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Safety and risk in electrical low-voltage installations

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Content overview

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(*1958 in Vienna) is the owner of diam-consult, a licensed consulting engineering office for physics focusing on risk analysis and protective technology in complex technical systems, since 2001. He studied technical physics at the Vienna University of Technology. As an expert for basic electrotechnical safety matters, he has been working in national, European, and international teams in the area of safe electricity application for more than 25 years.

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1. Introduction

1.1. *Safety, limiting risk and residual risk*

As an indispensable basic concept for all reflections on protective technology in low-voltage installations, the concept of security, is widely recognised today as "*freedom from unacceptable damage risks*."

This means that safety is freedom that excludes every *unacceptable* damage risk and enables to classify a situation clearly as "safe" or "dangerous". The purpose of the planning and execution of low-voltage installations is to achieve safety while excluding risks.

Many discussions that have been conducted on this field of topics relating to the clear delimitation of "safety" and "risk" have been known for years in professional circles [3], so that only a few core statements will be elaborated here.

The delimitation between risk and safety is ensured through the introduction of the term "highest acceptable risk", interconnections which are represented in Fig. 1-1.

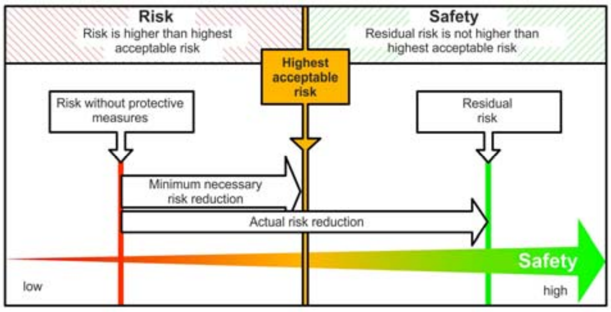

Fig. 1-1 Principles of safety philosophy for low-voltage installations and low-voltage equipment from a technical risk perspective. Reduction of the residual risk through additional measures that lead to clearly falling below the highest acceptable risk ("limiting risk") towards increased safety.

In practice, it must be ensured through adequate measures when planning and making equipment (e. g. low-voltage switchgear assemblies) that the risk that remains after the application of protective measures is as low as possible, and under no circumstances higher than the highest acceptable risk.

This "highest acceptable risk", also often called "limiting risk", must be achieved (with every switchgear assembly) in any case; in this respect, all measures that contribute to this limiting risk being achieved constitute minimal risk reduction measures. The requirements set forth in *the generally accepted technical standards*[1] define those *minimal protection requirements*.

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[1] Internationally-accepted technical standards (IEC), standards generally accepted in all European countries (EN), nationally-accepted technical standards (OVE, VDE …); for low-voltage switchgear assemblies, e. g. IEC/EN 6143 series.

However, this highest acceptable risk may not under any circumstances be confused with the concept of residual risk (see Fig. 1-1) because any technician entrusted with safety-relevant work must strive to keep the residual risk, which can never been completely excluded even when applying technical measures, *well below the highest acceptable limit*; i.e. as far as possible driving it in the direction of safety.

There are many motives for the realisation of (additional) measures in low-voltage switchgear combinations that go beyond the highest acceptable risk in the direction of higher safety.

The following motives can be stated by way of examples from practical experience:

- During the production, installation or maintenance in the switchgear assembly, conductive materials or assemblies may be left behind by mistake ("forgotten").
- Undetected material defects may exist or have been created during processing in the switchgear assembly.
- Small animals like mice, snakes, etc. getting into the switchgear assembly.
- Use of a switchgear assembly not suitable for the actual application, which may lead to overheating and subsequently to internal arcing.
- Unsuitable operating conditions (e. g. ambient temperature, humidity)
- Incorrect operation
- Insufficient servicing and/or timeouts during preventative maintenance

Switchgear assemblies that only fulfil the minimum requirements are very likely to fall below the highest acceptable risk in the direction of hazard when one of the aforementioned events occurs. If additional action is taken, the extent of damage in the installations and/or business interruptions with considerable consequential damages can be reduced. The same applies to any health impairments of employees that work in or near the plants. As it were, the low-voltage switchgear assemblies equipped with additional measures have some kind of "safety reserve".

