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WHITE PAPER

# Protection against electric arc

## Integration between Arc Guard System™ TVOC-2 and SACE Emax 2





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# 1 Introduction

In the last years a lot of users have underlined the question of safety in electrical assemblies with reference to one of the most severe and destructive electro-physical phenomenon: the electric arc.

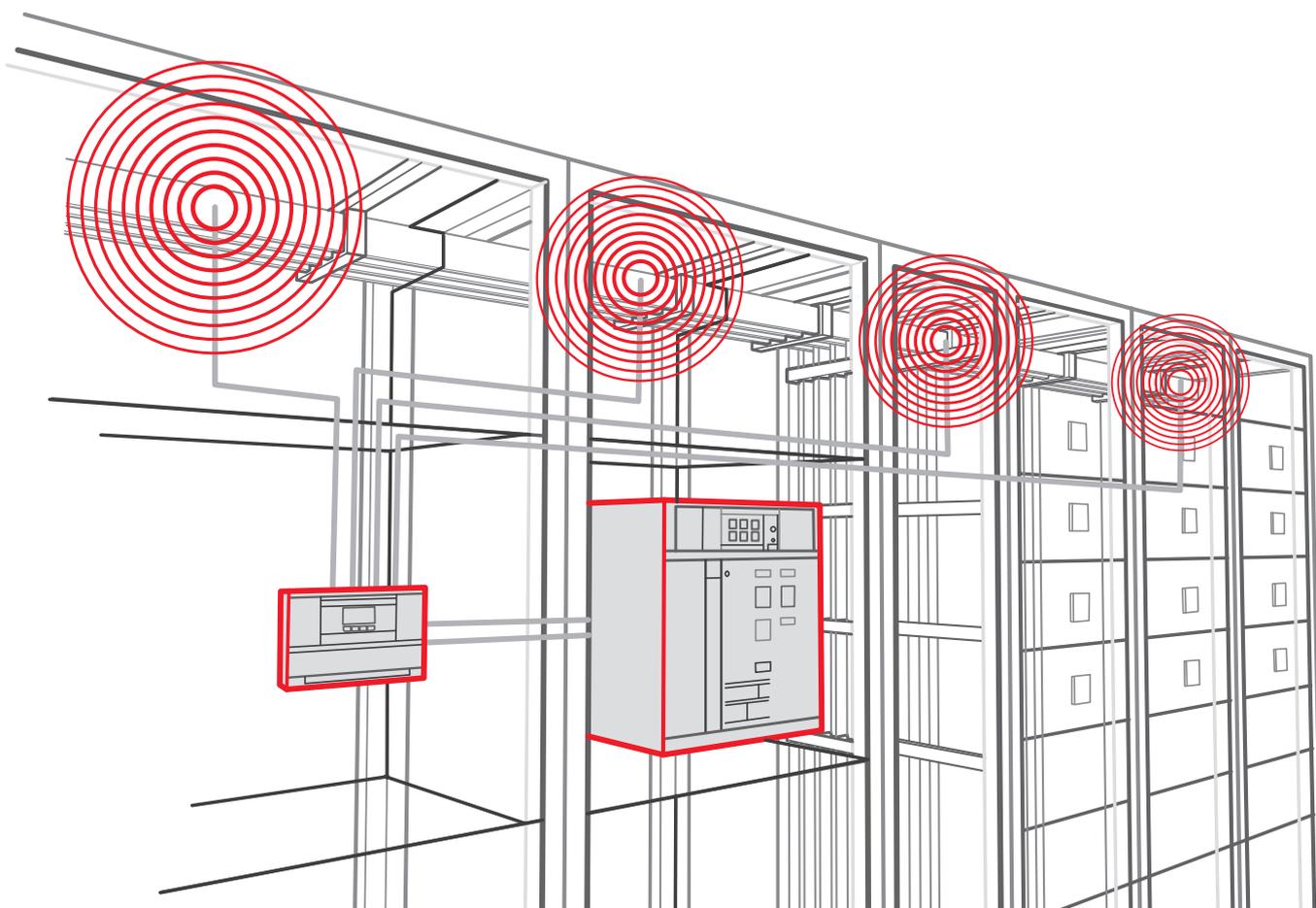
Such phenomenon generates internal overpressures and results in local overheatings which may cause high mechanical and thermal stresses in the equipment.

Arc accidents can happen due to several reasons, such as human mistakes, bad connections, animals, etc. Most often the accident occurs when someone is working in the switchgear for maintenance or installation. This is normally performed with an open cabinet door. Since the cabinet door is open the protection of arc-proof switchgear design will be significantly decreased. The arc guard system is therefore a natural part of a modern switchgear design.

Luckily accidents are quite unusual, but when they happen the consequences are often severe, resulting in heavy injuries or death. This is many times combined with long downtimes and destroyed equipment. For this reason it is crucial to build up a robust safety solution that works every time.

The purpose of this document is giving the necessary explanations for the correct use and proper integration between the Arc Guard System™ TVOC-2, a device which can detect an electric arc thanks to the optical sensors, and ABB SACE Emax 2 circuit breakers.

This document is not aimed at dealing with the concept of internal arc-proof assemblies, but at describing an active protection system used to limit the effects of the internal arc.



## 2 The electric arc

### 2.1 Electric arc phenomenon

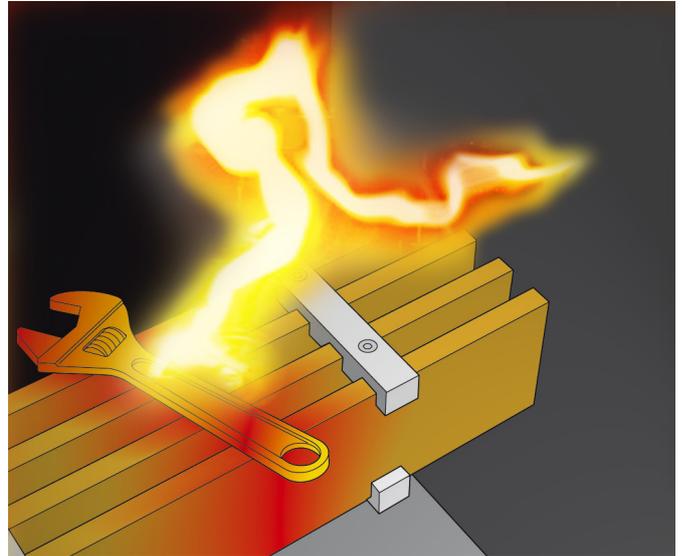
The electric arc is a phenomenon that takes place as a consequence of a discharge. This occurs when the voltage between two points exceeds the insulating strength limit of the interposed gas. In the presence of suitable conditions, a plasma is generated which carries the electric current till the opening of the protective device on the supply side. Gases, which are good insulating means under normal conditions, may become current conductors in consequence of a change in their chemical-physical properties due to a temperature rise or to other external factors.

To understand how an electric arc originates, reference can be made to what happens when a circuit opens or closes. During the opening phase of an electric circuit the contacts of the protective device start to separate thus offering to the current a gradually decreasing section; therefore the current meets growing resistance with a consequent rise in the temperature. As soon as the contacts start to separate, the electric field applied to the circuit exceeds the dielectric strength of the air, causing its perforation through a discharge.

The high temperature causes the ionization of the surrounding air, which keeps the current circulating in the form of electric arc. Besides thermal ionization, there is also an electron emission from the cathode due to thermoionic effect. The ions, formed in the gas and by collision due to the very high temperature, are accelerated by the electric field. The ions subsequently strike the cathode and the resulting collision releases energy causing localized heating and electron emission.

The electric arc lasts until the voltage at its roots supplies enough energy to compensate for the dissipated heat and maintains a suitable temperature. If the arc is sufficiently elongated and cooled it will eventually be extinguished. Similarly, an arc may originate also because of a short-circuit between phases. A short-circuit is a low impedance connection between two conductors at different voltages. The conducting element that constitutes the low impedance connection (e.g. a metallic tool left after maintenance on the busbars inside the enclosure, wrong wiring, or the body of an animal that entered the enclosure) is itself subject to the difference of potential and dangerous current passes through at a generally high value that is dependent on the characteristics of the resulting circuit.

The flow of high fault current causes overheating of the conductors (cables or busbars) up to the melting point of the lowest cross section. As soon as a conductor melts, conditions occur that are similar to those present during the circuit opening. At that point an arc starts that lasts either until the protection devices intervene or until the conditions necessary for its stability subside.



The electric arc is characterized by a combination of intense ionization of the gaseous means, by a drop of the anodic and cathodic voltage (10 V and 40 V respectively), and by a very high current density in the middle of the arc column (in the order of 10<sup>2</sup>-10<sup>7</sup> A/cm<sup>2</sup>). It is also characterized by an extremely high temperature (thousands of °C) located in the middle of the arc column and (in low voltage) at a distance ranging from microns to centimeters from the ends of the arc.



