British Standard

BRITISH STANDARD

BS 7354:1990

Incorporating Amendment No. 1

Code of practice for

Design of high-voltage open-terminal stations —

Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Power Electrical Engineering Standards Policy Committee (PEL/-) to Technical Committee PEL/92, upon which the following bodies were represented:

ASTA Certification Services
Association of Manufacturers Allied to the Electrical and Electronic Industry (BEAMA Ltd.)
British Railways Board
Copper Development Association
Department of the Environment (Property Services Agency)
ERA Technology Ltd.
Electricity Supply Industry in England and Wales
GAMBICA (BEAMA Ltd.)
Health and Safety Executive
Transmission and Distribution Association (BEAMA Ltd.)

The following bodies were also represented in the drafting of the standard, through subcommittees and panels:

Association of Consulting Engineers
Association of Supervisory and Executive Engineers
Electrical Installation Equipment Manufacturers' Association (BEAMA Ltd.)
Engineering Equipment and Materials Users' Association

This British Standard, having been prepared under the direction of the Power Electrical Engineering Standards Policy Committee, was published under the authority of the Board of BSI and comes into effect on 30 November 1990

The following BSI references relate to the work on this standard:
Committee reference PEL/92
Draft for comment 85/27094 DC

ISBN 0 580 18876 0

Amendments issued since publication

Amd. No.	Date of issue	Comments
7160	July 1992	Indicated by a sideline in the margin

Contents

Foreword

This British Standard has been prepared under the direction of the Power Electrical Engineering Standards Policy Committee. It supersedes BS 162:1961, which is withdrawn.

This code of practice represents a standard of good practice and takes the form of recommendations.

Attention is drawn to the following Regulations:

a) The Health and Safety at Work etc. Act 1974;

b) The Factories Act 1961;

c) The Electricity at Work Regulations 1989;

d) The Electricity Supply Regulations 1988.

In a limited number of locations the Mines and Quarries Act 1954 may apply. It is essential that all persons responsible for electrical work or operation make themselves acquainted with the appropriate standing regulations and statutory regulations.

It has been assumed in the drafting of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people for whose guidance it has been prepared.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 54, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

blank

Section 1. General

1.1 Scope

1.1.1 General

This British Standard gives recommendations for the design of high-voltage open-terminal stations.

This standard does not cover equipment included in installations for which separate standards exist. Such equipment should comply with the relevant separate standards. Some relevant British Standards are listed in Table 1.

1.1.2 International practice

Both UK and international practice concerning clearances are included in section 5. International practice is included to allow this standard to be applied to installations designed in the UK for construction overseas. See also note 1 to **1.3**.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover. (See also Table 1.)

1.2 Definitions

For the purposes of this British Standard the definitions given in BS 4727-2: Group 06 apply together with the following.

1.2.1
switchgear

a general term covering switching devices and their combination with associated control, measuring, protective and regulating equipment and also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures, intended in principle for use in connection with generation, transmission, distribution, and conversion of electric power

1.2.2
open-type switchgear

switchgear in which the live parts are not provided with protective covers

1.2.3
outdoor open-type switchgear

open-type switchgear suitable for installation in the open air, i.e. capable of withstanding wind, rain, snow, dirt deposits, condensation, ice and hoar-frost

1.2.4
indoor open-type switchgear

open-type switchgear designed solely for installation within a building or other housing, where the open-type switchgear is protected against wind, rain, snow, abnormal dirt deposits, abnormal condensation, ice and hoar-frost

1.2.5
busbar

a conductor forming a common electrical connection between a number of circuits

1.2.6
busbar connection

a conductor forming the electrical connection between a busbar and an individual piece of apparatus

1.2.7
connection

a conductor other than a busbar or busbar connection which carries current to or from an individual piece of apparatus

1.2.8
clearance

the distance between two conductive parts measured by a taut string

1.2.9
clearance to earth

the clearance between any conductive parts and any parts which are earthed or intended to be earthed

1.2.10
clearance between poles

the clearance between any conductive parts of adjacent poles

1.2.11
clearance between connections of the same pole

the total clearance between parts of the same pole separable electrically from each other by a mechanical switching device in the open position or by any other means

1.2.12
short-circuit

the connection of two or more points of different poles or parts of a circuit through a negligible impedance

1.2.13
short-circuit current

an overcurrent resulting from a short-circuit due to a fault or an incorrect connection in an electric circuit

1.2.14
short-time withstand current (of a circuit)

the current that a circuit or a switching device in the closed position can carry during a specified short time under prescribed conditions of use and behaviour

1.2.15
highest voltage for equipment (U_m)

the highest r.m.s. phase-to-phase voltage for which the equipment is designed in respect of its insulation as well as other characteristics which relate to this voltage in the relevant equipment standards. This voltage is the maximum r.m.s. value of the highest voltage of the system for which the equipment may be used

NOTE In systems with highest voltage for equipment equal to or greater than 123 kV, this voltage U_m in general does not materially differ from the highest value of the system operating voltage. Below 123 kV, the voltage U_m may be higher than the highest system voltage, since each standard value of the voltage U_m applies to different systems the nominal voltage of which may differ by as much as 20 % (for instance, U_m = 24 kV covers both 20 kV and 22 kV), and having therefore different values of the highest system voltage.

Table 1 — Relevant standards and documents

Item	Reference
Air compressor: code of practice	BS 6244
Air conditioning of building: code of practice	BS 5720
Air receivers: fusion welded steel	BS 5169
Batteries	BS 397 and BS 6290
Batteries: maintenance code of practice	BS 6133
Batteries: sulphuric acid	BS 3031
Busbars	BS 159
Bushings	BS 223
Cable boxes for transformer	BS 2562
Cable covers	BS 2484
Cables: compression joints	BS 4579
Cables: polyethylene, polypropylene and rubber	BS 6469 and BS 6899
Cables: mineral insulated	BS 6207
Cables: telecommunications	BS 3573
Cables: telecommunications (internal)	BS 4808
Cables: thermosetting insulator armoured	BS 5467
Cables: 1 000 V, paper insulated aluminium covered	BS 5593
Cables: up to 33 kV paper insulated lead covered	BS 6480
Cables: power and lighting, PVC	BS 6004
Cables: power and lighting, rubber	BS 6007
Cables: up to 1 000 V, PVC for switchgear and controlgear	BS 6231
Cable glands and sealing boxes for use in mines	BS 542
Cable sockets	BS 91
Capacitors: power	BS 1650
Cathodic protection	CP 1021
Conduit: steel	BS 31
Circuit-breakers: high-voltage	BS 5311
Construction electrical supplies	CP 1017
Contactors	BS 775 and BS 5424
Cranes: safe use of	CP 3010
Current transformers	BS 3938
Disconnectors and earth switches	BS 5253
Earthing	CP 1013
Fire detection and alarm system	BS 5839
Fire extinguishing installations	BS 5306
Flameproof enclosures	BS 229
Fuses	BS 88, BS 2692 and BS 3036
Indicating lamp colours	BS 4099
Instruments	BS 89 and BS 90
Insulating oil maintenance	BS 5730
Insulation co-ordination guide: high-voltage	BS 5622
Insulation co-ordination: low-voltage	PD 6499
Insulation and fillings for overhead lines	BS 3288, BS 137, BS 5419 and BS 5253

Table 1 — Relevant standards and documents

Item	Reference
Insulators post: guide	BS 3297
Interference radio abatement: code of practice	BS 5602
Interference radio measurement	BS 5049
Intruder alarm signalling: code of practice	BS 5979
Oil: insulating	BS 148
Ladders: fixed	BS 4211
Lighting: emergency	BS 5266 and BS 764
Lightning: protection of structures, code of practice	BS 6651
Lightning arresters	BS 2914
Line traps	BS 4996
Maintenance of switchgear/controlgear	BS 6423, BS 6626 and BS 6867
Meters	BS 5685
Motors	BS 5000
Motor starters and controllers	BS 587
Power line carrier systems	IEC 481
Pressure vessel access openings	BS 470
Reactors	BS 4944
Rectifier equipment (semiconductor)	BS 4417
Relays	BS 5992 and BS 142
Rubber mats	BS 921
Safety of machinery	BS 5304
Safety isolating transformers	BS 3535
Sealing compound	BS 1858
Surge diverters	BS 2914
Switches above 1 kV	BS 5463
Switches air breaker up to 1 kV	BS 5419
Switchgear assemblies up to 1 kV	BS 5486
Switchgear metal clad above 1 kV	BS 5227
Switchgear protective enclosures	BS 5420
Symbols	BS 3939
Tap-changers: applications guide	BS 5611
Tap-changers: on-load	BS 4571
Telemetry and control signals	BS 5863
Telephones: private	BS 6701
Television cabling	BS 6513
Terminals: marking of	BS 5559
Terminology: switchgear and controlgear	BS 4727-2: Group 06
Testing of SF_6 gas	BS 5270 and BS 5209
Transformer: current	BS 3938
Transformer: loading of	CP 1010
Transformer: oil gas analysis, guide	BS 5800
Transformer: power	BS 171
Transformer: power application, guide	BS 5953
Transformer: voltage	BS 3941
Valves, etc. for compressed air installations	BS 1123

1.2.16
rated voltage for equipment

the r.m.s. phase-to-phase voltage by which the equipment is designated and to which certain operating characteristics of the equipment are related

1.2.17
basic insulation level (BIL)

the voltage of the standard lightning impulse waveform that, under specified conditions, the insulation of a device is designed to withstand

1.2.18
switching impulse level (SIL)

the voltage of the standard switching impulse waveform that, under specified conditions, the insulation of a device is designed to withstand

1.3 Relevant acts and regulations

A list of some relevant acts and regulations is given in the foreword of this British Standard.

NOTE 1 The implementation of this standard in any country should take into account the safety legislation of that country covering such installations.

NOTE 2 The list of the publications referred to in this standard given on the inside back cover does not include all those given in Table 1.

Section 2. Switching arrangements

2.1 General

This section gives some guidance in the choice of switching arrangements. The continuity of service under fault and maintenance conditions for switching arrangements are categorized.

Figure 1 shows some commonly used switching arrangements. In a substation, flexibility can be achieved by the introduction of sectionalization of the busbars or by using different arrangements.

More than one of the examples shown in Figure 1 may be used on the same site but at different voltage levels.

2.2 Service continuity

When choosing a specific switching arrangement one of the prime considerations should be the effect of the loss of plant due to fault conditions or for maintenance.

In all the examples given, if line or transformer faults are considered continuity cannot be maintained on the affected circuits. Apart from these limitations a measure of service continuity can be maintained.

An assessment of the continuity that can be obtained from any example in Figure 1 has been categorized as follows and is shown in Table 2.

a) *Category 1*. No outage necessary within the substation for either maintenance or fault.

NOTE Category 1 necessitates no system outage but does not necessarily provide a secure supply, i.e. continuity of supply, for single faults even if these are limited to busbar and circuit-breaker faults.

b) *Category 2*. Short outage necessary to transfer the load to an alternative circuit for maintenance or fault.

c) *Category 3*. Loss of circuit or section.

d) *Category 4*. Loss of substation.

The above categories do not apply in situations where a fault occurs when maintenance is in progress on other equipment.

2.3 Choice of switching arrangements

Choice of switching arrangements may be influenced by:

a) the level of skill and experience of operating staff;

b) the future growth and development of the supply system;

c) economy in the early stages of development;

d) the ease of facilitating future extensions;

e) duplication of circuits to give alternative supply routes;

f) amount of power to be transmitted;

g) strategic importance of the circuits;

h) the service continuity of other significant parts of the network.

Considering the above influences on choice, the following gives suggestions regarding the application of the individual switching arrangements shown in Figure 1.

1) *Arrangements A, B and F.* Single busbar arrangements are more commonly used for local distribution systems.

Single busbar with transfer busbar and single busbar installations connected in a ring of stations offer limited systems security. These arrangements have no security against busbar faults, no switching flexibility, and involve fairly extensive outage for busbar and busbar disconnector maintenance.

Except in the case of single busbar with transfer busbar, circuits are lost during circuit-breaker maintenance unless some form of circuit-breaker by-passing facility is added.

2) *Arrangements C and D.* The duplicate busbar arrangement is recommended for large substations where security of supply is important. These are particularly suitable for highly interconnected power networks in which switching flexibility is important and multiple supply routes are available.

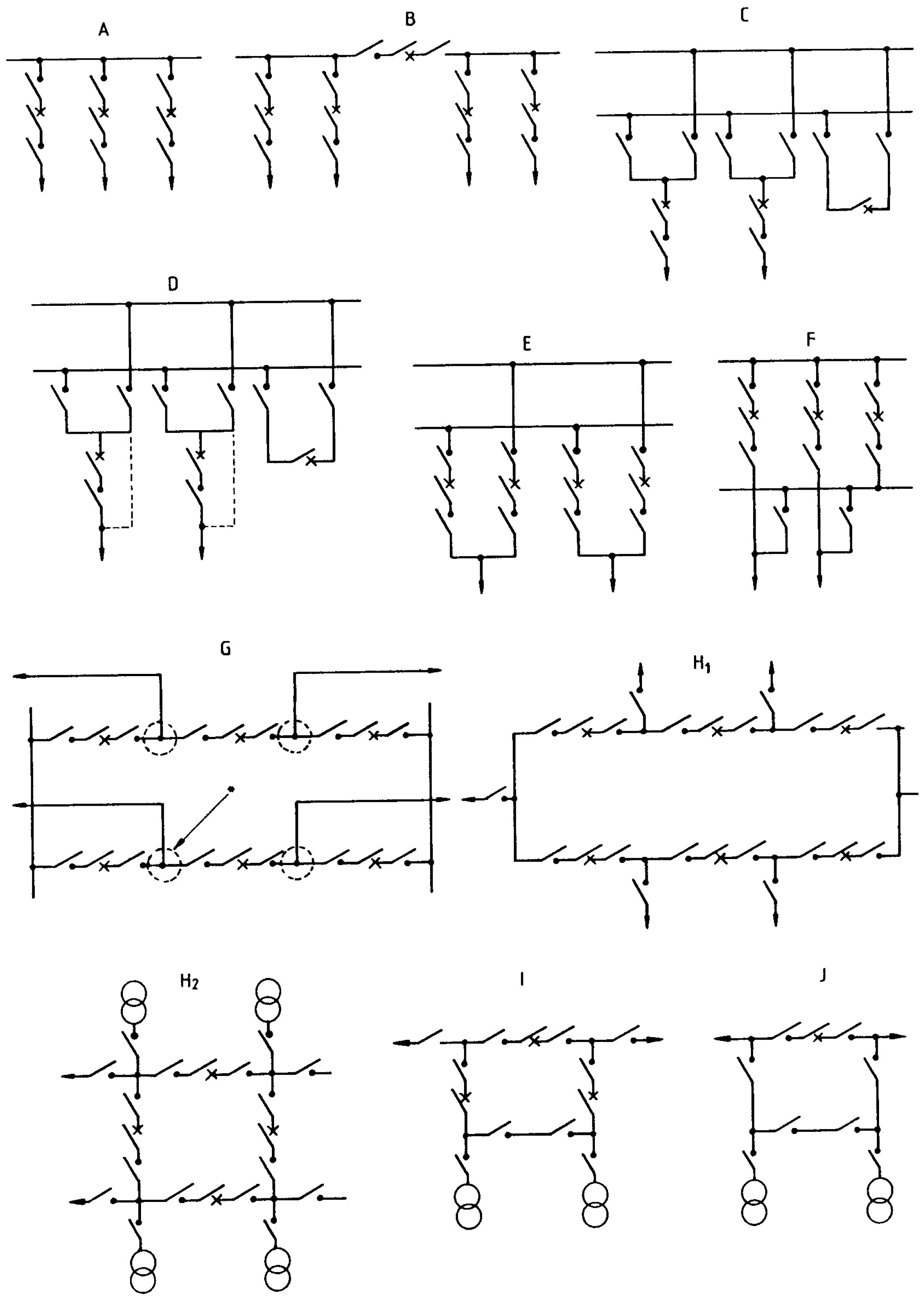
3) *Arrangements E and G.* The double circuit-breaker and 1½ circuit-breaker arrangements are particularly suitable for substations handling large amounts of power, such as those associated with generating stations.

It should be noted that to cover all contingencies of switching, the circuit-breakers and associated equipment in arrangement G should be capable of handling the combined load current of two circuits.

4) *Arrangements H_1 and H_2.* The mesh arrangements are particularly suited to applications where maximum security against busbar faults and minimum outage for maintenance are required.

It should be noted that equipment in the ring connections of the mesh should be capable of carrying the maximum load current that may occur due to any switching contingency.

5) *Arrangements I and J.* The single and three switch arrangements have limited application and are mainly suited to a ring system of supply feeding bulk supply points consisting of duplicate transformers or banks of transformers.



* See note 3 to table 2.

Key
× circuit breaker
O disconnector

Figure 1 — Commonly used switching arrangements

Table 2 — Analysis of service continuity

Type of arrangement (see Figure 1)	Service continuity category (see 2.2)	
	Circuit-breaker area	Busbar area
A Single busbar	3	4
B Single busbar with bus section circuit-breaker	3	3
C Double busbar	3	2 (see note 1)
D Double busbar with by-pass facilities	2 (see note 1)	2 (see note 1)
E Double busbar with double circuit-breaker	1 or 2	1 or 2
F Single busbar with transfer bar	2 (see note 1)	3
G Double busbar with 1½ circuit-breaker	1 or 2 (see note 2)	1 or 3 (see note 3)
H Mesh	1 or 2	3
I Three switch with by-pass	1 or 2	3
J One switch with by-pass	1 or 2	3

NOTE 1 To achieve these stated categories requires the inclusion of a bus coupler switch.
NOTE 2 Category 1 applies for maintenance conditions. Category 2 applies for fault conditions.
NOTE 3 Category 1 applies if maintenance is required on the busbars. Category 3 applies if a fault occurs or maintenance is required on circuit connections identified with an asterisk in Figure 1.

Section 3. Busbar connection and structures

3.1 General

It has been the practice in the United Kingdom and some other countries to assess the working loads or forces acting on substation equipment and supporting structures, and then to add safety factors when calculating stresses in materials and equipment. In some countries such practices are required by regulations, e.g. in the design of overhead lines.

