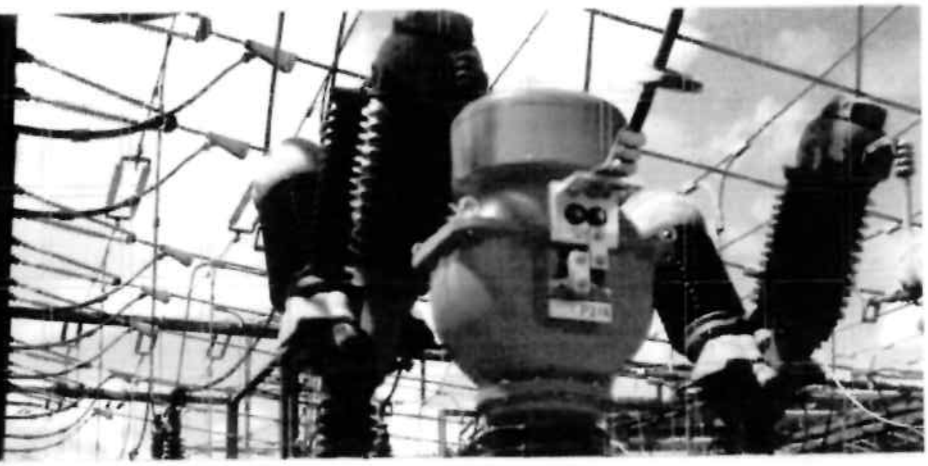
Institut für Elektrische Anlagen



Chapter 3: Procedure of Risk Analysis Regarding Earthing

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1 Chapter 3: Deterministic and probabilistic risk management processes

yellow … Theo: bitte telefonieren / anschauen

green … wird von Lothar erledigt z.B. mit Prof. Woess (Mathematik)

1.1 Introduction:

In case of an earth fault, according to the present version of EN 50522 <<< Theo: auf 50522 referenzieren?, the compliance concerning the permissible touch voltage U_T and the permissible body current I_B must be ensured for each fault point of the electrical grid.

In practice it is sometimes very expensive, if not impossible to reach the necessary touch conditions for each part of the electrical grid (e.g. small earthing systems on rocky surfaces) in an economic or technical reasonable way.

Based on these considerations and **because the complete absence of risk can never be obtained**, in some countries a risk-based analysis is described in their respective regulations. This approach is shown in Fig. 1 (shadowed green areas).

