

Internal Arcs: Operator safety and system reliability in MV switchgear



Powering Business Worldwide

INTRO

Eaton's vision is to improve the quality of life and the environment with power management technologies and services.

Quality equipment and solutions for personal safety are paramount to Eaton's design principles. Electrical workplace safety is critical in the Electrical Power industry, and thus for Eaton as well.

Internal arcs, although a very rare occurrence on IEC certified switchgear, present specific challenges for switchgear manufacturers and users; the effects and consequences can be devastating. Eaton applies the philosophy that it is even more important to prevent the occurrence of internal arcs. As such, Eaton have developed solid insulation and electrical field control technologies for our Medium Voltage (MV) switchgear, to accomplish insulation that ensures safe and high operational reliability, throughout its complete lifetime.

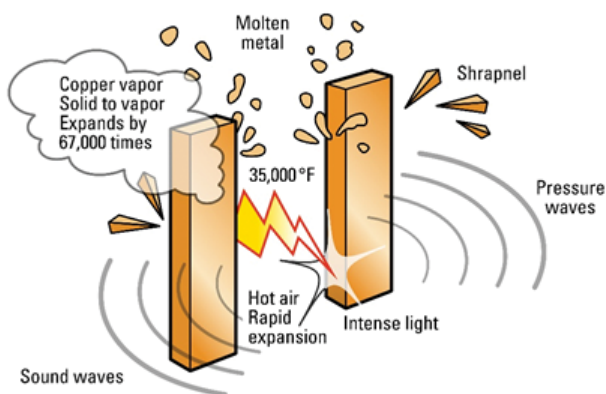
As a business leader, Eaton is positioned to answer tomorrow's electrical grid's most critical challenges today.

Overview

Economies need a reliable and safe supply of energy to grow, to enable manufacturing and to provide opportunities for entrepreneurs. Distribution System Operators (DSOs) are under continuous pressure to provide stable and uninterrupted power supply.

Being an energy leader and one of the most admired companies in the world (according to Fortune magazine's February 2018 list), Eaton takes their responsibility to the planet and its people seriously and it is reflected in our approach to safety.

In the rare event of an internal arc in switchgear, high-power electrical arcs occur inside an assembly. The arcing current can flow between phases and/or between one (or several) phases and neutral via ground (earth). The amount of energy released depends on the short-circuit current level, as well as other factors. Internal arcs cause extreme temperatures, pressures and outflow of evaporated hot gases. The consequences can be devastating, that can threaten human life, cause immense damage to property and of course the loss of supply. Temperatures of the arc can go beyond 10,000 oC.



Awareness of the risks of internal arcs have increased in recent years and more regulations and legislation have been put in place to protect people, ensure continuity of supply and limit damage to equipment and surrounding infrastructure.

Considerations for DSO's

Distribution System Operators (DSOs) are particularly concerned about safety and quality of power supply. The IEC 62271-200 document describes Internal Arc Classification (IAC) categories to give some basic safety information in the event of an internal arc.

General operations and maintenance activities can leave personnel vulnerable should an internal arc occur. In addition, the resulting downtime in the power network is unacceptable, as society demands a stable power supply. The prevention of internal arcs thus becomes crucial to any DSO.

In the event that an internal arc does occur, it needs to be addressed and solved quickly. Depending on the network configuration, once the faulty section has been identified, the network can be reconfigured, and the electricity supply restored. Once finally repaired, the network can be configured to its normal configuration. In MV switchgear, a spare panel can serve as a temporary solution if only one panel is affected. Although IEC 62271-200 does not specify that internal arcs need to be contained to single compartments or panels, it is important that the arc fault is contained to a single panel or compartment, instead of destroying the complete switchgear system. This is because restoring the power supply in MV switchgear would take longer in such a case and can be more problematic. If the incomer is affected, a redundant solution with a sectionaliser in the middle can offer a solution. Arc-proof switchgear offers clear benefits as it limits and contains internal arcs, and as such more and more DSOs are specifying this switchgear design.

Preventing Internal Arc by Design

Metal- or insulation enclosed MV switchgear is designed and manufactured to achieve a stable power network and to prevent internal arcs. Generally, this is achieved by applying good engineering practice and robust design. The switchgear must comply with IEC regulations, must be type tested, make use of reliable materials, undergo endurance and ageing tests, be subjected to scrutiny from analytical and Six Sigma tools and quality management to succeed.

