

How Medium Voltage Equipment Performance and Reliability Depend on Early Safety Considerations

by Didier Fulchiron

Executive summary

Implementation of Medium Voltage (MV) equipment safety best practices early on in the installation cycle reduces the potential of future electrical fault issues. Equipment performance and ROI decline when safety precision is not specified. This paper reviews MV equipment installation best practices and also discusses how to improve safety during maintenance phases.

Introduction

The high reliability performance of Medium Voltage (MV) equipment is dependent upon early consideration of safety-related issues. In fact, personal safety is enhanced when safety-related issues are addressed early in the equipment deployment cycle.

Many reliable designs have been compromised or have experienced electrical fault issues due to nothing more than a lack of safety planning during the design and installation processes. The electrical risk which is present during installation and service-related activities is compounded by the increased complexity of new, more technologically advanced power networks. This paper reviews the conditions that impact risk levels, both in terms of occurrence probability and severity. Guidance is provided on how to manage these risks.

Scope

“Risk analysis should be performed at the earliest stage, when all options are still open.”

Installations under consideration

MV equipment may be installed indoors or outdoors, on the ground, in vaults, on a pole, or in a building. This paper will only address installations within buildings but many of the practices discussed can be applicable to numerous situations and environments. The particular environment found within a building has a tremendous impact on the global safety level of the installation. The surrounding physical environment influences continuous service conditions as well as equipment access, maintenance, and, in some cases, fault consequences. Non-electrical hazards can also be present within electrical installations and numerous workforce conditions outside of electrical hazards can lead to accidents.

When addressing safety concerns, a focus on equipment alone represents a narrow approach. The context of where and how that equipment is operated is always of importance. A global analysis addressing potential risks should include a study of influencing parameters. Such parameters determine the occurrence probability and the possible severity of safety issues. The table in the **Appendix** of this paper illustrates a consolidation of the various interdependences that are discussed.

Although published best practices (i.e., installation standards like the IEC 61936-1, and application of local regulations, installation and operation rules as mandated through local standards) provide a sound basis for installation design, they don't address all the specifics of a given location. More detailed analysis is required to identify both the remaining risks and the mitigation of the possible negative consequences.

Undesirable events and associated causes

A safety or risk analysis should begin by identifying those events or situations to be avoided. From such a starting point, a sequence of events can be constructed that will reveal some possible contributing risk factors. Once identified, these factors can be analyzed so that protective measures can be put into place. In the realm of electrical installation safety, two major situations are identified during most failure occurrences: the arcing fault, generating significant physical damage to property and possible injuries to people in the vicinity, and the electrical shock of individuals. These two categories are analyzed in more detail below. The risk analysis should also consider consequences such as a fire started after an internal arc, or other safety issues not directly linked with any electrical event.

Arcing faults

Arcing faults occur as a result of flashover between energised conductors, or between conductors and earth – most often the frame of the equipment. The dielectric breakdown resulting in the flashover could be spontaneous, linked with some ageing effect of the insulation, or could be accidentally caused by a foreign object or an overvoltage. Depending upon the fault current involved, the energy released by the arc could be major or minor. The situation will depend upon the characteristics of the electrical network (short-circuit current, neutral management) and from the fault location (in the case of a 3-phase fault). In most

cases, the level of released energy is very high and causes significant damage to the physical installation and possible harm to nearby individuals (excessive heat, gas, sound, impact).

The IEC 62271-200 standard, which addresses metal-enclosed MV switchgear assemblies, provides a table with possible arc fault locations (within the switchgear assembly) and possible causes. The standard also provides examples of internal arc preventive measures. The table illustrates that multiple factors could contribute to arc fault including equipment design, installation, operation, service conditions and electrical parameters. Most of the causes considered in this table could also apply to any arc fault outside a switchgear assembly (e.g., on the connection point of a transformer).

