HAZARD AND RISK ASSESSMENT OF HV SWITCHGEAR ASSEMBLIES – A VITAL POINT FOR PRODUCT SAFETY

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ABSTRACT

This paper introduces the basic principles of risk assessment and presents an assessment customised for HV equipment, using the example of metal-enclosed switchgear according to IEC 62271-200. Since no specific risk assessment guidelines are available for HV switchgear, the assessment guidelines of the EU Machinery and Low-voltage Directives are used as templates and adapted to HV equipment, although HV equipment does not fall under these directives. The tailored assessment refines the "intuitive" procedure of the product standard to an integral approach. In this way a manufacturer can fulfil his obligation to market safe products, follow up on the state of scientific knowledge and explicitly connect hazards to the respective sections of the standards. This method may also be used for HV installations.

INTRODUCTION

High-voltage switchgear – as every product – must comply with essential safety requirements which are given by the relevant legislation on industrial safety and the free movement of goods. In the area of machinery and low-voltage equipment the requirements are specified by EU Directives and related harmonised standards (figure 1). HV switchgear and controlgear, often being part of a machinery installation, is explicitly excluded from these EU Directives, however, it is not excluded from safety requirements as laid down in general product safety legal requirements.

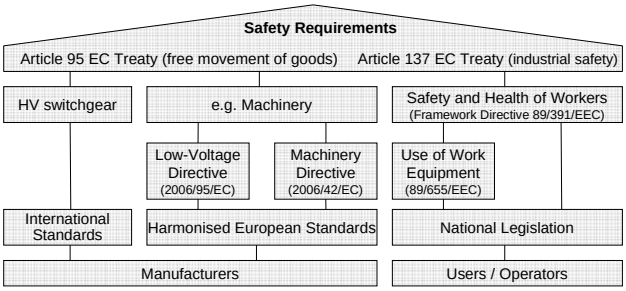

Figure 1: Fundamental safety requirements in Europe

An essential element to implement the state of art into safe product design is the identification of hazards which may be caused by a product. Both the probability that a hazard results in a harmful event and the possible degree of harm determine the risk which must be reduced to a tolerable level. IEC standards focus on safety requirements [1]. Insofar it can be presumed that a product standard addresses all relevant hazards of a product. Authorities acknowledge this in principle by presuming conformity with safety requirements if a product is built to such a standard.

In reality however, this is not the full view. Users may be aware of alleged or factual hazards which may not be covered by the standards. This should not be seen as a deficiency of standardization. Standards reflect the state of the art at the time they are published. When the state of the art evolves the standards will follow. The time in between requires special attention of the manufacturer.

Therefore the manufacturer should, apart from the application of standards, assess the products for any potential hazards, which – for whatever reason – could present more than a tolerable risk. The extra effort is acceptable, as "new" risks will require measures anyway if they are no longer seen as tolerable.

RESPONSIBILITY DURING PRODUCT LIFE

Safety requirements accompany a product throughout its entire life cycle. The equipment manufacturer has solely responsibility for a product from the development until the delivery. The user in turn begins to share responsibility with the installation of the equipment, as he is in charge of the conditions on site. In this phase the manufacturer gives guidance how to correctly transport, install and commission the equipment. The user accounts for application and operation of the equipment. However the manufacturer still is involved as he has the product monitoring duty.

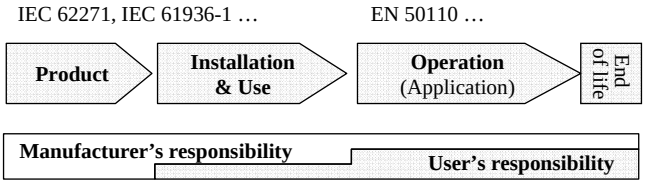

Figure 2: Responsibilities during product life

PRINCIPLES OF RISK ASSESSMENT

Safety-related risk assessment includes a series of steps, illustrated in figure 3 and described in the following for HV switchgear:

(A) Limits and scope of use of the switchgear assembly;
- design and type of switchgear and rated values
- ambient conditions
- Intended work procedures, besides the regular switching operations, e.g. maintenance, cable testing, work on LV control equipment.

