A matter of timing

An active protection device that reacts quickly to internal arcing enhances operator safety and equipment availability

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Switchgear arcing can have serious consequences. It only takes a few milliseconds for an arc to form, but the energy level built up throughout its duration is astounding, and can result in serious injury or, in very rare cases, even death. Numerous arc protection devices exist to reduce the duration of the fault current feeding an arc, but these do not necessarily prevent damage from occurring. The damage that results from an arcing accident depends on the arcing current and the time taken to intervene and extinguish it, and of the two parameters, only time can be influenced.

ABB's product portfolio contains several reliable protection systems, some of which can extinguish an arc in less than 50 ms. This portfolio has been further enhanced with what is known as an Arc Eliminator. For switchgears, this device is an extra safety feature, much like the airbag in a car, that combines the positive characteristics of other ABB protection devices. It is a fast-closing earth switch that can make a complete busbar short-circuit in less than 5 ms. It is defined as an active protection system that has been integrated into ABB's UniGear switchgear. In addition to speed, the Arc Eliminator gives important savings in terms of repair cost and downtime.

Switchgear internal arcs may happen because of defective insulating materials, improper bus joints, poor maintenance, animal intrusion, or simply human error. But when they do occur, and if there is little or no protection in place, the resulting damage can often be extensive or even fatal [1]. An arc[1)] causes a rapid rise in the temperature of the surrounding air and in the pressure inside the enclosure, and the energy release is equivalent to that of an explosion.

The occurrence of such a fault leading to personal injury in modern medium voltage air insulated switchgear (AIS) and gas insulated switchgear (GIS) is extremely rare. This is mainly because operators are well protected against internal arcs by passive protection systems, such as the switchgear structure. In other words, the switchgear enclosure is capable of withstanding the pressure and heat generated by the arc, and the installation of an exhaust duct directs the hot gases away from the operator working area 1. Additionally, the duration of an arc, and hence the damage it causes, is limited by the choice of an appropriate relay protection system.

Prudence and certain international standards Factbox say that people should not work on, or even be near, exposed live components. However, no matter how carefully safe work practices are followed, risks exist when it comes to electrical equipment. There will always be occasions, such as when a problem cannot be uncovered by troubleshooting the equipment in a de-energized state, where it is necessary to work on energized equipment. On these occasions, a conventional protection relay's driven breaker operation requires a minimum of between 100–200 ms to extinguish a fault. During this time, operator safety is guaranteed by the switchgear structure. Unfortunately, the same cannot be said for the electromechanical equipment in the compartment where arcing occurs. The first 120 ms of the fault is considered the dynamic phase of arcing during which high pressure develops and hot gases expand. These combine to completely destroy whatever was in the

Factbox Standards defining electrical safety requirements in the workplace

The foremost consensus standard on electrical safety is the US NFPA 70E "Standard for Electrical Safety Requirements for Employee Workplaces" [2]. In this standard, it clearly states that workers should not work on or be near exposed live parts except for two reasons, as stated in NFPA 70E-2000 Part II 2-1.1.1*):

- When de-energizing introduces additional or increased hazards (such as cutting ventilation to a hazardous location)
- When equipment design or operational limitations (such as when voltage testing is required for diagnostics) make it otherwise difficult

In the US, non-adherence to these regulations and practices is considered a violation of law and is punishable by a fine and/or imprisonment. In Canada, a similar standard, "Arc flash/electrical safety in the workplace," CSA Z460, which addresses worker safety with respect to internal arc or flash hazard, is currently being defined.

Footnote

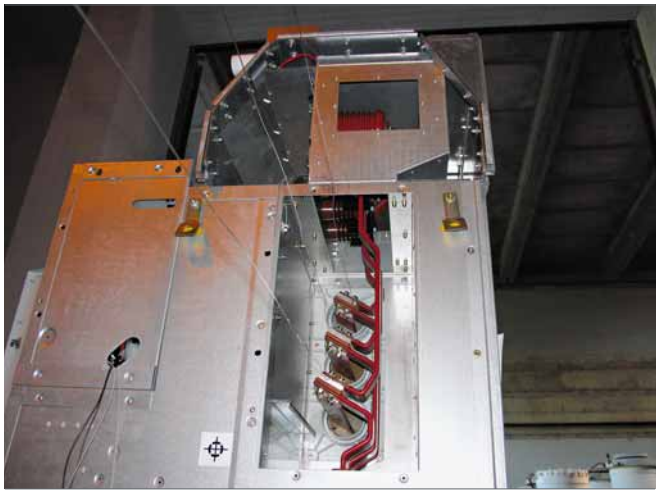
*) More detailed information can be found at http://ecmweb.com/ops/electric_top_five_keys (October 2007).