1.2 Risk and consequential damages

Reflections on the minimal residual risk which is achievable through technical measures, however, especially in commercially and/or industrially used plants, must increasingly occur against the background of the possible *consequential damages* to be expected.

Consequential damages are costs that arise during business interruptions. Business interruptions in manufacturing companies can have a multitude of reasons, like e.g. shortage of raw materials, unplanned downtimes of production facilities as a result of occurring malfunctions caused by mechanical, electrical or control issues.

However, consequential damages also include costs which inter alia arise as a result of insufficient reliability of power supply (e. g. through nuicance tripping of protective equipment during storms), in case of breakdown of a plant, part of a plant or operating equipment.

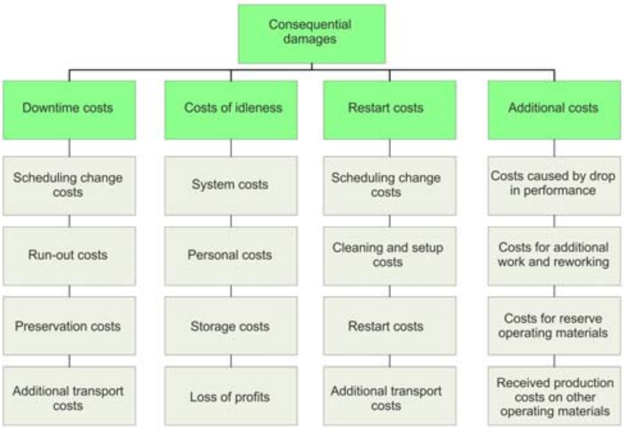

Fig. 1-2 Consequential damages (cost types) in the case of downtime of electrically powered production or processing plants

Without claiming to be exhaustive, major components of possible consequential damages are summarised in Fig. 1-2.

Of particular significance are business interruptions that occur as a result of a failure of power supply following damage or partial or complete destruction of the power distribution system (substation, main distribution boards and sub-distribution boards, cables and wiring systems). The particular significance of this group of business operations is that downtime costs and additional costs strongly increase with increasing length of interruption. In many cases, short-run servicing of the plant and the replacement of the operating equipment necessary for servicing (e. g. circuit breakers, bus systems) is not possible.

2. System protection and consequential damages

Installation-specific consequential damages can be detected with the help of the Damage Interruption Function. Recovery costs, e.g. of the low-voltage switchgear assemblies and damaged system parts, must naturally always be added.

2.1 Damage Interruption Function

The Damage Interruption Function[2](S), in a few publications [6] also referred to as Customer Damage Function[3], can be defined as the functional connection between the emerging damage in an electrical installation during failure of the installation(or during its restricted operation) and the duration of interruption.

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[2] Damage Interruption Function

[3] This designation appears especially in publications and in calculation methods the content of which regards the evaluation of customer-specific damage in the case of breakdown of the public distribution network.

The function can show points of discontinuity if damage to the means of production occurs when a specific value of the duration of interruption is exceeded. A good example are preparations (e. g. food) which can no longer be further processed after a specific duration of process interruption and must be thrown away.

