresponds to a pressure of 20–30 t/m². If an unhindered **pressure wave** spreading can not take place, one runs the risk of destroying the electrical installation and its surroundings mechanically. Thus doors and coverings can be blown up, casings, compartments and partitions can burst and break down.

The **optical radiation** and a convective heat transfer of the flowing **hot plasma and gas**, and plasma jets occurring on the arc roots result in thermal exposures and damages. Dependent on the intensity of the electric arc, the heat flux can ignite nearby flammable materials. The molten metallic splashes which originate from the electric arc increase the **fire hazard**.

3.2 Effects on the human body

Due to the physical arc consequences described, according risks result for persons working at or in the vicinity of live parts, a direct exposure is likely because the equipment is opened for these working activities.

The main hazards of personal injuries result from:

- Pressure effects, forces on the body and shrapnel due to the rapid heating-up of the arc surrounding gas

- Sound emission with acoustic stress
- Electromagnetic, particularly high intensity optical radiation (visible light, ultra violet, infra-red) that is likely to cause irreversible damages of skin and eyes
- Extremely high thermal impacts due to the optical radiation and the hot plasma cloud and gas flow (heat flux)
- Toxic gases and hot particles caused by burning and pyrolysis of surrounding materials (inclusively electrodes).

By the sudden pressure rise due to the striking of the electric arc **detonation noise** results with sound pressure peak levels of eventually more than 140 dB (un-weighted) which may lead to auditory damages to human beings.

People working in the danger zone may be exposed to toxic degradation products originating from the electric arc with the consequence that, besides the harmful burn effects to the skin, there may also be serious lung damage due to inhalation.

The main risks consist in the **thermal hazards**. High risks for personal injury result from the ignition of the garments and other items worn by persons. Irrespective of the protective clothing a victim of an electric arc has been wearing, there is another aspect that is of interest to the development of preventive measures, namely the distribution of external surface burns. Thus the Institute for the Investigation of Electrical Accidents in Germany made a study of this very topic. They evaluated severe electric arc accidents that had occurred in 1998 in Germany. Medical documents of 61 cases were available. The evaluation referred to thermal damage of the affected part of the body.



Fig. 3.1: Installation after an electric arc accident (source: Schau)

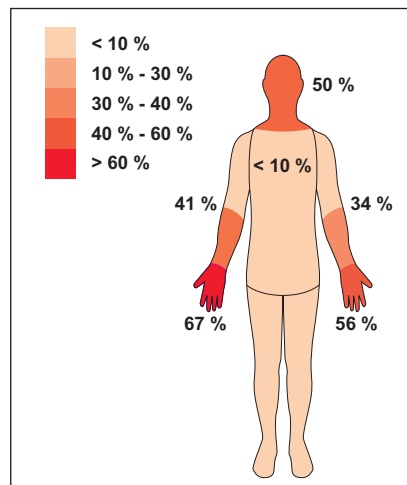


Fig. 3.2: Distribution of thermal injuries

3 Hazards of fault arcs

Thermal damage included first or even higher degree burns. The results are summarized in the illustration (see Figure 3.2). It has to be emphasized that the most severely affected parts were the hands and head including the neck; in more than 2/3 of the accidents the right hand was injured and in approximately half of the accidents the face and neck regions were impacted. In addition, the forearms (41 % of the right and 34 % of the left) were quite often injured. All other parts of the body were damaged up to a level of 10 %. However, very severe and lethal consequences are likely particularly in case of large-area burns on the main body.

4 Arc thermal risk parameters and their evaluation

4.1 Essential arc parameters

Direct and indirect exposures resulting from fault arcs are mainly depend on the

- electrical arc energy $W_{\text{arc}} = W_{\text{LB}}$
- arc active power $P_{\text{arc}} = P_{\text{LB}}$
- time duration of arcing $t_{\text{arc}} = t_k$
- distance to the arc a .

The arc energy is a well defined measure and rating of the specific conditions of the fault location. It is dependent on the electric power system parameters and the construction of the electric power equipment.

Regarding the thermal arc effects, furthermore, the energy density received at the surface affected is of importance. This is the incident energy E_i . It can be a direct exposure incident energy E_{i0} or, if it is considered on the back of PPE, a transmitted incident energy E_{it} .

Following the most important risk parameters are: arc power, arc energy, incident energy.

The relationship between the incident energy and the electric arc energy is very complex and sophisticated. There is in principle a proportionality, but the transmission function f_T is nonlinear:

$$E_i = f_T \cdot W_{\text{arc}} \text{ with } f_T = f(x_1, x_2, x_3, x_4, x_5, x_6).$$

The main principle influences are

- x1 – distance a to the arc axis (approximately inversely proportional to the square)
- x2 – arc space environment (open arc, box arc, walls, ...)
- x3 – type of electrode configuration (vertical, horizontal, barriers, 2-phase/3-phase)
- x4 – electrodes gap d
- x5 – electrode material
- x6 – level of system voltage and current.

These factors determine what type of arc is formed and represent the heat transmission conditions.

Essential definitions and terms are summarized in Annex 2.

4.2 Calculation and measurement of thermal risk parameters

In the standardized electric arc test methods copper calorimeters are used to measure the incident energy. The maximum value of the temperature rise dT_{max} of the defined calorimeter copper disc (delta peak temperature) is proportional to the incident energy E_i (see Figure 4.1):

$$E_i = \frac{m \cdot c_p}{A} \cdot dT_{max}$$

with

- m – mass of calorimeter copper disc
- A – cross sectional area of calorimeter copper disc
- c_p – specific heat capacity coefficient of copper
- dT_{max} – delta peak temperature (maximum temperature rise) of the calorimeter.

The delta peak temperature is the difference between the maximum temperature during the test exposure time of 30 s and the initial temperature of the sensor.

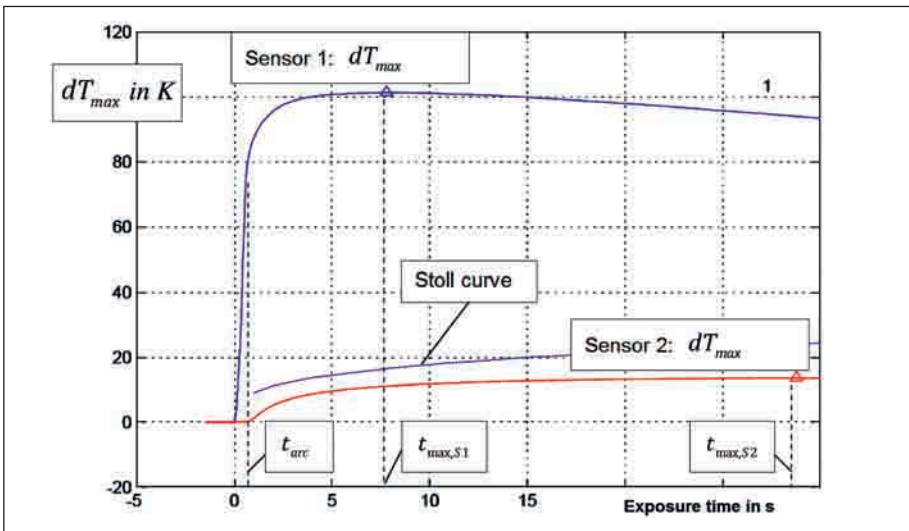


Fig. 4.1: Temperature rise course during an arc test (example with sensor 1 directly exposed and sensor 2 behind PPE)

5 Standardized test procedures for PPE products against thermal arc hazards

5.1 General

Necessary base for the assessment of PPE and their selection for practical use are reproducible product tests. The PPE have to be tested for proving its resistance as well as its protection effect (heat attenuation) against the thermal effects of electric fault arcs (see Fig. 5.1).

PPE must meet these two requirements regarding arc flash risks. In the past the considerations and tests were only focussed on flame resistance and proving PPE to do not aggravate the arc consequences. To be flame retardant, is a very important base for PPE but not sufficient. PPE components such as textiles of garment and clothing, gloves and visors must also limit the incident energy to a non-dangerous degree. According tests of products as well as systems are necessary with measuring the incident energy.

Today there are 2 different test methods standardized for testing of textile material and clothing and meeting the requirements mentioned above:

- The Arc rating test according to IEC or EN 61482-1-1 [3] and
- The Box test according to IEC or EN 61482-1-2 [4].

Both test methods use different test-set-ups, arc configurations and types, test parameters, test procedures and result parameters. The results cannot be neither physically compared nor mathematically transformed into each other. PPE have to be tested and assessed either to the one or the other method.



Fig. 5.1: Test mannequin with a jacket exposed to an arc in a box test

	IEC 61482-1-1	IEC 61482-1-2
Set-up	Long open arc	Arc in a box
Test energy	Variable adjusted by arc duration at constant test current	constant, two possible levels (classes)
Heat transfer	All directions: mainly radiation	Focussed: Radiation, convection, metal splash
Test result	Arc rating (ATPV or E_{BT50})	Arc flash protection class: y/n

Tab. 5.1: Specifics of the two standardized test procedures optionally to be used

Important is that the test results are energy levels up to which the PPE shows arc resistance and protection. In the past, both manufacturers and users compared tested material or clothing and considered the application very often only on the basis of the prospective test current value (8 kA in case of ATPV testing, 4 or 7 kA respectively in box testing) without taking into consideration the other important set-up parameters determining energy levels (that means: exposure levels and, thus protection levels).

The test procedures of IEC 61482-1-1 (methods A and B) [3] determine a quantitative value characterizing the thermal protective performance of the material or clothing: the Arc Thermal Performance Value (ATPV) or the Break Open Energy (E_{BT50}) respectively. The value (material property) makes it possible to compare different materials to each other. It is also possible to compare this value to the predicted incident energy of an electric arc accident in any particular working environment, based on the information gained by means of according procedures of the risk assessment of that environment (e.g. IEEE 1585 or NFPA 70E, see chapter 8).

Material or clothing tested by the box test method with constant test parameters show protection at minimum up to the class energy level, the actual protection level may be higher. The test parameters are in general not the PPE application limits. Protection is almost given up to system currents and voltages, arc durations and exposure distances as long as the class energy level is not exceeded. The necessary arc flash class has to be selected on the base of a risk analysis. Other methods as mentioned above must be used because the according arc energy levels have to be found (see chapter 8).

5.2 Arc rating test IEC 61482-1-1

How the test works

The test is performed on flame resistant fabrics intended for clothing used in protection against momentary electrical arc flashes. The test set-up consists of two vertically positioned rod electrodes (stainless steel) with an arc gap d of 300 mm, where the electric arc is ignited. Three sample holder panels are positioned at a distance of 300 mm from the longitudinal axis of the electrodes, spaced at 120° from each other. Each sample holder has a minimum dimension of 550 mm x 200 mm (height x width) and is equipped with two calorimeters made of electrical grade copper. The test set-up provides an uninterrupted formation and propagation of the arc in all directions (see Figure 5.2).

Before testing, the test specimens are washed 5 times in accordance with ISO 6330, method 2A, and drying by procedure E (tumble drying) unless otherwise specified in the care labelling.

The materials are fastened to each of the three vertical sample holders, enabling the simultaneous testing of three samples during each arc shot. The calorimeters behind the fabric samples measure the temperature rise and thus the heat flux transmitted through the sample. At the same time additional calorimeters, placed beside each sample holder, serve the purpose of measuring the total incident energy. Software is used for the acquisition of all of this temperature data, for a period of 30 s after ignition of the arc.

The test method prescribes a minimum of 20 data points for statistical significance, and since each test generates three data points, this translates to a requirement of at least 7 electric arc shots to be performed for each test series. The incident energy level is varied by adjusting the arc duration (combustion period of the arc), while the test current level (prospective current) is held at 8 kA. The variation of the arc duration directly affects incident energy. The incident energies of the test exposures should result in a distribution of recorded heat rises both above and below the Stoll curve.



Fig. 5.2: Set-up of the arc rating test (with electrode configuration, sample holders and calorimeter sensors around it)

The electric supply voltage should be sufficient to allow for the discharge of an electric arc with a gap of up to 305 mm. In practice this corresponds to a mid-voltage source (e.g. around 3 kV AC). This source voltage guarantees ignition and stability of the arc throughout the whole test period.

What the test measures

This method utilizes a logistic regression model to determine the arc rating of materials for clothing. This arc rating (either ATPV or E_{BT50}) is expressed in kJ/m^2 (or cal/cm^2). The Arc Thermal Performance Value (ATPV) of a material is the incident energy on a material or a multilayer system of materials that results in a 50 % probability that sufficient heat transfer through the tested specimen is predicted to cause the onset of a second degree skin burn injury based on the Stoll curve, without breakopen. Annex 3 shows an example test report.

