Development of standards for MV Switchgear for Arc Flash protection

Bryan Johnson
ABB South Africa
Internal Arc in Switchgear
What is an internal arc

Characteristics of 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 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×
Causes of an internal arc

Rodents, Reptiles and insects

Faulty insulation or operation

Accidents during work

Mislaid and forgotten tools
Effects of an Internal arc fault

- Pressure increase in an enclosed compartment
- Rapid onset (<15 ms) results in explosive forces
- Thermal effects, and hot gases present
- The longer the arc is allowed to burn the greater the risks of damages, and injuries to nearby personnel.

Consequences of Internal arc fault:

- **Conventional protection device**
  - Dramatic consequences expected
  - Severe injuries and equipment damage
  (Dependant on switchgear design)

- **Fast protection devices**
  - Limited consequences expected for people and equipment damage
  (Dependant on switchgear design)

Graph showing the time in ms vs. consequence of internal arc fault.
Phases of an Internal Arc

Four phases of the pressure curve for an internal arc fault

1. Compression Phase
2. Expansion Phase
3. Emission Phase
4. Thermal Phase
Criteria to pass arc test

Criteria for switchgear to comply with IEC 62271- 200 Annexure A

1. Correctly secured doors and cover do not open
2. No fragmentation of the enclosure occurs within the test time
3. Arcing do not cause holes in the accessible sides, up to height of 2m
4. Indicators do not ignite due to effect of hot gases
5. The enclosure remains connected to its earthing point

UniGear ZS1 undergoing an internal arc test
Internal Arc
IAC Classification

- **IAC**: internal arc classified
- A, B or C: a distinction is made between two types of accessibility in the site of installation:
  - **Accessibility type A**: restricted to authorized personnel only. Distance of indicators 300mm from the panel;
  - **Accessibility type B**: unrestricted accessibility, including that of the general public. Distance of indicators 100mm from the panel;
  - **Accessibility type C**: restricted by installation out of reach. The minimum admissible height of installation shall be stated by the manufacturer.
- **FLR**: access from the front (F – Front), from the sides (L – Lateral) and from the rear (R – Rear);
- \(i\): test current (in kA);
- \(t\): arc duration (max. 1s).

According to the standard, the IAC qualification is a mandatory part of the type plate on every panel (e.g. IAC AFL 31.5kA x 1s)
Fault persists even if CB is operated by arc protection system.

Incomer cable fault has to be cleared by remote CB. Therefore switchgear must be able to withstand an arc fault for ≥ 500 ms.
Internal Arc
IEC 62271 -200 Type test.

Type test comprises of:

- Simulation of an internal fault in a switchgear compartments
- Resulting in a destructive arc
  - Fire and hot gases
  - Fast pressure rise
- Simulation of an operator standing next to the switchgear by means of cotton indicators

After the fault current has been switched off:

- Assessment of the test:
  - Visual inspection
  - High-speed video
  - Oscillograms
- If test was successful, a type test report can be issued
- A type test report provides evidence for health and safety of operators!

UniGear ZS1 with arc ducting undergoing an internal arc test
Standards for MV Switchgear
IEC 60694 Common Specifications for switchgear

Standard concerned mainly with the electrical capability of switchgear, i.e. Ratings and functionality.

Type testing consisted of:

- Short time current withstand
- Dielectric withstand
- Temperature rise
- IP rating
IEC 60298 Additional standard for switchgear

Standard in addition to the established IEC60694 standard where safety from internal arc is then considered:

Type testing consisted of:

- Internal arc testing for operator safety
- Short time current withstand
- Dielectric withstand
- Temperature rise
- IP rating

First edition 1990
IEC 62271-200 New Classifications for Switchgear (Replacing IEC 60289)

Broader definition “Metal Enclosed” with specific definitions to cover all types of switchgear

- Partitioning – (PM, PI)
- Interlocking – (Tool / Interlock based)
- Loss of service continuity (LSC)
- Internal arc classified IAC AFLR according to the new IEC 62271-200 Annex A

First edition of standard 2003
Metallic segregation classification PM

Metal enclosed switchgear
Metallic segregation of all the compartments
Metallic shutters operated by the apparatus movement
Closed door apparatus racking
Busbar segregation on every third panel
Loss of Service Continuity Simplified

