

WHITE PAPER

ARC FLASH HAZARDS

Emax 3 integrated solution

ENGINEERED
TO OUTFIT



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1. Introduction

Electric shock and Arc flash are among the most significant risks associated with electrical energy. Shock occurs more frequently and can cause injuries ranging from mild to severe burns, lifelong effects, and even death. Arc flash typically causes serious, life-altering burns and can also be fatal. It is considered one of the most lethal types of industrial accidents.

An arc flash is a dangerous condition associated with the sudden release of energy caused by an electrical arc. Arc flashes are particularly hazardous due to the extremely high current and energy levels involved, representing not only a significant

operational risk but also a serious threat to personnel safety. The arc flash hazard refers specifically to the risk this phenomenon poses to individuals working on or near energized electrical components. The primary type of injury associ-



ated with an arc flash event is a thermal burn, the potential severity of which can be quantified using various recognized methods. However, additional injuries and health risks may also arise due to pressure waves, intense sound, flying debris, toxic vapors, intense light, and indirect causes such as falls.

Arc flash incidents are preventable, as they are often caused by inadequate safety measures, lack of training or improper handling of electrical systems.

This white paper provides an overview of arc flash, outlining its causes and its impact on both personnel and equipment. It reviews key stan-

dards and regulatory frameworks related to arc flash hazards and highlights the main methods used to mitigate associated risks. A new integrated solution integrated into the Emax 3 is also introduced.



2. Arc flash causes

Causes

An arc flash occurs when current flows through the air between two live conductors (phase-to-phase or phase-to-ground), creating a short circuit. If not promptly cleared, such faults can escalate into a three phase fault, the most severe form of arcing fault.

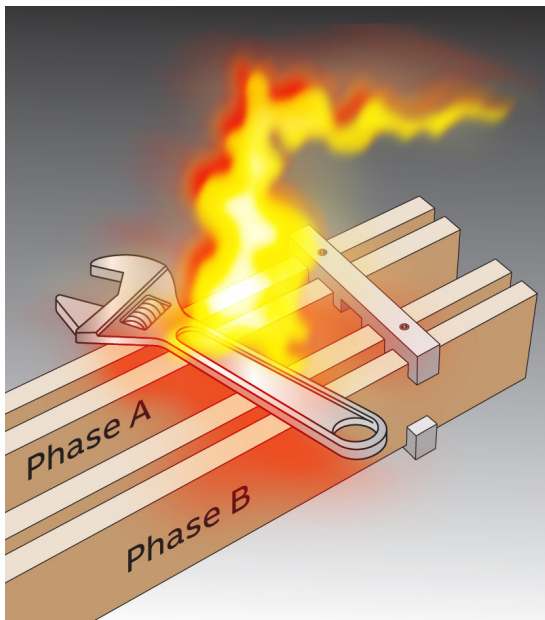
Arc flashes are frequently caused by **human** intervention during live work activities and typically result from inattention, insufficient training, or failure to follow established safety protocols and protective measures. Common examples include:

- improper use or handling of tools, such as accidentally dropping tools onto live bus-bars;
- manual operations like racking in/out with draw-outable equipment.
- closing circuit breakers under fault or short-circuit conditions.

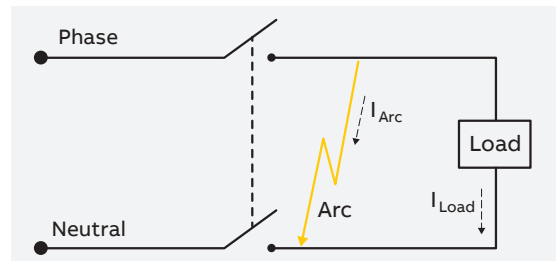
However, arcing faults can also occur due to non-human factors, such as:

- **Contamination:** dust, moisture, or other impurities on the surfaces of live parts can reduce insulation resistance, between conductor or between conductor and ground potentially triggering arcs in the presence of overloads or overvoltages;
- **Corrosion:** degradation of energized conductor terminals can weaken electrical contacts, promote oxidation, and increase the likelihood of arcing between live conductors;
- **Overvoltages:** transient or sustained overvoltages, particularly in confined spaces or within electrical enclosures, can initiate arc flash in the absence of proper insulation or spacing.

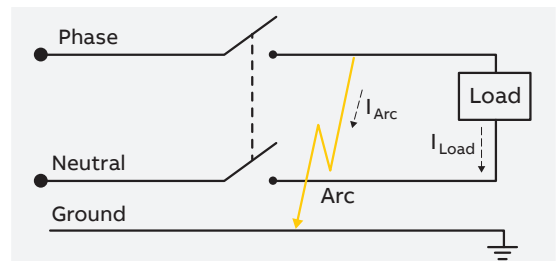
Parallel Arc Fault



Parallel arc (phase-to-phase)



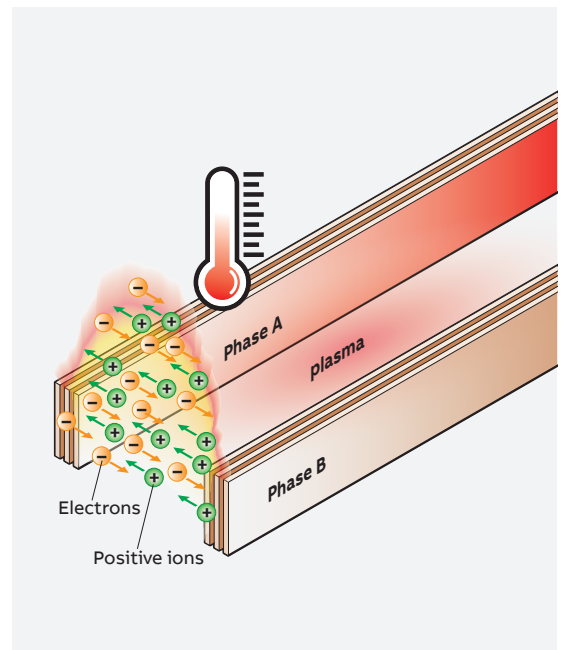
Parallel arc (phase-to-ground)



One of the most frequent causes of arc flash events is the accidental presence of a conductive object left inside the switchgear during maintenance or manual operations. Under typical conditions, atmospheric air is non-conductive and acts as an insulator. However, when a conductive object is unintentionally placed between conductors, or between a conductor and ground, the insulation distance is suddenly bypassed or reduced. This situation can lead to two distinct scenarios that trigger the formation of an electric arc.

In the first scenario, the object creates a direct short circuit, allowing a large fault current to flow. This sudden, intense current generates significant thermal energy, rapidly heating the surrounding air. At sufficiently high temperatures, thermal ionization occurs: electrons gain enough energy to escape air molecules, generating free electrons and positively charged ions. In this ionized state, air becomes conductive, allowing current to flow through the plasma in the form of an electric arc. In the second scenario, the object does not directly connect the conductors but instead reduces the physical distance between them or introduces features (such as sharp edges or conductive dust) that locally intensify the electric field. As the separation decreases, the electric

field may exceed the dielectric strength of air. Once this threshold is crossed, the electric field becomes strong enough to strip electrons from air molecules, initiating ionization. The resulting plasma turns the air into a conductive medium, triggering an electric arc.



2. Arc flash causes

Phases of an Arc Flash Event

The formation of an electrical arc, resulting in an arc flash event inside equipment, is a complex process that heavily depends on the internal geometry of the compartment. Key influencing factors include the width, depth, presence and position of internal barriers, the orientation of arcing conductors, and the direction of power flow. The description provided below is a simplified model intended to offer a general understanding of the main physical phenomena involved in an arc flash event. It does not account for all the variables that may affect pressure development and damage in real-world installations.

Compression Phase

During the compression phase, the electric arc generates significant heat, causing the air near the arc to become much hotter than the air farther away. As the arc continues to burn, thermal energy spreads more evenly throughout the cubicle by convection and radiation. This heating causes the air molecules inside the cubicle to move faster and collide more energetically, resulting in an increase in internal pressure.

Expansion Phase

This rapid increase in pressure eventually causes a mechanical failure of the cubicle, resulting in the formation of a hole or rupture. The superheated air, under high pressure, begins to escape through this opening, marking the start of the expansion phase.

From this point the internal pressure decreases as the hot air escapes and expands outside the cubicle.

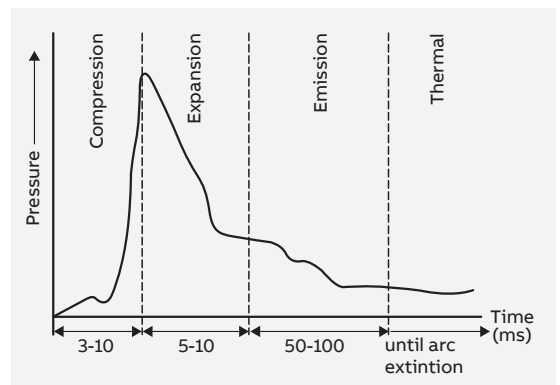
Emission Phase

During the emission phase, a dynamic balance is established inside the cubicle. The electrical arc continues to release energy, maintaining a high internal pressure (though lower than during the expansion phase) while hot gases escape through the rupture. This ongoing energy input compensates for the loss of gas, keeping the internal overpressure nearly constant throughout the phase.

Thermal Phase

During the thermal phase, the intense heat generated by the arc can cause erosion of nearby metals and insulating materials. These materials may vaporize, and in some cases, form molten droplets of metal or insulation.

Additionally, the extremely high temperatures cause thermal decomposition of surrounding materials, leading to the release of gases and fumes as byproducts of melting or chemical breakdown. This thermal phase ends until the circuit is interrupted by an automatic circuit breaker. The resulting damage from this phase can affect the materials inside the switchgear, often requiring maintenance or replacement of components



3. Consequences and hazards

The occurrence of arc flash events within switch-gear assemblies can lead to severe consequences, impacting both personnel safety and equipment integrity.

Temperature

The temperature generated by an arc flash can reach 7000 to 8000°C, and under extreme conditions, it may exceed 20000°C, approximately four times the surface temperature of the sun.

On humans, such intense heat can cause severe burns, ranging from first-degree to third-degree, even at a distance. On electrical systems, these temperatures can cause severe damage, including melting of conductors, deformation of components, and a high risk of fire, potentially leading to total equipment failure.