### 2.2 Effects of the electric arc inside switchgear and controlgear assemblies

In the proximity of the main boards, i.e. of large electrical machines, such as transformers or generators, the short-circuit power is high and consequently also the energy associated with the electric arc resulting from a fault. Without going into complex mathematical descriptions of this phenomenon, the first instant of the arc formation inside a cubicle can be described in 4 phases:

1. compression phase: in this phase the air volume occupied by the arc is overheated generating a continuous contribution of energy. Due to convection and radiation the remaining volume of air inside the cubicle warms up. Initially there are temperature and pressure values different from one zone to another;
2. expansion phase: at the moment internal pressure increases a hole is formed from which overheated air is able to flow out. In this phase, the pressure reaches its maximum value and then begins to decrease as hot air is released;

## 2 The electric arc

3. emission phase: in this phase, due to the continuous contribution of energy by the arc, nearly all the air is forced out under a slow and almost constant overpressure;
4. thermal phase: after the expulsion of the air, the temperature inside the switchgear reaches almost that of the electric arc. This final phase lasts until the arc is quenched. Due to the extremely high temperatures, all insulating materials undergo erosion and produce dangerous gases, fumes and molten material particles into the immediate environment.

Should the electric arc occur in open configurations, some of the described phases would not be present or could have less effect; however, there will be a pressure wave and a rise in the temperature of the zones surrounding the arc. Here is some data to understand how dangerous it is being in the proximity of an electric arc:

- **pressure:** It is estimated that a person 60 cm away from an electric arc of 20 kA is subjected to 225 kg of force. Additionally, the sudden pressure wave can cause permanent injuries to the eardrum;
- **temperature:** an electric arc can reach about 20000°C;
- **sound:** sound levels can reach 160 db, a shotgun blast is only 130 db.

### 2.3 Effects of the electric arc on human beings

From the above, it is evident that the electric arc represents a very dangerous hazard for people. The hazards to which a person is exposed due to the release of energy generated by an arc event are:

- inhalation of toxic gases
- burns
- injuries due to ejection of materials
- damages to hearing.



#### Inhalation of toxic gases

The fumes produced by burnt insulating materials and by molten or vaporized metals can be toxic. The fumes are caused by incomplete burning and are formed by carbon particles and other solid substances suspended in the air.



#### Burns

The high temperature levels of the gases and the expulsion of incandescent metal particles may cause severe burns. Burns of all degrees can result from an electric arc event. Red-hot solid bodies, such as metal fragments from the assembly, can cause third degree burns while superheated steam can cause burns similar to those caused by hot liquids. Finally, radiant heat generally causes less severe burns.



#### Injuries due to ejection of materials

The ejection of loose parts caused by the electric arc can result in injuries to the most susceptible parts of the human body as, for example, the eyes. The materials expelled may penetrate the cornea and can permanently damage it. The extent of the resulting lesion depends on the characteristics and on the kinetic energy of these objects. Similarly, gases can cause severe damage to the mucosa of the ocular region, while depending on the wavelengths, both ultraviolet and infrared rays can injure the cornea and retina.



#### Damages to hearing

The electric arc manifests itself as a real explosion, with sounds that may cause permanent injuries to hearing.

## 3 Assemblies equipped with devices limiting internal arc effects (active protection)

### 3.1 Introduction to active protection

Safety of the operator and for the installation in case of arcing inside LV switchgear can be obtained through three different design philosophies:

1. assemblies mechanically capable of withstanding the electric arc (passive protection)
2. assemblies equipped with devices limiting the effects of internal arcing (active protection)
3. assemblies equipped with current limiting circuit breakers or fuses.

These three solutions (also combined together) have found a remarkable development in the industrial field and have been successfully applied by the main manufacturers of LV switchgear and controlgear assemblies.

In the following pages, we review combinations of devices that provide active protection.

However, it must be kept in mind that an active protection, in comparison with a passive one, is intrinsically more complex due to the presence of additional electromechanical/electronic devices which can be subject to faults or tripping failures.

With active protection it is meant to guarantee the resistance to internal arcing by installing devices limiting the arc. Two possible approaches for limiting the destructive effects of the arc:

- by means of overpressure detectors, or
- light arc detectors (Arc Guard System™ TVOC-2).

The first consists in installing in the assembly arc detectors which sense overpressure.

As already specified the overpressure wave is one of the other effects occurring inside an assembly in case of arcing. As a consequence it is possible to install some pressure sensors that are able to signal the pressure peak associated with the arc ignition with a detection time of about 10 to 15 ms. This signal operates on the supply circuit breaker without waiting for the trip times of the selectivity protections to elapse. Such a system, if the discrimination between different protection zones is not required, does not need any electronic processing since it can act directly on the shunt opening release of the supply circuit breaker. Obviously, it is essential that the device is set at fixed trip thresholds. When an established internal overpressure is reached, the arc detector intervenes.

However, it is not easy to define in advance the value of overpressure generated by an arc fault inside a switchboard.

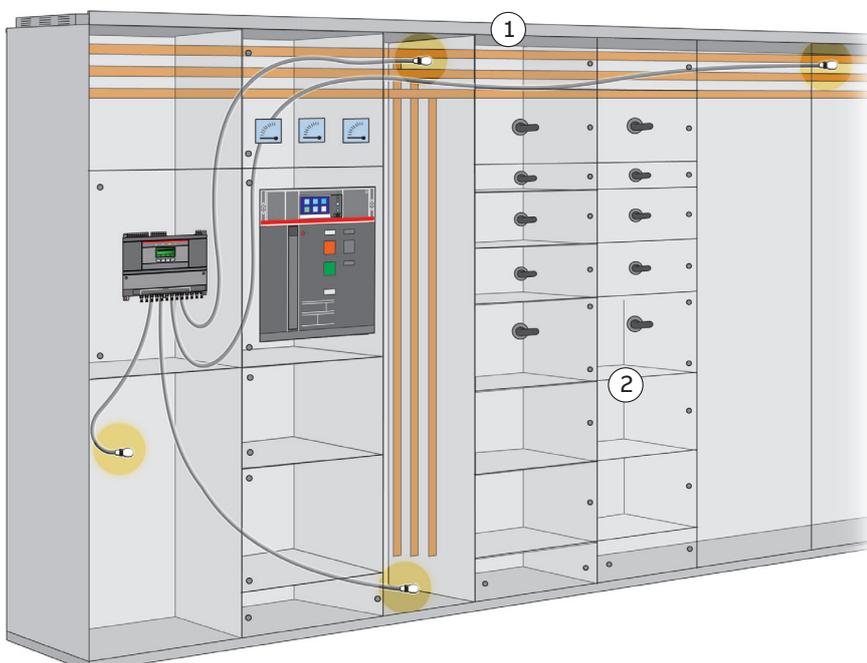
The second possibility consists of installing in the assembly, detectors which sense the light flux associated with the electric arc phenomenon (arc detectors).

The operating logic of an arc detector is as follow: the intense light radiation generated by the arc inside of the switchboard is detected by the sensors.

The arcing control system detects the event and sends a tripping signal to the circuit breaker. In this case the reaction time of the detection is about 1 ms.

Figure 1 shows the possible installation areas where this device can be positioned inside a switchboard. Ideally, one detector should be installed in each column. To minimize detection time the cables should be fiber optic and the length kept at a minimum.

Figure 1



Example showing the position of detectors in:  
1. Horizontal and vertical bus bar system  
2. Circuit breaker cubicle

### 3 Assemblies equipped with devices limiting internal arc effects (active protection)

To avoid false light detections, a current sensor can be positioned upstream from the main circuit breaker. In the event of an arc, the current sensing unit detects the current while the sensors detect the light radiation. After processing this combination, the system will then trigger the opening of the circuit breaker.

Since time is of the essence, it by-passes the the over-current settings of the circuit breaker which could be delayed for various reasons such as:

1. selectivity requirement
2. connections of capacitor banks
3. electrical components with high inrush currents.

