Session Eleven:
Development of Standards for MV Switchgear Rated for Arc Protection

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Introduction

Switchgear standards historically considered the electrical capability of switchgear with little regard to the effects of internal arc. To achieve some degree of safety users and manufacturers have considered, measures ranging from PPE, specific operating procedures, through to remote control and arc detection systems, however these measures do not change the characteristics of the switchgear, and therefore the switchgear / switch room should still be considered a high risk area.

In 1990 the IEC 60298 “Specification for MV Switchgear” included for additional requirements for resistance against internal arc, and thereby introduced the concept of safety for operators against the effects of internal arc. Since 2003 this standard has been superseded by the IEC62271-200 standard which includes for a broader definition of metal enclosed switchgear and a clear classification of the internal arc certification. The standard makes provision for a comprehensive series of standards that will cover the full range of standards applicable to medium voltage switchgear.

How manufacturers have incorporated the requirements of the IEC62271-200 standard into their designs, is illustrated by way of example with ABB UniGear ZS1 switchgear for air insulated switchgear (AIS) and ZX switchgear, Gas insulated switchgear (GIS).

What is an internal arc fault?

An internal arc…

- is the result of a rapid release of energy due to an arcing fault between phases, neutral or a ground.
- arises when at least part of the current passes through a dielectric, usually air
- dissipates maximum peak power
- has a temperature up to five times the surface temperature of the sun (20,000°C)
- has a light intensity more than 2000 times that of normal office light
- causes volumetric expansion of approximately 40,000 x

Arc faults are usually caused by external factors outside the control of the manufacturer; the occurrence of an arc can never be totally prevented or predicted. Typically arc faults occur when:

- there is an ingress of foreign material, water, insects or rodents
- mislaid or forgotten materials, tools, loose wires, test connections
- faulty insulation, derogation of insulation
- insufficient over voltage protection
- Incorrect operation, incorrect interlocks, or disregard for operating rules

Any one of the above can trigger the internal arc. Once the arc is ignited the surrounding air is ionised so the arc will continue to burn at a high temperature until
interrupted. The arc can be divided into four phases. During phases 3-4 hot plasma (gasses, particles, molten metal and any other material damaged by the arc) will be released from the switchgear to the surrounding atmosphere endangering people in the vicinity. The danger comes from two parts, hot plasma being released and a shock wave that is released from the faulted cubicle.

Four phases of the pressure curve for
an internal arc fault

1. Compression Phase
2. Expansion Phase
3. Emission Phase
4. Thermal Phase

1. Compression phase: t=0 -10 ms, the volume of the air where the arc develops is overheated due to the release of energy. The remaining volume of air inside the cubicle heats up from convection and radiation. Initially there are different temperatures and pressures from one zone to another;

2. Expansion phase: The expansion phase starts when the maximum pressure has been reached and the pressure relief flaps have opened. This phase lasts approximately 10 to 20 milliseconds.

3. Emission phase: due to continued contribution of energy by the arc, nearly all the superheated air is forced out by an almost constant overpressure, This continues until the gas in the cubicle reaches the arc temperature. This phase typically lasts up to 50 - 100 milliseconds in small cubicles, and in larger cubicles it can be considerably longer;

4. Thermal phase: after the expulsion of the air, the temperature inside the switchgear nears that of the electrical arc. This final phase lasts until the arc is quenched, when all the metals and the insulating materials coming into contact undergo erosion with production of gas, fumes and molten material, referred to as plasma in this paper. The greatest damage typically occurs during this phase, when the thermal stress caused by the radiated heat is responsible for severe burns and ignition of clothing.
What is PPE?

Personal protective equipment (PPE), serves to eliminate or reduce the effects of burning caused by the arc plasma in the event of an internal arc.

Historically, electrical protective clothing and conductor guarding was first applied to the prevention of electric shock injuries. In the 1970s, users and manufacturers began recognising and addressing the electric arc hazard.

In the early 1990s, Occupational Safety and Health Administration (OSHA) regulations and National Fire Protection Association (NFPA) standards began incorporating specific requirements to protect personnel from electric arc burns.