(B) The next step entails the examination of the associated hazards, for example those due to

- electric shock
- arc faults
- electromagnetic fields
- stored charges (electrical / mechanical)
- mechanical hazards.

The examination of hazards must also take into account the history of service experience, i.e. knowledge about possible minor and major failures on the equipment.

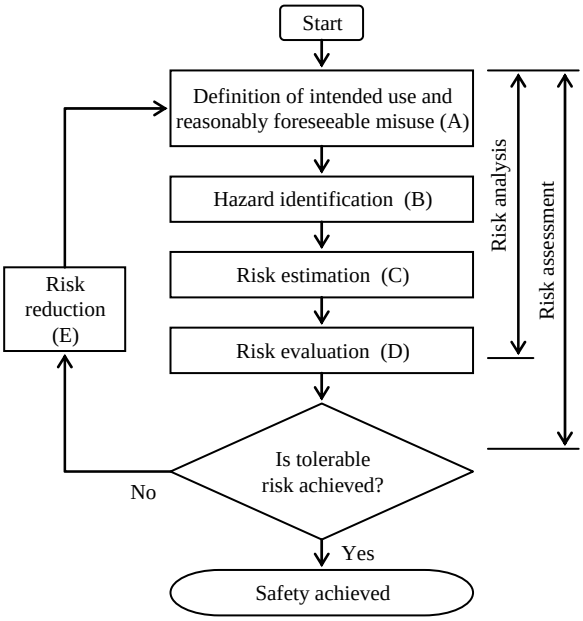

Figure 3: Risk assessment process

(C) The subsequent risk estimation considers the severity of harms and their probability of occurrence; such as the

- level and extend of damage caused e.g. by arc faults
- switching rate and probability of a failure on switching operation.

(D) Finally an evaluation is carried out to determine whether a tolerable risk has been achieved or a risk reduction through further measures is required. This can be done by using a risk graph, e.g. to [2], [3] or [4]. The graph results in a classification of the risk. It is dependant on the specific industry, which risk class is tolerated in this area.

(E) Risk reduction implies priorities. Whenever possible the design itself should be inherently safe, supplemented by protective devices and information for the user. For example the switchgear assembly is

- manufactured to the state of the art, i.e. according to IEC 62271 series [5], [6];
- correctly installed and earthed to IEC 61936-1 [7], EN 50522 [8]
- adequate network protection is used.

In case of existing "old" switchgear, retrofitting may also be an appropriate measure to improve the safety by design.

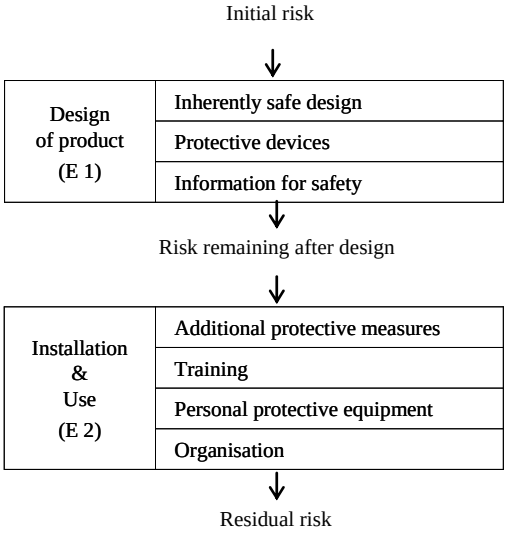

Figure 4: Risk reduction and its priorities

(E 2) Examples for measures against the risk remaining after design:

- precautionary measures to IEC 61936-1, e.g. clauses Installations and Safety measures
- basic principle to EN 50110, Operation of electrical installations [9]
- organisation, e.g. work procedures, surveillance, operation permit, training
- personal protective equipment (not required for metal-enclosed switchgear to IEC 62271 series).

IS SWITCHGEAR TO IEC STANDARDS SAFE?