Single pole solid insulation is another preventative measure in MV switchgear, and this type of switchgear has been installed and in use in the Netherlands and Scandinavia since the 1960s and to date, in most countries around the world. IEC 62271-201 is dedicated to guarantee the quality.

Controlling Internal Fault Effects

Internal arcs are very rare, but the consequences potentially catastrophic. As such, protection systems and internal arc proof enclosures, are applied to limit and control the effects of potential faults.

Limiting the Arc Duration

In addition to overcurrent protection, typical arc detection systems react on light or pressure. This means that the duration of an arc can be limited to an acceptable value (approximately to a maximum of one second). Arc eliminators can short circuit an internal arc very quickly (in a few milliseconds) to limit or even eliminate any serious impacts or effects.

An arc detection system minimizes the energy during an arc as well as the impact but does not prevent the arc from occurring.

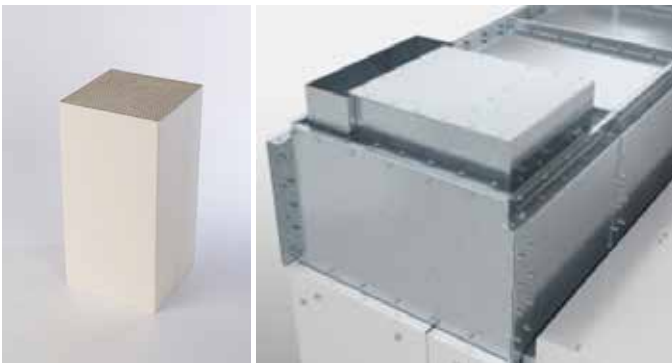
Arc Resistant Switchgear

Understanding arc behaviour and developing and testing internal arc-resistant switchgear, has enabled manufacturers to create robust systems.

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 has a relative low arcing energy. These measures support to control the arc inside the housing and by doing so reduce the effect of the arc.

Dealing with the effects of the arc

One must consider the inevitable fact of dealing with the effects of the arc by leading the high temperature of the gasses and fire away from persons present. Venting can also be conducted into a cable cellar/ trench if available, or with the use of a duct to the outside, with due consideration of safety for passersby. A more cost-effective alternative is a special arc chimney with arc absorbers, made of ceramic or steel, in-line with the arc channel, this excellent solution can absorb a significant portion of the arcing energy before the gases are expelled. This reduces the amount of exhaust, and temperature of the gasses and increases safety if persons are present. This special arc chimney with arc absorbers can be utilised for venting inside the switch room in applications where one would need to reduce high pressures, and high temperatures without having the luxury of a cable cellar/ trench, or the means of safely venting via a duct, to the outside atmosphere or specific dedicated room. Eaton has tools for calculation of anticipated pressure inside the switch room.



Picture of arc absorber block and arc absorber unit (Power Xpert UX)

The test to prove IAC classification is described in the IEC 62271-200. A rack with fabric indicators is positioned at a fixed distance from the switchboard. During an arc test the fabric must not ignite. Other criteria tested in the IAC are:

- no opened doors
- no projection of parts >60 gram (= 2.1 Ounce)
- no holes in enclosures on classified sides
- no burnt fabric indicators due to the expulsion of hot gasses
- earth connections still intact

The Best of Both Worlds

Single pole solid insulation helps to prevent arcs, and when combined with an arc-resistant enclosure, maximum safety and protection from internal arcs can be achieved.

In the figure below the Ring Main Unit (RMU) is air-insulated, with single-phase solid insulation in a very compact design (350mm panel width up to and including 24kV). The internal arc classification IAC AFLR 20kA-1s with an arc duct is according to IEC 62271-200



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

Insulation Mediums for MV Switchgear

In MV switchgear several materials are utilized for insulation. Among the most common are ambient air, solid insulation or the use of SF₆ gas. New gasses, possibly more environmentally friendly than SF₆, have been introduced to the insulation process. Their dielectric properties, as well as long term behaviour, has to be investigated further, tested, and yet to be proven before it is accepted more widely by the market place.

1. Solid insulation utilizing Polycarbonate and Thermoplastic

Eaton uses solid insulation materials around live parts. These materials allow our design engineers to shape the parts for optimal insulation, robust construction and cooling.