NFPA 70E is a standard that pertains to the selection and use of protective clothing amongst various other safety instructions and system development guidelines. The selection of personnel protective equipment should be determined by the potential hazard and the parts of the body that could be exposed to the hazard.

Note:

Although discussed first PPE should be considered the last line of defence in the protection of personnel from injury. In the IEC62271-200 no provision for switchgear tested in relation to personnel protective equipment is made. The need for PPE should therefore not be required if the switchgear is fully tested according to the IEC specification, and can be reduced to a practical level. However, other standards will sometimes require PPE irrespective of engineering, which will reduce risk. NFPA70E requires that non-melting PPE (HRC0) be used even when internally arc proof equipment is being switched with the doors closed.
What are Operating procedures and access control?

Operating procedures and access control are commonly used practises in many environments, that state how equipment should be operated and procedures that restricts access to equipment under certain conditions. It would be safe to say that all work environments utilise some degree of operating procedures, practises and access control.

Some customer procedures may even forbid operation of energised equipment of a certain standard, type or design. In practise however restrictive operation of equipment is difficult to implement, and sometimes not possible to implement. It would therefore make sense that any new equipment designed for operation should be capable of safe operation and restrictive operation or access control would not be necessary.

Note:

By using Internal Arc Classified switchgear, the need for special operating procedures and access control can be minimised, reduced to acceptable limits or even eliminated. This will enable maximum functionality of equipment without excessive restrictive time consuming policies hampering the availability of equipment.

What are remote switching operations and remote racking mechanisms?

It is a common belief that providing remote closing and opening of circuit breakers together with motorised racking systems would make the switchgear safe to operate, but this is a misperception. In addition the use of motors for remote racking of the circuit breaker necessitates that the circuit breaker racking system does not require any supervision, and / or adjustments during racking. This may sound like a simplification of the issue; however experience has shown that remote racking of switchgear can be problematic, jamming during operations making the switchgear more dangerous due to half connected circuit breakers.

Note:

For switchgear fitted with remote operation some risks are removed during operations while it is being operated, however remote operation does not address the risks present when the switchgear is not being operated.
What are Arc detection systems?

Arc detection systems are protection systems that use sensors to detect the presence of an internal arc and then isolate the faulted section by opening of the incoming or feeder circuit breaker. In general three types of systems exist, as follows:

- **a)** Light detection systems
- **b)** Pressure rise detection systems
- **c)** Micro switches situated on pressure relief devices.

a) Light arc detection systems can normally detect an arc very quickly within less than 5-10mS, and send the trip signal to the circuit breaker to clear the fault. Depending on the circuit breaker the clearing time will vary from 50-100ms. The total clearing time will therefore be the sum of the relay detection time and the circuit breaker clearing time. The REA light arc detection system as shown from ABB uses current and the presence of light to detect a fault. This ensures that faults are truly present before issuing a trip signal.

b) Pressure rise detection systems work on the principle of pressure switches fitted within the enclosure. These will typically detect a fault within 10-20ms before sending a trip signal to the circuit breaker.

c) Micro switches fitted on pressure relief flaps can detect a fault within a similar time as pressure detection systems 10-20mS, and will send the corresponding trip signal to the appropriate circuit breaker. Again the internal arc clearing time is dependant on the circuit breaker clearing time. The cost benefit of this system is significant compared with the light arc detection system, for a small sacrifice in opening time.

In all of the above cases the switchgear must be able to withstand the pressure rise caused by the internal arc, for a reasonable test time of 1 second. Fitting of an arc detection system alone does not make the switchgear internal arc compliant. Caution should also be exercised on incoming or ring cables where back feed exists, which can not be effectively protected using arc detection systems, unless special measures are taken.

Note:

The arc detection system should be seen as a safety enhancement and not as a substitute for internal arc tested switchgear.
IAC requirements

The latest IEC 62271-200 standard takes into account the latest manufacturing techniques as well as the requirements of users including safety and functionality. The standard is a broad definition that covers all types of metal enclosed switchgear, AIS and GIS switchgear. Internal arc classification (IAC) is given as AFLR $I_kA/s$.

