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**ENGINEERING GUIDE
ON EARTHING SYSTEMS
IN POWER STATIONS**

**Working Group
23.04**

October 2002



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**CIGRE Study Committee 23
Working Group 04**

ENGINEERING GUIDE

ON

EARTHING SYSTEMS IN POWER STATIONS

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October 2002

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Annex 2: General table with reference to different standards

Annex 3: List of symbols

Annex 4: Examples and details of earthing systems

1 Objective and Scope

This report identifies the current practice of safety earthing systems in power stations. The objective of the report is to give suggestions and useful proposals for planning, design, calculation and construction of earthing systems in order to provide safe and effective installations. The contents of this report can also be used for checking of existing earthing systems.

This report has been prepared on behalf of Cigré Study Committee 23 (Substations and Electrical Systems in Power Stations). Study Committee 23 decided in their meeting in August 1994, that a report on safety earthing in power stations should be prepared by Working Group 23-04. Comparable reports have been prepared or will be prepared in future for gas-insulated substations (GIS) and air-insulated substations (AIS) by Working Group 23-02 /26/ and Working Group 23-03 /27/ respectively.

Functional earthing and electromagnetic compatibility are beyond the scope of this report as they belong to the scope of Study Committee 36.

The report is not intended to be a theoretical paper, but rather an engineering guide including reference to different rules and standards as applied in various countries. Special attention is given to current practice for different types of power stations.

The report will consider the interconnection of the earthing systems in power stations with the systems of associated extra high voltage substations. Test methods, mathematical analyses or quantitative analyses of the effects of lightning surges are not considered in this report.

A questionnaire (Annex 1) has been prepared and circulated to the members of the Working Group 23-04 to get additional information about the practice in other countries and utilities. These details have been included in the report.

2 Introduction

In general, electrical installations and therefore those in power stations, require an appropriate earthing system to protect human life against excessive touch and step voltages and to keep transferred potential to a minimum.

Today's high earth-fault currents in power stations underline the importance of earthing systems and the need for low resistance of the earthing grid.

The design of earthing systems has on one hand to meet technical requirements, but on the other to meet financial constraints.

The basic technical requirements are given in guidelines and standards, which may differ from country to country. This report tries to indicate main differences. For installations with voltages up to 1000 V most standards give fixed rules, while in general, earthing systems for electrical installations with nominal voltages above 1 kV need particular design.

This report leads the reader systematically through the design of earthing systems and the relevant standards starting with a list of definitions, symbols and standards.

The general design of earthing systems is detailed in §4 and § 5 deals with the specific design of the components of earthing systems such as earth electrodes and earthing conductors with regard to corrosion, mechanical stability and thermal stress.

§ 6 discusses earth electrode and tolerable touch voltages. The report concludes with examples of practical layout and recommendations for detailed design.

For the sake of consistency of the report reference has mainly been made to German VDE-standards and comparable IEC-standards, instead of a discussion of data from different standards throughout the text of the report.

Reference to relevant data in other guidelines and standards has been summarised in a general table (Annex 2). But this table contains only a selection of known guidelines and standards, because it is impossible to consider all existing guidelines and standards.

3 Definitions, Symbols and Standards

3.1 Definitions

As the terminology of guidelines and standards differs from country to country, the main terms are defined in this report as follows mainly according to IEC 50 (826) /16/ (except § 3.1.4, 3.1.5, 3.1.6)

3.1.1 Earth

The conductive mass of the earth, whose electric potential at any point is conventionally taken as equal to zero.

3.1.2 Earth Electrode

A conductive part or a group of conductive parts in intimate contact with and providing an electrical connection with earth.

3.1.3 Earthing Conductor

A protective conductor connecting the main earthing terminal or bar to the earth electrode.

3.1.4 Earthing Grid

A system of horizontal earth electrodes that consists of a number of interconnected, bare conductors buried in the earth, providing a common earth for electrical devices or metallic structures, usually in one specific location /3/.

3.1.5 Earthing System

The complete interconnected assembly of earth electrodes and earthing conductors /7/.

3.1.6 Step Voltage

The difference in surface potential experienced by a person bridging a distance of 1 m with his feet without contacting any other earthed object /3/.

3.1.7 Touch Voltage

Voltage appearing during an insulation fault, between simultaneously accessible parts.

3.2 Symbols

All used symbols are listed in Annex 2.

3.3 Standards

The principal relevant standards, as far as known, are as follows:

3.3.1 International

IEC 364-5-54 / 1980: Electrical Installations of Buildings, Selection and Erection of Electrical Equipment, Earthing Arrangements and Protective Conductors.

3.3.2 European Union

prEN 50179 / 9.96 (draft): Erection of Electrical Power Installations in Systems with Nominal Voltages above 1 kV.

3.3.3 Belgium

RGIE / 1981: General Regulation about Electrical Installations.

3.3.4 France

NF C 13-200: High Voltage Electrical Installations: Rules

NF C 15-100: Low Voltage Electrical Installations

3.3.5 Germany

DIN VDE 0100, Part 410 / 11.91: Erection of Power Installations with Nominal Voltages up to 1000 V, Selection and Erection of Equipment; Earthing Arrangements, Protective Conductors, Equipotential Bonding Conductors.

DIN VDE 0141 / 7.89: Earthing Systems for Power Installations with Rated Voltages above 1 kV.

3.3.6 Italy

CEI 11-8 / 11.89: Earthing Systems.

CEI 64-8 / 10.92: Electrical Installations of Buildings

3.3.7 Netherlands

NEN 1010 / 1996: Safety Requirements for Low-Voltage Installations.

3.3.8 North America

IEEE Std 80 / 1986: Guide for Safety in AC Substation Grounding.

IEEE Std 665 / 1995 : Guide for Generating Station Grounding.

3.3.9 Norway

FEA - F / 1995

3.3.10 Sweden

STEV-FS 1988:1 and 2: Design and Maintenance of Electrical Installations.

3.3.11 United Kingdom

BS 7430 / July 1991, Code of Practice for Earthing Engineering Recommendation.

BS 7671 / 1992, 1994: Requirements for Electrical Installations

The standards detailed in the reference list are used and compared in Annex 2.

4 Design of Earthing Systems

4.1 General

An earthing system consists of two elements, the earth electrodes and the earthing conductors.

The design concentrates on the choice of conductor material, the adequate cross section and the determination of the configuration.

Starting points for design and dimensioning of an earthing system are:

- corrosion and mechanical stability of earth electrodes and earthing conductors
- maximum earth-fault current flowing through earth electrodes, earthing conductors and fault duration, causing thermal stress for the elements of the systems
- earthing voltages, depending on the soil characteristics

If the earthing system has been designed in accordance with the starting points as mentioned above a final check has to be made regarding the resulting touch potentials as required by the relevant standards.

The design of earthing systems for electrical installations with rated voltages up to 1000 V is normally fully covered by relevant standards. Therefore applicable standards will only be compared in this report and not discussed in detail, as these design rules may be assumed as common practice.

4.2 Maximum Earth-Fault Current and Fault Duration

The dimensioning of earthing systems is determined by the level of the earth-fault current entering the earthing grid and on the duration of the earth-fault. The latter is determined by the clearing time of the protection system.

For safety reasons it is recommended that the clearing time of the back-up protection be used in the design. Typical values range from 0,25 - 1,0 s. However, these values need to be checked separately for each case. In power stations the generator short circuit current with its high time constant needs to be paid particular attention.

In power stations with different voltage levels and a common earthing system the maximum earth-fault currents have to be calculated for each voltage level. The maximum current so derived is used as starting point for the design. The value of the earth-fault current is, to a great extent, dependent on the type of neutral earthing of the electrical system considered. The relevant fault duration has to be considered.

The calculation methods for earth-fault currents are not discussed further in this report as they are thoroughly dealt with in textbooks and standards. Only the generator earth-fault current will be paid special attention to.

4.3 Relevant Currents

Dependent on the type of power supply system the following maximum earth-fault currents have to be considered for the dimensioning of the earthing system according to DIN VDE 0141 / 7.89 /1/ (table 4):

type of power supply system	maximum earth-fault current I''_{kE}	
	earth electrode	earthing conductor
with isolated neutral	-	I''_{kEE}
with earth-fault compensation	-	I''_{kEE}
with directly or via low resistance earthed neutral	I''_{k1pol}	I''_{k1pol}
with earth-fault compensation and temporary directly or via low resistance earthed neutral	I''_{k1pol}	I''_{k1pol}

Table 0: Maximum earth fault current

I''_{kEE} = double earth-fault current
 I''_{kEE} shall be calculated according to DIN VDE 0102 / 1.90 /4/ resp. IEC 909 /5/ or the relation $I''_{kEE} = 0.85 I''_{k3pol}$ may be used.
 $I''_{k3pol} = I''_{k3} = I''_k$ = initial symmetrical short circuit current

I''_{k1pol} = initial single phase short circuit current
 I''_{k1pol} shall be calculated according to /4/ resp. IEC /5/.

4.4 Generator Voltage Level

The maximum earth-fault current I''_{kE} for the thermal design of the earthing system for the generator voltage level should be determined with reference to the neutral earthing of the power supply system (see § 4.3).

The earth-fault current is composed of two elements:

$$I''_{kEN} = I''_{kEG} + I''_{kEN}$$

I''_{kEG} = current contribution of generator

I''_{kEN} = current contribution of EHV-system (EHV = Extra High Voltage)

With regard to the fault duration, the contribution of the EHV-system I''_{kEN} is determined by the network protection. The contribution of the generator I''_{kEG} will continue as long as the generator is excited. The decrease of this contribution is, therefore, defined by the time-constant of the generator de-excitation. For practical reasons it is usual to use the clearing time of the network back-up protection.

Although the decaying generator element of the current still flows after clearing of the fault by the network protection this is not relevant for the dimensioning of the earthing system.

5 Design of Earth Electrodes and Earthing Conductors with Regard to Corrosion, Mechanical Stability and Thermal Stress

5.1 General

Earth electrodes, buried in earth or embedded in concrete, and earthing conductors have to be designed with regard to the earth-fault current and the earth-fault duration. The minimum sizes of earth electrodes and earthing conductors have to be considered in relation to corrosion and mechanical stability and independently of the earth fault current. In most countries these minimum sizes are specified in the relevant standards.

5.2 Choice of Material

The most common material used for earth electrodes and earthing conductors is copper. In addition to their high conductivity copper conductors have the advantage of being resistant to corrosion when buried. In case of particularly aggressive grounds the application of lead coated copper or tinned copper is recommended. Galvanised or corrosion-resistant steel is usually used for earthing rods. The aluminium enclosure of generator busbars is often used as earthing conductor.

5.3 Design of Earth Electrodes and Earthing Conductors of Power Installations with Rated Voltages above 1 kV

5.3.1 Design with Regard to Corrosion and Mechanical Stability

5.3.1.1 Earth Electrodes

For the design of earth electrodes with regard to corrosion and mechanical stability the minimum sizes shall be determined in accordance with table 1 (according to /1/ (table 5) and prEN 50179 / 9.96 (draft) /2/ (Annex A)).

5.3.1.2 Earthing Conductors

The minimum sizes for the design of earthing conductors with regard to mechanical stability are given in table 1 (according to /1/ (§ 4.3) and /2/ (§ 9.2.2.2)):

Material	Cross section in mm ²
Copper	16
Steel	50
Aluminium	35

Table 1: Minimum sizes of earthing conductors with regard to mechanical stability.

Material		Kind of Earth Electrode	Minimum Size				
			Core			Coating	
			Diameter mm	Cross Sect. qmm	Thickness mm	Single Value µmm	Average value µmm
Steel	Galvanised	Strip		90	3	63	70
		Profile/plate		90	3	63	70
		Pipe	25		2	47	55
		Round Rod f. Earth Electrode	16			63	70
		Round Wire f. Surface Earth Electrode	10				50
	Lead Coated	Round Wire f. Surface Earth Electrode	8			1000	
	Copp. Coated	Round Rod f. Earth Electrode	15			2000	
	Copp. Plated	Round Rod f. Earth Electrode	14,2			90	100
Copper	Bare	Tape		50	2		
		Roud Wire f. Surface Earth Electrode		25			
		Cable	1,8 SW	25			
		Pipe	20		2		
	Tinned	Cable	1,8 SW	25		1	
	Galvanised	Strip		50	2	20	40
	Lead Coated	Cable	1,8 SW	25		1000	
		Round Wire		25		1000	

Table 2: Materials for earth electrodes and their minimum sizes regarding corrosion and mechanical stability (SW=single wire)

5.3.2 Design with Regard to Thermal Stress

5.3.2.1 Earth Electrodes

Earth electrodes have to be designed with regard to thermal stress only in case of power supply systems with directly or via low resistance earthed neutrals (refer to § 5.3.2.2.). Power systems with temporary directly or via low resistance earth neutrals are also included. Where power supply systems have isolated neutral or earth-fault compensation, the minimum sizes (refer to § 5.3.1.1, table 1), have to be considered.

5.3.2.2 Earthing Conductors

The following minimum cross section A is required for the thermal design of earthing conductors:

$$A = I''_{kE} / G \text{ in mm}^2$$

I''_{kE} = maximum earth-fault current in A

G = earth-fault current density in A / mm²

G can be determined by calculation or can be derived from diagrams (fig. 1 and 2).