**LSC1**
Switchboard must be de-energised to work on any part

**LSC 2A**
Adjacent units can remain in service while maintenance is carried out on one unit.

**LSC 2B**
Same as LSC2A, but cables can remain energised
## Standards
### IEC 62271 – Series for MV switchgear

**Common numbering of publications**

<table>
<thead>
<tr>
<th>IEC 62271 series</th>
<th>NEW TITLE</th>
<th>OLD IEC NUMBER, IF ANY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Common specifications</td>
<td>IEC 60694</td>
</tr>
<tr>
<td>2</td>
<td>Seismic qualification for rated voltages of 72.5 kV and above</td>
<td>-</td>
</tr>
<tr>
<td>100</td>
<td>High-voltage alternating current circuit-breakers</td>
<td>IEC 60056</td>
</tr>
<tr>
<td>101</td>
<td>Synthetic testing</td>
<td>IEC 60427</td>
</tr>
<tr>
<td>102</td>
<td>High-voltage alternating current 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>104</td>
<td>Switches for rated voltages of 52 kV and above</td>
<td>IEC 60265-2</td>
</tr>
<tr>
<td>105</td>
<td>Alternating current switch-fuse combinations</td>
<td>IEC 60420</td>
</tr>
<tr>
<td>106</td>
<td>Alternating current contactors and contactor-based motor-starters</td>
<td>IEC 60470</td>
</tr>
<tr>
<td>107</td>
<td>Alternating current switchgear-fuse combinations</td>
<td>-</td>
</tr>
<tr>
<td>108</td>
<td>Switchgear having combined functions</td>
<td>-</td>
</tr>
<tr>
<td>109</td>
<td>Series capacitor by-pass switches</td>
<td>-</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>
All Standards are important for MV Switchgear

MV Switchgear - IEC 62271-200

Circuit Breakers - IEC 62271-100

Cable Compartment

Current transformers - IEC 60044-1

Earth Switches - IEC 62271 – 102

Voltage transformers - IEC 60044-2

Cable Live VDS - IEC 61243-5
Primary Distribution Switchgear, History of standards

Certification of switchgear

Switchgear is considered compliant if tested in accordance with test procedures and parameters of standard.

Certified and tested equipment can be considered as:

- Safe to operate
- High in quality
- Reliable
- Functional
Developments in switchgear and protection systems
Air Insulated switchgear
Cable VT moved to inside switchgear

Earlier Designs

Arc Gases Directed to Rear

Arc Gases “Blocked” or Directed to Rear

Newer Designs

Arc Gases Directed Upwards
Air Insulated switchgear

Busbar VT’s moved to separate panel

Earlier Designs

Arc Gases “Blocked” or Directed to Rear

Newer Designs

Arc Gases Directed Upwards
Air Insulated switchgear
Conventional O/C & E/F Protection

- Protection: Only over-current relay ($t>0.4s$)

Serious damage and injuries
Air Insulated Switchgear
REA Arc Protection

- Protection: Arc protection relay and over-current relay

I_{k}''

No major damage or personal injuries
Medium Voltage Switchgear
Arc Venting Ducts

Arc ducts
Ducting offered on top of the switchboard, provides for a safe method of venting and dealing with arc flash pressure, and hot gasses.

Absorber or exhaust vents are used to dissipate the hot gasses depending on the substation dimensions, and fault levels.
Primary Distribution Switchgear
Arc ducting systems introduced

Panel by panel relief
- Pressure relief to the top of the switchgear, with no ducts

Pressure relief via absorber
- Pressure relief via ducts and absorbers
- The pressure wave is cooled by absorbers and discharged into the switchgear room

Pressure relief to the outside
- Pressure relief duct extended up to an opening in the outside wall
Air Insulated Switchgear
Effects of sudden pressure rise
Air Insulated switchgear
Developments summarised

Arc Ducting

Compliance to standards

Closed door racking

Arc protection relays

Busbar Segregation

VT’s inside arc withstand area
What are the hazards to be considered for electrical switchgear

- Common and well understood hazard, is ELECTRIC SHOCK

- Less understood but some awareness is the risk of injuries and death caused by BURNING from an ARC FLASH

- Often not considered, but just as dangerous is the ARC BLAST / SHOCK WAVE.

Customers need to be aware of all the potential dangers for operating staff.

Arc Flash Accident
What can customers do?
Solutions, Substation Audits
Site Audit of installations.

- Collection of a host of data sets regarding the condition of the switchgear
- Inspection and testing of all the switchgear involved in the assessment
- Interview of the maintenance personnel most knowledgeable about the switchgear
- Assemble the collected information into template worksheets
- Application of rules to determine the overall risk for each circuit breaker
- Establish a risk profile of asset base
- Develop a risk mitigation plan with priorities for action
- Execute action plan
- Perform periodic re-assessments to monitor reduction in risk profile resulting from executing actions
Solutions – Services
Substation pressure rise calculation.

Calculation of estimated pressure rise in each substation for civil engineer estimation:

- Substations may require additional venting for pressure relief
- Substations may require reinforcing
- Substations may require complete replacement
Retrofit and protection systems

- Retrofit or upgrade of existing switchgear to arc fault capability
- Install arc fault protection devices

Upgrades have the advantage of being cost effective, however this may not be suitable to achieve required safety level.
Reduce fault level
Limit fault levels.

