Technical Series, Edition 7
Arcing Faults in Medium-voltage and Low-voltage Switchgear

Answers for infrastructure and cities.
Arcing Faults in Medium-voltage and Low-voltage Switchgear

An arc is created by ionisation of a gas (normally air) by means of an electric discharge between electrodes of different potential or phase angle, or between an electrode and earth. The term "arc discharge" is also common. If this effect is caused by a fault, such as a short-circuit inside a switchgear assembly, we refer to it as an arcing fault. Whereas the generation of an arcing fault in low-voltage switchgear often requires a short-circuit by direct contacting, not observing a minimum clearance in air between the live parts of a switchgear assembly will suffice to cause such a fault under medium-voltage conditions.

The probability that an arcing fault occurs in a switchgear assembly is low, but mustn't be neglected. We expect $10^{-4}$ incidents per annum for air-insulated switchgear and $10^{-5}$ incidents p. a. for gas-insulated switchgear. This means that statistically speaking, an arcing fault is caused in one of 10,000 (air-insulated) panels, or one of 100,000 (gas-insulated) panels.

Reasons for the generation of an arcing fault, also called "internal fault", may be as follows:

- Material or functional faults of equipment (e.g. insulation faults, defective contact spots, mounting faults)
- Wrong rating and dimensioning (e.g. abruptly blowing fuses)
- Overstress, pollution, humidity
- Operator faults and inattention when work is carried out (e.g. non-permissible working under live conditions)
- Small animals and foreign bodies (e.g. forgotten tools) which get into the interior of the switchgear
- Faulty execution of cable connections

When a gas plasma is created, temperatures of approx. 10,000 °C may be produced (even up to 20,000 °C at the point of outlet) and thus vaporizing the material at the point of outlet. This improves conductivity and the current flow is increased, which may, in turn, result in a further temperature increase. The process is described in four phases as shown schematically in Fig. 1.

1. Compression phase (with maximum overpressure)
2. Expansion phase (declining pressure)
3. Emission phase (gas emission)
4. Thermal phase (emission of heavy metal and insulating material vapours)

Arc flash tests for a switchgear panel demonstrated a pressure of approx. 10 t/m² for a given area load.

Fig. 1: Pressure development over time in case of an arcing fault
Standards
The industrial standard for switchgear is defined by international and national standards. A distinction is also made in the classification of faults, such as arcing faults, between low (up to 1 kV) and medium/high voltage (above 1 kV):

- **Medium and high voltage:**
  IEC 61936-1 (VDE 0101-1)
  Power installations exceeding 1 kV a.c. – Part 1: General requirements (Note: This standard does not apply to factory-assembled, type-tested switchgear and not for the requirements concerning work performed under live conditions)
  IEC 62271-200 (VDE 0671-200): High-voltage switches and switchgear – Part 200: AC metal-enclosed medium-voltage switchgear for rated voltages above 1 kV up to and including 52 kV

- **Low voltage:**
  IEC/TR 61641 (VDE 0100-500 Addendum 2):
  Low-voltage switchgear assemblies Part 1: Type-tested and partially type-tested assemblies - Technical Report: Guide for testing under conditions of arcing due to an internal fault

Testing of medium-voltage switchgear under conditions of arcing
A successful type test of medium-voltage switchgear also requires an internal arc classification IAC in accordance with IEC 62271-200 (VDE 0671-200). The classification distinguishes as follows:

- **Accessibility**
  - A Access only for qualified personnel
  - B Public access (meaning testing under tightened conditions)

- **Qualified, accessible sides of the switchgear:**
  - F Front
  - L Lateral
  - R Rear

- Test current and duration

Example: Internal arc classification IAC AR BFL 25 kA 1 s
The specification means that the rear side may only be accessed by qualified personnel whereas the front and lateral sides may be accessed by anybody. The internal arcing test was made with a test current of 25 kA for a duration of 1 second.

Note:
Medium-voltage switchgear is generally tested for accessibility of Type A. Only complete, factory-assembled stations (transformer / load-centre substations) are tested for Type B. Testing normal switchgear for conformance with Type B doesn’t make sense, since they will always be built into an additional station housing in public spaces.

