DEVELOPMENTS FOR MAXIMUM SAFETY IN MEDIUM VOLTAGE SUBSTATIONS REGARDING INTERNAL ARCS

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ABSTRACT

Apart from the quality of supply, personal safety is the most important aspect for a DSO. In line with this, the exceptional occurrence of internal arcs is more prominent on the agenda than ever before. Modern MV switchgear has either solid (possibly in combination with air) or gas insulation. Besides prevention of faults, single pole solid insulation can also be capable of controlling internal arcs to safe values, depending on the earthing philosophy of the network. Developments take place where solid insulation is being combined with arc proof enclosures, for example in ring main units (RMU's). Maximum prevention and control of internal arcs is achieved if those new types of RMU's are installed in arc proof substations.
Although the IAC classifications in the IEC standards are rather mature, not all possible situations are considered, like opened adjacent compartments in primary switchgear and faults in transformers and LV racks in substations.

INTRODUCTION

The probability of internal faults in Medium Voltage (MV) switchgear is very low. However, arcing energies (up to tens of MJ's), resulting in ejection of hot gases and pressure rise, can affect personal safety seriously. Therefore, the prevention and control of internal arcs is addressed more and more. Internal arcs in switchgear can be prevented effectively by robust design and single phase, solid insulation of live parts. An alternative approach is making the switchgear internal arc resistant; to be proven by prescribed tests in the relevant standards. Both philosophies are evolving and mixing up nowadays to achieve more safety. This paper provides overview and gives insights in the developments for safety at internal faults from a perspective of a network utility, IEC standardization and a supplier.

CONSIDERATIONS FROM A DSO

In the operation of their networks, two of the most important issues for Distribution System Operators (DSO's) are safety and quality of supply. Safety of course, is very important for both the own personnel, who can stand in front of a switchgear when an internal arc occurs, as well as for the environment. For example, toxic gases and high overpressures should be prevented as much as possible when the switchgear is placed in a building in which other people are present as well.
In a society that is becoming more and more dependent on electricity, the quality of supply is becoming increasingly important. This requires that the number of faults should be minimised and that any disturbance, when it occurs, should be solved quickly. Most faults occur in cables and joints. In this case the faulted section can be determined and then the network can be reconfigured to restore electricity supply. After repair of the damaged component, the network can be reconfigured to its normal configuration.
When a fault occurs in MV switchgear, restoring the supply to customers can be more problematic, as most switchgear is not redundant. As long as only one panel is out-of-service, it is generally possible to find a temporary solution; for example by using a spare panel. Therefore it is crucial that in case of the occurrence of an internal arc the fault is limited to the panel, or even compartment, in which it occurs, instead of destroying the complete switchgear. In the latter case, it can take long (more than a day) to restore power.
Experiences from Enexis show that at least once a year an internal arc heavily damages a primary or secondary switchgear installation (on an installed base of about 2000). Both safety as well as quality of supply requires that the effect of an internal arc, when it occurs, is limited as much as possible. Therefore DSO's more and more require switchgear that is arc-proof. Upon that, it is very relevant to discuss arc resistance per compartment and with open doors. This is currently not covered in IEC62271-200 and -201 [1,2].

PREVENTING INTERNAL ARCS BY DESIGN

Metal- or insulation enclosed MV switchgear is designed and manufactured for achieving a high availability of the network and to prevent internal arcs. Generally, this is achieved by applying good engineering practice and robust design. Many aspects contribute, such as IEC compliance, type testing, use of reliable materials, endurance tests, aging tests, the use of analytical & Six Sixma tools and quality management to a high extent.
Another preventing measure in this respect is single pole solid insulation. A classic, but actual example of this kind of MV switchgear is widely installed since the 1960's in for example The Netherlands and Scandinavia.[4]

CONTROLLING INTERNAL FAULT EFFECTS

Although internal arcs are rare, protection systems and internal arc proof enclosures are often applied to limit and control the effects of the faults.

Limiting the arc duration

In addition to overcurrent protection, typical arc detection systems react on light or pressure. As a consequence, the duration of the arc can be limited to an acceptable value (in nowadays practice maximum 1s). Furthermore, arc eliminators become available. These devices should short-circuit any internal arcing fault very quickly (down to even a few ms) to limit or even eliminate all serious effects [5].

Arc resistant switchgear

Manufacturers made a real competency of designing and testing internal arc resistant switchgear. Knowledge is gained about the behaviour of arcs. The pressure rise and burning behaviour can be predicted based on current, geometry and the kind of metal on which the arc has its foot points [6] [7].
Mechanisms are designed where an “arc burning place” is created successfully at the very moment of arcing, triggered by the arc pressure itself via a hinge construction. The arc stays at a fixed spot with small arcing distance and thus with a relative low arcing energy.
Arc coolers, made of ceramic or steel, absorb a significant portion of the arcing energy before the gases are expelled. This reduces the amount of exhaust, the temperature of the gasses and increases safety for the persons present.