For calculation, the earth-fault current density generally determined using the permissible final conductor temperature (refer to /1/ (§ 3.2.1)), with the following formula:

$$G = M \sqrt{\ln\left(\frac{v_e + v_0}{v_a + v_0}\right) * \frac{1}{\sqrt{t_F}}}$$

M = characteristic constant of material in A√s/mm² (table 3)

v₀ = characteristic constant of material in C° (table 3)

v_e = chosen permissible final conductor temperature in C°

v_a = initial conductor temperature in C° (table 4)

A summary of values to be applied in the formula is stipulated in tables 3, 4 and 5.

char. constant of material	Copper	aluminium	steel
M / A√s/mm ²	226	148	78
v ₀ / °C	234,5	228	202

Table 3: Characteristic constant of material according to /1/, /7/ and BS 7430 /20/.

Standard	initial conductor temperature
DIN VDE 0141	20°C
BS 7430	30°C
IEC 287	20°C
IEEE Std 80 – 1986	20°C
IEEE Std 665 – 1995	20°C
NEN 1010	30°C
NF C 13-200	30°C in air, 20°C in the ground
TS 41-24	30°C

Table 4: Initial conductor temperature

According to /1/ (§ 3.2) earthing conductors and earth electrodes are generally designed for a final conductor temperature of 300°C (except tinned or lead coated copper: 150°C). A final temperature higher than 300°C (respectively 150°C) is only allowable, if a reduction of the mechanical stability is permissible and a damage to the earthing conductor and its surroundings has not to be considered.

standard	final conductor temperature V _e
DIN VDE 0141 BS 7430	300°C (tinned or lead coated copper: 150°C). At temperature in excess of 200°C the conductor should be visible throughout its length, have ceramic or metallic supports (or an equivalent) and there should be no risk of organic materials being in contact with or adjacent to the conductor. Temperatures higher than 500°C are not recommended. Certain building materials likely to be adjacent to the conductor may present a fire risk if 150°C is exceeded.
BS 7671	Visible and in restricted areas: copper and steel: 500°C, aluminium: 300°C; normal conditions: copper, steel and aluminium: 200°C; fire

standard	final conductor temperature V_e
IEEE Std 80 - 1986	risk: copper, steel and aluminium: 150°C. For mechanical reasons annealing of a conductor is a consideration, it may be prudent not to exceed 250°C regardless of the type of connection used.
IEEE Std 665 - 1995	For bare conductors, not accessible in normal operation and which are not touching heat-sensitive materials: 500°C for copper and steel conductors, 300°C for aluminium conductors; for bare conductors, accessible in normal operation but not touching heat-sensitive materials: 200°C for all conductor materials. For insulated conductors, it is recommended: 1. To determine the maximum clearing time during which the conductor will be subjected to fault currents. 2. To obtain from the manufacturer the maximum safe temperature for the insulation for that time. 3. If those values are not available, it is suggested to use: 150°C for IPVC insulation, 220°C for butyl rubber, 250°C for XLPE, ethylene-propylene rubber and silicone rubber.
NEN 1010	In visible location and in special cases: copper and steel: 500°C, aluminium: 300°C; in rooms without fire risk: copper, aluminium and steel: 200°C; in rooms with fire risk: copper, aluminium and steel: 150°C.
NF C 13-200	Normally 200°C, but if the conductors are visible and located in reserved locations 300°C is allowed.
TS 41 -24	copper: 405°C, aluminium: 325°C

Table 5: Final conductor temperature

For final conductor temperatures of 300°C (bare or galvanised copper, aluminium and galvanised steel) or 150°C (tinned or lead coated copper) and initial temperature 20°C the selection of current density G with regard to thermal stress can be determined using fig. 1 (/1/, fig. 7) dependent on the earth-fault duration t_F ($t_F = \leq 5$ s, power supply system with directly or via low resistance earthed neutral):

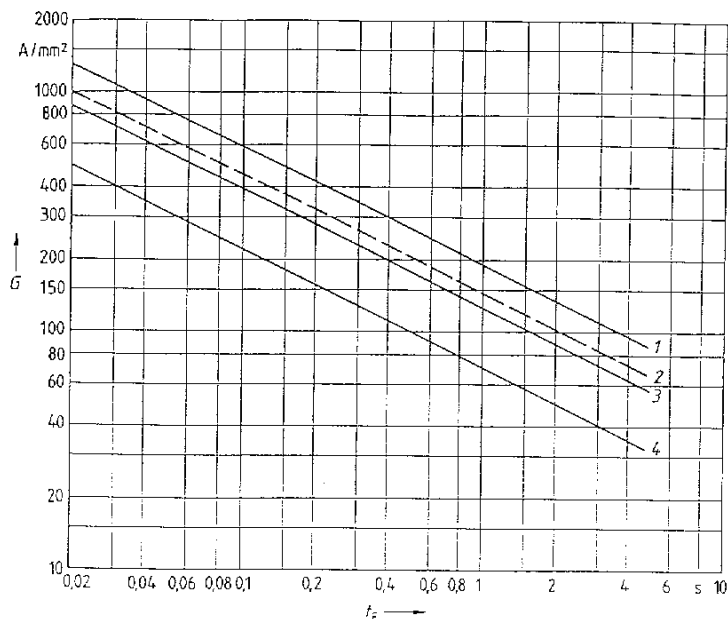


Fig. 1: Earth-fault current density dependent on earth-fault duration

t_F = earth-fault duration, clearing time of the back-up protection, in s

1 = copper, bare or galvanized, final conductor temperature 300°C

2 = copper, tinned or lead coated, final conductor temperature 150°C

3 = aluminium, final conductor temperature 300°C

4 = steel, galvanized, final conductor temperature 300°C

In case of earth-fault durations t_F above 5 s (power supply systems with isolated neutral or earth-fault compensation) fig. 2 can be used according to /2/.

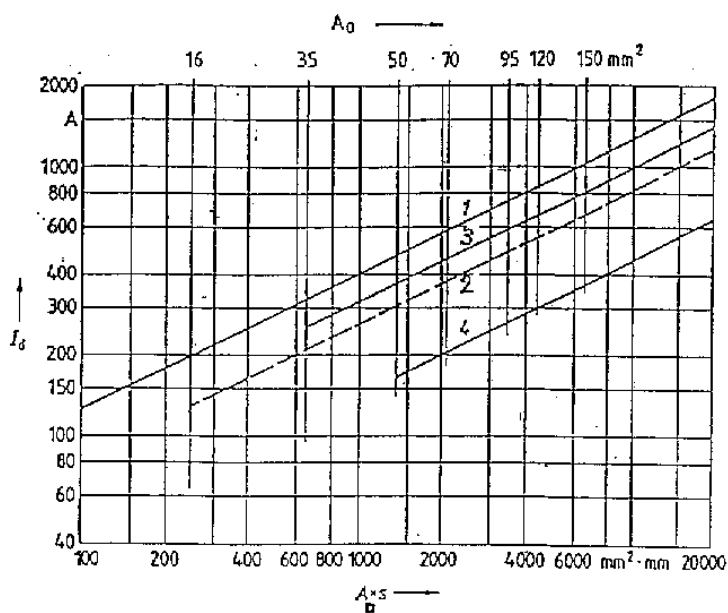


Fig. 2: Permanent current for earthing conductors with rectangular cross section respectively with round cross section

- I_d = permanent current in A
 A = cross section in mm² (rectangular cross section)
 s = profile circumference in mm (rectangular cross section)
 A_0 = cross section in mm² (round cross section)
 1 = copper, bare or galvanised, final conductor temperature 300°C
 2 = copper, tinned or lead coated, final conductor temperature 150°C
 3 = aluminium, final conductor temperature 300°C
 4 = steel, galvanised, final conductor temperature 300°C

If higher conductor temperatures than 300°C are approved dependent on the material or lower conductor temperatures are required dependent on the environment, the following conversion factors shall be used to derive permissible earth-fault current density from the diagrams above according to /1/(§ 3.2.1, table 6):

final conductor temperature/°C	Conversion factor for G
400	1.20
350	1.10
300	1.00
250	0.90
200	0.80
150	0.70
100	0.55

Table 6:. Conversion factor

5.4 Design of Earth Electrodes and Earthing Conductors of Power Installations with Rated Voltages up to 1000 V with Regard to Corrosion, Mechanical Stability and Thermal Stress

5.4.1 Earth Electrodes

For the design of earth electrodes with regard to corrosion, mechanical stability and thermal stress minimum sizes according to /6/(§ 4.2.3, commentary) shall be determined in accordance with § 5.3.1.1, table 1.

5.4.2 Earthing Conductors

For the design of earthing conductors with regard to corrosion, mechanical stability and thermal stress the minimum size shall be calculated according to /6/ (§ 4.3.1), as a protection conductor.

The minimum cross section has to be calculated according to a) or to be selected according to b) /6/ (§5.1):

- a) For determination of the cross section the following formula has to be used for earth-fault duration's $t_f \leq 5$ s (according /6/ (§ 5.1.1):

$$A = \frac{\sqrt{I_E^2 t_f}}{M}$$

- A = cross section in mm²
 I_E = earth-fault current in A

t_F = earth-fault duration in s

M = characteristic constant of material in $A\sqrt{s}/mm^2$ (see the values for M in table 3 in § 5.3.2.2)

- b) The earthing conductor shall have the following minimum cross section (copper) according to DIN VDE 0100, Part 540 /6/:

phase conductor cross section	earthing conductor minimum cross section
up to 16 mm ²	cross section of the phase conductor
above 16 mm ² up to 35 mm ²	16 mm ²
above 35 mm ²	half of the cross section of the phase conductor

Table 7: Minimum cross section of earthing conductor as protective conductor in relation to the cross section of the associated phase conductor

The design of earthing conductors with minimum cross section and corrosion in underground installations shall be in accordance with /6/(§ 4.3) and, in addition shall take the following into consideration:

material	minimum cross section
copper	25 mm ²
steel, galvanised	50 mm ²

Table 8: Minimum cross section of buried earthing conductor

5.5 Power Installations above 1 kV

5.5.1 EHV system

The following minimum cross section A is required as follows dependent on the type of power supply system, the respective earth-fault current and the clearing time of the back-up protection system:

$$A = I_{kE}'' / G$$

G has to be calculated according to § 5.3.2.2.

This minimum cross section is valid for earth electrodes and earthing conductors which carry the maximum earth-fault current.

In areas adjacent to EHV-substation and around the main transformer, the earth electrodes should form a meshed earthing grid. Due to the configuration of a mesh, the earth-fault current is normally split up and flows in parallel paths. In order to take into account adverse conditions, a ratio of 70/30 should be assumed. Therefore, the following minimum cross section for earth electrodes in areas adjacent to EHV-substation and around the main transformer is required:

$$A = 0.7I_{kE}'' / G$$

For practical reasons and in consideration of the most adverse conditions on which the layout is based, it is recommended that earthing conductors are used with a standard cross section area, e.g. copper, 70 or 95 mm².

5.5.2 Generator Voltage Level

Dependent on the type of power supply system, the respective earth-fault current I''_{kE} and the clearing time of the back-up protection system, the following cross section area A is required:

$$A = I''_{kE} / G$$

$$I''_{kE} = I''_{kE} = I''_{kEN} \text{ (see § 4.4)}$$

The enclosures of the isolated phase busbars can be used as the earthing conductor where the busbars are aluminium. For mechanical reasons, the final permissible conductor temperature of aluminium is limited e.g. 200°C.

As double earth faults cannot be excluded from isolated phase busbars, this current has to be calculated as follows:

$$I''_{kE} = I''_{kEE} = I''_{kEEg} + I''_{kEEN}$$

$$I''_{k3pol} = I''_{k3polG} + I''_{k3polN}$$

$$I''_{kEE} = \frac{\sqrt{3}}{2} I''_{k3pol}$$

The minimum cross section of the enclosures of isolated phase busbars used as earthing conductor has to be calculated with regard to thermal stress according to DIN VDE 0103 / EN 60865 / IEC 865-1:

$$A = \frac{I''_{kEE} \sqrt{m+n}}{S_{thr} \sqrt{\frac{t_{kr}}{t_F}}}$$

S_{thr} = rated short time current density in A / mm²

S_{thr} can be determined according to fig. 3a and 3b (DIN VDE 0103 / EN 69865, IEC 865-1)

t_F = earth-fault duration in s

t_{kr} = rated short circuit time in s (= 1s)

m = factor of the time-dependent heat effect, caused by the d.c. current part of the earth-fault current

n = factor of the time-dependent heat effect, caused by the a.c. current part of the earth-fault current

m and n can be determined according to fig. 4a and 4b (DIN VDE 0103 / EN 60865-1 / IEC 865-1)

However, the minimum cross section of the enclosure of the generator busbar for thermal stress with the permanent current A_{td} has to be larger than the minimum cross section for the thermal stress with the earth fault current A .

$A \leq A_{Id}$

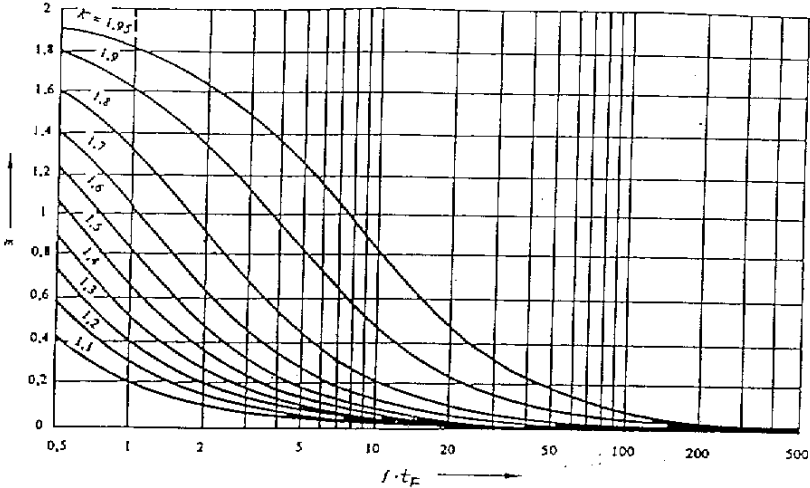


Fig. 3a: Factor m , time-dependent heat effect in a.c. power supply systems, caused by the d.c. current part of the earth fault current.