Specifying an Internal Arc Classified switchgear means that, in case of an arcing fault inside during normal service, the switchboard device will limit the exposure of nearby personnel to the arc effects. Such a specification by itself, however, is not enough to address all possible situations. The set up of internal arc-classified switchgear assumes that the installation conditions as defined by the manufacturer are respected; otherwise the performance could be compromised.

Contacts with live conductors or energized parts

Contact with live conductors (direct contact) can occur when conductors are not enclosed, (bare conductors within air insulated parts of the installation such as line connections), or when personnel are accessing a piece of equipment under live conditions.

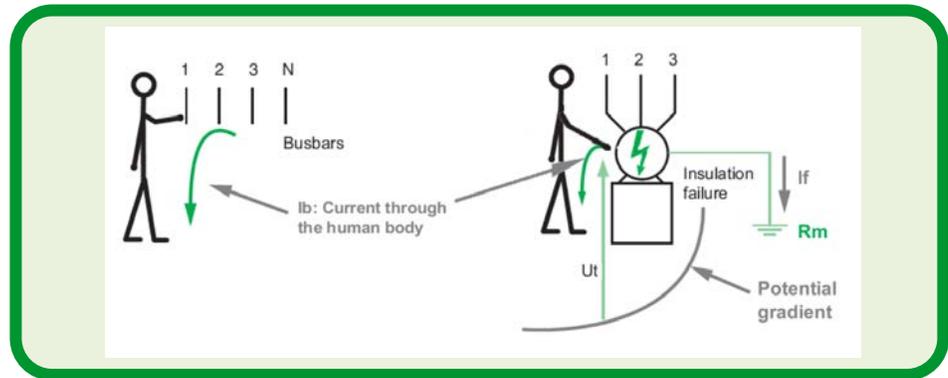
Standards and regulations that have been written to address desired installation procedures define minimal clearances to avoid accidental contacts with bare conductors. However, some situations could introduce risk factors not addressed by the regulations. Proper background information regarding the site involved and access restricted to only skilled individuals are some basic steps for safety. Influencing parameters and unusual situations should also be considered for a more comprehensive assessment of the risks.

In many instances live work procedures are well defined as the severity of working with live conductors makes operators aware of the delicacy of the situation. Live work situations are never considered as "usual" and, as a result, they are less prone to operator negligence. Accidental contacts rarely occur during live work.

Contact with energised parts (indirect contact) implies that a non-active conductive part (e.g. a frame or an enclosure) presents a safety threat due to lack of an efficient grounding connection which, in turn, can result in accidental energisation (see **Figure 1**). This can occur because of insulation failure, or the flow of a fault current through the part to ground when the impedance of the part and/or the grounding connection is not low enough. Such indirect contact situations are well documented as either "step voltage" or "touch voltage". The design rules that apply to grounding systems provide a relevant level of protection, provided that the connections remain effective and the values used for calculation are not exceeded.

Figure 1

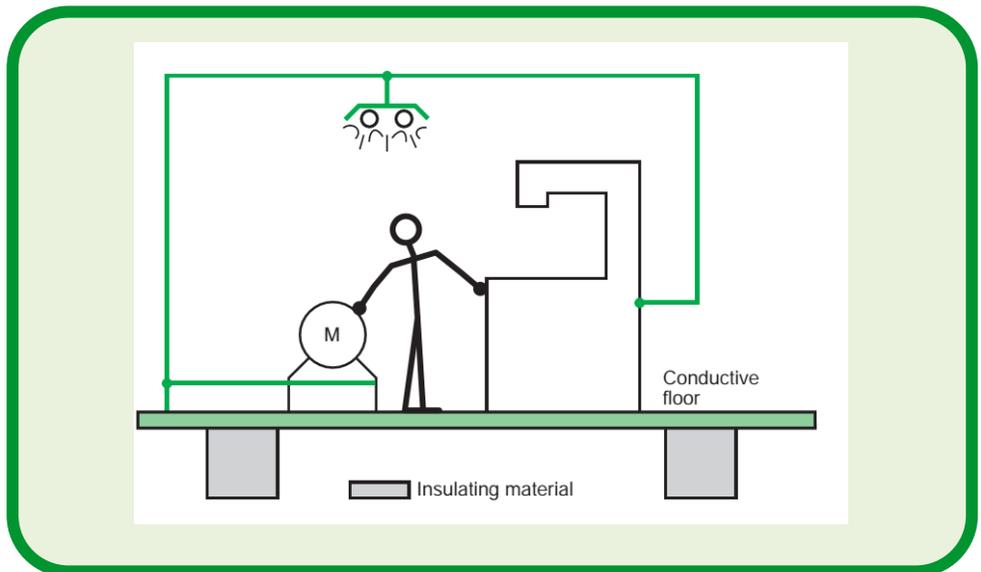
Direct contact versus indirect contact, both creating "touch voltages"