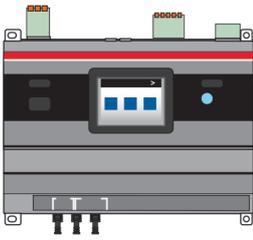


Figure 2: CSU-2 Current Sensing Unit

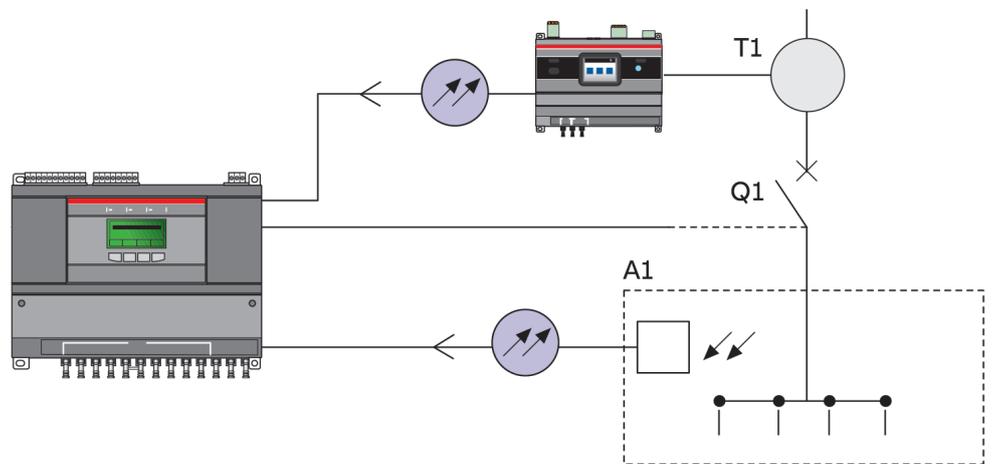
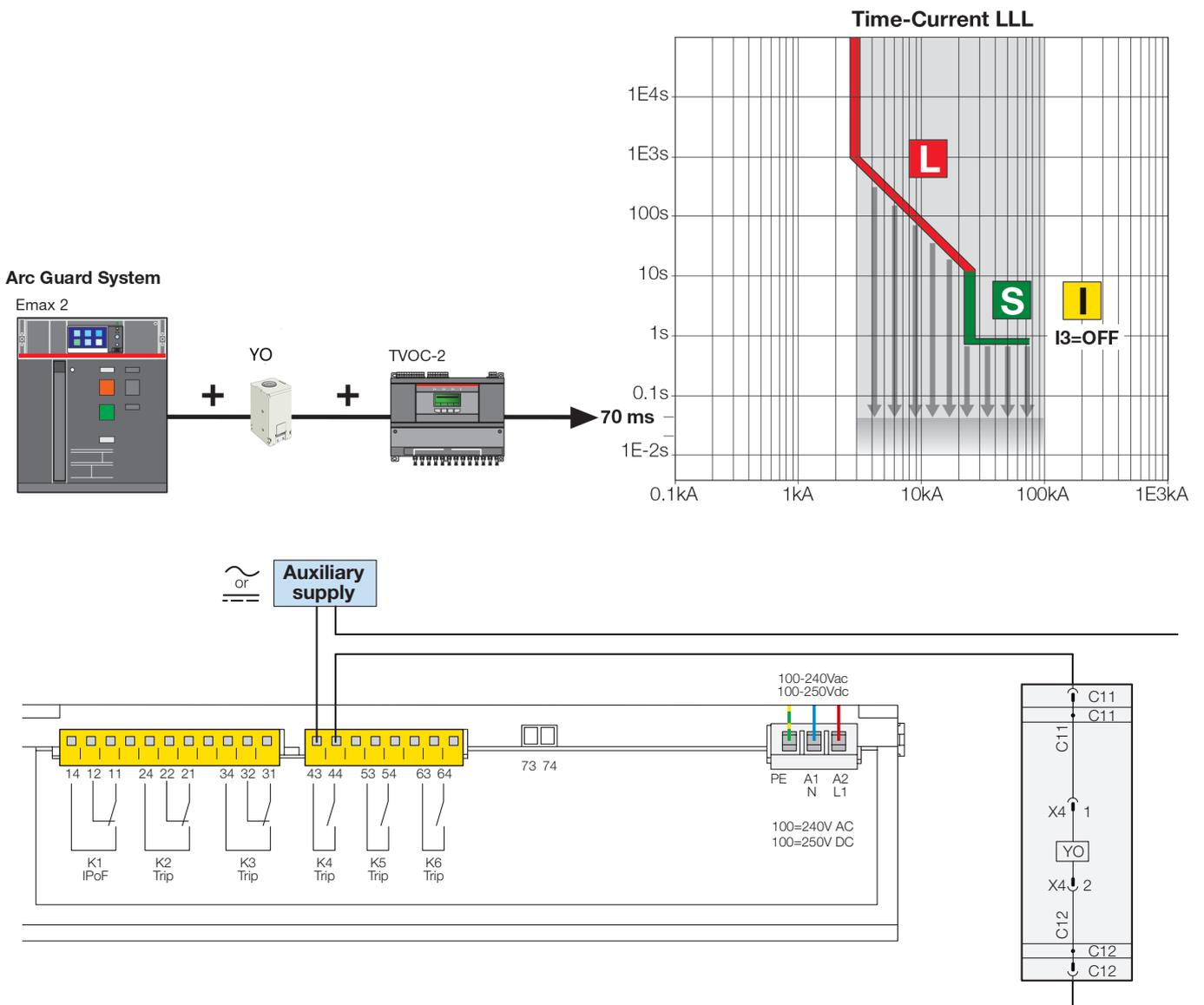


Figure 3: Connection diagram for TVOC-2 and CSU-2

**3.2 The solution with shunt opening coil: YO**

The Arc Guard System™ detects the arcing event and sends the trip signal to the circuit breaker in less than 1 ms. The following figure shows the Arc Guard System™ in series with a circuit breaker equipped with the opening release (YO) and TVOC-2:

It is necessary to connect the contact of the TVOC-2 (terminals (K4) n.43-44 or, as an alternative, (K5) n.53-54 or (K6) n.63-64) in series with the opening release (YO) of the circuit breaker (C11-C12 terminals).



# 3 Assemblies equipped with devices limiting internal arc effects (active protection)

## 3.3 The solution with digital input: Ekip 2K

Since time is so critical, there is an even faster solution available leveraging Emax 2's digital I/O. With the Ekip Touch/Hi-Touch trip units it is possible to substitute the YO in the previous system with the 2K digital I/O module. In fact, the inputs of the module can be configured and customized; in this case the input signal received from the TVOC-2 will be associated with opening the circuit breaker.

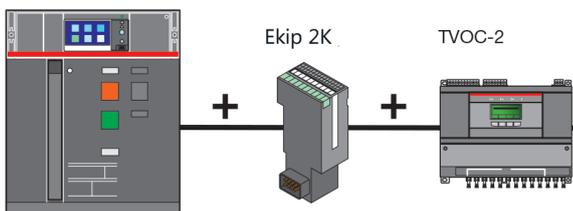
This option reduces the total clearing time by about 20ms because it opens the circuit breaker directly through the electronic unit rather than depending on the opening release (YO).

In addition its possible to configure the system activating a runtime verification of the control chain continuity, of the aux supply presence and of the TVOC-2 status. The outputs of the Ekip 2K module can be used to send alarms in these cases. How to implement these features is outside the scope of this document.

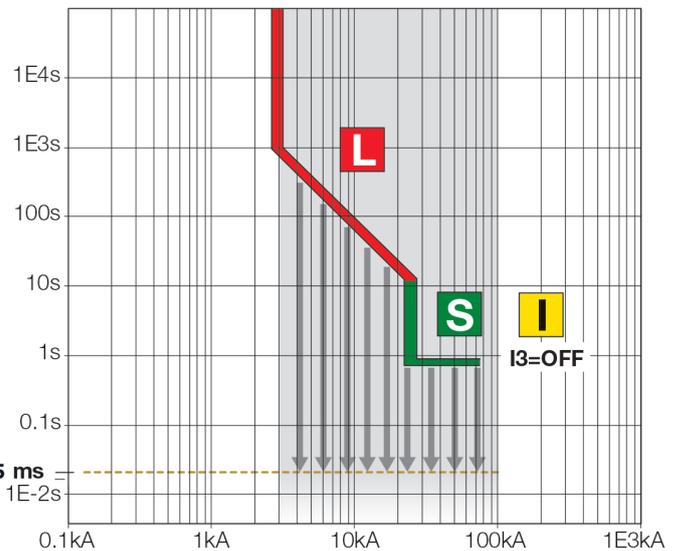
The connection between the input contact of the Ekip 2K module and TVOC-2 is found on page 16.

It is evident that the solution with the use of the module Ekip 2K reduces the total breaking times and therefore it clearly represents a more efficient solution if compared with the traditional one with SOR (shunt opening release).

Arc Guard System  
Emax 2



Time-Current LLL



### 3 Assemblies equipped with devices limiting internal arc effects (active protection)

#### 3.4 The solution with energy reducing protection algorithm: RELT Ekip 2K-3

When it comes to circuit breakers, a very common and rather simple arc flash mitigation solution is known as an Energy Reducing Maintenance Switch with local status indicator. Via an external input (usually a simple selector switch with LED status indication), the circuit breaker's thresholds and response times are decreased to much safer levels.

This is usually only enabled when personnel are near the live equipment, and when de-activated the circuit breaker returns to its normal protection settings.

The RELT (Reduced Energy Let Through) Ekip 2K-3 is an Emax 2 and Tmax XT dedicated module that is designed to receive the aforementioned input signal. Why not leverage the TVOC-2's output signal as the input to this module? By doing this, the TVOC-2 will ultimately trigger the circuit breaker's ultra-fast protection curve by skipping any intermediary devices.

Not only is this faster, but also provides both light detection via the TVOC-2 and current detection via the circuit breaker's protection algorithm

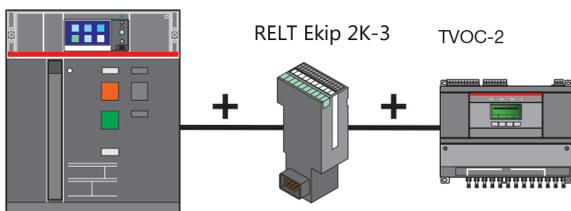
The following table shows the components and the relevant total breaking times.

Circuit breaker	Trip unit	Accessory	Arc monitor	Total breaking time*
XT7, E1.2-E6.2	Ekip Touch Ekip Hi-Touch	YO	TVOC-2	70 ms
		Ekip 2K		45 ms (1)
		RELT Ekip 2K-3		45 ms

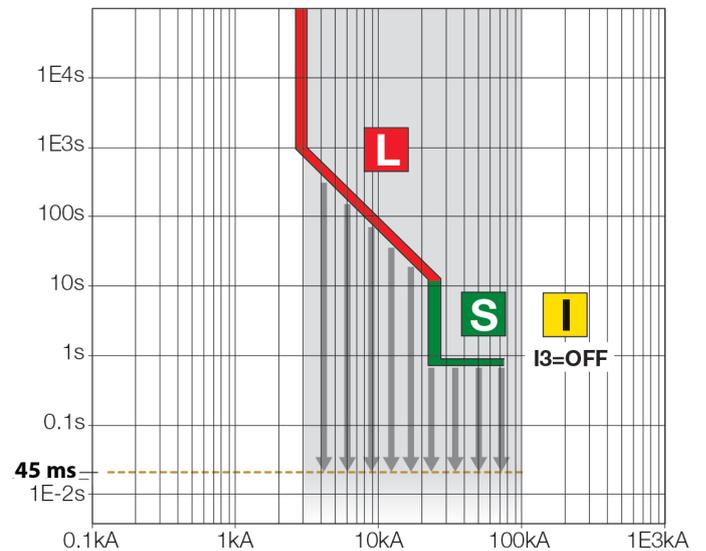
\* Total breaking time defined according to test conditions of the product standard IEC 60947-2

(1) ATTENTION: remember to manually setup delay to zero during configuration

Arc Guard System  
Emax 2



Time-Current LLL



**3.5 Examples of manageable operation logics**

TVOC-2 can individually command three different output contacts (each can have multiple breakers connected) since it has the possibility of associating a defined number of light sensors to each output contact.