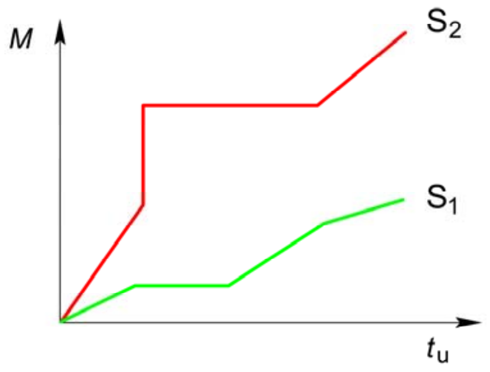

Fig. 2-1 Possible shapes of Damage Interruption Functions (S_1, S_2); M … damage (or consequential damages) in monetary units[4], t_u … duration of interruption of power supply, e. g. in hours

2.2 Detection of system-specific Damage Interruption Function

Consequential damages in the case of power failure can only be ascertained system-specifically with sufficient accuracy because of the major differences in the use of the installations.

Additionally, knowledge of the consequential damages, as expressed through the Damage Interruption Function, is also important for the interpretation of possible necessary backup power energy distribution systems. Also these backup power energy distribution systems[5] with their switchgear assemblies and the switchgear built in them must in many cases meet higher requirements than the minimum requirements stipulated in the *generally accepted technical standards*.

For the detection of specific system-specific Damage Interruption Functions from Damage Interruption Functions of more or less similar supply interruptions, detailed calculation concepts are available today (see [5] and therein cited literature).

Already on the basis of the incomplete overview provided in Figure 1-2, consequential damages, upon using the respective company-specific data, can be calculated for a specific electric system and compared with the costs for any additional constructive measures for the installation of the system.

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[4] Monetary unit (G): Monetary units can be defined as a specific amount of money, regardless of the respective currency, whereby the latter is also referred to as monetary unit.

Monetary units are often characterised with "G". As compared to the respective designation of a currency (e. g. euro), the monetary unit is rather the abstract form of a means of payment that appears repeatedly.

[5] Also for power backup energy distribution systems, which are planned and executed independently of those used for general power supply in normal operation, a Damage Interruption Function can also be ascertained as a basis for technical realisation.

For this, the data contained in the operational cost accounting of the respective company must be allocated to the individual cost types of the consequential damages, added up and represented as function of the duration of interruption (Table 2-1). A graphic representation of the appertaining Damage Interruption Function is shown in Figure 2-2.

Example of the evaluation of consequential damages (M) as function of the duration of interruption (t_u)						
		Consequential damages M [€] after t_u [hours] Duration of interruption				
	t_u	**3**	**6**	**12**	**18**	**24**
Shutdown costs						
	Scheduling change costs (information of customer about delays in delivery)	150	90	-	-	-
	Preservation costs (of semi-finished products and raw materials)	500	1000	2000	3000	4000
Downtime costs						
	Personnel expenses	**900**	**1800**	**3600**	**5400**	**7200**
	Loss of profits	**-**	**-**	**-**	**2000**	**3000**
Restart costs						
	Scheduling change costs (order restructuring)	-	-	90	150	150
	Cleaning and setup costs	-	-	500	500	500
Additional costs						
	Costs for spare operating materials	-	-	4000	8000	12000
	Contractual penalty (for failing to keep the delivery dates)	-	-	-	-	10000
Total consequential damages M [€]		1550	2890	10190	19050	36850

Table 2-1 Evaluation of the consequential damages M as function of the duration of interruption in the case of failure of the low-voltage switchgear assembly for the main distribution of a production/filling facility in the food industry; exemplary representation

For the calculation of the total damage, e. g. after a complete or partial destruction of low-voltage switchgear assemblies or system parts, recovery costs, e.g. of the low-voltage switchgear assemblies and damaged system parts, must be added.