The potential by itself is not dangerous, but differences of potential are very dangerous. The key point for individual safety is to maintain a situation of equipotentiality around the relevant installation. Such a situation comes into play when work is performed on transmission lines with operators at the line potential. In these cases a good interconnection must be assured for all conductive parts that an operator may touch (see **Figure 2**).

Figure 2

Equipotential bonding of all exposed conductive parts simultaneously accessible



Other events

Work accidents within electrical installations are not all necessarily electrical accidents. Sometimes access difficulties create numerous safety issues as do instances where the wrong tools are utilized. Some typical situations include the following:

- Falls from ladders or other staging device used for working in high places;
- Injuries after collision with parts of equipment due to lack of space during operation or maintenance;
- Injuries linked with moving heavy loads without proper lifting tools.

In order to avoid such mishaps, reviewing the tasks that need to be performed, the free space that is required to perform the task(s) and the documentation of recommended procedures ahead of time are all prudent safety best practices. The documented procedures should

include the list of tools that will be needed as well as an evaluation of the working conditions within the targeted space.

Influencing criteria

External influences may have a detrimental impact on equipment performance and lead to failure when specified environmental limits are exceeded or unanticipated constraints are applied. The most common failure mode is dielectric breakdown which can initiate an arcing fault. Initial risk analysis should consider existing service conditions over time and monitor possible changes to these conditions. While focus is placed on personal safety, equipment failure cannot be ignored as it is often a trigger for dangerous situations. Therefore, in order to contribute to overall safety, an active initiative should be put into place that minimizes the failure rate of equipment and installations.

Environmental conditions

The specified service conditions of pieces of equipment (cables, switchgear, transformers, protection and control devices) generally include temperature, humidity, altitude and similar values. Field experience shows that uncontrolled humidity conditions represent the most influential / detrimental parameter. This relative humidity and temperature have a significant impact. Other contributing factors include the presence of dust or corrosive gases. Humidity and temperature inside a switching room are usually a result of the design of the building and the room where the equipment is placed. Therefore service conditions could be included as a consideration – and within of the scope – of the building or room designer if safety is to be optimized. If not, then a plan will need to be put in place to control and monitor temperature and humidity levels.

Electrical parameters

At the design stage of an installation, the rated characteristics of the equipment are determined according to the forecasted service, meaning voltage, load currents, switching transients and such. However, it could happen that the rated characteristics are exceeded during the service life, for example due to:

- Addition of loads, increasing the continuous current;
- Reinforcement of the supply network, increasing the fault level;
- Addition of cables or capacitors, modifying the transient characteristics;
- Exceptional events, the probability of which is low enough to be considered during design as acceptable (e.g. high level lightning strokes).

When rated characteristics are defined and validated as maximum values, any excess leads to the probability of increased risk, if not to immediate failure. Consequences of any such evolution should be cautiously investigated. Since some changes may not be documented, a periodic review of the existing electrical conditions is recommended.

Basic design choices

Neutral management

Choosing the type of connection to earth of the neutral point of the power supply has a significant influence on installation performance. Such a choice is not always open at the design stage, as the neutral management may be imposed by the utility's network if no transformer is used at the delivery point. Some of the main influencers include the following:

- Fault level to earth, and protection scheme;
- Step and touch voltages;
- Transient voltages on equipment;

- Service continuity (sustained fault operation, or first fault trip).