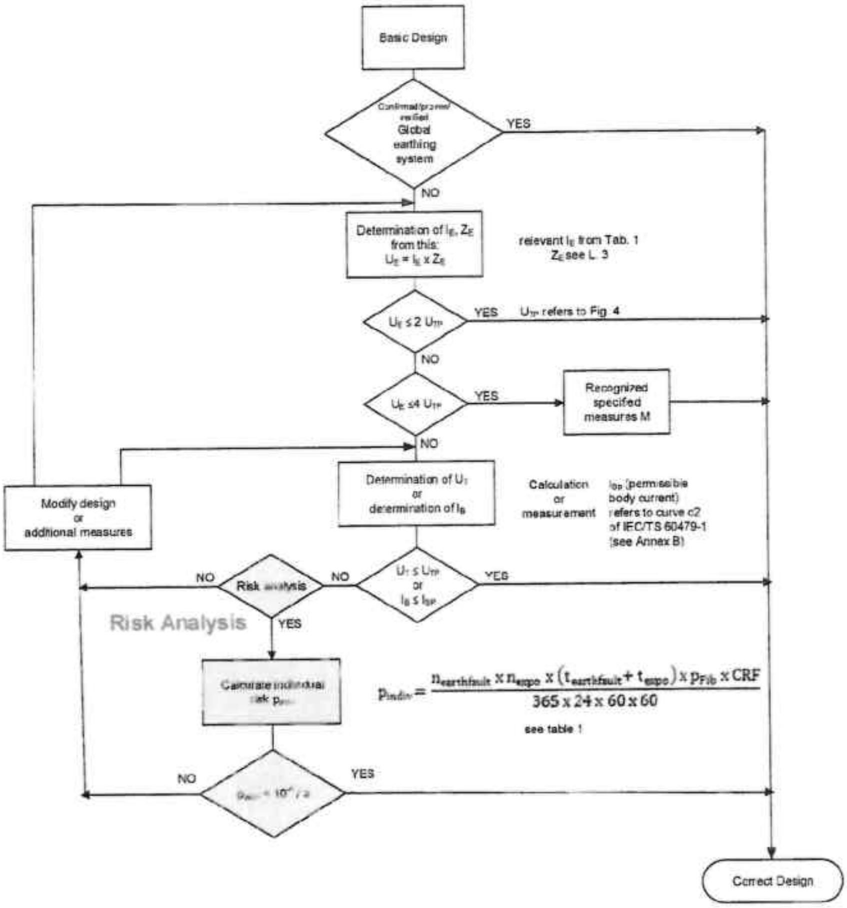


Fig. 1. Assessment scheme of earthing system regarding personal safety with taking account into a risk-based approach

Note: In the flow chart, also the role of a global earthing system is introduced as described in the present standard EN 50522.

1.2 Steps of the risk-based approach

1.2.1 General remark

The risk analysis and risk evaluation is carried out in three steps

1.) Calculating the probability of coincidence and taking other touch parameters into account
2.) Comparison with the permissible basic probability of 10^{-6} per individual and year
   irgendwie müssen wir auch noch Menschenansammlungen o.ä berücksichtigen, wir arbeiten gerade daran, die Vorgangsweise der australischen Norm transparent zu machen
3.) Comparison with a permissible probability limit

1.2.2 STEP 1a: Modeling and derivation of the basic formulas

General Considerations (tutorial) <<< klingt „tutorial" nicht zu schulmeisterlich?

The general stochastic derivation of the coincidence of two overlapping independent events 1 and 2, e.g. the occurrence of a EPR (1) and a contact situation (2), over a certain timespan, e.g. one year, is based on the

- frequency of occurrence of each event (f_1, f_2), e.g. per year, and on the
- duration of each of those events (T_1, T_2).

There are 2 possible, mutually exclusive, sequences (A, B) leading to such a coincidence:

Sequence A) While event 1 is already going on, event 2 sets randomly in

Sequence B) While event 2 is already going on, event 1 sets randomly in

Due to the rules of conditional probability, the frequency of sequence A is given by the product of the basic frequency of event 2 (f_2) and the probability that event 1 is already going on

$f_A = f_2 \times p_{event\ 1}$

$$f_A = f_2 \times p_{event\ 1} \qquad (1)$$

The latter is given by

$$p_{event\ 1} = f_1 \times T_1 \qquad (2)$$

resulting in

$$f_A = f_2 \times (f_1 \times T_1) \qquad (3)$$

The same consideration applies for sequence B:

$$f_B = f_1 \times p_{event\ 2} = f_1 \times (f_2 \times T_2) \qquad (4)$$

The superposition of two different, mutually exclusive events are

$$f_{coinc} = f_A + f_B = f_2 \times (f_1 \times T_1) + f_1 \times (f_2 \times T_2) = f_1 \times f_2 \times (T_1 + T_2) \qquad (5)$$

Mit Woess checken, ob rate of occurrence // frequency/year das Gleiche ist wie Wahrscheinlichkeit

These stochastic considerations are applied to earthing systems, regarding personal safety in case of an earth fault, the following designations are used.