The recommended practice is to establish the maximum force that any piece of equipment would be expected to withstand in its lifetime, rather than apply estimated safety margins over assumed working loads. In order to establish the total mechanical forces acting on electrical equipment and supporting structures it is necessary that consideration be given to forces resulting from:

a) short-circuit current;

b) wind loading;

c) deadweight;

d) ice covering (where appropriate);

e) conductor tension (where appropriate);

f) seismic forces (where appropriate).

Where a site is subject to earthquake, all parts essential to the safe and satisfactory operation of the station should be designed and installed in such a way as to have an adequate degree of resistance to expected disturbances. The design should be based upon stated values and factors indicating earthquake patterns and intensity which should be furnished by the purchaser.

3.2 Design parameters

3.2.1 General

All equipment should be designed to meet the maximum values of the following:

a) stated wind speed applied to the equipment, without ice covering, plus the appropriate short-circuit force;

b) stated wind speed applied to the equipment with a stated radial thickness of ice (where appropriate) but not including short-circuit force.

NOTE Where severe wind and icing conditions are persistent for a significant proportion of the year, special design procedures are necessary.

3.2.2 Force due to short-circuit

3.2.2.1 ***Forces between parallel conductors***

The internationally accepted formula for the force between two parallel conductors each carrying symmetrical current I is given by:

$$F = \frac{0.2KI^2}{d} \qquad (1)$$

where

F is the average force (in N/m);

I is the symmetrical short-circuit r.m.s. fault current (in kA);

d is the spacing between conductors (in m);

K is the stress factor.

Assuming the supporting structures and conductors to be rigid they will have to withstand the force due to the peak current which is $\sqrt{2}F$. At the beginning of a short-circuit the current may be approaching full asymmetry and have an instantaneous peak value which is a function of the X/R ratio of the circuit:

$$F_{max} = \frac{0.2KI^2}{d} \qquad (2)$$

where

X is the reactance;

R is the resistance.

NOTE Maximum values of the asymmetrical peak current can usually be taken as 2.5 times the symmetrical r.m.s. current and this gives a K value of 2.5^2 for the maximum force.

Practical connection systems however have considerable mass and a natural frequency normally lower than the supply frequency and hence would not respond to the maximum value of the asymmetrical fault current and therefore lower values than the maximum value of K can be used in the calculations.

3.2.2.2 ***Forces between rigid conductors***

Full scale tests on rigid busbar systems subjected to two-phase and three-phase faults have demonstrated that for practical design purposes a much lower value of K gives realistic results.

For two-phase faults a value of $K = 4$ and for three-phase faults a value of $K = 3$ should be used.

NOTE Forces due to single phase-to-earth faults are less than for the conditions described in this subclause.

3.2.2.3 ***Forces between flexible conductors***

In the case of flexible conductor arrangements, forces can be determined from **3.2.2.1** but the overall flexibility of conductor/structure is increased and the factor K becomes a function of span length as follows:

a) for a span of 15 m to 30 m, $K = 1.6$;

b) for a span of 60 m, $K = 0.8$;

c) values of K for a span of between 30 m and 60 m can be obtained by linear interpolation.

When multiple conductors are employed for a single phase, allowance should be made for the short time "snatch" force produced by the mutual attraction between parallel conductors. This force is a function of the conductor spacing and distance between spacers. Tests have shown that this force is not coincident with the maximum short-circuit forces between phases.

It has been found in practice that structures designed for normal working and dynamic load due to short-circuit forces between phases have been adequate to meet the impulse forces due to multiple conductors.

3.2.3 Force due to wind loading

It is essential that a maximum wind speed is stated by the user, and for calculation purposes this will be assumed to be acting normal to the axis of the conductor or item of equipment.

If the wind speed varies with height, this fact should be included in the information supplied. For UK practice, CP 3: Chapter V-2 gives further information. This document indicates that wind force is affected by height, type of ground and size of obstacles, e.g. buildings.

For a typical open-type station, the wind pressure P (in N/m^2) for a nominal height of 10.0 m is given by:

$$P = 0.613V^2 \qquad (3)$$

where

V is the windspeed (in m/s).

The force F (in N) applied to the conductor or item of equipment is given by:

$$F = PA \qquad (4)$$

where

A is the projected surface area (in m^2).

The force obtained from equation (4) is affected by the shape of the item concerned. CP 3: Chapter V-2 provides force coefficients (C_f) for this purpose, and equation (4) becomes:

$$F = PAC_f \qquad (5)$$

For items of equipment normally found in open-type substations the value of C_f rarely exceeds 1.0 and for practical design purposes the following values can be applied:

a) all cylindrical shapes including insulators, $C_f = 0.7$;

b) rectangular shapes, $C_f = 1.0$.

When applying the above, allowance should be made for increase in dimensions due to ice where appropriate. Lattice structures should be treated as a special case in accordance with CP 3: Chapter V-2.

3.2.4 Force due to deadweight

When calculating the deadweight of conductor or other items, the mass of an even thickness of ice should be included where applicable.

The thickness of ice should be stated by the user and its mass per unit volume calculated at 912 kg/m^3.

3.3 Factor of safety

Since the method described in **3.2** provides forces which are known maxima then the resultant stresses can be up to the maximum allowable, e.g.:

a) porcelain: guaranteed cantilever breaking strength;

b) drawn or extruded metals: guaranteed minimum proof stress;

c) cast metals: manufacturer's recommendation and/or manufacturer's experience.

3.4 Insulators

3.4.1 Post-type insulators for use as busbar or connection supports

Normally of porcelain construction, the location of post-type insulators for use as busbar or connection supports is largely dictated by the form of layout adopted and the maximum permissible conductor span between adjacent supports.

In selecting the correct insulator for a particular application, it is necessary for the designer to determine the following.

a) The mechanical strength required. This can be readily determined by the method described in **3.2**.

b) The electrical requirements. This data will determine the overall height of the insulator, the minimum height being dictated by the clearance requirements of **5.2**.

c) The minimum surface creepage. This will normally be specified to suit the pollution conditions prevailing on site.

3.4.2 Tension insulators

Tension insulators are normally of the cap and pin type and it is common practice to use overhead line insulators since these are established designs.

Appropriate insulators should be selected having regard to the mechanical strength and the number required in series for the electrical requirements. Units with different profiles are available and this enables selection to suit the specified creepage length.

3.5 Busbars and connections

The conductors used for busbars and connections will in general be of either rigid, tubular or flexible form, the choice largely being determined by the type of substation construction adopted.

The materials used should preferably be either copper or aluminium, to provide the highest current-carrying capacity for a given size.

Where flexible tensioned conductors are applied the size should be determined for both the mechanical strength and electrical requirements.

The size of tubular conductors can be determined in a similar manner and, particularly when applied to busbars, the maximum possible length or span should be utilized since this requires the minimum number of supporting insulators. These rigid forms of connection are prone to wind induced vibration and care should be taken to ensure that the maximum span determined from mechanical strength is adjusted as necessary to avoid this phenomenon.

As a guide, a tubular conductor rigidly fixed at one end and supported at the other is generally insensitive to vibration if the material frequency of oscillation is greater than 2.75 Hz.

3.6 Terminal fittings and clamps

Termination of busbars and connections on equipment terminals or supports is achieved by the use of correctly designed fittings or clamps appropriate to the application.

Clamps and fittings applied to tubular conductors should be of the split clamp or multiple half clamp bolted types and it is important that each length of conductor is equipped with a rigid clamp at one end and an expansion or sliding type at the other, to allow for equipment movement and thermal expansion.

When selecting clamps and terminal fittings the following should be taken into consideration:

a) materials should be compatible with the conductor and with the associated equipment terminal;

b) design should be such that the temperature rise at rated current is less than that of the conductor;

c) design should be such that visible corona or radio interference voltages are limited to acceptable values.

The making of bolted aluminium joints should comply with the supplier's recommended procedures.

Since joint faces between clamps and conductors are subject to deterioration, steps should be taken to ensure their effective longevity by preparation of the surfaces immediately prior to making the joint.

Preparation is particularly important where high resistance oxides form quickly, as in the case of aluminium, and where electrolytic action takes place, as in the case of dissimilar metals.

All joints should be protected against the ingress of moisture, where this would cause corrosive action, by the application of appropriate greases or sealants immediately after the joint has been made and in accordance with manufacturer's recommendations or instructions.

Manufacturer's recommended procedures should be followed.

3.7 Supporting structures

Structures for busbar supports should provide the minimum insulation clearance given in Table 3 and Table 4, and be designed to withstand static and dynamic loads. The latter can be determined from the method described in **3.2** but they should also comply with appropriate national standards.

Section 4. Main switching equipment

4.1 General

The main equipment incorporated in any of the switching arrangements in section 2 should be laid out as uniformly as possible in each bay. Distances between the circuit-breakers, current transformers, etc. on each phase of each circuit should conform with the minimum separation distance recommended by the manufacturers of the equipment, to provide adequate access for maintenance, temporary structures and all necessary clearances. Special consideration of seismic effects should be taken into account in the method of mounting equipment in the substation when specified by the customer.

Structures should conform with the dimensions recommended by the equipment manufacturer and be designed to withstand static and dynamic loads.

4.2 Circuit-breakers

Each circuit-breaker should be capable of operating as a three-phase group although it may be required to operate on one phase only when single phase auto-reclosure is required.

Indication devices, blocking devices and alarms provided for the operating pressure range should be accommodated centrally, preferably at a convenient height for inspection and with the minimum need for opening cubicle doors.

All cabling and power supplies to the operating mechanisms should be arranged vertically and in a manner to facilitate the easy erection of maintenance platforms. The separation of the phases and the location of all associated disconnectors should be in accordance with the manufacturer's recommendations to ensure the operational and safety working clearances in Table 3 or Table 4 can be obtained.

4.3 Disconnectors

It is essential that the adoption of any type in the layout of the station takes account of the minimum earth and phase clearances with the disconnectors in the open position and the safety working clearances for maintenance purposes.

4.4 Current transformers

The preferred position of current transformers is on the circuit side of and adjacent to the circuit-breaker for arrangements A, B, C and E of Figure 1. With the circuit-breaker by-pass arrangement D and the transfer busbar arrangement F, the current transformers are sometimes located on the line side of the by-pass connection to eliminate the need to switch the current transformer secondaries. The 1½ circuit-breaker arrangement G, the mesh arrangements H_1 and H_2 and section and couplers as shown in B, C and D may have current transformers on each side of each circuit-breaker but for some protection schemes current transformers on any one side may be omitted.

Consideration should be given to allowing space for a second current transformer should this be necessary in the future development of the substation.

Also, on feeder circuits, a current transformer on the circuit side of the incoming circuit disconnector is preferred for use in distance protection schemes. The mesh arrangements H_1 and H_2 usually have current transformers each side of each circuit-breaker but even if one of these can be dispensed with for some protection schemes, it is preferable to allow space for the current transformer to be included as a development of the station.

4.5 Capacitive couplers and voltage transformers

Voltage transformers and capacitor couplers together with line traps associated with line protection schemes should be connected electrically to the line at all times and should be located on the line side of the circuit disconnecting switch.

Capacitor type voltage transformers at this location assist in reducing the severity of incoming lightning overvoltages.

For the 1½ circuit-breaker arrangement G an alternative location for this equipment is at the position of the down droppers to the inter-busbar connections. Care should be exercised to ensure adequate clearance between the line connection and connections inboard of the line trap, as the time delay of an incoming lightning overvoltage traversing the line trap coil can produce a voltage difference up to the full overvoltage. The need for this clearance could increase the spacing between the phase connections. In view of these added complications the preferred practice is to locate the capacitive couplers and line traps for all schemes adjacent to the incoming line termination structure.

4.6 Surge arresters

A surge arrester is a protective device designed for repeated operation to limit voltage surges on an electrical power system to acceptable values. The operation of a surge arrester, unlike a spark gap, does not cause an interruption in supply.

There are two types of surge arrester. The first type consists of non-linear silicon carbide resistors connected in series with spark gaps. The second type consists of highly non-linear zinc oxide resistors which normally do not require series spark gaps. Elimination of the series spark gap is possible because the zinc oxide resistors can be dimensioned so that they present a very high impedance at normal system voltage and a comparatively low impedance at significantly higher voltages.

As a basic guideline, a surge arrester would normally be located as close as possible to the item of equipment requiring protection. It is essential that both the line and earth connections to the arrester should be as straight and short as practicable.

To aid the attainment of a co-ordinated insulation scheme, guidelines for the insulation and location of surge arresters are given in BS 5622-1 and BS 5622-2 and BS 2914. Complex cases, consisting of interconnected cables and lines will warrant specialized study.

NOTE This standard does not relate to zinc oxide surge arresters for which guidelines are in preparation.

Section 5. Layout

5.1 General

The layout of open-terminal high-voltage electrical equipment in switching stations should be arranged to ensure the integrity of the air space between all the conductors and live parts of the equipment for both the normal and abnormal voltage conditions expected to occur. Clearances given in this section do not apply to insulation paths that have been impulse tested. Safety to persons should be maintained by the provision of adequate clearance to live parts for maintenance, vehicular and pedestrian access and if necessary to barriers or fences.

The need for extending stations with the minimum of disruption to normal working or operating practice should be accommodated in the design and layout of the equipment.

Control buildings should be located to minimize lengths of control and protection cabling, arrangements of access roadways and other facets. These are all important considerations in the design of the stations, but are not referred to in this section because they are influenced by a variety of constraints particular to each site.

The general recommendations for clearances, safety and access are provided in this section.

5.2 Clearances

5.2.1 Provision of clearances for safety purposes

Safety clearances are distances in air applied in the design and layout of open-type high-voltage substations, or any other arrangement involving high-voltage switchgear apparatus, to enable persons to carry out work without danger.

Compliance with the relevant legislation and practice of the country where the installation is built is necessary for safe working and environmental conditions.

The safety legislation covering such installations in the UK include The Health and Safety at Work etc. Act 1974 and the Factories Act 1961. In particular the specific requirements of the Electricity (Factories Act) Special Regulations 1908 and 1944 apply to both factory premises and electrical stations as defined in section 123 of the Factories Act 1961. The Electricity Supply Regulations 1988 apply to public supply installations. Other legislation may apply elsewhere, particularly for hazardous areas.

The occupier of the site is responsible for ensuring adequate safety clearances and should therefore be fully conversant with possible system overvoltages, including lightning and switching and how these and other electrical phenomena could cause danger to persons operating or maintaining dead apparatus. In the UK it is not sufficient for the occupier to give precise instructions to persons doing work; due allowance should be made for their reasonable movements and actions. The occupier should provide work people with instructions for safety in work on the electrical installation(s), e.g. safety rules.

For a typical example of safety rules, including model form of permit-to-work, etc. see Appendix D of BS 6626.

To determine appropriate clearances for the purpose of design it is necessary to consider all types of operational and maintenance work which might reasonably be required to be done, the positions where people may be required to have access and the nature of their movements and actions.

The general approach herein is to require the designer of the substation to decide at which positions persons should stand to do work and provide appropriate clearances from the standing positions. Each safety clearance includes a basic dimension of 2.4 m (8 ft) which is widely accepted both in the UK and elsewhere as the vertical distance from a person's feet to the tip of the fingers of an upwards stretched hand. This distance is the minimum to be provided to any part of an insulator which is supporting a live conductor to avoid electrical shock.

The horizontal distance representing the reach of a person on a working platform is taken to be 1.4 m. This distance is considered to be a safe representation of practice, but is not as widely accepted as the vertical reach.

The following recommendations are intended primarily for the purposes of design and layout of high-voltage stations and cover arrangements of apparatus which would enable safety rules in general use to be complied with. Where these safety rules are not to be applied special arrangements should be made.

5.2.2 Arrangement of equipment

The arrangement of the equipment should be such as to allow the following.

a) *Access for operational purposes.* Access from without to a station should be prevented by a fence or barrier incorporating means to deter climbing. Within the station, additional fences or barriers should be provided to segregate zones of general and special authorized access and for personnel safety, e.g. around electrically-exposed ground mounted equipment. Safe access at ground level and to all operating positions at all times for the purpose of operation or inspection of the apparatus is necessary. Safety clearances from all live parts to ground level and to all operating positions are therefore required except where permanent screens or divisions around the live conductors are provided.

b) *Access for maintenance work.* Certain work, such as painting of steelwork, may be carried out without leaving ground level or operating positions. For the majority of work, however, unless the whole equipment is made dead and earthed it is necessary to arrange for it to be divisible into suitable work sections, and to provide appropriate physical separation of these work sections.

A work section should be capable of limitation by divisions, screens or other means of restricting access to live conductors, except where the live conductors are so placed in relation to the work section that spatial separation alone is equally effective in restricting such access.

A work section may be any convenient subdivision of a switching station and may include one or more items of equipment. The arrangement should be such that any part of the equipment upon which maintenance work is to be carried out can be isolated from adjoining equipment which may be live, and can be earthed before any work is carried out upon it. In addition, adjacent high-voltage apparatus busbars and connections should be arranged so that they may be isolated and earthed, unless they are already physically separated by an earthed screen or by the safety clearances given, in Table 3 and Table 4 as appropriate. Similar separation should be provided in respect of all permanent means of access or structures affording access to the equipment to be worked on. It should not be possible for anyone using permanent means of access to stand nearer to unscreened live equipment than is prescribed in Table 3 and Table 4.

Supporting structures for strained conductors should have fixed climbing facilities together with a means of preventing their unauthorized use to facilitate the changing of insulators or insulator sets. Fixed guard rails should be provided where necessary to conform with the prevailing safety regulations.

c) *Restriction of access.* Safety clearances should be maintained between the switchgear and any point at, or outside, the boundary to which the public has access.

Open-type fencing should not be regarded as a screen where taut string measurement is applied in determining safety clearances between switchgear and any point outside the boundary to which the public has access. Where the point-to-point distance is less than the safety clearances stated in Table 3 and Table 4, walls or solid screens should be used in place of open-type fencing.

NOTE 1 The safety clearances are applicable to three-phase systems having the neutral earthed solidly or through a resistor or reactor of low impedance. For other earthing arrangements special consideration should be given to increased safety clearances.