Single line diagrams

Preparing a single line diagram is often one of the first steps of the design of any electrical installation. The diagram organizes information about the loads, the power supply(ies) and some options for future operation. These diagrams reveal the following:

- Redundancy of circuits (influences service continuity, maintenance);
- Protection scheme (influences risk assessment, damage level, service continuity);
- Influence, if any, between loads (related with voltage drops, harmonics, and flicker).

The single line diagram can also have a significant influence on the safety of personnel throughout the installation's life time through the following points:

- Ease of earthing (grounding) operations (by the proper use of earthing switches);
- Capability for maintenance on dead switchboards (if redundancy, seen by loads);
- Opportunity to separate parts of equipment between several rooms (if any tie function).

Civil work

The civil work which will accommodate the MV portion of the installation could also have a significant impact on safety levels. In particular, two issues need to be addressed: risk of fault occurrence and risk of personal exposure. The risk of fault occurrence is affected by environmental stresses, by the possibility of animals or vermin accessing the equipment (see **Figure 3**), and by access of equipment to unskilled people. To manage these threats, the following actions are recommended:

- Control of climatic conditions around the equipment (e.g., temperature, humidity, ventilation);
- Protection against ingress of water, animals, dust; IP specification of the various pieces of equipment (which can enable remote monitoring) could address part of this concern;
- Access control (equipment in a given access zone should have the same skill level requirement).

The risk of personal exposure is directly linked with the presence of individuals in the vicinity of energised MV parts of installation. Such presence should be avoided as much as possible and civil work can help in several ways:

- Splitting the MV equipment between several rooms in order to never access a room with live equipment;
- Avoiding installation of auxiliary equipment (e.g., auxiliary power supply, communication) in the same room with MV equipment;
- Organizing remote operation of switchgear from an adjacent room.

The possibility of such undesirable events should be factored in when the design aspect of civil work occurs. When contemplating the risk of an arcing fault, the fact that operation is performed from an adjacent room is of little help if the wall between the rooms is going to collapse due to excessive pressure. Similarly, cable conduits or trenches should be checked to see what the impact of gas would be if no dedicated gas exhausts are built into the design.

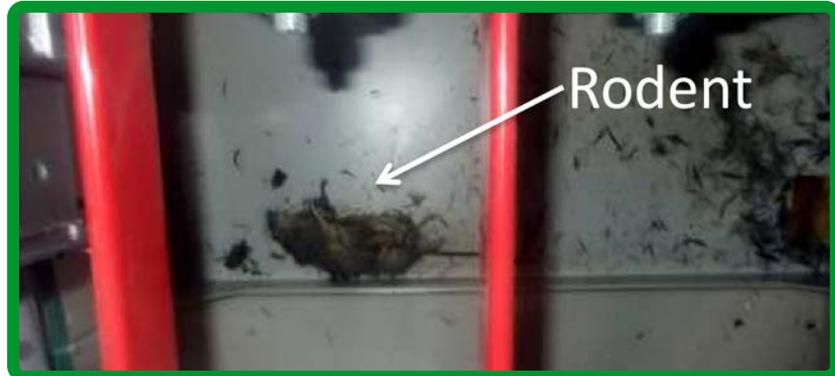
Ventilation

Proper ventilation is needed to cool a transformer in a substation; however, if airflow is poorly planned, air can trigger severe conditions on other components within a substation. Cold and damp air, as well as dust, has a direct negative impact on MV switchgear performance.

Areas that run the risk of explosion warrant automatic and fundamental arc effects mitigation and containment planning, as venting hot gases out can't be accepted. Other influences like dust in mining industries, or possible seismic events at the location, should also be listed as input for design criteria when switching rooms are constructed.

