SOLUTIONS FOR INTERNAL ARC PROTECTION ACC. IEC 62271-200 WITH PRESSURE RELIEF INTO THE SWITCHGEAR ROOM FOR GAS AND AIR INSULATED MEDIUM VOLTAGE SWITCHGEARS

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ABSTRACT

Internal Arc Classification (IAC) of medium voltage switchgear according to IEC and IEEE standards is one of the most important requirements to guarantee personal safety in case of internal arc faults. During the last years IAC became a common standard for personal safety. One of the challenges is the relief of the hot gases from the faulty switchgear. The most common solution is the relief through a pressure relief duct out of the switchgear building. For some applications like in the oil and gas industry or for other critical industries and utilities more specific requirements have to be fulfilled. The pressure relief has to be coordinated for the switchgear, the switchgear room and the building. This paper presents solutions for GIS and AIS to fulfil IAC requirements.

INTRODUCTION

Internal arcs occurring in metal-enclosed MV-switchgear are high current fault arcs. These arcs are initiated e.g. by surges in power grids, insulation failures or human errors. On average one arc fault happens per 10,000 switchgear and year. During such a rare event, a considerable amount of electrical energy up to 70 MJ.is dissipated in the apparatus within a few 100 ms. The core temperature of the arc rises up to 30,000 K. The arc roots are able to melt through the internal metallic enclosure of the switchgear within a few milliseconds. In a distance of 1 m the power density of radiation still reaches 105 W/m^2, which is about 100 times the value of normal solar radiation at the earth's surface. Up to 70% of the supplied electrical energy will be dissipated in the heating of the enclosed gas. This involves a significant increase of pressure inside the faulty compartment within a few ten milliseconds. In GIS a pressure increase up to 0.7 MPa, for AIS up to 0.15 MPa could be recorded. This causes an expulsion of hot gases, flames and fumes with temperatures up to 1000°K. Later on glowing or molten particles of metal and insulation materials can be emitted.

Personal safety

The major target of the Standards as IEC 62271-200 [1], IEC°62271-202 [2] or IEEE C37.20.7 [3] in consideration of internal arc fault is to ensure a minimum of protection for humans, e.g. operating personnel or pedestrians. This protection from the perilous effects of the phenomena mentioned above is valid for the vicinity of the switchgear [4]. The described internal arc test procedure is defined with the intention to verify the effectiveness of the design towards the personal protection in the worst case of an internal arc. It takes into consideration the impact of the overpressure, the thermal effect of the arc and ejected hot gases [5].
It seems appropriate to mention first some crucial test criteria according to IEC 62271-200:

- Correctly secured doors and covers do not open. Deformations are accepted up to a clearly defined degree (see IEC/IEEE).
- Projections of small parts, up to an individual mass of 60 g, are accepted.
- Arcing does not cause holes in the accessible areas up to a height of 2 m.
- Cotton indicators, simulating the clothes of persons in the vicinity of the switchgear, shall not ignite from the effect of hot gases.

Service Continuity for process industries

The topology of the switchboard has to allow for quick and short-term modifications of the network during service. This shall be possible without loss of operation. Modifications are required in case of grid disturbances or in case of service and maintenance. Power availability is often realized by means of redundant assets. As redundancy is a major cost factor, the reliability of the installed equipment is of high importance. This target can be achieved by a suitable design and quality of the installed switchgear and by the generic network structure with solutions like the bus section coupler and multi-bus-bar architectures. High quality switchgear should have a robust and partitioned design, independent from environmental impacts like humidity, pollution and small animals [6].
In industries it is often a requirement, that an internal arc fault in one cell of the switchgear must not influence the neighbouring cells. If the worst comes to the worst the influences should be acceptable for a conceivable period of time allowing further operation of the remaining parts of the switchgear-installation. This time period should last at least until the next scheduled maintenance event.

