

Internal Arc & Arc-flash in HV/MV Switchgear – White Paper



Partners in Power Engineering

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Executive Summary

Overview

Roxtec International AB (Roxtec) requested Threepwood Consulting Ltd. (Threepwood) to produce a report about internal arc type testing, arc-flash and how the various issues of switchgear explosions are managed. Roxtec produce a cable sealing product which helps switchgear pass internal arc type tests. Internal arc type tests are one of the most safety critical type tests for switchgear that impact the end user.

Internal arc and arc-flash are explained to help understand the subject and clarify a number of misnomers including that internal arc type tests are mandatory, when they are in fact an optional test within the IEC MV Switchgear Standard 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”*. Within North America, internal arc testing is prescribed in IEEE C37.20.7, *“Guide for Testing Metal-Enclosed Switchgear Rated Up to 38 kV for Internal Arcing Faults”*. Canada use CSA C22.2 No. 0.22-11 *“Evaluation methods for arc resistance rating of enclosed electrical equipment”* to evaluate internal arc rated switchgear.

Paper Summary

Internal arc type testing is very important to reduce the risk of exploding switchgear. There are a number of key considerations which are based around the management of risk. This White Paper is based on the principles laid out in the North America, National Institute for Occupational Safety and Health (NIOSH) safety approach and the UK Management of Health and Safety at Work Regulations, where risk is reduced through a hierarchy of control measures. It is important that each risk is assessed and prioritised.

Key Recommendations

Duty Holders (in the UK) and Safety Responsible Engineers (in North America) managing electrical networks, should be actively promoting replacement of oil switchgear as this type of circuit-breaker is not internal arc rated and can fail catastrophically. A key mitigation should focus on internal arc rated switchgear for asset replacement.

With existing switchgear, Duty Holders/Safety Responsible Engineers should review the hierarchy of risk and prioritise which actions need to be taken. Arc elimination and detection products should be considered, before considering personal protective equipment (PPE) requirements when operating switchgear.

When considering PPE, it is important to ensure that clothing and workwear worn by workers who operate on or near electrical plant or equipment is not flammable and would not contribute to the severity of any skin burns should an arc-flash incident occur. This is distinct from wearing arc-flash PPE, which when worn over clothing that is flammable could still pose a risk to the operator.

Switchgear manufacturers might wish to consider using modular/mechanical cable sealing methods in their cable sealing of connection compartments to reduce the risk from an internal arc. Cable sealing systems prevent causes of internal arc, e.g. water ingress, dust, vermin and reduce the spread of exhaust gas/flame, and consequently fire spread when an internal arc occurs.

1 Introduction

1.1 Background

Roxtec is a Company that produces sealing solutions for cables and pipes. They are aware of the potential dangers of internal arc and the possible ramifications from an arc-flash in Medium Voltage (MV) switchgear and want to promote the understanding of internal arc within switchgear. ABB recently used one of their cable sealing designs to help pass an internal arc type test, for ABB SafeRing/SafePlus 36 kV rated switchgear (see Figure 1 below). Roxtec subsequently commissioned this educational White Paper to explain the issues of internal arcing in switchgear. Arc-flash and arc-flash studies are also clarified.