A = Accessibility type A, Restricted to authorized personnel only, distance of indicators 300mm from enclosure.

B = Accessibility type B, Unrestricted accessibility including that of general public, distance of indicator 100mm from enclosure.

C = Accessibility type C, Restricted by installation out of reach, distance from indicator to be specified by manufacturer.

FLR = Access from the font (F= Front), the sides (L=Lateral) and the rear (R=Rear)

$I_kA =$ Test current in kilo amps

$s =$ Test duration in seconds

The test is carried out on all compartments of the switchgear, with indicators placed at the specified distance from the enclosure. A short circuit is created within the switchgear; the short circuit current is then injected for the duration of the test. The following criteria are considered for a successful test.

Criterion No. 1 Correctly secured doors and covers do not open. Deformations are accepted, provided that no part comes as far as the position of the indicators or the walls in every side.

Criterion No. 2 No fragmentation of the enclosure occurs within the time specified for the test. Projections of small parts, up to an individual mass of 60 g, are accepted.

Criterion No. 3 Arcing does not cause holes in the accessible sides up to a height of 2m.

Criterion No. 4 Indicators do not ignite due to the effect of hot gases. Should they start to burn during the test, the assessment criterion may be regarded as having been met, if proof is established of the fact that the ignition was caused by glowing particles rather than hot gases. Pictures taken by high-speed cameras, video or any other suitable means can be used by the test laboratory to establish evidence. Indicators ignited as a result of paint or stickers burning are also excluded.
Criterion No. 5 The enclosure remains connected to its earthing point. Visual inspection is generally sufficient to assess compliance.

Equipment that has passed the test is issued with a type test report. Verification of the type test documentation by users is important for users to ensure equipment purchased conforms to the required standard.

The rationale behind switchgear designs to meet the IEC 62271-200 standard.

According to the IEC 62271-200, the transfer of withdrawable parts to or from service position shall be carried out without reducing the specified level of arc protection. Closing, opening and racking operations from behind a closed door, ensures that the IAC rating is not compromised or reduced, therefore the switchgear can be safely can be operated electrically and/or mechanically without compromising the internal arc classification of the switchgear, and endangering the operator.

Switchgear designs have evolved to enclose all medium voltage components within the arc proof enclosure. ¹ For example voltage transformers are enclosed within the arc proof structure of the switchgear, so therefore the racking operations of busbar connected apparatus like VT’s, CB’s and contactors can be completed from the front of the switchgear, from behind a closed door without compromising the IAC rating of the gear.

In the case of LSC2B switchgear all cable connected apparatus such as voltage transformers, current transformers, surge arrestors, cable live indicators etc, these can only be accessed once the cable earth switch has been applied. The IEC standard defines LSC2B as: switchgear and controlgear where the cable compartment is also intended to remain energized when any other accessible compartment of the corresponding functional unit is open

¹ The exception to this is where screened systems are used or where apparatus are protected by HRC fuses. The rational is with screened systems only single phase earth faults can develop, and with fuse protection the let through fault current is limited by the fuse.
Example of an ABB MV Switchgear construction

### Important standards for MV switchgear in the IEC62271 series:

<table>
<thead>
<tr>
<th>IEC 62271 Series</th>
<th>High Voltage Switchgear and Controlgear</th>
<th>Old IEC Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1</td>
<td>Common specifications</td>
<td>IEC 60694</td>
</tr>
<tr>
<td>-100</td>
<td>High-voltage alternating current circuit-breakers</td>
<td>IEC 60056</td>
</tr>
<tr>
<td>-102</td>
<td>High-voltage ac disconnectors and earthing switches</td>
<td>IEC 60129</td>
</tr>
<tr>
<td>-103</td>
<td>Switches for rated voltages above 1 kV and less than 52 kV</td>
<td>IEC 60265-1</td>
</tr>
<tr>
<td>-105</td>
<td>Alternating current (AC) switch-fuse combinations</td>
<td>IEC 60420</td>
</tr>
<tr>
<td>-106</td>
<td>AC contactors and contactor-based motor-starters</td>
<td>IEC 60470</td>
</tr>
<tr>
<td>-200</td>
<td>AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV</td>
<td>IEC 60298</td>
</tr>
</tbody>
</table>

