

Reducing Arc Fault Hazards by means of Fuses

Arc fault hazard

Live working is becoming more important by two main factors: While customers are becoming less tolerant to power outages, at the same time, power utilities are reducing redundant distribution lines under cost pressure.

Men working on live systems are necessarily exposed to a higher risk of electric shock and exposition to incidental electric arcs, endangering their health and life. Managers, ordering subordinates to work on a live system, have to balance the risk of live working and the consequences of a power outage. Though, arc faults are very rare events, the risk has to be estimated high, as electric arcs can cause serious injury or death to workers. Risk assessment and selection of adequate personal protection equipment (PPE) are therefore a must before ordering men to live working.

The tremendous amount of energy released by arc faults within a fraction of a second is responsible for the potentially disastrous effects to equipment and human beings:

- Metal conductors are vaporized, resulting in hot vapours and hot metal droplets being propelled from the arc.
- Hot vapours and splashing molten metal can cause fire and severe burns to workers directly exposed or by ignited clothing.
- Sudden pressure built-up due to thermal expansion of heated air and metal vaporization can result in a detonation that may rupture eardrums, collapse lungs and knock workers back.
- Additional potentially harmful effects include intense light, electric shock, toxic degradation products and flying shrapnel.

Limiting prospective arc fault energy at the workspace by means of current-limiting fuses appears to be a preferred method to reduce arc fault hazards. For instance, it has been demonstrated through arc fault tests in the U.S. where the temperature and pressure were measured, that current-limiting overcurrent protective devices not only limit the damage to circuit components but can also measurably reduce personnel exposure to serious injury. Related tests based on European network conditions and standards are still to be done.

European Standards

European Standards exist for the qualification of protective clothing and other equipment for the protection of human bodies against the effects of incidental arcs:

- IEC EN 61482-1-1: "Live working – Protective clothing against the thermal hazards of an electric arc"
Test Method 1:
Method A: Determination of arc thermal performance value (ATPV) of materials for clothing of workers.
Method B: Evaluation of protective clothing design (called „Arc man test“).
- IEC EN 61482-1-2: "Live working – Protective clothing against the thermal hazards of an electric arc"

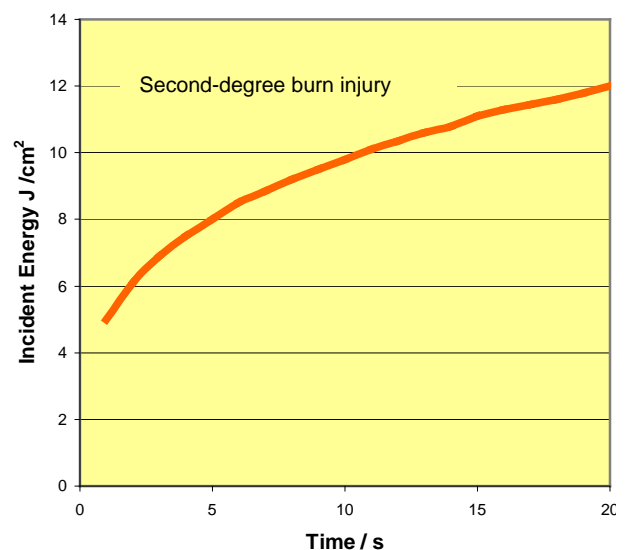


Fig. 1 - Human tissue tolerance to heat (Stoll curve)

Test method 2: Determination of arc protection class of materials by using a constrained and directed arc (box test)

Both International Standards measure the heat flux by means of calorimeters and describe the properties of materials and garments in response to convective and radiant energy generated by an electric arc. Unfortunately, the test parameters are much different and the results cannot directly be compared (table I)

Part 1-1 is primarily applied in North America and defines the arc thermal performance value (ATPV) of a material, which predicts the limiting incident energy at which a second-degree skin burn injury would begin based on the Stoll curve (fig. 1). The tests are based on a high voltage electric arc in open air.

Part 1-2 reflects the European practice and defines two classes of arc thermal protection (ATP) by the amount of prospective currents: Class 1 and class 2 for 4 kA and 7 kA respectively. The test set uses a parabolic test box that forms a constraint low voltage electric arc directed towards the specimen. Major acceptance criterion is a transmitted energy value below the Stoll curve (fig. 1).

None of these European Standards however, would give general rules or guidance on how to assess the risk of live working. The responsibility remains with the individual network operators.