RELEASE INTO THE ROOM

The simplest and most common design to comply with the standards is to enclose the switchgear by a rigid containment and attaching a duct, relieving the projected hot gases and particles out of the switchgear room. These ducts are specially designed add-ons to the switchgear. However this solution can cause a lot of non justifiable difficulties in terms of installation costs, building configurations and compliance with local building codes. Some customers, like O&G industries, have developed standardized buildings, like switchgear containers or pre-fabricated switchgear buildings. Here the pressure relief concept must comply with these buildings, without influences to the industrial surrounding.

Moreover, other customers such as Chemical and Automotive Industries want to get an installation concept, where the switchgear room is environmentally independent. Also an exchange of accidental contamination of adjacent rooms has to be strictly prevented. For such applications a solution with release inside the switchgear room comes into consideration.

Basic design strategies

Basic design strategies of MV-switchgears can be defined on the basis of the following objectives:

- Independence of environmental impacts like condensation, atmospheric pressure, dust, fumes, gases, small animals, oxidation and so on
- Maximum of operational reliability by minimizing causes of malfunction
- Maximum of protection for human contact (electric shock protection)
- Minimum of required space
- Minimum of maintenance requirements
- Easily manageable cable-connection technique
- Minimized costs
- Ecological
- Easily scalable and replaceable components
- Simplified and safe assembly

Basic design considerations

The simplest way of achieving personal safety is the use of a massive and rigid design. While such a concept will provide a maximum of protection, it means on the other hand high costs and more difficulties during the erection of the switchgear. With experience from testing and utilisation of modern simulation tools, it is possible to optimize design and cost, while still obeying safety requirements. As an alternative a flexible structural design can be applied. It might constitute a risk factor, although flexibility related to the huge mechanical stress during the internal arc test may be utilized. Making an optimal choice of the enclosure thickness depends on the experience of the designer, as he has to compromise between rigidity and flexibility. Modern simulation tools will be supportive for this challenge. Finally the internal arc test will be the practical and expensive proof.

A non-rigid, completely closed switchgear-installation could not withstand the pressure rise caused by an internal arc event. For this reason the pressure must be released. As explained above there are detailed requirements for a release into the installation room. The major technical challenges are the significant reduction of the arcing effects: pressure wave, ejected hot gases and glowing particles. This can be achieved by using energy absorbers. For such a concept thermal management at normal operation has to be taken into consideration. The pressure relief concept should not influence existing design criteria.

Concept for pressure relief inside the room

Arc energy absorbers - shortly named absorbers - consist usually of layers of expanded metal in all sorts of arrangement. Other types of absorbers exist as well, consisting of ceramics with a high thermal conductivity. Metal-absorbers are in use since the beginning of the last century, but were really scientifically investigated only from the eighties. They are used in electrical installation in order to reduce pressure and thermal stress in relief rooms and form also an obstacle for effluent flames and glowing particles. Physically speaking - absorbers have two main effects. First, they absorb heat energy, hence the name and second, which is more important, they constitute a resistance to the flow. Therefore and due to their topology, the absorbers act as a heat exchanger for the hot gases. The heat flux is directed from the gas to the metal during the entire arcing process. The heat transfer is depending on the temperature gradient at the boundary layer between gas and metal, on the velocity of the gas and on the thermal properties of the used metal. The heat flow can be increased by maximising the effective total area of the boundary layer. The total absorbed heat energy increases with the mass of used metal [7].