Correspondences:

- Event 1 → earth fault causing EPR
- Event 2 → contact of the individual
- Hence the quantities of formula (5) become:
- f1 → $f_{earth\ fault}$ … frequency of earth faults per year and e.g. substation
- T1 → $T_{earth\ fault}$ … duration of the earth fault
- f2 → $f_{contact}$ … frequency of contacts per year in the relevant location

- T2 → $T_{contact}$ … duration of the contact

From this, the individual risk of the person from an electrical installation in terms of probability per person and year is to be calculated. For the complete risk assessment, also the probability of heart fibrillation p_{Fib} and a so called coincidence factor CRF (further details see below) are taken into account.

$$f_{fat} = \frac{f_{earth\ fault} \times f_{contact} \times (T_{earth\ fault} + T_{contact}) \times p_{Fib} \times CRF}{365 \times 24 \times 60 \times 60} \quad (6)$$

f_{fat}	…	frequency [per year] / risk of the individual to come into potentially dangerous contact with the considered equipment with increased EPR
$f_{earth\ fault}$	…	frequency of earth fault situations for the considered equipment [number of earth faults per year], typical values: see table below
$T_{earth\ fault}$	…	typical duration of an earth fault situation [seconds], typical values: see table below
$f_{contact}$	…	frequency of contact of a single individual with the structure under consideration [number of contacts per year], typical values: see table below
$T_{contact}$	…	typical duration of each contact of a single individual with this structure [seconds/contact], typical values: see table below
p_{fib}	…	risk of ventricular fibrillation [p.u.]
CRF	…	coincidence reduction factor [p.u.]

Remark 1:

"Earth fault situation" means e.g. single phase-to-earth or cross-country faults. The type of earth fault situation which has to be analyzed depends on the network structure and the operators' experience.

Remark 2:

"Considered equipment": e.g. high voltage pylon, ring main unit – RMU, low voltage equipment galvanically connected to h.v. or m.v. equipment through a T-N-system etc.

The value for the single quantities mentioned above can be taken from the operators' experience or from the following tables. The indicated values are only typical values and should be chosen according to the actual situation.

Tables (selection of typical values)

Die Tabellen stammen aus verschiedenen Quellen. Ich schlage vor, dass wir diese Werte der WG präsentieren zwecks Ergänzungen etc.

The estimation of frequency and duration of earth faults can be carried out per piece of equipment (selection 1) or on a more global base (selection 2).

Table 1 Fault Statistics: Frequency ($f_{earth\ fault}$) and duration of earth faults ($T_{earth\ fault}$)

Equipment	Earth faults ($f_{earth\ fault}$) per year	Specification	Duration ($T_{earth\ fault}$) in s
m.v. pylon	1.1×10^{-3}	-	0.15 ... 0.5
m.v. RMU	2.5×10^{-4}	in low ohmic gr. netw. in resonant gr. netw.	0,5 ...3,0 1800 ... 7200
pole mounted tr.(m.v.)	1.7×10^{-4}	in low ohmic gr. netw. in resonant gr. netw.	1,0 ...3,0 1800 ... 7200
h.v. pylon	5.3 x10-4	-	0.15 ... 0.5
h.v. busbar section	1.7 x10-4	-	0.15 ... 0.5
h.v. circuit breaker	3.8 x10-4	-	0.15 ... 0.5
h.v. feeder bay	2.1 x10-3	-	0.15 ... 0.5
h.v./m.v. transformer	5.0 x10-3	-	0.15
Transmission Urban substation	0.1		0.15 ... 0.5
Distribution Urban substation (=?)	0.1		0.15 ... 0.5

Table 2: Frequency ($f_{earth\ fault}$) and duration of earth faults ($T_{earth\ fault}$) - selection 2

Considered equ.	Earth faults ($f_{earth\ fault}$) per km x year	Specification	Duration ($T_{earth\ fault}$) in s
m.v. overhead line	7.0×10^{-2}	in low ohmic gr. Netw.	0,5 ...3,0
		in in resonant gr. netw.	0,5 ...3,0
m.v. cables	2.0×10^{-2}	in low ohmic gr. netw.	0,5 ...3,0
		in resonant gr. netw.	0,5 ...3,0

Table 3: Contact Statistics: Frequency (fcontact) and duration of contact (Tcontact) [2] = EG0