1 The switchgear enclosure is capable of withstanding the pressure and heat generated by an arc

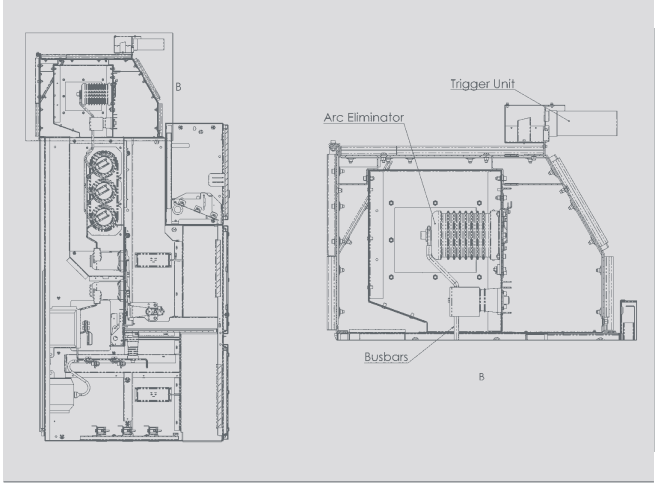
Footnote

1) The energy discharged in the arc is proportional to the square of the short-circuit current and the arc duration.

2a Arc Eliminator (AE) application on ABB's UniGear switchgear



2b Detailed drawing

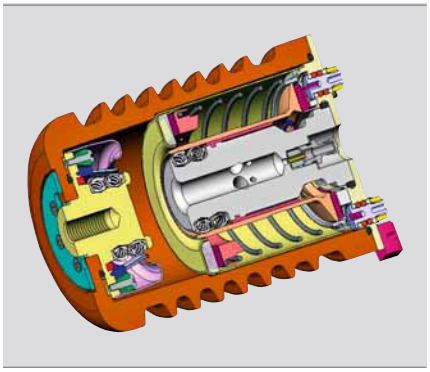


compartment, resulting in a temporary suspension of service and high repair costs.

Arc protection devices exist that can reduce the duration of the fault current feeding an internal arc, thereby significantly limiting the total electrical energy delivered to the fault. In fact, many ABB switchgears contain one of several arc protection systems available in the company's product portfolio, such as TVOC, REA, and FRD. Using either optical or pressure sensors, these electronic devices can detect the presence of an internal arc within a few milliseconds. However, the average intervention time required to eliminate the fault, taking into consideration the relay and circuit breaker time, is of the order 100 ms.

Current limiting devices can reduce both the magnitude and duration of the fault current. To do this, the device must be capable of operating within the first quarter of a cycle, thereby preventing the fault current from ever reaching the first peak of the asymmetrical waveform. An example of such a device is ABB's Is Limiter which has an extremely fast decoupling time of 1 ms. It can be installed in a dedicated switchgear unit, used in interconnections between systems, or in bus sections which are not adequately short-circuit proof when connected by a circuit-breaker. Even though it is costlier than other arc protection devices, the use of an Is Limiter in highly sensitive processes is justified especially when cost/benefit balance issues are considered.

3 Arc Eliminator (AE) single-phase pole cross-section



ABB's Arc Eliminator (AE) can short circuit an arc within 5 ms. It can be used as a standalone device in existing switchgear plants and provides the operator with increased protection.