Table I - Arc test parameters

| Test parameters | IEC 62482-1-1 | IEC 62482-1-2 |
|---------------------------------|-----------------|--------------------|
| Supply voltage | ≥ 2000 V | 400 V |
| Prospective test current | 8 kA | 4 kA or 7 kA |
| Arc duration | Variable | 500 ms |
| Arc gap | 300 mm | 30 mm |
| Electrode materials | Stainless steel | Al / Cu |
| Test distance (specimen to arc) | 300 mm | 300 mm |
| Arc environment | Open air | Parabolic test box |
| Test result | ATPV | ATP class |

Risk Assessment

Any decisions on whether live working can be justified and, if the answer is yes, what class PPE will be required must be based on thorough evaluation of arc fault hazards at the work site. The numerous risk factors to be considered, e.g. voltage level, work environment, worker’s training level and work diligence, arc energy available at the workspace etc. make arc fault hazard assessment rather difficult, very specific for the various jobs and to a certain extend unpredictable. On the other side, there is a viable interest to estimate the risk as close as possible to reality in order to select the PPE for adequate protection but to avoid unnecessary encumbrance of workers activities, which may again be the cause of accidental arc faults.

Incident energy levels are commonly used to evaluate the hazard of second-degree burns to bare skin and to evaluate the class of protective equipment required. Limiting values are derived from the Stoll curve (fig. 1). No second-degree burns are expected below an incident energy level of about 5 J/cm².

While the incident energy is somewhat uncertain to predict, the prospective bolted fault current at the work site can be calculated from network parameters. The energy emitted by the arc, i.e. the determining quantity of arc fault hazard, is about equal to the energy supplied $W_{arc} = U_{arc} I_{arc} t_{arc}$.

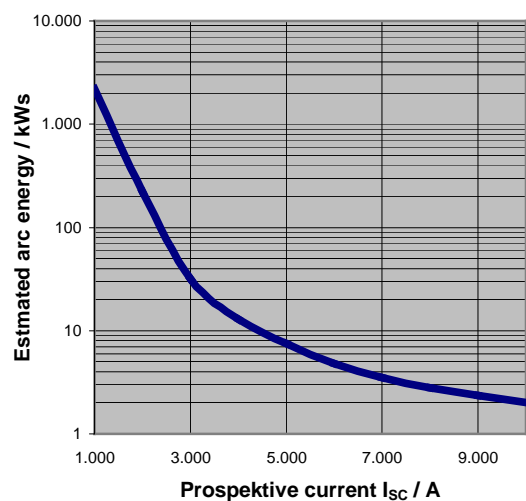


Fig. 2 - Approximated available arc energy (protective device: 250 A gG fuse)

Consequently, arc fault hazard is heavily influenced by the overcurrent protective device installed upstream the workspace. While the arc voltage U_{arc} in a l.v. distribution system is within a relatively small range of 80 V to 130 V, the prospective current and the arcing duration follows roughly the decline characteristic of the protective device, e.g. current-limiting fuse (fig. 2).

As there exists no formula to exactly calculate the incident energy from prospective bolted fault current and from fuse characteristics, only general rules can be given to reduce arc flash hazards by reducing the available arc fault energy at the work site.

Reducing the risk by means of fuses

Overcurrent protective devices exhibit time-current characteristics according to the overcurrent withstand of the equipment to be protected, i.e. the greater the current, the shorter the time to current interruption. **Since electric fuses do not exhibit intrinsic mechanical delays, they are very efficient in limiting currents up to the highest levels.**

At high current levels fuses represent current-limiting devices, i.e. they are able to interrupt high fault currents within less than $\frac{1}{4}$ cycle. Within this range, the time to fuse operation (fusing time t_f) is given by the formula $t_f \sim I^{-2}$ (derived from $I^2 t_f = \text{constant}$). The arc energy in this range would roughly be inverse to the fault current $W_{arc} \sim 1 / I_{arc}$:

The greater the fault current, the more efficient arc fault energy reduction by means of fuses will be.

Tests¹ have shown, that the incident energy at working distance to an electric arc does hardly exceed the energy level of 5 J/cm² as required for a second-degree burn injury of bare skin if fuses interrupt the arc in a current-limiting operation. Therefore, **whenever possible, upstream protective devices should be selected for current-limiting operation in case of accidental arc faults during live working.**