Location	Contact ($f_{contact}$) per year	Duration (Tcontact) in s	Remark
Transmission Urban < 66kV	100	4	
Transmission Urban > 66kV	135	4	
Distribution Urban	135	4	
Transmission distribution backyard	400	4	
Transmission distribution MEN	2000	4	
Aquatic (shower tap,...) 5 months/yr	400	60	societal based gatherig with population size of 50
Aquatic (shower tap,...) all year	960	60	societal based gatherig with population size of 50
Remote = ???	75	4	
Car engine heating	100	4	
Electric vehicle	500	2	
House backyard (cement mixer, water tap)	100	4	

Fibrillation Statistics

The parameter p_{fib} describes the characteristic survival rate depending on voltage - contact time - protective gear (shoes etc.)

For the worst case assumption, the value of p_{fib} = 1 p.u. is to be chosen.

Table 4: Fibrillation Statistics

p_{fib} = 1 p.u.

Other / more ideas e.g shoes, current path through the body (Huw, Australian Earthing Guide EG0?!)

CRF (Coincidence Reduction Factor)

The coincidence reduction factor CRF takes barriers, warning signs, etc. into account.

Table 5: Coincidence Reduction Factor

Barrier fence	0.1 p.u.
Insulation covering	0.4 p.u.
Restricted access	0.5 p.u.
Install sign	0.8 p.u.

1.2.3 STEP 1b: Calculating the probability of coincidence – multiple individuals

The risk for exposure of multiple individuals is derived from the a.m. risk of one individual to come into potentially dangerous contact with a structure with increased EPR by multiplication with the number of persons present at the same time during an earth fault and during this presence being in touch with the EPR from this structure.

$$f_{group} = f_{coinc} \cdot N \qquad (7)$$

N ... Number of number of persons present and touching the structure

<<< hier kenne ich mich noch nicht aus, wie man mit dem agglomerated / accumulated risk umgeht. Evtl. später ergänzen! Vorschlag: Australischen Ansatz weiterverfolgen.

1.2.4 STEP 2: Comparison with the permissible probability of 10^{-6} per individual an year

From various risk considerations, e.g. lightning protection, air traffic, bridges, household accidents, national risk assessment procedures for h.v. electrical equipment etc. for the fatality risks from electricity, a basic probability value of 10^{-6} per individual and year is taken as a common societally acceptable risk level in this document.

1.2.5 STEP 3: Comparison with a permissible probability limit

In some countries this probability limit is different for common public and workers.

1.3 Examples

1.3.1 Example 1: Jogger

Problem: A jogger goes for a run every day of the week. At the halfway point of each run, the jogger touches a metal gate next to a 275 kV tower for 1 s. Risk events occur for this type of OHL with a rate of 0.83/100 km/year. With an average tower spacing of 100 m, this results in an earth fault frequency per tower $f_{earth\ fault} = 0.83 / (100x10) = 8.3x10^{-4}$. Under the assumption that say five towers at each side contribute to significant EPR of the structure near the gate, the earth fault frequency has to be taken as $f_{earth\ fault} = 11 \times 8.3x10^{-4} = 9.1x10^{-3}$ per year. In other words, such an EPR happens once every $1 / 9.1x10^{-3} = 110$ "statistical" years. An EPR creates a touch voltage hazard on the gate for 1 s.

Solution:

$f_{earth\ fault} = 9.1 \times 10^{-3}$ per year

$T_{earth\ fault} = 1$ s

$f_{contact} = 365$ per year

$T_{contact} = 1$ s

CRF = 1 (worst case)

$p_{fib} = 1$ (worst case)

From these data, the individual risk of the jogger in terms of probability per person and year is calculated with equation (6):

$$f_{fat} = \frac{9.1x10^{-3} \times 365 \times (1+1) \times 1 \times 1}{365 \times 24 \times 60 \times 60} = 2.12 \times 10^{-7}$$

Assessment

This individual risk level is below the tolerable level of 10^{-6} defined above. Consequently, no further risk treatment action is necessary.