The Arc Eliminator (AE) merges the positive characteristics of the above fault limiting devices. It is considered the most optimal cost/benefit solution – one device can protect an entire busbar system – and is fast in that an arc is short-circuited to ground within 5 ms. A typical installation consists of an AE unit on each half busbar incomer for a system operated with open tie-breakers, and up to 10 panels are protected. Thermal damage, and consequently toxic arc gas release are drastically reduced to below one percent of what would be experienced in a one second internal arc test, making switchgear room pressure relief systems and exhaust conduits unnecessary. Even though the pressure rise is limited, it can still build up to a significant enough level before the AE can intervene, and switchgear relief systems, if present, will operate but with no release of hot or toxic arc gases.

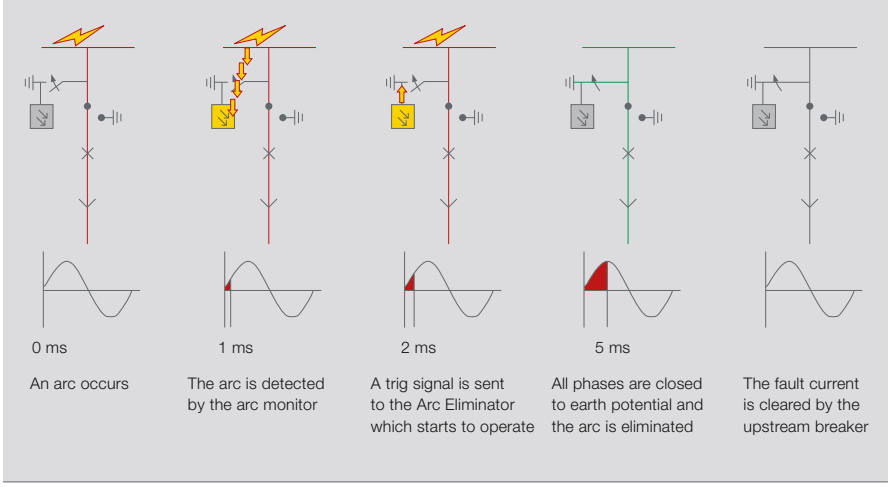
Initially developed and patented for ABB's AX1 AIS switchgear [3], the AE is now an integrated part of the company's UniGear AIS switchgear family 2. The set-up is such that a metal box containing the AE is located on the busbar system. An arc is quickly detected by fiber-optics situated in every switchgear compartment. A UniGear switchgear equipped with the AE was successfully tested in the CESI labs in Italy, and the results are detailed in [4] and [5].

The AE can also be used as a standalone device in existing switchgear plants, functioning as an "active" protection system which is capable of detecting and extinguishing a fault in a few milliseconds (much like the ABS in a car). Additionally, the AE also acts like an airbag in that it provides the operator with increased protection.

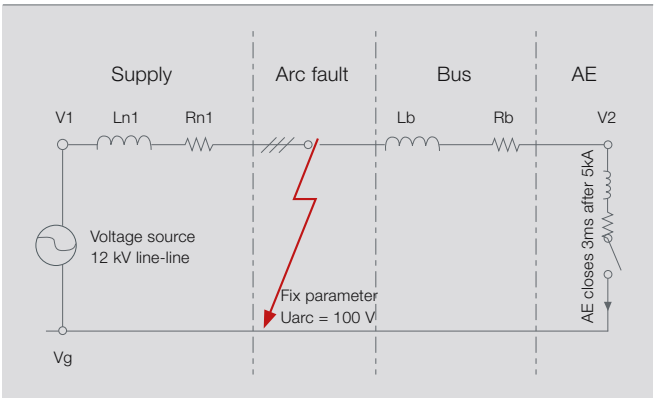
The Arc Eliminator (AE) device

Physically, the AE is a very fast-acting switch, and a single-phase pole cross-section is shown in 3. Each AE switch pole is contained within an epoxy insulator. Light sensors provide the tripping signal through the AE Control Unit (ECU) in the event of an open arc fault in the switchgear high-voltage (HV) compartment. The moving contact, driven by the Thompson coil repulsion effect at high speed, bridges the SF_6 insulating distance to create a short-circuit between the copper ground plate and the HV terminal. This short-circuit takes less than 5 ms to form 4. The arc requires a voltage of at least a 100 V in order to persist. However, after the contacts have closed, the voltage drops suddenly to