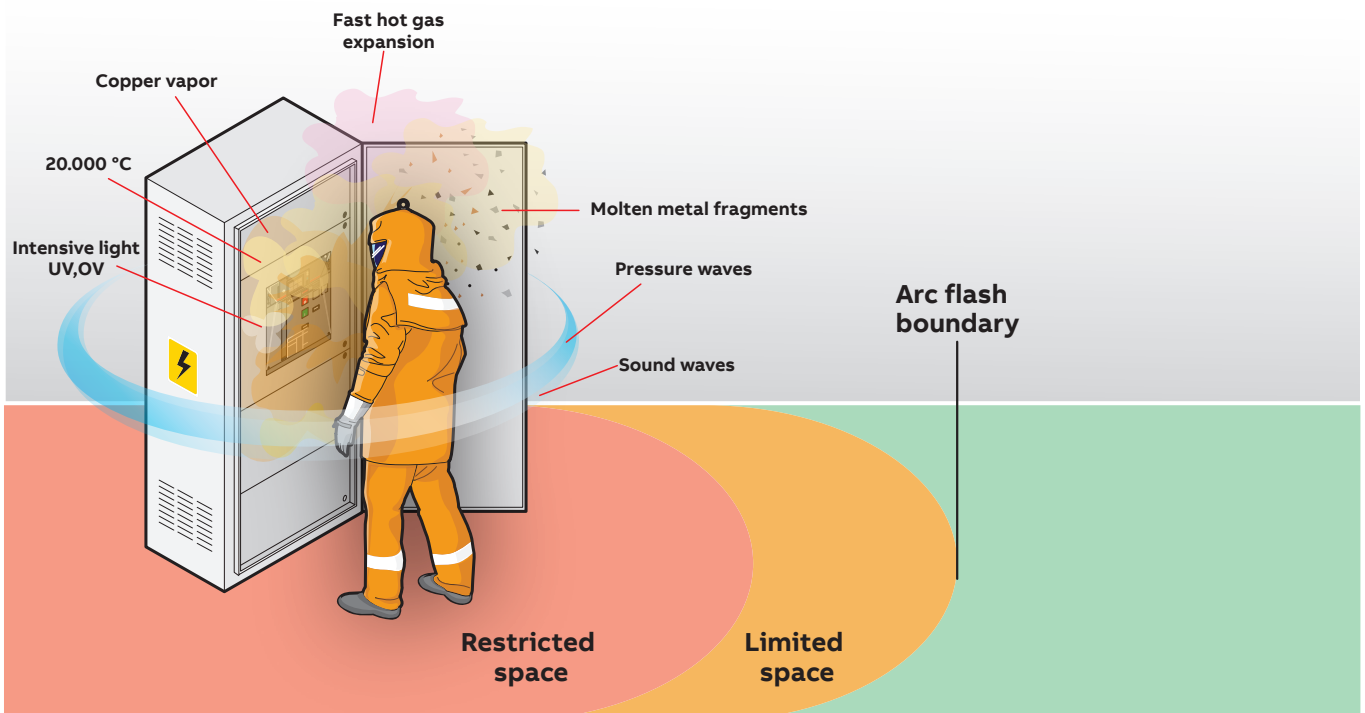
Pressure

An arc flash generates immense pressure, and a person may experience a force roughly equivalent to the weight of a car.

On humans, the direct effects of this pressure include blunt force trauma, eardrum rupture, and internal organ injuries. On electrical systems, the pressure can cause equipment damage, such as holes in structures or damage to equipment.

Sound

The force of the pressure wave from an arc flash is often accompanied by a loud shockwave. Sound levels generated by an arc flash can reach extraordinarily high levels, often reaching 160 dB, which is significantly higher than the sound of a shotgun blast (typically around 130 dB). This in-



3. Consequences and hazards

tense noise can cause immediate hearing loss, damage to the eardrum or significant auditory impairment.

Molten metal and shrapnel

Arc flashes can expel molten metal fragments, shrapnel, and hot gases from the electrical assembly, at speeds similar to a jet plane (700 MPH). On humans, these fragments are not only a threat to the eyes, where they can penetrate the cornea and cause permanent blindness, but act as true projectiles. They can pierce protective clothing, including arc-rated jackets, and inflict severe injuries comparable to gunshot wounds. On electrical systems, molten metal and shrapnel can damage components like cables and circuit breakers, leading to further failures.

Radiation

Arc flashes emit both ultraviolet (UV) and infrared (IR) radiation, which can cause serious harm. On humans, UV radiation can damage the cornea and retina, potentially leading to temporary or permanent vision loss, while IR radiation can cause thermal burns on exposed skin. On electrical systems, the intense heat associated with IR can contribute to the deterioration of nearby materials, such as insulation or plastic components.

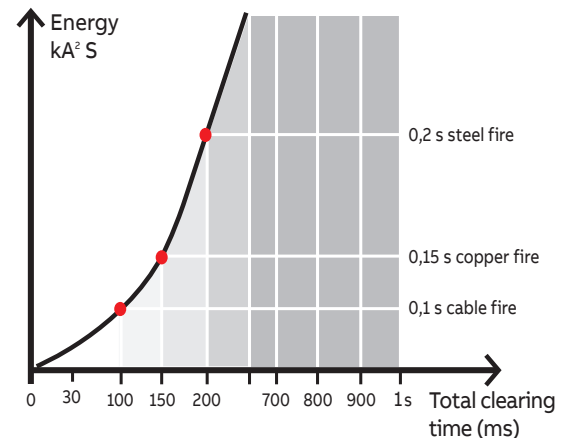
Toxic Gases

The gases produced by burnt insulating materials and molten or vaporized metals can be toxic. On humans, these fumes, produced by the incomplete combustion of insulating materials and the

vaporization of metals, can release toxic substances, such as carbon particles and other airborne solids. Inhalation of these gases can lead to respiratory issues, chemical burns, and long-term lung damage.

On electrical systems, while fumes do not directly damage components, the deposition of conductive or corrosive particles on surfaces can contribute to equipment degradation over time.

The Energy released by arc flash increases exponentially during the time. It is important to stop the as soon as possible in order to reduce negative consequences to both equipment and workers.



4. Standards and regulatory framework

Arc flash hazard primarily arises during electrical work and represents a significant safety concern for those working with or near energized electrical systems. Proper management of these risks is essential to prevent injuries and fatalities in the workplace.



Many countries have established regulatory frameworks, standards, and guidelines to encourage or mandate risk assessments and the implementation of appropriate control measures to reduce the risk of injury to electrical workers working around electrical hazards.

However, the approach to arc flash risk varies significantly across these frameworks. In some countries, national standards specifically address the evaluation and mitigation of arc flash risks, offering detailed guidance on how to assess and manage these hazards. In contrast, other standards provide more general safety guidelines that, even if they do not explicitly focus on arc flash, still contain principles applicable to arc flash risks. These broader recommendations emphasize the importance of protecting workers in and around electrical systems through hazard identification, risk assessment, and the implementation of effective risk control measures, such as proper equipment, work practices, and personal protective equipment (PPE).

Despite the variation in the level of detail regarding arc flash risks, the underlying goal remains the same: ensuring worker safety by identifying and mitigating potential risks associated with electrical systems.

1 European Standards: EN 50110-1

In Europe, the EN 50110-1 standard governs the operation of electrical installations and provides a framework for evaluating electrical hazards, including arc flash risks. Section B.6 of Annex B mandates an arc flash risk assessment whenever work is performed near an electrical installation or under energized conditions. The standard also outlines the use of personal protective equipment (PPE) to mitigate the effects of electric arcs. However, it emphasizes that no PPE can offer complete protection, reinforcing the need for

4. Standards and regulatory framework

comprehensive risk management to minimize or, in some cases, eliminate arc flash hazards. Even the use of arc-resistant switchgear does not fully eliminate arc flash risks. In fact, arc-resistant equipment can help control risk for certain tasks but not for others; therefore, it does not eliminate the need for an arc flash analysis or the consideration of additional risk controls, depending on the task. Even brief exposure to an arc flash can cause severe injuries, further highlighting the necessity of stringent safety measures.

While national regulations across Europe require arc flash risk evaluations, no single European standard provides a definitive methodology for assessment. As a result, many organizations rely on internationally recognized standards such as NFPA 70E, which are widely accepted as global benchmarks for arc flash risk assessment and mitigation.

2 The U.S. Regulatory Framework: OSHA and NFPA 70E

In the United States, the Occupational Safety and Health Administration (OSHA) is responsible for ensuring safe and healthy working conditions through workplace safety standards. OSHA's electrical safety regulations require employers to protect workers from electrical hazards, including arc flash incidents. To achieve compliance, OSHA references NFPA 70E, a standard that provides industry-recognized best practices for arc flash risk assessment, safe work procedures, and PPE requirements.

For an employer, adhering to NFPA 70E within the context of a qualified electrical safety program and an electrical maintenance plan (EMP, as defined in NFPA 70B), may help facilitate compliance with OSHA's electrical safety mandates. This standard offers detailed guidance on risk assessment,

hazard mitigation, and PPE selection, making it a crucial resource for organizations seeking to protect their workforce from arc flash-related injuries.

A key component of NFPA 70E is its arc flash risk assessment, as outlined in Article 130.5. This assessment is designed to:

- Identify arc flash hazards (if the electrical equipment is de-energized, for example, the hazard is not present).
- Estimate the likelihood and severity of potential injuries.
- Implement risk control measures based on the hierarchy of risk control, assessing whether additional protective measures, including personal protective equipment (PPE), are necessary.

To aid in this evaluation, Table 130.5(C) provides guidance on estimating the likelihood of an arc flash occurrence and identifying whether additional safety measures are necessary.

If the risk assessment determines that further mitigation is necessary, ABB recommends using the **Incident Energy Analysis Method** in accordance with NFPA 70E. This method is aimed to calculate the incident energy that defined as the amount of thermal energy (in cal/cm²) received at a specific distance from the arc source during an arc event. It can be calculated following IEEE 1584-2018 guide.

This analysis must be updated whenever changes are made to the electrical distribution system that could affect the results. Additionally, it must be reviewed at least every five years to ensure accuracy and compliance.