This makes it possible to use the arc monitor in all kinds of different complex multi-circuit breaker applications. The following pages report some examples of these applications trying to describe their operation logics.

As indicated in the previous pages, the Arc Guard System™ remarkably reduces the total breaking times in the event of an electric arc fastest, option being through the input of the Ekip 2K module.

As a consequence, it is evident that under these conditions it is not possible to obtain selectivity in the event of internal arc even if the arc is on the load side of an outgoing feeder.

The following example illustrates the above. Figure 4 shows the trip curves of three circuit breakers, one on the supply side (QF1) selective with the two outgoing feeders (QF2-QF3). As it can be seen, since every light sensor commands the main circuit breaker, in case of an internal arc, there will be a downtime for the whole plant.

Practically, it is as if the circuit breaker on the supply side had a protection function which would make it instantaneous and therefore, in an arc event, all the settings and time delays set according to the selectivity study become useless.

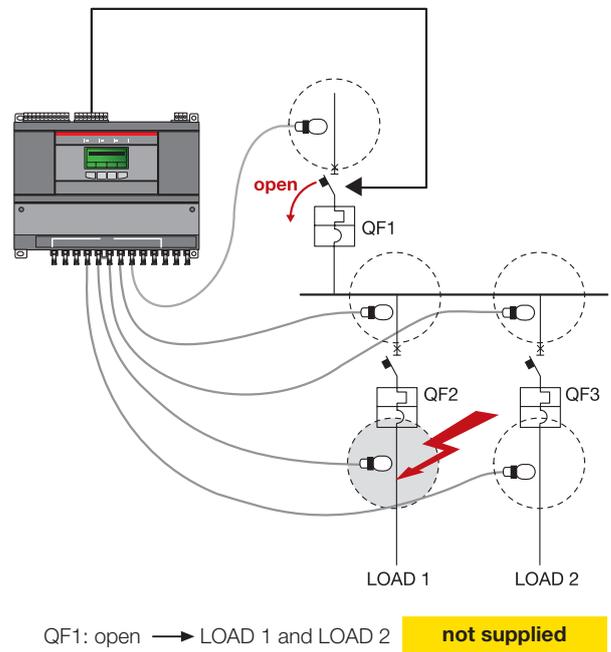
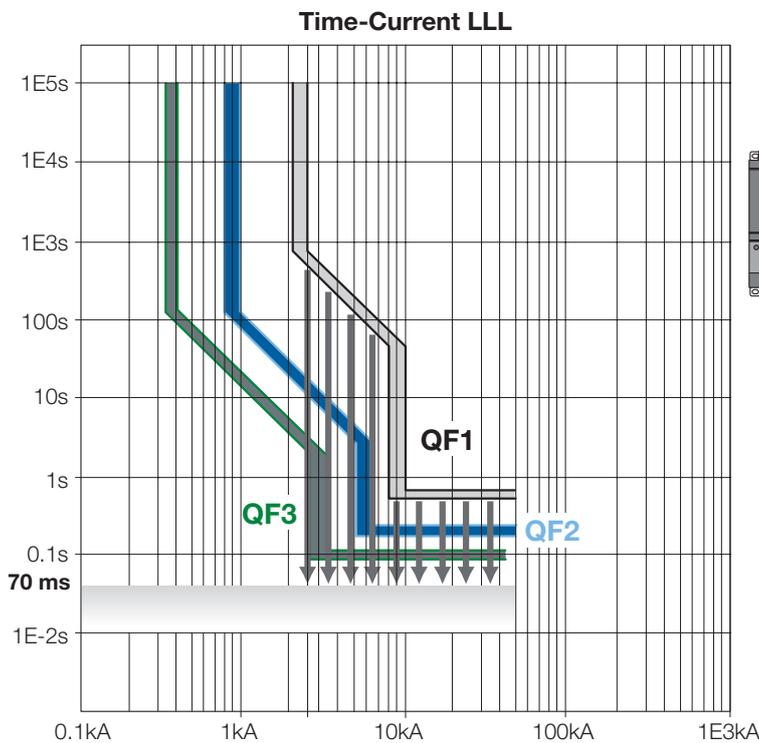


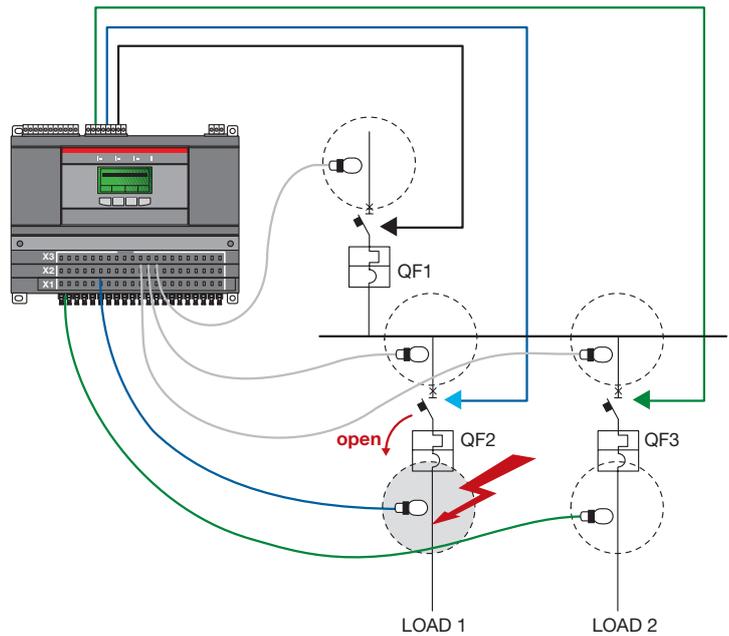
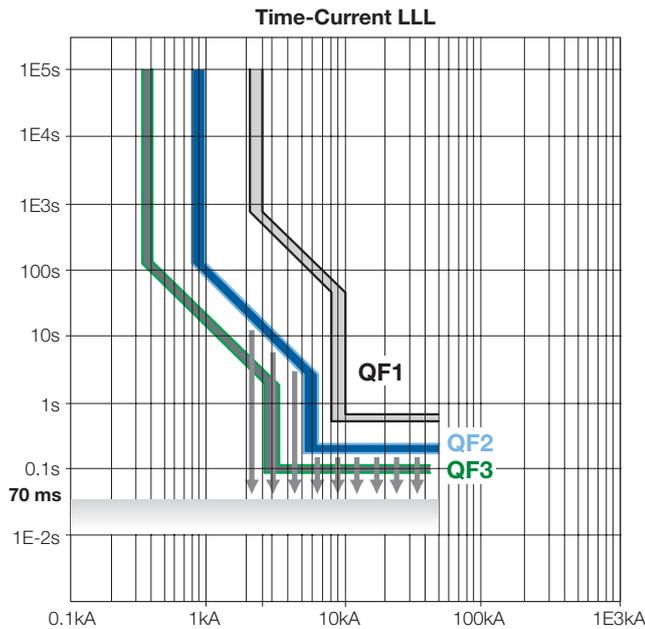
Figure 4

### 3 Assemblies equipped with devices limiting internal arc effects (active protection)

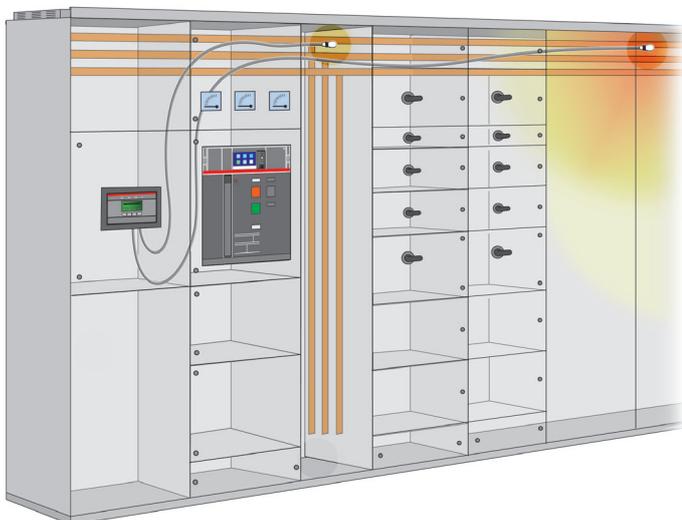
To maintain selectivity even during an arc event, it is possible to command up to three breaker outputs through a single TVOC-2. This is done by assigning to each light sensor the task of opening one of the three in this way the system is selective\* also in the event of an electric arc on the load side

of an outgoing feeder (in the example on the load side of QF2).