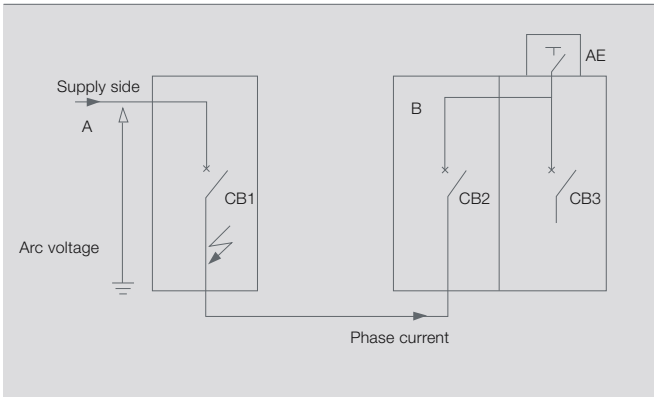
4 Arc Eliminator – event sequence description



5 Simulated circuit to verify that the parallel impedance of the power circuit is low enough to ensure arc extinction



6a Power test set-up



a value that cannot sustain the arc. The insulation properties of SF_6 allow for a very compact design, and the same pole is used across the 12–24 kV range. The actuating energy for the switch contacts is electrically stored and the amount available for operation is continuously supervised [6], as are the power supply, trigger circuit and controller integrity.

A UniGear panel typically accommodates three physically separated high-voltage compartments (busbar, circuit breaker and cable). If an AE electronics module can handle up to six optical fibers plus one electrical input, then one AE is directly capable of protecting up to two panels. This number can be increased to 17 thanks to the development of a special electronic interface which connects one AE with up to five TVOC devices, each equipped with nine optical fibers. The tripping time is not affected by the presence of the TVOC.

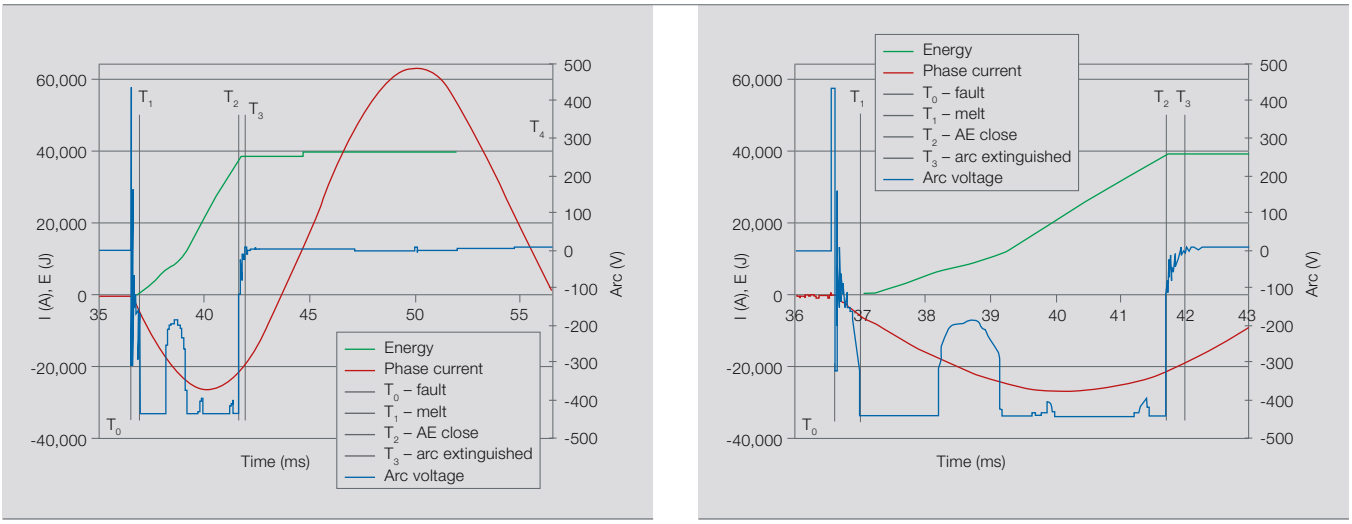
System operation

To verify the AE application in UniGear, the system operation and the maximum number of panels which can be protected by a single device must be evaluated. This depends on the impedance of the power circuit and the typical impedance of the UniGear switchgear busbar, Lb and Rb 5. The circuit in 5 is used to verify that the parallel impedance of the power circuit, ie, from the internal arc position to the AE short circuit to ground, is small as a function of the overall distribution system architecture, and therefore the voltage supplying the arc decreases with AE operation to extinguish the arc.