χ = factor for determination of the peak short circuit current
 f = frequency in Hz (e.g. = 50 Hz)

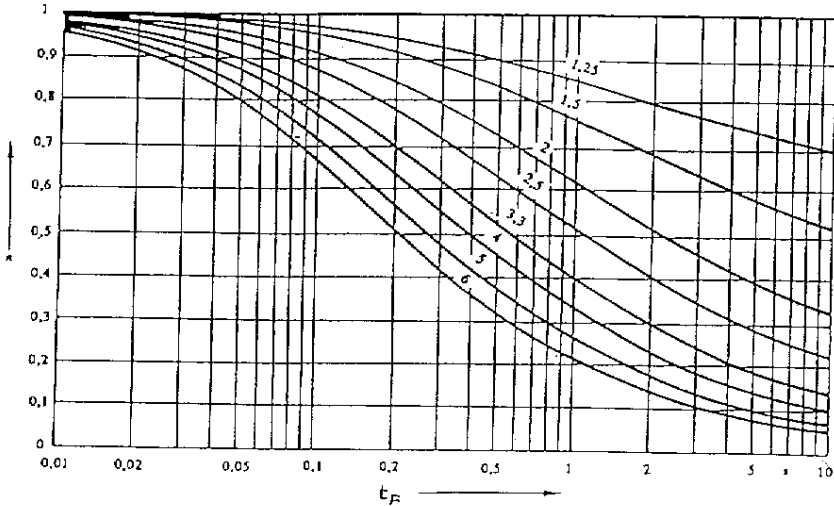


Fig. 3b: Factor n , time-dependent heat effect in a.c. power supply systems, caused by the a.c. current part of the earth-fault current.

I''_k = initial symmetrical short circuit current in A
 I_k = steady state short circuit current in A

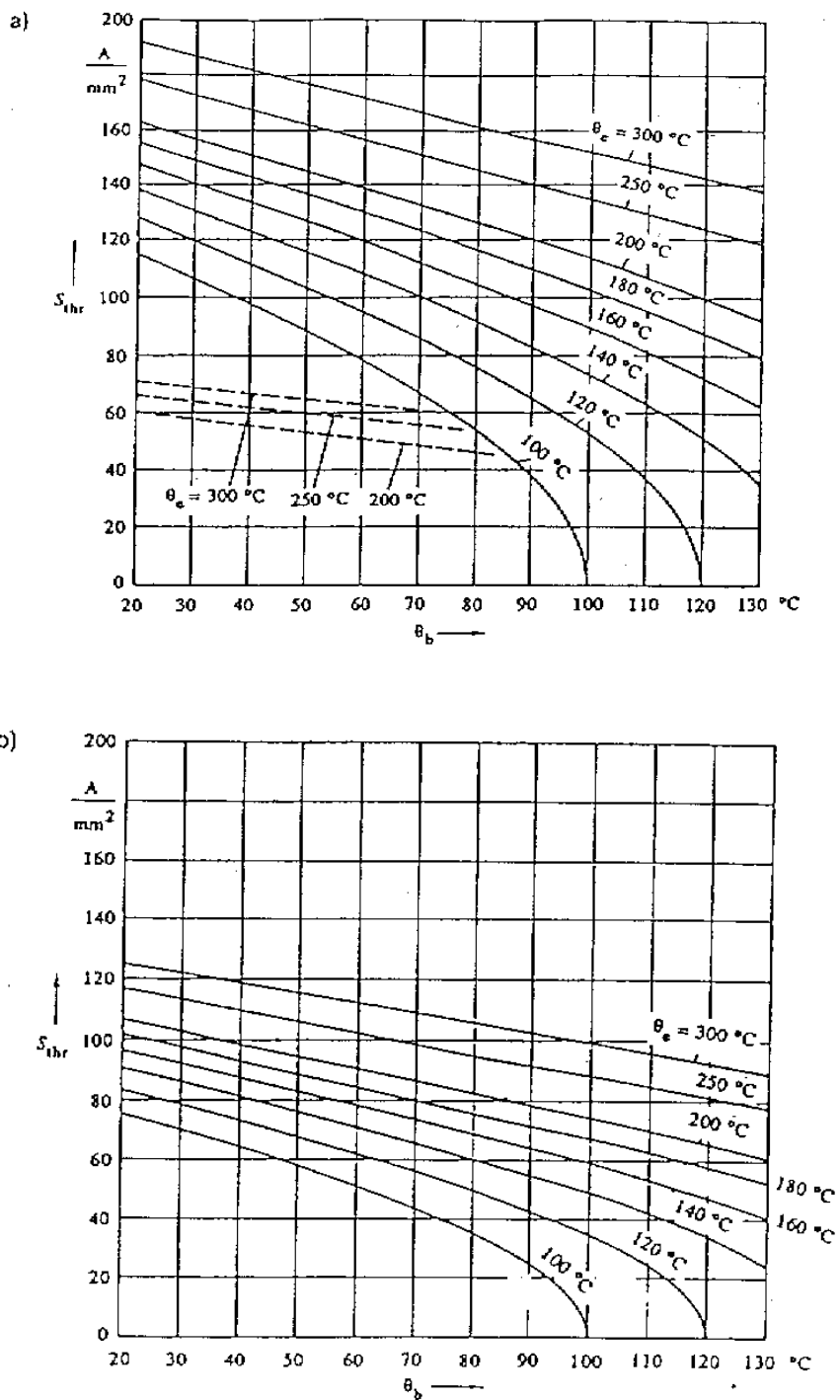


Fig. 4a, 4b: Rated short time current density, dependent on the conductor temperature

- θ_b = conductor temperature at the beginning of the short circuit
- θ_e = conductor temperature at the end of the short circuit

5.5.3 MV Auxiliary System

The following formula for the minimum cross section A is dependent on the type of power supply system, the respective earth-fault current and the clearing time of the back-up protection system:

$$A = I''_{kE} / G$$

However the minimum earthing conductor sizes according to § 5.3.1.2 also have to be taken into account.

For practical reasons and considering the most adverse conditions on which the layout is based, it is recommended that earthing conductors with standard cross section areas are used, e.g. copper, 70 or 95 mm².

5.6 Power Installations up to 1000 V

5.6.1 LV Auxiliary Systems

LV Power supply systems need to be assessed taking into consideration the type of neutral earthing used. The abbreviations used for the different types of power supply systems are defined in IEC 364-3: 1993 /11/.

5.6.1.1 TN System

If the LV power supply system is operated as TN system the neutral of the transformer has to be connected to the earthing system close by the transformer according to DIN VDE 0100, part 410 / 11.83 /10/ and IEC 364-4-41 /11/.

According to DIN VDE 0100, part 540 / 11.91 /6/ and IEC 364-5-54 /11/ the earthing conductors shall have the minimum cross sections mentioned in § 5.4.1.2.

5.6.1.2 TT System

If the LV power supply system is operated as TT system the neutral of the transformer has to be connected to the earthing system according to DIN VDE 0100, part 410 / 11.83 /10/ and IEC 364-4-41 /11/.

According to DIN VDE 0100, part 540 / 11.91 /6/ respectively IEC 364-5-54 /11/ the earthing conductor shall have the minimum cross section detailed in § 5.4.1.2.

5.6.1.3 IT System

If the LV power supply system is operated as IT system the neutral of the transformer is isolated according to DIN VDE 0100, part 410 / 11.83 /10/ and IEC 364-4-41 /11/.

According to DIN VDE 0100, part 540 / 11.91 /6/ respectively IEC 364-5-54 /11/ the casings of the components need to be connected to the protective conductor PE via the minimum copper cross-section according to § 5.4.1.2.

5.6.1.4 D.C. Systems

For d.c. installations above 60 V d.c., e.g. 220 V d.c., the protective measures have to be provided in accordance with DIN VDE 0100, part 410 / 11.83 /10/ and IEC 364-4-41 /11/. Protection by non-conducting locations or a protective conductor measure should be adopted. If a live conductor can be earthed (L-), protection by disconnection of supply similar to a TN

system should be applied; if no live conductor is earthed, protection by signalling similar to a IT-system should be applied (IT-system preferable). The cross sections of the protective conductors should be designed in accordance with DIN VDE 0100, part 540 / 11.91 /6/ respectively IEC 364-5-54 /11/ according to § 5.4.1.2.

Appropriate protection against direct contact must be selected (e.g. closed electrical operating area).

In power stations d.c. installations under/equal 60 V d.c., e.g. 24 V d.c., are used for I&C power supply systems. The reference conductor (M) of the 24 V d.c. supply system is bonded to the earthing system to reduce induced overvoltages caused by lightning surges, short circuits and earth-faults and electromagnetic interferences from high-frequency sources. Two different earthing systems are usual according to § 7.6.1. For practical reasons it is recommended that earthing conductors with standard cross section areas are used, e.g. copper, 70 or 95 mm².

6. Design of Earthing Systems with Respect to Tolerable Touch Voltage

The sizing of earthing systems for corrosion, mechanical stability and thermal stress when considering the maximum earth-fault current and duration (ref: § 4 and 5) results in a basic design of the earthing systems. This basic design also has to be checked for the tolerable touch potential.

The level and duration of the earth-fault current as limited by the type of neutral earthing not only determine the thermal stress of the earthing system, but also the potential rise of the earthing grid and, therefore, the touch potential.

6.1 Tolerable Touch Voltage

For power supply systems with rated voltages above 1 kV and earthed directly or via low resistance neutral, the tolerable touch potential can be determined using the fault duration. Assuming a particular fault duration t_F ($t_F \leq 5s$) for correct operation of protection devices and switchgear, the tolerable touch voltage U_B is given in fig. 5 according to /1/(§ 4.4.1):

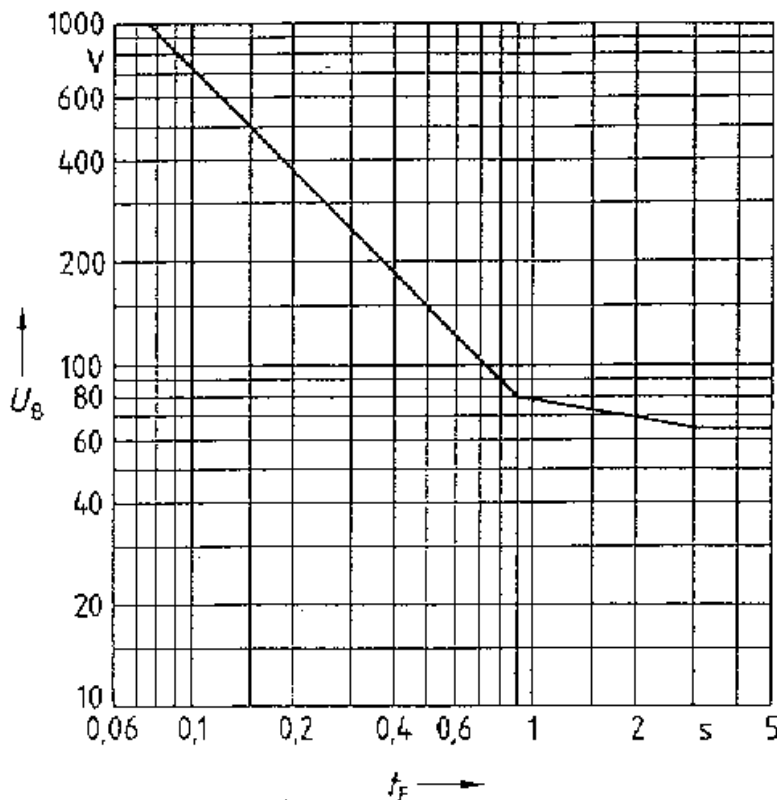


Fig. 5: Maximum tolerable touch voltage dependent on the fault duration ($t_F \leq 5s$).

For power supply systems with rated voltages above 1 kV and isolated neutral or earth-fault compensation the tolerable amounts to 65 V according to /1/(§ 4.4.2).

According to /1/(table 6) the tolerable touch potential will be maintained if one of the following conditions have been fulfilled:

- condition V1:

earth electrode voltage less than two times tolerable potential ($U_E \leq 2 \times U_B$)

- condition V2:

densely built area or industrial plant (power station)

According to /2/ 75 V is a tolerable potential for fault durations above 5s, independent of the type of neutral earthing.

For a.c. power supply systems with rated voltages up to 1000 V, the tolerable touch potential is 50 V for unlimited fault duration according to /10/ and other standards (d.c. power supply systems: 120 V).

6.2 Ground potential rise

The maximum voltage that a station grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth.

$$U_E \leq Z_E \times I_E$$

U_E = earth electrode voltage

Z_E = impedance to earth

I_E = earth-fault current

In order to determine the earthing current it is necessary to calculate the parts of the fault current flowing to overhead line earth conductors, cable screens or transformer neutrals. Because detailed information is often not available in the design phase of earthing systems in practice, it is recommended that the following reduction factors are used (results of earth-fault tests in MV cable systems) refer to /15/:

power supply system with	
isolated neutral or earth-fault compensation	$I_E / I''_{kE} \leq 0.40$
low resistance earthed neutral	$I_E / I''_{kE} \leq 0.10$

6.3 Impedance to Earth

The impedance to earth of the earthing system is a combination of the resistance to earth of the earthing grid and further impedances, which are connected in parallel such as overhead line earthing conductors, tower footing resistances, armouring and screens of cables with earth electrode effects of other earthing grids which are connected via conductive cable armouring and screens and PEN-conductors to the earthing system.