Configuration of a medium-voltage switchgear installation under the aspect of a hazard caused by an arcing fault
On the basis of IEC 61936-1 (VDE 0101-1), the following points should be observed when configuring medium-voltage switchgear.

a) Protection against operator faults, for instance ensured by the following measures:
   - Switch disconnectors instead of disconnectors
   - Make-proof switches
   - Interlocking devices
   - Unambiguous key locks
b) Keep operating aisles as short, high and wide as possible.
c) Use sealed encapsulations or covers instead of encapsulations with openings or meshed wire.
d) Deploy installations which are arc-fault-tested instead of installations in open design (e.g. installations in compliance with IEC 62271-200; VDE 0671-200).
e) Bleed off arc gases into a direction away from the operator personnel, and if required, out of the building.
f) Use current-limiting devices.
g) Ensure very short tripping times from fast-acting relays or devices that respond to pressure, light or heat.
h) Operate the installation from a safe distance.
i) Prevent the re-energization by use of non-resettable devices which detect internal equipment faults, incorporate pressure relief and provide an external indication.

According to this, the operating room must always be included in the protective measures to be taken against the effects of an arcing fault:

- A calculation of the dynamic pressure load on the operating room, from which an architect or structural engineer may recognize the stress on building structures, is recommended.
- The operating room must be equipped with pressure relief openings of sufficient cross section or with a pressure relief channel.
Siemens provides two calculation methods to establish rough guidance values for the room size and/or pressure relief openings during the planning phase.

**Estimation of pressure effects according to Pigler**
A simple method for rooms up to 50 m³ is based on F. Pigler [1] (if required, a calculation can be requested from the Central Consultant Support Team of Siemens TIP). Data on the room volume, the area of the free relief cross-section and the short-circuit current to be tested are entered into a matrix. This supplies a simple curve progression for the overload pressure (see Fig. 2).

**Finite-elements-simulation of pressure load under conditions of arcing**
Although the incidence of an internal fault (arcing fault) is very unlikely in type-tested air- or gas-insulated switchgear, the consequences of such a fault may be severe for the operating personnel as much as for the room itself. Therefore, appropriate pressure relief measures may have to be provided in the installation and room planning. To do so, there are various options, such as providing pressure relief openings, ducts or absorbers.

With the aid of ultra-modern FE (finite-elements) methods, pressure calculations can be spatially resolved in a given environment and can simultaneously be performed over the entire burning time of the arcing fault. Siemens offers the service of a numerical calculation on the basis of a 3D volume model, where the real installation of the switchgear, pressure development, reflection and arrangement of the pressure relief openings is taken account of (costs amount to 3,000 € and more depending on outlay; please refer to your TIP contact for such requests).

Various pressure load scenarios can be calculated for specific switchgear installation types, short-circuit currents and mounting locations. Thus the customer benefits from extended planning security and a cost-optimized solution.

The flow conditions are defined as framework parameters. Firstly, these are the switchgear steel sheets and secondly, the absorber sheets to be penetrated. At last, the pressure

---

**Fig. 2: Result of a pressure estimate based on Pigler [1]**

---

**Pressure calculation according to Pigler**
for switchgear types 8DJ, 8DH, 8DJH with absorber

<table>
<thead>
<tr>
<th>Room volume (Vr) in m³:</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free pressure relief cross-section (Apr) in m²:</td>
<td>0.5</td>
</tr>
<tr>
<td>Short-circuit current (Isc&quot;) in kA:</td>
<td>20</td>
</tr>
<tr>
<td>Maximum pressure (p(max)):</td>
<td>10 hPa after 146 ms</td>
</tr>
</tbody>
</table>

The result of these pressure calculations contains no statements about the pressure withstand capability of the building and its constructional parts (e.g., doors, windows). The layout of such parts regarding the calculated pressure characteristic must be done by the structural engineer. No responsibility can be accepted for consequential damages as a result of internal arcing.
Fig. 3: Example of a view of the switchgear room with user-selected measuring points

Fig. 4: Contour plotting of a simulation at the point 0.1 s
relief openings in the switchgear room are defined (see Fig. 3). But the model also allows to calculate a fully enclosed room, or factor in pressure relief openings with a pre-defined response pressure. As a result, the model yields the pressure rise and the flow conditions at any point of the finite-elements grid over time.

In addition, the pressure distribution on the walls of the switchgear room can be plotted as a contour at a given moment in time (see Fig. 4).