Preliminary results from simulation cases using between 4 and 10 panels have shown that current sharing between the fault (arc) and the AE is not a problem, even with a relatively large number of panels. It is also clear that the L/R ratio influences the current wave shape, and therefore the arc extinction capability. Larger L/R values mean the DC component decays at a slower rate, allowing the arc to live a little longer. The simulation results have been validated by power tests at the CESI labs [7], where a power cable was used to introduce a significant parallel impedance between the arc and the AE.

6a shows a test set-up in which an 31 kA internal arc starts in the CB1 panel and is transferred to the AE mounted on the CB3 panel. The corresponding graphs, using two different time scales, are shown in 6b. The quantities shown in these graphs are phase current (red), arc voltage (blue) and energy (green). At To, the supply

6b 31.5 kA arc transfer to the AE.



7 40 kA arc effects with AE intervention

voltage is closed on a three-phase fault which has been initiated by a low-section wire across the phases in the CB1 cable compartment. As the wire melts and an internal arc develops across the three phases, the voltage increases to several hundred volts (T1). At the same time, the current rises, flowing from the supply side to the arc location CB1. The energy input to the arc – which is accompanied with a flash of light – increases the air temperature and pressure. This flash of light triggers the ECU, immediately kick-starting the AE operation.

At T2, the AE grounds the three phases and closes, in parallel to the arc, a low impedance path causing the arc voltage to drop significantly. The current flowing in the arc diminishes and starts to flow out of CB1 through the cable connection into CB2, and from there to the AE. The entire process, from fault to detection to the AE closing sequence is completed within 5ms. By T3, the current has been fully transferred to the AE, the voltage drops to a few volts – depending on the parallel path length and impedance – and the current continues to flow until the upstream CB1 eventually cuts the supply. Because of its short-circuit ratings (31.5 kA, 3 s and 50 kA, 1 s), the AE can easily withstand the transferred current until this happens.

The T2–T3 transfer time, which can be anywhere between 0 and 2 ms, is influenced by the position of the AE with respect to the supply side, and the parallel impedance introduced by the new circuit when the AE closes. The 2 ms maximum value was evaluated during a 40 kA rms/100 kA peak internal arc test in CB1 using a 10 meter long cable, with a cross sectional area of 240 mm², connected to CB2.

The AE solution is simple, flexible, easy to install and very cost effective.

While the current, driven from the supply side, is not modified during the sequence, the AE operation strongly limits the voltage and therefore the energy input into the fault. In other words, when the AE kicks in, the energy input per period is substantially reduced to less than one percent of that during the free burning period (ie, from the current start to the closing of the AE) which lasted 5 ms, and this is illustrated by the "Energy" trace (in green) at T2 in 6b. Therefore all the effects normally associated with an internal arc are contained, resulting in no significant damage to the compartment.

In this test, the energy input to the arc during the 5 ms free burning period was about 40 kJ from phase one, and 94 kJ for all three phases. Had the internal arc continued for one second, the total energy released in the compartment would have been approximately 200 times that limited by the AE operation, ie, up to 2 MJ, thereby completely destroying all compartment inner components.

In any case, during the 5 ms free arc period, the switchgear must be able to withstand the forces associated with peak currents as well as the over-pressure that causes relief flaps to open. Weak structural parts may be damaged as a result. In 7 this kind of damage is shown by traces of smoke around the phase conductor and a buckled aluminum bottom plate.

All in the name of safety

Operator safety must be a priority for a medium voltage equipment manufacturer and it can easily be achieved using ABB's AE. The AE solution is simple, flexible, easy to install and very cost effective. An AE service kit allows customers to install this solution in existing switchgears with only minor modifications, thereby increasing the safety level of existing equipment.

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[6] **Breder, H.** (2003). Frequently Asked Questions on the AX1 Arc Eliminator system.
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