Figure 3

Small animals may trigger critical faults on energized parts, as this mouse in a busbar



The proper amount of space also needs to be factored in so that operators can be assured of safe and efficient work. Tight spaces increase the risk of abnormal situations like the impossibility of using a suitable ladder, or a limitation on the movements of the operator. Unfortunately, it is common to see additional pieces of equipment being installed in a switchroom over time. If such additional equipment was not forecasted when the initial space was configured, the crowding itself becomes a safety risk.

Lighting of the switching rooms is also a safety factor to consider. By providing clear visibility to all equipment and parts, it helps workers to avoid collisions and to manipulate their tools efficiently. Some regulations define a minimum lighting level for working areas, with various requirements between 200 and 600 Lux according to the kind of tasks performed.

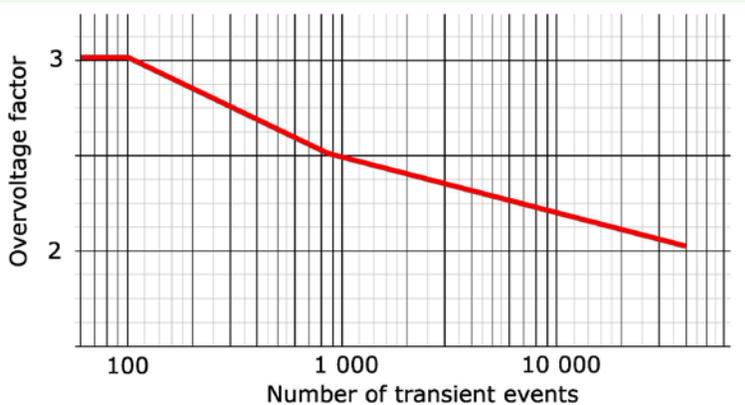
In regard to switchgear, several features can be specified which will influence work procedures and also impact the resulting safety of workers. Examples of these features include access conditions to high-voltage compartments (padlocks, interlocks, tools), the earthing (grounding) provisions which can include dedicated earthing switches, the proper identification of functions and circuits, the clarity of information regarding how to perform operations and how to check circuit conditions and so on. All these considerations will be influenced by the training level of operators, and the nature of local work habits.

In general, the equipment that is selected for installation needs to meet the performance criteria as defined by the operating parameters of the designated electrical installation. If some characteristics are easy to determine, such as service voltage, others could be more difficult to assess (such as the variation range of service voltage under multiple situations). In addition to those characteristics related to fault situations, as possible internal arc classification for switchboards for example, other characteristics also have to be assessed.

Network studies provide accurate and relevant data for supporting the specification of such characteristics (provided that input data are available). It can be difficult to acquire reliable data about a given connection point, and network operators could be reluctant to commit to particular fault levels, for instance. The challenge is even greater for acquiring data about any transient phenomena which could affect the equipment (see **Figure 4**). As a result, most simulations will require some conservative assumptions. If calculation results indicate a requirement just above an accepted threshold (e.g. 5 % above a common rating) the input data assumptions may have to be challenged.

Figure 4

Example of permissible transient overvoltages for capacitors over the service life.



Electrical characteristics

All the electrical characteristics of the various pieces of equipment should incorporate a built-in margin vis-a-vis the real (forecasted) operating conditions. A failure to do so will result in short term electrical faults or in pre-mature component aging (which in turn leads to medium term faults). Attention should also be paid to foreseeable future changes at the site (such as the evolution of a plant, the introduction of non-linear loads, or the modification of the starting sequence of a large motor) or to the supplying network (such as increase of the fault level, modification of the neutral management). The accumulation of many little changes, each of them considered as non-significant when implemented, may result in a global evolution exceeding the capabilities of the installed equipment. Keeping updated diagrams and documentation of all the modifications is critical in order to accurately assess the possible influence of a given change.

Audits should be launched on a regular basis in order to verify that the installation in question is still adequately documented. It could be valuable to request a third party to conduct such an audit. A "fresh set of eyes" may spot issues which would be missed by people familiar with the installation. Companies authorized to conduct regulatory inspections are usually also able to provide analysis and advice.