The following figure illustrates the above (to simplify the example only 5 light sensors of the 30 available have been represented).



QF1 and QF3 closed: LOAD 2 **supplied**  
 QF2 opened

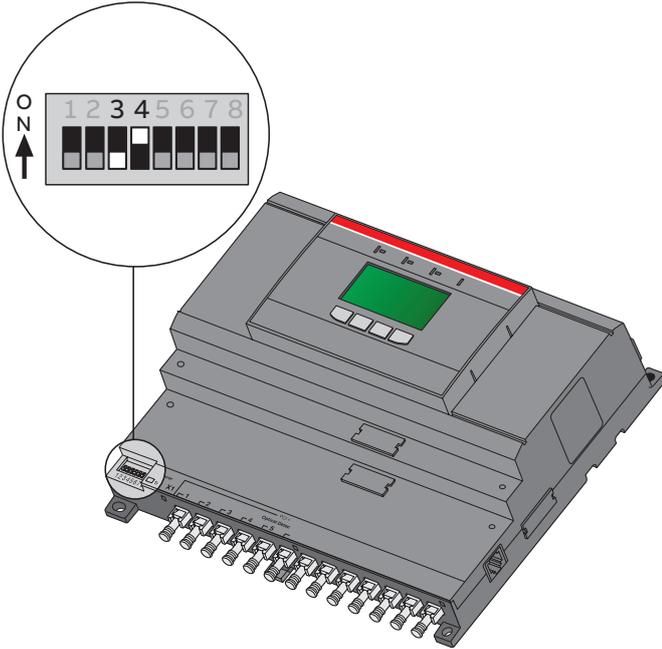


\* It is evident that in order to get a selective system, each light sensor must not be influenced by the light fluxes which do not affect its area; in order to do so it is necessary that between the sensors some obstacles are present (typically the metal enclosure of the cubicles) as shown in the figure. Furthermore, the light sensors must be positioned in a "strategic" way (after a thorough analysis) to define the interest areas and the operating zones. This is made easier also by the fact that we are considering large power distribution switchboards in which the internal dimensions and the metalwork structure are such as to allow the separation of the sensors according to their relevant operating areas.

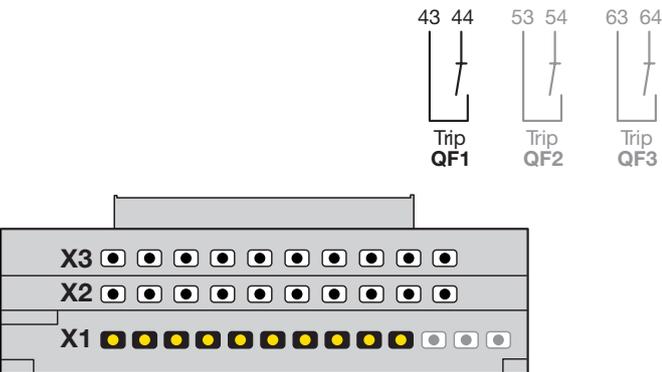
When the sensors cannot be completely masked and could be affected by flashes of light generated in areas outside the assigned protection zone, the actions of the protection system can be coordinated using the same strategies used for the logical selectivity between the circuit breakers (through communication and dialogue between the involved units to validate their opening), without the intrinsic delays associated with these procedures. How to accomplish this coordination is outside the scope of this document.

**From an operational point of view:**

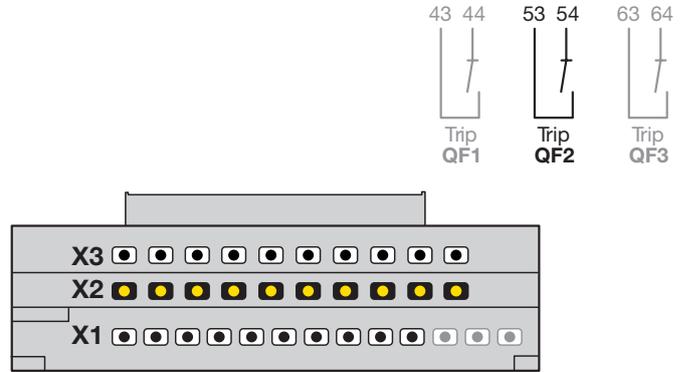
To set this function on the arc monitor TVOC-2 it is necessary to position correctly the dip switches positioned on the left side of the arc monitor as shown in the following figure:



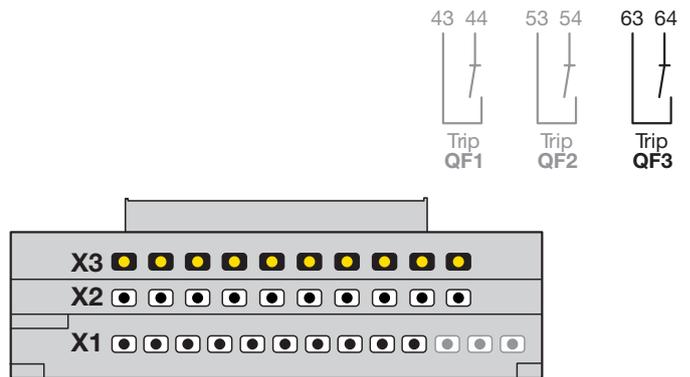
In this way, the TVOC-2 will make the circuit breakers QF1-QF2-QF3 trip as follows:



For each light signal detected by a light sensor belonging to the row of X1 detectors, TVOC-2 will command the tripping of QF1 circuit breaker only.



For each light signal detected by a light sensor belonging to the row of X2 detectors, TVOC-2 will command the tripping of QF2 circuit breaker only.



For each light signal detected by a light sensor belonging to the row of X3 detectors, TVOC-2 will command the tripping of QF3 circuit breaker only.

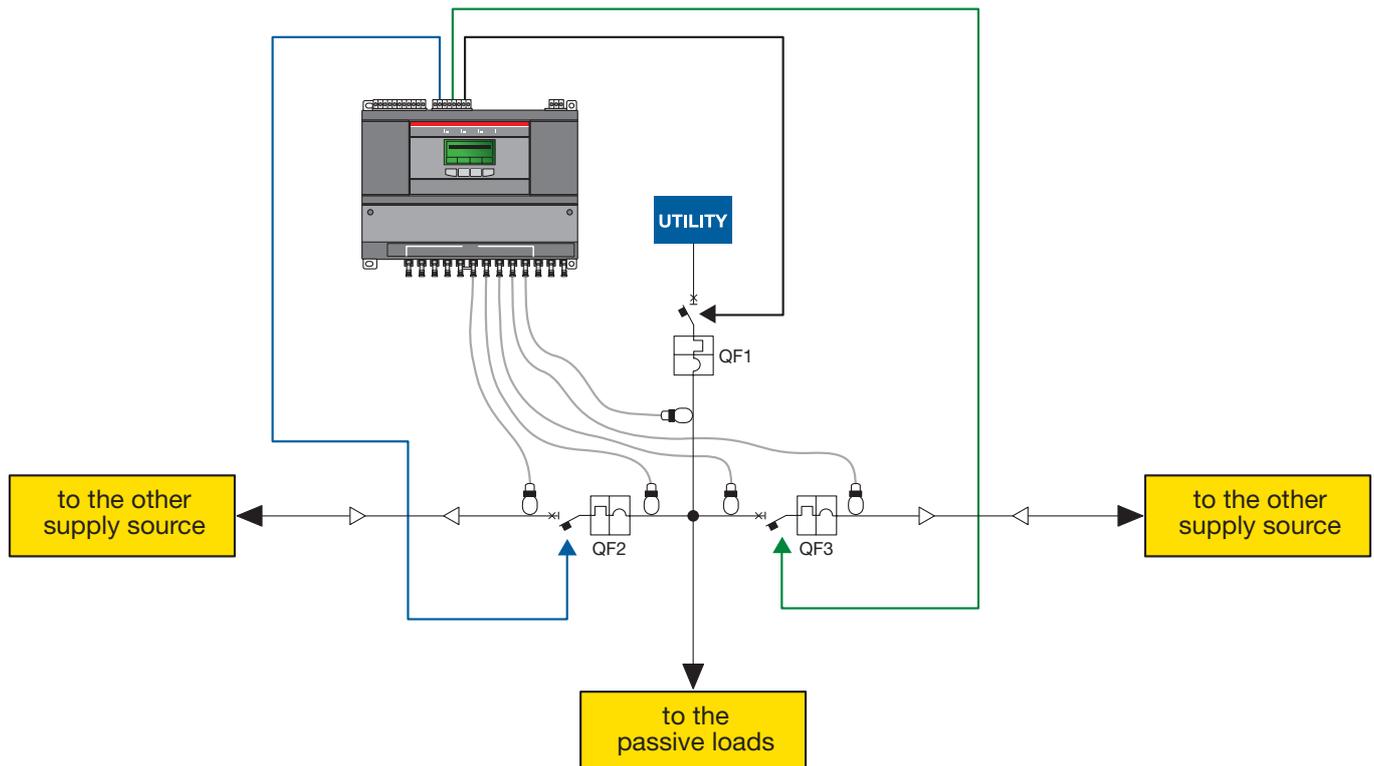
As regards the connections to be carried out between circuit breaker and TVOC-2, reference must be made to the example on page 15.

### 3 Assemblies equipped with devices limiting internal arc effects (active protection)

The figure below shows another application example in which the simultaneous opening of three circuit breakers is required.