When a material or material system exhibits physical holes or openings during testing, either to expose the panel or a non-flame resistant underlayer, this is called break-open. If break-open is observed during testing, a breakopen analysis will be performed utilizing logistic regression in the same manner as ATPV analysis. If the 50 % chance of material breakopen (E_{BT50}) occurs at a lower energy level than the ATPV, then the E_{BT50} must be reported as the arc rating.

Additionally, the test measures the Heat Attenuation Factor (or HAF). HAF is a measurement of the percent energy that is blocked by the material or material system.

How the test results can be used

The test procedure measures heat flux through test materials and thus enables an easy material comparison. Arc ratings can be used to assist in the selection of appropriate protective clothing, in accordance with the risk assessment.

5.3 Box test IEC 61482-1-2

How the test works

In the box test [4] arc resistance and protection are assessed for two different protection classes. An electric arc is fired in a 400 V AC test circuit, burning between two vertically arranged electrodes which are surrounded by a special test box made of plaster (Fig. 5.3).

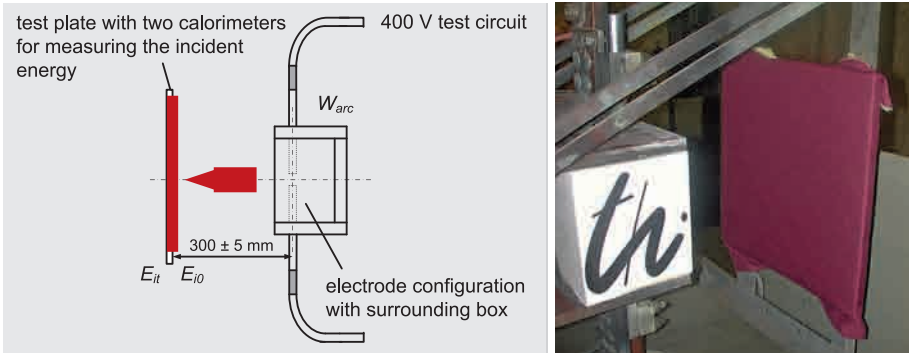


Fig. 5.3: Box test set-up for textile material testing of protective clothing: schematically (left) and in the test lab (right, reverse angle)

What the test measures

The arc flash classes are characterized by different levels of the electric arc energy, and the incident energy resulting. Tab. 2 gives an overview. The incident energy is the exposure level resulting at a distance $a = 300$ mm to the perpendicular arc axis.

Two calorimeters are used to measure the incident energy. Before a test series the direct exposure incident energy E_{i0} is measured without test sample in order to check the validity of the test conditions. During the test series the calorimeters measure the transmitted incident energy E_{it} behind of the samples.

	$W_{arcP} = W_{LBP}$ in kJ	E_{i0} in kJ/m ²
Class 1	158	135
Class 2	318	423

Tab. 5.2: Arc flash protection class test energy levels

Tests are distinguished for product assessment and certificating material and garment/clothing.

The material box test method is used to measure and find material response to an arc exposure when tested in a flat configuration. A quantitative measurement of the arc thermal performance is made by means of the energy E_{it} transmitted through the material. The tests are assessed by means of the criteria of Tab. 5.3.

Parameter	Criterion
Burning time	≤ 5 s
Melting	No melting through to the inner side
Hole formation	No hole bigger than max. 5 mm in every direction (in the innermost layer)
Heat flux	All value pairs ($E_{it} - t_{max}$) of the two calorimeters for a 4 of 5 tests series are below corresponding STOLL limit

Tab. 5.3: Test acceptance criteria

Final result of testing is the categorization to the protection classes (prove of passing test class conditions), meaning the test proves if protection class 1 or 2 according to the corresponding test class conditions is achieved. The test is considered as passed, if all of the criteria according to Table 3 are met. Within one test, four valid arc shots are made under unchanged conditions within a series of maximum 5 shots.

Fig. 5.4 shows an example of material testing of a 2-layer system of an fabric with a total area mass of 460 g/m^2 . The class 2 box test is passed. The full notified body test report of another textile material example passed the class 1 test is shown in Annex 4. It is the same fabric type tested also in an arc rating test those results are shown in Annex 3.

The garment box test method is used to test the function of the protective clothing after an arc exposure including all the garment findings, sewing tread, fastenings and other accessories, no heat flux will be measured. The materials of the garment must have passed successfully the material box test and the garment must fulfil the criteria burning time, melting and hole formation also according to Table 3. After exposure fasteners shall be functional. Accessories shall have no negative influence to the results of the burning time, melting and hole formation. The incident energy is not measured because of the influence of the design of the garment (e.g. pockets, flaps etc).

How the test results can be used

PPE arc flash protection class (or test class) necessary has to be found by risk assessment. The arc energy expected and the arc energy protection level have to be determined for the specific working environment (see Par. 9).

In the box test PPE is exposed, in addition to radiation, also to convective heat (plasma and gas cloud) and metal splash (electrodes being of aluminium and copper). Thus, PPE tested protects also against these dynamic and thermal consequences at the according energy level.

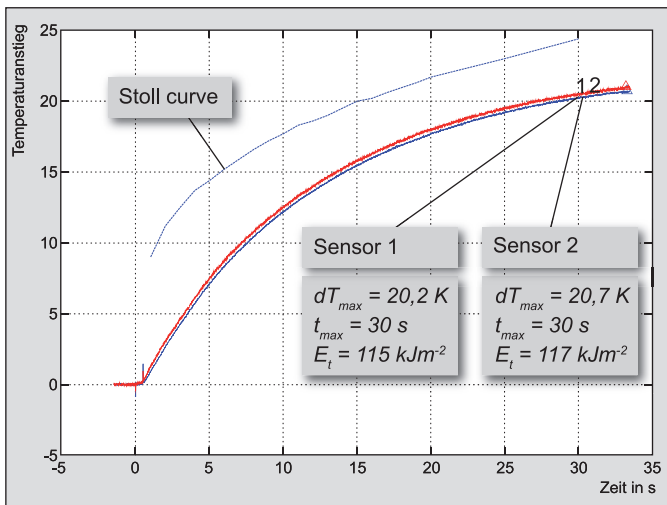


Fig. 5.4: Result of a class 2 box test of a 2-layer textile material system (above) and test sample before testing (below left) and after arc exposure (below right)

6 Textile material and protective clothing

6.1 Arc thermal protection requirements – IEC 61482-2

Electric fault arcs are of general risk for workers. An electric fault arc can particularly occur in case of electrotechnical work at or near to live parts. Protective clothing according to IEC 61482-2 [5] reduces the thermal arc hazards of electric fault arcs and contributes to the protection of workers against these risks.

The product standard IEC 61482-2 specifies requirements and test methods applicable to materials and garments for protective clothing for electrical workers against the thermal hazards of an electric arc based on

- relevant general properties of the textiles, tested with selected textile test methods, and
- arc thermal resistance properties, such as
 - the arc rating of materials according to IEC 61482-1-1, or
 - the arc flash protection class of materials and garments (Class 1 or Class 2) according to IEC 61482-1-2.

Requirements do not address electric shock hazards, the present standard is applicable in combination with standards covering such hazards. The standard does not contain requirements for the protection of head, hands and feet.

Textile material and clothing according to the product standard IEC 61482-2 is tested by using a real electric arc as sources of thermal effects. The hot plasma and gases in and around the arc column are the source of the heat flux and, consequently, the thermal effects. Details about heat transfer and test set-up according to IEC 61482-1-1 and IEC 61482-1-2 are given in chapter 5.

The standard IEC 61482-2 covers protective clothing against thermal arc hazards in general, not for a limited voltage level or range only, although the test methods use set-ups with a defined test voltage. The mode and violence of heat transfer is only less specific for arcs burning in a LV circuit or in a MV and HV one. Electric power and arc duration are the primary influencing parameters and characterize the thermal source. Clothing withstanding the incident energy levels of the tests will have the according arc thermal protection effect in a LV or a MV/HV installation as well.

6.2 Assessment parameters

Flame resistance and flame spread

Garments intended to protect against the thermal risk of an electric arc shall not aggravate the risk by ignition. Therefore all fabrics claiming compliance with the IEC 61482-2 shall achieve a specified limited flame spread index when tested in accordance with ISO 15025 Procedure A and classified according to ISO 14116. Hereby it is guaranteed that by a 10 s direct flame contact the material does not show flaming debris and the lowest boundary of any flame does not reach the upper or vertical edge of the sample. Also the spread of a possible afterglow in the undamaged area is excluded.

If a single-layer material is used in the garment, this material shall fulfil the limited flame spread index 3. Additionally to the requirements above this means the preclusion of hole formation and no afterflame time > 2 s.

If a multi-layer material is used in the garment, the following requirements shall be fulfilled:

- all outer layer and innermost layer materials shall fulfil the limited flame spread index 3,
- all middle layers shall fulfil in minimum the flame spread index 1.

Also the main seams of the garment shall offer a suitable flame retardant behaviour. Therefore the sewing thread used for these seams shall be tested according to ISO 17493 with the temperature of 260 °C. Furthermore neither accessories nor closures used in the garment shall contribute to the severity of the injuries to the wearer in the event of a momentary electric arc. Generally, all parts of a garment shall be made of arc thermal resistant materials.

Tear resistance and dimensional change

Besides the flame retardant behaviour of the materials, requirements for general properties of the textiles are of relevance for the user for safety and durability reasons. Therefore the standard defines minimum requirements for the outer materials used in the garment.

The outer fabrics shall have a tear resistance of at least 15 N (for weight higher than 220 g/m²) or at least 10 N (for weight within 150 g/m² and 220 g/m²) tested according to ISO 13937-2. The tensile strength shall be at least 400 N (for weight higher than 220 g/m²) or at least 250 N (for weight within 150 g/m² and 220 g/m²) tested according to ISO 13934-1. If the garment is made of knitted outer material, i.e. polo shirt or pullover, these test methods are not applicable. In such a case the burst strength according to ISO 13938-1 shall be determined and shall be of at least 200 kPa.

To guarantee an appropriate usability after the care procedure defined by the manufacturer also the dimensional stability of the outer material is specified. When tested in accordance with ISO 5077 the woven outer material shall have a dimensional change not exceeding $\pm 3\%$ in the machine and the cross directions. For knitted material the requirement is $\pm 5\%$ as maximum.

Arc thermal resistance

Because the protective clothing covered by IEC 61482-2 shall have certain resistance properties to the thermal effects of an electric arc the most important material parameter is the arc thermal resistance. The two international test methods mentioned in chapter 5 shall provide information on the resistance of clothing to the thermal effects of electric arcs. Each method gives different information. To be in accordance with this standard, a product shall be evaluated by using IEC 61482-1-1 or/and IEC 61482-1-2. Depending on the needs, the users will specify for one test method or the other. Material test as well as garment test shall be performed. For garment certification both the material and garment shall fulfil the requirements.

When tested according to IEC 61482-1-1, the protective clothing made of the tested material shall be assigned a corresponding ATPV of the material. A protective clothing will demonstrate a minimum arc thermal resistance, if the ATPV is at least 167.5 kJ/m^2 (4 cal/cm^2). The higher is the ATPV value, the better is the thermal resistance under higher incident arc energy (higher current value, longer exposure time). In case that no ATPV can be determined, the E_{BT50} shall be determined and assigned to the tested material. The minimum E_{BT50} demonstrated by the material shall be at least 167.5 kJ/m^2 (4 cal/cm^2).

When tested according to IEC 61482-1-2, the protective clothing made of the tested material shall be assigned a Class 1 or a Class 2 depending on the test conditions and the resulting arc thermal protection. Protective clothing will demonstrate a minimum arc thermal protection, if it passes the Class 1 test. A Class 2 indicates a higher arc thermal resistance by higher incident arc energy.

Besides fabric related requirements, the IEC 61482-2 also regulates important safety relevant aspects for the garment. Each garment designed to protect the upper part of the body shall have long sleeves and no exposed external metal shall be permitted. A worker should have the full body protected.

If due to comfort requirements the garment is produced of materials with different arc thermal resistance performance for the front and back (rear or dorsum) the exact information shall be given where the weaker area is located. This can be done by means of a drawing of the garment including dimensions and warning indication in the instructions for use. But it must be emphasised that such garments shall fulfil at least the requirements of Class 1 according to IEC 61482-1-2 or a minimum ATPV

rating of 167.5 kJ/m^2 (4 cal/cm^2) according to IEC 61482-1-1 at all areas. The front side of the garment and the complete sleeves (all around the arms and over the complete length of the arms) of the garment shall fulfil the same arc thermal resistance requirements.

However the end user has to consider that the use of the standard IEC 61482-2 is not obligatory. Especially for Europe where the basic safety and health requirements of the document Council Directive 89/686/EEC are relevant for all kinds of PPE, the fulfilment of the standard does not automatically obtain the assumption of conformity with these requirements. Nevertheless until there is no alternative assessment available, the consideration of the requirements given in IEC 61482-2 has to be seen as best available option.

