THE NEW STANDARD IEC 61482 AND EXPERIENCES WITH THE BOX METHOD FOR TESTING OF CLOTHING FOR PROTECTION AGAINST THE THERMAL HAZARDS OF AN ELECTRIC ARC

Holger Schau, Technische Universität Ilmenau/Germany

1 Introduction

There is a general hazard and potential risk of human injury due to electric arcs particularly in case of fault arcs which may internally occur with short-circuits in electric installations. These arcs cannot be avoided totally. In particular those people are concerned, working at, in or in the vicinity of these installations for professional reasons, particularly in case of live working. Their working clothing may essentially contribute to protect them particularly against the thermal arc consequences or be actually a base for the according protection.
It is of greatest importance for the personnel mounting, repairing, maintaining or operating electrical equipment and installations to be safely protected in each situation actually. There may not result any unacceptable health risk, the suitability of clothing has to be analysed and proved. The properties and requirements to be fulfilled by protective clothing as well as the way and procedures for proving and testing have to be defined. Particularly, reliable tests are necessary to confirm the working clothing to be arc resistant and guaranteeing the protective level required. Test method, procedure, set-up and parameters must meet the according practical needs. The test conditions have to be selected and terminated in accordance with the relevant power network and installation ones, and the practical exposure scenarios as well. Furthermore, quantitative assessment and evaluation is necessary in testing. The calorimetric arc effects are to be measured, a calorimetric analysis of the tests has to be carried out.

2 Hazards due to electric fault arcs

Huge amounts of power are converted in case of arcing. Electric fault arcs are very intensive energy sources, particularly heat sources. Direct consequences of electric fault arcs are

- a pressure wave with high gradient
- radiation in the overall wave length range
- metal particles and splash

and following

- over pressure
- forces on the body
- sound emission
- optical radiation (intensive light)
- heat flux[1]-[5].

The arcing faults are stochastic processes. As the result, the arc effects and consequences have also stochastic characteristics [3]. Exposure indices and arc parameters are distributed in scattering ranges and have to be statistically considered.

As shown by field tests and experimental studies [4] [5] the direct and indirect arc consequences generally depend on the

- arc energy
- arc power
- time duration of arcing
- distance to the arc.

Often there is a direct proportionality between the arc energy W_{LB} and the effects (exposures EXP) [5], especially in case of the thermal arc effects

$$EXP = a + b\, W_{LB}.$$

Regarding the personal risks it has generally to be distinguished between direct and indirect exposure.

The arc energy to be expected in case of arcing results from the power conversion in all arcs engaged in the fault.

$$W_{LB} = \int_0^{t_k} \sum_{\upsilon} u_{LB} \cdot i_{LB} \cdot dt = P_{LB} \cdot t_k$$

It depends on the total arc power P_{LB} and the arc duration t_k. The arc duration is equal to the fault duration and is determined by the clearing time of the network short-circuit protection [1][2]. The arc power

$$P_{LB} = k_P \; S_k''$$

is depending, on the one hand, on the network short-circuit capacity

$$S_k'' = \sqrt{3} \; U_{Nn} \; I''_{3p}$$

On the other hand, arc power is determined by the electric circuit (power system: mains voltage U_{Nn}, short-circuit current I''_{k3p}, network impedance resistance-to-reactance ratio R/X) and the electric plant (construction), expressed by the parameter

$$K_p = P_{LB} / S_k'' .$$

This factor (see Fig. 1) is mainly a function of the arc voltages

$$U_{LB} = f\,(d;\, I''_k;\, U_{Nn};\, R/X)$$

and, thus, a function of the electrode gap that is determined by the conductor spacing and the construction of the electric plant [3].
The arc energy is a well defined measure and rating of the concrete conditions of the fault location. On the base of the arc energy it is possible to assess what actual arc

hazards have to be covered by certain test conditions and, vice versa, how far special test conditions cover the arc risks practically existing.

For the thermal arc effects furthermore the energy density received at the surface affected is of importance. This is the incident energy E_i [6].