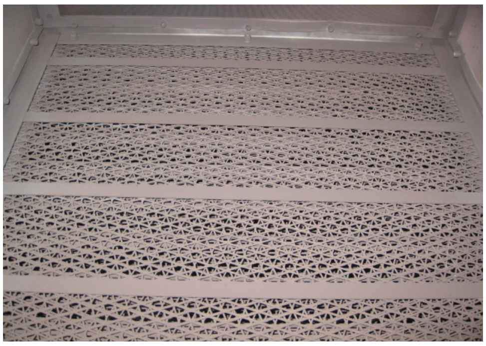

Figure 1: Absorber arrangement after test

The flow resistance depends on the topology of absorbers. By streaming through the absorber, the kinetic energy of the gas decreases due to the friction forces and turbulences. The effective open cross section of the pressure relief is also reduced due to the absorber. Both properties reduce the pressure stress behind the absorber significantly. The flow resistance Δp is described by the pressure loss formula [8], [9]:

$$\Delta p = \xi \cdot \rho \cdot \frac{v^2}{2} \qquad (1)$$

with ξ being the empiric pressure loss coefficient, ρ the density of the gas and v the velocity of the gas. From equation (1) follows that the flow resistance increases with the velocity of the gas. In case of an arc fault, velocities are high and lead therefore to a large flow resistance. In case of normal operation of the switchgear, velocities are low due to natural convection, causing little resistance to the cooling air flow. Also exhaust-channel-systems can give increase the flow resistance and improve the cooling of the hot gases. One more method is the usage of deflectors at the end of the release routes to divert the hot gases and the glowing particles away from protected areas [10].

Thermal management requirements have to be considered for normal operation condition as well. Any kind of enclosure surrounding the cubicles or even obstacles at the ventilation openings causes a lower cooling performance. Ideally, natural ventilation is sufficient for operation. Because of low flow velocities absorbers will not block the outflow of heated air. Absorber dimensions should be considered to keep convectional cooling at an appropriate level. Absorbers will usually be positioned at the top of a switchboard. This also is the typical outlet location for ventilation. Inlets should be positioned near the bottom. In a pressure relief duct such inlets need to be equipped with pressure flaps. Inlets at the top are possible, too. The continuity of the gas flow must be taken into consideration. The positioning of inlet and outlet must allow a preferred flow direction. When applying forced cooling with absorbers at the outlets, the mass flow should be at the lower required level, as the flow resistance of the absorber rises rapidly with velocity [11].

GIS like GHA, comply with latest ecological requirements thanks to its high dependability, operating reliability, maximum operator safety and ergonomic operator guidance. GHA is designed as a single or double busbar system and offers through its compact and clear modular construction both a maximum of flexibility and reliability. AIS like PIX are a result of more than 80 years of experience combined with new proven design features and innovative components. PIX is designed as single or double busbar version with withdrawable vacuum circuit breakers.

Table 1: Ratings of tested GIS and AIS switchgear

Type	GHA	PIX
Rated Voltage	12-40,5 kV	17,5 kV
Rated Current	2500 A	3150 A
Rated Frequency	50 Hz	50 Hz
Short-circuit current	40 kA / 3s	40 kA / 3s
IAC-Class	AFLR 40kA/ 1s	AFLR 40kA/ 1s

Both types of switchgear are equipped with exhaust ducts for pressure relief to atmosphere and where qualified for IAC-AFLR 40kA/1s. By above mentioned rules, both types of switchgear had been successfully adapted and tested for pressure relief into the room.

SOLUTION FOR GIS

Figure 2 shows the MV-switchgear GHA equipped with an exhaust duct for the release of gases exterior to the building. This metal-enclosed and compact apparatus is segregated into four compartments by earthed metal panels. The compartments containing circuit breaker and busbar are SF_6 insulated and are constructed as steel tanks with individual rupture discs. The cable compartment uses air insulation and is equipped with a separate pressure flap. At the rear side of the units a pressure channel provides a buffer volume prior entering the pressure relief duct.