Personal Protective Equipment (PPE)

To effectively mitigate arc flash risks, the primary objective is to reduce both the likelihood of occurrence and the severity of potential injuries. This is achieved through the application of the hierarchy of controls, prioritizing hazard elimination, engineering controls, and administrative measures. However, when residual risk remains, the final layer of defense is the correct use of Personal Protective Equipment (PPE). PPE is specifically designed to protect workers from thermal hazards. It can include arc-rated clothing (shirts, pants, coveralls), insulated gloves and tools, face shields or arc flash suits with balaclavas, safety glasses or goggles, hearing protection. The appropriate level of PPE must be selected based on the calculated incident energy, following the Incident Energy Analysis Method defined in NFPA 70E. This method uses data such as available fault current, system voltage, and protective device clearing time to estimate the potential thermal energy released during an arc flash. NFPA 70E Table 130.5(G) provides guidance for PPE selection:

- for incident energy levels from 1.2 cal/cm² up to and including 12 cal/cm²
- for levels greater than 12 cal/cm²

PPE must meet or exceed the calculated incident energy. Once PPE has been selected, its use is mandatory whenever a worker must cross the Arc Flash Boundary (AFB).

The Arc Flash Boundary (AFB) is the distance from an arc source at which the incident energy equals 1.2 cal/cm², the threshold for a second-degree burn without PPE. Anyone crossing this boundary must wear appropriate arc-rated PPE. The AFB is determined through an arc flash risk assessment.

Arc flash equipment labels

Upon completion of the arc flash study, companies must affix warning labels to all electrical equipment that presents an arc flash risk. According to NFPA 70E, Section 130.5(H), electrical equipment (e.g., switchboards, panelboards, industrial control panels, and motor control centers) that may require energized access must be labeled with:

- the nominal system voltage,
- the arc flash boundary, and
- information to select the appropriate PPE.

ABB suggests to include the available incident energy and the corresponding working distance.

An example of a label is shown in the picture.

1 – Arc Flash Header

2 – Arc Flash Boundary

3 – Working Distance

Defined by IEEE 1584 as the distance from the potential arc point to a worker head and torso.

Incident energy increases significantly as this distance decreases, making it a critical safety factor.

4 – Personal Protective Equipment (PPE)

5 – Nominal System Voltage

Displays the system voltage (e.g., V, VAC, or VDC), helping assess shock hazard levels.

6 – Location and/or Device

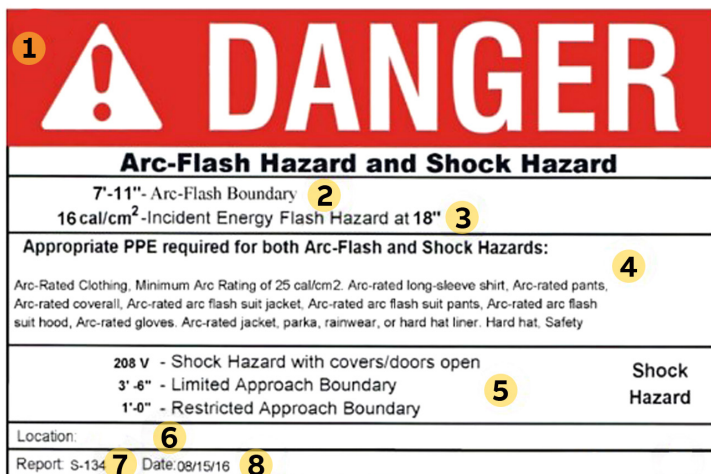
Specifies the exact location or identifier of the equipment to which the label applies.

7 – Arc Flash Study Report #

References the report from which the label’s data was derived. Useful for traceability and verification.

8 – Date

Indicates when the arc flash risk assessment was conducted. This helps ensure compliance with the five-year review rule or updates following any system changes.



4. Standards and regulatory framework

3. Canadian standards: CSA Z462 – Workplace Electrical Safety

CSA Z462: Workplace Electrical Safety is the foundational standard for managing electrical hazards in Canada. It is modeled closely on NFPA 70E but adapted to reflect Canadian regulations, such as those enforced by provincial Occupational Health and Safety (OHS) laws.

CSA Z462 defines the minimum requirements for identifying arc flash and shock hazards, conducting risk assessments, and applying protective boundaries. It emphasizes that employers must implement an Electrical Safety Program (ESP) that includes documented procedures, proper training, and the use of personal protective equipment (PPE).

4. INTERNATIONAL FRAMEWORK: IEEE 1584-2018 and IEC 60947-9-2:2021

4.1 IEEE 1584-2018

The IEEE 1584-2018 guide, developed by the Institute of Electrical and Electronics Engineers (IEEE), is often used in conjunction with NFPA 70E. It provides a precise methodology for calculating arc flash incident energy and the arc flash boundary. Like NFPA 70E, IEEE 1584 defines the arc flash boundary (AFB) as the safe distance

from the arc flash source where the incident energy drops to 1.2 cal/cm^2 , the threshold below which the risk of severe injury is significantly reduced.

By utilizing the accurate formulas provided in IEEE 1584, organizations can achieve a higher level of precision in determining the necessary safety measures against arc flash hazards.

4.2 IEC 60947-9-2:2021

It specifies the requirements for active arc-fault mitigation devices (AFMDs) intended to detect and mitigate the effects of arc faults in low-voltage switchgear and controlgear assemblies. These devices must be capable of detecting the arc within a very short time (typically a few milliseconds) and initiating an appropriate action, such as tripping a circuit breaker, to limit the duration and energy of the arc. The standard defines performance criteria, testing methods, interface requirements, and safety considerations for both detection and mitigation components, whether they are separate or combined.

Emax 3 with Ekip Arc-Flash 6F modules and arc flash detectors complies with IEC 60947-9-2:2021 as a combined Internal Arc Classification Device (IACD). It integrates high-speed arc detection and interruption functionalities into a single unit, offering fast and reliable protection against arc faults.

5. Arc Flash risk assessment and mitigation strategies

An arc flash risk assessment is a systematic process used to identify arc flash hazards within an electrical system and to determine appropriate mitigation measures in order to **reduce the likelihood and the severity of its consequences**.

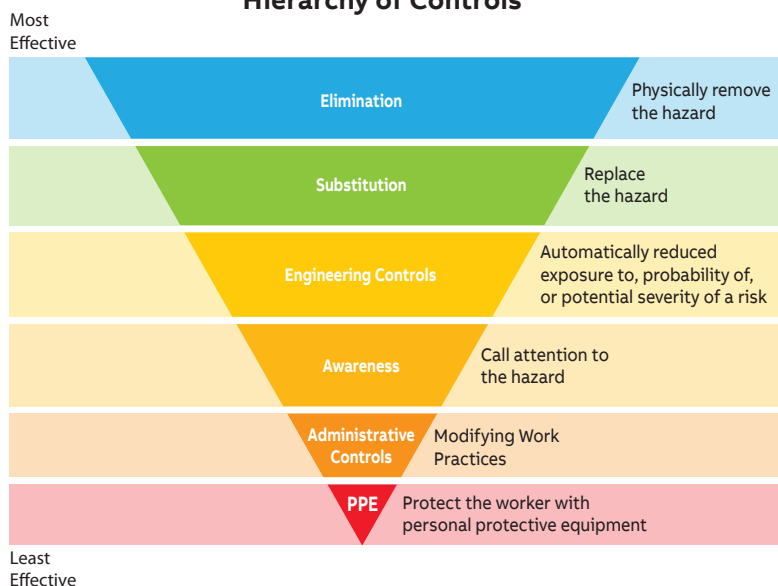
The arc flash risk assessment process can be structured into four key phases: Predict, Prevent, Process, and Protect.

1. **Predict** involves calculating the incident energy at a specific working distance from a potential arc source to determine the severity of an arc flash and its thermal impact. The IEEE 1584-2018 guide is the most widely recognized for performing these calculations.
2. **Prevent** refers to the application of the hierarchy of risk control measures, focusing on elimination, substitution and engineering controls.
3. **Process** pertains to the implementation of administrative controls such as safe work procedures, policies, and practices.
4. **Protect** represents the final level in the hierarchy of risk control. It addresses any residual risk by providing personal protective equipment (PPE) as the last line of defense, once all other mitigation strategies have been implemented.

The intent of defining and following a hierarchy of risk control measures is to determine the most effective preventive or protective actions for minimizing the risk associated with an arc flash hazard. Each successive method in the hierarchy is considered to be less effective than the one preceding it.

In practice, a combination of control methods is often necessary to provide adequate protection for workers.

Hierarchy of Controls



1. Elimination – Physically remove the hazard

Elimination is the most effective method of risk control and it is applied during the conceptual design phase, where the high-level decisions such as energy sources are made.

Arc flash hazards can be eliminated by ensuring personnel are never exposed to energized conductors. This can be achieved by physically separating workers from energized components, or through the use of additional barriers and compartmentalization within equipment. To be considered elimination, the measure must be both permanent and comprehensive. Temporary measures, such as turning off equipment or relying on administrative procedures, do not constitute elimination.

These solutions primarily reduce the likelihood of occurrence, as they eliminate or significantly limit exposure to the hazard. However, in many cases, complete elimination is not practical due to operational constraints.

2. Substitution – Replace the hazard

Substitution involves replacing the original hazard with one that is less severe or more easily controlled. For example, reducing energy by replacing 120 V control circuitry with 24 V AC or DC control circuitry.

3. Engineering Controls - Automatically reduced exposure to, probability of, or potential severity of a risk.

Engineered controls when applied and used properly are designed to reduce exposure to hazards, lower the likelihood of an incident, and/or mitigate the potential severity of its consequences. These controls are typically integrated during the detail design phase, where detailed decisions are made, such as what type of equipment to specify, how to distribute power from source to application point. To be considered engineered controls, the measure must operate automatically or passively, without requiring worker intervention during routine tasks. Some examples include the use of arc-resistant switchgear, the use of remote operation solutions, reducing the energy released in an arc flash by limiting the available fault current or by minimizing arc duration.:

3a) the use of **arc-resistant switchgear** reduces the severity of arc flash consequences on personnel. In the event of an internal arcing fault, the design of arc-resistant equipment redirects arc energy away from the worker, providing a physical barrier against thermal and pressure effects. It not only contains an arc that may occur inside the switchgear, but also ensures that the worker does not have their hands inside it, thus reducing the likelihood of

5. Arc Flash risk assessment and mitigation strategies

initiating the incident.

However, this protection is inherently limited to situations in which all enclosure doors remain closed. During maintenance or inspection activities that require access to the interior, personnel are exposed to potential hazards. Furthermore, although arc-resistant switchgear protects personnel outside the enclosure, internal components may still experience significant thermal and mechanical stress, since the energy is not rapidly interrupted. This can result in prolonged downtime, complex repairs, and increased replacement costs, especially if critical functional assemblies are affected. Therefore, arc-resistant switchgear is a passive solution that should be considered a valuable layer within a broader protection strategy, rather than a standalone solution.