Table 1
Classification of device, function or system protections

Function, device or system protection classification criteria		
What is protected	How it is protected	What data is acted upon
<ul style="list-style-type: none"> A load or circuit from damage due to external constraint (e.g. overload); 	<ul style="list-style-type: none"> By opening an electrical circuit, stopping a current flow By closing an electrical circuit, extinguishing an electrical arc or ensuring equipotentiality By preventing an action from happening 	<ul style="list-style-type: none"> Current, the most common (line, ground, differential or residual) Voltage (value, phase, transients) Non-electrical parameters (temperature, liquid level, pressure)
<ul style="list-style-type: none"> A system from consequences of a damaged load or circuit (e.g., short-circuit protection); 		
<ul style="list-style-type: none"> A process from dangerous behaviour (e.g. under-voltage protection to avoid spontaneous re-start) 		
<ul style="list-style-type: none"> A piece of switchgear from its own defect (e.g. under-pressure lockout) 		
<ul style="list-style-type: none"> People from consequences of abnormal operation of systems (e.g., arc fault effects mitigation systems); 		
<ul style="list-style-type: none"> People from consequences of their own mistakes (e.g. low level residual current protection); 		
<ul style="list-style-type: none"> Goods and properties from consequences of abnormal situations (e.g. leakage current protection to avoid fire ignition); 		

It is common to consider three key concepts in any power protection system: the collection of information (via sensors), the processing of information (via relays) and the action (via the switching device). Each of these elements has specific characteristics which need to be consistent with the parameters of the planned installation. All three elements have an impact on safety.

When a malfunction occurs, the knowledge of the goal, principles, and thresholds of these three elements provides valuable input for assessing the situation and restoring the service. A proper monitoring system is essential to gathering the information from the various points within the installation, and also in establishing a diagnosis before attempting any corrective action. The attempt to restore the situation while the cause of the protection operation remains unclear could worsen the situation and introduces a higher level of safety risk.

Operational choices

The method of operation of a given installation has a significant influence on the site risk and safety levels. Early design choices also impact safety. Knowing ahead of time how one would like to operate a given site actually becomes a key input for defining design constraints. The performance level of the installation should never endanger personal safety. Therefore, expected performance criteria should be defined before the design, and should influence the determination of choices that impact personal safety

Continuity of service

Service continuity should be defined at several levels and be based on the criticality of the application and of the connected loads. An analysis should be performed to determine the normal operating conditions (i.e. without any fault on the installation itself) and the various fault conditions. Under normal operating conditions, the concerns could include the following:

- Loss of incoming power
- Need for maintenance
- Changes in the installation over time

These variables, should they occur will have an impact on:

- The single line diagram
- Organisation of switching rooms and general layout
- Choice of equipment (e.g. Loss of Service Continuity classes for metal-enclosed switchgear)
- Skill level of maintenance operators

Service restoration is not worth a life

Operators should be aware of risks when attempting to perform service on MV equipment. They need to be provided with proper background information regarding the installation and the nature of the event that is prompting an intervention. Access should only be granted if proper tools and protective equipment are supplied.

Although these steps are time-consuming; dealing with an emergency in the proper fashion is a particular skill which has to be acquired through experience.

Service continuity (i.e., service restoration after a fault event), represents the most common circumstance under which established safety rules are violated. Urgency often leads to hasty actions. If an installation has not been designed and built to provide the proper conditions for dealing with fault conditions in emergency situations, the procedures should clearly state how choices can be made to ensure safety, even leading to service continuity worsening.

A risk assessment implies that some residual operational loss of service may have to be accepted, based on the criticality rating of each part of the installation. The work procedures and information available for the operators must be clear regarding in which situations a partial or total loss is anticipated – and accepted. In this way, the operators will experience no abnormal pressure for dealing with an emergency event in an unsafe way.

Maintenance policy

Maintenance, regardless of whether it is periodic, predictive or corrective implies human access to electrical rooms (and to conductive parts usually energized). As a result, maintenance policies need to define the following:

- When maintenance is to be performed;
- Which individuals are going to be performing the work;
- What are the pre-requisites;
- What are the defined working procedures.