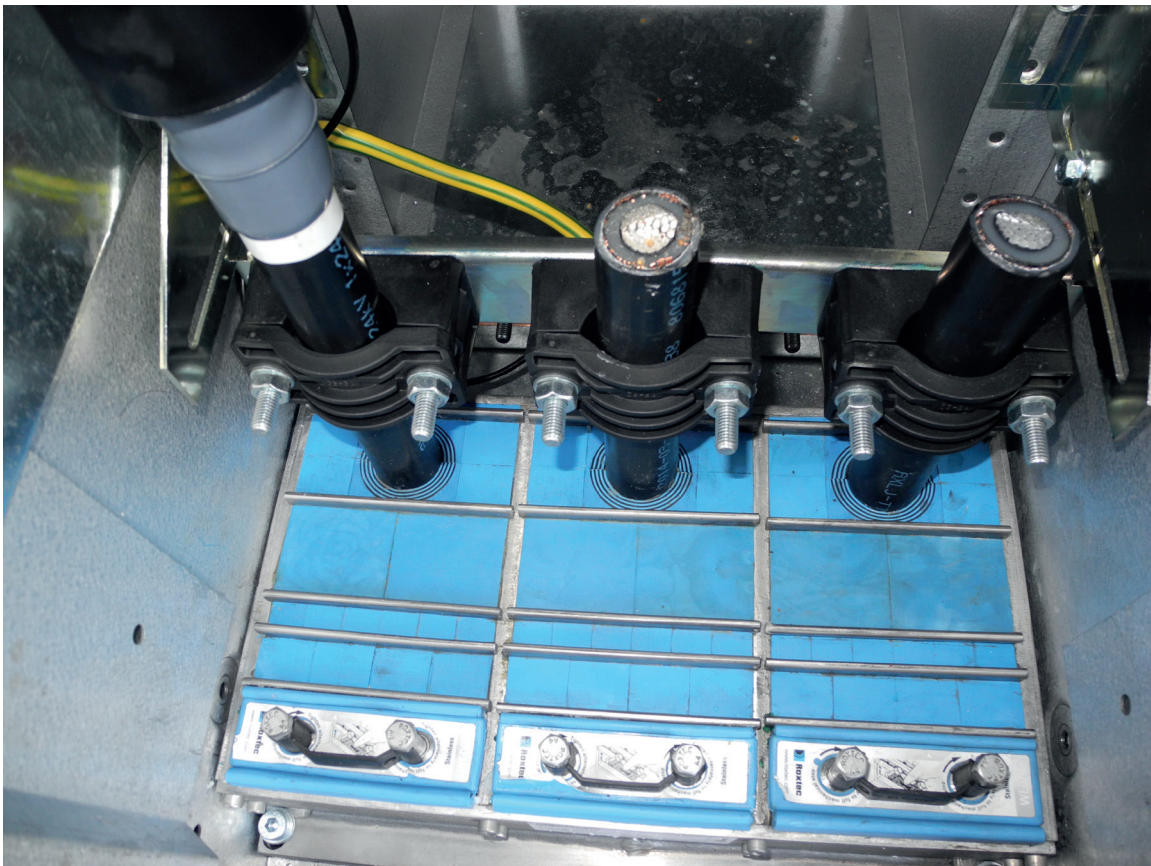


Figure 1, Roxtec cable sealing system used in an ABB internal arc test

This White Paper also highlights a safety concern when HV/MV switchgear fails catastrophically, particularly oil-filled switchgear assembly. Within IEC Standards, HV switchgear are used on systems above 1 kV up to 52 kV. In North America MV is any voltage between 600 V and 69 kV. An enclosed assembly of switchgear is generally made up of a number of components, e.g. circuit-breaker, earth switch, disconnecter, CT etc. The assembly is enclosed on all sides, top and bottom in such a manner as to provide a specified degree of protection. The switchgear assembly International standard, 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", contains an optional internal arc type test. Simply specifying switchgear to IEC 62271-200, does not mean switchgear is internal arc rated. IEC Standards are used in

Europe and other parts of the world, but generally not in countries that use IEEE North American Standards. IEEE have different standards to IEC, and IEEE have a dedicated standard for internal arc testing, as outlined in IEEE C37.20.7, *“Guide for Testing Metal-Enclosed Switchgear Rated Up to 38 kV for Internal Arcing Faults”*.

1.2 Scope & Purpose

The White Paper is written around HV/MV switchgear that may be used by electrical generators, utilities, industrial, rail and asset owners. Internal arc and arc-flash failures are explained within this White Paper.

It is intended that the internal arc type test is explained in simple terms so that that engineers, including those purchasing switchgear, have a clear understanding of issues associated with this type test. The White Paper does not take into account public safety issues that arise from the disruptive failure of switchgear.

The purpose of this White Paper is to:

- Highlight typical switchgear used;
- Describe internal arc testing;
- Highlight the effects and consequences of an internal arc and arc-flash faults;
- Detail worldwide standards and specifications that describe the internal arc test and arc-flash;
- Provide guidance when procuring, installing and maintaining switchgear with respect to internal arc/arc-flash capabilities.

2 MV Switchgear Applications & Requirements

Today, new MV switchgear used in substations include either withdrawable type or fixed pattern type. Historically, distribution and industrial networks used withdrawable type switchgear. The older technology used oil as the insulation and interruption medium which needed frequent maintenance. Withdrawing the oil tank allowed access to replace the oil when intrusive maintenance was carried out.

A major safety concern with oil switchgear is that when there is a failure within the interruption tank, this can result in a catastrophic uncontrolled failure, often resulting in loss of life. There have been a number of oil switchgear failures that have caused fatalities.

Newer withdrawable designs have now been introduced where the oil is replaced by either SF₆, vacuum or a combination of the two. A recent development, due to environmental concerns, is that SF₆ switchgear is now being phased out due to imminent changes in the European F-gas Regulation and confirmed in recent discussions with manufacturers. An important development with switchgear was the introduction by manufacturers of internal arc testing in the 1980s (see Clause 3 for details about internal arc testing).

The important thing to note is that oil switchgear cannot be internal arc rated, as failures generally cannot contain the associated fireball and explosion. SF₆ and vacuum interrupters don't require as many maintenance activities compared with oil switchgear. Consequently, manufacturers moved towards offering fixed type non-oil switchgear, which became popular with Duty Holders in the 1990s.

NOTE: In the UK, the Health and Safety Executive (HSE) is Britain's national regulator for workplace health and safety. HSE define the Duty Holder(s) as the person(s) appointed by a business with responsibility for maintenance of the overall standard and quality of the electrical installation.

There are still advantages of using withdrawable type switchgear and the pros and cons of using both types are shown in Figures 4 and 5.



Figure 2, Internal arc results for bulk oil switchgear for an 11 kV system

Figure 2 shows the consequence of an internal arc in oil and non-internal arc rated switchgear, clearly a safety concern. The doors visible at the left- and right-hand side of the Figure give a good representation of the scale of the fireball, should oil switchgear fail.

With a high calorific value, switchgear fires burn intensely and are notoriously difficult to control. The result from such an explosion could be significant downtime and cost. It is of prime importance for businesses to assess and mitigate switchgear failure risk.

As previously stated, not all new switchgear is internal arc rated. Within IEC Standards, internal arc rated switchgear manufactured prior to 2003 may only have been tested for internal arc in the main MV switching compartment, which was the optional requirements within IEC 60298 (the standard that was superseded by IEC 62271-200).

When IEC 62271-200 was implemented in 2003, if switchgear was internal arc tested, the main MV compartments were tested, i.e. the switching, busbar and connection compartments. It is also a common misnomer that the internal arc type test is mandatory. The internal arc type test is an optional test within IEC 62271-200.

Within North America, internal arc testing is prescribed in IEEE C37.20.7.