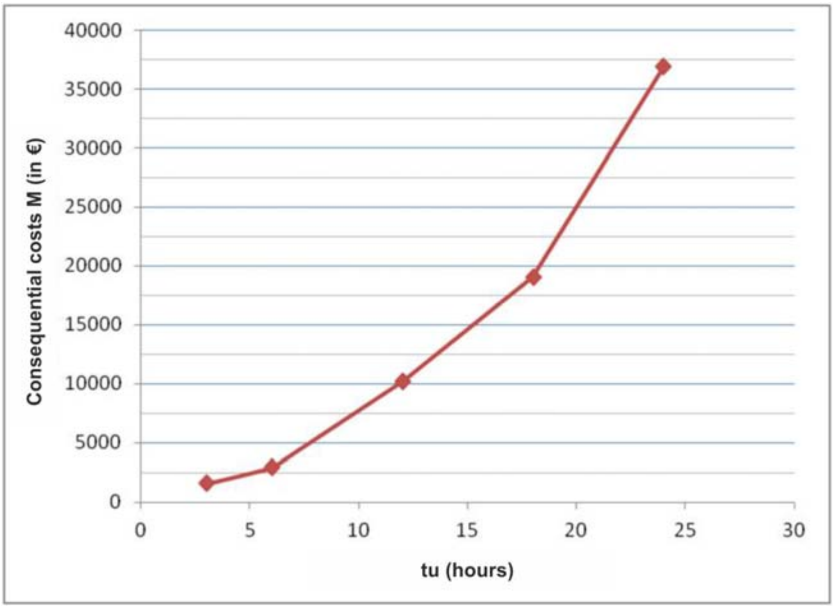


Table 2-2 Damage Interruption Function S; consequential damages M as function of the duration of interruption in the case of failure of the low-voltage switchgear assembly for the main distribution of a production/filling facility in the food industry; exemplary representation

2.3 Examples from the area of supply of information technological equipment

Low-voltage switchgear assemblies that support information technology equipment (IT equipment), that support business processes or such that manage the business process must always be carefully considered regarding their failure safety. In many cases, "only standard-compliant switchgear" is not enough.

System failures in this type of plants can cause considerable consequential damages, even when the period of interruption is only a few hours.

In [07], the following information can be found for IT equipment (already in 2007!):

"The costs for lost working time as result from hourly rate and number of concerned employees can always provide a very rough idea because other factors are usually more important:

Possibly, contractual penalties for untimely deliveries are to be paid, which is common practice in the automotive industry today.

Direct downtime costs also include any damage through loss of reputation that is difficult to quantify, like angry customers and suppliers.

The more business processes depend on IT, the more seldom cases will become in which the downtime of the IT system only has minor consequences. While, for instance, in such cases, you could at least still phone ten years ago, telephone exchanges are also integrated into IT today; at the same time, with e-mail, part of communication has shifted directly to IT."

A rough evaluation of the costs for the non-usability of IT equipment for a few branches is summarised in [07].

Industry	**Consequential damages / hour [$ US]**
Production	28 000
Logistics	90 000
Retail	90 000
Home shopping	113 000
Media (Pay per View)	1 100 000
Bank computing centre	2 500 000
Credit card processing	2 600 000
Broker	6 500 000

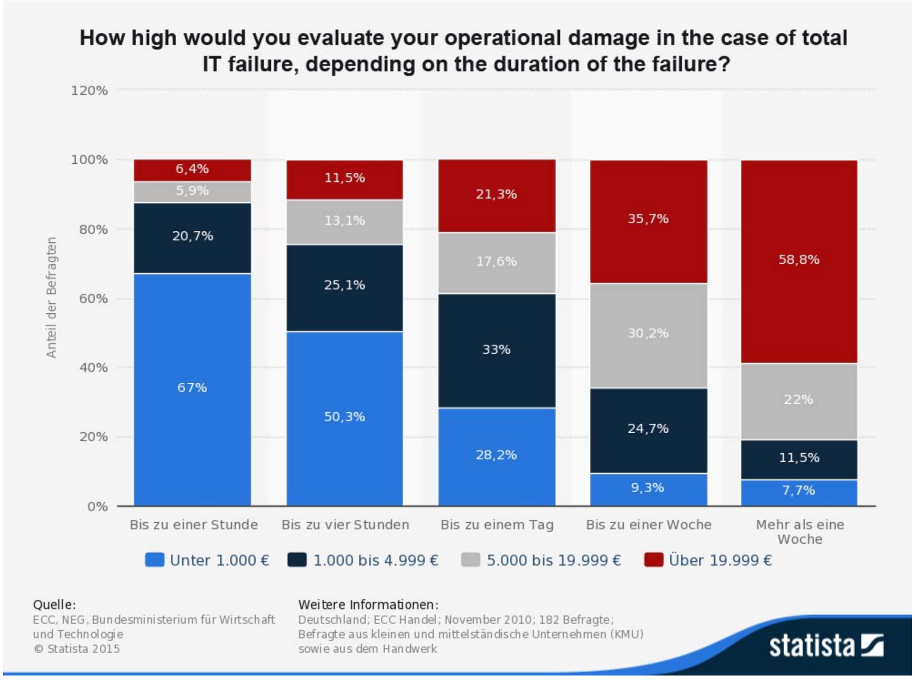
Table 2-2 Consequential damages per hour in the case of downtime of IT equipment; taken from [07]

