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This publication was developed as part of the event:

ICOLIM 2011 ; 10th International Conference on Live Maintenance ; May 31th - June 2nd 2011, Zagreb, Croatia.

Technische Universität Ilmenau / Fakultät für Elektrotechnik und Informationstechnik / Fachgebiet Elektrische Energieversorgung

Ilmenau, 2012

URN: urn:nbn:de:gbv:ilm1-2012200092

10. Međunarodna konferencija o radu pod naponom ICOLIM 2011
10th International Conference On Live Maintenance ICOLIM 2011

May 31st – June 2nd, Zagreb, Croatia 2011
ICOLIM
10th International Conference On Live Maintenance

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Abstract

The performance of personal protective equipment (PPE) and its contribution to increase personal safety in usual work places has to be proven by tests. One potential hazard for people are electric fault arcs occurring with short-circuits in electric power installations. There are very high risks for persons especially in case of direct exposure, e.g. during live working or working in the vicinity to live parts. Particularly radiation and convective heat is converted.
With the box test according to IEC or EN 61482-1-2 a method for testing protection textiles and clothing against the thermal hazards of electric fault arcs has already been existing and used in certification for several years. But as shown by arc accidents the face is also particularly affected by severe damages. Protective equipment for eye and face protection which is also tested for arc resistance and protection is necessary.
Based on basic investigations test principles for eye and face protection equipment against the thermal hazards of electric fault arcs have been developed and laid down in a new German test guide. The test set-up of the box test is suitable. It has been adapted and modified by a test head where test samples such as visors, visor-helmet combinations, face shields etc. are placed. The tests are carried out in accordance to the box test method of protective clothing (IEC/EN 61482-1-2).
The paper gives information on tests made according to this test guide. Furthermore general conclusions are drawn on how to test and how to standardize tests of PPE for eye and face protection. The principles will be introduced in E DIN 58118 becoming a supplementation to the German edition of EN 166. It can also be the base for an international or European standard later on.

Key words: live working, arc flash protection, personal protective equipment, eye and face protection, testing

1. Introduction

Electric fault arcs represent a high risk for people working at or in the vicinity of electric power installations. There is a particular risk due to the thermal effects of these arcs in case of live working when being exposed directly. In addition to the electric power system protection devices, personal protective equipment (PPE) is necessary for preventing injuries. Essential components of PPE are flame-retardant protective clothing, gloves, helmets, visors and other eye and face protecting equipment.
PPE must meet two requirements regarding arc flash risks: arc resistance as well as heat attenuation (arc protection). In the past, requirements and tests were mainly focussed on heat 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 must also limit the incident energy of fault arcs to a non-dangerous degree. Second degree skin burns have to be prevented.
Research work has been focussed, among others, to create materials with high heat attenuation (e.g. high arc thermal performance value ATPV) and develop test methods for proving arc thermal protection as well as resistance. In the following the progress in the second point regarding testing of eye and face protective equipment is considered.

2. Existing standards in eye and face protection against fault arcs

There is an ASTM standard F 2178 for testing face shields [1] which is in principle based on the same procedure as used in IEC 61482-1-1 for textile material and clothing testing providing the ATPV of PPE [2]. In Europe a comparable standard is sill missing up to now. The box test method developed to prove if requirements of certain protection classes (representing different protection levels) are met by textile material and clothing [3] is suitable to be adapted for face shield testing, too. Measurement of the incident energy is included in the test procedure for assessing the heat flux as a criterion and one result of testing. With GS ET-29 [4] a guide for testing and certificating PPE was developed on this base. Furthermore the principles were transferred in a new German standard draft E DIN 58118 [5] complementing the European standard EN 166 [6].
A number of research activities were necessary to introduce this test method. One key aspect of the box test method is the reproducibility of the test to assure the validity despite of the stochastic nature of arc processes and the limited number of arc shots within a test.
The box test method according to the standard IEC 61482-1-2 has already been described in detail [7-9]. In the following, this box test method is applied to test PPE for eye and face protection. The test set-up and procedure are modified to cover also the needs regarding testing of face shields, visors, combinations of helmet and visors etc. Covering as much as possible practical arc exposure conditions, the test shall simulate worst case heat transmission conditions, with making an abstraction from special geometrical and constructional installation sites, working positions etc. The tests are intended for the certification of single products but may also be the base for complex testing of PPE component combinations as used in practice.