A higher pressure in the range of factor five may be expected if conventional air insulation is used in switchgear design as against gas insulation.

**Configuration of a low-voltage switchgear installation**

The Technical Report of IEC/TR 61641 (VDE 0660-500 Addendum 2) describes a special test for low-voltage switchgear and controlgear which is not a binding rule in the sense of a design verification test or type test. Siemens, however, recommends this testing, since personal safety can be substantially affected. The type-tested Siemens SIVACON switchboards comply with these requirements. The criteria for evaluating the test under arcing fault conditions with regard to personal safety are as follows:

- Properly secured doors, covers, etc. may not open.
- Dangerous parts (e.g. large or heavy parts, parts with sharp edges) of the switchgear cannot fly off.
- No holes are formed in freely accessible outer parts of the enclosure.
- Vertically applied indicators (exception: indicators for detecting the heat effects of gases which are ignited by burning paint coats or adhesive stickers must be excluded from the evaluation) which were specially applied do not ignite.
- The protective earth circuit for parts of the enclosure which can be touched continue to function.
- In addition, the following must be observed concerning installation safety: The arcing fault is limited to a defined area and there will be no re-ignition in adjacent areas.
- Emergency operation of the switchgear is possible after the fault has been rectified, or respectively after the disconnection or removal of the affected functional units. This must be proved by an insulation test with 1.5 times the value of the rated operating voltage for the duration of one minute.

Depending on the network topology, the scope of damage caused by an arcing fault can be comparable to that in medium-voltage switchgear. Nevertheless, the issue of pressure calculation for the low-voltage range as well as for a transformer room has not yet been adopted as common practice. However, you should be well aware of the danger involved here. For this reason, it is urgently recommended to observe the installation instructions for the respective switchgear type. Siemens provides a tool for the configuration of a transformer room, which will be briefly described below.

**Configuration of a transformer box**

Like in medium- or low-voltage switchgear, there also is the hazard of an arcing fault in the transformer room. Compared to switchgear rooms the pressure rise is much higher here, since the space in the transformer room is often much more confined. The call for an appropriate verification of the pressure rise in case of an arcing fault is pushed by surveyors.

Siemens has developed a tool for the calculation of the pressure rise in case of an arcing fault which is based on the estimations of F. Pigler [1] and in-house experience (see Fig. 5; only available in German). For the use with GEAFOL transformers, such a calculation can be requested from the Central Consultant Support Team at the headquarter of Siemens TIP. Besides a graphical evaluation of the pressure development (Fig. 6), the data on ventilation and pressure rise is output in the documentation.
Belüftung des Transformator-Raumes und näherungsweiser Druckanstieg im Störlichtbogenfall

<table>
<thead>
<tr>
<th>Raumhöhe einschl. Doppelboden:</th>
<th>3,00 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raumbreite:</td>
<td>2,00 m</td>
</tr>
<tr>
<td>Raumtiefe:</td>
<td>2,00 m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Projektname:</th>
<th>Muster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearbeiter:</td>
<td>Mustermann</td>
</tr>
<tr>
<td>Datum:</td>
<td>01.01.2013</td>
</tr>
</tbody>
</table>

- **Trafos**
  - **Hersteller**: SIEMENS
  - **Typ**: Geafol
  - **Spannung**: 630kVA, 10/0,4kV, UK 6%, reduziert

- **Berechnung Trafverlustleistung PV**
  - **Trafos - Leerlaufen Verluste PV**: 1100 W
  - **Trafos - Kurzschlussverluste PV kopf**: 7500 W
  - **Trafos - Gesamtverluste QV**: 9350 W

- **Berechnung Zu-/Abluftquerschnitts A1, A2**
  - **Wirkliche Höhe H (siehe Bld)**: 2 m
  - **Kühl Lufttemperatur Luftaustritt b1**: 50 °C
  - **Kühl Lufttemperatur Luftanstrich b2**: 30 °C

- **Benötigte Lüftungsoffnung (A1/A2)**: 0,739 m²

- **Installierte Lüftungsoffnung B1/B2**: 1,000 m²

**Abschätzung Druckanstieg im Störlichtbogenfall**
- **Max. Kurzschlussleistung**: 250 kW
- **Mittelspannungs-Nennspannung**: 10 kW
- **Max. Kurzschlussstrom**: 14 A