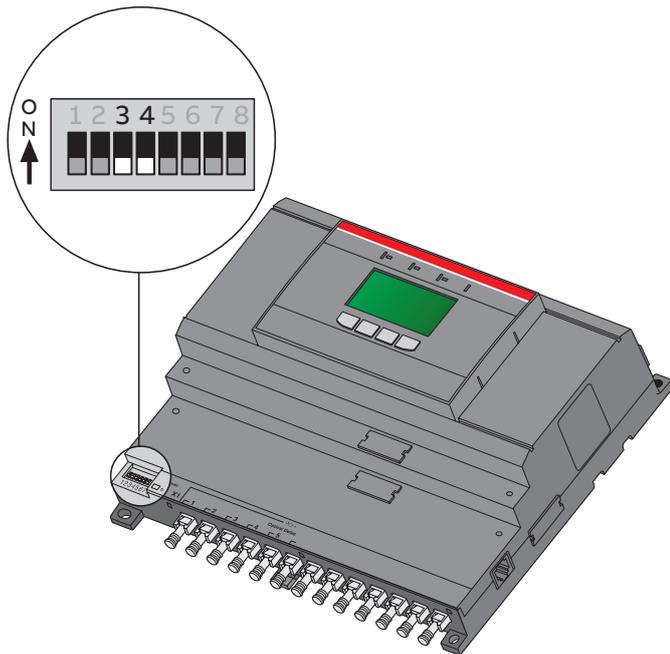
As it can be seen from the figure, it is evident that in the event of an electric arc it is not sufficient to make only one

circuit breaker open since the arc itself might be supplied by the other sources in parallel. In this case the opening of the three circuit breakers represent a fundamental aspect (also in this case to simplify the example only 5 light sensors of the 30 available have been represented).

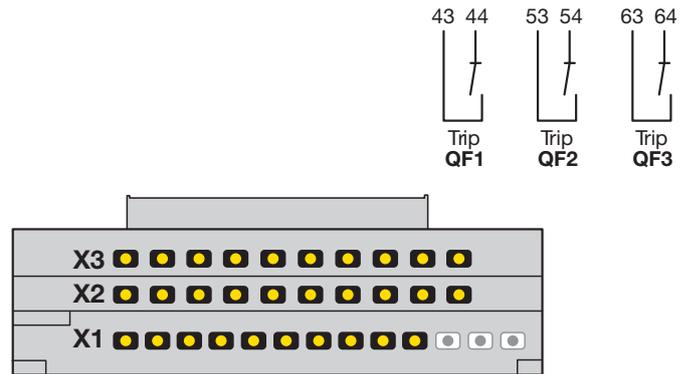


**From an operational point of view:**

To set this function on the TVOC-2 it is necessary to set correctly the dip switches positioned on the left side of the unit itself as shown in the following figure:



In this way, TVOC-2 will make the circuit breakers QF1-QF2-QF3 trip simultaneously:



For each light signal detected by a light sensor belonging to any row (X1-X2-X3), TVOC-2 will command the trip of all the circuit breakers QF1-QF2-QF3.

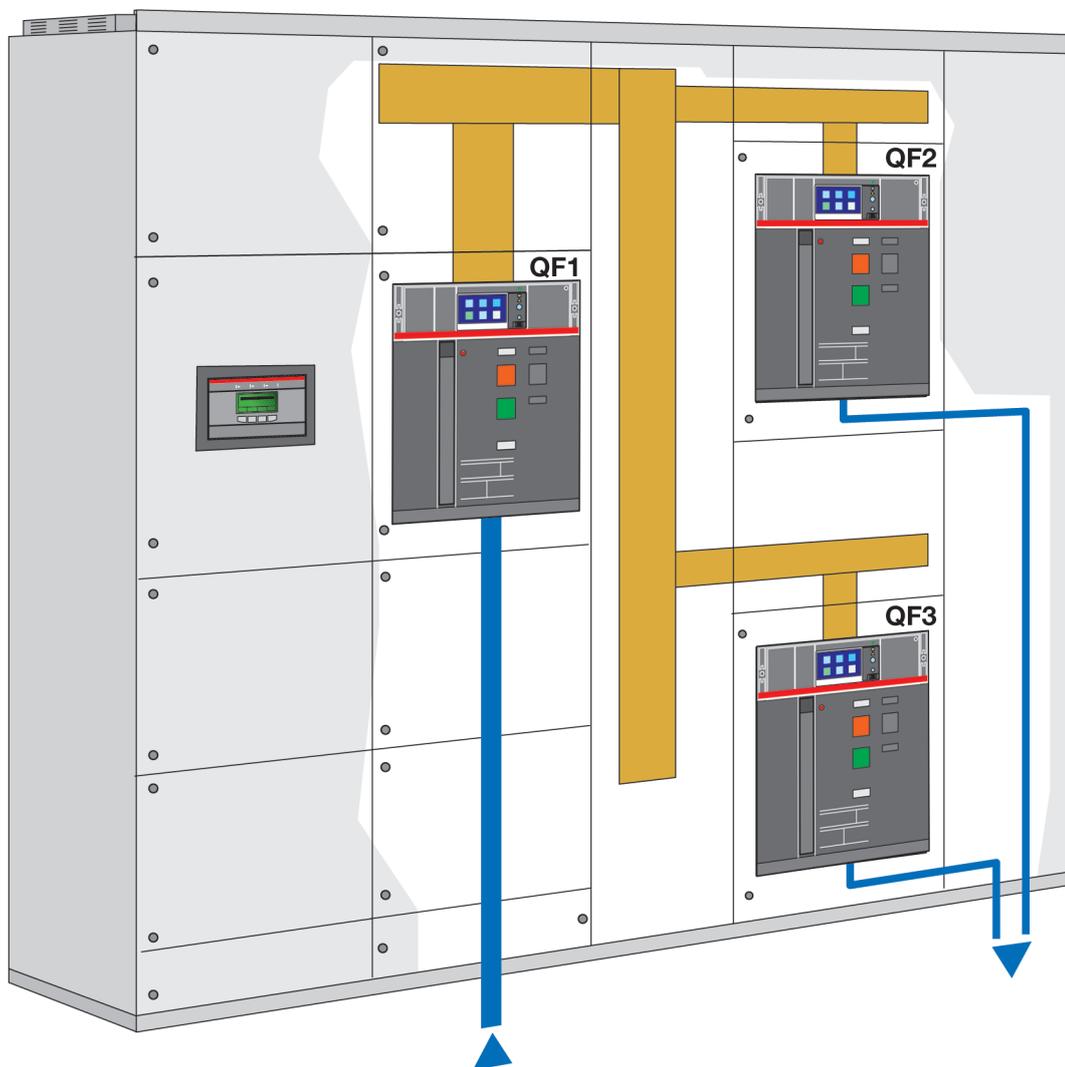
Refer to the example on page 15 for the wiring between the circuit breaker and the TVOC-2.

## 4 Application example

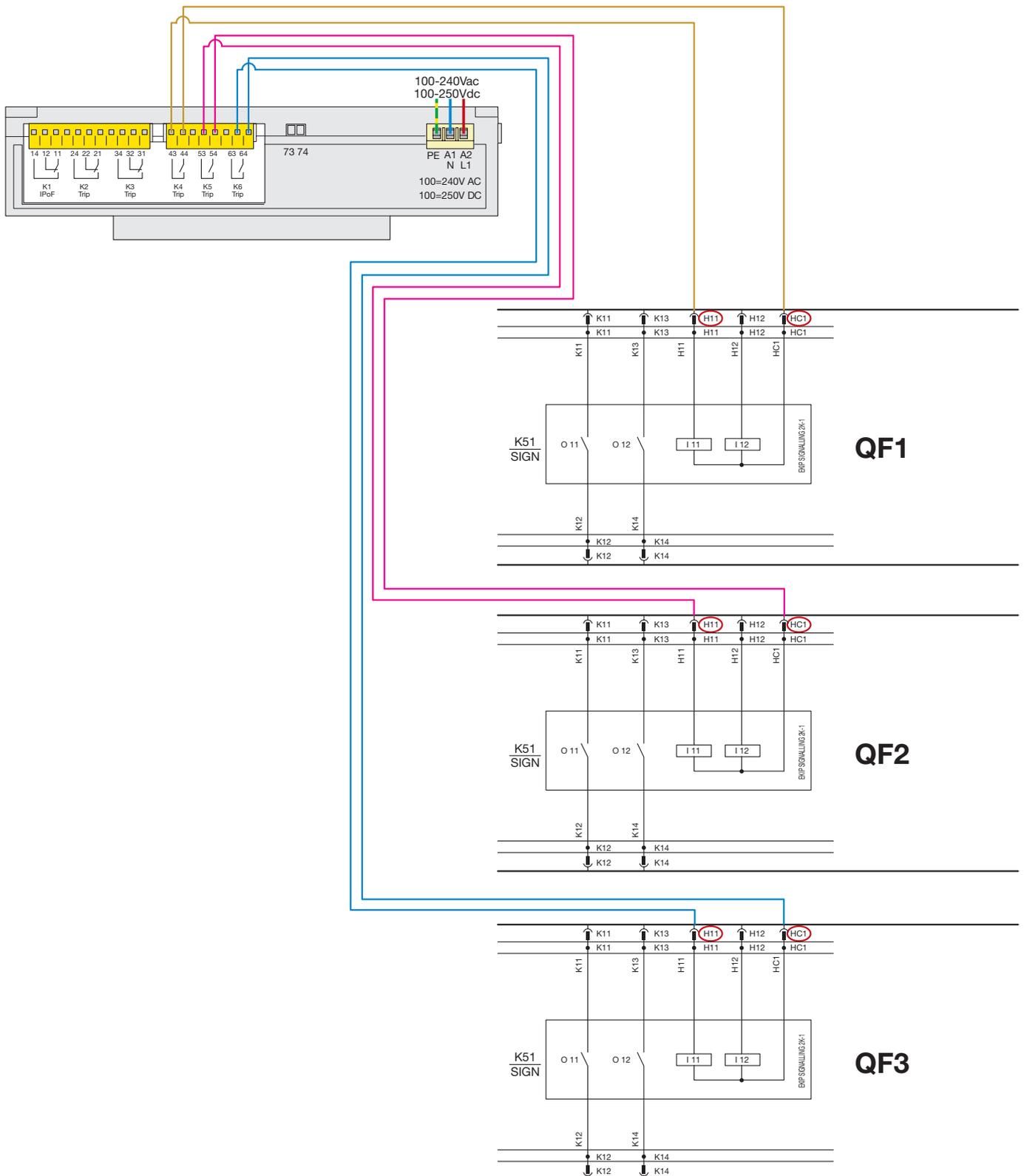
The following pages show an application example aimed at giving further information about the connections between Emax 2 circuit breaker with Ekip Touch/Hi-Touch, equipped with the Ekip 2K module, and TVOC-2.

