OPERATOR AND PUBLIC SAFETY REVISITED: THE APPLICATION OF IEC 62271-200/202 WITH SPECIFIC FOCUS ON INTERNAL ARC TESTING OF METAL-ENCLOSED SWITCHGEAR AND CONTROLGEAR

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ABSTRACT

Since January 1998, Eskom Distribution has latched on to the international initiative of internal arc testing of indoor metal-enclosed switchgear. Outdoor switchgear followed suit, four years later in August 2002. Operator and public safety has been put under the spotlight in the past few years following catastrophic failure of metal-enclosed switchgear – elevating arc flash safety and hazards to new levels. This has forced the utility to review the current design standards from a product compliance, testing and application perspective. This paper intends to share recent developments in the re-testing of metal-enclosed switchgear products to meet the safety requirements of the South African Occupational Health and Safety Act and industry-aligned requirements utilizing the recently published IEC 62271-200 and IEC 62271-202 as reference.

INTRODUCTION

Users in South Africa have a duty, in terms of safety legislation (most notably the Occupational Health and Safety Act 85 of 1993 [1]) to their employees and the public to provide an acceptably safe environment and to take reasonable measures to mitigate against possible dangers. Developments in distribution switchgear technologies have presented end users with a compelling argument for the use of equipment that is not only safer, but is more reliable and has a relatively low total cost of ownership. This includes switchgear having an insulating/interrupting medium of gas, air, vacuum and/or solid dielectric. In addition, modern compact switchgear is available that is 'sealed for life' – requiring minimal maintenance and intervention over its lifetime. With developments in both technology and knowledge, it is now possible to use switchgear that is fully tested not only to withstand the effects of, but to safely 'vent' the emissions generated by, an internal (arc) fault.

OIL-FILLED SWITCHGEAR AND ALTERNATIVE SOLUTIONS

The majority of oil-filled secondary switchgear, e.g. ring main units (RMUs), in the South African Electricity Distribution Industry (EDI) is classified as 'free-breathing' and therefore prone to moisture and pollutants – representing an 'uncontrolled environment'. In order to obtain access to the oil, the switchgear must be isolated and earthed in terms of operating regulations before any maintenance can be performed. Due to ever-increasing quality of supply expectations from customers, it is becoming increasingly difficult to schedule the onerous outages required. This reality, coupled with pressure on maintenance budgets, has resulted in instances where maintenance is simply not being scheduled. The above factors have all led to an all too common trend that the required maintenance is not being performed on aging oil-filled switchgear. This leads to a gradual deterioration of the insulating, and in particular, the interrupting properties of the oil. The probability of mechanism failure in an 'uncontrolled environment' also increases through lack of maintenance. As a direct result, numerous switchgear failures have occurred which have been accompanied, in many instances, by serious injuries, and in some more severe cases, fatalities. The overall risk of failure increases with the age of the inadequately maintained switchgear.

Issues pertaining to internal arc testing have emerged in the process of addressing the safety concerns around increasing switchgear failure risks. Prior to the advent of suitable alternatives to oil-filled switchgear (e.g. gas-insulated metal-enclosed switchgear), requirements such as internal arc classification could not be seriously implemented. At best, oil-filled switchgear having internal arc tested air-filled cable termination enclosures (i.e. excluding the main oil-filled enclosures) may be available. The now well known concept of internal arc classification (IAC) involves designing and testing equipment that, should an internal short circuit fault (arc) should occur in any of the switchgear enclosures, it will fail in a controlled, 'safe' and predictable manner. The nature of an internal arc fault in oil (i.e. between live parts not designed to interrupt current), is deemed to be uncontrollable. Explosion vents, if provided, would simply allow burning oil and vapour (at temperatures of a few thousand degrees Celsius) to spew into the surrounding atmosphere – resulting in significant damage to property and people. As a result, it is simply not possible or practical to internally arc test oil-filled switchgear. Photo 1 shows an example of a failure due to an internal arc fault in oil-filled switchgear. In contrast, internal arcs faults in air-filled and gas-insulated switchgear are classified as 'dry-arcs'. 'Dry-arcs' can be simulated in a test laboratory and therefore suitable methods developed to contain and/or safely vent the emissions (including conductive vapour and molten metal) created during an internal arc fault.