Modern metal-enclosed HV switchgear has implicitly undergone the procedure of risk assessment several times during its development cycles. The risk caused by HV switchgear is in fact low, as verified by long service experience. However, a rising issue is, whether standards for HV switchgear and controlgear really cover hazards comprehensively. Although IEC standards for HV products focus primarily on electrical safety, they do not explicitly link the requirements to the hazards of a product. Hence the method described here offers an approach for hazard identification (Step B, Figure 3) in order to close this gap on the basis of existing guidelines.

The assessment systematically links all presumable hazards to the risk reduction measures stated in the relevant standards and in the product operation and installation manuals. In this way it can be proven that all possible hazards from switchgear are covered and which risk reduction measures have been taken for each individual hazard.

METHODOLOGY FOR HV SWITCHGEAR

There are no risk assessment guidelines available explicitly for HV switchgear. As an alternative, the assessment guidelines of the EU Directives on machinery and low-voltage

equipment are used, although HV switchgear does not fall under these directives. In detail this assessment follows the principles and the identification of hazards according to the analogous application of

- Annex 1, Essential health and safety requirements relating to the design and construction of machinery of the Directive 2006/42/EC on machinery [10];
- Annex 1, Principal Elements of the Safety Objectives for Electrical Equipment, of Directive 2006/95/EC relating to electrical equipment designed for use within certain voltage limits[1] [11];
- Annex A, C and D of IEC Guide 116 [2] Guidelines for safety related risk assessment and risk reduction for low voltage equipment.

The switchgear assemblies considered below are manufactured to international standards, e.g. of the IEC 62271 series where design, construction and testing requirements rule out hazards or reduce them adequately. Hence this assessment does not carry out further evaluations if a hazard is already covered by the standard.

Furthermore, the hazard assessment of HV switchgear assemblies does not cover effects and/or consecutive faults, caused by the switchgear, on the power, auxiliary and/or communication networks to which the switchgear is connected. And it does not cover effects on the electrical operating area where the switchgear is installed. It concentrates on the possible hazards that the equipment itself may pose to any person in contact with this equipment.

HAZARD CATEGORIES

The hazards are divided into several main categories, where each category is further subdivided describing specific sources of hazards. The complete list facilitates a thorough check whether all aspects of safety are covered. The main categories are:

HC 1 Essential health and safety requirements
HC 2 Design and construction
HC 3 Information requirements
HC 4 Control systems
HC 5 Guards and protective devices
HC 6 Installation, operation and maintenance

Essential health and safety requirements (HC 1) deal with the basics, i.e. design and construction must ensure that operation and maintenance under specified conditions do not put persons at risk. Materials used must not endanger persons' safety or health. The design of the equipment must facilitate safe handling and operation.

Design and construction (HC 2) cover

- electric shock and other electrical hazards
- hazards arising from incorrect functioning
- hazards arising from electric, magnetic, and electromagnetic fields, other ionising and non ionising radiation
- mechanical hazards, fire hazards and others.

Information Requirements (HC 3) deals with the accompanying product documentation with instructions for transportation, (temporary) storage, installation, operation and maintenance, including correct markings and warning signs.

Control systems (HC 4) must be designed and constructed to prevent hazardous situations and that they can withstand intended operating stresses and external influences. A fault in the hardware, software or a foreseeable human error during operation must not lead to hazardous situations. Control devices must be clearly visible and it must be possible to operate them without ambiguity.

Guards and protective devices (HC 5) must be of robust construction, securely held in place, not give rise to any additional hazard, not be easy to by-pass or render non-operational, be located at an adequate distance from the danger zone. For example partitions and shutters must be designed so that they can be removed only with tools and only by means of an intentional action.

Installation, operation and maintenance (HC 6) deal with the possibility to carry out adjustment, maintenance and repair. The equipment must be designed and constructed to allow safe access to all areas where intervention is necessary. Corresponding locking facilities must ensure that all energy sources remain isolated and reconnection is prevented. This category also covers information how to proceed with the equipment at the end of its operating life, taking into account environmental requirements.