In case of internal arcing, the light sensors will command opening for all the circuit breakers in the assembly. The following Figure shows, a possible layout of circuit breakers inside the switchgear.

Please reference page 7 for the proper positioning of the light sensors.



The following electrical diagram shows the connections to be made between TVOC-2 and the trip units of the circuit breakers (power supply is needed) with Ekip 2K.

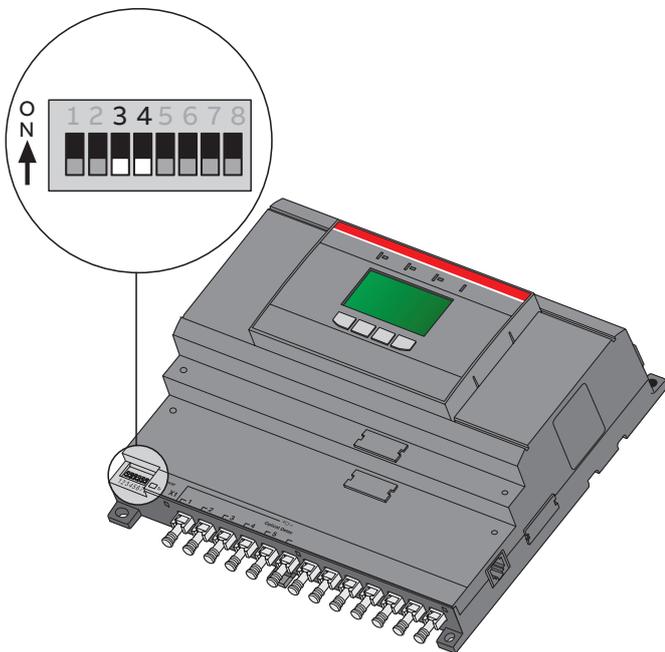


# 4 Application example

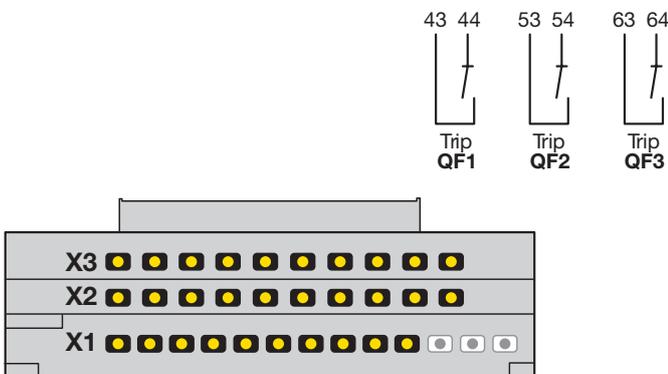
**⚠ ATTENTION: remember to manually setup delay to zero during configuration. ALWAYS make sure that the delay of the external trip unit is set to 0 to enable fast tripping with TVOC-2.**

**Configuration procedures:  
TVOC-2**

Since in case of detection by any light sensor the opening of all the circuit breakers is required, it is necessary to set accordingly the dip switches at the bottom of the module on its left side.



Having set the dip-switches 3 and 4 as shown in the figure, for every light flux detected by any sensor there will be the tripping of all the three circuit breakers.



For each light signal detected by a light sensor belonging to any row (X1-X2-X3), TVOC-2 will command the opening of all the circuit breakers QF1-QF2-QF3.

**Ekip Touch + Ekip 2k module  
(solution valid also in case of Ekip Hi-Touch)**

As previously mentioned to reduce the total breaking times it is possible to use the input digital contact of the Ekip 2k module.

This can be configured directly from the trip unit menu. The following pages show the navigation path to follow from the display of Ekip Touch.

1. From the Home page click on the fourth icon



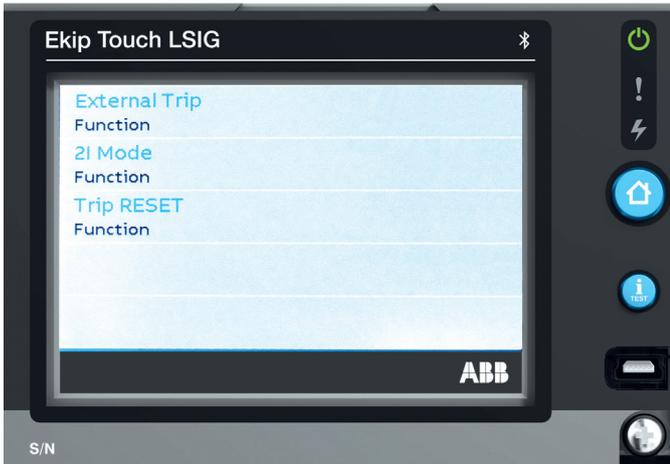
3. From the menu "Advanced" scroll and select "Functions"



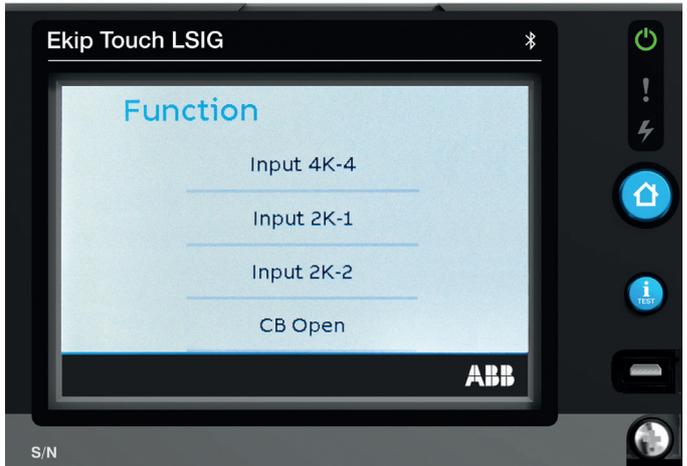
6. Insert the PIN, the default being "00001"



4. From the menu "Functions" select "External Trip"



7. From the menu "Function" scroll and select "Input 2K-1"



5. ⚠ From the menu "External Trip" set a delay to 0.0s and select "Function"



8. Click on "Confirm"



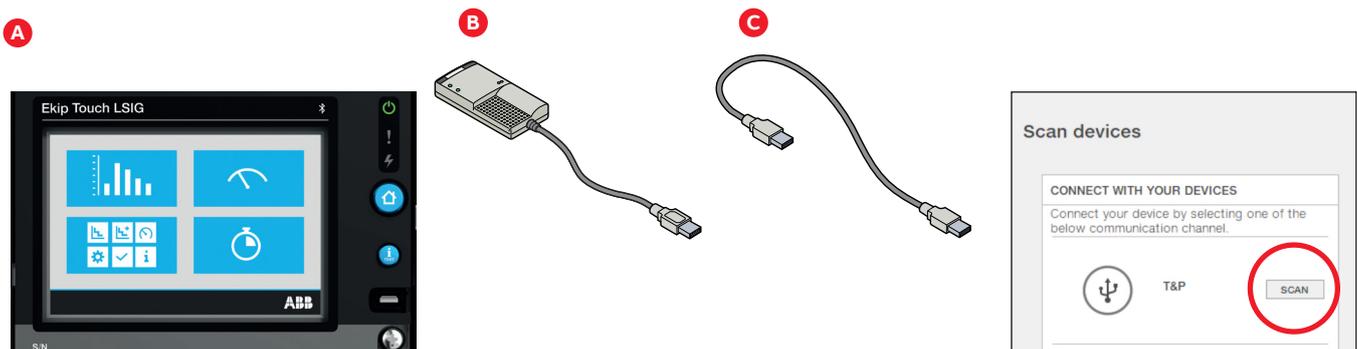
# 4 Application example

**⚠ ATTENTION: remember to manually setup delay to zero during configuration. ALWAYS make sure that the delay of the external trip unit is set to 0 to enable fast tripping with TVOC-2.**

To customize properly Ekip 2k module, in addition to the possibility of configuring it directly from the menu of the trip unit, it is also possible to configure it by means of Ekip Connect software. In the following pages, we will outline the steps needed to complete the programming.