NOTE 2 For open connections to neutral earthing switchgear and components, such as resistors, reactors or arc-suppression coils associated with three-phase systems, it is recommended that the clearances of Table 3 and Table 4 applying to the rated voltage and insulation level of the associated three-phase system should be employed.

NOTE 3 The limitation of work sections, with special reference to conditions in the UK, is dealt with in Appendix A. The principles involved in applying safety clearances are given in Appendix B.

5.2.3 Basic electrical clearance

This is the clearance to earth ascribed to insulation structures which have not been factory tested. BS 5622-2 proposes these clearances and unless otherwise agreed, or required by national legislation or practice, these proposed clearances should be used. Table 3, column 2 lists the basic electrical clearances used in the UK which incorporates the practice of increasing the clearance to 500 mm for all values of 33 kV [170 kV BIL (basic insulation level)] and below.

Table 4, column 3 lists basic electrical clearances used for international practice taken from BS 5622-2.

Basic electrical clearances do not include any additions for constructional tolerances, effects of short-circuit, wind effects, etc.

Table 3 — Clearances: practice used within UK

1	2	3	4	5	6
Nominal system voltage/BIL/SIL	**Basic electrical clearance (phase-to-earth)**	**Safety working clearance (vertical)**[a]	**Safety working clearance (horizontal)**[a] (see note 1)	**Insulation height (pedestrian access)** (see note 2)	**Phase-to-phase clearance**
kV	m	m	m	m	m
6.6/75	0.5[b]	2.9	2.3	2.1	0.25
11/95	0.5[b]	2.9	2.3	2.1	0.25
33/170	0.5[b]	2.9	2.3	2.1	0.43
66/325	0.7	3.1	2.5	2.1	0.78
132/550/650	1.1	3.5	2.9	2.1	1.4
275/1 050/850	2.1	4.8	3.9	2.4	2.4
400/1 425/1 050	2.8	5.5	4.6	2.4	3.6

NOTE 1 The safety working clearances (horizontal) in column 4 are regarded as minimum clearances.
For systems where the predominant voltages are higher (275 kV and 400 kV), it is practice in the UK that the horizontal and vertical clearances are equal, conforming to the minimum figures in column 3.

NOTE 2 The insulation height (pedestrian access) figures in column 5 are shown in respect of the appropriate system voltage as follows:

a) for systems predominantly involving distribution voltages, i.e. up to and including 132 kV, 2.1 m is the recommended minimum requirement;

b) for systems where the predominant voltages are higher, i.e. 275 kV and 400 kV, 2.4 m is the recommended minimum requirement.

The above figures are regarded as minimum clearances. Users and operators may wish to allow further clearance greater than that shown for the voltage level in column 5, particularly for equipment at the higher distribution voltages situated in a single compound with higher voltage equipment present in a compound subject to a greater clearance. In these circumstances, it might be convenient to design and operate to the clearance for the highest voltage equipment.

[a] Includes allowance, see **5.2.7**.
[b] Increased value, see **5.2.3**.

5.2.4 Increased switching impulse level (SIL) safety clearance

Where the switching impulse level (SIL) is the determining overvoltage, an additional clearance may be added to those given in **5.2.3** as a provision against the infrequent tendency for switching surge flashovers not to occur across the shortest gap, (anomalous flashover).

5.2.5 Personal reach

The vertical reach of a person with upstretched hand should be taken as 2.4 m. The horizontal reach should be taken as 1.4 m.

5.2.6 Safety clearance

The safety clearances given in Table 3, columns 3 and 4 represent practice in the UK and are derived by adding the basic electrical clearance (see **5.2.3**) and the personal reach (see **5.2.5**). The safety clearances in Table 4, columns 4 and 5 represent the clearances recommended for constructions outside the UK and are derived similarly up to 750 kV BIL but include an increased SIL safety clearance (see **5.2.4**) at appropriate levels as a provision against anomalous flashover.

5.2.7 Effect of hand held tool

A hand held tool can increase the reach of a person. An addition to the personal reach values (both vertical and horizontal) of 300 mm is included by some UK authorities.

5.2.8 Operational access clearance

The distance from ground level to the nearest point of any live metal or connections, necessary to permit pedestrian access for operational purposes should be not less than the safety clearance given in **5.2.6**. The same clearance is necessary to the top of vehicles accessing the operational areas.

5.2.9 Insulation height

The lowest part of any high-voltage insulation should be not less than 2.1 m above ground level to provide for pedestrian access, e.g. the pedestal insulator bases. Table 3 and Table 4 give the recommended clearances from the lowest insulation part of a support insulator to ground with respect to the insulation withstand level.

At the higher system voltages it is international practice where switching impulse levels are specified to add an additional SIL clearance because inherently there is a greater statistical probability of a flashover extending to a nearby object rather than occurring across the porcelain insulator. These additional SIL clearances are given in Table 4.

5.3 Access for maintenance

When access has been permitted to an installation for the purpose of maintenance, personnel should be made aware of the dangers of approaching live equipment by the use of barriers and warning notices surrounding the maintenance area (see Appendix A).

Doors and covers preventing access to live equipment should normally be kept locked.

Table 4 — Clearances: international practice

1	2	3		4		5		6	7
BIL	**SIL**	**Basic electrical clearance (phase-to-earth)** (see note 1)		**Safety working clearance (vertical)**		**Safety working clearance (horizontal)**		**Insulation height (pedestrian access)** (see note 2)	**Phase-to-phase clearance**
		A	**B**	**A**	**B**	**A**	**B**		
kV	kV	m		m		m		m	m
20		0.15		2.6		1.6		2.4	(see note 3)
40		0.15		2.6		1.6		2.4	
60		0.15		2.6		1.6		2.4	
75		0.15		2.6		1.6		2.4	
95		0.16		2.6		1.6		2.4	
125		0.22		2.7		1.7		2.4	
145		0.27		2.7		1.7		2.4	
170		0.32		2.8		1.8		2.4	
250		0.48		2.9		1.9		2.4	
325		0.63		3.1		2.1		2.4	
450		0.9		3.3		2.3		2.4	
550		1.1		3.5		2.5		2.4	
650		1.3		3.7		2.7		2.4	
750		1.5		3.9		2.9		2.4	
850	750	1.6	1.9	4.0	4.3	3.0	3.3	2.6	
950	750	1.7	1.9	4.1	4.3	3.1	3.3	2.6	
950	850	1.8	2.4	4.2	5.2	3.2	4.2	2.7	
1 050	850	1.9	2.4	4.3	5.2	3.3	4.2	2.7	
	950	2.2	2.9	4.9	5.8	3.9	4.8	2.7	
	1 050	2.6	3.4	5.3	6.4	4.3	5.4	2.7	
	1 175	3.1	4.1	6.0	7.3	5.0	6.3	2.8	
	1 300	3.6	4.8	6.7	8.2	5.7	7.2	2.9	
	1 425	4.2	5.6	7.6	9.2	6.6	8.2	3.0	
	1 550	4.9	6.4	8.5	10.3	7.5	9.3	3.1	

NOTE 1 Clearances under columns marked "A" are appropriate to "conductor-structure" electrode configuration. Clearances under columns marked "B" are appropriate to "rod-structure" electrode configuration.

NOTE 2 The "rod-structure" configuration is the worst electrode configuration normally encountered in service. The conductor-structure configuration covers a large range of normally used configurations.
The heights in column 6 related to SIL levels are based upon conductor-structure electrode configurations. Higher values should be agreed if the more onerous electrode configuration applies.

NOTE 3 Phase-to-phase clearances are under consideration.

Section 6. Auxiliary equipment

6.1 Battery systems

The rated supply voltage of closing and opening devices and auxiliary circuits is conventionally as follows, depending on whether the equipment has solenoid closing or otherwise.

a) Solenoid closing equipment:

coil rated voltage	110 V	240 V
operative voltage range	93.5 V to 115.5 V	204 V to 252 V

b) All equipment except solenoid closing equipment:

system nominal voltage	48 V	110 V
equipment rated voltage	54 V	125 V
normal working voltage	54 V	125 V
operative voltage range	37.5 V to 60 V	87.5 V to 137.5 V

NOTE For shunt and closing release coils see BS 6581.

Normally lead acid batteries of the Planté type are used but others namely flat plate and tubular lead acid types may be specified. More uncommonly nickel cadmium batteries may be used but these do not so readily integrate when attempting to harmonize voltage levels with those given in items a) and b).

The battery system should be designed so that it is capable of producing the required stored operations of the device if the device has a dedicated system, or in the case of large centralized battery systems in substations of operating the maximum number of devices associated with that battery under fault conditions and minimum battery voltage, for example operation of busbar protection.

Furthermore the battery system should be capable of meeting all the associated standing loads, e.g. lamps and relays, associated with high-voltage switchgear; these usually dictate the ampere hour capacity of the battery. For these reasons it is difficult to be specific as to the exact size or capacity of a battery for different substations and usually the experience of the manufacturer is necessary to evaluate the requirements based on the loadings, supply cycles and standby period as specified by the purchaser.

6.2 Pressurized air systems for operation of equipment

6.2.1 Central storage systems

Sufficient storage should be made available to ensure that the following occur.

a) The pressure of the largest single item of equipment including the distribution ring main where applicable can be raised from zero to normal working pressure without operation of the replenishment equipment.

b) When at its cut-in pressure the system capacity should be able to re-pressurize the maximum number of dependent equipments which can trip in the event of a busbar fault.

c) Notwithstanding item b), the minimum replenishment system storage pressure volume ratio should be sufficient to provide at least six close/open operations of a circuit-breaker.

d) The replenishment system should be arranged such that the local receiver can be raised to 95 % of normal pressure in not more than 5 min with the system at the cut-in level.

6.2.2 Unit systems

The system capacity should be such that two close/open operations of the circuit-breaker or switch-disconnector are possible with the system at cut-in level.

6.3 Mobile gas handling plant

Where large quantities of gas are to be handled and retrieved a mobile plant should be provided to transfer gas to and from gas filled equipment in order to permit maintenance on the primary equipment. This plant should be capable of evacuating and storing the largest quantity of gas specified, and of evacuating the largest volume specified to a vacuum of 20 mmHg[1)]. These two operations should not require an operating time in excess of 4.5 h. The plant should also be capable of extracting air at atmospheric pressure from the largest volume specified to a vacuum of 1 mmHg in a time not exceeding 2 h. The plant should be capable of returning gas to the equipment and re-circulating used gas through filters in order to achieve the specified moisture level for the gas in service.

The filling time for the largest volume specified from a vacuum of 1 mmHg to normal working pressure should not exceed 2 h.

The plant should be capable of being towed by a road vehicle.

1) 1 mmHg = 0.133 kPa.

Where smaller quantities of gas are used and retrieval is not required a small gas handling plant may be specified to enable the equipment to be safely filled and vented.

The plant should be capable of evacuating the largest volume specified and filtering the gas extracted to ensure the expelled gas is safe, i.e. non-toxic.

The plant should be capable of evacuating air at atmospheric pressure from the equipment and replenishing the gas at the end of a maintenance operation at ambient temperatures greater than – 20 °C. The extraction and filling times should be as for a large gas handling plant.

The plant should be mobile and able to be manoeuvred on a concrete surface by one person.

6.4 A.C. supplies

6.4.1 General

Station a.c. supplies may be categorized into essential and non-essential groups. Some supplies should be continuously available without any break whilst others can operate with a brief or long break. For example, system control and data acquisition (SCADA) computerized systems are intolerable of a break whereas transformer tap-changers requiring a firm supply can tolerate a brief loss without danger to the equipment. These two examples are quite common and the status of other supplies to a large extent is a matter of custom.

The sources of the a.c. supplies should be selected with due regard to the level of integrity required; alternative costs may vary and therefore due consideration of economics, security of supply and the integrity required should be made when selecting the preferred sources. Duplicate power sources should not be paralleled and interlocking of switchgear to prevent this occurrence should be provided.

For security of supply, it is good practice to have two independent sources of supply with the failure of one supply automatically initiating changeover to the alternative.

The equipment for a.c. supplies should comply with PD 6499 for insulation co-ordination, BS 5420 for the degree of protection, and with the relevant National Practice and Specifications.

6.4.2 Typical a.c. supply loads and rating

A list of the more common a.c. loads to be supplied is given in Table 5 which also indicates the normal range of power requirements, although these are dependent upon the size of the station and the type of equipment installed. The rating of the a.c. supply should take account of the diversity factors for each load. This factor may be a matter of judgement and for guidance an overall diversity factor of 0.7 applied to the sum of the individual loads typically can be used in determining the supply rating.

Where there are large motor loads, cognizance of the voltage drop due to motor starting current should be taken into account to ensure the voltage remains over 80 % of nominal. It may be preferable to err on the high side for the supply rating to ensure that there is no undue excessive voltage drop due to regulation and for unforeseen future loads.

6.4.3 Essential supplies

Supplies which should always be available, such as the supply to a computerized SCADA system which can give incorrect signals with a transient loss of supply, should be fed by an uninterruptable power supply (UPS), i.e. an inverted a.c. supply in combination with a battery.

Other supplies, such as to the transformer tap-change and cooling fans or pump motors, can accept a limited supply interruption not exceeding a few minutes. A diesel generator automatically run-up and connected in the event of the main supply failure is adequate for this purpose. The rating of the diesel generator can be limited to that necessary for only these types of essential loads. Alternatively, duplicate auxiliary transformers, or one auxiliary transformer together with a local distribution network supply with automatic changeover facilities, may adequately provide an acceptable level of risk for these loads. If it is deemed that the risk should be minimal a standby generator should also be provided.

Table 5 — Typical loads

Type of load	Typical range of loading rating
Circuit-breaker, a disconnector, etc. operation	0 kV·A to 0.5 kV·A
Transformer cooling and tap-change	0.3 % to 1 % transformer rating
Plant/kiosk heating	0 kV·A to 0.5 kV·A
Battery chargers and UPS systems	1 kV·A to 10 kV·A
Building heating, lighting and air conditioning	5 kV·A to 100 kV·A
Site lighting	0 kV·A to 1 kV·A per bay
SF_6 gas/oil treatment	0.5 kV·A to 10 kV·A
Compressors	5 kV·A to 30 kV·A per machine
Workshop supplies	3 kV·A to 30 kV·A
Fire water pumping	5 kV·A to 30 kV·A
Mess rooms	2 kV·A to 15 kV·A

Section 7. Earthing

7.1 Symbols

The symbols used in this section are as follows.

Symbol	Description	Unit
β	cable coupling factor	—
ρ	soil resistivity	Ω·m
μ	earthwires to phase conductors coupling factor	—
l	length of cable	m (or km)
l_R	length of earth rods	m
A	area occupied by the grid	m^2
a	cross-sectional area of conductors	m^2
C_s	step voltage coefficient	—
D	spacing between parallel conductors	m
d	diameter of buried conductor	m
E	system voltage	V
h	depth of burial of grid	m
h_r	depth of rock/stone covering	m
I_C	cable fault current	A
I_L	line fault current	A
I_t	tolerable body current for current duration	A
K	two layer reflection coefficient	—
k_i	current distribution factor	—
K_R	constant dependent on number, position and length of earth rods connected to the grid	—
L	total length of buried grid conductors	m
n	number of parallel conductors/cables/lines	—
n_R	total effective number of rods	—
R	resistance of grid to earth	Ω
R_T	lower footing resistance	Ω
r	equivalent circular plate radius	m
t	duration of earth fault	s
V	grid potential rise (GPR)	V
V_s	step voltage	V
V_T	touch voltage	V
V_x	voltage at x metres from grid edge	V
x	distance from grid	m
Z_C	cable sheath impedance to earth	Ω
Z_g	earthwire impedance to ground per span	Ω
Z_L	line earthwire chain impedance to earth	Ω
Z_T	overall impedance to earth	Ω

7.2 General

This section supplements the information in CP 1013 and includes a procedure for the design of the earthing system for switching stations.

NOTE CP 1013 gives guidance on the methods that may be adopted to earth an electrical system for the purpose of limiting the potential (with respect to the general mass of the earth) of current-carrying conductors forming part of the system and non-current-carrying metal associated with equipment, apparatus and appliances connected to the system. The latter aims at securing the safety of human life, of animals and of property and is sometimes known as equipment earthing.

The design of the earthing installation should ensure that when current is conducted to earth either during a fault to earth of the system or particularly when the fault to earth is within the station, the voltage difference between parts with which a person may be in simultaneous contact is kept to a safe value. Current paths through the body are generally those between the hand and one or both feet, usually referred to as touch voltage or between one foot and the other usually referred to as step voltage. A procedure for these calculations is given in **7.4**.

During fault conditions the voltage difference between equipment and the main body of earth should be controlled, to ensure that insulation breakdown or burning does not occur on apparatus connected to points outside the substation. Cable sheaths, metallic pipes, etc. which are connected to a remotely earthed structure but isolated from the station earth by insulation will transfer the potential of that structure into the station. Similarly, the voltage difference between earth points within the switching station should be controlled.

7.3 Earthing

7.3.1 General

In order to satisfy **7.2** the structures, equipment and metalwork in a station should be electrically connected by permanent connections to electrodes in contact with the general body of earth, so as to present a sufficiently low impedance path for fault currents. This should ensure that the potential of the station as a whole rises uniformly with respect to the general body of earth during fault conditions and dangerous potential differences will not appear between individual items of equipment.

7.3.2 Earth electrodes

The main earth electrode normally takes the form of a grid or mesh which is obtained by interconnecting bare buried earth cables or conductors which are joined together at crossing points. Within the grid the conductors should be laid in parallel lines preferably at reasonably uniform spacing and, where practicable, along rows of structures or equipment to facilitate the making of ground connections, and to keep the connections between equipment and grid as short as possible.

Table 6 — Maximum current density for earthing conductors and rods

Conductor	Current density for fault times of:	
	1 s	3 s
	A/mm^2	A/mm^2
Copper	200	115
Aluminium	130	75
Galvanized steel	80	45

The grid conductors should be buried at a depth where seasonal changes in temperature and rainfall cause minimal changes in the soil resistivity. Typically this necessitates a burial depth of at least 600 mm. Greater burial depths may be advantageous in desert regions or where severe freezing can occur for a significant part of the year.