6.3 Flammability of fabrics

It must be emphasised that all fibres, either natural or synthetic, can burn to some extent. Thus in standardisation the term “flame-resistant” is used. The fabrics are especially characterised by how they react after having been exposed to flames. The protective efficiency of a material lies in the fact that the user has to be insulated from the exposed heat energy and that the material in the specific areas that start burning cease to do so as soon as possible (see after-flame time). Ultimately, the user should not be injured by the material used. However, the protective clothing cannot ‘guarantee’ 100 % protection against exposure to a certain hazard.

6.4 Recommendations for specimen selection of material

If an electric arc hazard is at all possible at a workplace, work clothing of flame-resistant material shall be used.

As a result of a risk analysis (see chapter 8), and a knowledge of the relative thermal performances of various fabric systems according to one or the other test method described above, the appropriate level of protective clothing should be selected.

As a minimum guideline, for workplaces with electric arc hazard the persons concerned shall wear protective clothing with an ATPV of at least 167.5 kJ/m^2 (4 cal/cm^2) when tested according to IEC 61482-1-1 or with the protection level Class 1 of the IEC 61482-1-2 method (basic protection).

For increased hazard situations a garment with higher ATPV or a Class 2 garment should be selected (increased protection).

If the incident energy to be expected is higher the clothing then is likely to be alone not sufficient to provide the necessary protection.

It has to be emphasised that the tested materials do not resist each and every electric arc. An electric arc is an unexpected incident, the intensity of which can only be estimated by network parameters. However, additional danger and uncertainty arises by e.g. the distance the person concerned is standing away from the arc, its position etc. Generally, the necessary arc thermal protection performance is to be determined by risk analysis. Guidance for the appropriate selection of an ATPV is provided in other separate standards, e.g. in IEEE 1584 [6] and NFPA 70E [7], or product information (e.g. [8]). For the selection of protective clothing tested according to IEC 61482-1-2 (box test) the future German BGI guideline [9] (under preparation now) will offer practice-related assistance (see also Par. 8.3).

Due to the enormous variety of available woven and knitted fabrics, laminates and their combinations as material assembly it is hard to define minimum material weights. Besides, especially for materials with increased protection performance tests have always shown that the area weight of the material is not the only parameter of importance compared with the parameters' set of an optimal fibres selection, fabric construction and the arrangement of the material assembly (see also 6.6). Therefore the chosen fabric systems shall be tested in order to measure their specific arc thermal performance values.

The risk assessment may also be based on the determination of the arc energy and arc incident energy to be expected in case of an arc fault in the installations where the clothing is intended to be worn while working.

6.5 Quality assurance

The protection effect of a textile fabric against the thermal risks of an electric arc depends on different parameters. Besides the most important flame-retardant property also the fibre composition, the fabric construction and the area mass are relevant. As for each series production, deviations from the tested "master fabric" can not be totally eliminated. Especially for natural fibres equipped with flame-retardant properties the grade of flame-retardant fabrics can deviate from production to production.

Fabrics which have passed the electric arc test may not pass if other fabrics of another production are tested. Thus the production of flame-retardant fabrics have to be tested shortly afterwards with regard to the fact whether flame-retardant properties deteriorate or not.

There is no real alternative test to the arc thermal resistance test (destructive test) after completing the production phase for checking the conformity to the associated

requirement. Nevertheless both fabric manufacturer and garment producer shall prove that they have followed the same documented manufacturing process and assembly procedure as per the tested fabric and garment.

The manufacturers have to develop suitable random sample tests for this so that a constant quality can be guaranteed. Aging of the material which takes place in practice by use and numerous launderings has to be taken into consideration, too. As a critical parameter for the protection performance the limited flame spread shall be assessed and documented by the material manufacturer for the lot size. The lot size is, as a minimum, the amount of material delivered to the garment manufacturer. As a minimum unit a roll of material should be considered.

It shall be emphasised that there are very restrictive regulations for the production and use of personal protective clothing in many countries. In the European Community it is compulsory to do type tests for personal protective equipment before it can be placed on the market. PPE against electric arcs have to be seen as equipment of Category III according to PPE Directive 89/686/EEC. Therefore a quality assurance system or random tests taken by a certified test laboratory is required in order to guarantee the defined properties of the product during manufacturing.

6.6 Recommendations for wearing and cleaning

Protective clothing can only be effective if it is used and worn properly. When wearing protective clothing, all buttons or fasteners shall be closed, providing a barrier to the potential thermal hazard. Non-flame resistant undergarments worn should be constructed of natural fibre. Meltable synthetic non-flame resistant undergarments should not be allowed. Underwear melting under arc exposure may not be worn. Arc rated protective clothing shall cover all non-flame resistant clothing. Additionally, the outermost garment shall be flame resistant. Non-flame resistant garments (i.e. rainwear, jackets, cold weather garments, etc.) can ignite in an electrical arc and continue to burn, thus negating the protective capacity of the protective clothing worn underneath.

Often, comfort and ergonomic concerns are reasons cited for the inappropriate wearing of protective clothing. It is important that employees should be included in the process of selection and trial wearing of the protective clothing before purchasing. This employee involvement has been found to be beneficial as to both the selection of appropriate protective clothing and employee satisfaction.

Not only the upper part of the body shall be protected by the clothing. Although none of the standards described before is directed to test trousers, an intensive evaluation of the protection performance of these garments is necessary. For this the use of

identical material for jacket and trouser as well as the consideration of the design requirements given in IEC 61482-2 are essential. If as result of the risk assessment of the workplace the use of protective clothing for the upper part of the body is sufficient, the user has to guarantee the suitability of the selected trouser by itself. To avoid resulting uncertainties and possibly occurring risks, the selection of a complete suit of jacket and trouser or a coverall is recommended.

It can be recommendable to protect the neck by using clothing with collar.

Protective clothing and other personal protective equipment should be inspected prior to use. These must be removed from service if found to be defective. The performance of arc resistant protective clothing can be reduced or negated by flammable contaminants. It is imperative to regularly clean protective clothing to remove any possible contaminants. Protective garments are labelled as to the recommended washing procedures. It is important to follow these recommendations to maintain the protective characteristics of the garment. Additionally, garments should be repaired with components that are at least equivalent to the original. Additional cleaning and repair information can be obtained from the manufacturer.

The European Directive 89/686/EEC [1] requires that the manufacturer has to give product information for the user. The clothing shall be marked for example with the address of the manufacturer, number of standard, protection level, size of clothing, washing and/or dry cleaning procedure, comfort, ageing.

Additionally each product has to be equipped with “relevant information” for the customer in order to explain the kind of use, the level or classes mentioned, restrictions for use, warnings and information about storing, cleaning, decontamination, repairing and so on.

As additional important information it shall be emphasised that the garment is normally not an electrical isolated protective clothing, for instance according to EN 50286:1999. And the user has also to consider that the whole protection against the thermal risks of an electric arc requires, additional to a garment, suitable protective equipment for the head (face and eye protection) as well as for the hands. These items shall be tested according to the present available methods following IEC 61482-1-1 or IEC 61482-1-2, too.

7 Other PPE products: gloves, face shields

For other components of PPE, such as protective gloves, helmets, face shields or visors etc. so far there have not yet been requirements for products and testing in international harmonized standards.



Fig. 7.1: Set-up for glove testing with adapting the arc rating test (source: Dehn+Söhne GmbH + Co. KG)

The arc rating test as well as the box test method, in principle, enable tests of protective gloves and helmet-visor combinations. Modifications in the test set-up (sample and sensor arrangement) are necessary. Fig. 7.1 shows an according set-up for the arc rating test of gloves as used. An ASTM standard draft has been discussed for some time but not yet edited [10]. The box test set-up modification for gloves, as also be used, is presented in Fig. 7.2.

For testing face shields there is the ASTM standard F 2178 [11] which is also based on the arc rating test of IEC 61482-1-1, providing the ATPV. In Europe a comparable standard is still missing up to



Fig. 7.2: Box test set-up for glove testing with glove panels equipped by calorimeters

7 Other PPE products: gloves, face shields

now. With the Test Principles GS ET-29 [12] a guide for testing and certifying PPE was developed on the base of the box test in Germany. Meanwhile the principles were transferred in the new German standard draft E DIN 58118 [13] complementing the European standard EN 166 [14].

PPE shall be tested according to the international harmonized standards, that means either in adaption of the arc rating test or the box test. Then there is the great advantage that a complete protective equipment tested and assessed according to equal principles becomes available.

Annex 5 gives additional information and examples of testing of gloves and face shields by means of the box test method.

8 Risk assessment and calculation of arc risks

8.1 Selection of PPE and PPE test method

In general there is a Hierarchy of Control to identify the actions which should be considered in order following any generic risk assessment (according to the general principles of prevention of EU Council Directive 89/391/EEC). The use of PPE is an action at the end of this hierarchy of hazard control measures consisting in:

1. **Eliminate:** If the hazard is removed, all the other management controls, such as assessment, record keeping, training, auditing are no longer needed.
2. **Substitute:** If the hazard cannot be removed, substitute for a lower hazard. This may involve changes in electrical system design, fuse rating, types of other protection devices etc.
3. **Reduce:** Lower the exposure of the individual to the risk by minimizing the time the worker is placed within a position of risk.
4. **Adaptation:** Where possible adapt work to the individual, taking account of the individual's mental and physical capabilities.
5. **Technical Progress:** Take advantage of technical progress such as using remote operation of equipment, e.g. fault re-energizing devices, remote operation of switchgear/isolators etc.
6. **Isolation:** Place a barrier between the individual and the risk exposure either through physical means (screens/operation from separate control room) or by distance between the individual and the risk environment.
7. **Multiple controls:** This may utilize multiple methods of controls such as those technical and procedural controls identified above. Layering of controls will enhance the level of mitigation of risk to the individual if implemented correctly.
8. **Maintenance:** Introduce/develop planned maintenance and inspection regimes for plant and equipment to ensure correct operation of components and elements such as switches, circuit breakers, isolators etc. This may involve the development/introduction of a risk based maintenance program.
9. **Training:** Ensure that all staff are aware of the risks of operating equipment, what actions to take to mitigate the risk, are sufficiently competent to undertake

the work required and understand fully how to implement and use effectively safety standards/policies and safety related equipment including PPE. It includes that employees have to know how to control their own PPE.

10. **Personal Protective Equipment:** This should be used only as a means of last resort, after all other control measures have been considered and implemented. All PPE should be designed to appropriate standards and be capable of protecting the individual from risk of injury in reasonable circumstances. PPE should be worn, maintained, and cleaned in line with manufacturer's instructions.
11. **Emergency arrangements:** Such as alarm systems and back up controls. To be put in place when all else fails, this should consider what action to take when an event occurs so that the effect of the event on the individual can be minimized.

In case of live working or working near to live parts PPE is required.

The provision of PPE by the employer, as well as its use by the employee, is governed by national or international laws. Accordingly, the PPE provided must offer protection against the hazard being prevented without presenting an even greater hazard in itself. It must be suitable for the conditions present at the work place and be appropriate to the ergonomic needs and health requirements of the employees. Employees are required to properly use the personal protective equipment provided.

As the result of the PPE test methods protection levels are determined in form of incident energies (arc rating) or electric arc energies (arc flash protection classes) where the PPE selection has to be based on. The applier of PPE is confronted with the necessity to consider and handle these energy parameters. In order to provide support for this, it was resolved to compile information in form of procedures, described afterwards. Principles of risk analysis and arc flash studies are presented in the following.

Corresponding to the two different arc test methods there are also separate ways of selecting PPE: PPE tested in

- the arc rating test: is selected on the base of determining incident energies
- the box test: is selected on the base of determining the electric arc energies

to be expected in the work places under study. The methods for finding the expected values are tailored and parameterized either to one or the other type of arc test and its corresponding heat transfer characteristics. Thus misinterpretation may result

from not paying attention of the correspondences, e.g. by using the incident energy determination to select PPE tested according to the box test.

In 8.2 the procedures for selecting PPE of the arc rating test are presented. The method to be used in case of PPE classified by means of the box test is considered in 8.3.

8.2 Incident energy determination methods for selecting ATPV

Internationally recognized standards have been created to aid companies in both determining the hazards associated with electrical arcs as well as choosing the appropriate personal protective equipment for the worker.

NFPA 70E - *Standard for Electrical Safety in the Workplace*

NFPA 70E defines safe work practices for electrical workers. Within this standard, methods of hazard risk analysis and protection schemes are discussed. The standard requires that an arc flash hazard analysis be performed for work on or near energized equipment. This analysis will help to determine both the personal protective equipment needed as well as the arc flash protection boundary around the equipment where it should be worn.