1. Launch the free Ekip Connect software on the customer supplied laptop.
2. Connect one side of the micro USB cable **C** to the Ekip T&P module **B** and the other side to the Ekip Touch trip unit **A**. Connect the USB connection on the Ekip T&P module **B** to the customer supplied laptop.

You can confirm the proper connection is made when the green power led is on . Active communication will be indicated via the orange transmission indicator  blinking on the Ekip T&P module **B**.



Note: It may be necessary to scan for the trip unit via T&P before the device will appear in the Ekip Connect software

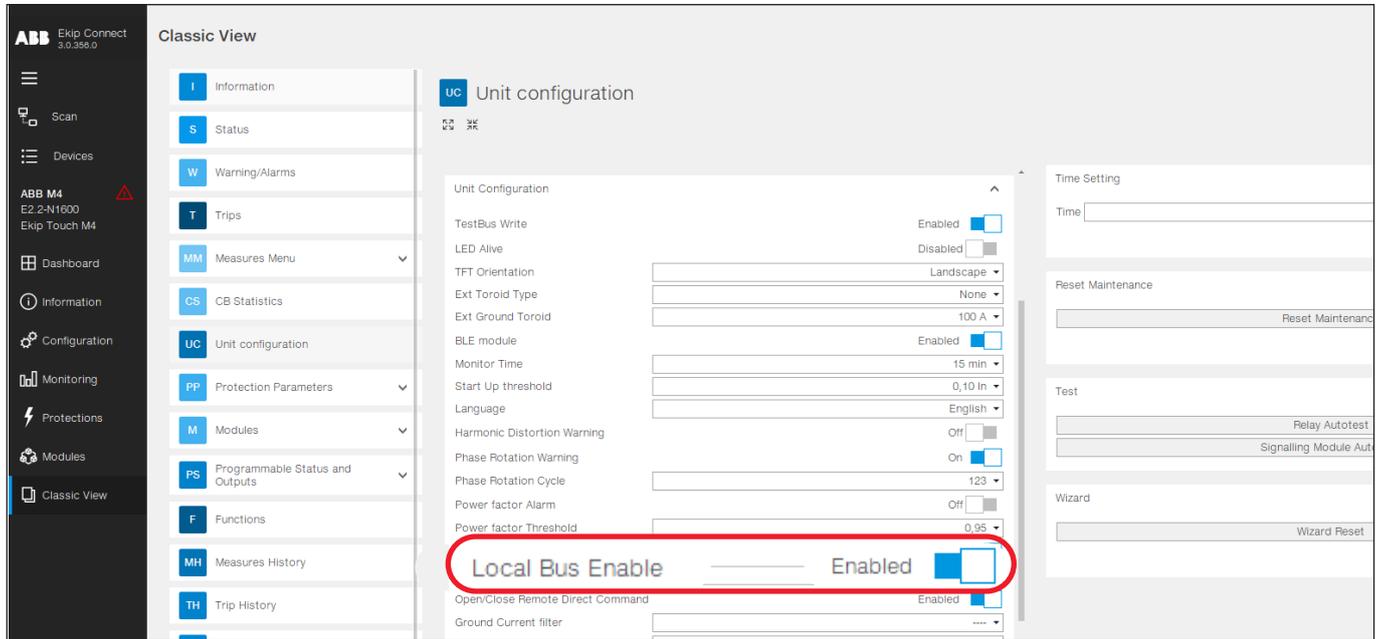
3. "Login" (default login PIN is 0001)



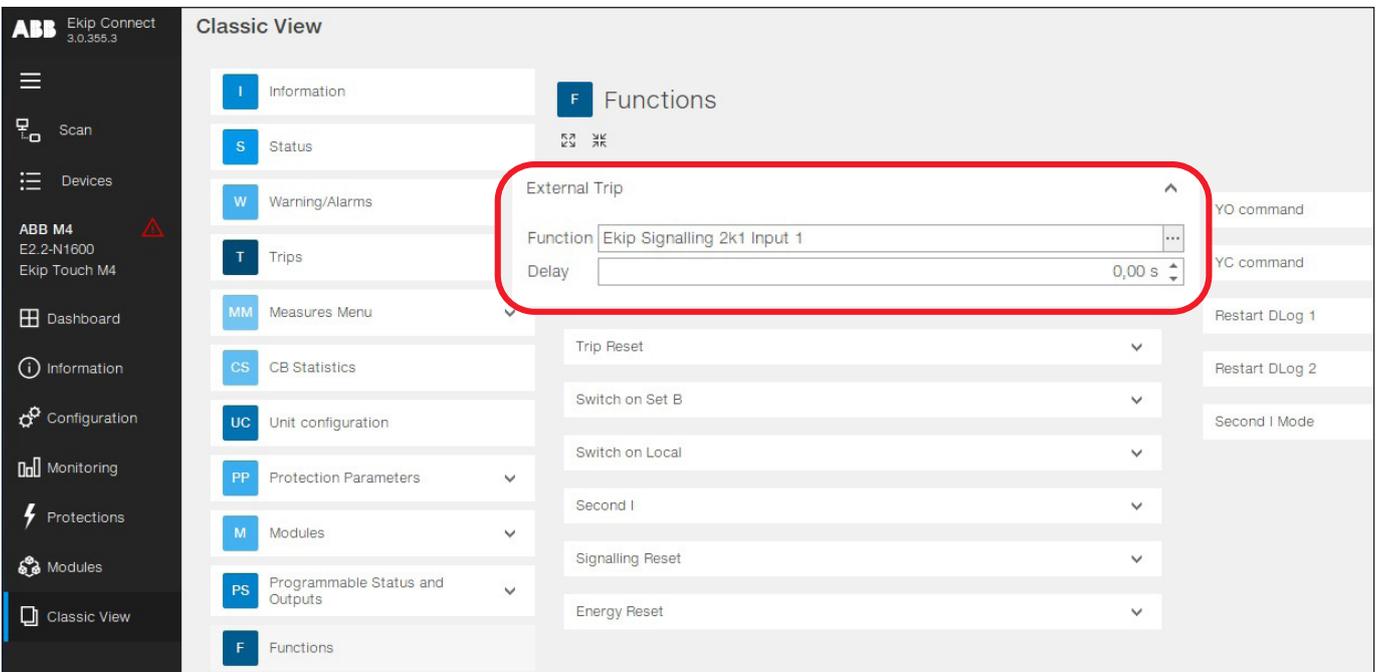
4. Select "Classic view" so all options are available. Now you are ready to begin programming.



5. Enable Local Bus to see Ekip 2K1 module



6. The next step is to program the signalling input of the 2K to trip the circuit breaker. In the left column select "Functions" and select "External Trip" in the main section of the window. ⚠️ Choose from the Function dropdown "Ekip 2K input 1" and set "Delay" to 0,00s.



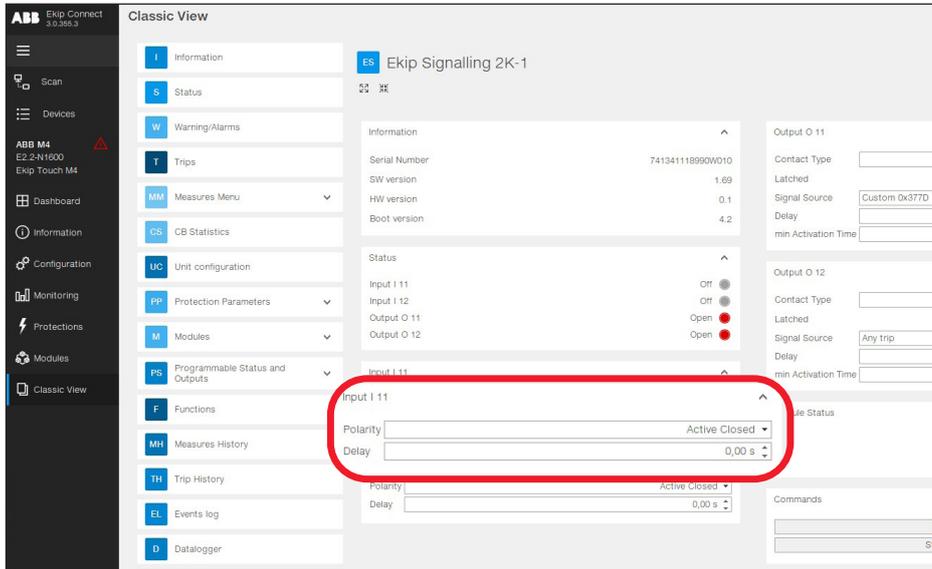
7. Click on "Apply" to save changes. The first time you submit any programming changes you will be asked for a PIN if it was not entered during login, the default PIN is "0001".



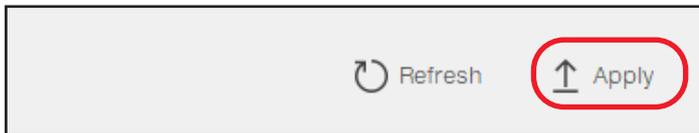
## 4 Application example

8. Next program the input of the Ekip 2K to be activated when receiving command by TVOC-2. In the left column select "Modules" > "Ekip 2k-1".

Ensure that the "Input I 11" polarity is set to "Active Closed" and "Delay" is set to 0,00s.



9. Click on "Apply" to save changes. The first time you submit any programming changes you will be asked for a PIN if it was not entered during login, the default PIN is "0001".





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