Eaton design and manufacturing experience has enabled us to construct smart single-phase insulated systems. Eaton's Xiria product family utilizes optimal field control through the special design of all primary components.

2. Solid insulation using cast resin technology

Diverse Epoxy resin (cast resin) is used as high-quality primary solid insulation material around live parts. Cast resin can also be shaped as required to create not only optimal electrical field steering, but also be used as construction material and for optimal cooling. Eaton has developed technologies to integrate conductors and vacuum interrupters directly into the molding and to make complex shapes. Optimal field control is utilized through the special design of all primary components. Epoxy resin is mechanically robust, such that single-phase internal arcs will not easily migrate to three -Phase faults.

This solid insulation is also used in the FMX system. Power Xpert® FMX is Eaton's IEC single busbar, solid- and air-insulated medium voltage switchgear system, for use up to 24 kV. The system also provides reliable switching, protection, metering and distribution of electrical energy. The modern design system uses Eaton's state of the art technology and is manufactured in accordance with the highest quality standards.

FMX also utilizes optimal field control through the special design of all primary components, is modular in construction and tested according to the latest IEC 62271 standards.



friendly than the previously used oil, and more compact than only just air options. Increased Vacuum technology is now days much preferred, as vacuum integrity is contained by a sealed-for-life system, has fewer moving parts, and provides maintenance-free operations with no impact on the environment. There is also the added cost, (related to responsible recycling of SF₆ gas and its very possible by-products of SF₆ switched gear at end of life) to consider.

When SF₆ is used, the gas is applied under pressure in a tank (requiring a pressure gauge) that has a pressure level above that of the atmospheric pressure.

Switchgear that uses SF₆ gas as an insulation medium, has a certain leakage rate. To maintain the insulation level within this type of switchgear, the pressure of the SF₆ contained in tanks must be checked. Should the level of gas drop, for any reason, the system loses its dielectric strength. This is not applicable for systems that use controlled air as an insulation medium.

With Eaton's SF₆ free switchgear, the owner does not have the additional maintenance cost required for SF₆ systems during the +/-30-year lifetime. The combination of vacuum interrupters for switching, solid insulation and clean air as insulation medium, are environmentally friendly and sustainable options for today's requirements, especially in markets lacking adequate SF₆ disposal facilities. Eaton SF₆ free MV switchgear systems maintain the same levels of quality throughout the service lifetime of the system.

3. Insulation with a gas (SF₆-gas)

Eaton Medium voltage systems up to and including 24kV are SF₆ free and use vacuum technology for switching. MV Switchgear is generally enclosed in a metal structure. Early in the 20th century, MV switchgear utilised oil, and air as a medium in the circuit breakers. Technological advancements led to the introduction of gas (SF₆, or Sulphur Hexafluoride) as an interruption medium and insulator in the late 1950s, along with vacuum circuit breakers shortly after that. As a gas-insulator, SF₆ was superior in performance, by providing less risk with fire and explosion as opposed to oil, also supposedly cheaper and more environmentally



Gas Insulated Switchgear (GIS) with SF₆, is unfortunately still used extensively around the world. However, SF₆ poses significant risk to both human health and the environment based on possible operating conditions (extreme heat), possible leakage and the inappropriate disposal of the equipment at the end of its life cycle. SF₆ is one of the seven greenhouse gases listed in Kyoto Protocol

(Source: https://ec.europa.eu/clima/policies/strategies/progress/kyoto_2_en) and also in the Hazardous Substances Databank (HSDB). Releasing one kilogram of SF₆ into the atmosphere has the same emission effect as almost 24 tonnes

(Source: <http://orca.cf.ac.uk/113976/1/energies-11-02037.pdf>) of CO₂ on global warming. It is also considered to be the most potent greenhouse gas with an expected atmospheric lifespan of more than 3,200 years. When SF₆ decomposes (mainly due to heat caused by arcing), it produces by-products such as HF, SOF₂, SO₂F₁₀, SO₂, all very hazardous to human and animal life

(Source: https://www.epa.gov/sites/production/files/2016-02/documents/sf6_byproducts.pdf).

The disposal of these gasses require workers to wear safety gear with hazard material suits to dispose of it safely. Should it not be disposed of in a safe and responsible manner, humans and animals (and the environment) could suffer severe health consequences from the released SF₆ gasses and its residual volatile material.