ABB provides a range of solutions compliant with established standards, such as IEC/TR 61641 in Europe and IEEE C37.20.7 in the United States.

- 3b) the use of **remote operation** solutions allows specific tasks to be performed from a safe distance, significantly reducing personnel exposure to arc flash hazards and lowering the likelihood of accidental contact or dropped tools that can consequently create an arc flash.

Emax 3 supports the use of remote operation solutions with:

- **Remote Opening/Closing:** the Remote Control digital upgrade enables users to

open or close the circuit breaker from a remote location via the EPiC mobile app.

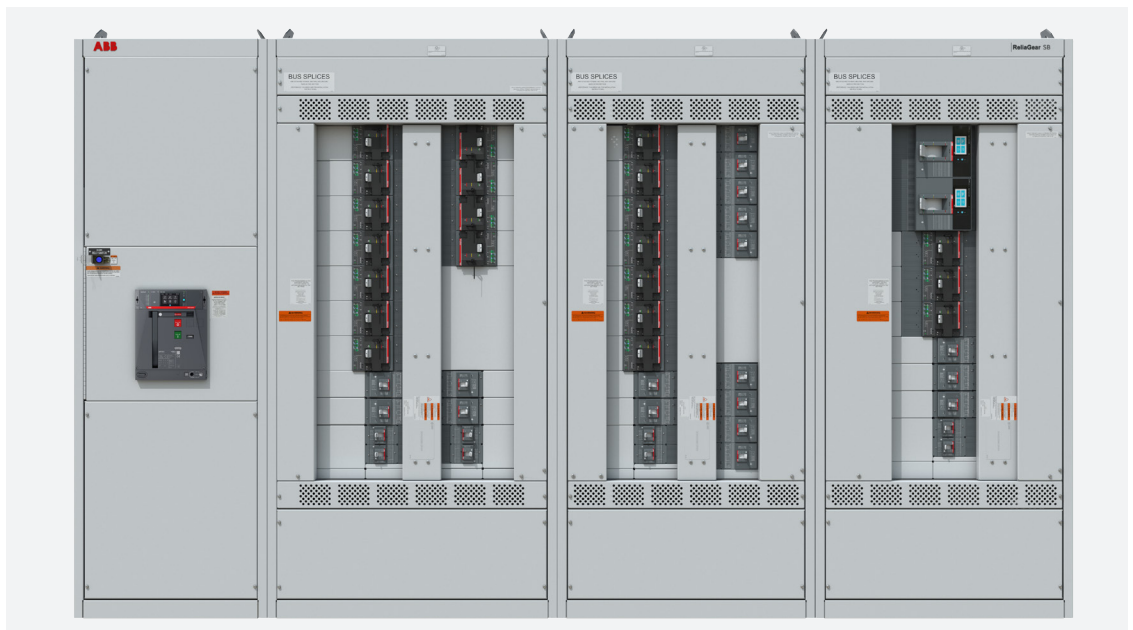
- **Communication Modules:** they enable seamless integration with supervisory systems, supporting remote control and monitoring of the circuit breaker parameters.
- **Sense Coils (YO-S, YC-S, YU-S):** they provide the same actuation functionality as standard coils (YO, YC, YU), while also enabling real-time status monitoring. They track parameters such as the number of operations, winding continuity, supplied voltage, and overall health index, and deliver status feedback to Ekip Aware trip unit. They support remote actuation via multiple communication protocols and enable Condition-Based Maintenance (CBM) and Reliability-Centered Maintenance (RCM).

- 3c) Reducing the energy released in an arc flash **by limiting the available fault current**, for example:

- Employing High Resistance Grounding (HRG) for three-phase systems
- Using current-limiting devices

These active solutions do not affect the likelihood of an arc flash occurring, but they reduce the severity by limiting the available energy.

- 3d) Reducing the energy released in an arc flash **by minimizing arc duration**. These active solutions do not affect the likelihood of an arc flash occurring, but they reduce the severity by limiting the available energy.



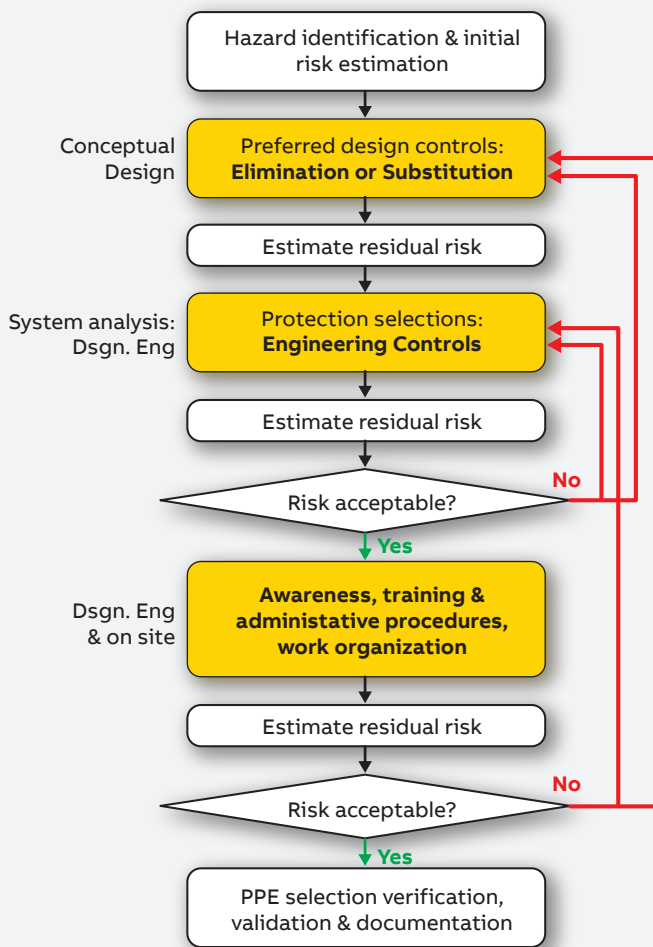
Emax 3 supports energy reduction with:

- **Zone Selective Interlocking (ZSI)** enhances protection by allowing downstream circuit breakers to signal upstream circuit breakers during a fault. This signal prompts the upstream breaker to delay tripping, giving the nearest circuit breaker a chance to clear the fault first. If the downstream circuit breaker does not respond, the upstream device trips immediately, bypassing delay settings. ZSI helps reduce arc flash energy by limiting the total clearing time when coordination is possible. However, it may introduce a brief delay (typically 2–3 cycles) if the primary breaker fails to operate, allowing the arc to persist slightly longer.
- **External arc flash relays** use optical sensors to detect the intense light emitted during an arc flash event. ABB offers solutions such as the TVOC-2 relay, which is SIL-2 certified. The TVOC-2 can initiate the tripping command via

the opening release (YO) or activate digital inputs through interface devices like Ekip Signalling 4k or Ekip Signalling 2k. These systems can achieve total clearing times in the range of 50–70 milliseconds, faster than conventional protection methods. This rapid response substantially reduces arc energy, enhancing safety for both personnel and equipment.

However, some installations may encounter limitations due to the relay’s fixed logic or configuration constraints. Additionally, external relays (e.g., CSU-2) or complementary solutions are required to implement dual-condition logic, based on both light and current detection, ensuring reliable arc flash discrimination.

- **Emax 3 integrated arc flash** solution enables faster total clearing times and reduces the energy released compared to systems based on external arc flash relays. This integrated approach also minimizes space requirements and offers greater flexibility in logic configuration, thereby enhancing overall protection performance and adaptability to complex system architectures. The dual-condition logic, combining arc flash light detection with current measurement, is implemented using the circuit breaker’s integrated current sensors, without the need for external devices.



Design process incorporating the Hierarchy of Risk Controls. Source: Leveraging Prevention Through Design Principles (PtD) in Electrical Installations, H. Landis Floyd II and Marcelo E. Valdes, 2021

4. Awareness - Call attention to the hazard

Awareness focuses on alerting personnel to the presence of electrical hazards through signs and labels, lights, barriers and barricades and alerting personnel. While this control method does not eliminate the hazard, it supports safe behavior by improving the visibility and understanding of risks in the work environment.

Examples include:

- Arc flash warning labels on equipment
- Visual and audible hazard indicators
- Digital tools that deliver real-time hazard information. Accessing trip unit settings and event data through a computer or mobile device rather than scrolling through a circuit breaker HMI makes safety information more accessible and actionable. Ekip Connect 3 or EPiC mobile app improve both the visibility of risk and the likelihood that personnel will respond appropriately.

It is important to note that the effectiveness of awareness controls is closely tied to administrative measures, such as consistent training, and the maintenance of warning systems to ensure legibility, visibility, and comprehension. These controls are inherently vulnerable to human error in interpretation and response

5. Arc Flash risk assessment and mitigation strategies

5. Administrative Controls – Modifying Work Practices

Administrative controls include safe work practices, standard operating procedures, maintenance programs, personnel selection, training, work scheduling, permitting systems, audits, and management of change. These controls focus on influencing human behavior to minimize risk. Examples are:

- Lockout-Tagout (LOTO) procedures.
- Energy Reducing Maintenance Switch (ERMS / ABB RELT Protection)
- Remote Racking Devices (RRD)

Well-designed equipment can further support these measures by making them easier to implement, more reliable, and less prone to human error. For instance, embedding IR windows changes how personnel perform infrared surveys, while the use of continuous thermal sensors can eliminate the need for IR surveys altogether.

The effectiveness of administrative controls is highly dependent on human performance and operational discipline of supervision and support personnel throughout the organization.

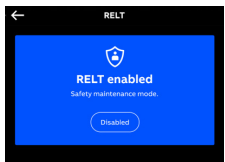


Emax 3 solutions include:

- **Remote Racking Devices:** Emax 3 offers two solutions for performing circuit breaker rack-in/rack-out operations remotely, reducing the need for personnel to be positioned in front of the switchgear and thereby enhancing safety:
 - Classical solution (RRD): an external motor can be installed when needed. This solution is available for E1.3, E2.3, E4.3, and E6.3 models.
 - Embedded solution (RRD-E): a motor permanently installed inside the circuit breaker. This option is available for E4.3 and E6.3 models, and operation can be controlled via the EPiC mobile app or through an external controller.
- **Energy Reducing Maintenance Switch (ERMS / ABB RELT Protection)**

This solution allows a worker to set a faster instantaneous trip while working within the arc flash boundary and then return the trip unit to a normal setting after the potentially hazardous work is completed. Emax 3 solution consists of Reduced Energy Let Through (RELT) mode that complies with NEC standard 240.87. The RELT function can be activated in multiple ways:

- **Ekip RELT Module + External Input Signal** (e.g., remote switch): this allows activation of the RELT mode from a remote location, even outside the arc flash boundary, before personnel enter the hazardous area. A local status indicator confirms whether RELT mode is active.
- **Trip Unit HMI:** RELT mode can be enabled directly on the circuit breaker's HMI, pro-



viding a local and manual control option without the need for additional modules.