Photo 1 – Oil switchgear failure due to an internal arc

Sulphur hexafluoride (SF6) has proven itself to be a preferred gas for filling enclosures – for example busbar compartments housing live equipment in compact switchgear. SF6 offers superior performance in terms of insulation and arc extinction. Amongst other benefits, it allows for reduced clearances between live conductors and thus smaller, more compact switchgear when compared to air-insulated switchgear. As the energy released during an arc between live conductors is proportional to the arc length, these reduced clearances also result in lower arc energy released. The expected service life before maintenance/re-filling of SF6 enclosures is up to 30 years. Arcing does cause decomposition of the gas, but in very small amounts. The products of decomposition are toxic and react with water, but since the tanks are sealed and filtered neither of these issues present a problem.

It is worth noting that oil, when used purely as an insulating and/or cooling medium (e.g. in conventional power transformers), is not considered to present the same safety risk as when used in switchgear. The principle of operation of a transformer (i.e. mutual induction) is different to that of oil-filled switchgear, where contact separation through moving parts occurs in the oil. The drawing of an electrical arc within oil and in particular contaminated oil between conductive parts not designed to interrupt current (i.e. under conditions of a short circuit internal arc) results in the rapid expansion of the oil and vaporisation of moisture in an uncontrolled and explosive manner as described above.

SAFETY REVISITED

Risk

Safety is achieved by reducing risk to a tolerable level. Tolerable risk is determined by the search for an optimal balance between the ideal of absolute safety and the demands to be met by a product, process or service, and factors such as benefit to the user, suitability for purpose, cost effectiveness, and conventions of the society concerned. ‘Risk’ is considered to be the combination of the probability of occurrence of a harm and the severity of the harm [2]. It follows that there is a need to continually review the tolerable level of risk – in particular when developments in both technology and knowledge can lead to economically feasible improvements – in order to greatly reduce the risk associated with the use of a product, process or service.

Internal arc

In essence, an internal arc is a short circuit between components having different electrical potentials within a chamber filled with a particular insulating medium. It is an uncontrolled conduction of electrical current from phase to earth and/or phase to phase accompanied by the ionization of the surrounding medium (e.g. air/SF6). Because of the expansive vaporization of conductive metal, a line-to-line or line-to-ground arcing fault can escalate into a three phase arcing fault in less than 1 ms. Arc energy is a function of system voltage, short circuit current, and the time until the upstream protection operates. Voltage is a function of system design, current is a function of system design and operation. Arc time is a function of protective device response. The heat energy and intense light at the point of the arc is called an arc flash. Arc flash energy absorbed by a person is a function of arc energy, distance from arc and personal protective equipment (PPE) – where applicable. An internal arc is accompanied by a rapid rise in pressure followed by a burn-through period as indicated in figure 1.