The effect of the addition of rods to the station grid is generally small unless they reach to lower soil levels having a reduced resistivity. Additional rods within an area enclosed by rows of rods have little value in reducing the overall resistance.

The conductor size should be capable of carrying the maximum earth fault current for 1 s or 3 s (as required by the protection system). Where multiple parallel paths are provided, each conductor should be capable of carrying 60 % of the maximum earth fault current for the same period of time.

To prevent overheating of bolted or brazed connections the maximum current density of the earthing conductors and rods for a fault time of 1 s or 3 s should not exceed the values given in Table 6.

To prevent excessive temperature rise of the soil adjacent to earth conductors or rods the soil current density (in A/mm^2) should not exceed the value given by the following expression:

Current density at electrode surface =

$$= 10^{-3} \times \sqrt{\left(\frac{57.7}{\rho t}\right)} \qquad (6)$$

As well as an adequate thermal capacity, conductors should also have an adequate mechanical strength to avoid damage in handling. Typical practice is to use 95 mm^2 copper cable as the smallest conductor. For other materials a larger size may be necessary, particularly in corrosively hostile ground.

7.3.3 Materials of earth electrodes

Copper is by far the most common metal used for below ground earth conductors. Apart from its high conductivity, it has the advantage of relative freedom from underground corrosion, thus the designer can be confident that the integrity of the underground grid will be maintained over the years. Copper clad steel is usually used for the earth rods and could be used for the conductor itself. Unfortunately, however, a grid of copper or copper clad steel forms galvanic cells with other buried metal in its vicinity and is therefore likely to hasten their corrosion.

In circumstances where there is a considerable quantity of other buried materials, i.e. steel pipe, conduit, cable sheaths, etc., the use of a galvanized steel conductor for the earth grid can be considered, thus avoiding or minimizing the underground corrosion.

Rarely is aluminium used as the earth conductor in the main buried earth grid because aluminium has a high corrosive rate in certain soils. Aluminium is frequently used however for above ground earthing, mainly where non-metallic structures are employed in the substation design. When this is the case, care should be taken with the jointing between the aluminium and copper.

7.3.4 Joints of earth electrodes

In view of the high temperature likely to be attained under fault conditions, joints should be welded (including cold pressure welding), bolted, compressed, high pressure riveted, riveted, sweated or brazed. Brazed joints without additional mechanical retention should only be used where the process and conditions of jointing will ensure consistently sound joints. Joints which may require subsequently to be broken should be bolted and should have the joint faces suitably treated.

7.3.5 Fencing

Metallic fence earthing is of major importance because more dangerous "touch" potentials may be involved, and the fence is often accessible to the general public. Fence earthing can be limited to two general procedures as follows:

a) electrically connecting the fence to the earth grid, locating it within the grid area or alternatively just outside;

b) independently earthing the fence and placing it outside the grid area at a convenient place where the potential gradient from the grid edge is acceptably low.

In the first of the above procedures, the fence potential rises with that of the earth grid and may assist in reducing the station earth resistance by increasing the effective area and due to the addition of fence earth rods. It also obviates any risk of inadvertent electrical connection between the fence and the earth grid. A perimeter conductor connected to the earth grid can with advantage be laid a short distance (approximately 1 m) outside the fence and parallel to it, thus decreasing the possible touch potential to which a person or animal outside the fence may be subjected. This perimeter conductor may incur significant cost and there may be problems of land ownership or pilfering of the buried conductor which degrades an otherwise sound engineering procedure. The fence should be bonded electrically to the grid on each side. The connections should be located adjacent to each corner and at each crossing of the fence by overhead lines, and their maximum spacing in metres should not exceed $0.25r$ (where r is the equivalent circular plate radius). Gate posts forming part of the fence should be connected together below ground.

Where the fence and the attached earth rods are connected to the grid they become the edge of the grid. The area within the fence should be used to determine the radius r (see **7.4.2**). However, the fence should not be taken into account when determining the number of parallel buried conductors, or for the total length of conductor when determining the resistance.

Where the fence and the associated earth rods are not connected to the grid, the fence voltage may typically be taken to be 70 % of that of the grid potential rise (GPR). Care should be exercised in making this assumption, as it is true only when all metalwork in the ground connected to the grid is insulated for 2 m each side of the fence and when no local large differences of soil resistivity, compared with the average value, could cause a closer voltage coupling of the fence and the grid.

Particular care should be taken with water pipes, cables, etc., and these should be insulated where they pass below or close to the fence. This insulation need only be nominal, so a few layers of PVC tape covering can be a good safeguard. Where disconnecting links and connections are provided to allow the fence to be connected, the link box should be located 2 m from the fence and the connection between it and the fence insulated to maintain separation of the fence and grid when they are required to be independent.

7.3.6 Incoming overhead lines

Where the earthwires of overhead transmission lines end at the terminal towers and are not connected to a point on the station structure, the base of the terminal tower should be tied solidly to the station earth grid. By so doing, a substantial proportion of the ground current may be diverted away from the station earth grid, and advantage can be taken of this situation in the design of the grid. If the tower lies outside the station fence, the connections between the station grid and the base of the tower should be buried and insulated where they pass under an independently earthed fence, to ensure isolation from the fence.

It should be realized, however, that connecting the station grid to the transmission line earthwires will usually have the overall effect of increasing the hazard at the tower bases, while lessening it at the station. This is due to the fact that each of the nearby towers will share in each voltage rise of the station grid whatever the cause, instead of being affected only by a local insulation failure or flashover at one of the towers. On the other hand, when such a tower fault occurs, the effect of the connected station grid should decrease the magnitude of gradients near the tower bases.

7.3.7 Services

For excessive potential rises of the station with respect to the outside surrounding earth which may ensue during earth fault conditions, special care is necessary with services such as water pipes, railway lines, and telephone or pilot cables which enter the station. Water pipes and cable sheaths or armour (which are more or less in direct contact with soil) should be tied to one station grid, to avoid hazards within the station area.

Where it is thought desirable to prevent transferred potentials outside the grid boundary, insulating sections can be inserted. It is essential, however, that these insulating sections are a minimum of 4 m, to avoid shunting by the adjacent soil. Cement or plastics piping is often suitable for water pipes. With railway lines, two sets of insulating joints will be necessary to provide against the shunting of a single set by the adjacent soil or a metal waggon passing over the track.

In severe cases, isolating transformers may be necessary for telephone connections. It may be necessary to treat pilot cables as live conductors and they should be insulated from the station earth system by insulation adequate to withstand the maximum grid potential rise. In the case of non-cross-bonded flat formation power cables, it is the practice to run an earth conductor along with the cables.

Similar hazards need to be considered in the case of portable tools, etc. which are supplied electrically from the station, and are used outside the area of the grid, where the potential is held within safe limits. To avoid these hazards, the supply circuit should be isolated from the station earth, the neutrals and machine frames should be earthed at the site of work, and the maximum fault current to the local earthing should be limited to a low value which will not itself cause dangerous gradients.

The diversion of current into the sheaths of cables carrying fault current provides similar advantages to those described in **7.3.6** for earthwires but in the case of cables, the diverted current can be very much greater.

7.3.8 Cable sheaths

While as a general rule the sheaths on main and auxiliary or multicore cables should be connected to the station earth system, it may be necessary, where single core cable terminations are employed, to provide a light insulation between cable sealing ends or cable sheaths and the earthed structures supporting them in order to prevent circulating currents.

7.3.9 Surge arresters

An earth electrode, which may be part of the grid, should be provided as near as practicable to each set of surge arresters. The connections thereto should be as direct as possible. Earth connections to surge arresters should not pass through iron pipes, which would increase the surge impedance of the connections. The earth connections of the arresters should be interconnected with the main earthing system since, to be effective in protecting the station equipment, a definite connection of low impedance between the equipment and the arresters is essential.

7.3.10 Operating mechanisms and control kiosks

Operating handles of disconnectors, circuit-breakers or earth switch mechanisms require special attention against hazards. It is relatively easy to protect against these hazards by earthing the mechanism with a connection to the main earth grid, preferably passing under the operator's stance position, and entirely separately from that employed for earthing the bases of disconnectors, earth switches, or circuit-breaker structures, so that a short definite connection exists between the hands and feet of any operator. The further contribution to safety given by an insulating link in the mechanism drive is less definite than that obtainable from an efficient earth connection.

7.3.11 Fixings

Earth conductors should be clear of the surface of structures, walls, or equipment to which they are fixed. If flat strap conductor is used and it is to be drilled for fixing, then the diameter of the hole should not exceed 33 % of the width of the conductor. Where it is required to connect portable earthing equipment, a parallel loop in the earth conductor should be provided at a suitable height, to avoid damage to the main earth conductor due to the forcing on the clamps.

7.4 Design considerations

7.4.1 General

The formulae provided in this section for the calculation of the GPR, grid resistance and touch and step voltages are based upon the soil having a constant resistivity. For general design work this is in practice necessary, as actual ground conditions generally are not precisely known. Computer programs are available but their results can only be as accurate as the information on soil conditions. The formulae, which are simple yet consistent with the accuracy with which the data is usually known, should provide a useful guide to the efficacy of the grid design.

The step voltage formula presented is the same as the formula given in IEEE 80 but whereas the IEEE 80 document uses the mesh voltage as the touch voltage, UK practice and this document define the touch voltage differently. In practice the voltage at the surface of the ground is a maximum adjacent to a corner of a grid. UK practice is to define touch voltage as the sum of the step voltage plus the voltage difference between the ground surface adjacent to a corner and the grid beneath.

A buried grid of conductors is assumed to occupy an area within straight boundary lines joining the extreme ends of the conductors. This area is referred to as the grid area and where the grid and fence are bonded together the fenced area is the grid area.

7.4.2 Equivalent circular plate radius

The expressions for touch and step voltages and some expressions for the resistance of a grid include a radius r (in m) which is the radius of a solid circular plate having the same area as the grid as follows:

$$r = (\text{grid area}/\pi)^{0.5} \quad (7)$$

7.4.3 Calculation of electrode resistance

An approximate simple expression for the resistance R (in Ω) of a thin solid circular plate buried to a depth of 0.5 m in soil having a uniform resistivity ρ (in Ω·m) is:

$$R = \frac{\rho}{4r} \qquad (8)$$

As a grid is not a solid circular plate but typically is made up of a grid of buried conductors having a combined length of L metres, a simple approximate expression which does not take into account the burial depth h is:

$$R = \frac{\rho}{4r} + \frac{\rho}{L} \qquad (9)$$

A more accurate expression which incorporates h and also the effect of earth rods connected to the grid is:

$$R = \rho \left\{ \frac{1 + \left(\frac{r}{r + 2.5h} \right)}{8rK_R} + \frac{1}{L} \right\} \qquad (10)$$

where

K_R is a constant dependent upon the number, position and length of earth rods connected to the grid given by the following equation:

$$K_R = (1 + n_R l_R^2/10r^2) \qquad (11)$$

where

l_R is the length of the earth rods (in m).

The total effective number of rods n_R is the sum of the rods connected at the periphery plus half of those connected within (this takes some account of the current distribution between rods).

This more accurate expression (equation [10]) is recommended for use in the expressions for the calculation of V_T and V_S.

NOTE Equation (10) differs from a similar expression recommended in IEEE 80 and approximates more closely to experimental values given in EPRI EL3099.

7.4.4 Calculation of grid potential rise (GPR)

Each of the overhead line earthwires and continuously earthed cable sheaths which are connected to the grid will assist in reducing the sum impedance to earth. As well as determining the grid resistance, using the expressions given in **7.4.3**, the effective impedance of each overhead line and cable sheath has to be established. It is necessary that all these are summated as parallel impedances in the general expression for the overall impedance to earth (in Ω) as follows:

$$Z_T = \left(\frac{1}{R} + \frac{1}{Z_{L1}} \cdots \frac{1}{Z_{Ln}} + \frac{1}{Z_{C1}} \cdots \frac{1}{Z_{Cn}} \right)^{-1} \qquad (12)$$

where the symbols are as defined in **7.1**.

The effective impedance of an overhead line earthwire and its connections to earth via the towers is given by the expression:

$$Z_L = \{0.5\, Z_g + (Z_g R_T)^{0.5}\} \qquad (13)$$

where the symbols are as defined in **7.1**.

The impedance of a cable sheath to earth is not very sensitive to the size of the cable or the depth of its burial. It varies with the length of the cable l and eventually attains a constant value. The impedance Z_C (in Ω) can be obtained from published data or from the following:

$$Z_C = \frac{1.2\rho}{0.85l} \quad \text{for } l < 60\sqrt{\rho} \qquad (14)$$

or

$$Z_C = 0.4\rho^{0.55} \text{ for } l \geq 60\sqrt{\rho} \qquad (15)$$

The metallic sheath of a cable which is earthed at both ends will act as a return path for that part of the conductor current which is inductively coupled to it. The remainder will enter the station grids to which it is connected. Table 7 shows some of the most common connection arrangements and gives empirical expressions appropriate to each for the calculation of the current via the grid.

The GPR is the product of Z_T and the sum of the currents from each line and/or cable circuit. Each source current should be taken as the foreseen ultimate development source current at its position in the system. Each source current has then to be reduced to take account of the current which will be induced in the overhead earthwire or cable sheath, as these currents do not pass through the grid. Thus GPR (in V) is given by:

$$\text{GPR} = Z_T \{I_{L1}(1-\mu_1)\ldots I_{Ln}(1-\mu_n) + + I_{C1}\beta_1 + \ldots I_{Cn}\beta_n\} \quad (16)$$

where

$\mu_1 \ldots \mu_n$ are line$_1$ ... line$_n$ coupling factors (typically having a value of 0.3);

$\beta_1 \ldots \beta_n$ are cable$_1$ ... cable$_n$ coupling factors (see Table 7).

7.4.5 Calculation of touch voltage

Touch voltage is defined as the sum of the voltage across 1 m of surface along a diagonal outside the corner of a grid with the voltage difference of the grid with the ground surface above. The corners are where the maximum voltage gradient occurs.

NOTE 1 IEEE 80 uses the mesh voltage as the touch voltage, and therefore it is necessary for this to incorporate a spacing factor.

NOTE 2 IEEE 80 also calculates the step voltage over the surface from the grid diagonally at a corner. UK practice is to calculate the touch voltage at the grid corner. Thus the two practices correspond for step voltage but not for touch voltage.

To take account of the greater current at the peripheral conductors compared to those within the grid, both practices multiply the step voltage basic expression by a factor k_i. American practice uses $k_i = (0.172n + 0.656)$. UK practice uses $k_i = (0.15n + 0.7)$ and applies this factor to the sum of the vertical voltage and step voltage. The complete expression for the touch voltage for UK practice is as follows:

$$V_T = \frac{\rho V}{\pi R L}\left\{\ln (h/d)^{0.5} + + \left(\frac{1}{2h} + \frac{1}{D+h} + \frac{1-0.5^{n-2}}{D}\right)\right\} k_i \quad (17)$$

or

$$V_T = \frac{\rho V}{\pi R L}\{\ln (h/d)^{0.5} + C_s\}\, k_i \quad (18)$$

where the value of coefficient C_s is shown in Figure 2.

NOTE For flat strip conductor use an equivalent diameter, d = (width/ π).

The resistance R is dependent upon the grid depth h (in m) and on any earth rods connected to it, as shown in **7.4.3**.

There are limitations which apply to both national practices, as follows:

$n \leq 25$

$0.25\ m \leq h \leq 2.5\ m$

$d < 0.25\ h$

$D > 2.5\ m$

Otherwise the expression is suitable for rectangles up to 2.5 : 1 ratio with square meshes, using for n, a value of $(n_x \times n_y)^{0.5}$.

For practical grid arrangements of $r > 5$ m and for depths h0.25 m and < 1 m, a useful approximate expression providing values of V_T within 5 % of the full expression is as follows:

$$V_T = V\left[\frac{\ln (h/d)^{0.5} + \frac{1}{2h} + \frac{2}{D}}{2.8\,(n+1)K_R}\right] k_i \quad (19)$$

7.4.6 Calculations of step voltage

Both UK and American practice is the same for the calculation of step voltage V_S. This is the voltage over 1 m of surface diagonally outwards from a corner of a grid. The expression used is as follows:

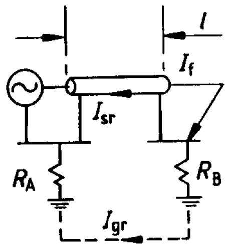
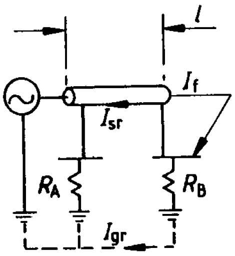
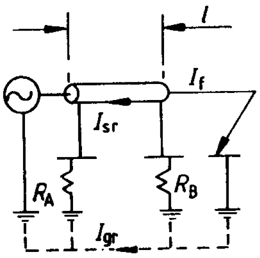
$$V_s = \frac{\rho V}{\pi R L}\left(\frac{1}{2h} + \frac{1}{D+h} + \frac{1-0.5^{n-2}}{D}\right) k_i \quad (20)$$

The same limitations as given in **7.3.5** apply.