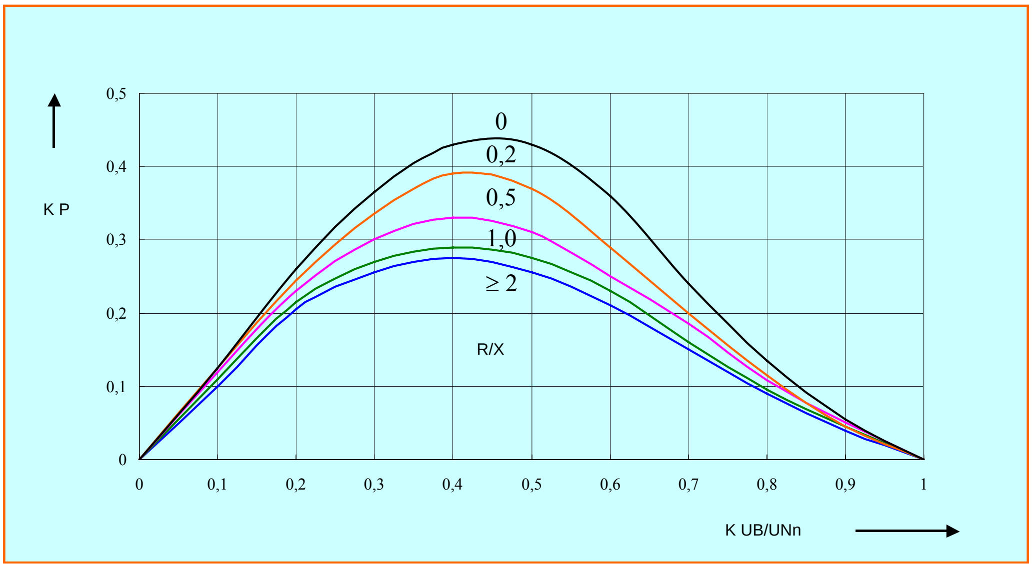

Figure. 1: Factor k_P for determination of arc power [3]

3 Standards in the field of protective clothing against electric arcs

3.1 Existing standards

At present there is with IEC 61482-1 only one international standard [7]. This standard is presently under maintenance. It is a test standard specifying testing of material and garments for clothing against the thermal hazards of electric arcs. The tests are aimed to determine the arc thermal performance value ATPV. This ATPV is a material property characterising the protective effect referring to second degree skin burns.

For testing an open electric arc in a MV test circuit is fired. The protection effect of the material is determined by measuring the heat flux. The test current in the electric circuit and/or the arc duration are changed as long as the limiting conditions of second degree skin burns have been reached.

In the European standardisation there is only a CENELEC Technical Specification CLC TS 50354 [8] at present. It is also a test standard but quite different to the ATPV test according to the IEC mentioned. This standard is based on tests with a directed arc in a LV test circuit. There are fixed test parameters characterising protection classes. The performance of the materials and garments is only visually be assessed, there is no heat flux measurement.

Regarding the requirements for protective clothing against the thermal hazards of electric arcs there is no standard up to now. However an according standard is urgently needed in order to have a base for assessing, classifying and certificating clothing with respect to the use for protecting personnel when working in electric plants (service activities, live working, working in the vicinity of live parts).

3.2 Development in standardisation

Presently there a several activities for changing and improving the situation described. In future both different practice-oriented test standards as well as a standard regarding the requirements for arc protective clothing will be available for use (Fig. 2).