**Transformatorschutz mit Leistungsschalter**
- **Schutzleistung b++ (zwischen 0 und 1 s)**: 0,005 kW

**Transformatorschutz mit Hf-Sicherung**
- **Gilt für Kurzschlussströme > 40x kN der Hf-Sicherung**
- **Druckansaug ohne Zu-Ablüftöffnung**: 42 A
- **Druckansaug mit Zu- und Ablüftöffnung**: 4,2 A

Fig. 5: Screen display of the Siemens calculation tool for calculating a transformer room
Influencing factors on the overpressure and pressure effects

The findings of a series of pressure calculations provide an overview of the pressure behaviour with regard to a variation of the framework parameters (in our example: room dimensions, size of the pressure relief openings, use of pressure-reducing absorbers at the switchgear).

Fig. 7 shows that a pressure absorber is very effective in small rooms, whereas an extremely large opening only yields a minor pressure reduction.

---

**Fig. 6: Pressure curve progression for a model calculation of a transformer room**

Unaffected pressure curve progression in the room (CB / HV HRC)

---

**Fig. 7: Overpressure response of a Siemens 8DJH switchgear substation**
(calculated after one second of arcing fault duration and 16 kA short-circuit current)
A pressure rise in case of an arcing fault must be taken into consideration for the planning of a building, or else damage or destruction of the building structures would be possible. Table 1 contains guidance values for the permissible static pressure in buildings dependent on the wall material in new condition.

Besides the building material, dimensions, thickness and restraint (fixed-end) pressure of the wall in the building structures also play a part for the pressure load. The layout of the building for the calculated pressure must be performed by the structural engineer, since there are no generally valid and binding figures. For your guidance, some values from Report [2] are listed here as an example.

Tab. 1: Stress-taking capability of different wall materials in case of overpressure [1]

<table>
<thead>
<tr>
<th>Type of wall</th>
<th>Permissible overpressure in the room in hPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gypsum board</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Brick wall without side connection (e.g. between concrete pillars)</td>
<td>10</td>
</tr>
<tr>
<td>Brick wall with reinforcing iron, wall thickness ≥ 24 cm (e.g. between concrete pillars)</td>
<td>25</td>
</tr>
<tr>
<td>Precast concrete members</td>
<td>50</td>
</tr>
<tr>
<td>Cast-in-place concrete</td>
<td>&gt;70</td>
</tr>
<tr>
<td>Concrete cell</td>
<td>130</td>
</tr>
</tbody>
</table>

Tab. 2: Effects as a function of the overpressure magnitude [2]

<table>
<thead>
<tr>
<th>Consequences</th>
<th>Peak overpressure [hPa] = [mbar]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct personal injury</td>
<td></td>
</tr>
<tr>
<td>Unpleasant bang effect in deep frequency</td>
<td>1.5</td>
</tr>
<tr>
<td>Very loud bang</td>
<td>3</td>
</tr>
<tr>
<td>People are blown over</td>
<td>10</td>
</tr>
<tr>
<td>Pressure-related limit value for damage effected by explosives and cast missiles</td>
<td>15</td>
</tr>
<tr>
<td>Lower threshold of tympanic membrane rupture</td>
<td>175</td>
</tr>
<tr>
<td>Damage to the tympanic membrane</td>
<td>300</td>
</tr>
<tr>
<td>Lower threshold for damage to lung</td>
<td>850</td>
</tr>
<tr>
<td>Lower threshold for severe damage to lung</td>
<td>1,850</td>
</tr>
<tr>
<td>Lower lethality threshold</td>
<td>2,050</td>
</tr>
<tr>
<td>Glass panes</td>
<td></td>
</tr>
<tr>
<td>Occasional breakage of large panes under tension</td>
<td>2</td>
</tr>
<tr>
<td>Glass breakage owing to sound waves</td>
<td>3</td>
</tr>
<tr>
<td>Breakage of small panes under tension</td>
<td>5</td>
</tr>
<tr>
<td>Destruction of 10 % of window panes</td>
<td>10</td>
</tr>
<tr>
<td>Destruction of 50 % of window panes</td>
<td>30</td>
</tr>
<tr>
<td>Destruction of 75 % of window panes</td>
<td>50</td>
</tr>
<tr>
<td>Damage to building</td>
<td></td>
</tr>
<tr>
<td>Damage on window frames, doors and roofs</td>
<td>5</td>
</tr>
<tr>
<td>Minor damage on roofs</td>
<td>20</td>
</tr>
<tr>
<td>Destruction of roofs and walls of wooden sheds or dwellings</td>
<td>60</td>
</tr>
<tr>
<td>Little to medium damage on dwellings</td>
<td>120</td>
</tr>
<tr>
<td>Destruction of masoned walls</td>
<td>200</td>
</tr>
<tr>
<td>Medium to severe damage to dwellings</td>
<td>350</td>
</tr>
<tr>
<td>Almost complete destruction of normal buildings</td>
<td>400</td>
</tr>
<tr>
<td>Destruction of multi-storey buildings, destruction of 50-cm brickwork</td>
<td>500</td>
</tr>
<tr>
<td>Damage to infrastructure</td>
<td></td>
</tr>
<tr>
<td>Dented sheet steel plates</td>
<td>75</td>
</tr>
<tr>
<td>Slightly deformed steel frames of skeleton buildings</td>
<td>95</td>
</tr>
<tr>
<td>Ruptured oil tanks</td>
<td>215</td>
</tr>
<tr>
<td>Destruction of concrete steel walls</td>
<td>350</td>
</tr>
<tr>
<td>Empty rail cars thrown over</td>
<td>460</td>
</tr>
<tr>
<td>Loaded freight cars thrown over</td>
<td>600</td>
</tr>
<tr>
<td>Loaded freight cars destroyed, 99 % damage to horizontally stored pressurized containers, chemical reactors and heat exchangers</td>
<td>750</td>
</tr>
</tbody>
</table>
Reduction of the probability that an arcing fault will occur