Any scheduled, periodic or predictive maintenance should allow for more than enough time to ensure that safety aspects and procedures are adhered to. Preparation time should be built into the overall schedule.

In a corrective action scenario, the preparation stage window is narrow, as the pressure from users or an emergency event (such as a fire) is elevated. An experienced professional operator helps to maintain safety under such situations of duress.

The pre-requisites for any maintenance operation represent a critical success factor. These include the following:

- The knowledge of the general setup (e.g., buildings, rooms, supply circuits);
- The identification of the piece of equipment under consideration;
- The technical knowledge and training for intervention on such equipment

- The proper definition and securing of the work area.

The responsibility for managing pre-requisites in maintenance situations can be shared by multiple individuals. For example the preparation steps of separation, earthing, and locking can be executed by a team leader, while other individuals can perform the actual maintenance. Under the pressure of exceptional events, the compliance with such an organisation is sometimes challenged, and rules may be breached.

A maintenance program should balance between worker safety and other performance parameters of the installation. A common example could involve special protection settings during maintenance work to limit the possible consequences of any electrical fault occurring during the work. Such special settings usually impair the global performance of the protection plan by forbidding auto-reclose attempts and by weakening coordination schemes. Such approaches can impact service continuity.

A maintenance policy should clearly define the task limits for each individual involved in the intervention. For example, is the person in charge of monitoring an installation able to perform any action, or should he refer to other persons for actions? Are these other persons actually available on short notice to deal with events? What is the back-up plan in case the designated individual is unavailable that day?

Equipment maintenance policies should be built around the recommendations issued by the various manufacturers of the pieces of equipment. However, both the type of service required and the local conditions could influence how that maintenance needs to be performed. The field experience of maintenance personnel should be leveraged in order to adapt to changes (e.g. changing the period for a given maintenance operation, or moving from periodic to predictive maintenance). A maintenance policy should be reviewed both periodically and immediately after any known changes to the installation.

Attention should also be paid to so-called general maintenance like room cleaning, vent cleaning, the condition of doors and other openings, plumbing checks, etc. as they can introduce change to the electrical installation environment. Oftentimes, if different organisations are responsible for electrical maintenance and general maintenance, unanticipated safety issues could arise.

Work procedures

Work procedures are established in order to achieve several goals:

- To provide a check-list for the operators
- To formalise safety policies and rules
- To build a referential of good practices

Work procedures should not be regarded as constraints. They should be recognized as a means for better defining operations, tools, and methodology surrounding the safety aspects of maintenance and should be viewed as a tool for keeping track of lessons learned. When the steps for accomplishing a specific task are written down, an opportunity presents itself for challenging old habits. In addition, it helps to share a common understanding among stakeholders (workers and management). Both parties share a similar concept as to why a given tool is necessary, how long an operation may take, which knowledge is applied, and what restrictions should be recognized and respected.

Most common pieces of PPE

General:

- hard hat
- non-flammable garments

Garments

- gloves
- glasses
- safety shoes

Electrical:

- isolating gloves
- facial screen
- arc rated garments

Tools and personal equipment

Not all interventions require tools, but working in a high voltage environment requires specialized equipment adapted to the task at hand. Such equipment is not restricted to personal protective equipment (PPE) which may be necessary and/or mandatory under some conditions, but also to practical day-to-day equipment and attire (such as flashlights, or clothes appropriate to the climatic conditions).

Doing what it takes to make a maintenance worker more physically comfortable contributes to safety by creating circumstances and an atmosphere less prone to possible mistakes. Some protective equipment is viewed as burdensome, and, as a result, this equipment is sometimes neglected. To avoid a situation where safety is compromised, any need for such equipment should be duly documented to ensure proper understanding of the risks and the reasons why such safety equipment is being recommended or mandatory.