3. Arc testing of PPE for eye and face protection

The box test has been investigated and modified with the aim to enable tests of PPE for eye and face protection, too. Fig. 1 shows the modified test set-up. There were numerous investigation for finding and verifying the suitable set-up and test procedure. A test head with 4 calorimeters for measuring the transmitted incident energy (for assessing skin burns behind the PPE [10]) is used. 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 is placed in a distance of 350 mm, centred to the test arc axis horizontally and vertically. The calorimeters in the eyes region are at a wider distance to the arc because of the head form. Very important is also the chin calorimeter indicating the heat in the lower part of the head, and especially the hot gas flow underneath to the PPE.
The test configuration shown in Fig. 1 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.
An example of incident energy values as test results measured in case of calorimeter direct exposure by using the test head for visor testing is shown in Fig. 2. The incident energy values are used for assessing the risk of second degree skin burns in the face area (behind the visor) being one of the essential criteria for passing the test as well.
The box test can be carried out in one of two possible arc protection classes. The test levels are characterized by the electric arc energy and the incident energy resulting in a distance of a = 300 mm to the arc. They represent the exposure levels as well as the control parameters of the tests. There are validity check ranges of these parameters resulting from the random statistical deviations of these parameters and given by the standard deviation from the statistical mean value. The single tests of a series for testing a product are only valid if the electric arc energy lies within the range in each shot, and the direct exposure incident energy of a shot before

and after the series with test samples, too. The procedure and validity check parameters are coincident to IEC 61482-1-2 [3] (see also clause 4).

Fig. 1: Test set-up with test head equipped by calorimeters (left) and position of the test sample (example: visor-helmet combination, right)

The heat transmission and attenuation is measured by the incident energy. In the shots without test sample the direct exposure incident energy is determined by means of two calorimeters in a test plate in a distance of a = 300 mm to the arc. The direct exposure incident energy is calculated from the maximum temperature (delta peak temperature) measured by a calorimeter by multiplying with a constant calorimeter factor. The transmitted incident energy indicating the heat flux transmitted through the PPE is measured by the calorimeters in the test head. For assessing the heat transfer it is not only enough to consider the maximum temperature but also the total curve of the temperature rise. In order to pass a test it is necessary that no one of all calorimeters shows an exceeding of the Stoll limits [10] in its total temperature (or "incident energy") curve. No point of the temperature curve may exceed the Stoll curve. That is different to testing of textile material or clothing where only the incident energy as one point (maximum) is considered. The reason is that the temperature rise is very rapid in case of visors. Resulting from the convective heat transmission there is an additional delayed increase of the temperature with a very low gradient so that the absolute maximum of the temperature can be reached after several seconds (e.g. occasionally even after 10 s or more).
The Stoll limit is then not more exceeded under circumstances. But the first high temperature rise values at the beginning resulting from transmitting arc radiation are over the Stoll limit and characterize the exposure energy. In case of textile testing the conditions are different in general. The maximum temperature rise indicates the time when the energy input is finished, the temperature then decreases because the cooling process dominates. Thus the temperature rise maximum characterizes the energy exposure and has to be taken for the comparison to the Stoll limit.

4. Guaranteeing quality and reproducibility of testing

The experiences in using the box test method confirm the tests to be very close to practice as well as reproducible.
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. For calibration the test system voltage (no-load), the prospective test current as well as the response of the calorimeter measurement-chain to a defined heating source have to be recorded.
The test apparatus setting has to be checked for each test series. Values recorded should be the arc current, arc voltage, arc duration and arc energy. 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.