A survey [8] of ECC retail conducted in Germany in 2010, in which 182 persons from small or mid-sized businesses and trade participated, produced the following result (Table 2-3):

Question: How high would you evaluate your operational damage in the case of total IT failure, depending on the duration of the failure?

In the case of a failure up to four hours 50.3% of those surveyed already estimated the damage to an amount between 1000 up to 4999 € and 11.5% of those surveyed estimated the damage to an amount above € 19,999.

In the case of a failure up to a week, 35.7% of those surveyed already estimated the damage to an amount above € 19,999.



How high would you evaluate your operational damage in the case of total IT failure, depending on the duration of the failure?

Quelle:
ECC, NEG, Bundesministerium für Wirtschaft und Technologie
© Statista 2015

Weitere Informationen:
Deutschland; ECC Handel; November 2010; 182 Befragte; Befragte aus kleinen und mittelständische Unternehmen (KMU) sowie aus dem Handwerk

Table 2-3 Results of a survey of small and mid-sized businesses (SMEs) and trade; taken from [8].

2.4 Action planning

For a specific planning of actions (that go beyond the minimum requirements of IEC 61439 and/or EN 61439) for the reduction of the residual risk in low-voltage switchgear assemblies, it is necessary to answer a key question, which is

How great is the importance/significance of the low-voltage switchgear assembly for the maintenance of operations and safety of the employees working next to the switchgear assemblies? (See Section 3)?

Assistance with answering this key question may be answers to the following questions:

1. What are the technical impacts of a failure of a switchgear assembly?

2. How high are the consequential damages; what does the damage interruption function look like?

3. What are the possible effects of a failure of the switchgear assembly on the employees ensuring servicing?

How are the *preventative maintenance measures* that are carried out regularly to prevent failures and to keep operating equipment in proper condition and *servicing*, e. g. repair, replacement of defective parts, carried out in practice?

4. How great is the damage to the company´s image because delivery times cannot be kept?

5. What are the impacts of a failure of a switchgear assembly on the environment?

3. Protection of employees and responsibility

3.1 Principles

Besides the consequential damages, there are also substantial references from European and national employee protection requirements urging to go beyond the (minimum) requirements stated in the *generally accepted technical standards* when planning and executing low-voltage switchgear assemblies.

3.2 Safety, state of the art and responsibility

Already in the Directive of the European Union from 1989 (see [10], in particular Article 6 (2)), the general principles for the safety and health protection of employees regarding all aspects concerning work are specified as an obligation of the employer.

Among other things, these are especially:

1. Prevention of risks
2. Combating risks at source
3. Consideration of the "human" factor at work, particularly with regard to the design of workplaces as well as the choice of work equipment and the choice of working and production methods, especially in respect of alleviating monotonous work and work at a predetermined work rate as well as reducing their effects on health.
4. Consideration of the state of the art
5. Elimination or reduction of hazards
6. Planning of risk prevention with a view to ensuring a coherent linking of technology, work organisation, working conditions, social relationships and impact of the environment on the workplace.
7. Precedence of collective risk protection over individual risk protection

Point 4 on this list clearly stresses that employers, in their efforts to create safe working conditions (workplaces), must follow *state-of-the art technology* and the latest insights in the field of work structuring.