There are essentially three types of hazard risk analysis methods discussed.

1. A detailed hazard risk analysis that calculates the available incident energy available as a result of an electrical arc. This method involves first determining the system, installation parameters and modes of operation. Next the bolted fault currents are calculated and the corresponding arcing currents are estimated. Note that the arcing currents are highly dependent on the protective devices and resulting duration of the arc. Using this information, along with system voltages, equipment configurations and working distances, the available incident energy (in cal/cm²) is calculated. Calculation methods and formulae are available in the NFPA 70E standard as well as in the IEEE 1584 Guide. Using the resulting calculated energies, the appropriate PPE is chosen to have arc ratings equal to or greater than the calculated incident energy.
2. Example job tasks are given in tabular form. The job tasks are organized by both the type of equipment and the system voltage. The associated hazard risk categories (HRC) are given for each task. The HRC level corresponds to minimum arc ratings of protective clothing that are appropriate to wear for the given task. Guidance is also given in additional tables for other personal protective equipment for the specific HRC.

3. A simplified two-category approach based off the job task matrix where PPE is chosen based off of system voltage levels only. With a few exceptions, HRC 2 clothing is recommended for voltages under 1000 volts and HRC 4 clothing is recommended for job tasks above 1000 volts.

It is important to note that the arc flash protection boundary must be determined for either option chosen above. Arc rated clothing is required when working within the arc flash protection boundary. Options 2 and 3 are useful for companies who have highly diverse electrical systems.

IEEE 1584 – IEEE Guide for Performing Arc Flash Hazard Calculations

This standard defines a methodology for performing a detailed arc flash hazard analysis. Information is gathered about each piece of equipment within the electrical system, e.g. system voltage, fault currents, potential durations and working distances. Calculations are made to determine both the potential incident energy (in cal/cm²) and the arc flash protection boundary.

8.3 Calculation of expected and equivalent arc energy for selecting box test protection class

The selection of PPE or the box test class for its testing requires a risk analysis in which the electric arc energy W_{arc} to be expected in the work place(s) under consideration has to be determined as well as the equivalent arc energy W_{prot} characterizing the PPE protection level for the work activity conditions (see procedure scheme in Fig. 8.1).

The arc energy $W_{arc} = W_{LB}$ to be expected depends on the power system conditions, that means on the system short-circuit capacity S_k at the possible fault locations and the short-circuit duration t_k that is determined by the electrical protective devices (clearing time of the breakers, fuses or occasionally special protection devices) and to be derived from the switching characteristics. Furthermore it is dependent upon the switchgear conditions characterized by the factor k_P taking into account the kind of arc burning and the fault place electrode geometry. This factor may approximately be determined by means of the arc voltage from Fig. A1 in Annex 1 and [15]. For a rough estimation without considering the switchgear geometry the maximum values of the k_P curves may be used. Furthermore the value ranges also given in Fig. A1 were found to be typically for usual power installation configurations and may be used as approximate values, too. In both cases the practical problems in finding the geometry parameters are avoided at accuracy expenses.

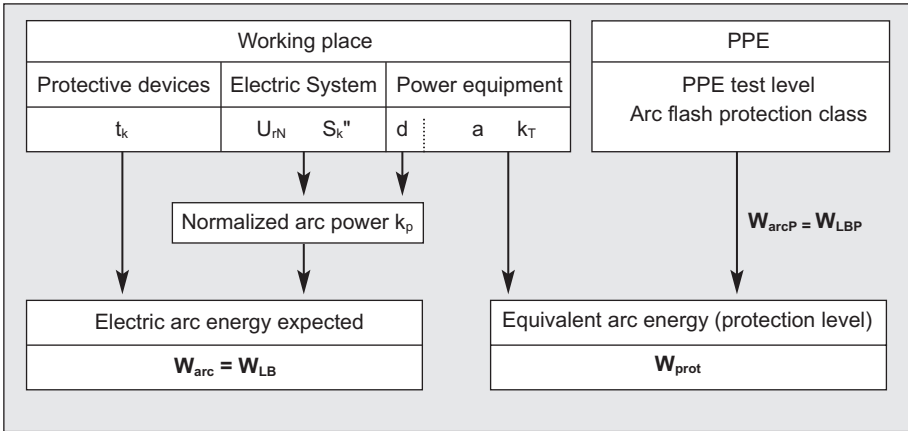


Fig. 8.1: Overview on parameters and procedure for risk analysis in connection with box-tested PPE

The largest arc energy level determined for the case under study has to be compared with the protection level W_{prot} (equivalent arc energy). The equivalent arc energy is that one where the protective effect of the PPE is still given for the according exposure distance a (see Tab. 8.1).

Class	Protection degree	Test level W_{arcP}	Protection level W_{prot}
1	Basic protection	158 kJ	$(1 \dots 2,4) \cdot \left(\frac{a}{300 \text{ mm}}\right)^2 \cdot 158 \text{ kJ}$
2	Increased protection	318 kJ	$(1 \dots 2,4) \cdot \left(\frac{a}{300 \text{ mm}}\right)^2 \cdot 318 \text{ kJ}$

Tab. 8.1: Protection levels of PPE tested according to the box test

The PPE test level $W_{\text{arcP}} = W_{\text{LBP}}$ is valid for the heat transmission conditions and the exposure distance of $a = 300 \text{ mm}$ of the box test set-up. Following the equivalent arc energy has to be determined by

$$W_{\text{prot}} = k_T \cdot \left(\frac{a}{300 \text{ mm}}\right)^2 \cdot W_{\text{arcP}}$$

W_{arcP} is the test level arc energy according to Table 5.2. The factor k_T takes into account the electric power installation, particularly the volume of the opened compartment where the arc is expected to burn. As a standard and particularly for narrow constructions with side and back walls and low volume (house service boxes, distribution boards etc.) this factor is $k_T = 1$, for wider burning ranges (e.g. mainly back

walls) it may be assumed as 1.5 to 1.9, and in case of open arcs as 2.4.

Annex 6 contains a detailed instruction for the risk analysis. Furthermore practical examples are presented.

A **basic arc protection** is generally necessary and to be provided by the use of according PPE if there is any risk of an electric fault arc and arc exposure in all the working activities (electro-technical work) and working environment. In case that arc-risky working is more often and/or often done at power equipment of higher rating an **increase arc protection** is necessary. The decision for one or the other protective level has to be based on the arc energy comparison.

Annex 7 presents an overview on work activities in different L.V. electric control and power equipment ($U_n = U_{nN} \leq 1000 \text{ V}$) with the references to PPE required.

Class 1	$a = 300 \text{ mm} \sqrt{\frac{k_p \cdot U_n \cdot I_{k3p}'' \cdot t_k}{(1 \dots 2, 4) \cdot 91 \text{ kJ}}}$
Class 2	$a = 300 \text{ mm} \sqrt{\frac{k_p \cdot U_n \cdot I_{k3p}'' \cdot t_k}{(1 \dots 2, 4) \cdot 184 \text{ kJ}}}$

Tab. 8.2: Minimum working distances (arc flash boundaries)

On the other hand, in case of special working activities and extreme arc risks and/or equipment rating the certain application must be considered and a conclusion drawn if live working or working at opened equipment is permitted or not, or the PPE have to meet special requirements. If the increased protection level of PPE is exceeded, there are the following practical alternatives:

- Reducing arc duration by using according protective devices (e.g. ultra-fast fuses, special arc detecting and extinguishing systems)
- Instructing for keeping minimum working distances (see Tab. 8.2)
- Testing PPE on higher energy levels
- Permitting work live working activities.

8.4 Empirical relationship between ATPV and box test protection class

The test methods according to IEC 61482-1-1 and IEC 61482-1-2 differ totally in their principles and technical characteristics. But there is a common point: the measurement of the incident energy by calorimeters and its evaluation by means of the STOLL-CHIANTA criterion for second-degree skin burns [2].

There is no mathematical-physical transformation of the results of the both test methods because of the technical differences in the procedures, but a correlation may be made empirically.

A pure empirical correlation of test result was made with typical woven fabrics which were tested both, by box method and ATPV one. Figure 8.2 shows the principal correlation found for typical arc protective fabrics made of Aramides and FR Cotton. Generalizing it can be pointed out that box test arc protection class 2 is often safely just given for $ATPV > 30 \text{ cal/cm}^2$.

Class 1 means about $ATPV = 4 \dots 30 \text{ cal/cm}^2$. The range between approximately $24 \dots 34 \text{ cal/cm}^2$ is a mix zone, where class 2 can be passed or failed in dependency on the specific fabric properties. The box test classes cover each a wide ATPV range.

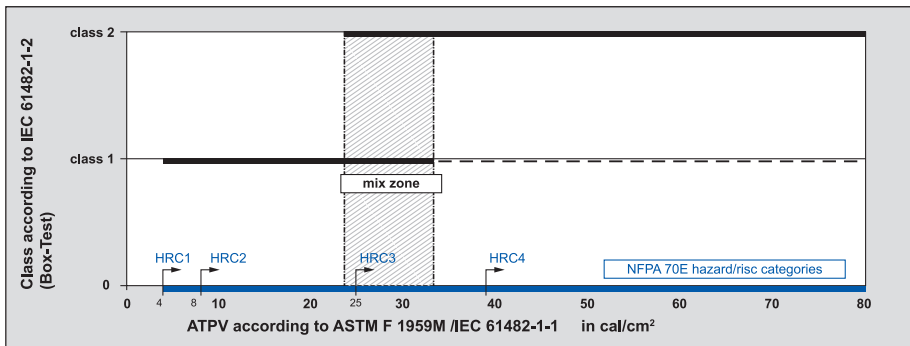


Fig. 8.2: Empirical relationship between ATPV and the arc protection class for typical arc protective woven fabrics/fabric assemblies made of Aramides and FR Cotton (based on [8] and test results of Kinectrics, Toronto, and STFI, Bonn)

The information of Fig. 8.2 may not be used for characterization of a non-tested material or PPE product. These considerations are thought for giving a rough estimation but not for replacing according tests as well as practical decisions or PPE selection. If the actual characterization of a product is needed, the according test is necessary to be made.

Different textile materials, of course, have in each case their own relationships of actual test results. The “generalization” of Fig. 8.2 is made for several textile materials only and represents the knowledge of today. It is not transferable to other PPE. In case of e.g. face shields quite different relationships will exist.

9 References

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Annex 1

Arc thermal risk parameters – definitions and terms

The electric arc energy is determined by the power conversion in all arcs engaged in the fault:

$$W_{\text{arc}} = W_{\text{LB}} = \int_0^{t_k} \sum_V u_{\text{LB}} \cdot i_{\text{LB}} \cdot dt = P_{\text{LB}} \cdot t_k.$$

It depends on the total arc active power P_{LB} and the arc duration t_k . In case of a 3-phase arcing fault the arc active power

$$P_{\text{arc}} = P_{\text{LB}} = k_P S_k''$$

is depending, on the one hand, on the electric network short-circuit capacity (3-phase)

$$S_k'' = \sqrt{3} U_n I''_{k3p}.$$

On the other hand, arc power is determined by

- the electric circuit (power system)
 - mains voltage $U_n = U_{rN}$,
 - short-circuit current I''_{k3p} ,
 - network impedance resistance-to-reactance ratio R/X
- and the electric equipment (construction): conductor spacing d .

This is expressed by the parameter

$$k_p = P_{\text{LB}} / S_k''.$$

The parameter k_p is the normalized arc power. It may simplified be approached by the curves of Fig. A1.1 and is mainly a function of the arc voltage

$$U_B = f(d; I''_k; U_{rN}; R/X)$$

and, thus, a function of the electrode gap that is determined by the conductor spacing d and the construction of the electric plant. Empirical equations for determining the arc voltage are given in special literature, e.g. in [15]. Special knowledge is required, among others, regarding the power equipment construction.