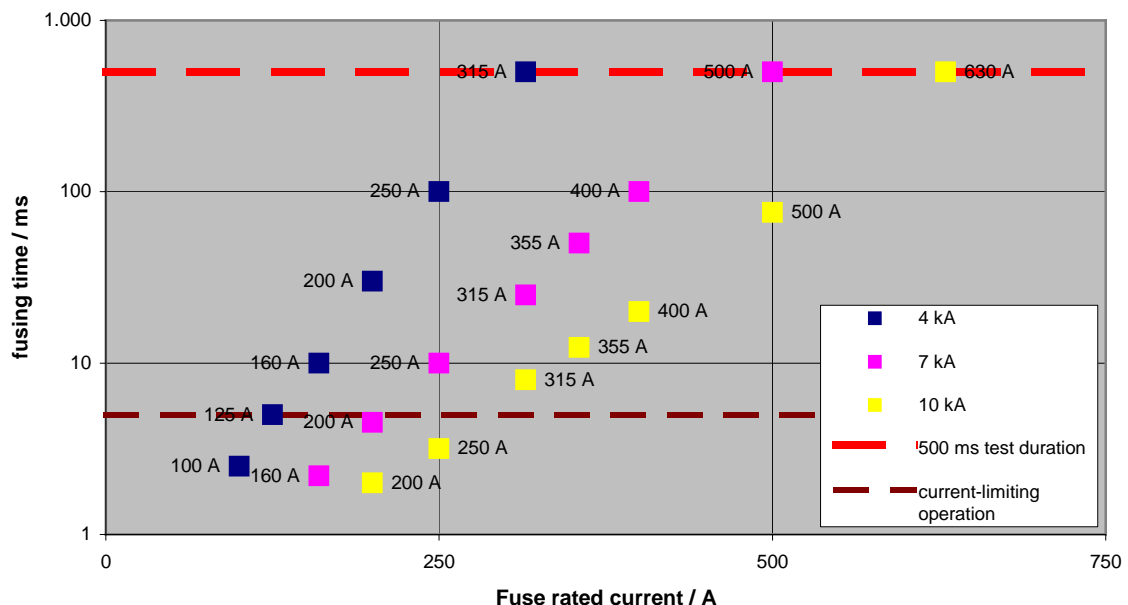


Fig. 3 - Arcing time limitation by means of gG fuses depending on various prospective currents

¹ Richard L. Doughty et alii: The use of current-limiting low-voltage fuses to reduce arc-flash energy, IEEE Trans. Vol. 36 Nr. 6 Nov./Dec. 2000

It has, however, to be kept in mind that the arc current is depending on the arc voltage and can be significantly (up to 50 %) less than the bolted short-circuit current. Test results referring to prospective (bolted short-circuit) currents can therefore not be applied to others than the tested configuration.

If fault currents drop below the current-limiting range, incident energy and arc fault hazard will significantly increase due to longer arcing time (fig. 2). That means the location closest to the feeder transformer does not necessarily represent the work site with the greatest arc-flash risk.

But even in the range of non-current-limiting operation common gG fuses would usually limit the arcing time and consequently the arc fault hazards. Figure 3 gives a comparison of the fusing times of gG fuses versus the test duration of 500 ms for classification tests of protective equipment class 1 and class 2. (10 kA prospective current was included as this non-standard test current is also quite common.) The fusing time values in figure 3 are based on arcing currents reduced to 80 % of the prospective currents.

Where required, a higher level of arc energy limitation may be achieved by means of fast acting gR fuses temporarily installed for live working. gR fuses have a much lower threshold for current-limiting operation (see fig. 4) and are therefore even more efficient in arc fault energy reduction. gR fuses may only temporarily be installed because of their higher power dissipation.

Conclusions

Seemingly, appropriate fuses are able to reduce arc fault energy significantly and would in certain cases allow for lower class PPE than derived from standard arc duration and prospective short-circuit currents only. Before doing so, the relationship of fuse protected arc fault and incident energy needs to be established by stage tests based on European test standards and network conditions.

The same applies to the assumption that the maximum prospective current would represent the worst case of arc fault hazard. The incident energy at minimum fault current should also be investigated.

More information and advice on this subject can be obtained from your fuse specialists organized in [Pro Fuse International](#).

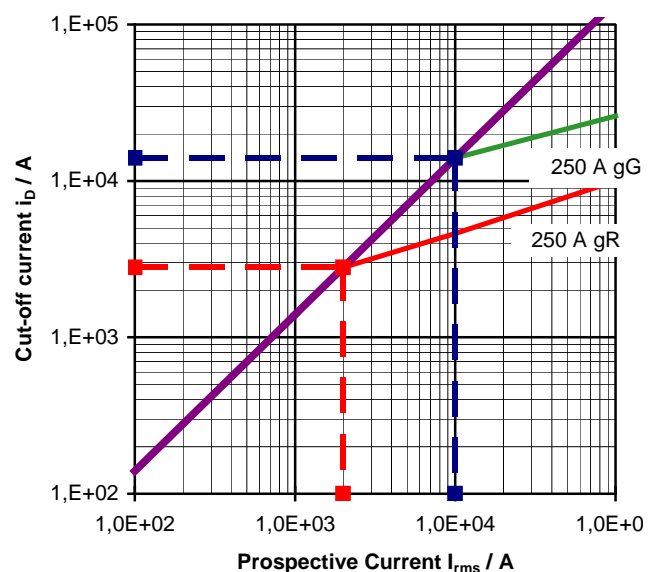


Figure 4 - Current limitation of general purpose gG and fast acting gR fuses