Technical aspects of the 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 network configuration and actual situation. An internal arc in switchgear causes high temperatures, an overpressure, together with the release of fire and smoke.

Two situations can be identified for a compartment containing all 3 phases in a metallic enclosure:

1. With gaseous insulation only

Because of the higher dielectric stress, a phase-to-phase (or to earth) breakdown will be most likely. The arc will develop within approximately 10 milliseconds (ms) into a 3-phase fault, resulting in a full rated short circuit. This type of incident will release high energy that will make the arc difficult to control.

2. With solid insulation per phase in air

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

- In a Peterson earthed network: only a few Amps will flow
- Floating neutral: depending on the size of the network, a capacitive earth fault current of several Amps to a maximum of approximately 500 A will be introduced as arcing current
- Impedance earthed neutral: a maximum fault current of 1,5 to 2,5 kA will occur, depending on the impedance in the neutral.
- Solidly or direct earthed neutral: Dependent on the actual impedances involved, an arcing current up to many kA's I can occur, (theoretically up to the 3 phase short circuit current value, but in practice generally limited to about 10 kA f(for most Utility networks)

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 they are not adequately insulated, a multiphase (3-phase) arc could develop within the compartment before the fault is cleared.

In cases 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 theoretically be the rated duration of the switchgear (in MV generally 3s), but in practice set on maximum 1 second.

Regarding case 1 and 2, the fault might be undetected, and no action is taken. This can result in a multi-phase fault.

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 specified as the standard in IEC 62271-200 ed.2 for compartments where all poles are individually insulated with solid insulation and, in the case of cable compartments, the cable connection is made by a plug-in or site made solid insulation connection.

Safety often comes down to the time it takes to detect a fault and to evacuate a building.

3. Status of IEC 62271-200 STANDARD

The regulations relating to MV metal-enclosed switchgear are IEC 62271-200. The ed.3 revisions should be published by 2020. No significant technical changes regarding internal arc testing are expected.

Preventing and curing internal arcs

1. Preventing internal arc is better than curing

Eaton is committed to creating safe switchgear for operators. One of the biggest potential threats to operators is an internal arc. Although it is very rare for an operator to be in front of (without operating) the switchgear at the exact moment an internal arc occurs, engineers have designed and constructed switchgear to prevent internal arcs. Eaton supports the philosophy to prevent the arc from occurring in line with the relevant standard IEC 62271-200.

Experience and knowledge gained in working with solid insulation, cast resin technology, vacuum technology and electrical field control, have been applied in the design and development of the Xiria/FMX and UX systems to ensure that the switchgear is safe and has high operational reliability throughout its complete lifetime. The systems have been thoroughly IAC tested according to the latest standard IEC 62271-200.

Within the Eaton FMX/Xiria/UX systems design, a double prevention philosophy is applied. Firstly, the design is constructed in such a way that an internal arc is prevented. In the unlikely case that an internal arc does occur, the Eaton Xiria/FMX/UX systems are equipped to provide maximum safety to the operator and to control and minimize damage to the rest of the switchgear and containing room. FMX is even tested beyond IEC 62271-200 with opened cable compartment and indicators inside with an arc initiated in the busbar compartment

2. Preventing an Internal Arc

• The use of electrical field control

Engineers designed the primary conductors and its components based on Eaton's key technology for electrical field control. By means of special shapes and dimensions, Electrical Field Strengths are controlled, and the likelihood of flash-over (resulting in internal arcs) is minimized.

• Single pole insulated primary parts

All high voltage parts in the accessible compartments are single-pole insulated. The insulation material used for this can be epoxy resin (cast resin), and/or Polymer materials. Those are high-quality materials with optimal insulation characteristic resulting in minimized dimensions.

• Protected voltage transformers

Ferro-resonance causes damage to voltage transformers and consequently initiates an internal arc in the switchgear. The Eaton design prevents the voltage transformers from being affected by ferro-resonance by installing a resistor and a coil in the tertiary circuit of the voltage transformer.

• The integrated cable test facility

Internal arcs due to bad cable connections are becoming fewer, however, they do still occur. Therefore, cables should be tested before going live. The FMX system is equipped, and the Xiria system can be equipped, with an integrated cable test facility. This eliminates the need to remove covers and disturb cable connections.

3. Controlling an internal arc

An internal arc in switchgear causes an overpressure and the release of fire and smoke. By design, vacuum and air or solid insulated switchgear, present the least negative environmental impact after an internal arc event. The impact of an arc is twofold: an internal impact (in the switchgear) and an external impact (in the switch room).