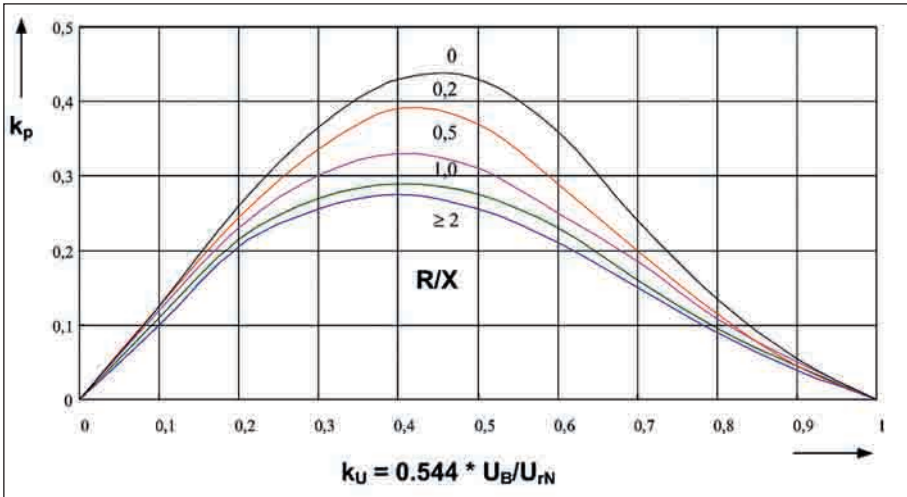


Fig. A1.1: Normalized arc power k_p for 3-phase arcing faults

For a rough estimation without considering the switchgear geometry the maximum values of the k_p curves may be used. The maximum values of the normalized arc power k_{pmax} can be calculated by

$$k_{pmax} = 0.29 \cdot (R/X)^{-0.17}.$$

Tab. A1.1 shows these values for worst case consideration. From practical experience the normalized arc power was found to be often within the guide value ranges indicated also in Tab. A1.1. Regarding the L.V. systems this guide value range is typical for installations of smaller conductor gaps d : $d \leq 40$ mm for equipment near to the transformer station, and $d \leq 70$ mm for equipment near to end-user equipment).

Consequently, the determination of arc power can be based on

- Taking into account power equipment geometry (relevant electrode gaps d)
- Guide values
- Maximum values of normalized arc power.

The approach to the actual values becomes smaller in the sequence of this list, the safety margins increase. With both, maximum values and guide ones, the practical problems in finding the geometry parameters are avoided at accuracy expenses.

The application of the calculation procedure is demonstrated in 8.5.

Maximum values		Guide values		
R/X	k_{Pmax}	system	k_P	validity range
< 0.1	0.45	L.V. (≤ 1000 V)	0.22...0.27	For $d \leq 40$ mm with equipment near to transformer; For $d \leq 70$ mm with equipment near to end-use
0.1	0.43			
0.2	0.38			
0.5	0.33			
1.0	0.29			
2.0	0.26	M.V. (> 1000 V)	0.04...0.10	
≥ 0.2	0.25			

Tab. A1.1: Maximum and guide values of the normalized arc power

Annex 2

Arc thermal risk parameters – definitions and terms

Arc Power P_{arc}

is the total active power converted in all arcs involved in arcing during the arc duration, depending on the according arc currents and the arc voltages. It is determined as mean value of the product of arc current and arc voltage. As normalized parameter k_p it is related to the short-circuit capacity and may be determined by means of the electric circuit parameters system rated voltage U_{rN} and prospective short-circuit current I_k " (see Annex 1)¹.

Arc energy W_{arc}

is the electrical energy (in kW or kJ) which is input and converted in fault arc during arcing. It is the product of arc active power P_{arc} and the arc duration t_{arc} (short circuit duration t_k), determined as integral (sum) of the product of the instantaneous arc voltage u_{arc} and arc current i_{arc} , and the time increment dt over the arc duration.

Incident energy E_i

is the total heat energy per area unit (in kJ/m^2 or kWs/m^2 or cal/cm^2)² received at a surface as a result of an electric arc. It has to be distinguished between direct exposure incident energy and transmitted incident energy. In testing it is measured by copper calorimeter.

The **direct exposure incident energy E_{io}** is the heat energy density resulting direct from the electric arc without PPE influences. It becomes effective if no PPE is used. Measuring calorimeters are directly exposed to the arc effects.

The **transmitted incident energy E_{it}** is that heat measured on the back of PPE in testing and becoming effective if PPE is used. It is that part of the total heat energy set free (direct exposure incident energy) transferred through the PPE.

1 The arc current flowing actually though the arc during the arc duration is subject of stochastic variations with time due to the nonlinear arc impedance. There is a difference between the arc current and the prospective short-circuit current I_k " because of this impedance; the r.m.s. value of the arc current i_{arc} is smaller than that one of I_k ". The prospective short-circuit current flows if the arc electrodes are bridged by a metallic connection of neglectible impedance (bolted short-circuit). The prospective short-circuit current characterizes the electrical fault arc environment (power system). The test current I_p adjusted for PPE testing in the electric test circuit is also indicated as prospective short-circuit current because reproducible test conditions may only be defined and provided by means of it.

2 kJ/m^2 and kWs/m^2 are equivalent units. The transformation rules into cal/cm^2 are: $1 \text{ cal/cm}^2 = 41.868 \text{ kJ/m}^2$; $1 \text{ kJ/m}^2 = 0.0023885 \text{ cal/cm}^2$.

Stoll criterion/Stoll curve

is a curve of thermal energy and time produced from data on human tissue tolerance to heat and used to predict the onset of second-degree burn injury [2]. The relationship is described by

$$E_{IStoll} = 50.204 \text{ kW} \cdot \text{m}^{-2} \cdot t_{max}^{0,2901}$$

(see Fig. A2.1). The curve is used as criterion on whether a person is protected against inadmissible skin burns or not, and thus for assessing if a PPE test is passed from the heat transfer point of view.

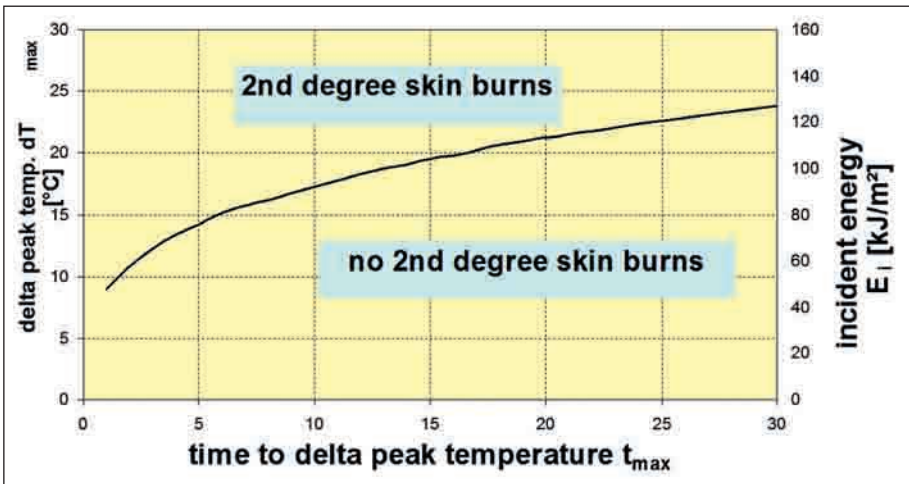


Fig. A2.1: Stoll curve – Criterion for the onset of second degree skin burns according to [2]

Arc flash thermal protection

Is the proved property of PPE to show arc thermal resistance (withstand arc thermal stress) and prevent second degree skin burns. It is the degree of thermal protection offered against electric arc under specific arc testing conditions. Tests can be made as arc rating test with an open test arc [3] or as box test with a directed arc [4].

Arc thermal resistance

is the ability of PPE to withstand thermal effects of an electric fault arc. Criteria are ignition and afterflame (burning time), break-open and hole formation, melting and melting-through, charring, shrinking, dripping, embrittlement.

Arc rating

Is the result of the arc rating test. It is determined as ATPV or E_{BT50} indicating the incident energy level of arc flash thermal protection of PPE tested by means of an open arc.

ATPV

Is the arc thermal performance value. It is a PPE material property indicating the result of PPE testing by means of an open arc (arc rating test). It is that direct exposure incident energy of an open arc which causes, as a result of the PPE, a transmitted incident energy equal to the Stoll limit for the onset of 2nd degree skin burns. In arc testing it is, according to the definitions in [3], the incident energy on a material or a multilayer system of materials that results in a 50 % probability that sufficient heat transfer through the tested specimen is predicted to cause the onset of a second degree skin burn injury based on the Stoll curve, without break-open.

Break-open

Is the material response evidenced by the formation of one or more openings in the material which may allow flame to pass through the material. It is the result of arc rating testing with an open arc in such cases where the PPE material shows break-open before the transmitted incident energy exceeds the Stoll limit. The break-open threshold energy E_{BT50} is the incident energy on a fabric or material that results in a 50 % probability that sufficient heat transfer through the tested specimen is predicted to cause the tested specimen to break open.

Arc flash protection class

is a category of arc thermal performance of PPE tested in the box test. It is the energy level of arc exposure adjusted in the test. Tested PPE shows arc thermal protection at minimum up to the class energy level³. Two classes are defined for box testing. Class 1 means a basic personal arc protection, class 2 an increased one.

Test energy level

is the level of electric arc energy W_{LBP} and according direct exposure energy E_{IOP} adjusted in the box test in the fault arc protection class selected and used for exposure of PPE. It characterizes the energy level up to which the PPE at least shows protection in practical work scenarios if the heat transmission is comparable⁴.

PPE protection level (equivalent arc energy) W_{prot}

is the equivalent electrical arc energy resulting in the same box test direct exposure incident energy level E_{IOP} also under heat transmission conditions that are different to the box test conditions regarding arc exposure distance a and transmission factor k_T .

³ In general the actual exposure energy limit up to which protection is provided is higher.

⁴ Because extreme heat transmission conditions exist due to the box test set-up, in practice the protection limit will be higher in many cases.


In case the transmission conditions are the same as the box test ones the equivalent arc energy is equal to the test energy level W_{LBP} .

Transmission factor k_T

is a parameter ranging between 1.0 and 2.4. It considers the influence of the power equipment construction surrounding the arc electrodes. In case of small compartments or narrow side and back walls around the arc electrodes resulting in small volumes the factor is 1.0.

Annex 3

Test report of an arc rating test – Determination of the ATPV of an example fabric

Date: Wed, Jan 12, 2011	High Current Test Laboratory Kinectrics Inc., Canada Test Summary	
Report # PO # XYZ		
Client Client name address		
Fabric description 340 g/m ² Navy Sateen - 87% cotton / 12% nylon / 1% antistat		
Reference Standard IEC 61482-1-1:2009 Live working- Flame resistant materials for clothing, Thermal hazards of an electric arc.		
Test Parameters: Test current: 8kA Distance to Fabric: 30 cm Arc Gap: 30 cm		
Number of samples analysed: 21 Incident Energy Range: 12 to 18 cal/cm ²		
Summary The arc rating of this material is intended for use as flame resistant clothing for workers exposed to electric arcs. The material used in this test method are in the form of flat specimens, actual performance of the complete garment may vary depending on the final design and assembly of the garment. This test method does not apply to the electrical contact or electrical shock hazard. Based on the data obtained and analysed in accordance with the latest version of the applicable standards, the following Arc Rating was calculated.		
Arc Thermal Performance Value, ATPV = 14.2 Cal/cm² Heat Attenuation Factor, HAF = 81.8%		
Data and observations of the fabric samples after the arc exposure were collected and summarized in the attached table. The graphs and statistics on the attached sheets provide more detailed information to better understand the Arc Rating assigned to this material. The client shall review this full report, the video recordings of the arc exposure and the photographs of the samples after the test to determine if the material meets the intended specification.		
Test performed by: Laboratory Name Address		Client contact information Client information Address

IEC 61482-1-1:2009

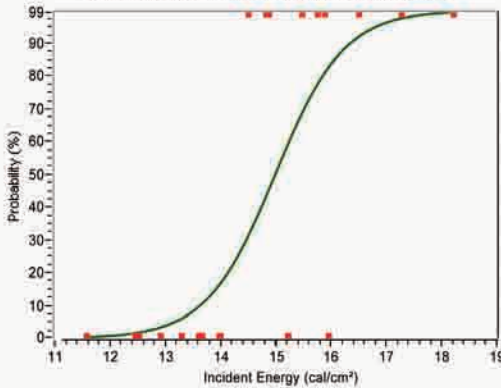
Live working- Flame resistant materials for clothing, Thermal hazards of an electric arc.