For practical grid arrangements and with the same limitations as given in **7.4.5**, a useful approximate expression for step voltage is as follows:

$$V_s = V\frac{\left(\frac{1}{2h} + \frac{2}{D}\right) k_i}{2.8(n+1)\,K_R} \quad (21)$$

Table 7 — Formulae for the calculation of the current to ground from metallic sheathed cables

Cable circuit	Type of cable	*C*	Formulae for per unit ground current $\beta = I_{gr}/I_f$
	PILCSWA, three core PICAS, three core PILC, three single core PICAS, three single core	76 28 350 76	$$\frac{\frac{C}{(a+9E)}}{\sqrt{\left\{\left(\frac{C}{a+9E}+\frac{R_{AB}}{l}\right)^2+0.6\left(\frac{\rho}{aE}\right)^{0.1}\right\}}}$$
	PILCSWA, three core PICAS, three core PILC, three single core PICAS, three single core	76 28 350 76	$$\frac{\frac{C}{(a+9E)}+\frac{R_A}{l}}{\sqrt{\left\{\left(\frac{C}{a+9E}+\frac{R_{AB}}{l}\right)^2+0.6\left(\frac{\rho}{aE}\right)^{0.1}\right\}}}$$
	PILCSWA, three core PICAS, three core PILC, three single core PICAS, three single core	76 28 350 76	$$\frac{\frac{C}{(a+9E)}+\frac{R_{AB}}{l}}{\sqrt{\left\{\left(\frac{C}{a+9E}+\frac{R_{AB}}{l}\right)^2+0.6\left(\frac{\rho}{aE}\right)^{0.1}\right\}}}$$

Key

a is the conductor cross-sectional area (in mm^2)
E is the system voltage (in kV)
l is the length of the cable (in km)
I_{gr} is the ground return current (in A)
I_{sr} is the sheath return current (in A)
I_f is the fault current (in A)

$R_{AB} = R_A + R_B$
PILCSWA paper insulated lead cables steel wire armoured
PICAS paper insulated corrugated aluminium sheath
PILC paper insulated lead cables

The constant *C* reflects the physical construction of the sheath; it may vary ± 15 % depending on the manufacturer. For cross-linked polyethylene (XLPE) or synthetic insulation cables use 0.9*C* for the equivalent construction paper insulated cable, for steel wire armoured (SWA) copper screened cables use 1.5*C*, and for unarmoured copper screened cables use a *C* value of 450.

7.4.7 Calculation of hot zone

The surface potential, created where current passes to or from a grid, decays from the edge of the grid to nominal zero as the distance from the grid increases. Telecommunication cables within this zone which are connected to other earth electrodes assume a different potential to the ground surface under this condition. The International Consultative Committee for Telegraphs and Telephones[2)] (CCITT) recommends limits to this difference of potential and some national standards impose these or other limits. Typical values are 430 V or 650 V and in some instances higher voltages. The surface of the ground surrounding a station in which the voltage rise is in excess of the limiting value is termed the hot zone.

[2)] Publications available from International Telecommunications Union (ITU), Place des Nations, CH 1211 Geneva 20, Switzerland.

The expression usually adopted to calculate the hot zone boundary V_x (in V) (measured from the grid edge) is derived from:

$$V_x = V\left\{\frac{2}{\pi}\text{ arc sin}^{-1}\left(\frac{r}{r+x}\right)\right\} \quad (22)$$

From this expression the distance x of the hot zone is given by:

$$x = r\left\{\left(\frac{1}{\text{arc sin }\frac{\pi V_x}{2V}}\right) - 1\right\} \quad (23)$$

where V_x is the limiting voltage and arc sin is in radians.

NOTE 1 The voltage over the surface outwards from the grid edge varies along the periphery of the grid, it being greatest at the corners. This variation reduces with the distance out from the grid edge and in homogeneous ground eventually becomes zero.

NOTE 2 It is assumed that the variation is negligible at the hot zone boundary but the expression does not correctly identify the surface voltage close to the grid edge. Over the first few metres from the edge of the grid it can be taken that the voltage to remote earth decreases as the square root of the distance. The expression to use over the initial few metres is as follows:

$$V_x = V\left(1 - \frac{x^{0.5}\, V_T}{V}\right) \quad (24)$$

7.4.8 Allowance touch and step voltages

The effect of a voltage applied to the body varies significantly from person to person. On a balance of probabilities, the time dependent body current used to establish the tolerable voltage is the curve c_2 of Figure 5 of PD 6519-1:1988. Body resistance also varies but most standards use a value of 1 000 Ω. The contact resistance at the surface of the ground also adds resistance which limits the body current and a value of 3ρ per foot is taken. There is growing international acceptance that footwear resistance should be taken into account and this now is UK practice. Footwear resistance is taken as 4 000 Ω per foot.

NOTE When calculating the contact resistance values, an assumption is made on the area of the foot.

The general expression for allowable touch voltage V_T, for which the two feet are in parallel in the conceived circuit is:

$$V_T = I_t\left\{\text{body resistance} + \frac{(\text{footwear} + \text{contact resistance})}{2}\right\} \quad (25)$$

Similarly the allowable step voltage V_s, where the feet are in series in the conceived circuit is expressed as:

$$V_s = I_t\,\{\text{body resistance} + 2\,(\text{footwear} + \text{contact resistance})\} \quad (26)$$

where

body resistance = 1 000 Ω;

footwear resistance = 4 000 Ω;

contact resistance = 3ρ Ω;

I_t is taken from curve c_2, Figure 5 of PD 6519-1:1988.

If a surfacing of crushed rock is applied over the station area, which has a higher resistivity than that of the underlying soil, an effective resistivity ρeff. (in Ω·m) given as follows replaces the soil resistivity ρ in equations (25) and (26).

$$\rho_{\text{eff.}} = \rho_{\text{rock}}\left(1 + \frac{K}{20}h_r\right) \quad (27)$$

where

K is the two layer reflection coefficient given by:

$$K = \frac{\rho_{\text{soil}} - \rho_{\text{rock}}}{\rho_{\text{soil}} + \rho_{\text{rock}}} \quad (28)$$

(K usually is negative)

h_r is the depth of the rock layer (in m).

The permissible voltages vary with the duration of the fault, i.e. with the time period *t*, for which the body may be subjected to the voltage.

For stations having high speed electronic protection, *t* may be taken as 0.2 s. For stations equipped with electromagnetic high speed relays, *t* may be taken as 0.3 s. For stations having overcurrent and earth leakage protection, the clearance time is current dependent and the fault time *t* may be up to 1 s.

Figure 3 can be used to determine the allowable touch and step voltages without a surface layer of crushed rock and for a layer 0.08 m deep.

NOTE Whilst an exceptionally low value of footwear resistance has been used and is justified by tests, the puncture strength of worn footwear has not been well researched. Until further information on this aspect is available it is recommended that a limiting value of 5 kV for touch and step voltages should be applied.

7.5 Interconnecting two station grids

Frequently, higher-voltage stations are situated close to lower-voltage stations. There may be separation between the two, e.g. for an access road, or they may be within the same fenced area. Even if the grids are not directly connected by earthing conductors, there will be a voltage gradient over the ground surface at both due to fault current flowing in one of the grids. The grids can be interconnected and so behave as a single grid with the advantage of a correspondingly lower resistance.

A method of assessing the touch voltage when grids are electrically bonded together is given in IEEE 80.

The typical reduction in the touch voltage due to interconnecting the station grids is shown in Table 8.

Table 8 — Reduction of touch voltage due to interconnecting grids A and B, referred to the new station (B) touch voltage

$\frac{\text{Area of grid B}}{\text{Area of grid D}}$	$\frac{\text{Combined grid touch voltage}}{\text{New grid touch voltage}}$
3	0.8 (approximate)
2	0.7
1	0.55
½	0.45
⅓	0.4

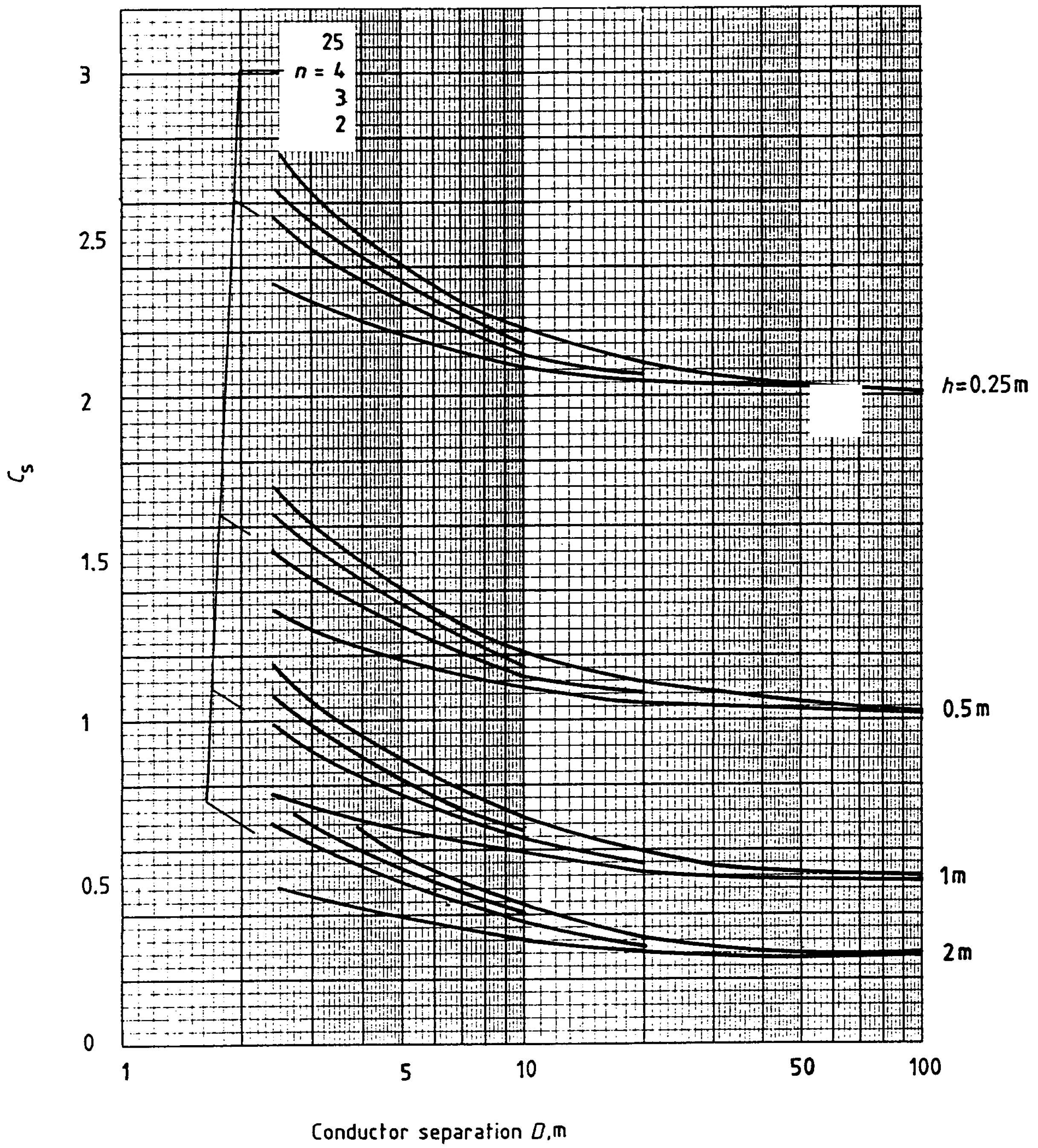
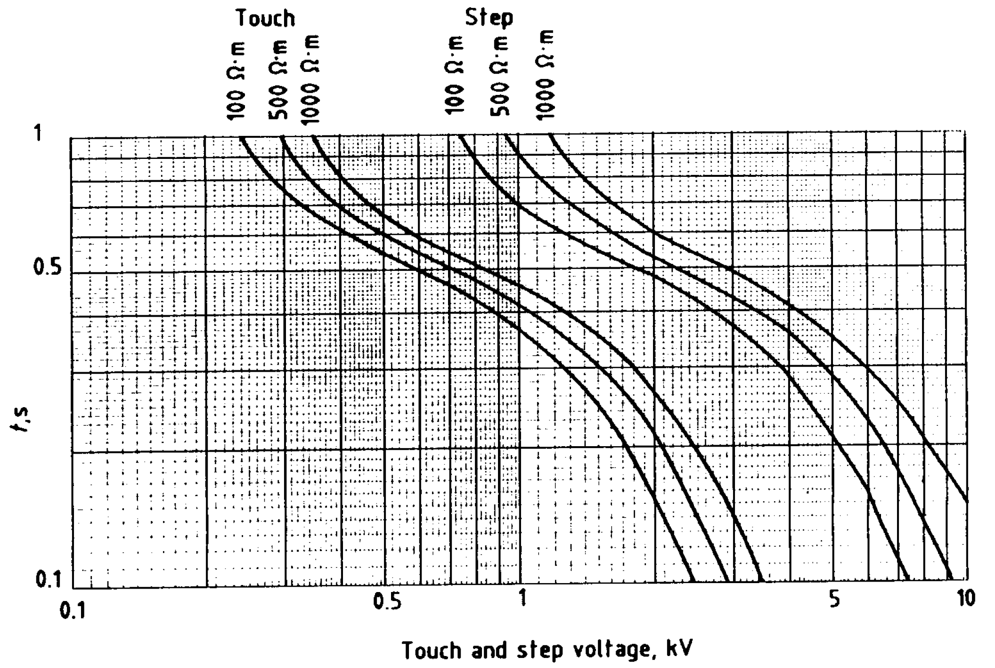
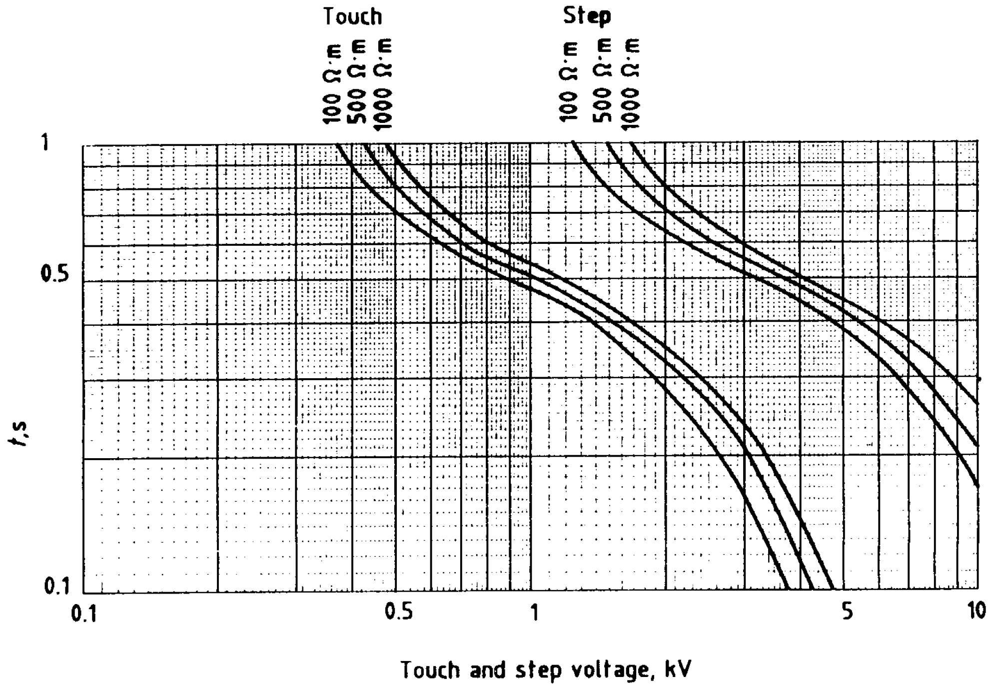


Figure 2 — Step voltage coefficient C_s



(a) Without crushed rock layer



(b) With 0.08 m crushed rock layer

Figure 3 — Allowance touch and step voltages

Section 8. Control, indication and interlocking

8.1 Control

Switchgear should be arranged in such a manner that circuit-breakers, switch-disconnectors, disconnectors and earth switches can be opened and closed safely when required. This should apply whether the initiating signal is remote, local, or the operation is performed manually.

All remote control, relay, alarm and instrumentation facilities should be located within the main plant building, and mounted on cubicles arranged in suites.

All control, alarm, instrumentation and indication facilities should be grouped on a per-circuit basis each on its own section or complete control panel. Closing circuits, tripping circuits and signalling circuits should be separately fused and should be provided with suitable means of isolation.

Relays and metering should be physically segregated on panels or rocks on a per-circuit basis.

All power operated equipment should be capable of operation either locally or remotely. A facility for selection of remote or local control should be provided adjacent to the equipment being controlled, but the two methods should not be capable of being in operation simultaneously.

All circuits, control switches, etc. should be clearly labelled as to their purpose and function in accordance with section 9. Circuit labels should be provided on the front and rear of each panel and on the outside of the cubicle doors.

All control and relay panels should have a continuous earth bar of cross-sectional area not less than 70 mm^2, run along the bottom of the panels, each end being connected to the main earthing system. Metal cases of instruments and metal bases of relays on the panels should be connected to this bar by conductors of cross-sectional area not less than 2.5 mm^2.

8.2 Indication

Equipments having contacts which perform the function of opening and closing in the high-voltage system should have devices which indicate the position of those contacts. Arrangements should be made for the status of the opening and closing positions to be displayed at remote locations.

Alarm and indication equipment as necessary should be provided in the control room to indicate the operation of the main and back up protection systems, operation of the equipment alarms including those on the power transformers, reactors and switchgear and all other alarms which are required for the satisfactory operation of the complete installation.

Indicating devices should be provided adjacent to the circuit-breaker control handle or switch to show whether the circuit-breaker is open or closed.

A common bell or buzzer should be provided to give audible alarm when any circuit-breaker has tripped automatically. Means should be provided for silencing the audible alarms whilst leaving it free to sound when the tripping of any other circuit-breaker occurs.

Indicating lamps and lamp holders should be so arranged that replacement of lamps and the cleaning of glasses and reflectors employed can be readily effected.

8.3 Interlocking

8.3.1 General

Means should be provided which ensure the correct sequence of operation of the switchgear. When maintenance is to be done on the switchgear the method of interlocking should result in the removal or locking on of a unique device, e.g. key, which ensures that the equipment to be maintained remains safe.

All disconnecting and earthing devices within a station should be interlocked in a manner that ensures that they always operate safely. The system employed should satisfy two distinct categories as follows.

a) *Operational interlocking*. Interlocking associated with normal system operation and switching and intended to ensure that a predetermined switching sequence is satisfied. Such interlocking can be achieved by electrical means in a manner that permits the equipment to perform any safe operation for either local or remote conditions.

b) *Maintenance interlocking*. Interlocking associated with a series of switching operations to render the equipment or sections of the station safe for access and maintenance by personnel. Such interlocking preferably should be achieved by mechanical interference type interlocks.

