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RISK ANALYSIS AND ASSESSMENT IN CASE OF ARC FLASH HAZARDS IN THE LV RANGE

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ABSTRACT

Electric fault arcs occurring with short-circuits in electric installations are enormous sources of power. There are particularly thermal effects (radiation, heat flux) with high risks for persons especially in case of direct exposure, e.g. during live working. Personal protective equipment (PPE) can essentially contribute to increase the personal safety.
The selection of protective measures or the assessment of their efficiency requires a risk analysis. Since the thermal arc hazards are proportional to the electric arc energy as well as the incident energy in the exposure distance the risk assessment has to be based on the energy conditions to be expected in the application fields under consideration The paper gives an algorithm for analyzing the thermal arc risks for finding the necessary protection class of PPE according to the box test levels for protective clothing.

Index Terms – Electic power installations, low-voltage, arc flash protection, live working, risk analysis, personal protection equipment

1. INTRODUCTION

In case of fault arcs occurring with short-circuits in electric power installations huge amounts of energy are converted. There is the risk of personal injury and damages of the equipment, the electric power supply may be interrupted with enormous outage costs. Besides of the pressure rise, light and sound emission, particularly the thermal arc consequences in form of hot metal particles and mainly of the intensive heat flux due to radiation and convection of hot gases are of high risk potential. If persons and equipment shall be protected efficiently the electric arc energies and/or incident energies have to be limited. There are different protection targets.

Efficient protection measures to be seen in the switchgear construction, the selection of the electrical protection devices and the use of personal protection equipment (PPE) for persons who are likely to be directly exposed to an arc, require a risk assessment with determining the arc energies and incident energies to be expected in case of accidents and failures where fault arcs can occur.

2. HAZARDS DUE TO ELECTRIC FAULT ARCS

Electric fault arcs being huge energy sources, the energies converted during an arcing fault at the fault point are in the range of some Megawatts depending on the short-circuit capacity of the electric power system and the clearing time of the protection devices. The temperatures in the arcs exceed 10,000 °C. 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.

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

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

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

Especially in case of the thermal arc effects there is a direct proportionality between the arc energy W_{LB} and the effects (exposures)

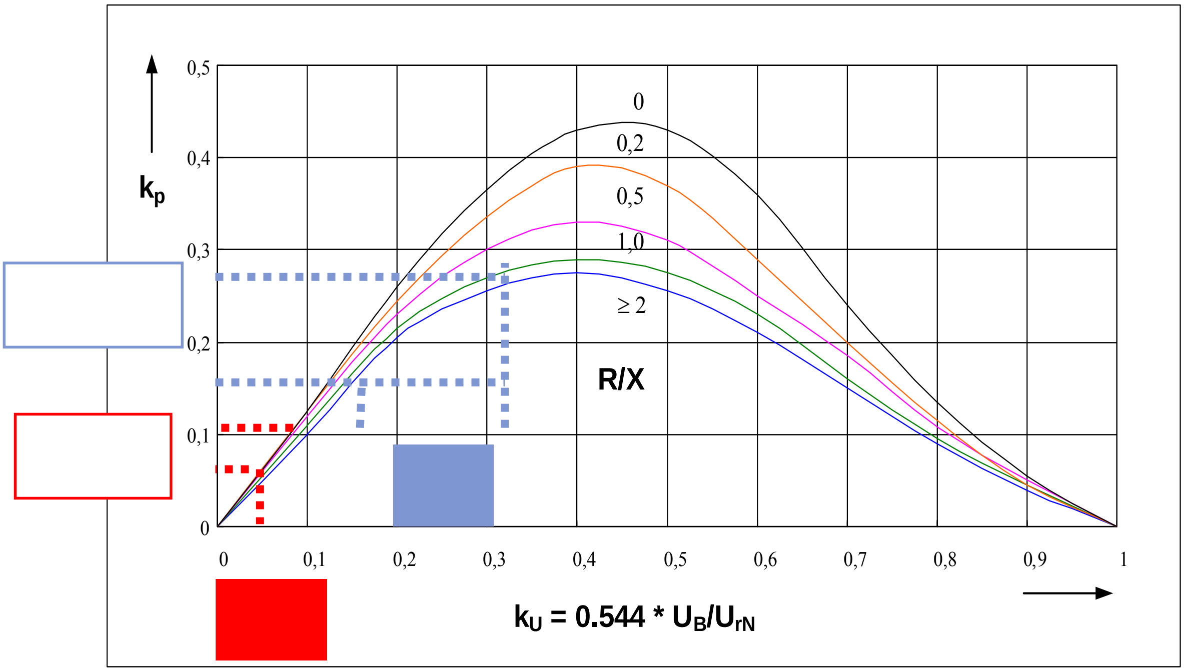

Figure 1: Factor k_P for the determination of the electric arc power and energy [1]

$E_{i0} = a + b\,W_{LB}$.