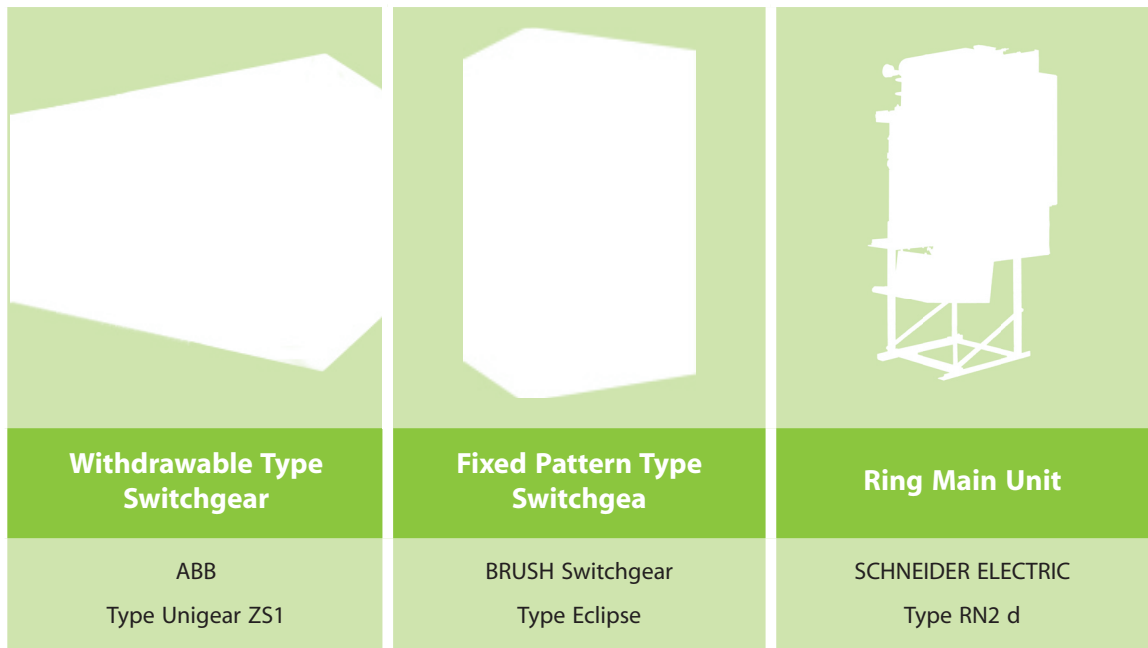


Figure 3, Types of MV switchgear

NOTE: Pictures in Figure 3 are courtesy of ABB, BRUSH Switchgear & Schneider Electric.

MV Withdrawable Type Switchgear – ABB Unigear ZS1


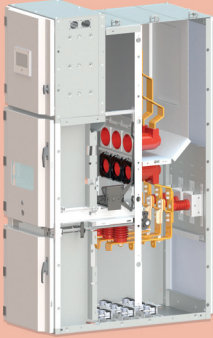
| | |
|---|--|
|  |  |
| <p>Advantages</p> | <p>Disadvantages</p> |
| <ul style="list-style-type: none"> ■ Usually have good cable access. ■ Good access for cable test equipment and maintenance of the circuit-breaker. ■ Can replace a faulty circuit-breaker quickly and can be worked on easily. ■ Should use this type of breaker with excessive operations, e.g. for generator or arc furnace control. This will lead to more frequent maintenance requirements. ■ Retrofit options available. ■ Easy to see where the earthing is applied. ■ Breakers can be interchangeable if they have the same rating. | <ul style="list-style-type: none"> ■ Have more potential failure points. ■ Not as many options offered by manufacturers for this type of equipment. ■ Internal arcs may occur when withdrawing or inserting the circuit-breaker without full internal arc protection. ■ Can be less reliable due to more components. ■ Trucks can be top heavy and require maintenance. |

Figure 4, Withdrawable Type Switchgear Advantages/Disadvantages

NOTE 1: Pictures in Figure 4 are courtesy of ABB.

NOTE 2: Comments above apply to general withdrawable designs and not just the ZS1 variant.

MV Fixed Pattern Type Switchgear – BRUSH Eclipse Type


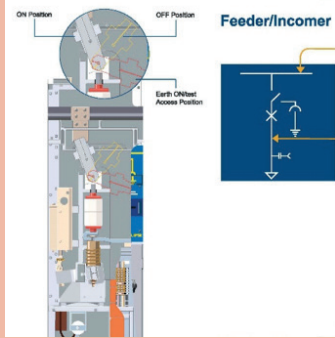
| | |
|---|---|
|  |  |
| Advantages | Disadvantages |
| <ul style="list-style-type: none">■ Maintenance Free Switching Compartments (mechanism exception).■ Smaller size and less moving points (particularly with a magnetic actuator compared with moving springs and associated linkages).■ Usually, less expensive than withdrawable types.■ These breakers are usually operated behind a closed door, so can be fully internal arc tested and hence safer to operate compared with a non-internal arc rated withdrawable types. | <ul style="list-style-type: none">■ The busbar earthing arrangement is not very flexible. Special busbar earthing devices may be required on the busbar run.■ Failure mode could lead to having an outage on half the switchboard.■ Many of the fixed pattern designs have limited access to cable terminations.■ Cannot physically see the earth switch applied in the earth position, this is reliant on indicating labels). |

Figure 5, Fixed Pattern Switchgear Advantages/Disadvantages

NOTE 1: Pictures in Figure 5 are courtesy of BRUSH Switchgear showing Eclipse Type Switchgear used on 11 kV Systems.

NOTE 2: Comments above are about general fixed pattern designs and not just the Eclipse variant

The switchgear shown above are enclosed in a complete assembly that is made up of several MV compartments.

3 Internal Arc and Arc Flash Explained

3.1 Switchgear Failure

Due to various failure modes, MV switchgear can explode and lead to an associated pressure rise. If metal-enclosed switchgear is not designed to contain the arc, this can lead to switchgear literally exploding catastrophically and subsequent inferno. Consequently, this can result in fatalities, serious injury, damage to substations and buildings, along with damage to other plant and equipment. The subsequent outage can be lengthy and very expensive.