8.3.2 Principles

When designing an interlocking scheme the following assumptions should be made based on specific duties for disconnectors:

a) disconnectors are capable of switching the capacitive current of associated connections;

b) disconnectors have zero load making and breaking capacity;

c) disconnectors are not capable of making or breaking transformer magnetizing current;

d) disconnectors are capable of the duty imposed when operated under parallel switching conditions;

e) it is not possible to close or open any earth switch unless the point of application is disconnected from all possible sources of supply, and the power operating devices of associated disconnectors are isolated from their remote control position;

f) it is not possible to operate any disconnectors if an associated earth switch is already closed;

g) disconnectors concerned with supplies from a remote point cannot be fully interlocked and should carry a warning notice to this effect and similar notices should be applied to earth switches.

Section 9. Marking and identification

9.1 General

Clear and unambiguous labelling of switchgear and other equipment is a major factor in reducing the possible occurrence of human error faults and is recommended for the efficient and effective operation of a system.

It is good practice for any circuit-breaker, disconnector, earthing switch, etc. of a certain nominal voltage and used for a particular purpose to be given a consistent designation throughout the system, no matter where it may be located.

An example of a typical identification system for equipment is detailed in Appendix D.

9.2 Phase marking of busbars and main connections

Busbars and main connections should be identified and preferably be designated as phase 1, phase 2 and phase 3 in words or by L_1, L_2 and L_3 respectively in order of phase sequence. Phase 1 (L_1) should be designated so as to conform with an appropriate national standard or by agreement with the user where there is no such standard. When neutral connections are required to be identified they should be designated neutral or N. Alternatively, identification may be by colour coding suitably cross-referenced to reflect each phase.

9.3 Equipment identification

Each item of equipment or part where appropriate, should be labelled to indicate to which phase (L_1, L_2 or L_3) the item or part of item is connected. Phase identification can be achieved using labels and/or marked discs to indicate the phase, section or compartment of the equipment.

Each item of equipment should be labelled to clearly indicate the following:

a) the primary circuit designation;

b) the function and place in the circuit;

c) the phase to which it is connected.

Such identification should be clearly visible at the control and operating position of the equipment and from the normal direction of approach to the item. In cases where the item or items are fenced, the identification should be either:

1) visible from outside the access gate; or

2) an additional label positioned at the access gates and visible from the normal direction of approach.

The identification of equipment at all other locations, e.g. remote control panel, control room mimic diagram and relay panel, should be consistent and compatible with those at the equipment.

9.4 Labels

Substantially non-corrodible labels, indelibly and legibly marked and of suitable size, should be provided and effectively secured by, near or on each item. In all cases the label should be positioned so as to leave no doubt as to the item to which it refers.

Section 10. Insulation co-ordination

10.1 General

The main objectives of insulation co-ordination are to minimize the interruptions to the supply and at the same time to confine those unavoidable insulation failures to the least damaging location.

Outdoor high-voltage switchgear installed in a station may be subjected to the following.

a) *Lightning overvoltages:* by a direct strike to the station overhead connections or from the occurrence of a strike to the overhead line towers, overhead earthwires or the main conductors. Voltages can also be induced on the main conductor from strikes to ground in the vicinity of the lines but it is generally accepted that these induced voltages are of significance only to lines of 66 kV and below.

b) *Switching overvoltages:* occurring when the operation of the switchgear creates an overvoltage, e.g. due to energizing a line or by chopping low inductive currents.

c) *Temporary power frequency overvoltages:* caused by a sudden reduction of load impedance, usually due to switching at another station.

10.2 Selection of BIL

In general terms, the exposure to lightning strike is a function of the ground area of the station plus a ground area which is equivalent to four times the line tower height times the line length, for each line. Due to attenuation of the travelling voltage wave on a line, the pertinent length of line usually is from 2 km to 5 km, as the voltage is reduced to a harmless amplitude after travelling more than this distance. Even so, the area of significant exposure of the lines usually is many times greater than that of the station, hence the greatest danger is a line strike rather than a direct strike to a station.

The probability of line insulation failure due to a direct strike can be reduced to an acceptably low value by the application of overhead earthwires to the lines and wires or structure spikes to a station as discussed in **10.4**.

The probability of a station insulation failure can also be reduced to an acceptable value by the choice of BIL and the application of surge arresters and rod-gaps.

For system voltages of highest voltage for equipment up to 36 kV, BS 5622-1 allows two alternative BILs nominated as list 1 and list 2. Only if rigorous studies are made confirming the lower value of list 1 will be adequate should this lower value be selected, otherwise the higher list 2 value should be selected. For values of 52 kV and 72.5 kV there is only one recommended value of BIL in BS 5622-2.

For equipment rated 123 kV and above there are a varying number of choices of BIL, although these are restricted by compatibility with a switching impulse level (SIL) at 300 kV and above. Other constraints in the choice of BIL are the frequency of lightning (IKL level) and airborne pollution, both of which mitigate against choosing the lower values. Table 9 shows the most commonly specified BIL levels for system voltages of 123 kV and above. When surge arresters are installed at each line entry to the station, a BIL of one level lower than some of the values shown in Table 9 could be selected; however studies should be made showing the amplitudes of reflected voltages on the station connections to confirm the choice.

All the equipment for use at the same operating voltage in a station should normally have the same BIL. An exception to this is that equipment directly protected by a surge arrester, e.g. transformers, may have a lower BIL commensurate with the protection afforded by the surge arrester. Usually one BIL level lower is used.

10.3 The location and use of rod-gap protection

Rod-gap flashover causes an earth fault. The current is limited only by the system impedance and will initiate tripping of the circuit-breakers by the protective relay system of the zone in which the rod-gap is situated. Preferably rod-gaps should be located at the terminal tower tension insulators, in the path of incoming lightning overvoltage surges. If the connection distance from the terminal tower location to the line disconnector is too great to prevent an excessive voltage occurring at the latter, rod-gaps should be located at the disconnector as well. For the terminal tower located rod-gap to effectively protect the line disconnector, the connection distance (in m) should not exceed the length determined from the following empirical equation:

$$\text{Separation distance} = 0.6\ (\text{BIL} - \text{rod-gap flashover voltage in kV}) \quad (29)$$

Rod-gaps elsewhere in the station are unnecessary unless they are required by the manufacturer for the insulation co-ordination of equipment, e.g. to ensure any flashover occurs externally rather than internally on oil or gas filled equipment.

10.4 Station direct lightning strike protection

10.4.1 General

The usual methods of shielding station equipment and connections are overhead earthwires across the station and spikes added to the structures within the station. Separately supported very tall spike structures are a special case of protection.

All methods rely upon the screening effect provided by the overall array. Within the array boundary the wires or spikes co-operate to provide a significantly greater protection than the sum protection of the individual wires or spikes. Outside the boundary the protection afforded is that of each boundary wire or spike acting as though in isolation. Thus the inner zone and outer zones together should protect all connections and equipment, including transformers if any. Line overhead earthwires assist in the protection of the station but it is preferable to consider this assistance as an additional safety and to arrange the station overhead earthwires or spikes to provide the desired protection. Figure 4 identifies the protection zones.

For direct lightning strike protection, which cannot be absolute unless the station is totally enclosed, 0.1 % failures per annum is regarded as a satisfactory level of protection for design purposes.

10.4.2 Inner-zone protection

The minimum vertical spacing of the earthwires and the highest live conductors is shown in Figure 5(a) and similarly for the top of spikes in Figure 5(b). For earthwires the horizontal spacing *S* usually is a bay width or multiples of a bay width. The spacing *S* of spikes, which also are usually mounted at spacings determined by bay width and that of the lines of structures, is the longest diagonal distance within each group of four spikes.

10.4.3 Outer-zone protection

The exposure, and therefore the protection, of the highest live part of equipment situated in an outer zone is a function of its height, the horizontal separation between this point and the protecting earthwire or spike and the height of these. The protection afforded can be determined using Figure 6.

10.5 Selection of SIL (for highest voltage for equipment of 300 kV and above)

The two principal sources of switching overvoltages are line energizing overvoltages and the disconnection of small inductive currents, e.g. transformer magnetizing current and shunt reactor currents. Neither of these types of switching has a voltage waveform of the test wave detailed in BS 923, which represents the lowest expected withstand voltage of any wave available in test laboratories. The withstand voltage of insulation will in practice be slightly higher than that obtained with the test waveform, giving a small safety factor.

Line energizing overvoltages expected in service can be determined by studies, and from the results a suitable SIL may be selected from the choices given in Table IV of BS 5622-1:1979. Experience suggests that the lowest value of this SIL usually is satisfactory for line energizing overvoltages where the line length is 100 km or less or where shunt compensation, at the remote end from the point of switching, equal to or greater than 50 % of the line charging volt-amp reactive (VAR) is connected.

Current chopping overvoltages, which are developed across the inductance being switched, are associated with a small amount of energy which can repeatedly be discharged without harm by a surge arrester protecting the inductive equipment and in so doing the voltage amplitude is restricted to a value safely below the lowest SIL level appropriate to the system operating voltage given in Table IV of BS 5622-1:1979. If surge arresters are not used, the voltage amplitude can be restricted to a safe low value by the use of opening resistors on the circuit-breaker if necessary.

Table 9 — Station BIL

Isokerannic level	System voltages (in kV) of:							
	123	145	170	245	300	362	420	525
IKL 0 to 30 and light pollution	450	550	650	850	1 050	1 175	1 300	1 425
IKL 30 to 90 or heavy pollution	550	550	650	950	1 050	1 175	1 300	1 425
IKL > 90 or very heavy polution	550	650	750	1 050	1 050	1 300[a]	1 425	1 550[b]

[a] A significant proportion of special cases require a BIL greater than the maximum level of 1 175 kV.
[b] In some cases of extreme pollution, a level of 1 800 kV may be appropriate.

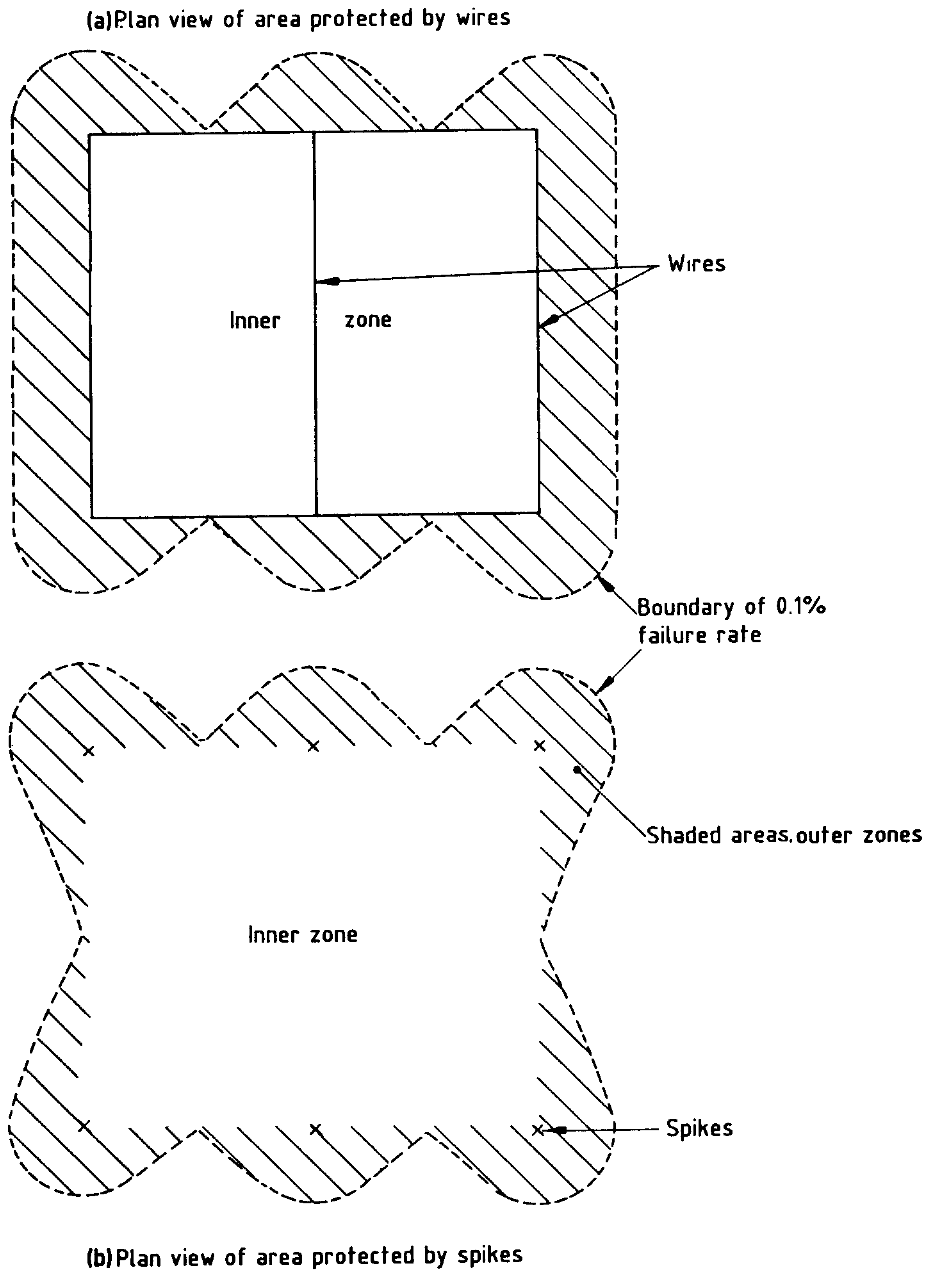
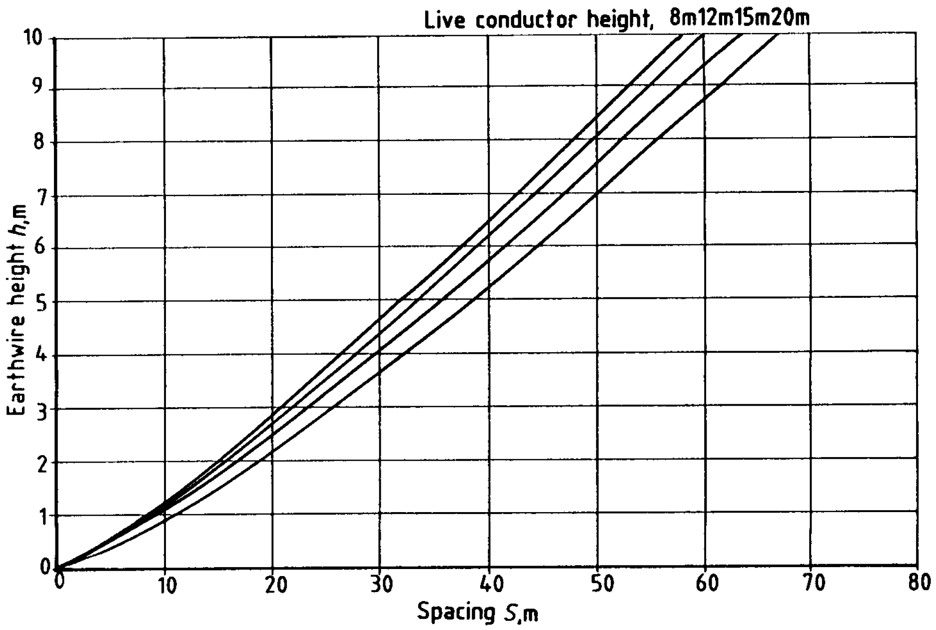
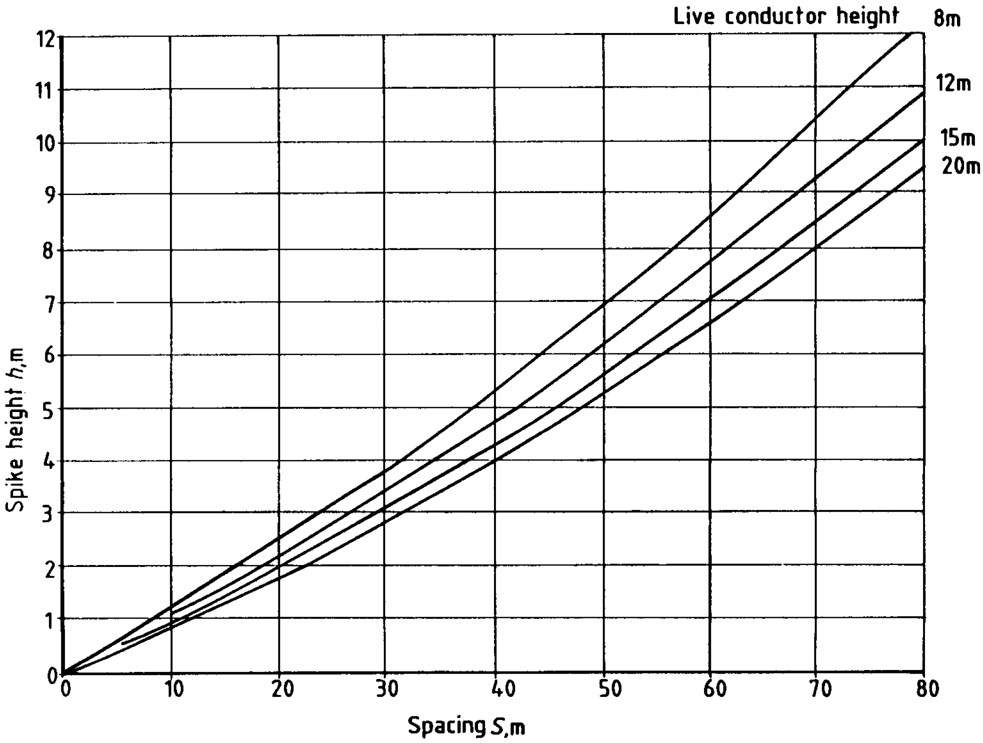