EXAMPLE OF HAZARD ASSESSMENT AND DOCUMENTATION

As an example one hazard of the section "Protection against electric shock and other electrical hazards" is taken from the hazard category HC 2 design and construction. The assessment refers to metal-enclosed switchgear assembly according to IEC 62271-200 [6], internal arc classified (IAC) and installed in accordance with the manufacturer's instructions given by the installation and operating instruction manual. The columns in table 1 represent:

(a) number of item,
(b) designates the hazard,
(c) defines the hazard and corresponding requirement in column (b) adapted to HV switchgear,
(d) states whether the requirement in column (b) is applicable or not applicable to HV switchgear assemblies,
(e) explains the statement in column (d) and describes what kind of protective measures are taken to reduce a potential hazard or risk.

1 Colloquially called "Low-voltage Directive" (up to 1000 V_{ac})

Item	Hazard	Definition	Assessment	Observation
(a)	(b)	(c)	(d)	(e)
2	**Design and construction**			
2.1	*Protection against electric shock and other electrical hazards*			
2.1.1	Leakage current	Possible leakage currents must be limited during normal operation and – where applicable – during maintenance, when parts of the enclosure are open.	Applicable	Switchgear assembly complies with the requirements relevant to leakage currents: a) during normal operation: design and test of the metal enclosure according to IEC 62271-200, clauses §5.3.2, §5.102 and §6.10.3 b) during maintenance: design and test of non-metallic partitions and shutters according to IEC 62271-200, clauses §5.103.3.3 and §6.104.2

Table 1: Hazard assessment documentation

EXAMPLE "LEAKAGE CURRENT"

How does IEC 62271-200 cover the requirements regarding leakage currents?

a) Under normal operation all doors and covers are closed and the earthed metal enclosure prevents leakage currents. The relevant design clauses §5.3 of IEC 62271-1 [5] and §5.3.2 of IEC 62271-200 [6] refer to the reliable earthing of all metallic parts that may be touched during normal operating conditions.

b) During maintenance, when the enclosure may be open, protection against leakage current is given by both metallic or non-metallic partitions and shutters.

For metallic partitions and shutters provisions for earthing are covered by §5.103.3.2, IEC 62271-200, whereas for non-metallic subclause §5.103.3.3 defines the requirements for insulation tests and §6.104.2 for leakage current measurement.

CONCLUSION

The paper presents a procedure to systematically identify all relevant hazards of HV switchgear. Furthermore these hazards are linked to the particular clauses of the product standards. This procedure improves the quality of the development process and ensures the appropriate level of safety of the products.

The procedure compiles the relevant hazards associated to HV switchgear equipment and to verify the appropriate risk reduction. The identification of hazards to the principles of the risk assessment and the state of the art technology shows for specific switchgear assemblies that there remain no risks or only risks reduced to a tolerable level. The original hazards are reduced to a tolerable level by measures and tests in accordance with the applied international standards; these measures concern design and construction as well as instructions for installation, operation and maintenance.

The procedure described is not restricted to equipment itself, but it can also be applied to HV power installations. In this case, a broader set of standards, i.e. also standards for installation, earthing etc. must be considered.

REFERENCES

[1] ISO / IEC Guide 51, Safety aspects – Guidelines for their inclusion in standards

[2] IEC Guide 116, Guidelines for safety related risk assessment and risk reduction for low voltage equipment

[3] IEC 61508-5, Functional safety of electrical / electronic / programmable electronic safety-related systems – Part 5: Examples of methods for the determination of safety integrity levels

[4] ISO/TR 14121-1, Safety of machinery – Risk assessment – Part 2: Practical guidance and examples of methods

[5] IEC 62271-1, High-voltage switchgear and controlgear – Part 1: Common specifications

[6] IEC 62271-200, High-voltage switchgear and controlgear – Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV

[7] IEC 61936-1, Power installations exceeding 1 kV a.c. – Part 1: Common rules

[8] EN 50522, Earthing of power installations exceeding 1 kV a.c.

[9] EN 50110, Operation of electrical installations

[10] Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery; http://eur-lex.europa.eu

[11] Directive 2006/95/EC […] relating to electrical equipment designed for use within certain voltage limits; http://eur-lex.europa.eu