The catastrophic failure described above is known as an internal arc fault, which is generally very low probability in modern switchgear, providing that the switchgear has been designed, manufactured, tested, installed, operated and maintained adequately. Some switchgear is type tested during its design stage to pass an internal arc type test. Switchgear that has been designed to contain the arc should fail safely, thus avoiding risk to operators and preventing lengthy rebuilding time following catastrophic failure, should they occur.

NOTE: A type test is a conformity test made on one or more items representative of the production line. In the case of internal arc, the tests are destructive, but need to pass certain criteria.

An arc-flash (also called a flashover) is the light and heat produced as part of an arc-fault, a type of electrical explosive path. Calculations are carried out to determine the incident energy levels, expressed as cal/cm². In other words, the standard provides mathematical models for designers and facility operators to determine the arc-flash hazard distance and the incident energy to which workers could be exposed during work on or near electrical equipment, when a fault occurs. This value enables asset owners to work out the appropriate PPE that needs to be worn for protection, following the IEEE 1584 American Standard, Guide for Performing Arc-Flash Hazard Calculations.

The severity of exposure to an arc-flash is determined by the calculated incident energy that a worker could be exposed to and the number of workers exposed. The magnitude of the incident energy is determined by a number of factors including:

- Operating voltage;
- Fault current;
- Equipment class;
- Working distance;
- Type of neutral earthing;
- Arc duration.

In summary energy levels need to be reduced where possible, which minimises the risk to workers operating on and around the switchgear.

3.2 Legal Implications for Duty Holders & Safety Responsible Engineers

It is important that Duty Holders and Safety Responsible Engineers should focus on elimination of hazards, using suitable engineering controls and implementing safe systems of work (see Figure 6 below) before considering the type of PPE that operators should be wearing. In the UK, the HSE advocate taking other safety measures that

can be put in place to prevent any type of plant and equipment catastrophic failure in the first place (elimination). The Electricity at Work Regulations 1989 (as amended) emphasise the need for Duty Holders to make suitable inspections of plant and equipment, to adequately maintain plant and equipment and to safely operate plant and equipment. In Schedule 1 of the Regulations, prevention includes adapting to technical progress, where internal arc classification (IAC) fits nicely into this key risk avoidance.

In North America, the National Institute for Occupational Safety and Health (NIOSH) advocate the risk mitigation levels shown in Figure 6. The hazards from arc-flash and electrical explosion are not new in the UK and have been managed using a hierarchy of control measures consistent with the Management of Health and Safety at Work Regulations 1999 (as amended), which are similar to those shown in Figure 6. Arc-flash calculations are not a direct legal requirement in the UK, unlike in North America, where Asset Owners must carry out arc-flash studies and provide appropriate signage.

The focus on using PPE to reduce the exposure to arc-flash stems from American Standards. In the UK, there is currently no specific regulation that mandates the wearing of flame resistant (FR) or arc resistant clothing for operating electrical plant/equipment, given that PPE is at the bottom of the hierarchy of risk mitigation measures.

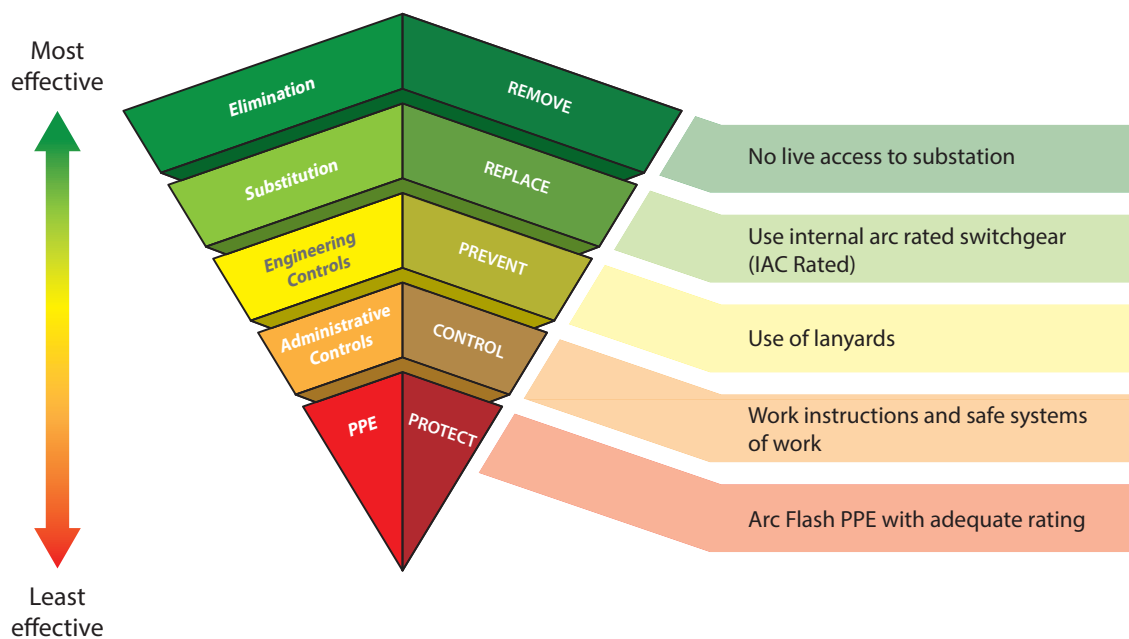


Figure 6, Hierarchy of arc-flash mitigation based on UK health and safety legislation & NIOSH requirements

However, employers have general duties to ensure the health, safety and welfare of employees, and there are a number of legal requirements that companies have to comply with.

Representatives of the HSE over the years have actively promoted Asset Owners and Duty Holders focusing on elimination, engineering controls and safe systems of work, ahead of spending time and resource on working out appropriate levels of PPE and arc-flash distances. Arc-flash calculations are the last level of protection that should be considered, when all other levels of mitigation have been thought through (see Figure 6). Arc-flash calculations can help in determining any risk (risk assessment) as opposed to defining the level of PPE. Duty Holders and Safety Responsible Engineers need to

ensure they primarily focus on the applying the first four levels of Figure 6 ahead of PPE considerations.