- **EPiC Mobile App** (only if Ekip RELT module is installed): this setup enables remote activation via smartphone, useful when approaching the equipment. The wireless communication offers safe and convenient access to enable RELT mode from a distance.
- **Communication Module:** if a communication module is installed, the RELT mode can be activated remotely via supervisory control systems, such as a SCADA.

When the RELT protection is enabled, the local status indicator and/or the blue-highlighted HMI interface inform the worker that the RELT protection is engaged. Once the indicator is no longer blue, it confirms that the protection has returned to normal operating conditions after the maintenance work is completed. Additionally, a delay-off (timing) function can be configured, allowing the RELT mode to remain active for a predefined period after deactivation is requested. This provides the worker with sufficient time to safely exit the arc flash boundary before the circuit breaker returns to its standard protection settings.

The primary advantage of this system lies in its ability to significantly reduce the energy during an arc flash event, allowing total clearing time and thereby enhancing worker safety during maintenance activities. However, the RELT function is specifically designed for maintenance phases and does not offer enhanced protection during normal operation, where trip settings revert to standard parameters that may allow higher energy faults. This limitation means that if RELT is not enabled the risk from arc flash energy remains significant. Additionally, the reliance on manual activation and deactivation introduces the potential for human error, such as forgetting to enable RELT mode before work or failing to revert to normal settings afterward, which could compromise protection coordination or cause unnecessary trips.

6. Personal protective equipment - Last line of defense to protect the worker

PPE mitigates residual risks when other controls cannot eliminate hazards. PPE must be appropriate for the incident energy level and used in conjunction with other protective measures. While essential, PPE is the least effective control measure because it relies on consistent human compliance.

6. Emax 3 integrated arc flash solution

The Emax 3 circuit breaker integrates active arc flash protection without the need for an external relay, maximizing safety, reliability, and simplicity. This integrated solution works with only two additional components in conjunction with the Emax 3 circuit breaker:

- 1- arc detectors
- 2- Ekip Arc-Flash 6F module

Arc detectors

Two types of arc detector are available based on specific application requirements:

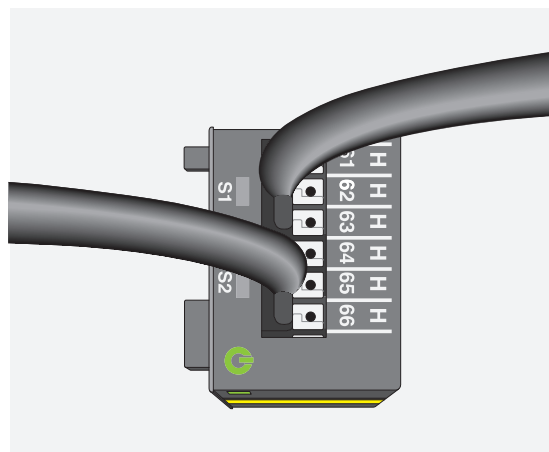
- **Light-Sense Detectors** are point detectors that are triggered when sufficient intensity of arc light (above 8000 Lux) is detected.
- **Light & Pressure-Sense Detectors** are point detectors that are triggered when both arc light (above 8000 Lux) and pressure (0.2 bar above ambient pressure) are detected simultaneously. This dual-condition logic helps to reduce false trips by confirming that the detected light originates from an arc flash event. If only the light or only the pressure exceeds its respective threshold, the detector does not trigger and does not send a signal to the trip unit.

Both types of detectors:

- do not require calibration
- can reliably detect arc flash light occurring within a maximum distance of 1.5 meters. However, depending on the switchgear configuration and the presence of reflective metallic surfaces, the arc flash light may be detected at greater distances due to light reflection.

Ekip Arc-Flash 6F module

The dedicated cartridge module serves as the connection point between the arc detectors and



the Emax 3, eliminating the need for external relays.

- Each module has two inputs called channel S1 and S2.
- Each channel can accommodate up to three detectors in series (which can be mixed between the two types).
- Up to two modules (Ekip Arc-Flash 6F-1 and Ekip Arc-Flash 6F-2) can be installed in the cartridge area
- Auxiliary supply is needed (Ekip Supply Lite or Ekip Supply Evo Modbus TCP)
- Each Emax 3 can manage a total of 12 detectors.
- Continuous monitoring for each channel check if at least one detector or cable for each channel is broken. Alarms can be sent to the supervision system.
- Commercial 3-conductor shielded cables (Belden 8772 or similar) can be used to connect the module with detectors.
- The maximum length between the module and the last detectors is 100m. The appropriate length can be chosen directly in the field based on the installation requirements, eliminating the need to choose pre-configured length in advance.

Protection function

When triggered, the detector sends a signal to channel of the module to which it is connected. To enable an Emax 3 trip, a protection function must be enabled and assigned to each channel.

- Two different protection functions are available (AF1 and AF2), which can be used to adapt to different working conditions.
- Protection functions are automatically visible in Ekip Connect or EPiC when at least one Ekip Arc-Flash 6F is installed. No additional digital upgrade is required
- An optional current check can be enabled for each protection function:
 - The current measured by internal Rogowski coils is compared with a configurable threshold
 - This adds an additional condition for tripping

Logics between different circuit breakers

In a system with multiple circuit breakers, each Emax 3 can have dedicated arc flash modules and

6. Emax 3 integrated arc flash solution

detectors to protect its own zone, ensuring plant selectivity without the need for an external relay to manage this selectivity.

In addition, by utilizing Com Link or Ekip Signaling modules, it can send signals to trip other circuit breakers (even those different from Emax 3) based on where the arc flash has occurred, thus enabling selectivity for the application. In this way, the Emax 3 incorporates and enhances the functionalities of an external relay, allowing for the transmission of signals to different circuit breakers to ensure selectivity.

BENEFITS

Enhanced Safety

The integrated Emax 3 solution represents a significant safety advancement in arc flash protection. Thanks to its fast total clearing time, arc flash faults can be cleared in less than 40 ms using light sensing, significantly reducing the risk of electrical hazards. This rapid response minimizes incident energy during an arc fault, potentially allowing for a lower PPE category based on arc flash risk assessment, while also helping to protect equipment from the damaging effects of such events.

Improved Reliability

Integrated watchdog functionality ensures that detectors and cables are continuously monitored, supporting a high level of reliability for the electrical system.

Reduced Downtime

Thanks to the advanced integrated solution, arc flash incidents are swiftly identified, minimizing incident energy and its impact on the electrical system compared to external relay solutions. This results in shorter downtime and reduced costs due to fewer damages, allowing for a quicker return to standard operations.

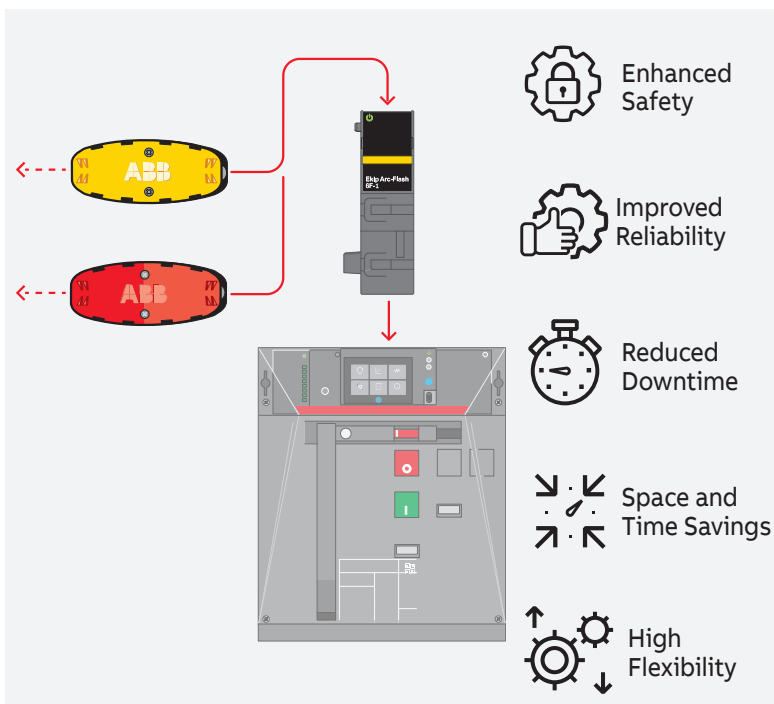
Space and Time Savings

Installing the Ekip Arc-Flash 6F module in the cartridge area and connecting the detectors is quick and straightforward, eliminating the need for external relays and resulting in significant space savings. The dual-condition logic, combining arc flash light detection with current measurement, does not require any additional devices, which leads to fewer wires and connections, thereby reducing installation time and the potential for errors.

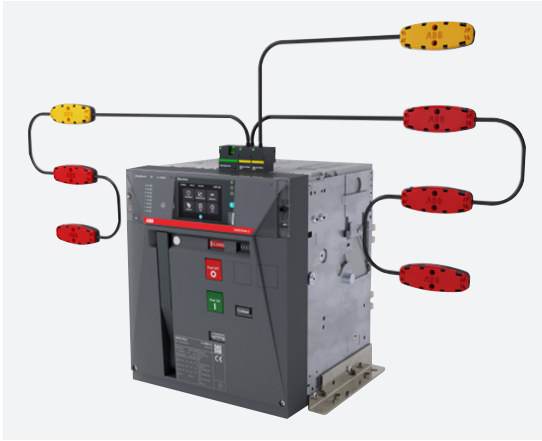
Protection and logics configuration can be completed in just a few minutes using the Ekip Connect or EPiC app.

High Flexibility

The system easily adapts to many plant configuration or tripping scheme. Each Emax 3 can be equipped with its own dedicated arc flash module and detectors to independently protect a specific zone. Alternatively, all detectors can be connected to a single Emax 3, which functions as a central processing unit. Based on the fault location, it sends trip commands to the appropriate circuit breakers. This architecture supports customized protection schemes tailored to installation requirements and system complexity.