Figure 4 — Protection zones

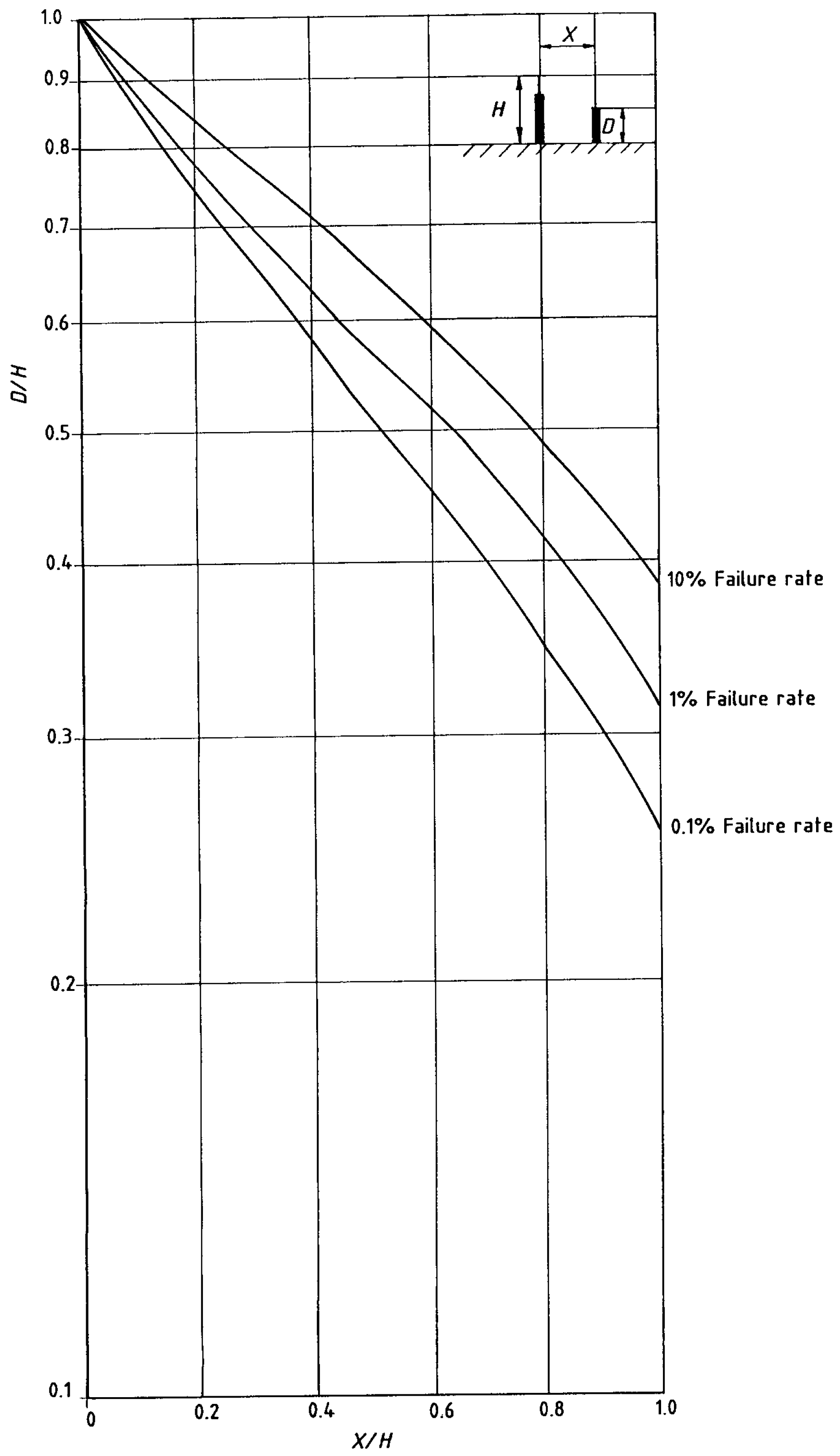


(a) Earthwires



(b) Spikes

Figure 5 — Station shielding for 0.1 % failure rate for inner zones only



Key
H is the height of spike or earthwire above ground
D is the height of object above ground
X is the distance of object from plane of spike or earthwire

Figure 6 — Outer type protective zones (for a single spike, for the outboard side of a row of spikes and for the outboard side of an array of earthwires)

Appendix A Limitation of work areas

In some countries there may be specific legal requirements relating to work activities in the vicinity of live high-voltage equipment and such requirements need to be recognized and accommodated when the equipment is designed, constructed and installed.

In general it will not be adequate to place reliance for safety on working clearances (see **D.11.1** of BS 6626:1985) and warnings to persons of the dangers involved. Systems of work need to be devised which will minimize the probability and consequences of error and ensure that persons only work in safe areas and on equipment which has been made safe, for example, by appropriate isolation and earthing.

Whenever the arrangement of the substation or switching station is such that parts of the station remain live whilst work is proceeding in other parts, the work section in which the maintenance is being carried out should be limited by permanent screens, permanent fencing or by temporary enclosure. Safe access to the delimited area should be provided.

A temporary enclosure may be in the form of ropes or barriers indicating the boundary at ground level of the work sections inside which it is safe to carry out the proposed work. The work section should be clearly defined by the use of flags by day, or if otherwise not sufficiently illuminated, by the use of coloured lights at night placed on separate supports within the work section. Warning notices should be appropriately positioned. As compared with permanent barriers however temporary methods of limitation entail increased responsibility and care in supervision to ensure their safe use and effectiveness. Where temporary screens are used the provision of permanent fixing sockets is recommended.

It should not be possible for a man working on dead equipment to pass via the structures or any other means of access beyond the limits of the work section. Accordingly on any structure within the work section, by which access can be had to live equipment, temporary or permanent screens, which would prevent passage beyond the safe limits via the structure, should be provided. The same considerations apply to large items of equipment which are in practice used to provide access for work, e.g. the tops of transformers. Alternatively access may be restricted by eliminating from the design of structural steelwork or similar structures those parts which could be used as a means of access between the work section and live gear.

Appendix B Application of safety clearances

B.1 Figure 7 has been prepared to illustrate the principles involved in applying safety clearances to the design of switching stations. Typical simplified outlines of circuit-breakers, etc. have been shown and a knowledge of the principles will allow application to equipments of particular design. The diagram illustrates typical applications of the three essential clearances.

B.2 In order to work on electrical equipment, isolation from all sources of supply is necessary. A circuit-breaker is not reliable for this purpose and only disconnectors with visible air gaps should be considered as providing the required isolation.

B.3 It cannot be assumed that safety clearance is provided just because complete isolation is available. The access for work condition should be assessed for each item of equipment, the objective being to enable safe access for work with the minimum operational circuit outage.

Appendix C Notes on the provision of safety clearances and work sections

C.1 Employment of safety clearances

It is important to note that clearances are applicable in all cases where work in the presence of unscreened live conductors is involved. Where, however, equipment adjacent to the points of work is made dead and earthed solely to maintain these clearances but not for the purpose of work thereon, the electrical clearances only may be necessary between such equipment and other equipment remaining live. Also the clearances between live conductors and screens or enclosures need not exceed the electrical clearances, but if these screens or enclosures are temporary, clearances are applicable during the work of erection or removal; preservation of these clearances may then require the temporary isolation and earthing of further items of equipment.

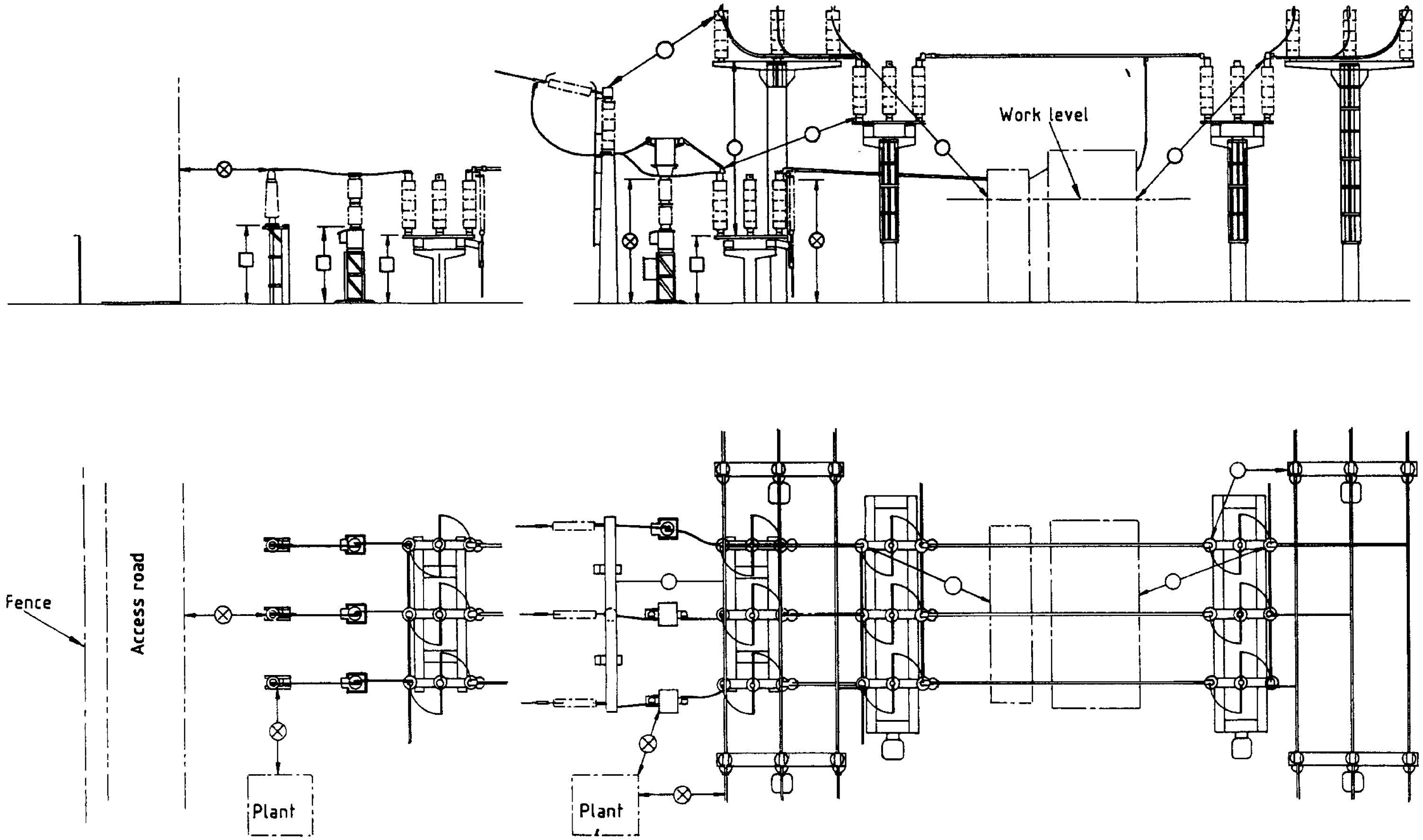
C.2 Work when all apparatus is live

Subclause **5.2.1** requires that all parts which can be made live should be situated at not less than a minimum distance from ground level or access ways, if it is to be safe for a man to move about and work amongst the equipment when it is live, always provided that:

a) he remains at ground level or adheres to permitted access ways;

b) he does not use long tools or materials, i.e. not longer than 300 mm;

c) he does not remove or open any screens, enclosures or divisions surrounding live material.



(a) Cable entry

(b) Overhead line entry

Key

Indicates insulation height from ground or permanent access ways as defined in **5.2.9**.

Indicates operational access clearance from ground, permanent access ways, buildings, fences etc. as defined in **5.2.8**.

Indicates safe working clearance from position at which men may stand to work, as defined in **5.2.6**.

Figure 7 — Application of safety clearances

Any work, therefore, that can be done from these positions and with the provisos given in items a) to c) may be carried out without the necessity for the further precautions referred to in **C.3**. Such work normally includes:

1) local operation of the equipment on site, e.g. disconnector, earth switches, on-load tap-changers of transformers and circuit-breakers;

2) inspection of the equipment from ground level or permanent access ways;

3) painting (with a normal brush) the equipment, supporting steelwork and other parts, as far as a man can reach from the ground or permitted access;

4) normal testing and adjustment of switchgear operating and transformer tap-changing mechanism;

5) testing of control cables, protective gear and compressed air systems.

It is recommended that, unless otherwise required by the purchaser, the disposition of equipment should be such as to provide the necessary clearances throughout the station which would enable the above work to be done in safety while all the equipment is live.

The occupier should make his own arrangements for special conditions such as the carrying of ladders and other long objects in live stations.

C.3 Work requiring isolation of apparatus

Work which involves leaving ground level, deviating from permitted access ways or infringing the provisos set out in items a) to c) of **C.2** makes it necessary that at least some of the apparatus is made dead and earthed.

The extent to which the substation equipment has to be made dead is dictated by the space required to do the work intended, and the preservation of safety clearances around this space.

In the simplest case where no provision is made for the sub-division of a station for the purpose of work, the whole of the station, including any incoming circuits, should be made dead and earthed before it is safe to do work on any of the equipment. This procedure is seldom convenient operationally and provision is usually made for sub-division of the station equipment by disconnector and the creation of work sections. The nature and extent of this sub-division will depend on how much of the station can, for operational reasons, be taken out of commission at any one time, having regard also to the frequency of the particular maintenance work required. The extent of sub-division provided in the design of the station is therefore normally a matter for agreement between purchaser and manufacturer.

Consideration should be given to providing for the following work without the necessity for interruption of any circuit other than that containing the equipment upon which it is necessary to work:

a) drawing off and replenishment of insulating medium in circuit-breakers and transformers;

b) inspection or replacement of circuit-breaker contacts and interrupting parts;

c) inspection and maintenance of transformer tap-changing equipment;

d) cleaning of bushings or insulators associated with circuit-breakers or transformers.

It is necessary to provide for work areas of sufficient dimensions to cover not only the positions that a man may occupy in carrying out the work, but also the means of access to these positions. The conductors of circuits other than that containing the equipment worked on, which it is desired to retain live and in service during the work, should then be so arranged as to provide the safety clearances from them to the boundary of the work area.

It should be noted that the whole of the equipment on which work is being done need not be within the limits of the work area, provided that the parts lying outside it can be satisfactorily reached by a man standing at a point within these limits, and provided that he is prevented from moving beyond that point in the direction of live conductors.

C.4 Special maintenance work

Other maintenance work, for which no arrangements for access are made in the design of the equipment, so that, for example, loose ladders, cradles or similar equipment will be employed, can only be carried out in safety by ensuring that in every case sufficient radial clearance separates the workman from any adjacent live metal, supplemented when and where necessary by divisions, screens or similar protection. Such maintenance should be undertaken only under safety rules laid down by the occupier; if the facility is desired of working with adjacent gear live on certain parts to which the above applies, the only provision which can be made in the design of the switchgear is to allow the clearances of Table 3 or Table 4 from the actual point of work to the nearest live conductor, or such other clearances as the occupier's safety rules may prescribe. Accordingly, if work of this nature is required with adjacent equipment live, the purchaser should state this in his enquiry or order and should indicate the method of working proposed and any special rules which will apply.

It is not normally economical to provide safety clearances exceeding those of Table 3 or Table 4 such that work other than normal maintenance can safely be carried out with adjacent equipment live.

For any other work and special work, such as extensions or large-scale renewals, or work involving the handling of long lengths of material, special precautions may be necessary, such as the isolation and earthing of additional portions of the station.

C.5 Safety clearances to boundary fences and roads

To provide for adequate maintenance of boundary fences whilst adjacent switchgear is live, it is recommended that the safety clearances stated in Table 3 or Table 4 should be maintained from the top of the boundary fence around the substation to live parts and exposed insulators of switchgear. Where, due to site limitations, it is necessary to employ clearances less than those stated in Table 3 or Table 4, the safety rules of the occupier of the station will determine the extent to which the switchgear should be made dead during maintenance of the boundary fence.

NOTE 1 In the UK the height of the boundary fence should be in conformity with the Electricity Supply Regulations, 1988.

It is recommended, where roads within the substation are intended for use when the substation is live, that, between the kerb lines of the road, the distance from the top of any vehicle using such roads and from the kerb lines themselves laterally, to live parts and exposed insulators of switchgear should be not less than the safety clearances of Table 3 or Table 4.

NOTE 2 In the UK, the clearances from overhead connections to ground should in such cases not be less than those laid down in the Electricity (Overhead Line) Regulations 1970.

C.6 Checking of designs

The adequacy of safety clearances cannot be checked directly while the station is live; there is accordingly a risk that those responsible for work in these conditions may assume that, wherever means of isolation for maintenance is provided, the main items of equipment are so placed that the necessary clearances for normal maintenance work are available. Nothing can remove from those responsible for such work the onus of assuring themselves that the safety clearances are adequate for the work intended and, if not, of making dead such further equipment as will give that assurance. Nevertheless, those responsible for the design of the station should, in the first place, verify that clearances adequate for the normal maintenance work are provided, wherever the means of isolation for such work is available; if, for any reason, these clearances are not provided, a clear indication should be given of the means of limitation of access necessary in substitution or the equipment should be so grouped that the absence of safety clearance is obvious.

Appendix D Example of an equipment item numbering system

D.1 General

This appendix details an example of a system for the numbering of switchgear and other equipment, and should be read in conjunction with section 9.

A comprehensive summary of the nomenclature and numbering of open-type switchgear is shown in Table 10. Whilst the implementation is illustrated in Figure 8 and Figure 9(a) to Figure 9(h) for certain station arrangements, the indication of more than one earth switch on any busbar is not intended to imply that all are necessary.

The double busbar 1½ switch layout in Figure 9(i) is not suited to the numbering system described in **D.2** but it illustrates an acceptable system for this particular application.

D.2 Busbars

The numbering and nomenclature of busbars other than those associated with generating plant auxiliaries should be as follows:

a) nominal busbar voltage (400 kV, 275 kV, 132 kV, etc.);

b) busbar identification (main busbar, reserve busbar, etc.);

c) busbar section number (1, 2, 3, etc.).

An example of the above numbering would be:

275 kV main busbar 1

Sections of busbars of the same nominal voltage and identifications should be numbered consecutively from one end of the substation to the other. Main and reserve busbars should have corresponding numbering.

In the case of busbars with sectioning facilities the word "section" followed by a consecutive number or letter should be added, e.g. 3.3 kV unit board 1 section 1.

In the case of stations where one section of one busbar is common to two sections of an associated busbar, the former should bear the numbers of both corresponding sections of the latter, e.g. 400 kV main busbar 1, 400 kV main busbar 2, 400 kV reserve busbar 1/2.

In the case of a mesh type station the corners of the mesh should be numbered consecutively in an anti-clockwise direction when viewed from above.

The busbar section number should be omitted in those cases where the busbar identification for a particular voltage is applicable to a single busbar having no sectioning facilities, e.g. 275 kV main busbar.