The UK Energy Networks Association (ENA) Model Distribution Safety Rules follow the same philosophy. They state the following hierarchy for the operation of switchgear.

All switchgear operations Shall, so far as reasonably practicable, be planned and completed in accordance with the following hierarchy:

- (i) Remotely via remote control facilities;
- (ii) Remotely on site via control panels in a different room to the switchgear being operated;
- (iii) Remotely via a control panel in the same room as the switchgear being operated;
- (iv) Remotely via an Approved umbilical device or similar; or
- (v) via the operating facilities on the switchgear.

The current European Standard EN 50110-1, *“Operation of electrical installations – Part 1: General requirements”*, does not address the above hierarchal order of controls: The only limited entry is made in Clause 5.2.1 which ends with the text *“Operating activities may be carried out locally or by remote control.”*

The text is in fact the wrong way round as every opportunity should be taken to eliminate risk, therefore remote operation should be considered first.

When considering PPE, it is important to ensure that clothing and workwear worn by workers who operate on or near electrical plant or equipment is not flammable and would not contribute to the severity of any skin burns should an arc-flash incident occur. This is distinct from wearing arc-flash PPE, which when worn over clothing that is flammable can still pose a risk to the operator. However, layering of arc-resistant clothing can provide increased protection for the operator against exposure to the thermal effects of an arc flash.

It is important that Duty Holders and Safety Responsible Engineers, ensure they prioritise their focus and attention on the upper levels of Figure 6, which are most effective in mitigating risks.

4 Design Standards

4.1 Internal Arc Detail

The internal arc type test in IEC 62271-200 is an optional type test for ground mounted switchgear. Internal arc testing is not mandated, unless specified in an appropriate standard. Internal arc testing is intended to verify the effectiveness of the switchgear design in protecting persons in case of an internal electrical explosion, to safely contain any internal pressure rise and vent the flame and exhaust gas into designated areas. Upon successful testing, switchgear is assigned an internal arc classification (IAC).

In simple terms, an arc-flash inside the switchgear is deliberately initiated. To pass the test, the MV switchgear compartment under test, needs to fail in a safe and controlled manner, prevent injury to persons nearby and not cause damage to adjacent assemblies.

A weakness of the internal arc type test is that it does not replicate the associated pressure rise within a substation, which is also a significant hazard. Internal arc testing is carried out to see how the switchgear fails within the assembly, and the subsequent pressure release in a substation or building is not part of the test. If the internal arc exhaust flame and gases are released into the substation or building, a subsequent pressure rise may cause structural damage. It is important to appreciate that, if the substation does not have sufficient volume, the classification may be invalid.

MV compartments are designed to withstand very fast pressure rise, resulting from faults within the switchgear. In order to pass the test, each MV compartment needs to have a mechanical strength that can contain an overpressure and, where necessary, means to vent any exhaust in a controlled manner into certain areas.

To carry out the internal arc test, an arc is initiated in each MV compartment with 0.5 mm² fuse wire wrapped across each phase. The rated fault current is applied for a set duration, usually 1 second. Typical fault currents are 25 kA for 11 kV, and 31.5 kA for 33 kV systems.

In the test, arc voltage, current and pressure are measured, as well as high-speed infrared and optical imaging are used, to demonstrate if the test passes successfully. When there is an electrical fault within electrical equipment, an arc fault is fed from up to three live phases. The current from the live phases will return either on the live phases or via a neutral or earth/ground system.

To pass the test in each of the designated MV compartments, the following criteria need to be met:

- **Criterion No. 1** Doors remain correctly secured and covers do not open.
- **Criterion No. 2** No fragments or other parts of the assembly, of an individual mass of 60 g or more, are ejected.
- **Criterion No. 3** Arcing does not cause holes by burning through any of the classified sides up to a height of 2 m.
- **Criterion No. 4** Chequered black cotton indicators (shown in Figure 7) do not ignite during the test and within 1 s after the current duration, where:
 - the horizontal plane represents the top of a person's head.
 - the vertical plane represents a person standing at that position by the switchgear.
- **Criterion No. 5** The enclosure remains connected to its earthing point.



Figure 7, ABB SafeRing/SafePlus 36 kV switchgear under internal arc testing

NOTE: Chequered indicators surrounding the switchgear shall not ignite during the internal arc test.

It is important for the Duty Holder to request internal arc rated switchgear at MV and LV. LV switchgear can be internal arc tested in accordance with IEC/TR 61641 *“Enclosed low-voltage switchgear and controlgear assemblies – Guide for testing under conditions of arcing due to internal fault”*.

For switchgear that is not internal arc rated the following risk mitigation can be considered.

- Operating the switchgear remotely minimises the risk to operators under normal operating conditions. This can be in the form of SCADA control or plug in umbilical lead. These allow the operator to be a safe distance from the switchgear in the unlikely event of an explosion.

It is recommended that when HV or LV indoor switchgear is to be replaced, replacement switchgear is specified with an adequate internal arc classification.

Some manufacturers offer retro-fit optical arc-flash sensing devices available on the market, which could be considered depending on the anticipated remaining life of the switchgear. Sensors available in the market today detect light from an arc-flash inside switchgear very quickly, typically less < 100 ms, and trip the incoming supplies to the switchgear. Some concern has been expressed whether the sensors fail safe.

4.2 IEEE Internal Arc Requirements

North American Arc resistant testing standards are defined by ANSI/IEEE C37.20.7. This standard defines two levels of accessibility to switchgear assemblies.

Type 1 provides protection only when in front of the switchgear.

Type 2 provides protections on all sides. In addition, a suffix is added to define arc performance for control compartments and between vertical sections of the switchgear.