In most cases the parallel impedances are neglected and the impedance to earth Z_E is assumed equal to the resistance to earth R_A :

$$Z_E = R_A$$

The resistance to earth of the earthing grid can be calculated from area covered by the earthing grid and the specific soil resistivity.

The area of the interconnected earthing grid of the power station is A_a .

The radius r of an equivalent circular plate results in:

$$r = \sqrt{\frac{A_a}{\pi}}$$

A_a = area covered, in m^2

The resistance to earth R_A can be calculated, refer to /1/(§ 3.1.2) as:

$$R_A = \frac{\rho_E}{4R}$$

$R_A = \rho_E/4r$ in ohm

ρ_E = specific soil resistivity in ohm x m

Typical soil resistivity values according to TS 41-24 /7/ (Appendix B, table 1):

type of earth	resistivity / ohm x m
loams, garden soils, etc.	5 - 50
clays	10 - 100
chalk	30 - 100
clay, sand and gravel mixture	40 - 250
marsh, peat	150 - 300
sand	250 - 500
slates and slately shales	300 - 3.000
rock	1.000 - 10.000

Typical soil resistivity values according to IEEE Std 80-1986 /9/:

type of earth	average resistivity / ohm x m
wet organic soil	10
moist soil	100
dry soil	1.000
bedrock	10.000

7. Earthing System

7.1 Foundation Earth Electrodes

Reinforced concrete foundations are normally used as foundation earth electrodes in new buildings. The required equipotential bonding in buildings with electrical installations is made much more effective by such foundation earth electrodes. In practice, the impedance to earth ranges from 1-10 ohm for good soil conditions. Foundation earth electrodes ensure constant values for the impedance to earth throughout the year.

The material used for foundation earth electrodes is steel strips with a minimum cross section of 90 mm² or steel bars with a diameter of 10 mm have to be used. The steel can either be galvanised or untreated.

The reinforcement bars of the foundation can be used as earth electrodes. As welding of structural steel mats is often not allowed, the use of special earth electrodes for foundation earthing is recommended (see Annex 3: Examples and details of earthing systems according to German utility practice, fig. 01, details in fig. 03 - 10).

For extended foundations of power station buildings the following measures are applied in practice, though deviations and other solutions are used in other countries.

Steel electrodes should be laid in the base concrete-layer, and they should be totally encased in concrete and protected from corrosion. The minimum distance to the foundation subgrade should be 5 cm. The steel electrodes should form a meshed grid with the maximum mesh width of 10 m. The steel electrodes should be welded at each node of the grid. It is recommended that some steel electrodes and structural steel mats are wrapped together.

An alternative to this method is to lay copper wires in a mesh arrangement under the foundations in the soil.

Block foundations need to be interconnected, and the exposed connecting conductors need to be protected against corrosion. Expansion joints outside the concrete are bonded with expansion straps of copper conductor.

Indoor earthing systems (earthing conductor, equipotential bonding) are connected using a number of risers from the foundations.

7.2 Outdoor Earthing System

Potential grading earth electrodes should surround the power station buildings and transformers (see Annex 3: Examples and details of earthing systems according to German utility practice, fig. 02, details in fig. 07 and 11). The recommended distance to the foundation is 1 m (according to TS 41 - 24 /7/). This gives a sufficient mechanical protection to the conductors and should ensure that they will normally be below the frost line. The potential grading electrodes around the buildings and transformers are connected to the indoor earthing system via the copper risers mentioned above.

Additional vertical rod electrodes are effective for use in power stations constructed on small areas where the improve the resistance to earth.

Copper Earth grids using copper with a minimum cross section of the value according § 5.5.1 (reduced cross section) are installed under the main transformer and the adjacent EHV substations. Copper conductors with standard cross sections are installed in parallel for this requirement. All EHV installations carrying full fault current should be connected to the earthing grid by copper earthing conductors with a minimum cross-section of the value according to § 5.5.1 (full cross section). Again, copper conductors with standard cross section areas should be laid in parallel.

Earth grids using single copper conductors with standard cross section area are sufficient for other areas.

There should be 2 to 4 connections between earth installations around buildings, transformers and earthing systems of the adjacent EHV substation area forming a meshed earthing grid.

The lightning protection system is connected to the earthing grid. In most cases no extra demands on the earthing system need to be considered.

No specific measures are required for perimeter fences constructed of non-conductive material. However, perimeter fences made of conductive material eg lighting masts and oil tanks should be earthed by a surface earth electrode of a distance of approximately 1 m, away. Gate posts should be bonded together with the surface earth electrode to ensure that different potentials do not increase when 2 posts are bridged by a person opening the gate.

Care shall be taken that earthing systems of adjacent power stations of different owners are compatible with each other.

The earthing grids of the power stations and adjacent EHV substation should be interconnected by at least two earthing conductors of standard cross section area according to § 5.5.1 and laid in separate routes.

7.3 Indoor Earthing System

An indoor earthing ring of bare copper bars is installed as earthing conductor in buildings with a MV installation. All earthing conductors should be connected to this earthing conductor ring. Copper conductors using standard cross section areas according to § 5.5.3 should be used for earthing conductors.

Several connections should be made from the indoor earthing system to the outdoor system.

7.4 Earthing of Electrical Components

7.4.1 EHV Equipment

EHV equipment adjacent to power stations are connected with copper conductors according to § 5.5.1 and 7.2 to the outdoor earthing grid (cross section according to § 5.5.1).

7.4.2 Main Transformer

The main transformer will be connected with copper conductors according to § 5.5.1 and 7.2 to the outdoor earthing grid (cross section according to § 5.5.1).

7.4.3 Generator, Generator Busbar

The enclosures of generator busbars are used as earthing conductor between generator, main transformer and unit auxiliary transformer. The connection to earthing system design as described in § 5.5.1.

For reasons of standardisation, the neutral point cubicles of generators are connected to the earthing system via copper conductors of standard cross section area.

7.4.4 MV-Switchgears

Both ends of the MV-switchgear panels are connected to the earthing grid with copper conductors of standard cross section area as described in § 5.5.3.

7.4.5 LV-Switchgears

Both ends of LV switchboards are connected to the earthing grid with copper conductors of standard cross section area as described in § 5.6.1.

7.4.6 LV-Transformers

The tanks and neutrals are connected to the earthing grid by copper conductors with standard cross-section area as described in § 5.5.3.

7.4.7 MV-Motors

Motor casings are connected with copper conductors of standard cross section area to the earthing grid.

Cable armouring and screens are earthed at both ends according to § 5.5.3 (it is French practice, however, to earth armouring and screens only on one end if the touch voltage is low enough. This prevents currents from flowing over armouring and screens).

7.4.8 LV-Motors

The protective conductor of power cables are connected to the earthing connection of motor casings and to the protective earthing busbar of the LV-switchgear. Steel armouring of the power cables are earthed at least at one end.

7.4.9 Cable Trays and Cable Supporting Structures

Cable tray/ladder sections are connected to the earthing grid by copper conductors with the standard cross section area according to § 5.5.3. The cable tray/ladder are coupled with special earthing bolts suitable for the tray system.

7.5 Earthing of Non-Electric Components

Metal parts inside or outside of buildings, such as main pipes, vessels, crane tracks, constructions, cable supports and grillwork are earthed with copper conductors with standard cross section areas according to § 5.5.3.

Branching and connections to vessels, tanks and machine sets are connected once at each branch from the main line.

If vessels and tanks are fixed to their metallic/steel supports with a conductive path (welded or screwed, e.g. M10), the earthing of the support construction is sufficient.

Metal door frames and windows, ceiling reinforcements, guard-rails and stairs are only earthed if the distance to electrical equipment is less than 2 m to avoid undue touch potential.

7.6 Earthing Practice of I&C-Equipment

7.6.1 Reference Conductor (M) and Screen Earthing (A)

In order to operate the instrumentation and control (I&C) systems without adverse effects from lightning and interference voltages, it is required that the reference conductor (M) of the 24 V d.c. switchgear is earthed. In the case of a central earthing system, the reference conductors of all 24 V d.c. switchgear are connected through isolating links to the central earthing point. The screens of all I&C cables are earthed on one side via separate screen busbars (A) in all 24 V d.c. switchgear at the central earthing point.

In newer power stations and nuclear power stations it is usual to use the multiple earthing systems (intermeshed earthing). In all I&C cabinets the reference conductor is connected with the equipotential bonding system. The screens of all I&C cables are always connected on both sides in the respective cabinet.

In central earthing systems, the insulation resistance of the reference conductor and cable screen system has to be retested in fixed intervals, if necessary, and earth-fault location has to be established and the earth-fault removed. It should be demonstrated that the reference conductor system is earthed only at one point. On the other side potential differences in the electrical auxiliary systems caused by earth-faults or short circuits do not have any significant impact on the I&C equipment.

For a central earthing systems earth-fault location is simplified by opening the detachable links from the reference conductors (M) to the central earthing point.

7.6.2 I&C-Cabinets

The metallic housing of the I&C cabinet is directly connected to the indoor earthing conductor.

The housings of the cabinets have to be connected together conductively.

8 Measurements of Specific Soil Resistivity

8.1 Significance of Soil Resistivity

The resistance of the earthing system has to be calculated before designing the earthing installation of power stations. This value is essentially dependent on the specific soil resistivity in the area of the installation. It may vary considerably in the range between 10 to 1000 ohm x m depending on the type of soil and moisture. It may also change considerably with depth, which is significant for installations covering larger areas. Measurements of specific soil resistivity at the site of planned installations are, therefore, very important for the correct design of earthing installations.

8.2 Measuring Techniques for Determining Specific Soil Resistivity

The earth resistance can be determined by means of a voltage and a current measurement. For this purpose a test current is injected into the earth by electrodes. This method will, however, only indicate soil resistance in the immediate surrounding of the electrodes including the contact resistance of the electrodes. In order to eliminate the electrode resistance and to measure soil resistivity and in deeper layers, a compensation method for elimination of the electrode resistance is used, such as the Wenner method with 4 electrodes /13/. The Wenner's four-pin method is the most commonly used technique according to IEEE Std 80 - 1986 /3/.

This method is especially suited for measuring the soil resistivity in greater depths using electrodes which will only have to be driven into the ground up to 0.5 m deep.

Besides two outer current electrodes two intermediate (inner) potential electrodes are placed at equal distances apart in a straight line. The voltage measured between the inner potential electrodes is divided by the current between the outer electrodes resulting in a resistance value. Where there is a large distance between the electrodes compared to the depth of the electrodes driven into the ground, the following equation gives the specific soil resistivity

$$\rho_E = 2\pi a R_M$$

ρ_E = specific soil resistivity in ohm x m according to tables in § 6.3

a = distance between adjacent electrode in m

R_M = resistance, measured, in ohm

By increasing the spacing between the adjacent electrodes the soil resistivity is measured in greater depth. Generally it can be assumed, that the measured depth is equal to the electrode spacing. Since homogeneous soil up to greater depth is rare, soil resistivity will generally vary with increasing electrode spacing. The values measured will, therefore, be considered as apparent soil resistivity.

8.3 Method of Evaluation of Specific Soil Resistivity

As a consequence of real soil structure, however, several horizontal layers of different soil resistivity may be present.

For the special case with two different layers becoming effective with respect to electrical conditions, the solution of a gradient problem will indicate the top layer depth and the specific resistivity of the two layers (Tagg's method). Practice has shown that even in the case of

extended installations the changing values of the apparent resistance can be interpreted by use of a layer soil structure /14/ (IEEE Std 80-1986: Two layer soil model).

8.4 Determination of Apparent Resistivity

Starting from the physical conditions the average value is determined by averaging the conductivity values measured:

$$\rho_A = \frac{1}{\frac{1}{n} \sum_{i=1}^n \frac{1}{\rho_{A_i}}}$$

ρ_A = average apparent soil resistivity

n = number of measurements for one electrode spacing

ρ_{A_i} = apparant resistivity, measured for one electrode spacing

9 Summary and Conclusions

This report identifies the current practice of safety earthing engineering for engineers in power stations with regard to the basic technical requirements as given in guidelines and standards.

These guidelines and standards differ from country to country and will change in the next years, specially in Europe, as a result of the electrotechnical standardisation within the European Union. A direct comparison of guidelines and standards in tables, as a result of this study, is not possible. Therefore a general table with references to different standards has been included.

Practice of safety earthing in electrical power systems does not really differ from practice in distribution systems.

Generally speaking (exception in North America) the same guidelines are applied in both cases. The application domain can be derived from the general table.

No difference has been experienced for different types of power stations.

However, the IEEE (North America) has developed separate guidelines for power stations (IEEE 665 1998) and substations (IEEE 80 -2000) due to two major differences in that Generating stations 1) usually occupy a much larger physical area and 2) have numerous large buried structures and foundations. Although both of these characteristics have a significant impact in lowering the overall resistance of the station, the effect of such supplemental grounding structures is not taken into account by the simplified equations in IEEE 80 - 2000.