Client: Client name
address

Fabric: 340 g/m² Navy Sateen - 87% cotton / 12% nylon / 1% antistat
Description:

Determination of ATPV, 50% Probability of 2nd Degree Burn

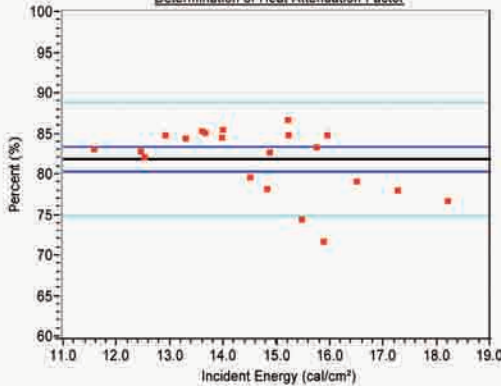


ATPV = 14.2 cal/cm²

Probability of Burn	Ei
5%	13.2
10%	13.6
20%	14.1
30%	14.5
40%	14.7
50%	15.0
60%	15.2
70%	15.5
80%	15.9
90%	16.4

Pts = 21
 # Pts above STOLL = 9
 # Pts Break-Open = 1
 # Pts always <STOLL = 3
 # Pts always >STOLL = 9
 # Pts within 20% = 19
 # Pts in mix zone = 9

Determination of Heat Attenuation Factor



HAF = 81.8 %

Confidence Intervals
 95% CI = 80.3 , 83.3

Data pts

Best Fit

95% CI

95% CI pts

Annex 4

Test report of a box test – Determination of the arc flash protection class of an example fabric

Extract of a Certificate Report

Enclosure 1 to Certificate Report No. Z 3709/XX-4791/XX		 SÄCHSISCHES TEXTIL FORSCHUNGS INSTITUT e.V.
PRÜFSTELLE TEXTIL <small>Durch die DGA Deutsche Gesellschaft für Akkreditierung (DGF) anerkannt im Deutschen Akkreditierungsamt - akkreditiertes Prüflaboratorium. Die Akkreditierung gilt für die in der Urkunde aufgeführten Prüfverfahren.</small>  		
<small>Durch die Zentralstelle der Länder für Sicherheitstechnik (ZLS) akkreditierte Prüfstelle für Produkte im Sinne der EG-Richtlinie für Persönliche Schutzausrüstungen 89/686/EWG und des 99-Art. 2 Gerätesicherheitsgesetz.</small> 		
<small>Wird der Federation International de L'Automobile (FIA) FIA zugelassene Stelle zur Prüfung von Fahrzeugen bestimmter Schutzleistung für Auto-Rennfahrer gemäß Standard FIA 8856-2000.</small>		
UNTERSUCHUNGSBERICHT TESTREPORT		
Order No. STFI:	1083/XX	
Order No applicant :		
Date of Test Report:	01 January 2011	
Testing officer:	Mehner	
Manufacturer:		
Applicant:		
Testing application:		
of	01 January 2011	
order receipt on	01 January 2011	
sample receipt on	taken from order A 0713/XX	
<small>Textilforschungsinstitut STFI e.V. Mehr als 100 Jahre Erfahrung in der Textilprüfung nach DIN EN ISO 9001 Textilverfahrensinstitut der Prüfstände des STFI e.V. Mehr als 100 Jahre Erfahrung in der Textilprüfung nach DIN EN ISO 9001 Es gelten die allgemeinen Geschäftsbedingungen des STFI e.V. und der DGF (www.stfi.de/geschaeftsbedingungen)</small>		www.stfi.de
<small>Verwaltungssitz: Post: 01109 Dresden, Furtak</small>	<small>Sächsisches Metallprüfungsamt e.V. Bismarckstr. 25, 76201 Chemnitz, Germany</small>	<small>Unter der Fiktivadresse Dr.-Ing. Stephan Köhler</small>
		<small>Stamm: +49 (0) 371 31 24 7 10 Telefax: +49 (0) 371 31 24 7 10</small>
		<small>© STFI Herstellung: August 2010</small>



Test specimen: fabric for protective clothing

Marking by applicant	Coding in Test House	Coding for arc testing
fabric Ref. S/853 87% cotton / 12% nylon / 1% antistat. approx. 340 g/m ² royal blue or other colours of the same dye stuff class	sample 01	08-DU1 / 08-DU2 08-DU4 / 08-DU5

The sampling was carried out by applicant. In the testing house are no knowledge's about method of sampling

Test program/Test conditions:

Technical type examination in accordance with EN 61482-1-2:2007-01 in connection with IEC 61482-2 Ed.1 2009-04.

Implementation of the pre-treatment:

5 washing treatments according to ISO 6330:2000, method 2A/+E, Wascator

Property	Test method
<i>according to IEC 61482-2:</i>	
Dimensional change after 5 washing cycles	EN 25077:1993/ EN ISO 3759:1995/ EN ISO 6330:2000
Limited flame spread after 5 washing cycles	EN ISO 15025:2002 surface ignition, flaming time 10s
Tear strength	EN ISO 4674-1:2003, method B
Tensile strength	EN ISO 13934-1:1999
Arc thermal resistance requirements:	EN 61482-1-2, material box test method ¹⁾ class 1...4 kA class 2...7 kA

1) Arc thermal resistance test according to EN 61482-1-2

Testing of fabrics according to EN 61482-1-2:2007-01, "Live working - Protective clothing against the thermal hazards of an electric arc - Part 1: Test methods - Method 2: Determination of arc protection class of material and clothing by using a constrained and directed arc (box test)".

Test conditions:

- prospective electric arc current: **4 kA** (corresponding to **Class 1** of EN 61482-1-2)
- Arc duration: 500 ms
- Voltage of open test circuit: 400 V AC (50 Hz)
- Copper- / aluminium electrodes: electrodes gap 30 mm
- Electrodes distance to sample: 300 mm

The tests were carried out in co-operation with High Current Testing Thomas v. Freyberg at the International Institute for Product Safety in Bonn/ Germany. The Sub-lab works on basis of quality management system for the test method. A representative of STFI was present during the tests.



Test results:

Property - fabric		Dimension	Test results	
			fabric [redacted]	
			S/853	
<u>IEC 61482-2</u>			S/853	
Dimensional change	lengthwise	%	-2,2	
	across	%	-1,2	
Limited flame spread			lengthwise	across
further flaming to top or sides			no	no
hole formation			no	no
flaming, melting debris			no	no
afterflame time		s	0	0
afterglow time		s	0	0
Tear strength	lengthwise	N	38	
	across	N	34	
Tensile strength	lengthwise	N	1082	
	across	N	615	

Arc thermal resistance requirements	Measure	Test results			
		fabric [redacted]			
		S/853			
		08-DU1	08-DU2	08-DU4	08-DU5
class 1 / 4kA					
Burning time	visual	0 s	0 s	0 s	0 s
Hole formation	visual	no	no	no	no
Melting through to the inside	visual	no	no	no	no
Maximum temperature rise dT_{max} at the backside of the specimen	calorimeter 1	10,6 K	9,7 K	10,0 K	9,4 K
	calorimeter 2	8,9 K	9,4 K	9,7 K	8,6 K
Maximum time t_{max}	Computer data				
	calorimeter 1	18,5 s	14,7 s	14,7 s	19,5 s
	calorimeter 2	22,3 s	25,6 s	25,3 s	23,2 s
Comparison: allowed temperature rise to avoid burning 2nd degree (STOLL-values at time t_{max})		20,7 K	19,4 K	19,4 K	21,0 K
		21,9 K	22,8 K	22,7 K	22,1 K
Acceptance criteria		met	met	met	met

Test results refer to the delivered specimen. Test protocols and statistical information about test data can be viewed in the test house. This Test Report consists of 3 pages with 1 enclosure and should not be published in parts.

Dr.-Ing. Matthias Mägel
Head of the testing department



Fabric certificate on a box test (example)

Testing and fabric certificate with arc flash protection class and requirements according to IEC 61482-2

ZERTIFIZIERUNGSTELLE PSA		
<p>Durch die Zentralfabrik der Länder für Sicherheitstechnik (ZLS) akkreditierte Zertifizierungsstelle für Produkte im Sinne der EG-Richtlinie für Persönliche Schutzausrüstungen 89/686/EWG und des §9 Abs. 2 Gerätesicherheitsgesetz, Kenn-Nr. 0516</p>		 ZLS-ZE-693/09
Certificate		
Technical type-examination No. Z 3709/XX-4791/XX		
Date: 01 January 2011		
Applicant:		
Manufacturer:		
Application of:	01 January 2011	
Test specimen:	Fabric Ref. S/853	
Type and designation:	87% cotton / 12% nylon / 1% antistat. approx. 340 g/m ²	
Intended use:	fabric for protective clothing against thermal hazards of an electrical arc	
Results of the technical type examination:	Test Report STFI No. 1083/XX of 01 January 2011 Certification Report STFI No. Z 3709/XX-4791/XX of 01 January 2011	
<p><u>This Certificate applies the suitability of tested fabric s/853 with essential requirements of document Council Directive 89/686/EEC. The fabric is suitable for using for protective clothing against thermal risk of an electrical arc and meets the requirements of Class 1 - 4kA according to EN 61482-1-2:2007.</u></p>		
<p>This Certificate is not a proof for norm conformity of protective clothing produced from it with regard to processability and design. This is not an entitlement to use the CE- or GS-Mark. It is valid - in dependence on the validity of the test and certification foundations - by 01 January 2014. To renew the validity of the certificate is possible on application.</p>		
<p>This document consists of Certificate and Certificate Report with 3 pages and 2 enclosures.</p>		
 Dipl.-Ing.-Ok. Andreas Berthel Managing Director STFI e.V.	 Dipl.-Ing. Hendrik Beier Head of Certification Department Notified Body No. 0516	
In German: Die Zentralfabrik der Länder für Sicherheitstechnik, Aves 235, D-37081 Jöhnde, Tel. (0530) 471-10000, Fax (0530) 471-10001, www.zls.de In English: Central Fabrication Institute for Safety Technology, Aves 235, D-37081 Jöhnde, Germany, Tel. +49 (0) 530 471-10000, Fax +49 (0) 530 471-10001, www.stfi.de		

Annex 5

Arc testing of gloves and face shields by means of the Box Test

Testing gloves

The principle set-up of the box test is modified as shown in Fig. A5.1. In glove testing two sensor panels are used in parallel. One test panel carries the test sample, and the calorimeter of this panel measures the transmitted incident energy. The other one is not covered, so the calorimeter measures in each shot the direct exposure incident energy at the same time.

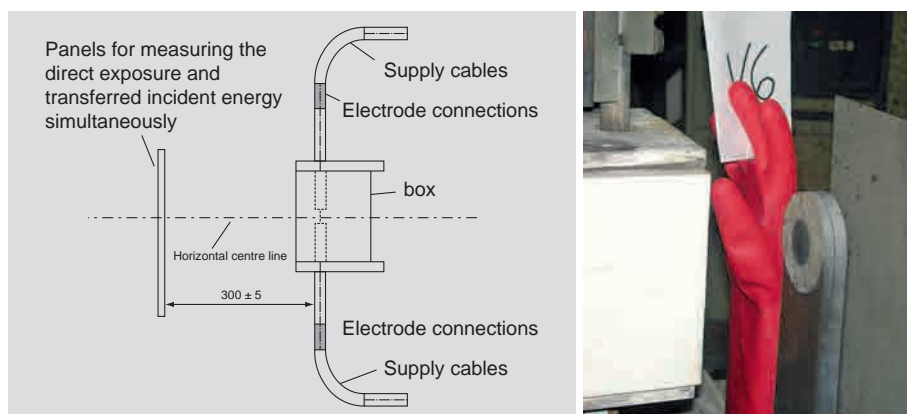


Fig. A5.1: Box test set-up for glove testing with glove panels equipped by calorimeters

For testing gloves an additional protection class 3 characterizing a higher level of arc exposure can be applied. This level is reached by reducing the distance of the panels (sample, calorimeters) to the arc to $a = 150$ mm with the arc energy level of class 1. This arc flash protection class 3 is interesting because of the closer distance the hands or gloves, respectively, have got in practical working activities (compared to body and face of persons). Test examples are shown in the Fig. A5.2 and A5.3.

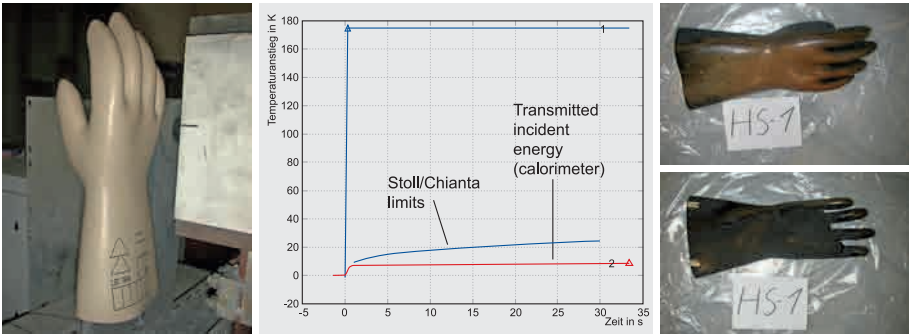


Fig. A5.2: Result of a voltage-class-1 latex glove under arc test class 3 conditions (test passed)

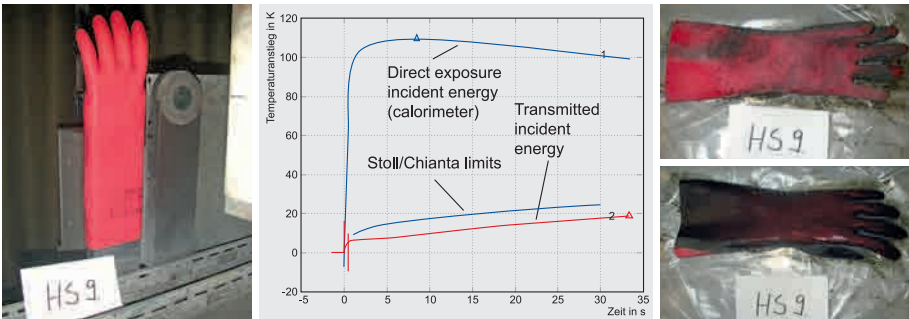


Fig. A5.3: Test of voltage-class-0 latex glove with textile in-liner under arc test class 2 conditions (test passed)

Testing face shields

For testing visors a test head with several calorimeters for measuring the transmitted incident energy (for assessing skin burns behind the visor) is used.