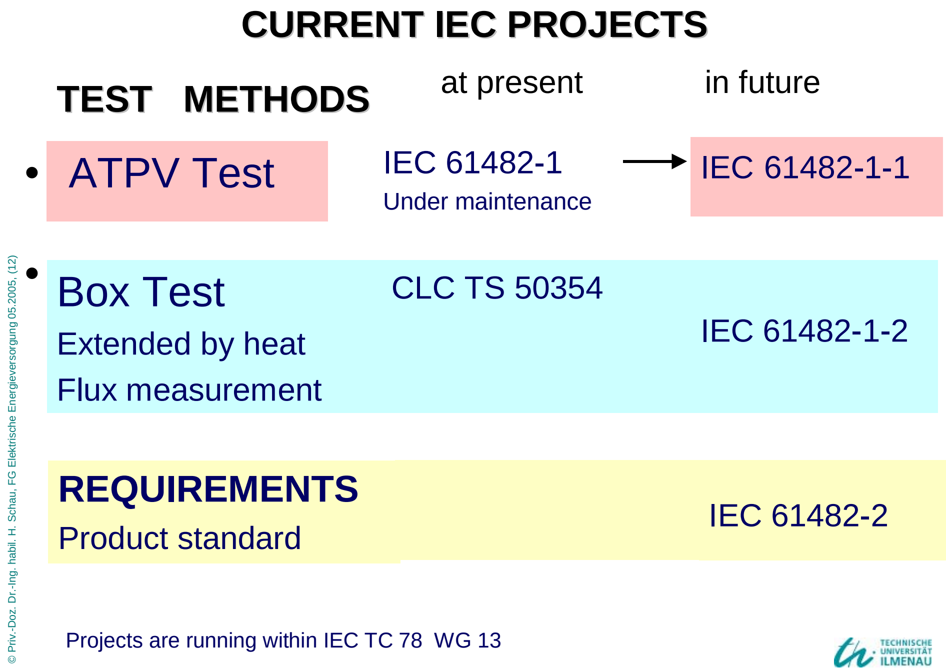

Figure 2: Current IEC projects for protective clothing

In the international standard IEC 61482 Part 1 there will be two principle test methods in next future. Both methods have already being used in practice for several years. They show differences in the test targets and procedures as well. For this the new test standard IEC 61482-1 is divided into two sub parts: IEC 61482-1-1 [9] and IEC 61482-1-2 [10] (see Fig. 3).
The new **IEC 61482-1-1** is based on the existing IEC test method and specifies methods directed to determine the material property parameter ATPV – arc thermal performance value [9]. It 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 without break-open .
This ATPV is used to assess the material or garment of a clothing with respect to its protection effect against thermal arc consequences. In US and Canada working activities have been classified by means of ATPV levels for a few years. There are standards and recommendations for categorisation. From risk assessment is known what ATPV has to be required or observed for a certain work.
The IEC 61482-1-1 test is based on an open arc fired in a 6 or 10 kV test circuit (MV conditions) between electrodes with a 300 mm spacing. It is oriented to the specifics and requirements in Northern America and also used mainly there.
In Europe there are only few experiences regarding this ATPV classification and application. Therefore, another test method has been established and set up here. It is widely spread in testing and certificating material and clothing. This method will be

specified in the new **IEC 61482-1-2** which is under consideration and preparation presently (CD level) [10].