1.3.2 Example 2: Concrete Mixer

Problem: An amateur worker uses a concrete mixer in his back garden. The l.v. supply is carried out as TN system, which is centrally grounded (no multiple earth neutral, MEN) in the RMU. An earth fault at the m.v. side of the RMU transformer is tripped by protection within 0.5 s and may cause a transferred EPR through the protective earth wire of the l.v. installation into the metal frame of the concrete mixer.

Solution:

The numbers are taken from tables 1 and 2:

$f_{earth\ fault}$ = 2.5 x10^{-4} per year

$T_{earth\ fault}$ = 0.5 s

$f_{contact}$ = 100 per year (value for back garden)

$T_{contact}$ = 4 s (value for back garden)

CRF = 1 (worst case)

p_{fib} = 1 (worst case)

From these data, the individual risk of the amateur worker in terms of probability per person and year is calculated with equation (6):

$$f_{fat} = \frac{2.5x10^{-4} \text{ x } 100 \text{ x } (0.5+4) \text{ x } 1 \text{ x } 1}{365 \text{ x } 24 \text{ x } 60 \text{ x } 60} = 3{,}6 \text{ x } 10^{-9}$$

Assessment

This individual risk level is below the tolerable level of 10^{-6} defined above. Consequently, no further risk treatment action is necessary.

1.3.3 Example 3: ....

Problem: max 6 lines of text

....

Solution:

The numbers are taken from – e.g. -tables 1 and 2:

$f_{earth\ fault}$ = ... per year

$T_{earth\ fault}$ = ... s

$f_{contact}$ = … per year

$T_{contact}$ = … s

CRF = 1 (worst case)

p_{fib} = 1 (worst case)

From these data, the individual risk of the amateur worker in terms of probability per person and year is calculated with equation (6): >>> Example

$$f_{coinc} = \frac{2.5x10^{-4} \text{ x } 100 \text{x} (0.5+4) \text{ x } 1 \text{ x } 1}{365 \text{ x } 24 \text{ x } 60 \text{ x } 60} = 3{,}6 \text{ x } 10^{-9}$$

<u>Assessment</u>

....

More Examples: WG please help!

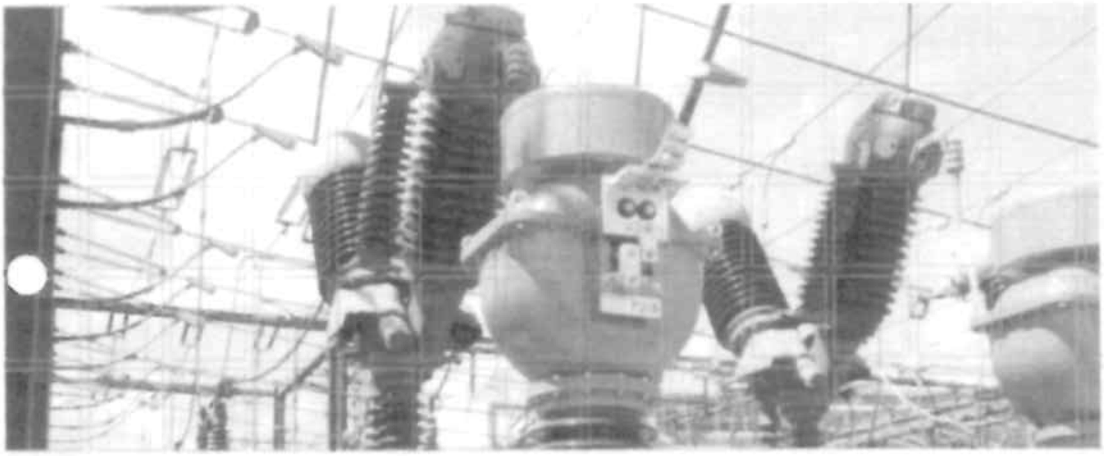
2 References

[1] EG-0, Power System Earthing Guide, Part 1: Management Principles, Mai 2010

[2] ENA – Power System Earthing guide

[3]

WISSEN ▪ TECHNIK ▪ LEIDENSCHAFT



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