References

- /1/ DIN VDE 0141 / 7.89: Earthing Systems for Power Installations with Rated Voltages above 1 kV.
- /2/ prEN 50179 (VDE 0101) / 9.96 (draft): Erection of Electrical Power Installations in Systems with Nominal Voltages above 1 kV AC.
- /3/ IEEE Std 80 - 1986: IEEE Guide for Safety in AC Substation Grounding
- /4/ DIN VDE 0102 / 1.90: Short Circuit Currents Calculation in Three-Phase A.C. Systems
- /5/ IEC 909: Short Circuit 0

- /6/ DIN VDE 0100, Part 540 / 11.91: Erection of Power Installations with Nominal Voltages up to 1000 V, Selection and Erection of Equipment; Earthing Arrangements, Protective Conductors, Equipotential Bonding Conductors
- /7/ Technical Specification (TS) 41 - 24, Issue 1: 1992, Publication of the Electricity Association, Great Britain: Guidelines for the Design, Installation, Testing and Maintenance of Main Earthing Systems in Substations
- /8/ IEC 287: Calculation of the Continuous Current Rating of Cables (100% Load Factor)
- /9/ IEEE 665-1995 : Guide for Generating Station Grounding
- /10/ DIN VDE 0100, Part 410 / 11.83: Erection of Power Installations with Rated Voltages up to 1000 V, Protective Measures, Protection against Electric Shock
- /11/ IEC 364: Electrical Installations of Buildings
- /12/ DIN VDE 0551 / 9.95: Isolating Transformers and Safety Isolating Transformers-Requirements
- /13/ Wenner: A Method of Measuring Earth Resistivity. Bull of the American Bureau of Standards. Report 258 (1916)
- /14/ Tagg: Earth Resistances. Tower House, London 1964
- /15/ Dr.-Ing. M. Feydt: Earthing Systems of Power Installations in densely built areas and its influence on the earth-fault voltage
- /16/ IEC-Publication 50 (826) / 1982, Amendment 1 / 1990
- /17/ CEI 11-8 / 12.89: Grounding Systems
- /18/ STEV-FS 1988: 1 and 2, The Swedish Regulation for Design and Maintenance of Electrical Installations
- /19/ NEN 1010 / 1998: Safety Requirements for Low-Voltage Installations
- /20/ BS 7430 / 1991: Code of Practice for Earthing

/21/ BS 7671 / 1992: Requirements for Electrical Installations

/22/ RGIE / 1981: Regulation about Electrical Installations

/23/ CEI 64-8/4 / 10.92: Electrical installations of buildings

/24/ NF C 13-200: High voltage electrical installations

/25/ NF C 15-100: Low voltage electrical installations

/26/ WG23-02 Gas Insulated Substations

/27/ WG23-03 Air Insulated Substations

Annex 1: Earthing systems in power plants; Questionnaire about the practice

RWE Energie AG
KF-TE, Mz/Wa

Essen, May 8, 1995

Earthing systems in power plants

Questionnaire about the practice

1 Standards and guidelines

Which international and national standards and guidelines do you have to take into consideration?

a) for nominal voltages up to 1 kV:

.....

b) for nominal voltages above 1 kV:

.....

c) for communication systems:

.....

If in your country other standards than VDE standards are used, please enclose copies.

2 Internal guidelines and recommendations

Which internal guidelines and recommendations do you use in your company?

.....

please enclose copies

3 Tolerable touch voltage

- a) Which maximum tolerable touch voltage is permissible dependent on the limit of the time duration? Please indicate the diagram or the chapter in the respective standard
-

- B) Which maximum tolerable touch voltage is permissible in case of unlimited time duration

.....V

4 Minimum dimensions of earthing electrodes with regard to corrosion and mechanical strength.

Material		Form	Minimum dimensions		
			Diameter/ mm	Cross section/ Mm ²	Thickness/ mm
steel	galvanised	Tape			
		Profile			
		Earth rod			
		Round wire for surface earth electrode			
	copperplated	Round bar for deep earth electrode			
copper	bare	Tape			
		Round wire for surface earth electrode			
		Cable			
		Earth rod			
	tinned	Cable			
	galvanised	Tape			
..... others					

If the dimensions of earthing electrodes are according to standards, please indicate the chapter and table number. In case of practical use, please indicate the data with*)

5 Minimum cross section of earthing conductors with regard to thermal stresses

Which cross sections of earthing conductors are permissible according to standards or do you use in your power plants. In case of practical use, please indicate the data with*)

- a) steelmm²
- b) coppermm²
- c) aluminiummm²

6 Foundation earthing

Which minimum width of meshes do you specify?

.....m

7 Potential control earth electrodes

Power plant buildings and transformer foundations should be surrounded by potential control earth electrodes. Please indicate:

- a) the distance to the foundation
- b) the depth to be buried

8 Measurement of touch voltage

Do you carry out measurement of earth potential rise and touch voltages after completion of installation?

Yes/no

9 Drawings

Are the drawings about the complete carried out earthing system (HV, MV, LV, DC) within the buildings of you powerplants, please enclose copies.

10 Details

Do you have drawings about carried out details for connecting the outdoor and the indoor earthing systems. If yes, please enclose copies

Annex 2: General table with reference to different standards					
Chapter	Term	VDE(G)	BS7430/1991 (UK), /20/	BS7671/1992(UK),/2 1/	TS41-24, Issue 1, 1992 (UK),/7/
5.3	Design of earth electrodes and earthing conductors of power installations with rated voltages above 1 kV				
5.3.1	Design with regard to corrosion and mechanical stability				
5.3.1.1	Earth electrodes <i>minimum size</i>	§5.3.3.1.1, Table 1 (see report)	§9.2, Table 4, Page 16		
5.3.1.2	Earth conductor <i>minimum size</i>	§5.3.1.2, Table 2 (see report)			
5.3.2	Design with regard to thermal stress				
5.3.2.1	Earth electrodes				
	low resistance earthed neutral <i>minimum size</i>	§5.3.2.2, Formula (see report)	§9.2, Table 4, Page 16		§8.3.2, Formula, Page 10
	isolated neutral <i>minimum size</i>	§5.3.1.1, Table 1 (see report)	§9.2, Table 4, Page 16		§8.3.2, Formula, Page 10
5.3.2.2	Earthing conductor				
	<i>minimum size by calculation</i>	§5.3.2.2, Formula (see report)	§13, Formula, Page 28		§8.3.1, Formula, Page 9
	<i>minimum size from diagrams</i>	§5.3.2.2, Fig 1 and 2 (see report)			
	<i>initial conductor temperature</i>	20 C	30 C		§8.3.1, Page 9: 30C
	<i>final conductor temperature</i>	300 C (Tinned or lead coated copper: 150 C)	§13, Table 10, Page 29		§8.3.1, Page 9: Cu: 405C, Al:325C
	<i>conversion factor table</i>	§5.3.2.2, Table 6 (see report)			

Annex 2: General table with reference to different standards					
Chapter	Term	VDE(G)	BS7430/1991 (UK), /20/	BS7671/1992(UK),/2 1/	TS41-24, Issue 1, 1992 (UK),/7/
5.4	Design of earth electrodes and earthing conductors of power installations with rated voltages up to 1000 V with regard to corrosions mechanical stability and thermal stress				
5.4.1	Earth electrodes <i>minimum size</i>	§5.3.1.1, Tabel 1 (see report)		§542-02, General requirements, page 93	
5.4.2	Earthing conductor and protective conductor				
a)	<i>minimum size by calculation, $tF < 5s$</i>	§5.4.2, Formula (see report)		§543-01-02, Formula page 94	
b)	<i>minimum size by selection</i>	§5.3.2, Table 7 (see report)		§543-01-04, Table 54B, Page 96	
	Earthing conductor buried in earth <i>minimum size</i>	§5.4.2, Tbaie 8 (see report)		§542-03-01, table 54A page 93	
5.5	Power installations above 1 kV				
5.5.1	EHV-system <i>Design of earth electrodes and earthing conductors</i> <i>Assumption of reduced earth-fault current</i>	§5.5.1 (see report)			
5.5.2	Generator voltage level Generator busbar as earthing conductor <i>minimum size</i>	§5.5.2, Formula (see report)			

Annex 2: General table with reference to different standards					
Chapter	Term	VDE(G)	BS7430/1991 (UK), /20/	BS7671/1992(UK),/2 1/	TS41-24, Issue 1, 1992 (UK),/7/
6	Design of earthing systems with respect to tolerable touch voltage				
6.1	Tolerable touch voltage				
	Power supply system with rated voltages above 1 kV				
	fault duration < 5 sec.				
	Low resistance earthed neutral <i>tolerable touch voltage</i>	§6.1, Figure 5 (see report)			
	Isolated Neutral Tolerable touch voltage	65 V			
	Fault duration >5 sec. independent of the type of neutral earthing Tolerable touch voltage	75 V			
	Power supply system with rated voltage up to 1000 V for unlimited duration Tolerable touch voltage	50 V			
6.2	Earth electrode voltage assumption of reduction				
	Factors for calculation of earth fault currents	§6.2 (see report)			
6.3	Impedance to earth				
	soil resistivity	§6.3 (see report)	§7, table 1, page 11		App. B, Ttable 1, page 48

Annex 2: General table with reference to different standards					
Chapter	Term	VDE(G)	BS7430/1991 (UK), /20/	BS7671/1992(UK),/2 1/	TS41-24, Issue 1, 1992 (UK),/7/
7	Earthing system				
7.1	Foundation earth electrodes <i>minimum cross section in practice</i>	Steel strips: 90mm ² , steel bars: 10 mm (diameter)			

Annex 2: General table with reference to different standards					
Chapter	Term	CEI 11-8 / 1989 (I), /17/	CEI 64-8/4 / 1992 (I), /23/	IEEE Std 80-1986	IEEE 665-1995
5.3	Design of earth electrodes and earthing conductors of power installations with rated voltages above 1 kV				
5.3.1	Design with regard to corrosion and mechanical stability				
5.3.1.1	Earth electrodes <i>minimum size</i>	§2.2.03, Annex B, table		§12 page 81 - 90	
5.3.1.2	Earth conductor <i>minimum size</i>	§2.3.02, page 7 Cu:16, Al:35, Steel:50mm ²		§9 page 63 - 70	§5.8 page 42
5.3.2	Design with regard to thermal stress				
5.3.2.1	Earth electrodes				
	low resistance earthed neutral <i>minimum size</i>	§2.2.07, Formula, page 6		Refer to IEEE 665	§5.3.1.3 Page 19
	isolated neutral <i>minimum size</i>	§2.2.07, formula, page 6		Refer to IEEE 665	§5.3.1.8 page 21
5.3.2.2	Earthing conductor				
	<i>minimum size by calculation</i>	§2.3.02, formula, page 7		§9.3, formula eq. 30 page 64	§5.2.6 page 12 5.8.3, formula, page 43
	<i>minimum size from diagrams</i>			§9.4, fig 14, page 68	
	<i>initial conductor temperature</i>	30 C			§Ammex A page 47
	<i>final conductor temperature</i>	400 C		§9.5, Page 69	§Annex A Page 47
	<i>conversion factor table</i>				§ 5.2.7.2 page 13-14

Annex 2: General table with reference to different standards					
Chapter	Term	CEI 11-8 / 1989 (I), /17/	CEI 64-8/4 / 1992 (I), /23/	IEEE Std 80-1986	IEEE 665-1995
5.4	Design of earth electrodes and earthing conductors of power installations with rated voltages up to 1000 V with regard to corrosions mechanical stability and thermal stress				
5.4.1	Earth electrodes <i>minimum size</i>			§12 page 81 - 90 same as above 1000V	Refer to IEEE 80
5.4.2	Earthing conductor and protective conductor			§9 page 63 - 70 same as above 1000V	§5.8 page 42 Same as above 1000V
a)	<i>minimum size by calculation, $tF < 5s$</i>			9.3, formula eq. 30 same as above 1000V	§5.8 page 42 Same as above 1000V
b)	<i>minimum size by selection</i>			§9.4 page 66 same as above 1000V	See IEEE 80
	Earthing conductor buried in earth <i>minimum size</i>			§	§
5.5	Power installations above 1 kV				
5.5.1	EHV-system <i>Design of earth electrodes and earthing conductors</i> <i>Assumption of reduced earth-fault current</i>			§	Annex C
5.5.2	Generator voltage level Generator busbar as earthing conductor <i>minimum size</i>			Refer to IEEE 665	§ 5.3 page 19 - 21

Annex 2: General table with reference to different standards					
Chapter	Term	CEI 11-8 / 1989 (I), /17/	CEI 64-8/4 / 1992 (I), /23/	IEEE Std 80-1986 (US), /3/	IEEE 665-1995
6	Design of earthing systems with respect to tolerable touch voltage				
6.1	Tolerable touch voltage				
	Power supply system with rated voltages above 1 kV			§6 page 43 - 48	§5.2.7 page 13
	fault duration < 5 sec.				§5.2.7.1 page 13
	Low resistance earthed neutral <i>tolerable touch voltage</i>			§ 6 page 43 - 80	§5.3.1.3 page 19
	Isolated Neutral Tolerable touch voltage			§6 page 43 - 80	§5.3.1.8 page 21
	Fault duration >5 sec. independent of the type of neutral earthing Tolerable touch voltage			§6 page 43 - 80	Refer to IEEE 80
	Power supply system with rated voltage up to 1000 V for unlimited duration Tolerable touch voltage			§6 page 43 - 80	Refer to IEEE 80
6.2	Earth electrode voltage assumption of reduction				
	Factors for calculation of earth fault currents			§13 page 91 - 106	§5.2.8.1 page 14
6.3	Impedance to earth				
	soil resistivity			§11 page 75 - 80 Table 4	Refer to IEEE80

Annex 2: General table with reference to different standards					
Chapter	Term	CEI 11-8 / 1989 (I), /17/	CEI 64-8/4 / 1992 (I), /23/	IEEE Std 80-1986	IEEE 665-1995
7	Earthing system				
7.1	Foundation earth electrodes <i>minimum cross section in practice</i>			Refer to IEEE 665	§ 5.5.5.8 page 32 § 5.7.4 page 37