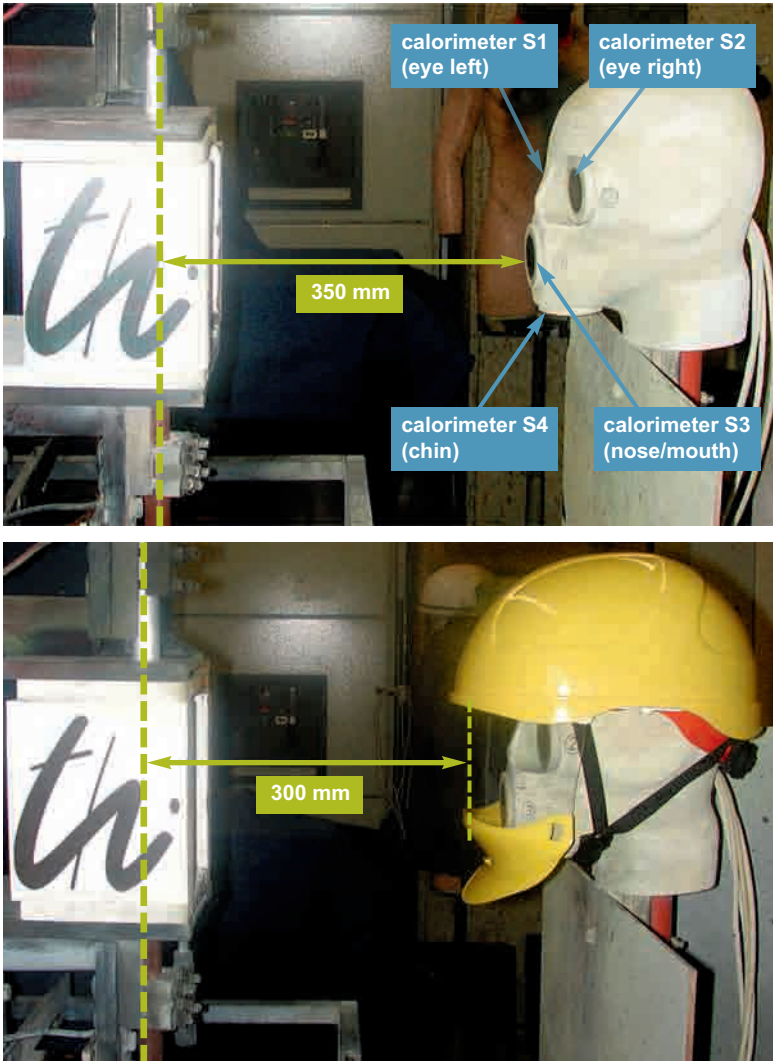


Fig. A5.4: Test set-up with test head developed for visor testing

The calorimeters are measuring the heat exposures at different face regions. The closest position (to the arc axis) has got the calorimeter in the mouth/nose region. It should be placed in a distance of 350 mm, centred to the arc axis horizontally and vertically. Very important is also the chin calorimeter indicating the heat in the lower part of the head. The test configuration as shown in Fig. A5.4 is suitable for assessing the visor behaviour and effects in the standard wearing position because of mounting the visors on the helmets. Worst case testing of the helmet arc resistance is not possible with this configuration. For this the helmet should be centred to the arc axis also horizontally in separate tests.

Figure 8.5 shows an example of the results of a class 1 visor test.

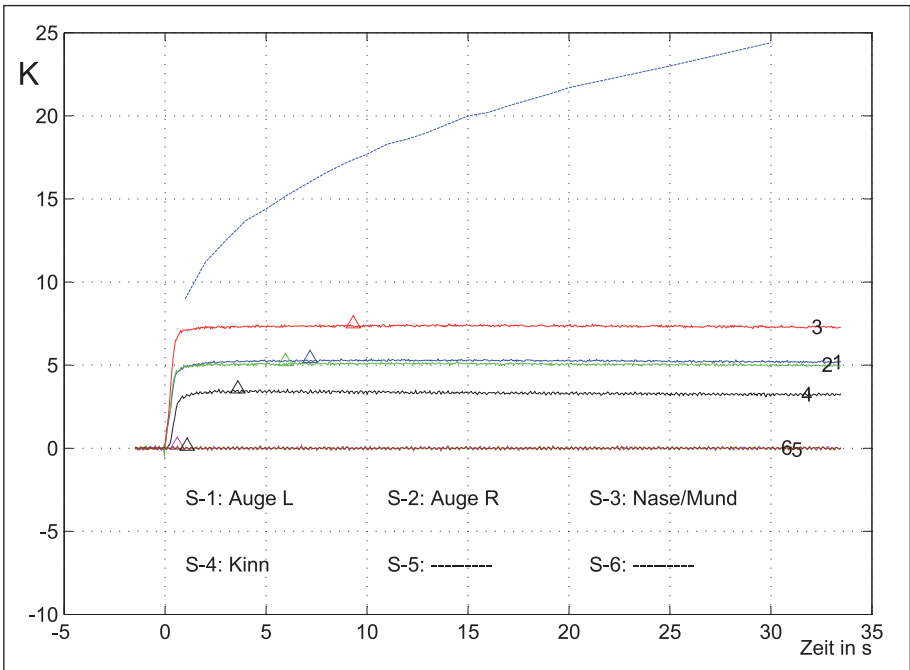


Fig. A5.5: Calorimeter responses of a class 1 box test of a helmet-visor combination (test is passed)

Annex 6

Arc risk calculation algorithm for the selection of PPE tested according to the box test

A6.1 General advices

Arcing processes as well as arc parameters generally escape exact calculations. Very complex non-linear relationships, mutual interdependences and influences being strongly changing with time and cannot be defined, prevent exact evaluation practically. The external behavior of an electric fault arc is stochastic and subject of very strong statistical dispersion. The determination of arc parameters is generally reduced to empirical consideration with more or less well approaching to reality. With respect to practicability simplest empirical calculation basics are used in the following. Nevertheless such approaches require a number of basic data of the electric power system, equipment and protective devices. In the algorithm 3 steps of consideration are offered to the user for determining energy values. These steps are based on different input data and, thus, require various efforts for analyzing, but also result in a differentiated accuracy:

- **EV** – the use of extreme values for worst case consideration abstracting from equipment specifics and covering all possible influences, and result, under circumstances, in a distinct safety margin in the case under study
- **GV** – the use of guide values sparing detailed analysis and covering a larger number of practical cases
- **DV** – the use of detailed values taking into account equipment data for an exacter estimation with the consequence of higher expenditures in calculation.

The need of input data and calculation expenses increases with higher requirements to accuracy and abstention of safety margins. Worst case considerations are helpful for users without detailed information or knowledge, or if rough estimations of safety needs or necessary measures are aimed at. No detailed knowledge and experiences in arc risk estimation are necessary. Because of the likely poor accuracy these considerations can lead, under circumstances, to the result that no practical solutions for protection by only the PPE can be found. Regarding the use of the guide values no accuracy and probability statement of the results is possible.

Experiences and additional knowledge regarding arcing faults and risks are essential for the detailed consideration. It is the most exact alternative. It can be recommendable, under circumstances, to include engineers skilled and experienced in this field in the analysis work, or make demands upon the support of experts for arc risk assessment.

A6.2 Working steps of the algorithm

Based on the specific work place conditions, the following steps have to be performed.

step	Determination/procedure	Result parameter	result
1	<p>Power system analysis System voltage (network rated voltage)</p> <p>Power equipment analysis Conductor spacing (electride gap)</p>	<p>U_{rN}</p> <p>d</p>	
2	<p>Short-circuit current calculation (acc. IEC 60909) Maximum current value Minimum current value Impedance ratio</p>	<p>$I''_{k3p \max}$ $I''_{k3p \min}$ R/X</p>	
3	<p>Arcing fault duration Fault current attenuation: DV: k_B acc. to [15] or GV: $k_B = 0.5$ Minimum fault current: $I_{kLB} = k_B \cdot I''_{k3p \min}$</p> <p>Clearing time: From I-t characteristic of protective device by means of I_{kLB}</p>	<p>k_B</p> <p>I_{kLB}</p> <p>t_k</p>	
4	<p>Expected arc energy at work place Short-circuit calacity: $S''_k = \sqrt{3} \cdot U_{rN} \cdot I''_{k3p \max}$</p> <p>Normalized arc power: DV: k_P acc. to [15] or GV: k_P acc. to Tab. A1.1 EV: $k_{Pmax} = 0.29 \cdot (R/X)^{-0.17}$ (or Tab. A1.1)</p> <p>Arc power $P_{LB} = k_P \cdot S''_k$</p> <p>Arc energy $W_{LB} = W_{arc} = k_P \cdot S''_k \cdot t_k$</p>	<p>S''_k</p> <p>k_P</p> <p>P_{arc}</p> <p>W_{arc}</p>	
5	<p>Working distance</p>	a	

6	Standard box test level of arc energy W_{arcP}	W_{arcP1} W_{arcP2}	158 kJ 318 kJ
7	PPE protection level W_{prot} Transmission coefficient DV: 1...2.4 acc. to equipment volume GV: 1 EV: 1 Equivalent arc energy (protection level) $W_{prot} = k_T \cdot \left(\frac{a}{300 \text{ mm}} \right)^2 \cdot W_{arcP}$	k_T W_{prot}	
8	Result Comparison: $W_{arc} ? W_{prot}$ PPE: $W_{arc} \leq W_{prot1}$ PPE: $W_{arc} \leq W_{prot2}$		Class 1 Class 2

A6.3 Exercise examples and case studies

A6.3.1 Work in the LV main distribution board of transformer sub-station

In a first example the risk analysis shall be made for work activities in the LV switch board of a transformer station 20 kV/0.4 kV. Typical live works are switching activities such as inserting and withdrawing fuses or cleaning. It shall be assumed that there is a switching state with only one feeding transformer. The transformer has a rated capacity of 400 kVA with a normalized short-circuit voltage of 4 %. The protective device for interrupting fault in the work place region is the transformer NH fuse 400 kVA (400 V AC, operational characteristic gTr) with the I-t curve shown in the diagram of gTr fuse characteristics in Fig. A6.1.