Suffix B designates equipment where normal operation of the equipment involves opening the door or cover on compartments specifically identified as low-voltage control or instrumentation compartments.

Suffix C designates equipment where isolation from the effects of an internal arcing fault is desired between all adjacent compartments within a switchgear assembly.

Suffix D designates specifically where some external surfaces of the equipment are inaccessible and no need exists to use a Type 2 design.

4.3 Arc-flash Detail

Demand for arc-flash studies is rapidly growing, as a result of the awareness of North American IEEE Standard 1584, *“Guide for Performing Arc-Flash Hazard Calculations”*. It is common for Companies in the UK with American owners to carry out arc-flash studies to comply with North American legal requirements in the National Electrical Code. There is also a strong driver from North American insurance companies that insure electrical assets.

In the UK, the HSE has reinforced the importance of risk assessment and control measures to eliminate or reduce the risk of exposure to electric arc, where arc-flash PPE should be considered as a last line of defence – not the first.

Suitable and sufficient risk assessments of arc-flash hazards should assess whether existing mitigations, engineering controls and safe systems of work are effectively in place and minimise the risk of exposure to arc-flash to an acceptable level. Such assessments should be a precursor to carrying out detailed arc-flash studies.

Duty Holders and Safety Responsible Engineers are responsible for ensuring that electrical plant and equipment are fit for purpose and maintained adequately. Before arc-flash studies can be considered, it is essential that Duty Holders and Safety Responsible Engineers have undertaken recent fault level and protection studies, as the results from these studies are necessary to carry out incident energy calculations. It is good practice to undertake regular reviews of these studies (approximately every 5 years or when there are material changes to the fault level and protection systems) to ensure the plant is still within rating and that the protection will operate correctly in the minimum time to minimise the risk of plant failure and to reduce incident energy levels.

NOTE: Every 5 years assumes no major network changes on the network.

As previously stated, it is not a specific legal requirement to carry out arc-flash calculations in the UK, unlike in North America. The HSE advocate that Duty Holders prioritise effort into ensuring arc-flash risks are properly assessed and mitigated in accordance with the Management of Health and Safety at Work Regulations. This occurs through a hierarchy of control measures (shown in Figure 6), where the use of PPE is lower down the hierarchy than implementing engineering controls and safe systems

of work. Notwithstanding, it is essential that all operational activities are covered via appropriate risk assessments.

Generally, incident energy levels are greater at HV than LV, for equivalent working distances, because the fault level is greater. This is not always the case, as occasionally the incident energy levels at incoming LV switchgear busbars could be larger than at the HV busbars due to differences in switchgear construction and fault clearance times. Generally, the risk from LV equipment with an operating voltage of 230 V or less, particularly where it is supplied by small transformers (125 kVA or less), is considered to be small and does not need to be included in arc-flash hazard assessment. This would include 230 V AC battery charging equipment.

In general, equipment that has been properly designed, constructed, tested, installed, commissioned and maintained does not present a risk of electric shock or burn injury when properly used. In particular, modern switchgear that has an internal arc classification (IAC) is designed to release the energy caused by an internal arc away from an operator standing in front of the switchgear.

Unsafe conditions of electrical plant and equipment, e.g. lack of maintenance, or unsafe operational activities, may lead to arc-flash hazards. A summary of the main hazards that are known to result in arc-flash accidents / incidents are summarised below.

Indoor rated plant and equipment located in poor environments where dust/moisture can accumulate on the surface of insulation or where relative humidity is high are more susceptible to partial discharge (PD) activity and eventual arc-flash than equivalent plant and equipment that is in a warm, dry and dust/moisture free environment.

- Overstressing plant beyond nameplate ratings.
- Poor or lacking maintenance practices. Maintenance induced failures via contamination or high-test voltages can be problematic.
- Inadequately trained and experienced operational/maintenance personnel including contractors.
- Plant and equipment which has not been modified in accordance with the manufacturer's instructions.
- Racking in/out withdrawable switchgear (that is not internal arc rated), where there is a risk of arc-flash caused by mechanical damage to insulation caused by incorrect positioning and/or electrical breakdown.
- Working in live compartments.

It is appropriate that important mitigation steps are adopted to prevent arc-flash for each of the above steps. PD is the consequence of failure modes that are found in switchgear. PD is a dielectric issue and needs investigation for the root cause.

5 Internal Arc Design Standards

Internal arc type testing demonstrates that switchgear, in the event of disruptive failure, should prevent injury, as it is designed to fail safely. This should reduce risk to persons in electrical substations in the event of a catastrophic failure. However, the IAC rating, declares the maximum fault and duration that can be tolerated. It also shows the physical location of where persons can safely be positioned within the substation.

For MV switchgear operating above a system voltage of 1 kV and up to 33 kV, internal arc tests are prescribed as an optional type test in IEC 62271-200. A successful internal arc type test, demonstrates that the switchgear can fail in a controlled manner within a designated area of the substation. This test is optional within IEC 62271-200, therefore it needs to be specified, if required by the user.

In the UK, Duty Holders are recommended to request internal arc tests with a 1 s duration. The internal arc rating demonstrates that the build-up of pressure within the switchgear is contained and released in a controlled fashion. IEC 62271-200 and IEEE C37.20.7 do not prescribe the internal arc duration. In the UK, Distribution Network Operators (DNOs) generally specify 1 s due to the historic design of protection schemes. For the IAC of 1 s to be effective the main protection installed needs to clear a fault in this time.

The IAC verifies that switchgear MV compartments can contain a maximum design rated arc fault current for the specified duration, and that the hot gases generated during a fault, are directed safely away from operators.