Annex 2: General table with reference to different standards					
Chapter	Term	NEN1010/1998 (NL),/19/	NEN1041/1991 (nl)		RGIE/1981 (B), /22/
5.3	Design of earth electrodes and earthing conductors of power installations with rated voltages above 1 kV				
5.3.1	Design with regard to corrosion and mechanical stability				
5.3.1.1	Earth electrodes <i>minimum size</i>		3.3.31		
5.3.1.2	Earth conductor <i>minimum size</i>		3.3.51		
5.3.2	Design with regard to thermal stress				
5.3.2.1	Earth electrodes				
	low resistance earthed neutral <i>minimum size</i>		3.3.51		
	isolated neutral <i>minimum size</i>				
5.3.2.2	Earthing conductor				
	<i>minimum size by calculation</i>				
	<i>minimum size from diagrams</i>				
	<i>initial conductor temperature</i>				
	<i>final conductor temperature</i>				
	<i>conversion factor table</i>				

Annex 2: General table with reference to different standards					
Chapter	Term	NEN1010/1998 (NL),/19/	NEN1041/1991 (nl)		RGIE/1981 (B), /22/
5.4	Design of earth electrodes and earthing conductors of power installations with rated voltages up to 1000 V with regard to corrosions mechanical stability and thermal stress				
5.4.1	Earth electrodes <i>minimum size</i>	8.542.2.3			
5.4.2	Earthing conductor and protective conductor				
a)	<i>minimum size by calculation, $tF < 5s$</i>	543.1.1			
b)	<i>minimum size by selection</i>	543.1.2			
	Earthing conductor buried in earth <i>minimum size</i>	table 54 A			
5.5	Power installations above 1 kV				
5.5.1	EHV-system <i>Design of earth electrodes and earthing conductors</i> <i>Assumption of reduced earth-fault current</i>				
5.5.2	Generator voltage level Generator busbar as earthing conductor <i>minimum size</i>				

Annex 2: General table with reference to different standards					
Chapter	Term	NEN1010/1998 (NL),/19/	NEN1041/1991 (nl)		RGIE/1981 (B), /22/
6	Design of earthing systems with respect to tolerable touch voltage				
6.1	Tolerable touch voltage				
	Power supply system with rated voltages above 1 kV				
	fault duration < 5 sec.		3.3.21		
	Low resistance earthed neutral <i>tolerable touch voltage</i>		attachment E		
	Isolated Neutral Tolerable touch voltage		attachment E		
	Fault duration >5 sec. independent of the type of neutral earthing Tolerable touch voltage		attachment E		
	Power supply system with rated voltage up to 1000 V for unlimited duration Tolerable touch voltage	8.410.101			
6.2	Earth electrode voltage assumption of reduction				
	Factors for calculation of earth fault currents	413.1.4.2			
6.3	Impedance to earth				
	soil resistivity				

Annex 2: General table with reference to different standards					
Chapter	Term	NEN1010/1998 (NL),/19/	NEN1041/1991 (nl)		RGIE/1981 (B), /22/
7	Earthing system				
7.1	Foundation earth electrodes <i>minimum cross section in practice</i>				

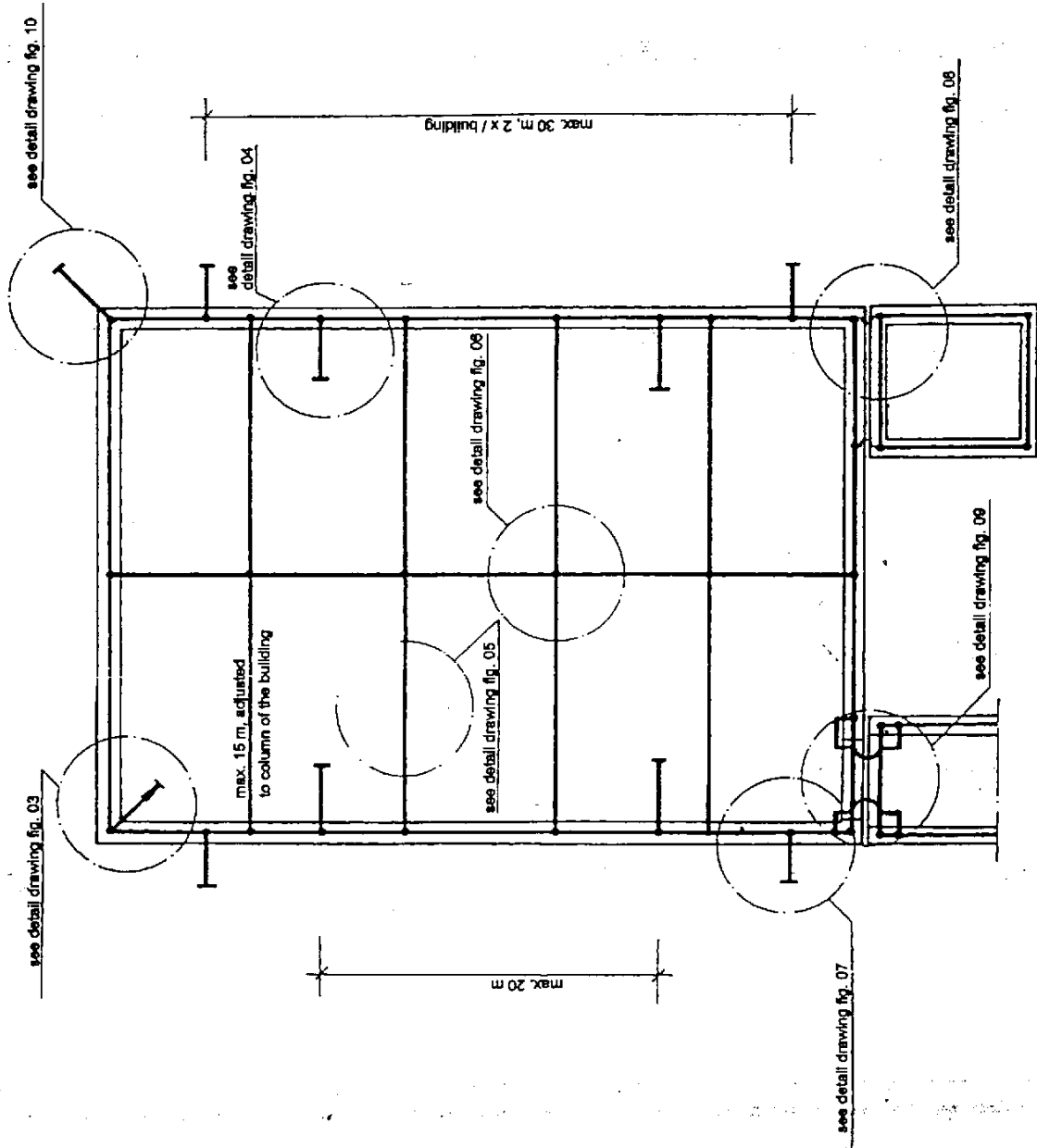
Annex 3

List of Symbols

A	= cross section in mm ²
A _a	= area covered, in m ²
A _o	= cross section in mm ² (round cross section)
A _□	= cross section in mm ² (rectangular cross section)
f	= frequency in Hz
G	= earth-fault current density in A / mm ²
I _d	= permanent current in A
I _E	= earth-fault current in A
I _k	= steady state short circuit current in A
I _k ''	= initial symmetrical short circuit current in A
I _{kE} ''	= maximum earth-fault current in A
I _{kEG} ''	= maximum earth-fault current, current distribution of generator, in A
I _{kEN} ''	= maximum earth-fault current, current distribution of EHV-system, in A
I _{kEE} ''	= double earth-fault current in A
I _{k1pol} ''	= initial single phase short circuit current in A
M	= characteristic constant of material in A√s/mm ²
R _A	= resistance to earth, in Ohm
R _M	= resistance measured, in Ohm
r	= radius of equivalent circular plate in m
s	= profile circumference in mm
t _F	= earth-fault duration, clearing time of the back-up protection, in s
U _B	= tolerable touch voltage in V
U _E	= earth electrode voltage in V
Z _E	= impedance to earth in Ohm
ϑ _o	= characteristic constant of material in °C
ϑ _e	= chosen permissible final conductor temperature in °C
ϑ _a	= initial temperature in °C
K	= factor for determination of the peak short circuit current
Θ _b	= conductor temperature at the beginning of the short circuit in °C
Θ _e	= conductor temperature at the end of the short circuit current in °C
ρ _A	= average apparent soil resistivity in Ohmm
ρ _{Ai}	= apparent resistivity, measured for one electrode spacing, in Ohmm
ρ _E	= specific soil resistivity in Ohmm

Annex 4: Examples and details of earthing systems

Fig. 04 Foundation Earth Electrodes



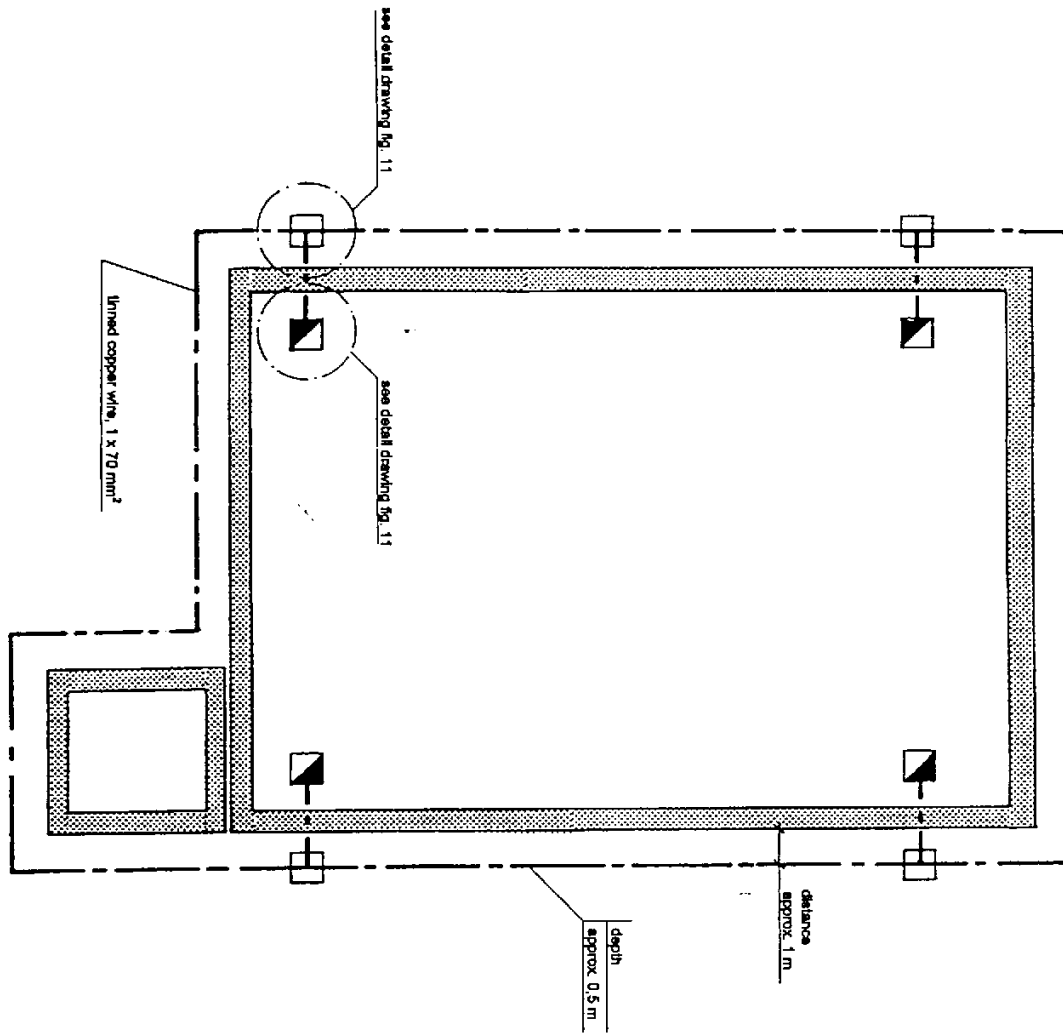
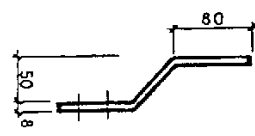
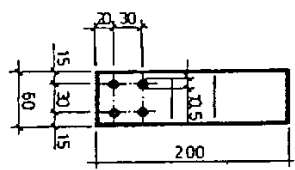
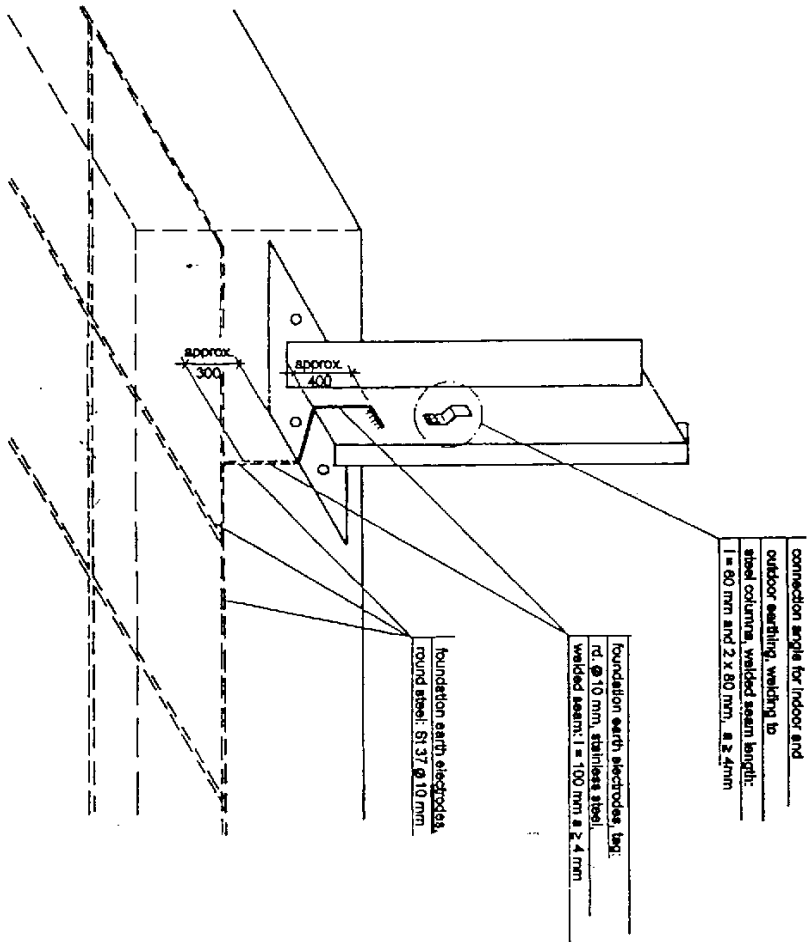