7. Set up via Ekip Connect



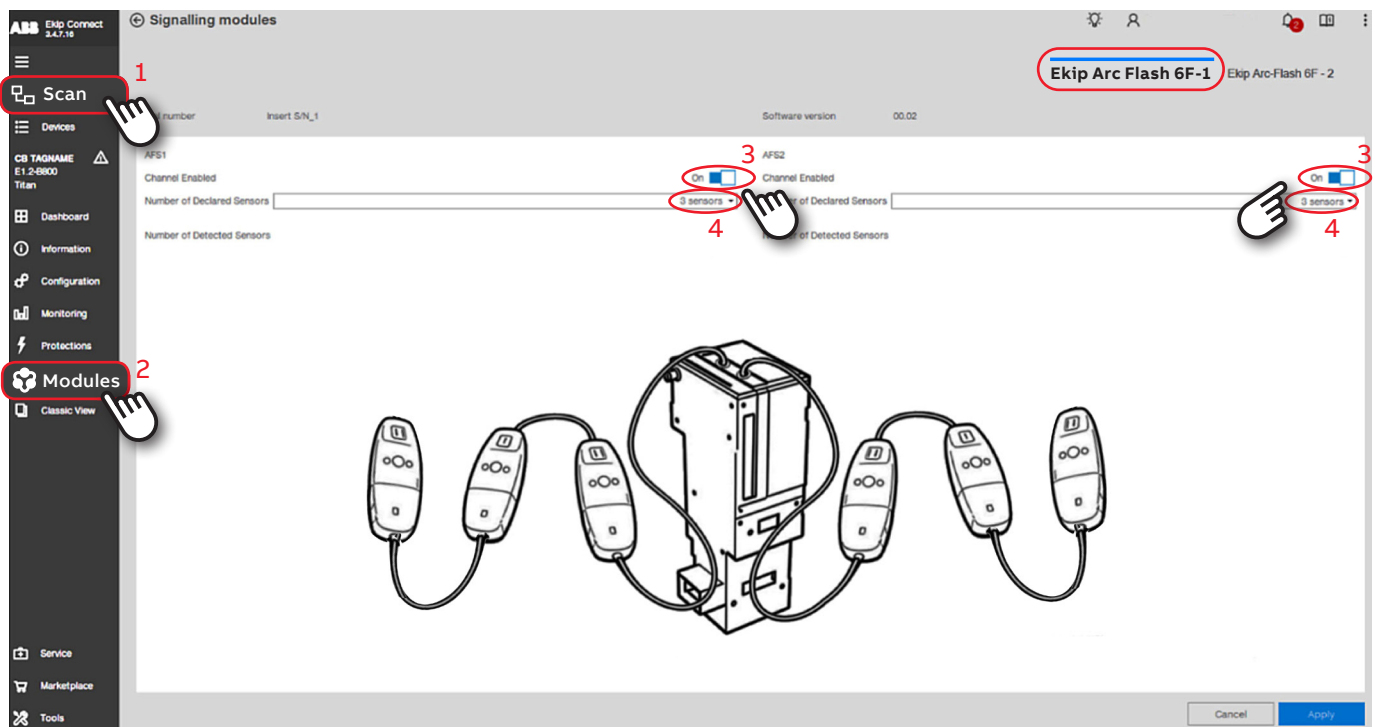
This section outlines the steps required to enable arc flash protection.

Let's suppose to have an Emax 3 with:

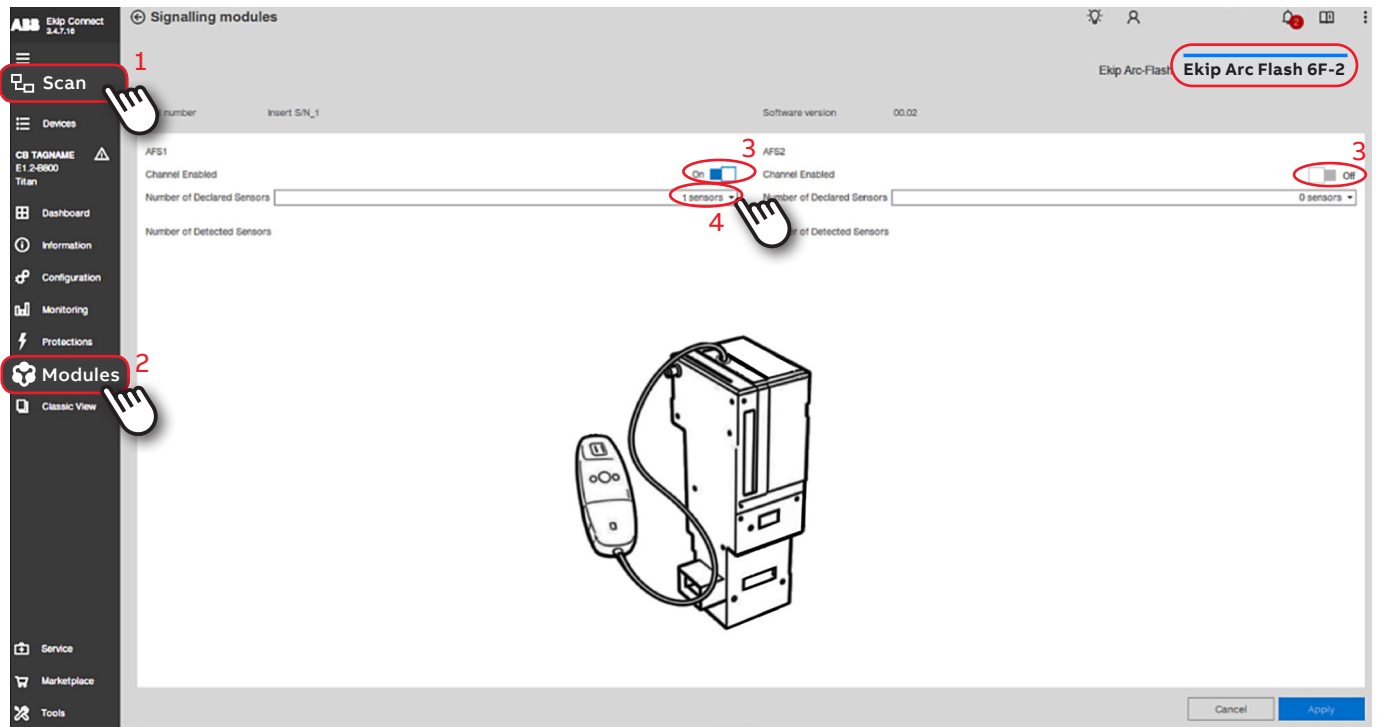
- Two Arc-Flash modules
- 1st and 2nd channel of the 1st module has 3 detectors in series
- 1st channel of the 2nd module has only 1 detector
- 1st channels of the 1st and 2nd module don't need the dual-condition logic (light + current)
- 2nd channel of the 1st module needs the dual-condition logic (light + current)

Module configuration

1. Connect Emax 3 device to laptop via USB-C cable.
2. Click on Modules, then select Signalling and choose Arc Flash.
3. For the installed modules, the channels to which detectors are connected must be enabled.
4. Set the number of installed detectors. If the number of installed detectors differs from the number detected by Ekip Aware, a warning will appear at the bottom of the screen. This indicates that the correct number of detectors has not been entered, or that there may be issues with the cables or detectors.



7. Set up via Ekip Connect



Protection functions configuration

1. Click on Protections, then select Arc Flash . Two independent protection functions are available (AF1 and AF2).
2. Enable the protection function switching it to On
3. Signal/Alarm signal: this option allows to either trip Emax 3 or to generate only an alarm when the detectors are triggered. If the current check is enabled, both the triggering of the detectors and current exceeding the set threshold must be satisfied simultaneously in order to trip or generate an alarm
4. Current Check: if enabled, this option adds an additional condition by comparing current measured by internal Rogowski coils with a settable threshold
5. Each protection setting can be configured for each channel of each module.

ABB Ekip Connect 3.4.7.16

Arc Flash Protection 1

Protection behaviour: Alarm signal (3) | Trip

Current Check

Current Threshold: 0.30 In (600 A) | 2.00 In (4000) | 10.00 In (20 kA)

Select channels that trigger Arc Flash protection

Triggered By:

- S1 Channel: On (5)
- S2 Channel: Off
- S3 Channel: On (5)
- S4 Channel: Off

On (2) | Off (4)

ABB Ekip Connect 3.4.7.16

Arc Flash Protection 2

Protection behaviour: Alarm signal (3) | Trip

Current Check

Current Threshold: 0.30 In (600 A) | 2.00 In (4000) | 10.00 In (20 kA)

Select channels that trigger Arc Flash protection

Triggered By:

- S1 Channel: Off
- S2 Channel: On (5)
- S3 Channel: Off
- S4 Channel: Off

On (2) | Off (4)

8. Arc detector installation

Commissioning arc flash protection in low-voltage switchgear requires particular attention to ensure both the reliable detection of arc faults and the minimization of false trips.

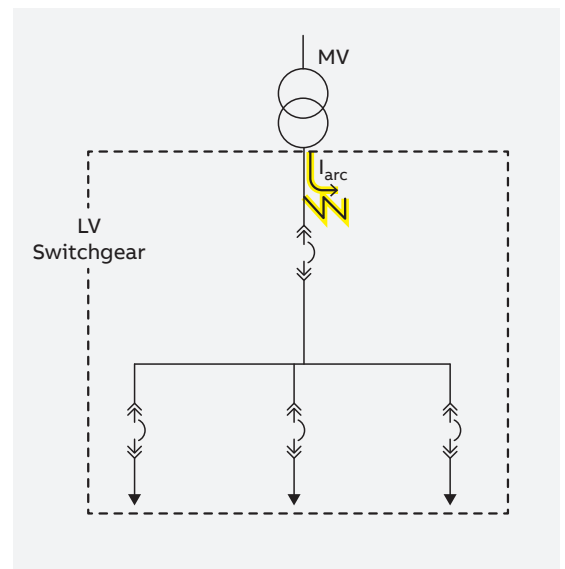
Since switchgear configurations can vary significantly, general guidelines can be provided.