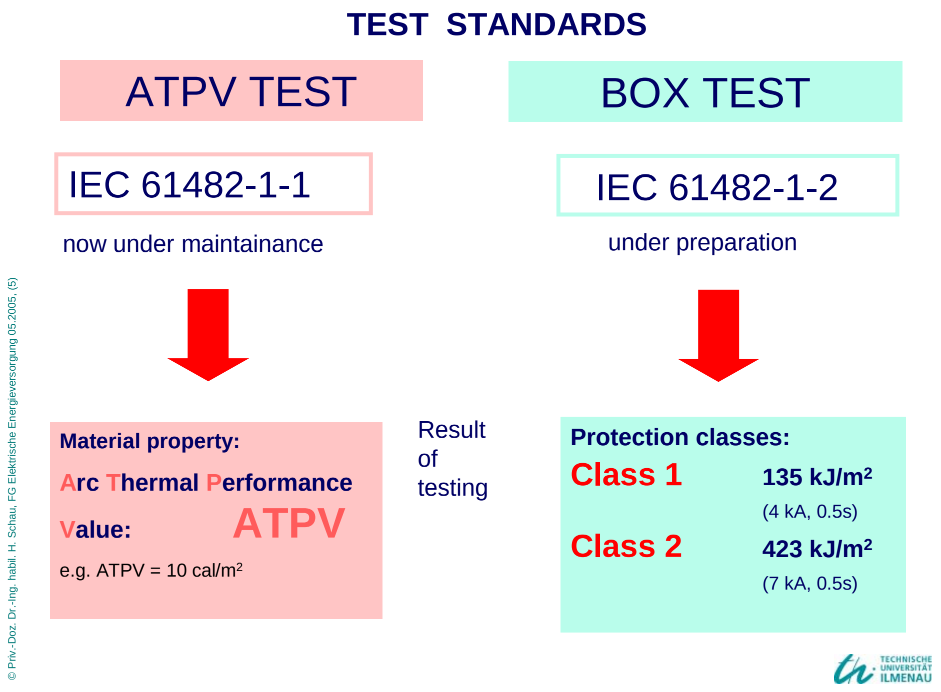

Figure 3: Future test standards within IEC 61482

This new sub part of IEC 61482 specifies procedures to test materials and garments intended for use in heat- and flame-resistant clothing for workers exposed to electric arcs. In difference to test methods in IEC 61482-1-1 a directed and constrained electric arc in a low voltage circuit will be used. The test method is aimed to give a decision if arc thermal protection is met under defined conditions. Two protection classes can optionally be tested. Protection class 1 and 2 are safety requirements covering actual risk potentials due to electric fault arcs to a very large extent. The test methods are not directed to measure the ATPV.
In this so-called Box Test materials, material-assemblies and protective clothing is evaluated using a directed electric arc under defined laboratory conditions. A practical scenario concerning test set-up and test conditions, electrical and constructional parameters is selected. The test conditions represent the typical low voltage environmental ones during service. As shown by statistics, serious electrical accident with fault arcs occur in LV power installations mainly.
Test set up and conditions are based on the specifications of CENELEC TS 50354 (former existing as pre-standard ENV 50354) [8]. In the Box Test the procedure is extended and supplemented by a quantitative measurement of the heat flux or energy transmitted through the material.
In the following this Box Test will be considered in more detail.

Besides of the test standards IEC 61482 will have a part 2 regulating the requirements of protective clothing. This new standard **IEC 61482-2** [11] is applicable to protective clothing used for electrotechnical work if there is an electric arc hazard.

The standard will specify requirements and test methods of 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 (ATPV), when tested according to IEC 61482-1-1, or
    - the arc protection class of materials and garments, when tested according to IEC 61482-1-2.

To be in accordance with the 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.
The requirements of this standard do not address electric shock hazards, but the standard is applicable in combination with standards covering such hazards.
The following requirements are considered:

- Design requirements for protective clothing
- General material requirements
    - Limited flame spread of material
    - Mechanical properties of woven outer material
    - Burst strength of knitted outer material
    - Dimensional change due to laundering and/or dry cleaning of outer material
- Arc thermal resistance requirements
- Marking
- Instructions for use.

The protective clothing covered by this standard must have certain resistance properties to the thermal effects of an electric arc.
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 167,5 kJ/m² (4 cal/cm²). The higher is the ATPV value, the better is the thermal resistance under higher incident arc energy (higher current value, longer exposure time).
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 of the test conditions and the resulting arc thermal protection. A 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.
Protective clothing tested according to IEC 61482-1-2 conforms with the requirements of the PPE Directive 89/686/EEC (Annex II, 1.1.2.2).
If a garment is made of different materials or different layers (e.g. only the front part of the garment is made of more material layers), than this has to be clearly stated in the instructions for use. If other material(s) are used for the back (rear or dorsum) they shall fulfil at least the requirements of Class 1 according to IEC 61482-1-2 or a minimum ATPV rating of 167,5 kJ/m² (4 cal/cm²) according to IEC 61482-1-1. The label of the garment shall reflect the lowest of these ratings.

4 Expreiences with the Box Test method

4.1 Procedures and results of testing

The box test according to [10] is tailored to the special European needs. The test principles and procedures are described in detail in [6]. Furthermore it has already been reported about experiences in testing and application of tests in [12] and [13].

Figure 4: Box test set-up

The test box set up (see Fig. 4) is introduced to meet typical high risk conditions and particularly to cover actual arc exposure conditions in low-voltage systems, e.g. service entrance boxes, cable distribution cabinets, distribution substations or comparable installations where the electric arc is directed to the front of a worker at the height of his breastbone. Under these test conditions the incident energy of the electric arc will be higher than in other working positions.
The test parameters of both protection classes are summarized in Tab. 1.

Table 1: Test parameters and conditions

			tolerance
test current	class 1 4 kA	class 2 7 kA	+/- 5 %
test voltage	400 V AC, 50 Hz		+/- 5 %
arcing time	0.5 s		+/- 5 %
electrodes	aluminium (top) copper (bottom)		
electrode gap	30 mm		+/- 1 mm
distance a	300 mm		+/- 5 mm

a – distance arc to calorimeter respectively to test specimen

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 transmitted through the material.
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.
Testing refers to the thermal arc effects; it does not apply to other effects like noise, light emissions, pressure rise, hot oil, electric shock, the consequences of physical and mental shock or toxic influences.
Conditions simulated by the tests are worst case ones for switchgear assemblies and installations in LV power systems in the according short-circuit current range. Under circumstances in certain electrical installations the real short-circuit currents to be expected may be higher.
The conditions also allow to take into account, additionally to those of radiation and convection, the thermal arc consequences which may result from the amplifying effect of installation back and side walls.