Fig. 02: Potential Grading
Earth Electrodes



connection angle:
S137, galvanized

Fig. 03: Connection to Steel Structure

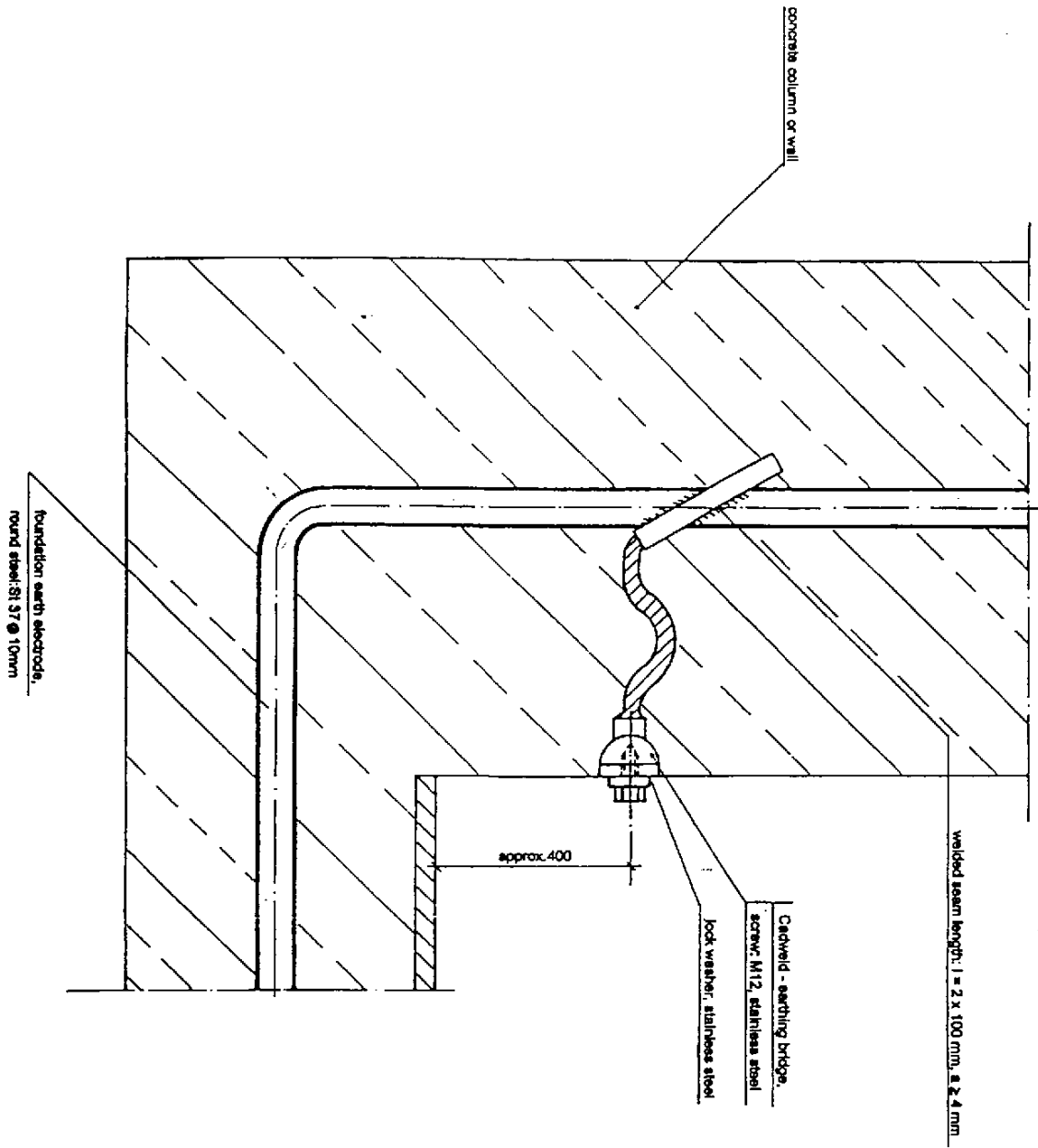


Fig. 04: Connection Point
to Foundation
Earthing Electrodes

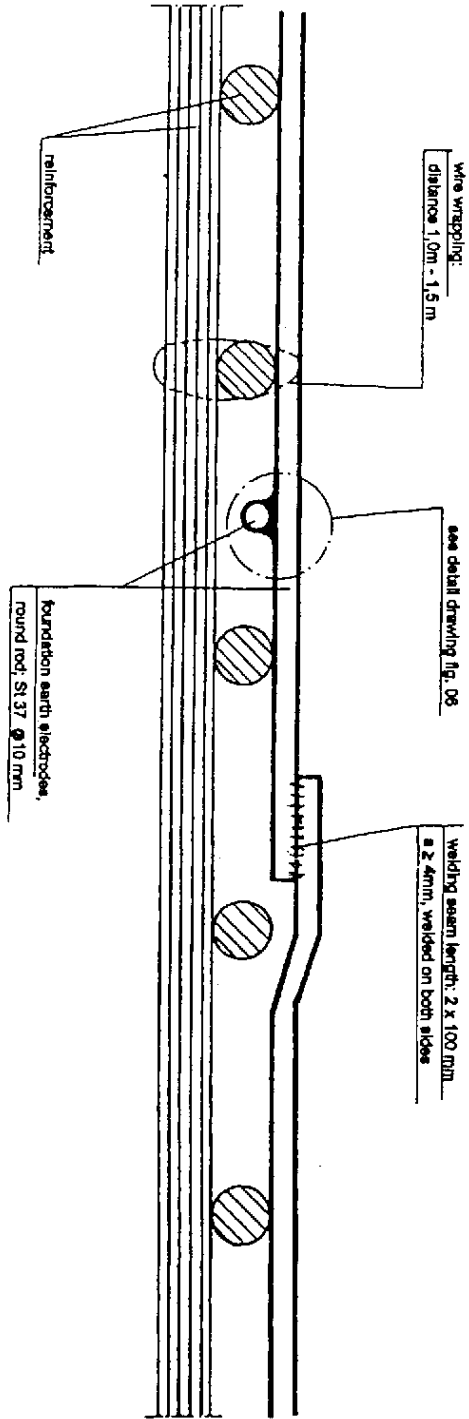


Fig. 05: Connection to Foundation
Earth Electrodes and
Wrapping of Reinforcement

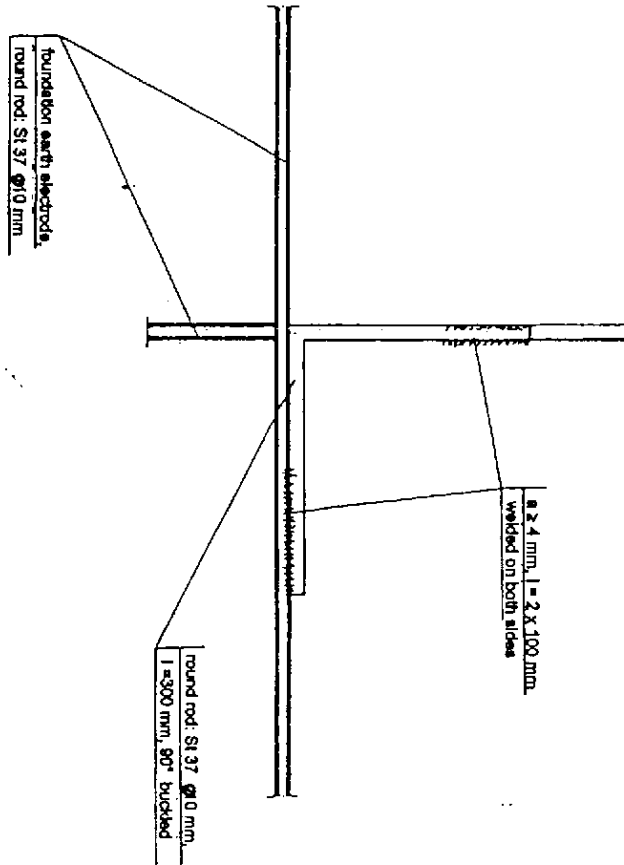


Fig. 08: Connection to Foundation Earth Electrodes

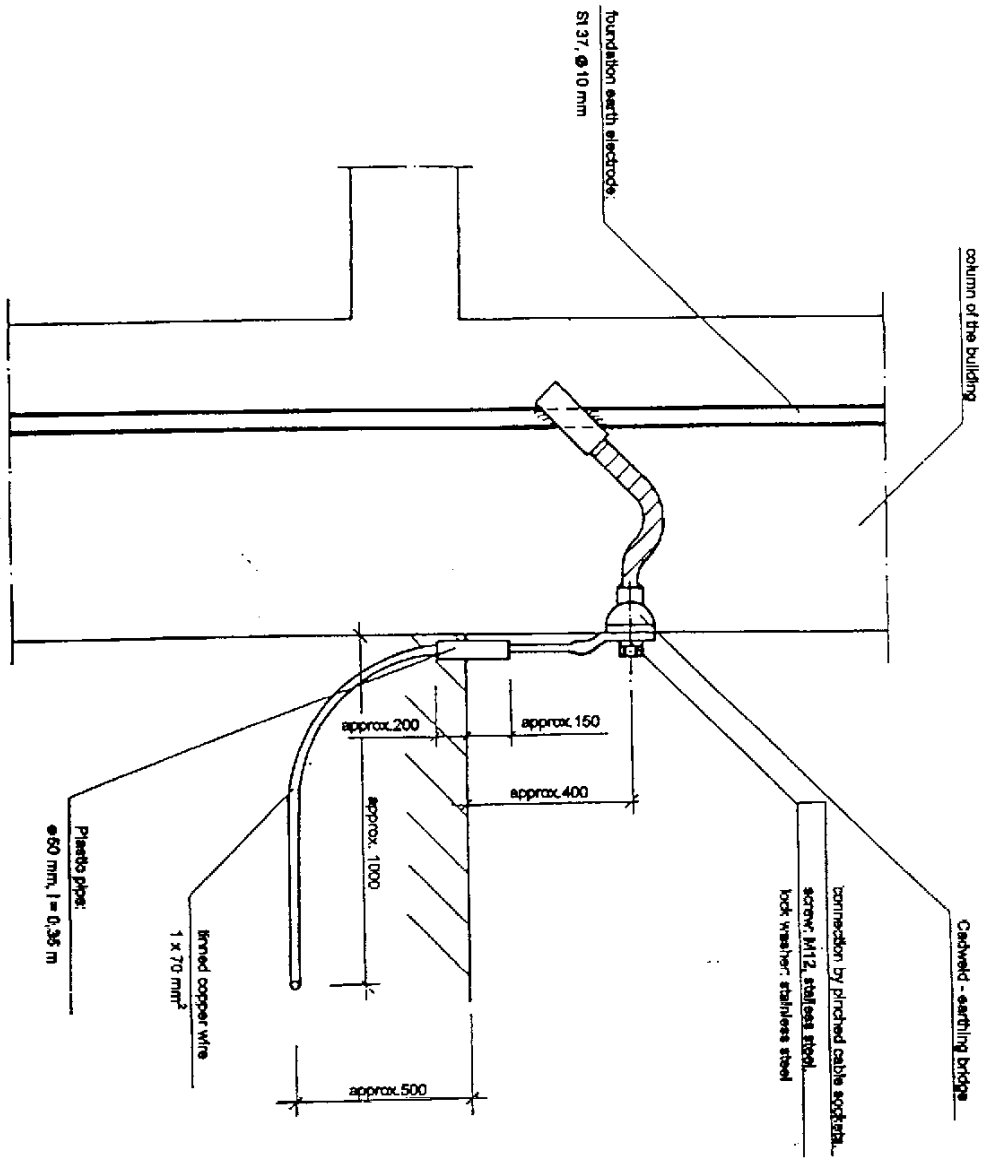
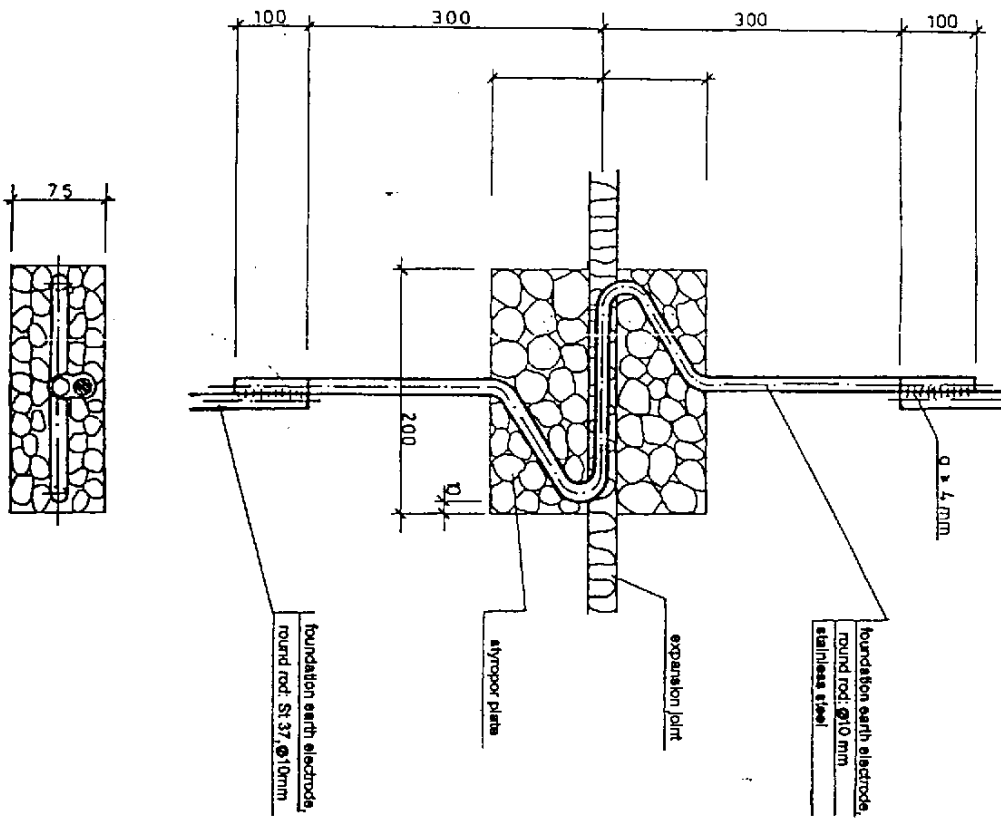