Other important standards for components:
- IEC 60044-1 for Current transformers
- IEC 60044-2 for Voltage transformers
- IEC 61243-5 for VDS system for Cable Live Indicating Systems

Note:
Certification of individual components within the switchgear is just as important as the certification of the switchgear itself.
**Gas and arc ducts**

Arc ducting systems have been introduced to control, reduce or remove the plasma and the steep rise in pressure from the switch room. Generally three types exist, namely:

- plasma deflectors
- plasma absorbers
- arc ducting

Depending on the room dimensions the expected fault level, duration, and type of switchgear a suitable arc ducting system can be chosen.

Gas / plasma deflectors generally divert gasses away from the front or sides of the switchgear to the rear.

Plasma absorbers reduce the temperature and pressure rise and allow for safe venting within the switch room.

For higher fault levels and/or safety arc ducting systems are employed to vent the plasma to outside the switch room, and completely eliminate the risks associated with burning from the arc or the sudden pressure rise within the switch room.

Containing the plasma to the faulted compartment of the faulted cubicle and dealing with these gasses in a manner that does not effect other cubicles or personnel in the switch room, has the desired effect of ensuring the arc fault does not spread into adjacent cubicles resulting in the destruction of the complete switchboard, or damage to the building or personnel within the building.

**Busbar segregation.** The busbar compartment is normally a common compartment so a special insulated non, metallic busbar segregation plate is desired. The segregation plate must not compromise the type test requirements of the switchgear, while providing sufficient strength to contain the arc pressure within the faulted compartment. Switchgear designs that incorporate this into their portfolio ensure that damage to switchgear is limited making repair quicker and easier. It is desirable to have busbar segregation fault levels >31.5kA, either for every cubicle or every third cubicle.
The considerations for the switch room.

Providing IAC rated switchgear in itself does not provide for full protection against the effects of internal arc failure. As MV switchgear is designed for indoor use, most MV switchgear designs have to be mounted within a building or a weather proof enclosure. The height of the roof has a significant impact on the IAC rating as hot gasses can bounce off the roof of the building causing injury to the operator or possibly damage to the building. The level of the required roof height is dependant on the fault level, and the height and position of the pressure relief vents. The table below shows the recommended roof height using UniGear ZS1 switchgear without any gas ducts fitted.

<table>
<thead>
<tr>
<th>A = Switchgear height &gt;2200 &lt; 2720</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internal arc fault current for 1 sec.</strong></td>
</tr>
<tr>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>B = Roof height &gt; 4 M</td>
</tr>
<tr>
<td>B = Roof height &gt; 3.5M &lt; 4 M</td>
</tr>
<tr>
<td>B = Roof height &gt; 3M &lt; 3.5 M</td>
</tr>
</tbody>
</table>

* Can be reached at lower fault duration (500ms) or with arc limiting devices.

As can be seen the IAC rating generally declines significantly with the height of the ceiling. The easiest manner to ensure the IAC rating is not affected by the building dimensions is to install gas ducts, vented to the outside of the switch room.

If venting to the outside of the switch room is not possible then plasma absorbers may be more suitable. Plasma absorbers work on a similar principle to that on a vehicle silencer, where the gas exhaust path is increased and cooled by passing the gasses through a series on cooling plates. The energy from the hot gasses is absorbed by the plates while the steepness of the pressure wave is reduces. The down side of the plasma absorber is that it adds resistance to the exhaust path causing back pressure, which in turn puts stress on the switchgear. Plasma absorbers can generally be used effectively for fault levels of 25kA or less.
In addition the pressure rise in a switch room as a result of the internal arc has the same effect as a blast wave, which can injure personnel or damage buildings. Where the shock wave is restricted and cannot vent to the outside atmosphere the wave will bounce off walls creating a doubling effect.