- IS Limiter, Fault limiting device to reduce fault levels:
- Install reactors
- Use fuse protection to limit let through fault level

Arc limiting devices requires sound knowledge of system and skilled expertese to maintain system
New switchgear

- Replace the switchgear with complete new switchgear cubicles.
- Certification is in accordance with the latest IEC standards.

New switchgear offers protection to the latest standards, giving absolute peace of mind.
Personal Protective Equipment
Determine appropriate level of PPE.

- PPE should be last resort, but play an important part.
- PPE at a low level <10 cal/CM\(^2\) should be everyday wear for field staff.
- PPE at a higher level should be mandatory when operating switchgear.
- PPE guideline NFPA70E Guideline should be followed to determine requirements
**Arc Eliminators**

- Exemplary pressure curve, with and without UFES, in a compartment of an air insulated medium voltage switchgear, for an internal arc fault current of 130 kA (peak) / 50 kA (rms)

Arc Eliminators short out open arcs very fast to minimise damage.
The Ultra Fast Earth Switch (UFES) Concept

- > 25 years experience
- > 2 Mio. vacuum interrupters in service
- Highly reliable

- > 50 years experience
- Fastest switching device, worldwide approved

Ultra Fast Earthing Switch type UFES
(Primary switching element)
UFES Arc Eliminator
Differentiation

Conventional protection device
- Fault detection by standard relay
- Clearing of the arc fault current by the upstream circuit-breaker

Fast-acting protection relay with supplementary equipment (e.g. \( I_{th}\)-limiter)
- Fast fault detection by special protection relay
- Clearing of the arc fault current by the upstream circuit-breaker

Ultra Fast Earthing Switch type UFES
- Ultra-fast fault detection by UFES electronic type QRU1
- Ultra-fast extinction of the internal arc by switching of the UFES primary switching element type U1
- Final clearing of the fault current by the upstream circuit-breaker
UFES Arc Eliminator
Fault detection

Electronic device for measurement, logic and tripping, type QRU1

- 9 optical inputs for light detection
- 3 current inputs
- Extendable up to 150 supplementary optical inputs with light detection system type TVOC-2
- Exact identification of fault location
- Watchdog function
- Test mode for complete functionality check for installed condition
- Simple configuration
UFES Arc Eliminator
Switching Element
UFES Arc Eliminator
Switching Principle

Position before tripping

Moving direction

Current flow after tripping

Vacuum device

Drive
UFES Arc Eliminator
Event sequence

1. Formation of an internal arc

[Diagram showing electrical components and a graph with two lines indicating short-circuit current $I_k$ and DC component.]
UFES Arc Eliminator

Event sequence

1. Formation of an internal arc

2. Detection of the internal arc by light and/or current monitoring
UFES Arc Eliminator

Event sequence

1. Formation of an internal arc

2. Detection of the internal arc by light and/or current monitoring

3. ~1-2 ms after detection
   Tripping of the UFES primary switching elements by the electronic device (optional also tripping of the upstream circuit-breaker)
UFES Arc Eliminator

Event sequence

1. Formation of an internal arc

2. Detection of the internal arc by light and/or current monitoring

3. ≈ 1.2 ms after detection
   Tripping of the UFES primary switching elements by the electronic device (optional also tripping of the upstream circuit-breaker)

4. ≤ 4 ms after detection
   Creation of a solid, 3-phase short-circuit earthing by the UFES primary switching elements, resulting in the consequent interruption of the arc voltage. The internal arc will extinguish.
UFES Arc Eliminator

Event sequence

1. Formation of an internal arc

2. Detection of the internal arc by light and/or current monitoring

3. \( \sim 1.2 \text{ ms after detection} \)
   Tripping of the UFES primary switching elements by the electronic device (optional also tripping of the upstream circuit-breaker)

4. \( \leq 4 \text{ ms after detection} \)
   Creation of a solid, 3-phase short-circuit earthing by the UFES primary switching elements, resulting in the consequent interruption of the arc voltage. The internal arc will extinguish.

5. After \( 80 \text{ ms} + \text{time} \times \)
   Final clearing of the fault current, flowing through the primary switching elements, by the upstream circuit-breaker.
UFES Arc Eliminator
Retrofit solutions

**Top-mounting**

- For all air insulated switchgear with minimum panel width of 800 mm.

- Connection to the busbar of the switchgear system by copper bars.

- UFES service-box with pressure relief can be directly mounted over pressure relief of switchgear.

- Smooth exchange process of UFES poles.

[UFES Simulation](#)

[LMR Type test](#)
UniGear portfolio

Medium Voltage products Air Insulated Switchgear

- 12 - 17.5kV and 24kV
- IEC 62271-200