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

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

in the fault.

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. 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_{rN}, 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

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

and, thus, a function of the electrode gap that is determined by the conductor spacing and the construction of the electric plant.

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 .

3. DETERMINATION OF ARC ENERGY

For risk assessment, besides of the practically expectable arc energy levels, the arc resistance provided by the applied protection equipment and means has to be considered. It may be proved that the exposures to be expected are not higher than the arc resistance energy levels.

3.1. Expected arc energy (exposures)

The arc energy W_{LB} 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 protection devices (clearing time of the breakers, fuses or occasionally special protection devices) and to be derived from the switching characteristics:

$$W_{LB} = P_{LB} \cdot t_{LB} = k_P \cdot S_k'' \cdot t_{LB}$$
$$= k_P \cdot \sqrt{3} \cdot U_{rN} \cdot I_{k3}'' \cdot t_{LB}$$

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 U_B from Fig. 1 [1]. For a rough estimation without considering the switchgear geometry the maximum values of the k_P curves may be used:

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

Furthermore the value ranges also given in Fig. 1 were found to be typically for the 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.

The largest arc energy level determined for the case under study has to be compared with limits characterizing the aimed protection target.

3.2. Arc resistance energy level

It is known from empirical investigations that the arc energy has to be limited in LV switchgear assemblies to about

- 250 kJ to achieve personal protection outside of a not-opened system
- 100 kJ to achieve system functional protection (limited post-fault system operation) [1]

under the condition that the installation or switchgear system was tested and proved that the system remained closed and the arc consequences limited to the inner system.

Regarding the thermal hazards of persons due to direct arc exposure when the system is opened (e.g. live working), the incident energy E_i is the decisive factor depending on the arc energy, the heat transmission conditions and the exposure distance a:

$$E_i = \frac{f(a)}{k_T} \cdot W_{LB}$$

The occurring incident energy may not cause 2nd degree skin burns. According physiological limits are given by the so-called Stoll criterion. The transmission factor k_T characterizes the influence of the system conditions on that arc energy fraction thermally impacting. Selecting of PPE may be based on the incident energy levels E_{i0P} which occur in the PPE test. For the box test of protective clothing according to IEC or EN 61482-1-2 these values are known for the two different protection classes. Tab. 1 gives an overview on these levels.

Table 1: Statistically confirmed exposure values [2]

	W_{arc} in kJ		E_{io} in kJ/m²	
	Mean value	± 2*s	Mean value	± 2*s
Class 1	158	±34	135	±56
Class 2	318	±44	423	±78

2*s – double standard deviation

Furthermore the corresponding arc energy levels W_{LBKl} which result in the incident energies in an exposure distance of a = 300 mm (according to the test set-up) are given. From this an equivalent arc energy $W_{LBä}$ may be found for any distance one likes by using the indirect quadratic distance proportionality experimentally confirmed:

$$W_{LBä} = k_T \cdot \left(\frac{a}{300mm}\right)^2 \cdot E_{i0P}$$

The equivalent arc energy is that one where the protective effect of the PPE is still given for the according exposure distance a. Hence it has to be used for the comparison with the expected arc energies

$$W_{LB} \le W_{LBä}\ .$$

4. SUMMARY

Electric fault arcs are of potential risk for the injury of persons working in or at electrical power installations, particularly when there is the danger of a direct exposure as in case of live working or working in the vicinity of live parts. Personal Protective Equipment (PPE) may and must essentially contribute to the necessary protection.

For selecting protection measures such as PPE the electric arc energy parameters (electrical input and heat transfer) to be expected in the consideration field have to be determined and compared with target levels resulting from the required equipment arc resistance.

The determination of the arc energy parameters is not simple. There are large application ranges to be covered, much different electric system conditions, very various switchgear and power installation constructions, very different types and settings of the short-circuit protection devises (tripping times) etc. Furthermore the electric fault arc is a thermodynamic system and of stochastic nature. The heat transmission conditions are still more variant and predictable. By means of empirical considerations based on a large number of power lab measurements and fault evaluations an approach of determination is presented and used. It allows to find expected arc exposures with a certain accuracy and probability. The risk analysis and assessment may be based on it.

5. EFERENCES

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Part 1: Test methods – Method 2 – Determination of the arc protection class of material and clothing using a constrained and directed arc (box test)