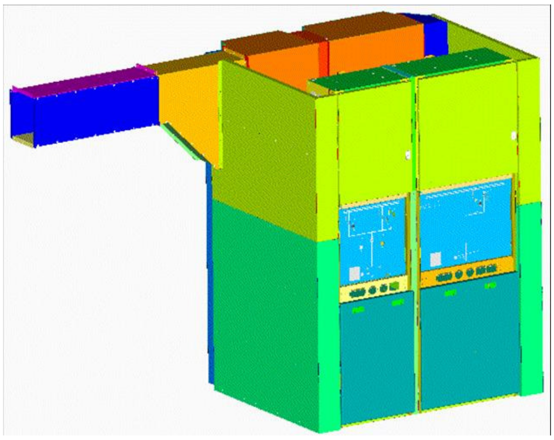

Figure 2: Panels with pressure relief duct, Front view

Figure 3 shows the final solution for pressure relief into the room.

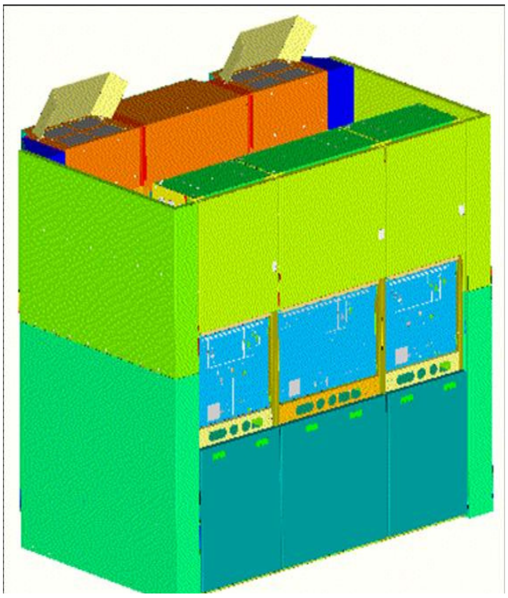

Figure 3: GIS-Panels with pressure release into the Room, Front view

The absorbers are installed in the top of the pressure channel. As before the pressure channels of all cubicles are connected to each other to form a large buffer volume. Due to this, all parallel absorbers are involved in the pressure relief out of the pressure channel. Figure 4 shows the measured pressure behaviour at different locations in the cubicle.

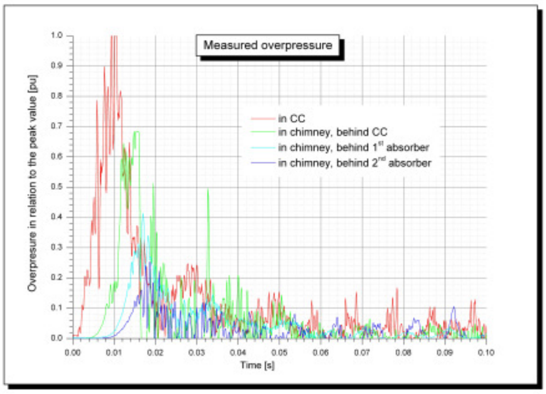

Figure 4: Measured values in normalized scale after ignition in the CC (40 kA / 1s)

It can be clearly seen, that the pressure is subsequently reduced by all components of the designed pressure relief system. Finally the pressure peak is reduced by more than 75 % inside the channel before relief into the switchgear room. The remaining 25 % are additionally reduced by the final absorber. Figure 5 shows the simulation results of the pressure curves including a typical MV switchgear room with a volume of 40 m³. The room is considered as completely closed.

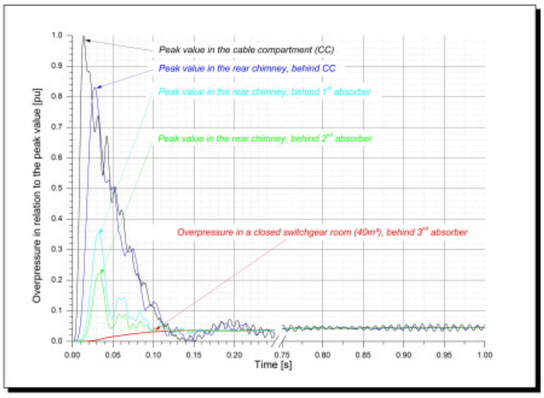

Figure 5: Simulated values in normalized scale after ignition in the CC (40 kA / 1s) including the switchgear room

It can be seen, that the peak value of pressure in the switchgear room is less then 5 % of the initial value in the CC.