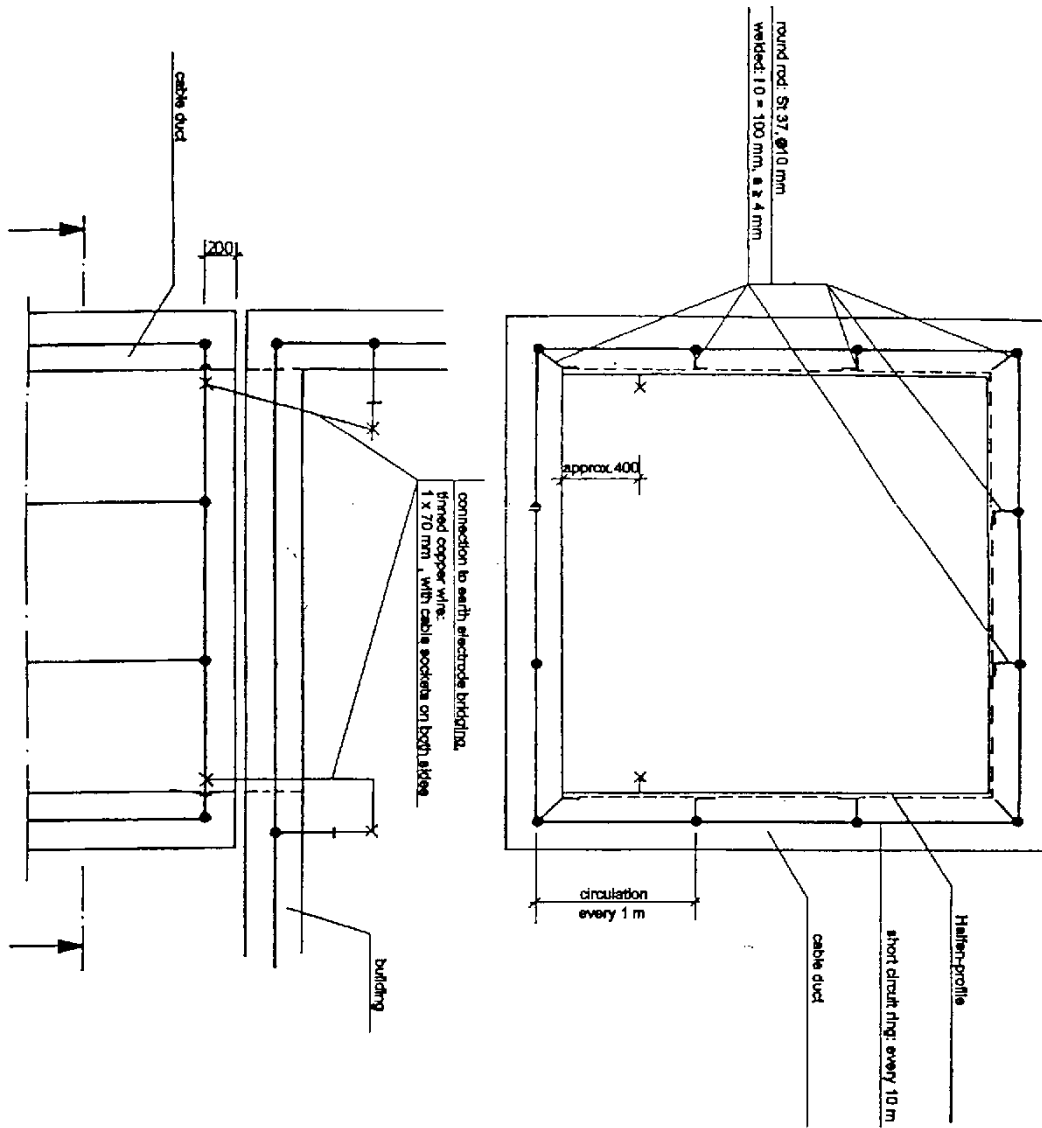


Fig. 07: Connection Potential Grading
 Earth Electrode to
 Foundation Earth
 Electrode



using of covered expansion joint
bridging only in case of
not visible bridging

Fig. 08: Covered Expansion Joint



variable bridging,
expansion joint between cable
duct and building

Fig. 09 Variable Expansion
Joint Bridging,
Cable Duct-Building

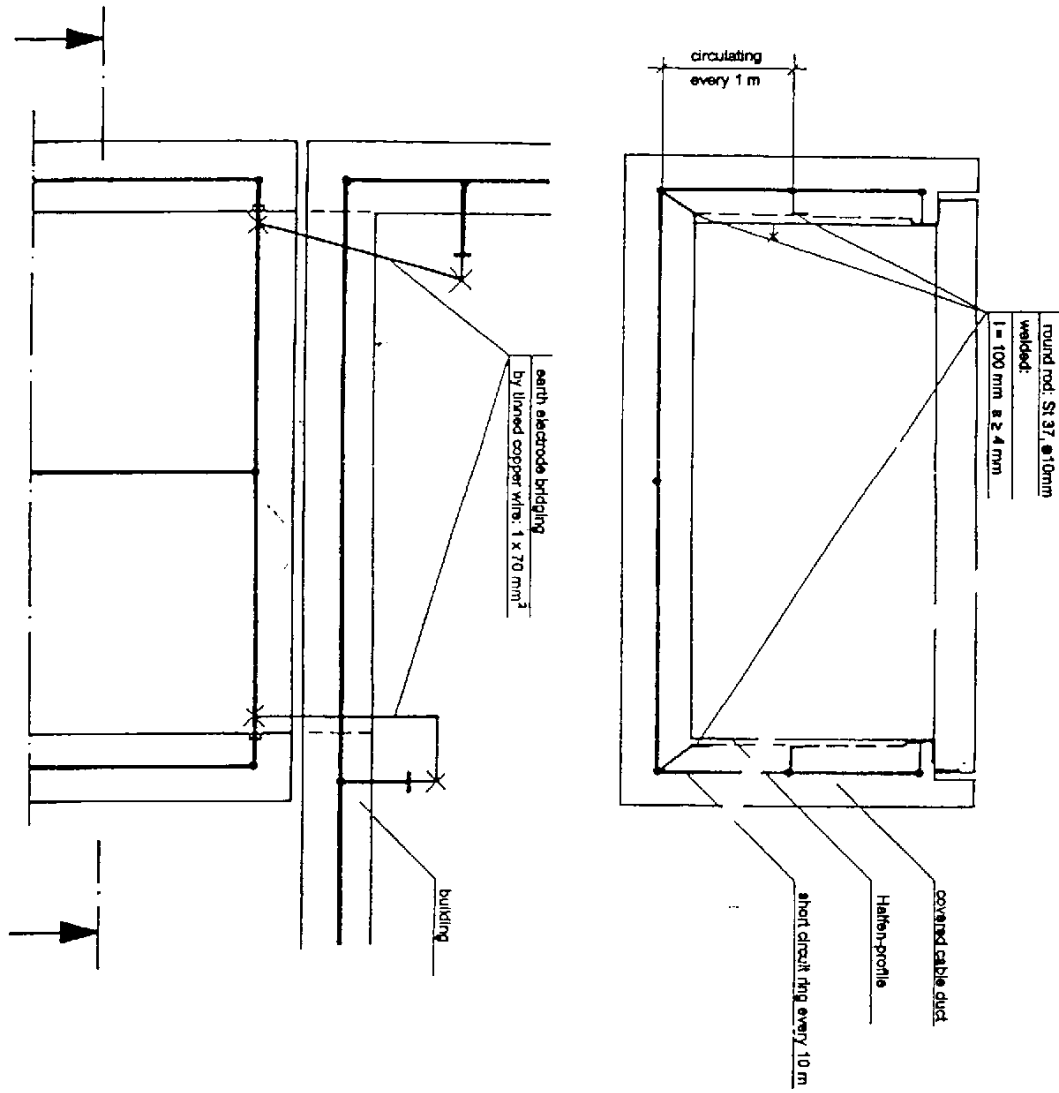


Fig. 10: Visible Expansion
Joint Bridging
Covered Cable Duct-Building

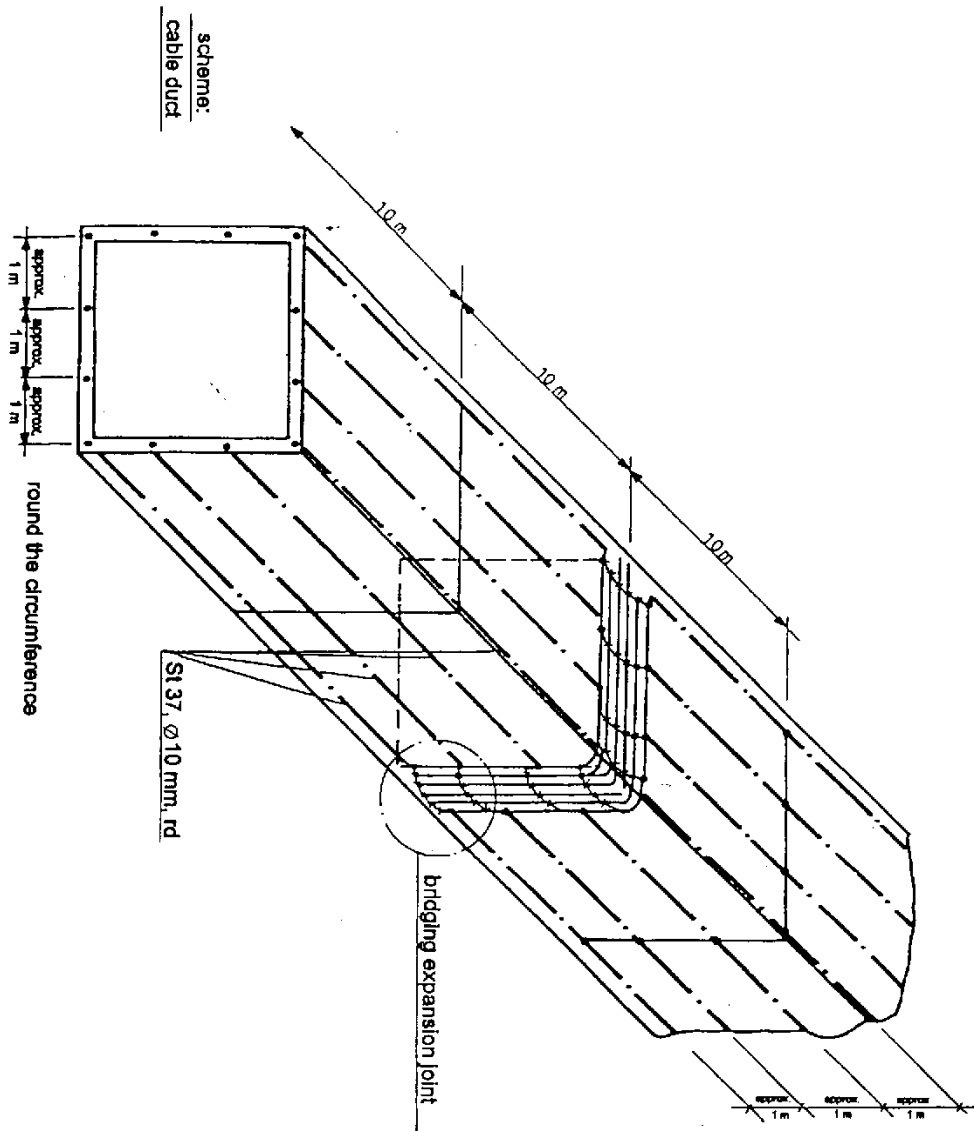


Fig. 11: Earthing, Cable Duct