Practical Tips

- **Group detectors by zone:** detectors that must trigger the same action (e.g., tripping the same circuit breaker or sending the same trip signal) can be connected to the same channel (S1, S2, S3, or S4) and/or associated with the same protection function (AF1 or AF2).
- **Orient detectors toward high-risk locations:** focus on areas with a higher likelihood of arc faults, such as busbar joints and mechanical connection points, where both electrical and mechanical stresses tend to concentrate.
- **Consider physical obstructions:** while metallic surfaces inside the switchgear reflect arc light and aid its propagation, physical barriers (e.g., partitions, dividers, or internal components) may limit visibility. In such cases, consider installing additional detectors facing different directions to ensure comprehensive coverage and increase system reliability.
- **Choose accessible, clean locations:** select detector locations that minimize the accumulation of dust or foreign debris and allow for easy inspection and maintenance.
- **Ensure compliance with creepage and clearance standards:** avoid placing detectors directly on live or energized components. Even if detectors and cables are fully insulated and have no exposed live parts, their placement and routing must still comply with industry standards for over-surface (creepage) and through-air (clearance) distances. These requirements are essential to maintaining electrical safety and reducing the risk of surface

discharges or arcing, especially in the presence of dust, humidity, or high voltage gradients.

- **Minimize false trips by using multiple detection criteria:**
 - **Light + Current Detection:** combine optical light detection with current sensing in the protection function. The dual-condition logic helps distinguish real arc faults from non-hazardous light sources, such as camera flashes or handheld tools used during maintenance.
 - **Light + Pressure Detection:** this combination is especially effective when the current condition alone cannot confirm a fault such as in main cable compartments. For example, when monitoring joints between incoming cables and busbars, the fault current might not pass through the downstream circuit breaker and therefore might not be detected by its Rogowski coil. In these cases, using both light and pressure sensors ensures that arc faults are reliably identified, even without measurable current.



Example installation scenarios

The following configurations illustrate common use cases for proper arc detector installation:

1. Single incomer
2. Dual incomers with Tie Breaker (Main-Tie-Main configuration)

Two operating modes can be considered:

- **With selectivity:** only the breakers related to the affected zone are opened. This mode requires proper switchgear design and effective compartmental segregation to work correctly.
- **Without selectivity:** each arc flash event causes all circuit breakers to trip. In this case, internal segregation between compartments is not necessary for arc flash selectivity.

Although similar protection objectives can often be achieved through a variety of approaches, the following examples are provided purely for illustration purposes.

Each installation must be individually assessed based on its specific requirements (such as selectivity) in order to adopt the most appropriate solution.

In the following drawings, each red block represents a light-segregated zone, meaning no light can pass from one zone to another.

1. Single incomer

• **Selectivity**

Referring to the following diagram, when there is an arc incident in the feeder circuit breaker compartments (BC2, BC3, and BC4), the dedicated feeder circuit breaker should trip. Since the arc fault can occur either upstream or downstream of the circuit breaker and it is not possible to distinguish the exact location, maximum safety must be ensured by tripping both the dedicated feeder circuit breaker (CB2, CB3 or CB4) and the main circuit breaker (CB1). As an alternative, two detectors can be installed in the same compartment and connected to two separate channels. The first detector, connected to the first channel, operates without requiring current verification (no dual-condition logic), while the second detector,

connected to the second channel, does require current verification. This setup allows the system to distinguish whether the fault occurred upstream or downstream of the feeder circuit breaker, enabling selective tripping (first of the feeder circuit breaker, and if necessary, also of the main circuit breaker).

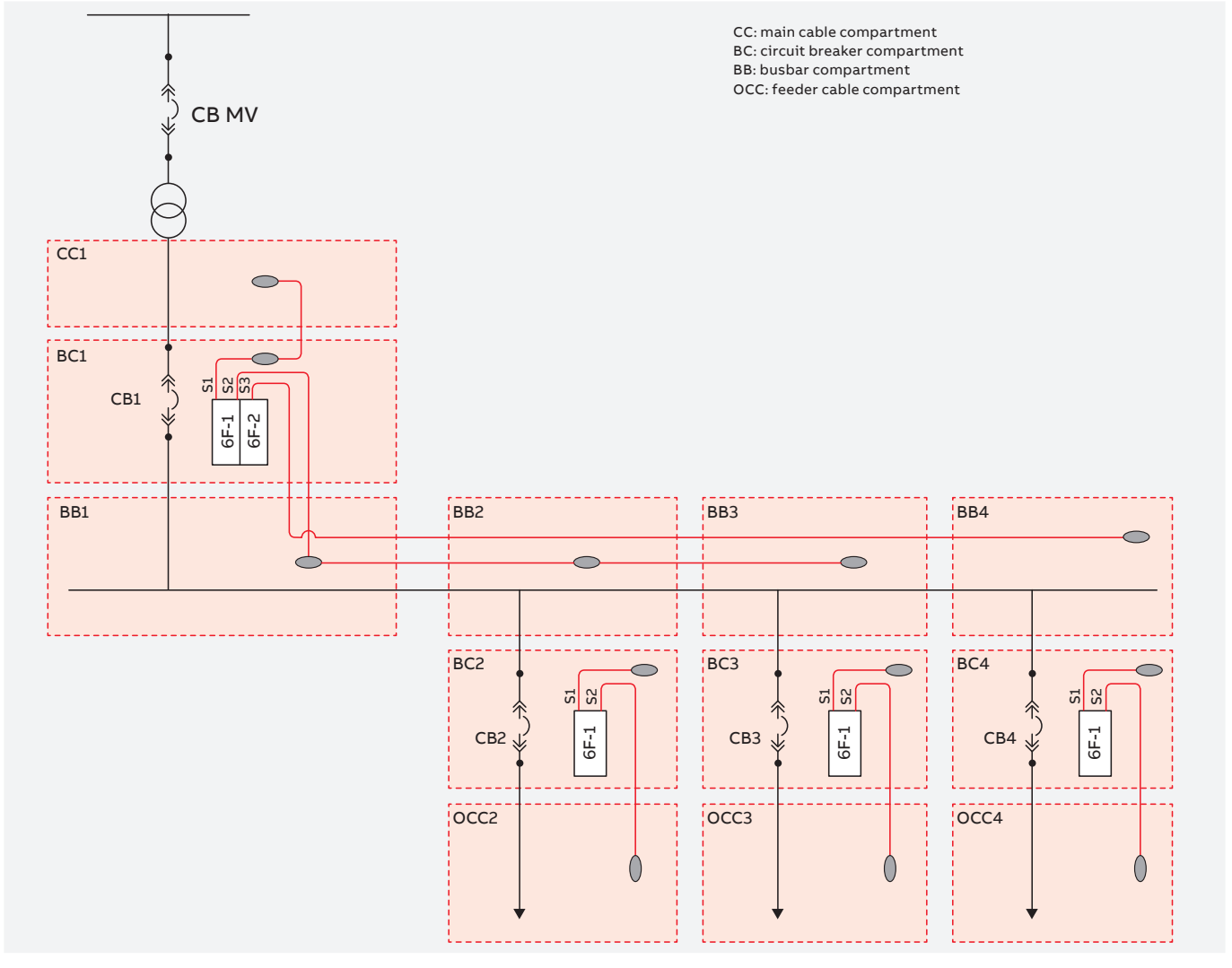
When there is an arc flash inside the feeder cable compartments ((OCC2, OCC3 and OCC4), only the dedicated feeder circuit breaker should trip.

When there is an arc flash inside the main circuit breaker compartment (BC1), the main cable compartment (CC1), or the busbar compartments (BB1, BB2, BB3, BB4), CB1 should trip. To ensure safety, an additional trip signal can be sent digitally or via communication modules to the medium-voltage circuit breaker (CB MV).

Single incomer - selective solution

	Ekip Supply	Ekip Arc Flash 6F-1	Ekip Arc Flash 6F-2
CB1	1	1	1
CB2	1	1	/
CB3	1	1	/
CB3	1	1	/
Total	4	4	1

8. Arc detector installation



	Channel	Number of arc detectors in series	Trip criteria			Protection	Zone protected	Trip	
			Current I >	Light L >	Pressure P >				
CB1	Ekip Arc Flash 6F-1	S1	2	X	✓	optional for dual-condition	AF1	CC1 BC1	CB MV1 (via digital signal or communication protocol)
		S2	3	optional for dual-condition	✓	X	AF2	BB1 BB2 BB3	CB1
		S3	1	optional for dual-condition	✓	X	AF2	BB4	CB1
CB2	Ekip Arc Flash 6F-1	S1	1	X	✓	optional for dual-condition	AF1	BC2	CB2 CB1
		S2	1	optional for dual-condition	✓	X	AF2	OCC2	CB2
CB3	Ekip Arc Flash 6F-1	S1	1	X	✓	optional for dual-condition	AF1	BC3	CB3 CB1
		S2	1	optional for dual-condition	✓	X	AF2	OCC3	CB3
CB4	Ekip Arc Flash 6F-1	S1	1	X	✓	optional for dual-condition	AF1	BC4	CB4 CB1
		S2	1	optional for dual-condition	✓	X	AF2	OCC4	CB4