The overpressure created by an internal arc will, in most standard switchgear, be guided out of the switchgear by means of a pressure relief duct. Next to the duct, an arc channel may be installed to guide the arc output outside of the switch room. The Eaton Xiria switchgear design is constructed in such a way that both impacts (of complication and expense) are significantly reduced and consequently, a less complicated arc channel is needed.

- **No phase-to-phase short circuits minimize pressure**

Within the Eaton switchgear system, all high voltage parts in accessible compartments, are single pole insulated. The advantage of this single pole construction is that the only conceivable internal fault is a single-phase short circuit, possibly due to a cable connection failure (when single-core cables are connected, as is standard practice today). The material used for insulation, such as epoxy or polymer, further influences the duration of the arc positively. Epoxy is a high-quality material with optimal insulation characteristics.

Within the Eaton Xiria systems all high voltage parts are also single-pole insulated. The only possible internal fault is that of a single-phase short circuit, possibly due to a cable connection failure (when single-core cables are connected).

Eaton equipment has been tested in accordance with the highest IEC standards, which implicates testing with a 3-phase short circuit.

Xiria, FMX, and UX systems are IAC classified. Xiria is classified AFLR 20 kA-1s and FMX is AFL 25 kA-1s. Because the FMX systems are often installed against a wall, this classification creates a safe situation for the operator. UX is even classified AFLR up to 50 kA-1s.

- **Channel the gasses by means of a duct**

The overpressure created by an internal arc will, in standard switchgear, be channeled out of the switchgear by means of a pressure relief duct. This duct is normally an additional compartment to the switchgear and therefore increases the panel dimension. Both UX and Xiria can be delivered with a channel to bring the gasses outside the switchroom

- **Arc chimney with integrated arc absorbers**

The arc chimney with integrated arc absorbers can be located in a smaller switch room (especially when there is no possibility to vent down or backwards). In standard switchgear, gasses caused by an internal arc are guided out of the switch room by means of an extra duct and arc channel connected to the switchgear. These additions require extra space and consequently increases installation and building cost.

Should it not be possible to vent into the cable trench/cellar or into an adjacent room, the Eaton system design, offers the possibility to safely vent into the switch room. In this case, a special arc chimney is installed at the back of the panel. The arc chimney contains integrated arc absorbers that break and filter hot gasses and glowing particles significantly. The Power Xpert FMX system has as standard arc absorbers integrated per panel. The Power Xpert UX and the Xiria platform can have arc absorber units as an option to vent inside the switchroom.

4. Preventing above the standard

Eaton conducted a test on its FMX switchgear to better understand the effect of an internal arc fault in the busbar system (when the switchgear was in service). The test was performed 3-pole at 25 kA-1s, with indicators in the opened compartment without a circuit breaker in place. The result was that no indicators were burnt. Apart from some anticipated hearing problems afterwards, personal safety was not impaired or impacted in this situation.

Conclusion

Human safety when dealing with electrical energy is not negotiable, and switchgear manufacturing companies should strive to create the safest possible systems for both their personnel and the environment. Preventing internal arcs from occurring is preferable to controlling it and single-phase solid insulation in combination with electrical field control are highly effective in this respect. Solutions can be just as compact as gas-insulated solutions.

The ideal state of “zero risk” can be approached by specifying the correct equipment. Switchgear users deserve equipment that has been subjected to rigorous testing and switchgear that carries approved testing agency documentation to prove it. Internal arc classification (IAC) is addressed in IEC standards.

Eaton products and systems are all designed to prevent internal arcs, and upon that tested and qualified according to the IEC standards including the IAC classification. Specific internal arc tests had been performed in line with customers’ expectations, even beyond the demands in the actual IEC standards. The right equipment ensures safe working conditions for operators and ensures continuous power supply in business-critical environments.



Xiria product family – Ring main unit and extendible secondary switchgear solutions



Eaton is a power management company with 2018 sales of \$21.6 billion. We provide energy-efficient solutions that help our customers effectively manage electrical, hydraulic and mechanical power more efficiently, safely and sustainably. Eaton is dedicated to improving the quality of life and the environment through the use of power management technologies and services. Eaton has approximately 100,000 employees and sells products to customers in more than 175 countries.

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