In the intense debate about the detection and quenching of an arcing fault, technically very sophisticated and expensive solutions tend to be touted. Whereas Siemens has for long favoured the prevention of arcs by complete insulation of all live parts inside the assembly (busbars, terminations, transfer points, etc.). Such passive precautions rule out an arc, hence it needn't be detected, nor quenched.

Active systems for the detection and quenching of internal arcs as a result of a fault must be serviced and do not encompass any advantages in terms of system availability. The effects of the arcing fault when occurred (contaminations, metal splashes, etc.) may be minor, but usually they need to be removed. Furthermore, the shutdown device of the active system must be replaced. This can be a laborious, time-consuming work. In 80% of all cases, switchgear installations are mounted at a wall. In case of an appropriate form of inner separation and division, the busbars are separately enclosed with partitions, which drives up the work and downtime involved for a simple cleaning procedure or replacement (dismantling of the affected panel, if necessary, dismantling of the entire switchgear assembly to access the main busbars).

Monitoring the outgoing feeder areas of the switchgear when using an active system is not recommended for reasons of supply reliability, since arcing faults in this area shall be cleared by the upstream protective device. Or else, such a fault would result in the complete shutdown of the whole switchgear.

In order to monitor the feed-in area (cable termination compartment), the system must influence the upstream protective device. This counteracts the advantage of fast tripping and disconnection by the active system in the event of such a fault.

Siemens also provides an active system for arcing fault detection and quenching, but favours the passive system which is more beneficial for the customer (complete insulation of busbars and terminals), since
- the economic aspects, such as investment and servicing costs, are much more favourable
- the availability of the switchgear, in combination with downtimes near nil, is enhanced
- personal safety is improved
- operational reliability is higher than with a function-controlled, active system
- feed-in and outgoing feeder areas (including compartments in withdrawable-unit design) and busbar compartments can be insulated by design
- there is long-standing, exclusively positive experience with the passive protection system.

Fig. 8: Passive system for the prevention of an arcing fault by means of an insulated busbar, panel connector, and incoming/outgoing feeder
The fundamental prerequisite for the safety and quality of the passive system is the proper mounting of the insulation. For Siemens switchgear, there are special mounting instructions which also specify the properties and arrangement of the materials to be mounted (see Fig. 9).

Fig. 9: Work instruction for mounting a passive system for Siemens switchgear

Footnote


[2] Die Risikoanalyse mittels Konsequenz und Eintrittswahrscheinlichkeit – Methodik am Beispiel des Druckbehälterversagens im Erdgasfahrzeug; 2012 - C. Glanz, Bergische Universität Wuppertal, Fachbereich Maschinenbau/Werkstofftechnik