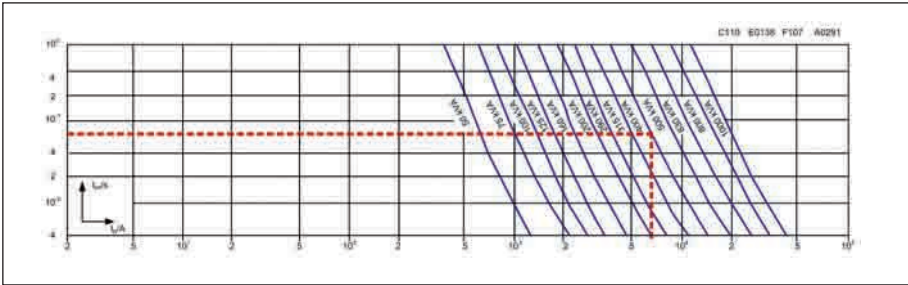


Fig. A6.1: Time current characteristics of NH fuses gTr 400 V AC

The risk analysis will be based on the extreme values. This is the worst case consideration covering all possible influences and including safety margins. Following the steps of A6.2 the calculations result in:

Step	Determination/procedure	Result parameter	Result
1	Power system analysis: System voltage (network rated voltage)	U_{rN}	400 V
	Power equipment analysis: Conductor spacing (electride gap)	d	Not relevant
2	Short-circuit current calculation (acc. IEC 60909)		
	Maximum current value (prospective short-circuit current)	$I''_{k3p \max}$	14.1 kA
	Minimum current value (prospective short-circuit current)	$I''_{k3p \min}$	12.7 kA
	Impedance ratio	R/X	0.16
3	Arcing fault duration		
	Fault current attenuation: DV: k_B acc. to [15] or GV: $k_B = 0.5$ (EV)	k_B	0.5
	Minimum fault current: $I_{kLB} = k_B \cdot I''_{k3p \min} = 0.5 \cdot 12.7 \text{ kA} = 6.35 \text{ kA}$	I_{kLB}	6.35 kA
	Clearing time: From I-t characteristic of 400 kVA gTr fuse acc. to Fig. A6.1 with $I_{kLB} = 6.35 \text{ kA}$	t_K	0.072 s

4	Expected arc energy at work place Short-circuit calacity: $S_k^* = \sqrt{3} \cdot U_{MN} \cdot I_{k3p\ max}^* = \sqrt{3} \cdot 400V \cdot 14.1\ kA = 9.77\ MVA$	S_k^*	9.77 MVA
	Normalized arc power: DV: k_P acc. to [15] or GV: k_P acc. to Tab. A1.1 EV: $k_{Pmax} = 0.29 \cdot (R/X)^{-0.17}$ (or Tab. A1.1)	K_P	0.396
	Arc power $P_{LB} = k_P \cdot S_k^* = 0.396 \cdot 9.77\ MVA = 3.869\ MW$	P_{arc}	3.869 MW
	Arc energy $W_{arc} = k_P \cdot S_k^* \cdot t_k = 0.396 \cdot 9.77\ MVA \cdot 0.072\ s = 279\ kJ$	W_{arc}	279 kJ
5	Working distance	a	300 mm
6	Standard box test level of arc energy W_{arcP}	W_{arcP1}	158 kJ
		W_{arcP2}	318 kJ
7	PPE protection level W_{prot}		
	Transmission coefficient DV: 1...2.4 acc. to equipment volume GV: 1 EV: 1	k_T	1
	Equivalent arc energy (protection level) $W_{prot} = k_T \cdot \left(\frac{a}{300\ mm}\right)^2 \cdot W_{arcP} = 1 \cdot \left(\frac{300\ mm}{300\ mm}\right)^2 \cdot W_{arcP}$	W_{prot1} W_{prot2}	158 kJ 318 kJ
8	Result Comparison: $W_{arc} ? W_{prot}$ PPE: $W_{arc} = 279\ kJ > W_{prot1} = 158\ kJ$ PPE: $W_{arc} = 279\ kJ < W_{prot2} = 318\ kJ$		Class 2

The arc energy expected at the work place is at maximum 279 kJ.

For the work activities under study it can be concluded that the working distance becomes not below 300 mm. That is the minimum distance between the upper torso and the arc in a normal working position of a person. Since, furthermore, worst case thermal transmission conditions are assumed the protective level of the PPE for the working place (equivalent arc energy) is equal to the PPE test level of arc energy. Consequently, PPE of the box test protection class 2 is necessary and provides protection.

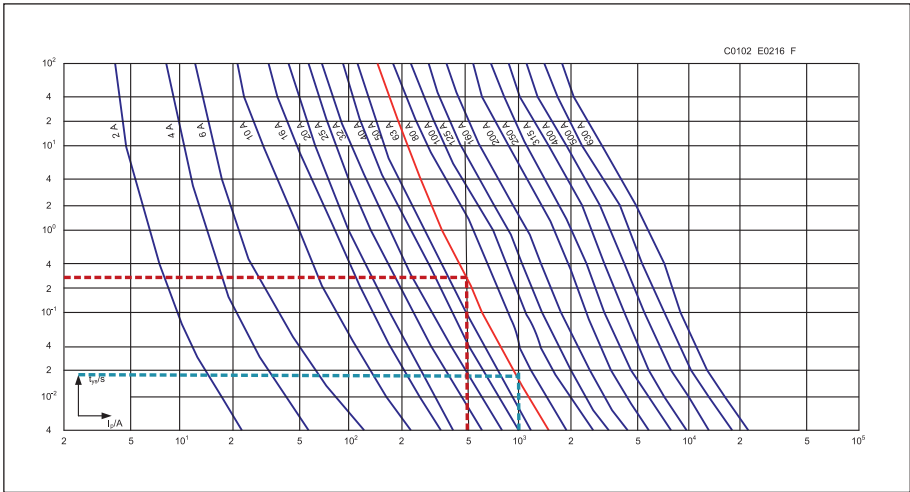


Fig. A6.2: Current-time characteristics of NH fuses gG 400 V AC

A6.3.2 Work in house installations

A further example to be considered are live working activities in the house installations behind the house service box fuses.

The installation is supplied by an house connection box with a rated current of $I_N = 63 \text{ A}$ at $U_{rN} = 400 \text{ V}$. From the short-circuit calculation a prospective short circuit current of $I''_{k3p} = 4 \text{ kA}$ is obtained. The supply is protected by a 63 A NH gG fuse. First, the clearing time of the fuse will be determined. This has to be based on the actual arcing fault current. The guide value of 0.5 is assumed for taking into account the current attenuation¹, meaning that the arc current is half of the size of the prospective short circuit current, i.e. 2 kA. From the fuse characteristic (Fig. A6.2) a release time t_k lower than 10 ms can be read for a current of 2 kA. The fuse behaves current-limiting, thus an exact clearing time cannot be predicted. For safety reasons the short circuit duration is appointed to $t_k = 10 \text{ ms}$ in such cases.

The normalized arc power will be determined also by means of the guide values applicable for low-voltage systems (0.22 to 0.27): a value $k_P = 0.25$ is chosen².

- 1 As mentioned above, experience shows that the current attenuation in LV systems ranges between 0.5 and 1.0 in most of the cases.
- 2 Experience shows in accordance with the typical conductor spacing in end-use LV equipment that guide values of normalized arc power are in this range; $k_P = 0.25$ characterizes very well most of these conditions.

According to the equation

$$W_{\text{arc}} = k_P \cdot \sqrt{3} \cdot U_N \cdot I_{k3p} \cdot t_k$$

$$\begin{aligned} W_{\text{arc}} &= 0.25 \cdot \sqrt{3} \cdot 400 \text{ V} \cdot 4 \text{ kA} \cdot 0.01 \text{ s} \\ &= 6.928 \text{ kJ} \end{aligned}$$

an arc energy of about 6.9 kJ has to be expected in the case of an arcing fault in the installations downstream the house connection box.

In the next step the protective level of the PPE at the working place under consideration (equivalent arc energy which the PPE selected will offer protection up to) is determined. In house installations we have small-scale systems with side, rear and bulkheads which are similar to the geometry of the box, consequently a transmission factor of $k_T = 1$ has to be used³.

The working distance a is assumed with $a = 300$ mm. Consequently the protection levels are equal to the test levels: $W_{\text{arcP1}} = 158$ kJ (for class 1) and $W_{\text{arcP2}} = 318$ kJ (for class 2).

Finally, from the comparison to the expected arc energy of $W_{\text{arc}} = 6.93$ kJ follows that PPE of class 1 provides the necessary protection.

Tab. A6.1 summarizes the calculation steps. For studying similar cases, in addition, different prospective short circuit currents at the work place (2 kA, 1 kA) were considered, too.

³ The value of k_T will become 2.4 for open systems. Practically, this means that the PPE is exposed by the 2.4 times smaller thermal energy in case of an open arc at the worksite (compared to the narrow box construction).

Working place	Behind house connecting box		
Electrical data:			
U_{nN}	400 V		
I_N	63 A		
I''_{k3p}	4 kA	2 kA	1 kA
S''_k	2.771 MVA	1.386 MVA	0.693 MVA
Protection device	fuse NH 63 A gG		
current attenuation factor k_B	0.50		
Fault current $I_{kLB} = k_B * I''_{k3}$	2 kA	1 kA	0.5 kA
clearing time from characteristic with I_{kLB} (Fig. A6.2) t_k	10 ms	18 ms	300 ms
Normalized arc power k_P (LV: 0,22 ... 0,27)	0.25		
Arc energy expected $W_{arc} = k_P * 1.73 * U_{rN} * I''_{k3p} * t_k$	6.93 kJ	6.24 kJ	51.96 kJ
Determination of the equivalent energy	Class 1	Class 2	
Test level of arc energy Transmission coefficient k_T $k_T = 1$ small compartments or narrow side and back walls $k_T = 2.4$ open arc	158 kJ 1	318 kJ	
Working distance a to the active parts	300 mm		
PPE protection level at work place $W_{prot} = k_T * (a/300 \text{ mm})^2 * W_{arcP}$	158 kJ	318 kJ	
Decision for the PPE $(W_{arc} \leq W_{prot})$	6.93 kJ < 158 kJ Class 1	6.24 kJ < 158 kJ Class 1	51.96 kJ < 318 kJ Class 1

Tab. A6.1: Arc risk calculation for house installation (variants)

Annex 7

Matrix of work activities at LV power equipment and PPE required

Type of Equipment* Work Activity*	Measurement and control installations, fuse rating up to 16 A	Power or energy control and metering installations, fuse rating up to 100 A	Building installations, fuse rating up to 63 A	Cables, control boards and switchgear assemblies	Overhead lines
Approaching of voltage and phase detectors	-	Class 1	Class 1	Class 1 or 2 depending on arc energy	Class 1 or 2 depending on arc energy
Approaching of test, measuring and adjustment items	-	Class 1	Class 1	Class 1 or 2 depending on arc energy	Class 1 or 2 depending on arc energy
Inserting and removing of NH fuse cartridges being not protected against direct touching	-	Class 1	Class 1	Class 1 or 2 depending on arc energy	Class 1 or 2 depending on arc energy
Test activities for fault identification and location in auxiliary electric circuits	-	Class 1	Class 1	Class 1 or 2 depending on arc energy	-
Functional checks of devices and installations, setting into operation and testing depending on arc energy	-	Class 1	Class 1	Class 1 or 2 depending on arc energy	Class 1 or 2 depending on arc energy

Control, maintenance and replacement activities	-	Class 1	Class 1	Class 1 or 2 depending on arc energy	Class 1 or 2 depending on arc energy
Switching activities in connection with the 5 safety rules	-	Class 1	Class 1	Class 1 or 2 depending on arc energy	Class 1 or 2 depending on arc energy
Live working, such as connecting, mounting, montage and de-montage, preparation, oiling, covering, cleaning**	-	Class 1	Class 1	Class 1 or 2 depending on arc energy	Class 1 or 2 depending on arc energy

* valid for power equipment in LV systems (U_{rN} up to 1000 V AC)

** work activities belonging to are mounting of cable branch-T for house connection, montage/de-montage of single fuse-link strips/blocks and fuse switching disconnectors in cable distribution boards, changing power meters and switch timers, suspension of customer plants, montage work for fault location in auxiliary circuits, bridging or by-passing of partial circuits, maintenance in electric equipment, covering of non-insulated LV conductors or lines.

Summary of symbols

a	mm	Exposure distance, working distance
ATPV	cal/cm ² or kJ/m ²	Arc Thermal Performance Value
c _P	Ws*m ² /kg*K	Specific heat
d	mm	Electrode gap
dT _{max}	K	Delta peak temperature (maximum temperature rise)
E _{BT50}	cal/cm ² or kJ/m ²	Break-open incident energy (50 % value)
E _i	kJ/m ² or cal/cm ²	Incident energy
E _{i0}	kJ/m ² or cal/cm ²	Direct exposure incident energy
E _{it}	kJ/m ² or cal/cm ²	Transmitted incident energy
f _T		Transmission function
I'' _k	A	Prospective subtransient short-circuit current (rms value)
I'' _{k3p}	A	Prospective three-phase short-circuit current (subtransient)
I'' _{k3pmax}	A	Maximum prospective three-phase short-circuit current (subtransient)
I'' _{k3pmin}	A	Minimum prospective three-phase short-circuit current (subtransient)
I _{kLB}	A	Actual arcing fault short-circuit current
i _{LB}	A	Arc current, instantaneous value
I _N	A	Fuse rated current
k _B		Current attenuation factor
k _P		Normalized arc power
k _{Pmax}		Maximum value of the normalized arc power
k _T		Transmission factor
k _U		Voltage factor
m	kg	Mass
P _{arc} = P _{LB}	kW	Arc active power
R	Ohm	Resistance (of the network impedance)
R/X		Impedance ration, resistance-to-reactance ratio
S'' _k	MVA	Short-circuit capacity
t	s	time
t _{arc} = t _k	s	Arc duration, short-circuit duration (clearing time)
t _{max}	s	Time to delta peak temperature, time period of heat transfer
U _B	V	Arc voltage (mean value)
U _{LB}	V	Arc voltage, instantaneous value

Summary of Symbols

$U_{rN} = U_n$	V	Power system rated voltage
$W_{arc} = W_{LB}$	kJ	Electric arc energy
$W_{arcP} = W_{LBP}$	kJ	Arc energy of arc flash protection class, test level
W_{prot}	kJ	Equivalent arc energy, protection level
X	Ohm	Reactance (of the network impedance)
x_i		Influence parameter



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