Steps in planning can be taken to avoid such negligence situations. For example, in the realm of arc-flash protection, specialized equipment should be required as soon as a live piece of switchgear is open, regardless of the reason. When organizing single line diagrams which include dual-feeding options, design work can be performed that will allow the board to be de-energised before access.

Working with the tools (anywhere from a screwdriver to a crane) suited for the task is also a contributing factor to safety. Using the wrong tool can lead to injuries or falls. Work procedures should list any unusual or specialized tools that are needed to accomplish a given task. Limiting the overall volume of tools to be used within a given installation also helps to ensure that these tools will be readily available for use when needed.

Training of operators

Operators become knowledgeable and more safety aware when they receive relevant, consistent training. Following is a list of circumstances which should trigger a training refresh of maintenance workers:

- Changes of individuals in the work force;
- Introduction of new pieces of equipment;
- Evolution of the process or of the operating conditions of the installation.

Beyond providing updates, training helps to maintain the efficiency and confidence of operators when they are confronted with less-than-routine tasks. Doubts during emergency situations can lead to increased risk. Regular reviews of working procedures are the best way to increase situational awareness. Although work rules can be driven by both company policies and external regulations, safety considerations should never wait for regulation.

Conclusion

Despite the crucial importance of system safety surrounding an MV installation, most safety initiatives are viewed as unstructured and difficult to implement. Often carried out as art rather than science, common processes are riddled with missteps, incorrect assumptions, and miscommunication. MV installation safety begins at the initial design process. When safety is not considered early in the planning process, the result can be an irreversible compromise between performances of the MV network – including operation efficiency, costs, and service continuity – and personal safety.



About the author

Didier FULCHIRON graduated as an engineer from the "Ecole Supérieure d'Electricité" (France) and joined Merlin Gerin as a power test engineer in 1981. He took on several positions in the MV switchgear design department, as well as strategic marketing of protection relays. He gradually became more and more involved in standardisation work and is currently in a position dedicated to standardisation. He has published several "Cahier Technique" (technical papers) and has presented at industry conferences.

APPENDIX

Illustration of the multiple interdependencies when considering overall safety

The table below can be referenced by stakeholders early in a project in order to analyze possible scenarios and to better understand the possible ramifications of choices made.

		Cell is ticked when the item below has an influence on the item																						
		Civil work	Selection of equipment	Installation rules	Single line diagram	Auxiliaries	Grounding system	Maintenance programme	Maintenance work	Periodical inspections	Access rights management	Tools and PPE	Live work or not	Internal arc	Arc flash exposure	Indirect contact	Direct contact	Fire	Fall	Smoke/gases inhalation	Insulation coordination	Fault level calculation	Transients analysis	Protection scheme
Initial design	Civil work	x																						
	Selection of equipment	x	x		x			x	x	x	x	x		x	x	x	x	x			x			
	Installation rules	x	x		x	x			x	x	x	x				x	x	x						x
	Single line diagram	x	x						x	x	x	x												
	Auxiliaries																							
Maintenance items	Grounding system		x	x				x	x							x					x	x		x
	Maintenance programme		x		x				x	x	x	x		x	x				x					
	Maintenance work										x	x			x	x	x		x					
	Periodical inspections							x			x													
	Access rights management	x			x				x															
	Tools and PPE		x									x			x	x	x			x				
Possible events	Live work or not		x					x	x		x			x	x	x								x
	Internal arc	x	x								x	x	x					x	x	x				x
	Arc flash exposure		x						x	x	x	x							x	x			x	x
	Indirect contact																		x					
	Direct contact		x	x				x	x		x								x					
	Fire	x	x		x						x									x				x
	Fall	x	x					x	x			x												
Smoke/gases inhalation	x										x													
Electrical studies	Insulation coordination		x	x		x			x															x
	Fault level calculation		x		x	x				x				x	x	x								
	Transients analysis		x			x		x																
	Protection scheme		x		x	x		x	x					x	x	x								
Operation	Remote operation or not	x	x		x	x		x	x	x														x
	Skilled/unskilled operators		x	x							x	x			x		x							
	Operation rate		x					x			x													