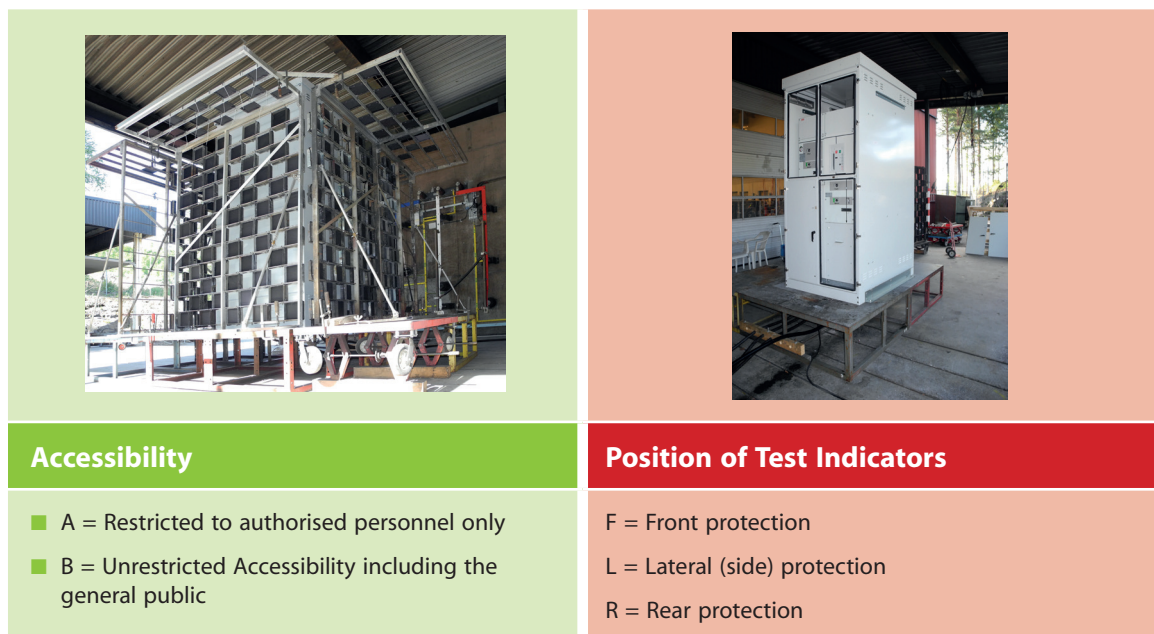


Figure 8, IAC Designation

The photographs in Figure 8 (courtesy of ABB) show 36 kV SafeRing and SafePlus switchgear prior to internal arc testing at SATS (Scandinavian Association for Testing of Electric Power Equipment) Certification, Trondheim, Norway. The level of accessibility and protected position of the boxed cotton test indicators determine the designations for accessibility and position of the IAC. The test indicators were placed to represent the categories of accessibility and position in Figure 8. The IAC designations, verified by arc testing, are shown on the switchgear nameplate, along with the root mean square (r.m.s) arc fault current and duration.

NOTE: IEC 62271-200 & IEEE C37.20.7 internal arc classifications enables benchmarking testing of switchgear, but it does not guarantee a specific performance in a substation building.

For AF (Internal arc classified equipment – see Figure 8) the internal arc classification does not provide evidence that a resulting pressure wave will dissipate safely within a substation building, where a subsequent pressure rise may cause structural damage.

The internal arc type test is carried out in simulated conditions, and not in an enclosed substation volume. The test consists of two perpendicular walls and a ceiling – the resultant flame/pressure wave is not replicated in a confined environment, as would be the case following an internal arc failure inside a substation building. Consequently, although the IAC classification may be compliant, it could still cause damage to the substation building containing the switchgear, resulting in structural/mechanical damage. This can be compared to any type of explosion in a confined space. The results of such, could be potentially life-threatening structural damage, e.g. the roof collapsing.

On any internal arc classified switchgear, it is important that the Duty Holder and Safety Responsible Engineer understands where the hot gasses are vented. The vented gases could be ejected either within the substation building, or externally, depending upon the type of switchgear specified. Where external venting takes place from the substation building, it is very important to consider where the venting gases are ejected, to prevent any hazard to people and equipment in the exhaust zone.

It should be noted that the risk of fatalities and serious injuries are vastly reduced when adequately specified internal arc rated switchgear is installed. This assumes that people are positioned in the prescribed areas when a catastrophic failure occurs.

During catastrophic switchgear failure, the pressure wave is released from the switchgear via a combination of a pressure relief device and sometimes combined with a specially designed venting compartment(s). Video evidence is usually taken during the type test (but is not mandatory). Duty Holders and Safety Responsible Engineers, may request this from the manufacturer, as it could help determine the direction of exhaust gas and how it is released from the switchgear. Some manufacturers are reluctant to release this information.

Some manufacturers record the pressure build up, both within and immediately outside the switchgear, and this information could also be available and helpful to work out maximum pressure rise. This is an optional requirement, but it is good engineering practice to know what pressures were evident during the test. This data can be used in any subsequent pressure rise modelling, as prescribed in IEC 61936-1, *“Power installations exceeding 1 kV a.c. – Part 1: Common rules”*.

It is very difficult for standards and specifications to cover all substation designs as the possible test permutations would be numerous. It is important that the Duty Holder and Safety Responsible Engineer evaluates each installation against the standard or specification. Where there are any concerns, these should be raised with the manufacturer. Within IEC 62271-200, rating acronyms are used to describe a successful switchgear internal arc testing arrangement, as summarised in Figure 8.

When designing switchgear, containing an internal arc is difficult to achieve due to the large energy levels and pressure wave which poses very high dynamic mechanical and electrical stress in the MV compartment under test. Strengthening the compartment with additional mechanical support and thicker diameter metals helps. The pressure wave tries to find the weakest points in compartments, and this could be where cables are connected. The Roxtec cable sealing system has been tested by ABB, for its suitability to contain the pressure rise, see Clause 6 below.