THE BEST BOTH WORLDS

Maximum safety can be reached when single pole solid insulation is combined with arc resistant enclosures. Figure 1 shows an example of such a switchgear. The RMU is air insulated, with single phase solid insulation in a very compact design (350mm panel width for 24kV). The internal arc classification IAC AFL 20kA-1s is according to IEC62271-200 [1].

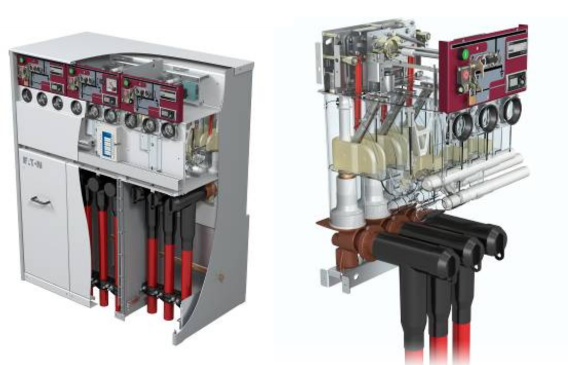

Figure 1 Compact, air insulated RMU,with single phase solid insulation plus arc proof metal enclosure.

INTERNAL ARC PROOF SUBSTATIONS

As next level of addressing safety, complete MV/LV substations are designed and tested for controlling effects of internal arcs according to IEC62271-202 [3]. At the moment, transformer and LV are excluded in this respect. The RMU is often installed on a buffer volume created in the substation. Theory and practice show that many parameters influence the overpressure, temperature and exhaust [6]. The volumes and geometry of the ring main unit (A), buffer (B) and substation (C) (see figure 2) play an important role, just as the cross sections and absorbing properties in the openings in-between.

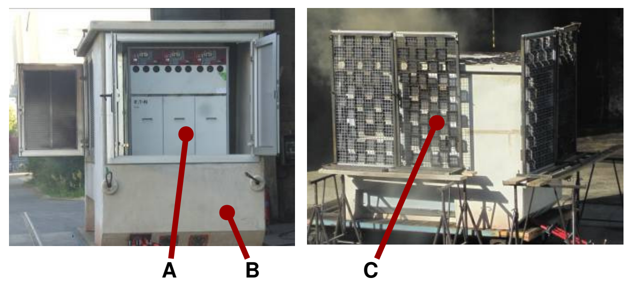

Figure 2 MV/LV substation just after internal arc test.

Switchgear rooms in buildings, where the walls might be unable to withstand overpressures or hot gases should be subject to comparable considerations.

OCCURRENCE OF INTERNAL ARCS

An internal arc will start with a dielectric breakdown of the insulation medium. The resulting arc current is highly dependent on the actual situation. Two situations can be distinguished for a compartment that contains all 3 phases in a metallic enclosure:

With gaseous insulation only

Because of the higher dielectric stress, a phase to phase breakdown will be most likely. The arc will develop within appr. 10 ms into a 3-phase fault, resulting in the full rated short circuit.

With solid insulation per phase

A dielectric breakdown will generally start as phase to earth fault. The corresponding arcing current is dependent on the neutral treatment of the network:

1. Peterson earthed network: only a few Amps will flow
2. Floating neutral: depending on the size of the network, a capacitive earth fault current of several Amps to max appr. 500 A will be introduced as arcing current
3. Impedance earthed neutral: a fault current of 1,5 to 2,5 kA will occur
4. Solidly / direct earthed neutral: Dependent on the actual impedances involved, an arcing current up to several kA’s will occur.

The ability of the other two poles with their solid insulation to withstand the occurrence of the fault current in the compartment is essential; if this withstand ability is not adequate, a multiphase arc will develop within the compartment before the fault is cleared.

In case 3 and 4 above, the fault current will be in the short circuit (>>) range of the protection relay, so the maximum duration of this fault will be theoretically the rated duration of the switchgear (in MV generally 3s), but in practice set on maximum 1s.

Regarding case 1 and 2, the fault might be undetected or no action is foreseen for longer times, so eventually a multiphase fault might develop. Also a cross country fault might start if the insulation in the network is insufficient to withstand the increased voltage level in the two unaffected phases. A 2-pole ignition is prescribed as general case in IEC 62271-200 ed.1 [1] for cable compartments when all poles are insulated and the cable connection is made by a plug in or site made solid insulation connection. When discussing safety aspects, an issue is the possibility to detect the fault and the subsequent time to leave the building / switch off the faulted panel in case persons are present.

Utmost safety gives the situation as applied for decades in Sweden, where single pole solid insulated switchgear is applied in Peterson earthed grids, with earth fault protection. Any dielectric failure will start as a single phase to ground arc of only a few Amps. This earth fault will be switched-off immediately.