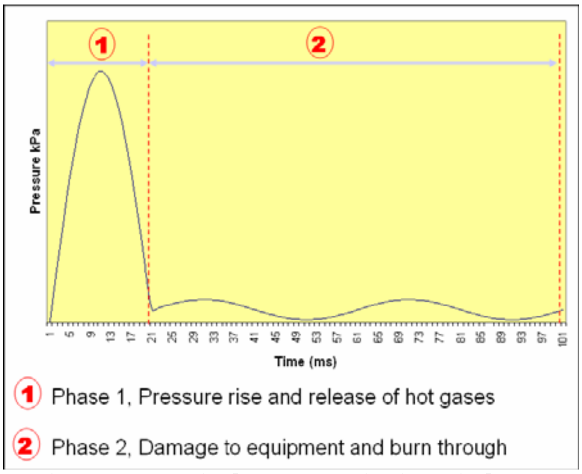

Figure 1 – Typical pressure rise in switchgear

In the absence of suitable pressure release mechanisms (e.g. ‘venting ducts or flaps’), arc faults are extremely dangerous and potentially fatal as temperatures at the arc can reach four times the temperature of the sun's surface. The high arc temperature vaporises the conductors in an explosive change in state from solid to vapour. Copper vapour expands to 67 000 times the volume of solid copper. Photo 2 shows an example of the release of arc flash energy where inadequate pressure release mechanisms were provided. However, through the specification and design of internal arc classified switchgear, where the energy and emissions resulting from and internal arc are suitably vented away from the operator and/or people in the vicinity, the ‘safe’ working distance can be effectively managed.

The most common causes of an internal arc fault are:

- General inadequate maintenance;
- Insulation defects due to quality deterioration of the components (including oil). The causes can, for example, be adverse environmental conditions, a highly polluted environment and lack of maintenance;
- Overvoltages of atmospheric origin or generated by operation of a component (inadequate insulation co-ordination);
- Incorrect operations due to not respecting the procedures or to inadequate training of the personnel in charge of the installation;
- Breakage or tampering of the safety interlocks;
- Overheating of contact areas, due to the presence of corrosive agents or when connections are not sufficiently tightened;
- Entry of vermin into the switchgear live compartments;
- Material left behind inside the switchboard during maintenance operations;
- Interference with cable terminations during cable testing – particularly when integral cable test facilities that are independent of the cable termination enclosures are not provided (thus necessitating access and interfere with the cable terminations);
- Incorrect installation (e.g. striker pin facing wrong direction) and/or replacement of MV HRC fuses (i.e.

all three fuses of the same make and rating not replaced at the same time after a fuse operation).

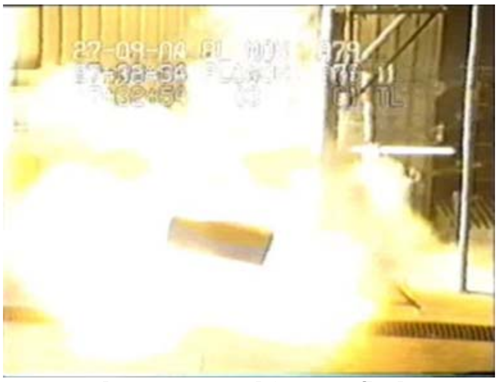

Photo 2 – Resulting arc flash

Risk reduction

The basic philosophy adopted for risk reduction can be summarised as shown in figure 2. It is important to note that, as always, personal protective equipment (PPE) should be considered as a last line of defence, and not as a replacement for appropriate equipment design and testing (e.g. internal arc compliance), safe work practices or engineering controls that can help limit exposure to arc-flash hazards.

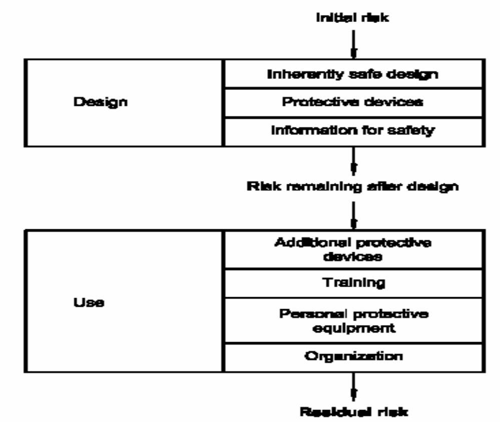

Figure 2 – Risk reduction

In South Africa, the Occupational Health and Safety Act has a general duty clause requiring employers to take reasonable precautions to ensure their employees' health and safety. In the absence of appropriate local electrical safety regulations relating to internal arc (as is the case in South Africa), users are encouraged to refer to the recommendations given in the National Fire Prevention Association document 'Standard for Electrical Safety in the Workplace' (NFPA 70E) [3] adopted by the U.S. Department of Labour, which requires that:

- 'Limited Approach', 'Restricted Approach', 'Prohibited Approach' and 'flash protection' boundaries need to be established in order to assure that personnel do not accidentally contact exposed, energized electrical equipment.
- Employees are aware of potential hazards when operating, changing the position of, or working in the proximity of energized electrical equipment.
- If an employee needs to enter a flash boundary to perform work that could possibly cause an arc flash, then appropriate PPE (personal protective equipment) needs to be worn.
- The type of PPE depends on the amount of energy to which an employee could be exposed.