6 Design Mitigation & Possible Consequences



ABB has achieved internal arc classification in the MV connection compartment of their 36 kV rated SafeRing and SafePlus switchgear. As part of their design, Roxtec cable seals were used. The successful test was carried out at 25 kA for 1 s and was classified AFLR, which is recorded in the SATS Certification Report of Performance RoP 15-B24.

AFLR, is where the flame and exhaust venting are taken away from the switchgear, so consequently it should be safe for persons to be stood on any side of the switchgear, should a failure take place.

When using a modular/mechanical cable sealing system, it should fulfil the following criteria:

- Proven capabilities to withstand blast loads, impulse and peak pressure.
- Proven fire performance.
- Appropriate IP and NEMA rating for:
 - Water;
 - Dust;
 - Corrosion.
- Proven capabilities to withstand vermin.

The modular / mechanical cable sealing systems design should include fire resistance performance as below:

- Reaction to fire: Material in the rubber blocks should be halogen free and does not contribute to the fire. It should have a limited amount of smoke developed and not form droplets that can spread fire or hurt people or damage assets.
- Resistance to fire: An installed system should resist a fire, thereby contributing to the prevention of fire spread.

The Roxtec cable sealing system fulfils the requirement for reaction to fire Class B-s1, d0 in accordance with EN 13501-1. Resistance to fire testing for the cable sealing is in accordance with EN 1366-3:2009 and classified in accordance with EN 13501-2.

To achieve the above classifications, the rubber cable sealing system goes through a series of type tests with a prescribed flame applied and the results observed.

Class “B” means that the material “self-extinguishes” after a short time, which means that the material itself, does not contribute to or fuel a fire (or as said in the classification “very moderate fire contribution”). A lower-class material, would mean that the rubber would continue to burn and thereby, also fuel the fire. For internal arc switchgear consequences, the rubber is expected not contribute to a fire within 1 second of initiation of the arc. Longer exposure may result in the rubber contributing to any fire.

The ‘s’ rating is “smoke development” and ‘s1’ is “very limited amount of smoke developed” (this is the best class if tested). This rating is important in applications where people are located, and especially in escape routes or emergency exits.

The 'd' rating is "droplets". If a material forms droplets when heated, the hot droplets may spread a fire. The Roxtec cable sealing system achieved the best possible classification in accordance with EN 13501-1, which is "d0".

Using an approved and tested modular/mechanical cable sealing system provides other benefits in switchgear design as mentioned below:

- As the rubber material is an excellent insulator, there are no metal edges or sharp points/edges. This will help the switchgear achieve a higher dielectric withstand, so helping achieve higher lightning impulse levels.
- The system provides excellent sealing properties so there will be less dust contamination, which again can maintain the MV dielectric properties of components used in the switchgear design.

"Future included": The possibility to expand or alter the number of cables without changing the design of the cable entry. Frame with spare blocks is tested for arc fault. Adding cables using the Roxtec design does not affect the performance of the cable entry seal or the switchgear housing.

7 Conclusions

The main conclusions of this White Paper are:

- C1 It is important the new MV/HV switchgear is internally arc tested to provide maximum protection to operators and those who work in proximity to this equipment.
- C2 MV/HV connection compartments need to be sealed to contain internal arcs.
- C3 An approved and tested modular / mechanical cable sealing systems helps prevent causes of arc like water, dust, vermin whilst mitigating dangers like blast loads, fire spreading in case of an arc-flash and can help switchgear pass internal arc type tests.
- C4 IEEE 1584 arc-flash calculations, to determine appropriate PPE, should be considered as a last line of defence.
- C5 Should oil switchgear fail, there is a high probability of fatalities for workers close by.

8 Recommendations

- R1 With regard to Internal Arc and Arc Flash, Duty Holders and Safety Responsible Engineers should ensure they prioritise the following mitigation to prevent switchgear failures:
 - 1 Elimination
 - 2 Substitution
 - 3 Engineering Controls
 - 4 Administrative Controls
 - 5 PPE
- R2 Switchgear manufacturers should consider using tested modular/mechanical cable sealing systems (or equivalent) to help pass internal arc tests within connection compartments.
- R3 A replacement plan for any oil switchgear should be considered by Duty Holders and Responsible Safety Engineers for long-term safety of workers.

9 Document History

| Version | Date | Amendment | Issued by | Authorised by |
|---------|----------|---|---------------------------------------|---------------------------------------|
| 0.1 | 15/07/20 | First issue | Ian Naylor Principal Consultant | Gary Eastwood Managing Director |
| 1 | 19/08/20 | Revised in accordance with comments from Roxtec | Ian Naylor Principal Consultant | Gary Eastwood Managing Director |

10 Appendix 1 – Ian Naylor Bio



Ian Naylor is a Principal Consultant working for Threepwood Consulting since 2015. Ian started life as a coal mining colliery electrician, involving maintenance of plant and equipment. Having obtained a Power Electrical Engineering Degree at Huddersfield University, Ian worked at Merlin Gerin in Leeds, carrying out internal arc type testing at Kema, in Holland.

Ian moved to Yorkshire Electricity and was responsible for the switchgear and plant specifications. In 2000 he became Standards Manager at the Electricity Association (EA)/Energy Networks Association (ENA) in London. He was responsible for the introduction of the ENA TS 41-36 Switchgear Specification.

Ian then spent 10 years working for Consultancy at EA Technology where he carried out various projects, involving MV/HV switchgear around the world, including the Middle East, the Far East, Australia and New Zealand.

Ian sits on the IEC Maintenance Team (MT)14 representing Great Britain. This committee is responsible for updating IEC 62271-200, which includes the internal arc type testing.

Ian now delivers various projects at Threepwood on various electrical assets to help mitigate the risks shown in Figure 6 of this White Paper.



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