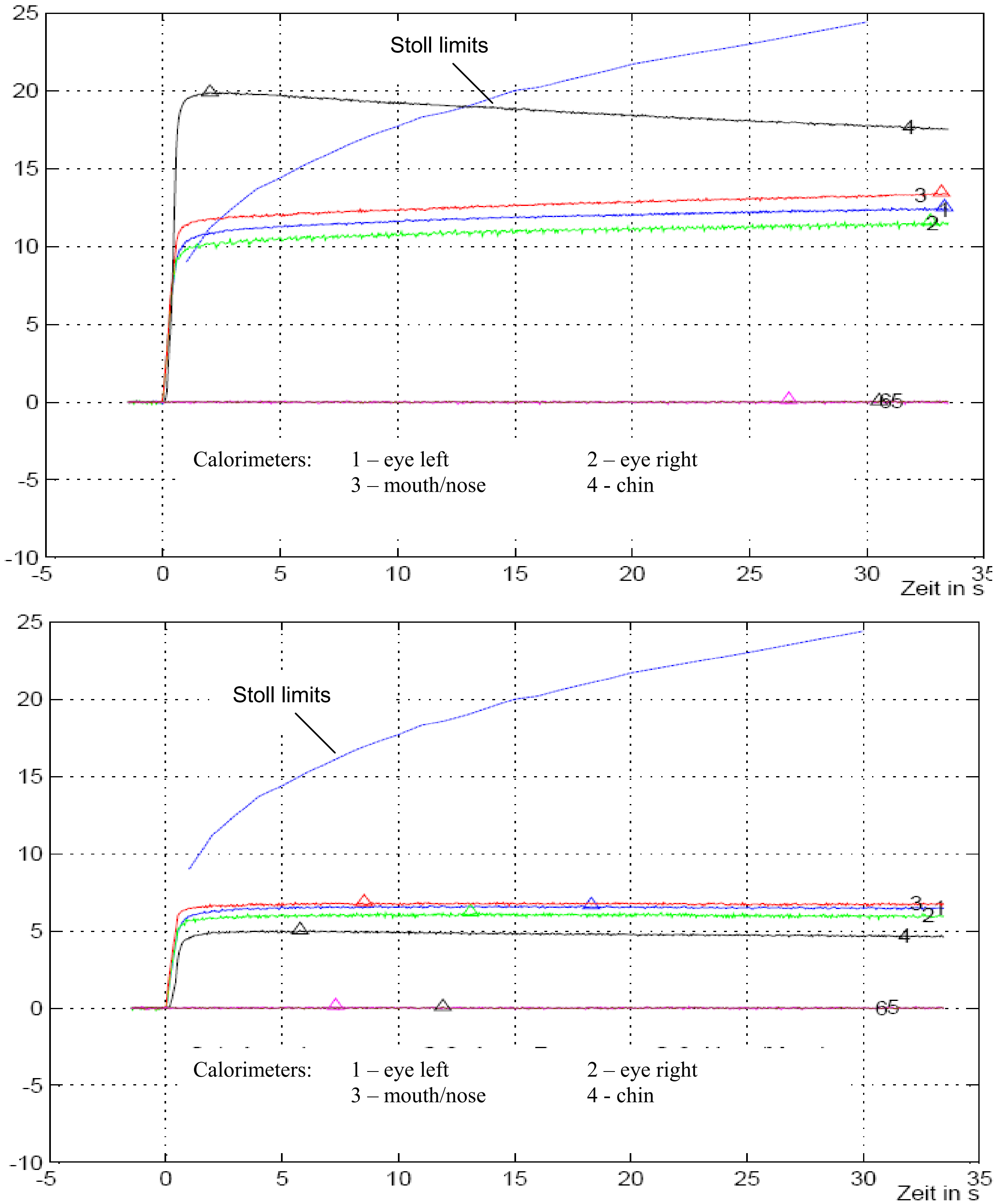

Fig. 2: Example of test results: a failed class 2 test (above) and a passed class 1 test (below)

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. When testing PPE (series of 4 or 5 sample arc shots [3]), reference test shots without samples shall be carried out with measuring the direct exposure incident energy E_{i0} before testing and after a test series. In the direct exposure shot before the test series, the direct exposure incident energy should not be below the long term mean value (Table 1).

Tab. 1: Test and arc protection levels as well as validity check ranges of the box test

class	Electric arc energy in kJ		Direct exposure incident energy in kJ/m^2	
	Level	Validity check range		Level
1	158	141…175	107…163	135
2	318	296…340	384…462	423

For each of the tests the arc energy values shall be determined. The arc energy and direct exposure incident energy characterizing the according test class are the relevant parameters for assessing the tests on how far the test conditions cover the needs resulting from risk assessment regarding the real fault conditions. 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 levels of the class tested and passed.

5. Summary and conclusions

Electric arcs are a potential risk for people and plant. Particularly the protection against electric fault arcs is of largest importance for preventing human injury while working in, at or in the vicinity to open or opened electric power installations. An essential contribution to this protection can be made by PPE. PPE must be tested under practically relevant and reproducible conditions.

With the box test a test method for analyzing arc resistance and protecting effect of PPE has been developed. The test procedure includes measuring of the heat flux.

This box method is very well reproducible, near to practice and relatively favourable in price. It has already being used for certifications.

The box test allows the classification of material and PPE products 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. Both risk assessment and classification have to be made by means of the arc energy.

The modifications investigated confirm the suitability of the method for testing also PPE for eye and face protection. With this, the existing gap regarding these essential PPE components can be closed. The base for standardization is also provided.

6. References

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Acknowledgment:

The work reported about was and is part of a research projects supported by the Berufsgenossenschaft Energie Textil Elektro und Medienerzeugnisse (BG ETEM) Cologne/Germany. The authors like to thank the BG ETEM for this essential support.