This would require an arc flash hazard analysis (risk assessment) to be carried out in order to determine the type of PPE needed for the arc energy level, the duration of the arc flash and the working distance (degree of exposure or impact). This is particularly critical for older installations that are not fully internal arc tested. For new equipment, it is possible to significantly limit the probability and impact of an internal arc – by providing switchgear that is specified and tested with a suitable internal arc classification (see below). An implication of having internal arc classified (IAC) switchgear in accordance with IEC is that the clothing category of PPE required would be entry level, i.e. a single layer of untreated natural fibre clothing without any arc rating ('cal/cm^2'). Note however that IEC states that classification IAC gives a tested level of protection of persons under *normal* operating conditions as defined in annex A.1 of IEC 62271-200 [4] (i.e. including manual operating and monitoring of switchgear at normal working distances). It is concerned with personnel protection under these conditions and not under maintenance conditions nor with service continuity. The latter would require additional safety measures to be taken. Here, requirements such as having metallic partitioning (PM) between enclosures and specifying an appropriate loss of service continuity (LSC) classification in accordance with IEC 62271-200 become relevant.

It is often necessary to look into the introduction of other possible 'supplementary' measures to reduce risk such as internal arc detection for rapid fault clearance, current limiting devices (e.g. HRC fuses in combination with switching devices), 'arc eliminators/suppressors', remote control facilities, motorised racking devices, pressure relief devices, and the transfer of withdrawable parts to or from their service positions only when the front doors are closed. A co-ordinated philosophy is required when approaching the subject of internal arc classification and specifying new equipment and safety measures. However, whether working with new or older equipment, the requirements of NFPA 70E should always be considered.

Specifications for new switchgear in Eskom

Eskom and other major utilities have recently been involved in the development and re-testing of switchgear products to meet the safety requirements of the Occupational Health and Safety Act and industry-aligned requirements utilising the recently published IEC 62271-200 as well as IEC 62271-202 [5] as reference.

The applicable Eskom specifications for distribution switchgear require that they be type tested to give them an internal arc classification (IAC) in accordance with the relevant IEC specifications. This has been made possible due to the specification and purchasing of air-filled and/or gas-insulated switchgear. The IEC specifications for internal arc testing (detailed in annexures A of IEC 62271-200 for metal enclosed switchgear and IEC 62271-202 for prefabricated substations) cater for two relevant categories of internal arc classification – based on the type of accessibility required by the user. Type A accessibility is restricted to authorised personnel only and Type B accessibility caters for unrestricted accessibility – including that of the general public. Different types of accessibility may be applied to various sides of the switchgear / enclosure – i.e. front [F], lateral [L], and rear [R].

For indoor metal-enclosed primary switchgear ('metal-clad'), the following is specified by Eskom Distribution:

Classification IAC	AR-BFL (IEC 62271-200)
Internal arc	25 kA 0,2 s (for 12 kV & 24kV)

Although the switchgear is generally housed indoors in a brick-built switch room, the rear of the switchgear is restricted to authorised personnel only, whereas the sides and front provide what Eskom classifies as unrestricted accessibility (e.g. taking into consideration the possibility of having personnel indoors that are not 'responsible' or 'authorised' in terms of the Eskom operating regulations). The 0,2 s arc duration is based on the fact that internal arc detection systems are specified for indoor switchboards. These internal arc protection schemes employ detectors sensitive to light that are installed in all switchgear enclosures to act as fast sensing devices in the event of an arc. They are designed to initiate an upstream circuit breaker trip in less than 0,1 s. Arc venting is required to be upwards (without exhausting ducts to the outside of the building) and the key switch room dimensions are standardised to coincide with the internal arc test requirements. The switch room is also designed for pressure relief (located in the switchroom doors). If necessary, upstream current limiting devices (e.g. air-core reactors) may be required to limit the prospective fault levels to within the IAC rating.