To reduce the effects of the pressure rise, buildings can be fitted with pressure relief devices. These devices remain closed during normal conditions providing protection from the elements, rodents, and people, and open once a preset amount of pressure is reached. With these devices fitted the pressure in the building can be relieved safely well before any destructive forces are placed on the building.

**Example of building failure from internal arc.**

**Arc eliminators**

The UFES is a new technology that is used to explain how an arc can be eliminated by detecting the arc and shorting out the arc before any significant pressure rise within the cubicle can develop. The UFES detection system will simultaneously send a trip signal to the upstream circuit breaker to clear the fault.

![Typical pressure curve within a cubicle for an internal arc fault of 40kA / 100kA peak](chart.png)
The system uses light and current detection that can detect a fault within 1-2 ms, and send a signal to the fast closing earth switch to close within < 4ms. The earth switch creates a short circuit across all three phases, and therefore the arc can no longer exist as the system is short circuited and therefore will be at zero volts.

The major benefit of this system is that the UFES can be retrofitted to any switchgear that does not conform to the IEC 62271-200 IAC classification, to make the switchgear safe for operation from the effects of internal arc faults.

Summary and recommendations
The improved level of manufacturing techniques has led to improved, safer and more reliable switchgear systems for AIS and GIS. An internal arc can occur at any time, usually caused by factors outside the control of the manufacturer, and may involve any people within the vicinity of the switchgear whether they were operating the gear of not.

The IEC 62271-200 standard provides a clear definition of classification for internal arc, and covers a broad range of switchgear. Users who specify this standard and enforce compliance to this standard by verifying type test certification from reputable manufacturers are assured of peace of mind as they are using the latest available standards for operator safety.

Certification of the switchgear is one part of the process in ensuring safe operation; a further consideration must be given to the building or enclosure, in particular in cases of small switch rooms and enclosures.

IAC classification can not be substituted with PPE, operating procedures, remote operation or arc detection systems.

Prevention is better that cure. Preventing the arc from occurring by specifying switchgear compliant to the relevant IEC standards is the first line of defense, see annexure 1. The next line of defense is providing a safe environment, taking into account the fault level, the network, the appropriate switchgear design together with the building design and the protection systems available. The last line of defense should be operating procedures, and the appropriate PPE.
Annexure 1. Check List for selecting switchgear, for safe operation and according to the relevant IEC standards.

<table>
<thead>
<tr>
<th>Question</th>
<th>No</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are all the applicable switchgear variants type tested for Internal arc classification to IEC 62271-200 according to the correct predetermined classification AFLR for 1 second?</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Are plasma / gas ducts available to vent arc gasses to safe area / outside the switch room?</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Is busbar segregation available, to prevent the spread of faults through the busbar compartment?</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Are CT’s type tested according to IEC60044-1.</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Are VT’s inside arc proof enclosure, and not mounted on top of switchgear?</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Can busbar VT’s be safely racked in and out of service from the front of the switchgear, while the switchgear is energised?</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Can cable connected VT’s be safely isolated from the busbars, in accordance with LSC2B requirements?</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Are VT’s type tested according to IEC60044-2?</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Are cable live indicating devices type tested for VDS according to IEC 61243-5.</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Are Circuit Breakers type tested according to IEC 62271-100.</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Do Circuit Breakers have extended mechanical endurance ratings for 10,000 mechanical operations, classification M2?</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Do Circuit breakers have interrupting parts with no maintenance requirements during the expected mechanical life, i.e. 30,000 no load operations on the interrupting part, Classification E2</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Do Circuit breakers have interrupting parts with very low re strike probability, Classification C2?</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Can Circuit breakers be racked, closed and opened both electrically and mechanically while the compartment door is closed. ABB can fit a device on the door so the mechanical operations can be carried out with the door closed.</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Do cable live indicating devices that conform to IEC 612324-5?</td>
<td>☐</td>
<td>✓</td>
</tr>
<tr>
<td>Are separate cable and busbar earth switches available and tested according to IEC 62271-102 so that safety earths can be achieved without using the circuit breaker.</td>
<td>☐</td>
<td>✓</td>
</tr>
</tbody>
</table>