Practically every workplace is affected by these requirements, also regarding the layout of the electrical low-voltage installation and with it the design of the low-voltage switchgear assemblies and/or the components used in them. Also in this respect, the *state of the art* is to be observed by employers with a view to also implementing this state of the art taking into account the existing risks.

Here it is particularly important that the *state of the art* in the sense of regulations for employee safety is not mistaken for the *state of technical standards*.

For example, the Austrian Employee Protection legislation B. [9] takes this into account in that it describes the state of the art exactly.

In § 2 (8) of [9], one can read:

> § 2 (8) State of the art
>
> State of the art in the sense of this Federal law is the stage of development of advanced technological processes, facilities and operating modes whose proper functioning is tried or proven and which is based on relevant scientific insights. When defining the state of the art, particularly similar processes, facilities and operating modes are to be used.

As a rule, the state of the art will be further advanced than technical standards. In the specific case of the planning, construction and running operation of low-voltage switchgear assemblies, this makes any considerations of employers *necessary whether it is not necessary to go beyond the requirements stipulated in the recognised rules of engineering when planning and executing the electrical system.*

As already represented in Section 1.1, only the minimum protective requirements are fulfilled when complying with the requirements of technical standards.

An example of measures that go beyond these minimum requirements are measures concerning arc fault protection which are discussed in Section 3.3.

These reflections on the safe design of workplaces become increasingly important in the case of a *work accident.* In many countries (including Austria [11]), administrative criminal proceedings are initiated if there is a founded suspicion that the work accident can be attributed to the culpable (intentional or negligent) behaviour of the employer. Under some circumstances, criminal court proceedings may also be initiated, for example for causing death by negligence, which may lead to the conditional or at most unconditional imposition of a term of imprisonment.

3.3 Arc faults in low-voltage switchgear assemblies

Protection against the effects of arc faults may be mentioned as an example of a measure that serves both the reduction of possible consequential damages and employee protection.

For arc faults, including in those installations that comply with the minimum requirements pursuant to IEC 61439 series (also pursuant to the previously applicable EN 60439 series), the following ignition causes can be specified:

- Condensation (humidity in the switchgear assembly)
- Pollution in the form of foreign deposits on busbars and parts of switchgear
- Transient overvoltages following storm and/or switching surges
- Premature (unnoticed) ageing of insulating materials following sporadic or thermal overload
- Loose or slack connections, defective contact points
- Working on parts of the substation

One of the possible consequences of the occurrence of arc faults is the complete destruction of the switchgear assembly.

In this respect, the steel-sheet housing, due to the high internal pressure from up to 15 - 25 t/m², also becomes a risk for the *surroundings and the persons working there*. It is not unusual for side walls, doors, built-in appliances to be ejected from the housing of the switchgear assembly under the influence of arc faults.

Here another possible consequence of arc faults, the emergence and spreading of so-called electrically ignited fires can only be pointed out.

A study conducted by the GDV (quoted in [4]) during the period from 1992 to 2001 mentioned "electricity"- with 24% - as the most frequent cause of major damage.

Measures that can minimise the effects of arc faults are specified in [12] or [13].

4. Summary

When planning and implementing low-voltage switchgear assemblies and the low-voltage installations supplied from them, it is in many cases necessary from a technical protection point of view to examine whether the minimum requirements specified in the *generally accepted technical standards* are sufficient for actual operation.

These studies follow, on the one hand, the Damage Interruption Function during complete or partial failure of such installations and the recovery costs for defective system parts and, on the other hand, the requirements (in many cases even stipulated by law) of employee protection and the associated liabilities of employers.

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