For outdoor secondary switchgear (e.g. RMUs and MV/LV miniature substations usually installed downstream of indoor metal-clad primary switchgear), the following is specified:

Classification IAC	AB (IEC 62271-202)
Internal arc	20 kA 0,5 s (for 12 kV); 16 kA 0,5 s (for 24 kV)

Outdoor secondary switchgear is normally installed in areas of general public accessibility – requiring type B accessibility on all sides (with all doors closed). In addition, with the front MV doors open (front access only), type A accessibility is required for the operator. The 0,5 s arc duration is based on the upstream protection settings typically applied for grading considerations. No internal arc detection systems are employed. As this type of outdoor switchgear is usually installed on solid concrete plinths (usually pre-cast) with cable trenches that are backfilled and sealed (using a concrete screed), venting of the switchgear can only be directed upwards – requiring a 2m high arc venting duct – an example of which is shown in figure 3. The duct/venting system is designed and tested to vent emissions resulting from an internal arc fault in any of the gas and/or air-filled enclosures within the switchgear (i.e. a common venting system for the SF6-insulated busbar enclosure/s and the air-filled cable boxes). Such a duct system can be applied to free-standing RMUs as well as RMUs installed within MV/LV miniature substations. The proposed IEC 62271-202 makes special provision for the MV interconnections (jumper cables) between the RMU T-off and the MV/LV transformer located in the miniature substation. The enclosure/compartment housing the interconnections may be excluded from the internally arc tested zone either by specifying a (fast operating) HRC fuse (i.e. fuse-switch combination) in the RMU T-off or, if a circuit breaker is specified, by using fully screened cable and separable connectors onto the transformer.

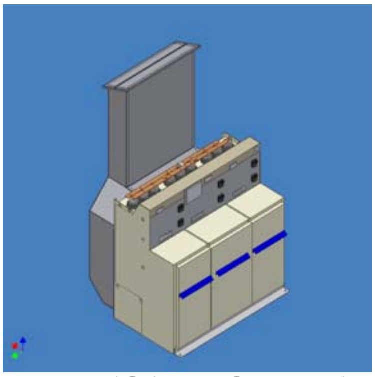

Figure 3 – RMU with internal arc venting duct for IAC AF-BFLR

CONCLUSIONS

Eskom and other major utilities in South Africa have responded to the changing risk profile associated with switchgear in the light of developments in both knowledge and alternative technologies. It is the view of the authors that the introduction of mandatory type testing for internal arc classified (IAC) switchgear and controlgear as detailed in IEC 62271-200 and IEC 62271-202, together with the implementation of safe working practices (such as those detailed in NFPA 70E), has greatly enhanced the employer's ability to specify acceptable equipment that significantly improves both operator and public safety.

Air and/or gas-insulated switchgear utilising vacuum and/or SF6 interrupting technologies provide the users with equipment that meets the required specifications and levels of performance in a world where there is an ever increasing focus on human safety (in respect to both employees and the general public), service delivery and cost reduction. These solutions offer improved reliability and require fewer and shorter scheduled power interruptions required for maintenance interventions.

REFERENCES

[1] Occupation Health and Safety Act (OHS Act) No 85 of 1993

[2] ISO/IEC Guide 51:1999, "Safety aspects – Guidelines for their inclusion in standards"

[3] NFPA 70E, "National Fire Protection Association – Standard for Electrical Safety in the Workplace (2004 edition)."

[4] IEC 62271-200, "High-voltage switchgear and controlgear – Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV"

[5] IEC 62271-202, "High-voltage switchgear and controlgear – Part 202: High-voltage/low-voltage prefabricated substations"