SOLUTION FOR AIS

Figure 6 shows the test setup of the air insulated switchgear PIX in the configuration with exhaust duct and release to atmosphere, including the test arrangement according to IEC 62271-200. Figure 7 shows the setup of the configuration with absorber on the top of a closed duct and release into the room.

Figure 6: PIX-Panels with exhaust duct

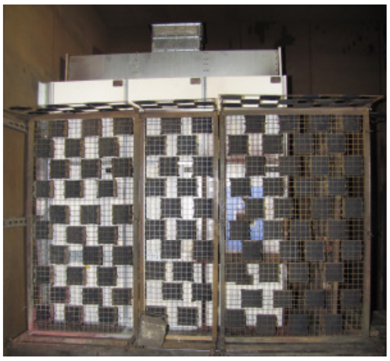

Figure 7: Panels with pressure relief into the Room

Figure 8: Test performed with 40 kA / 1s in CC, duct configuration

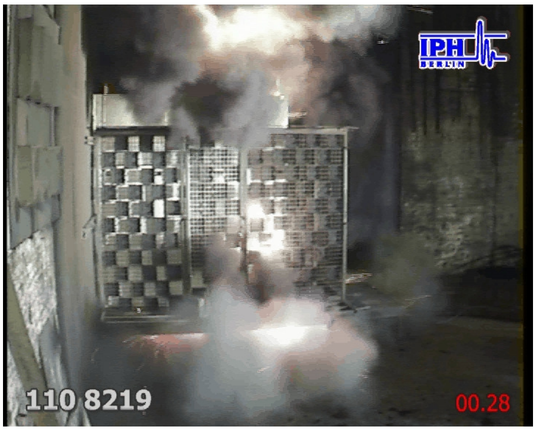

Figure 9: Test performed with 40 kA / 1s in CC, absorber configuration

The segregation concept of AIS is different to GIS. Due to this, the pressure relief channel is adapted on the top of the switchgear. Therefore the absorber was implemented external on the top of the pressure channel.

Figure 8 and 9 show a comparison of hot gas and glowing particle ejection, filmed during the internal arc fault tests with 40 kA / 1s by ignition in the CC.

The comparison of the gas exhaust with duct solution and absorber solution shows, that the absorber solution is not more critical than the common standard solution with pressure relief out of the room. The developed absorber solution does not only ensure the personal safety, it is also applicable to AFLR requirements. Figure 10 shows an internal arc test without absorber with relief into the room and AFL requirements.

Figure 10: Test with pressure relief into the room without absorber

It is clearly visible, that the exhaust of hot gases and glowing particles is more significant. This solution with pressure relief into the room without absorber is more critical than the absorber solution, especially for higher short-circuit current ratings. However, this test was also successfully passed.

CONCLUSION

Distribution switchgear has to comply with the relevant international standards. The personal safety with respect to internal arc protection is one of the most challenging design criteria. In addition, customers demand service continuity even in case of internal arc fault. Some customer applications require neither interaction to the outside environment nor influence to the building by the pressure relief construction. Therefore the relief into the switchgear room becomes necessary. In general there are two different approaches. The first one is to exhaust the hot gases through absorbers. The second one is the diffusion of the hot gases by deflectors. Both solutions are applicable. Nevertheless, the overall impact of the approach with absorbers had been proven to be more effective. The use of absorbers decreases the overpressure in the switchgear room significantly. Furthermore the exhaust of hot gases and glowing particles is reduced in comparison to the use of deflectors.

This paper describes the requirements and the solutions to this. Different design concepts for GIS and AIS had been developed, simulated and successfully type tested for IAC AFLR 40 kA / 1s according to IEC 62271-200.

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