• **No selectivity**

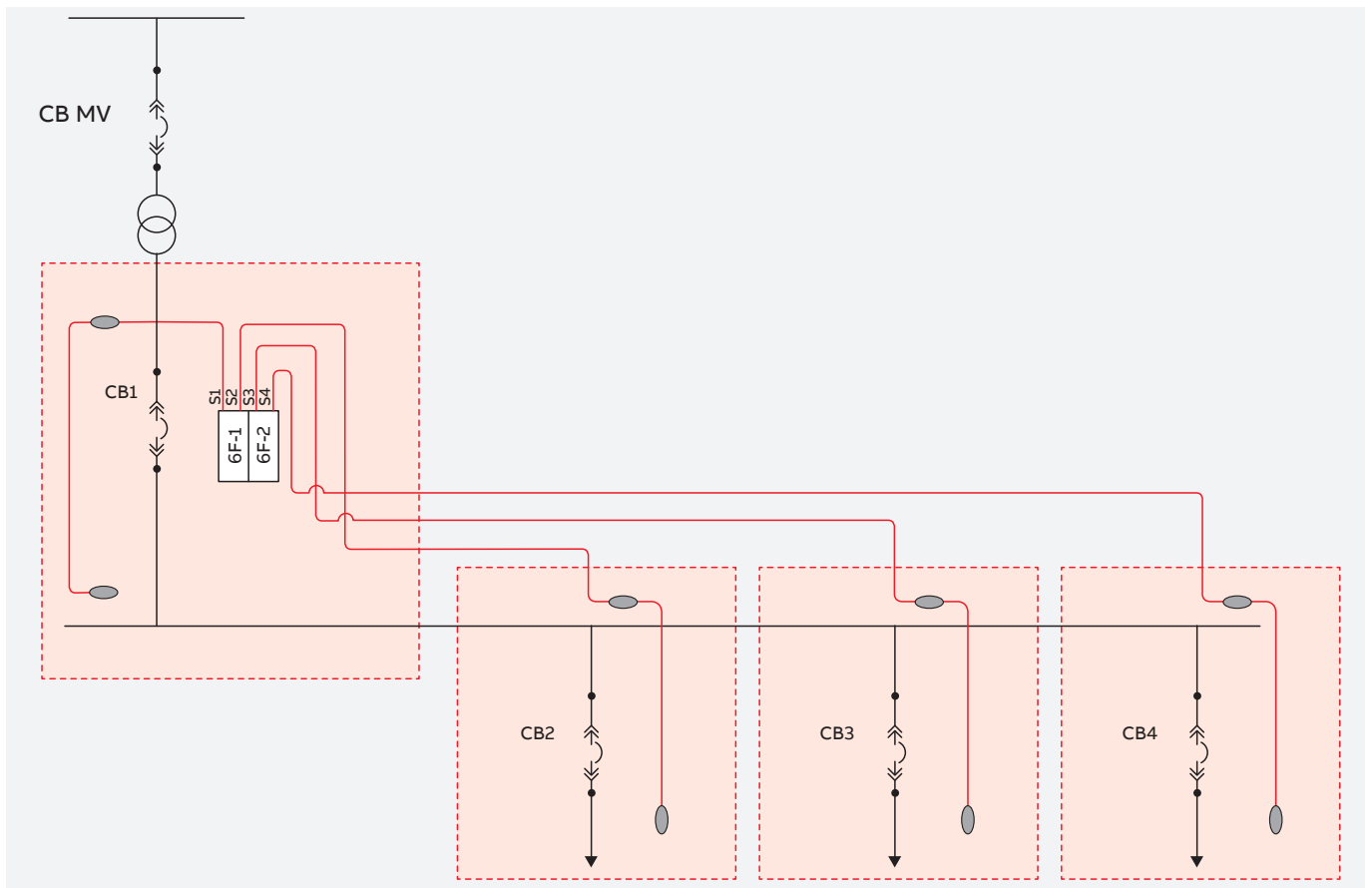
The primary objective is to eliminate the arc flash hazard from the installation by ensuring that the main circuit breaker (CB1) opens regardless of the arc flash location.

Switchgear segregation is no necessary for arc flash protection purpose.

In general, the arc flash light is reflected by metallic parts. To improve detection reliability, two detectors have been installed in each column.

One incomer without tie circuit breaker - no selective solution

	Ekip Supply	Ekip Arc Flash 6F-1	Ekip Arc Flash 6F-2
CB1	1	1	1
CB2	/	/	/
CB3	/	/	/
CB3	/	/	/
Total	1	1	1



	Channel	Number of arc detectors in series	Trip criteria			Protection	Zone protected	Trip
			Current I>	Light L>	Pressure P>			
CB1	Ekip Arc Flash 6F-1	S1	2	X	✓	optional for dual-condition	AF1	1st column CB1 CB MV (via digital signal or communication protocol)
	Ekip Arc Flash 6F-1	S2	2	optional for dual-condition	✓	optional for dual-condition	AF1	2nd column CB1 CB MV (via digital signal or communication protocol)
	Ekip Arc Flash 6F-2	S3	2	optional for dual-condition	✓	optional for dual-condition	AF1	3rd column CB1 CB MV (via digital signal or communication protocol)
	Ekip Arc Flash 6F-2	S4	2	optional for dual-condition	✓	optional for dual-condition	AF1	4th column CB1 CB MV (via digital signal or communication protocol)

8. Arc detector installation

2. Dual Incomers with Tie Circuit Breaker (Main Generator Configuration)

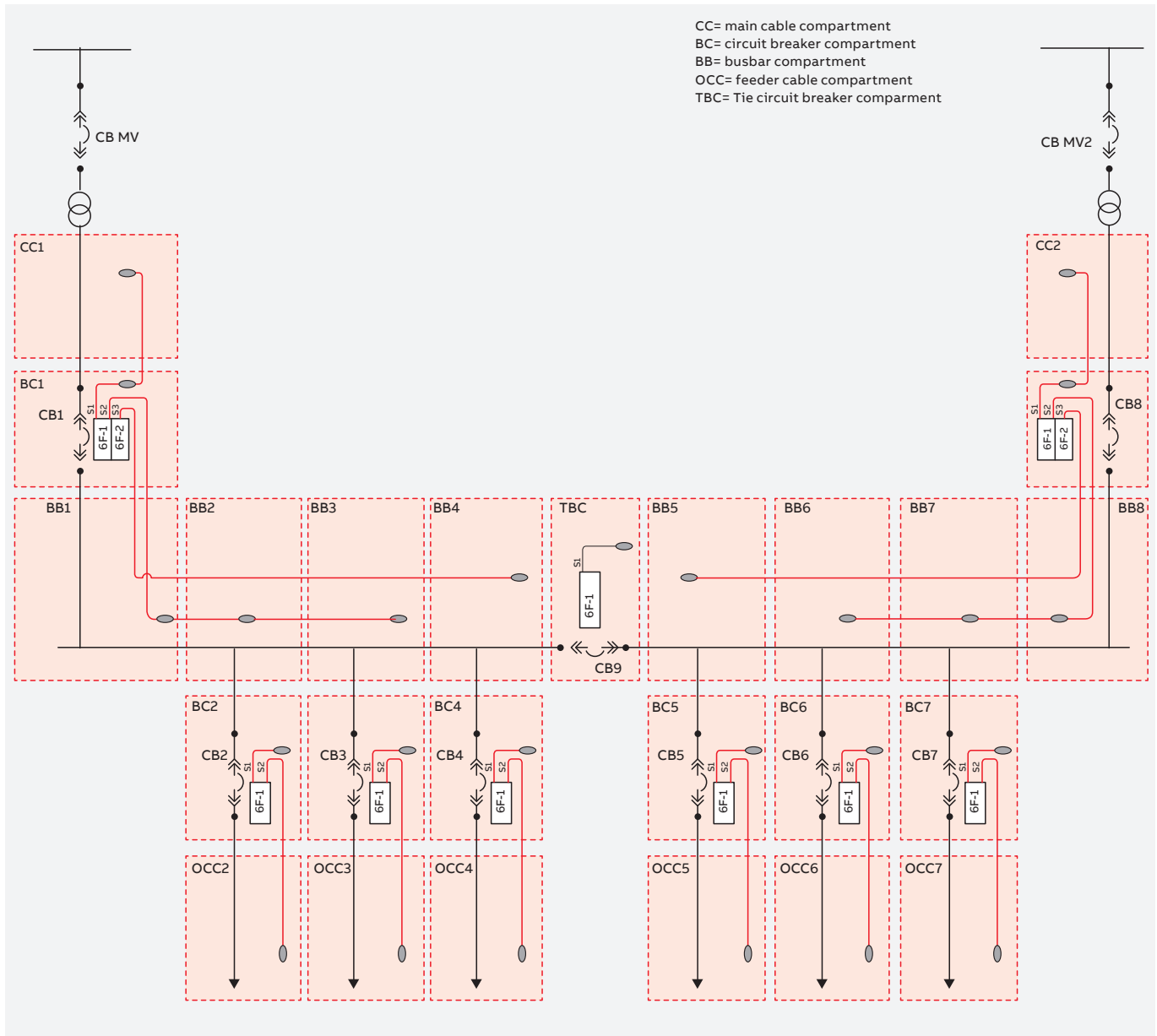
• Selectivity

Compared to the single incomer scenario, when a main circuit breaker trips, the tie circuit breaker (CB9) must also trip to isolate the faulted section from the rest of the system.

In the event of a fault at the tie circuit breaker itself, both main circuit breakers (CB1, CB8) must trip.

Dual incomers with tie circuit breaker - selective solution

	Ekip Supply	Ekip Arc Flash 6F-1	Ekip Arc Flash 6F-2
CB1	1	1	1
CB2	1	1	/
CB3	1	1	/
CB4	1	1	/
CB5	1	1	/
CB6	1	1	/
CB7	1	1	/
CB8	1	1	1
CB9	1	1	/
Total	10	10	2



				Trip criteria					
		Channel	Number of arc detectors in series	Current I>	Light L>	Pressure P>	Protection	Zone protected	Trip
CB1	Ekip Arc Flash 6F-1	S1	2	X	✓	optional for dual-condition	AF1	CC1 BC1	CB MV1 (via digital signal or communication protocol) CB9
		S2	3	optional for dual-condition	✓	X	AF2	BB1 BB2 BB3	CB1 CB9
	Ekip Arc Flash 6F-2	S3	1	optional for dual-condition	✓	X	AF2	BB4	CB1 CB9
CB2	Ekip Arc Flash 6F-1	S1	1	X	✓	optional for dual-condition	AF1	BC2	CB2 CB1 CB9
		S2	1	optional for dual-condition	✓	X	AF2	OCC2	CB2
CB3	Ekip Arc Flash 6F-1	S1	1	X	✓	optional for dual-condition	AF1	BC3	CB3 CB1 CB9
		S2	1	optional for dual-condition	✓	X	AF2	OCC3	CB3
CB4	Ekip Arc Flash 6F-1	S1	1	X	✓	optional for dual-condition	AF1	BC4	CB4 CB1 CB9
		S2	1	optional for dual-condition	✓	X	AF2	OCC4	CB4
CB5	Ekip Arc Flash 6F-1	S1	1	X	✓	optional for dual-condition	AF1	BC5	CB5 CB8 CB9
		S2	1	optional for dual-condition	✓	X	AF2	OCC5	CB5
CB6	Ekip Arc Flash 6F-1	S1	1	X	✓	optional for dual-condition	AF1	BC6	CB6 CB8 CB9
		S2	1	optional for dual-condition	✓	X	AF2	OCC6	CB6
CB7	Ekip Arc Flash 6F-1	S1	1	X	✓	optional for dual-condition	AF1	BC7	CB7 CB8 CB9
		S2	1	optional for dual-condition	✓	X	AF2	OCC7	CB7
CB8	Ekip Arc Flash 6F-1	S1	2	X	✓	optional for dual-condition	AF1	CC2 BC8	CB8 CB MV2 (via digital signal or communication protocol) CB9
		S2	3	optional for dual-condition	✓	X	AF2	BB6 BB7 BB8	CB8 CB9
	Ekip Arc Flash 6F-2	S3	1	optional for dual-condition	✓	X	AF2	BB5	CB8 CB9
CB9	Ekip Arc Flash 6F-1	S1	1	X	✓	optional for dual-condition	AF1	TBC	CB1 CB8 CB9



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