REVISION OF IEC 62271-200 STANDARD

The relevant standard for MV metal enclosed switchgear is IEC 62271-200 [1]. This standard is close to be updated to ed.2 (2011). This second edition includes the following significant technical changes:

- Category LSC2 is added to LSC2A and LSC2B.
- The introduction of specific ratings related to fault level to earth (clauses 4.5 to 4.7)
- Solid insulated high-voltage parts are no longer considered as a compartment on its own
- The introduction of an optional rating for "cable test voltage" and the associated requirements and type tests
- For testing the internal arc classification, when assigned by the manufacturer, more specific guidance is provided regarding test arrangement, room simulation and arc initiation.
- A single phase to earth ignition is also recognised for internal arc testing

The level of severity of internal arc testing is maintained without changes. Also the replacement of SF6 by air for testing is not changed from the current edition 1, although the effects might be different [8]. Numerical simulations to address pressure rises are widely investigated [9].

From the FDIS of IEC 62271-200 ed.2:

Table AA.1 – Parameters for internal fault test according to compartment construction

<table>
<tr><th></th><th></th><th>Test current</th><th>Number of phases / earth for arc initiation</th><th>Action if other phase affected</th></tr>
<tr><td rowspan="4">Three phase compartments, other than connection compartments :</td><td>with bare conductors</td><td>I_A</td><td>Three</td><td>N/A</td></tr>
<tr><td>conductors with site-made solid insulation</td><td>I_A</td><td>Three</td><td>N/A</td></tr>
<tr><td rowspan="2">conductors with non site-made solid insulation</td><td>87% I_A</td><td>Two</td><td rowspan="2">Repeat as 3 phase test</td></tr>
<tr><td>I_{Ae}</td><td>One phase and earth</td></tr>
<tr><td>Single phase compartments:</td><td></td><td>I_{Ae}</td><td>One phase and earth.</td><td>Repeat as 3 phase test</td></tr>
<tr><td rowspan="5">Connection compartments:</td><td>Connections uninsulated or fitted with site-made solid insulation</td><td>I_A</td><td>Three</td><td>N/A</td></tr>
<tr><td rowspan="2">Connections using outer cone plugs (screened or unscreened)</td><td>87% I_A</td><td>Two</td><td rowspan="2">Repeat as 3 phase test</td></tr>
<tr><td>I_{Ae}</td><td>One phase and earth</td></tr>
<tr><td rowspan="2">Connections using inner cone plugs</td><td>87% I_A</td><td>Two</td><td rowspan="2">Repeat as 3 phase test</td></tr>
<tr><td>I_{Ae}</td><td>One phase and earth</td></tr>
</table>

INTERNAL ARC TEST RESULTS

Premature to possible changes in next revisions of IEC standards, Eaton already performed several specific internal arc tests on their switchgear.

SVS: single-pole Internal Arc tests

SVS switchgear with its single pole solid insulation embedded primary parts was exposed to single pole to ground arcing tests at Kema laboratory. For all tests, the arc initiation was between cable connection L2 and nearest earthed metal part, supply from busbar side. Poles L1 and L3 had both an Elastimold cable plug and both were energized at 24 kV. Aim of these tests was to see if 1-pole earth faults would develop into a multiphase fault and whether the operator would be in the position to timely leave the station in case a fault would occur.

Tests performed:

- **2,65 kA during 3,7s** (impedance earthed neutral): See figure 3. After 1,4s a hole was burnt in the door and slight emission of gas was the result. The complete 3,7s the arc stayed 1-pole. This time gives a protection more than enough time to clear the fault. Personal safety is not impaired.
- **500 A during 30s** (floating neutral, very large cable network): Very clear to see and hear that something is going on inside the switchgear. After 6s a hole was burnt in the door, resulting in a lot of light, but no plasma came out. The fault stayed single pole for the complete testduration. Personal safety is not impaired.
- **9 A during 7** minutes (floating neutral, very small network): Some light is visible along the doors. Also some noise is audible. No hole is burned in the enclosure. The voltage indication (VPIS) indicates the earth fault. After 30s some slight smoke development above the switchgear. After 420s (7 minutes) the arc was still single pole. Personal safety is not impaired.

Figure 3 1-pole IAC test SVS, result after 2,65 kA-1s

The formal result was the IAC classification:
AFL (I_{AE} 2,5kA-1s).
The results demonstrate personal safety in the unlikely case of an internal arc in SVS in floating or impedance earthed networks, at least up till 2,5kA earth fault currents. Solidly earthed networks may have higher earth fault currents, but this type of neutral grounding is very rare in MV networks.

FMX with opened compartment IAC tested

Although not considered is the revised IEC 62271-200, Eaton decided to test the following situation on its switchgear FMX: "what will happen if an internal arc fault occurs in the busbar system (switchgear in service) when working in the opened cable compartment?"
The test was performed 3-pole at 25 kA-1s, with indicators in the opened compartment, see figure 4. The result was that no indicators were burnt. Apart from expected hearing problems afterwards, the personal safety is not impaired in this situation!

Figure 4 FMX, indicators in opened cable compartment

CONCLUSIONS

- Safety has an ever increasing importance
- Prevention of internal arcs is better than control. Single phase solid insulation is very effective in this respect
- Internal arc classification is addressed in IEC standards
- Edition 2 of IEC 62271-200 now also recognizes single pole to earth faults
- Specific internal arc tests had been performed in line with customers expectations, even when beyond the demands in the actual IEC standards

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