Result of testing is the protection class 1 or 2 according to the corresponding test class conditions. The test is considered as passed, if all of the following criteria are met.

Table 2: Test acceptance criteria

Parameter	Criterion
Burning time	$\leq$ 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 eight value pairs (E_{it} – t_{max}) of the two calorimeters for a 4 tests series are below corresponding STOLL values for 2nd degree skin burns [14]

In case of garment testing 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 2.. 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).

4.2 Guaranteeing quality and reproducibility of testing

Bright experiences in testing by using the box test method confirm the tests to be very close to practice as well as reproducible [12][13].
Essential factors influencing testing are the ambient test conditions (indoor/outdoor, temperature, humidity, wind etc.), the initial test conditions and the box conditions. Frequent calibration checks of the test arrangements and parameters are necessary [13].

The box made of plaster shall be prepared and conditioned before testing. It shall be cleaned after testing (one series) by removing metal particles and other sediments from the box surface, and has to be replaced after a appropriate number of tests (maximum 50 shots).

The test apparatus setting has to be checked for each test. Values recorded should be the arc current, arc duration, arc energy, and arc voltage. In addition, the ambient temperature and relative humidity shall be recorded. Influence of wind or air convection flow during testing shall be prevented.

Calorimeters must be calibrated and checked to verify proper operation [13].
Calibration oscillograms of the prospective test current adjusted and the test voltage proving the test conditions shall be recorded at least for each test series with unchanged test parameters. Before testing and after a test series, reference tests without material shall be carried out with measuring the direct exposure incident energy E_{io}.
It should be proved that this energy E_{io} of each sensor lies within a range of the double standard deviation ± 2 *s of the mean values according to Table 3. In the direct exposure shot before the test series, the direct exposure incident energy should additionally be greater than the long term mean value (Table 3).

Table 3: Statistically confirmed mean values of the direct exposure incident energy

Test current	Mean value E_{io} kJ/m² (cal/cm²)	Double standard deviation ± 2*s, kJ/m² (cal/cm²)
Class 1: 4 kA	135 (3,2)	± 56 (1,3)
Class 2: 7 kA	423 (10,1)	± 78 (1,9)

For each of the tests the arc energy values shall be determined. A test is only valid if the arc energy W_{arc} ranges between the double standard deviation ± 2*s of the mean values according to Table 4. Otherwise the test shall be repeated.

Table 4: Ranges of the permissible arc energy

Test current	Mean value W_{arc} kJ	Double standard deviation ± 2*s, kJ
Class 1 : 4 kA	158	± 34
Class 2 : 7 kA	318	± 44

The arc energy characterising the test class is also the relevant parameter for assessing the tests on how far the test conditions cover the needs resulting from risk assessment regarding the real fault characteristics. The arc energy to be expected in a real fault case at a certain fault location (plant, network) has to be compared with the arc energy level of the class tested and passed.

5 Summary

The risks for persons resulting from electric fault arcs require standards regarding protective clothing against the thermal hazards of these huge energy sources. In the future standard IEC 61482 both, standards for practice-oriented test procedures (Part 1) and for the material and clothing requirements (Part 2) will be available. The new standard parts are presently under maintenance and preparation with these aims.

The test standard will have two different test methods. One of them, the box test is particularly of importance for European testing and certification.
As shown by practice the test is well reproducible and accepted. It allows the classification of material and garments regarding the protection against the thermal hazards of electric arcs; two protection classes are defined. The classes are characterised by the level of electric arc energy. Quality assurance of testing as well as the estimation of practical hazards covered by the according test or class must be based on the electric arc energy and the direct exposure incident energy. Both risk assessment and classification have to be made by means of the arc energy.

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AUTHOR

Priv.-Doz. Dr.-Ing. habil. Holger Schau
Technische Universität Ilmenau, Faculty of Electrical Engineering and Information Technique, Department of Electric Power Sypply
Address: P.O.B. 10 05 65, D – 98684 Ilmenau / Germany
Tel.: ++49 3677 69 1489
Fax: ++49 3677 69 1496
E-mail: holger.schau@tu-ilmenau.de