The numbering and nomenclature of the principal busbars associated with generating plant auxiliaries should be as follows:

1) nominal busbar voltage (11 kV, 6.6 kV, 3.3 kV, etc.);

2) busbar identification (station board, unit board);

3) busbar number (1, 2, 3, etc.). This number should be the number of the associated transformer or generator.

An example of the above numbering would be:

3.3 kV unit board 1

D.3 Transformers

D.3.1 The numbering and nomenclature of transformers connecting transmission systems should be as follows.

All transformers connected to the high-voltage transmission system, either as interconnectors or when connected to a lower-voltage system should be separately designated. All such transformers should be numbered uniquely in relation to each other and to other transformers, e.g. supergrid transformer 1, station transformer 2, supergrid transformer 3, station transformer 4.

Where more than one transmission voltage is used it may be considered advantageous to use a different designation at each level, e.g. 400 kV: supergrid transformer, 275 kV: grid transformer, 132 kV: interbus transformer.

Other transformers at a particular named site should be designated by reference to the nominal voltage ratio and should be numbered uniquely, e.g. 11/6.6 kV transformer 1.

D.3.2 The numbering and nomenclature of transformers directly associated with a.c./d.c. converting equipment should be as follows.

A transformer directly connected to converting equipment and provided for the transmission of power should be designated "converter transformer". All such transformers should be numbered uniquely at a particular named site, e.g. convertor transformer 1.

D.3.3 The number and nomenclature of transformers directly associated with generating plant should be as follows:

a) a transformer directly connected to a generator and provided for the transmission of the generator output to the main system should be designated "generator transformer" and should be numbered the same as the associated generator, e.g. generator transformer 1;

b) a transformer provided to supply power station auxiliaries but not directly connected to a generator should be designated "station transformer". All such transformers should be numbered uniquely at a particular named site, e.g. station transformer 1;

c) a transformer provided to supply power station auxiliaries and directly connected to a generator should be designated "unit transformer" and should be numbered the same as the associated generator, e.g. unit transformer 1.

D.3.4 Where two or more transformers in a station or power station are banked on to a circuit-breaker on either the high-voltage or the low-voltage side the individual transformers should have the same number and be identified by the addition of a consecutive letter as a suffix, e.g. supergrid transformer 1A, supergrid transformer 1B.

D.3.5 The numbering and nomenclature of a transformer directly coupled to another transformer and provided to supply station auxiliaries should be as follows:

a) a transformer not providing a system neutral connection should bear the name of the transformer to which it is coupled followed by the words “auxiliary transformer”, e.g. supergrid transformer 1 auxiliary transformer;

b) a transformer not supplying its own site auxiliaries and not providing a system neutral connection should bear the name of the transformer to which it is coupled and the name of the site it is supplying, followed by the words “auxiliary transformer”, e.g. grid transformer 1 400 kV site auxiliary transformer;

c) a transformer providing a system neutral connection should bear the name of the transformer to which it is coupled followed by the words “earthing transformer”, e.g. grid transformer 1 earthing transformer.

D.4 Reactors, capacitors, synchronous compensators and boosters

The numbering and nomenclature of reactors, capacitors, synchronous compensators and boosters should be as follows:

a) nominal voltage (400 kV, 275 kV, 132 kV, 13 kV, etc.);

b) identification, e.g. series reactors, shunt reactor, busbar reactor, synchronous compensator, static capacitor and quadrature booster;

c) number.

In the case of equipment connected to a mesh type station the number used should be the number of the associated mesh corner.

In the case of equipment connected to a transformer tertiary winding the number should be the number of the associated transformer. If the associated transformer is a banked transformer the appropriate letter should also be included.

In other cases the number should be a sequence number.

Where two items qualify for the same number and nomenclature the word winding or bank should be added followed by an identification letter, e.g. 13 kV shunt reactor 4B winding A, 13 kV static capacitor 3 bank A.

The information given above for shunt reactors is illustrated in Figure 9(g).

D.5 Open-type switchgear

D.5.1 The numbering of open-type switchgear, including disconnectors and earthing switches can be represented by three numbers preceded by a letter, the letter being used to designate the voltage of the equipment,
e.g. 400 kV: X120, 275 kV: Y120, 132 kV: Z120.

D.5.2 The first number should be used to denote the sequence of switch groups in any one class in a station.

In the case of a generator circuit the first number should be the generator number.

In the case of a transformer circuit connecting busbars at the same named site, the first number should be the number of the transformer or transformer bank.

The switch groups of line circuits should be numbered from an end of the station that is not designed to be extended. If a station is designed to be extended in both directions the switch groups on one side of the station should be given odd numbers and those on the other should be given even numbers, commencing from a sectioning or other suitable point.

A transformer circuit connecting busbars at different named sites should be considered as a transformer circuit only at the station where the transformer is located, with the exception that line numbering be applied in the case of an earthing switch on the line side of the circuit disconnector. Other terminations of the circuit should be considered as a line circuit.

In the case of busbar coupler switches the number 1 busbar coupler switch should connect main and reserve busbars in section 1, number 2 busbar coupler switch should connect main and reserve busbars in section 2, etc.

In the case of busbar section switches, number 1 busbar section switch should connect busbar sections 1 and 2, number 2 busbar section switch should connect busbar sections 2 and 3, etc.

In the case of mesh type station equipment numbering should be determined by the corner number to which it is connected (bus section 1 should be between mesh corners 1 and 2, etc.).

Where the same switchgear is used to control a line and a local transformer, then line numbering should be applied to the switchgear.

D.5.3 The second number should be used to denote the class of switch group as given in the following list (the first and third number are represented by asterisks):

0	line
1	transformer high-voltage side main busbar section
2	mesh busbar interconnector (within a station)
3	bus coupler
4	static series compensators, e.g. reactors, capacitors
5	static shunt compensators, e.g. reactors, capacitors
6	reserve busbar section
7	(spare)
8	transformer low-voltage side generator
9	synchronous compensator

Switchgear inserted in lines associated with teed circuits at a named site other than the high-voltage terminations of the circuits should be considered as main busbar section switches.

Switchgear provided specifically for the purpose of swinging a transformer from one circuit to another should be considered as main busbar section switches.

D.5.4 The third number should be used to denote the function of the particular item of switchgear in the group as given in the following list (the first two numbers are represented by asterisks):

**0	circuit-breaker (excluding lines) circuit-breaker (2nd choice lines) circuit-breaker associated with main busbar on double switched equipment switching disconnector (lines)
**1	earthing switch
**2	by-pass disconnector
**3	circuit disconnector
**4	main bus disconnector
**5	circuit-breaker (lines) circuit-breaker (2nd choice excluding lines) circuit-breaker associated with reserve busbar on double switched equipment switching disconnector (excluding lines)
**6	reserve bus disconnector mesh opening corner disconnector
**7	circuit-breaker disconnector, busbar side
**8	main bus disconnector (2nd choice)
**9	reactor tie bus disconnector reserve bus disconector (2nd choice)

Where more than one item in a group qualifies for a particular number the number should be suffixed by consecutive letters, commencing from the circuit termination inwards to the busbar selector disconnectors.

In the case of banked circuits the numbers should be suffixed by the identification letter of the appropriate circuit in those instances where the items are not common to all the circuits of the bank. In general, a suffix should not be used for items common to all circuits for the bank except in those instances where the number is repeated, when an appropriate letter suffix should be added.

Table 10 — Summary of numbering system for 400 kV equipment, designated X

NOTE For 275 kV equipment use "Y" in place of "X" in the number.
For 132 kV equipment use "Z" in place of "X" in the number. (See **D.5.1**.)

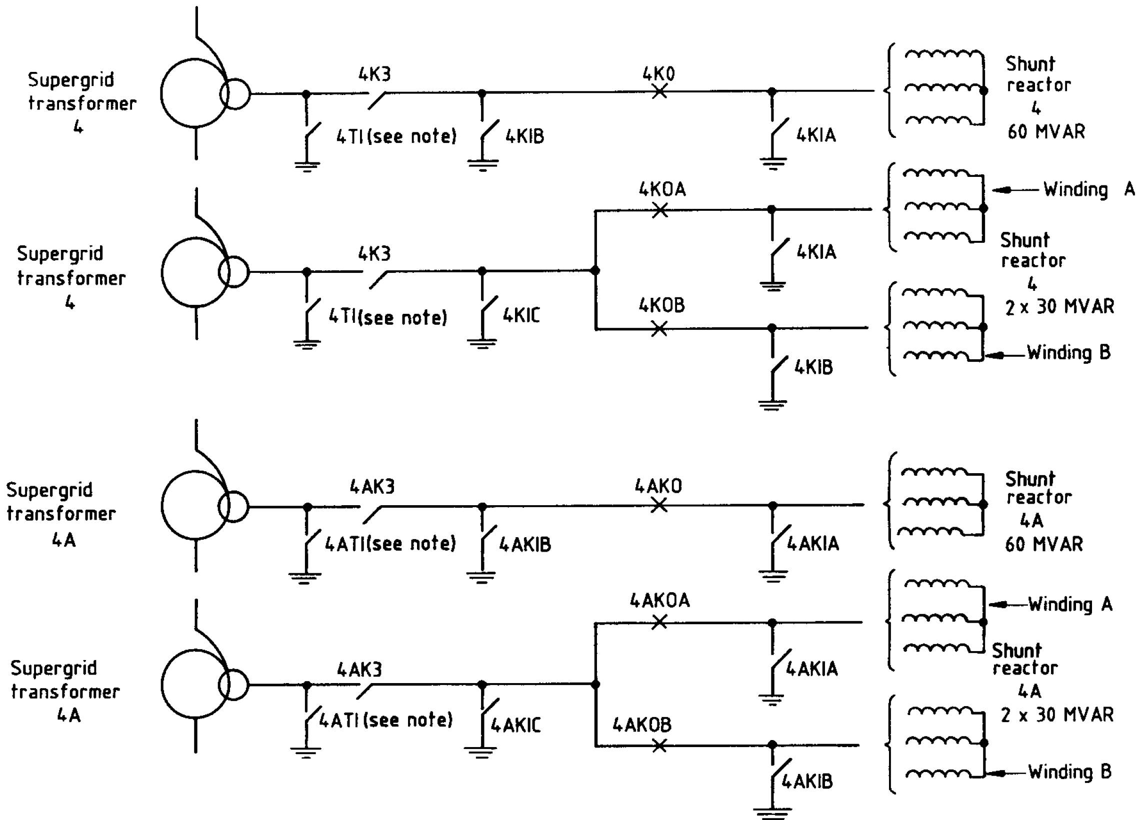
Title	Number
Switching disconnector	X[a]00
Line earthing switch	X[a]01
Line by-pass disconnector	X[a]02
Line disconnector	X[a]03
Main bus disconnector	X[a]04
Circuit-breaker	X[a]05
Reserve bus disconnector	X[a]06
Circuit-breaker disconnector (busbar side)	X[a]07
Transformer circuit-breaker	X[a]10
Transformer earthing switch	X[a]11
Transformer by-pass disconnector	X[a]12
Transformer disconnector	X[a]13
Main bus disconnector	X[a]14
Switch disconnector	X[a]15
Reserve bus disconnector	X[a]16
Main bus section circuit-breaker	X[a]20
Main bus section earthing switch	X[a]21
Main bus section disconnector (no. 1 side)	X[a]24
Switching disconnector	X[a]25
Mesh opening corner disconnector	X[a]26
Main bus section disconnector (no. 2 side)	X[a]28
Reserve bus section circuit-breaker	X[a]60
Reserve bus section earthing switch	X[a]61
Reserve bus section disconnector (no. 1 side)	X[a]66
Reserve bus section disconnector (no. 2 side)	X[a]69
Bus coupler circuit-breaker	X[a]30
Earthing switch associated with the bus coupler circuit breaker	X[a]31
Bus coupler main busbar disconnector	X[a]34
Bus coupler reserve busbar disconnector	X[a]36
Reactor circuit-breaker	X[a]40
Reactor earthing switch	X[a]41
Main bus disconnector (1st choice)	X[a]44
2nd reactor circuit-breaker where two per reactor	X[a]45
Reserve bus disconnector (1st choice)	X[a]46
Circuit-breaker disconnector (busbar side)	X[a]47
Main bus disconnector (2nd choice)	X[a]48
Reactor tie bus disconnector or reserve bus disconnector (2nd choice)	X[a]49
Reactor/capacitor circuit-breaker	X[a]50
Reactor/capacitor earthing switch	X[a]51
Reactor/capacitor disconnector	X[a]53
Transformer circuit-breaker	X[a]80
Transformer earthing switch	X[a]81
Transformer disconnector	X[a]83
Main bus disconnector	X[a]84
Switching disconnector	X[a]85
Reserve bus disconnector	X[a]86

[a] Denotes sequence of switch groups (see **D.5.2**).

Table 10 — Summary of numbering system for 400 kV equipment, designated X

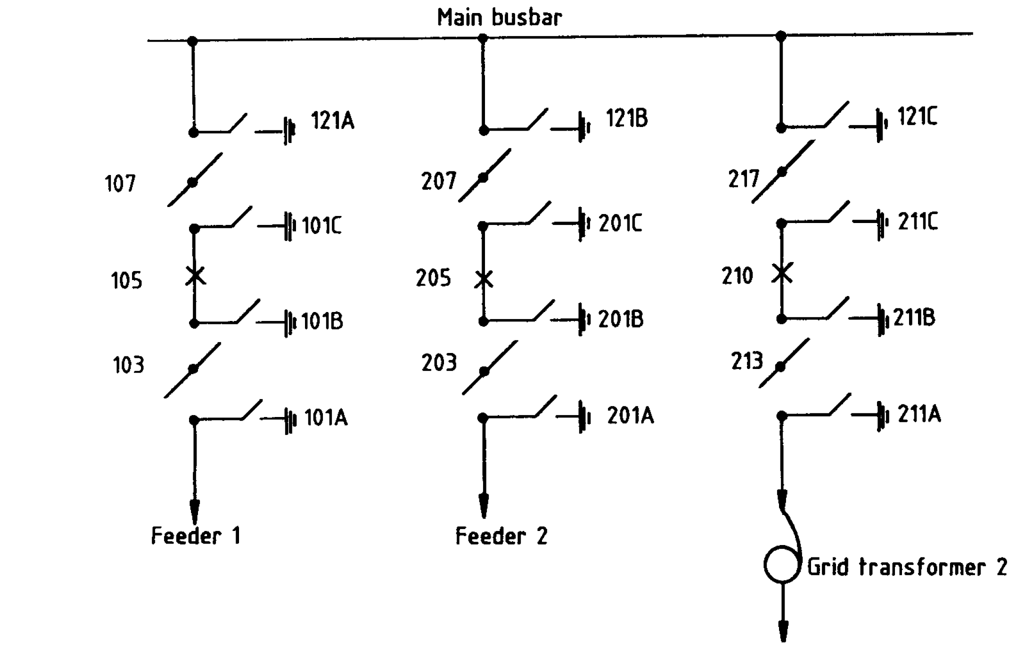
NOTE For 275 kV equipment use "Y" in place of "X" in the number.
For 132 kV equipment use "Z" in place of "X" in the number. (See **D.5.1**.)

Title	Number
Generator circuit breaker (where two per generator, main busbar)	X[a]90
Generator transformer earthing switch	X[a]91
Generator by-pass disconnector	X[a]92
Generator transformer disconnector	X[a]93
Main bus disconnector	X[a]94
Generator circuit-breaker where two per generator (reserve busbar) or switching disconnector	X[a]95
Reserve bus disconnector	X[a]96
Circuit-breaker disconnector (busbar side)	X[a]97
[a] Denotes sequence of switch groups (see **D.5.2**).	

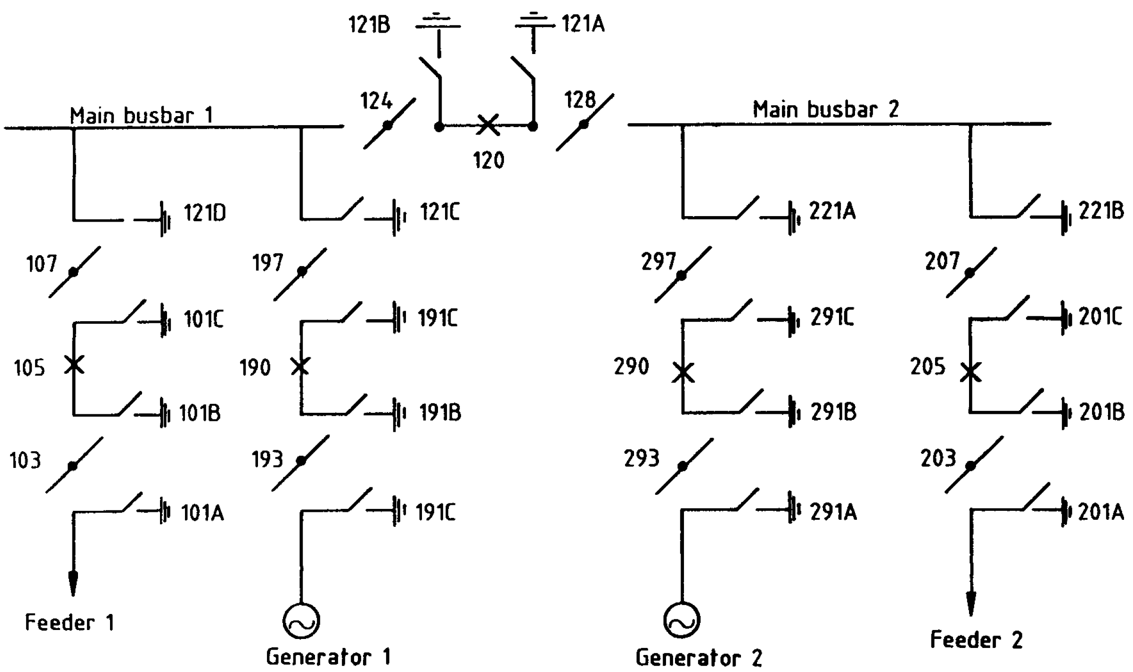


NOTE Suitable suffix to be added to 4 ATI if supergrid transformer voltage lower than 132 kV.

Figure 8 — Tertiary connected shunt reactor numbering and nomenclature

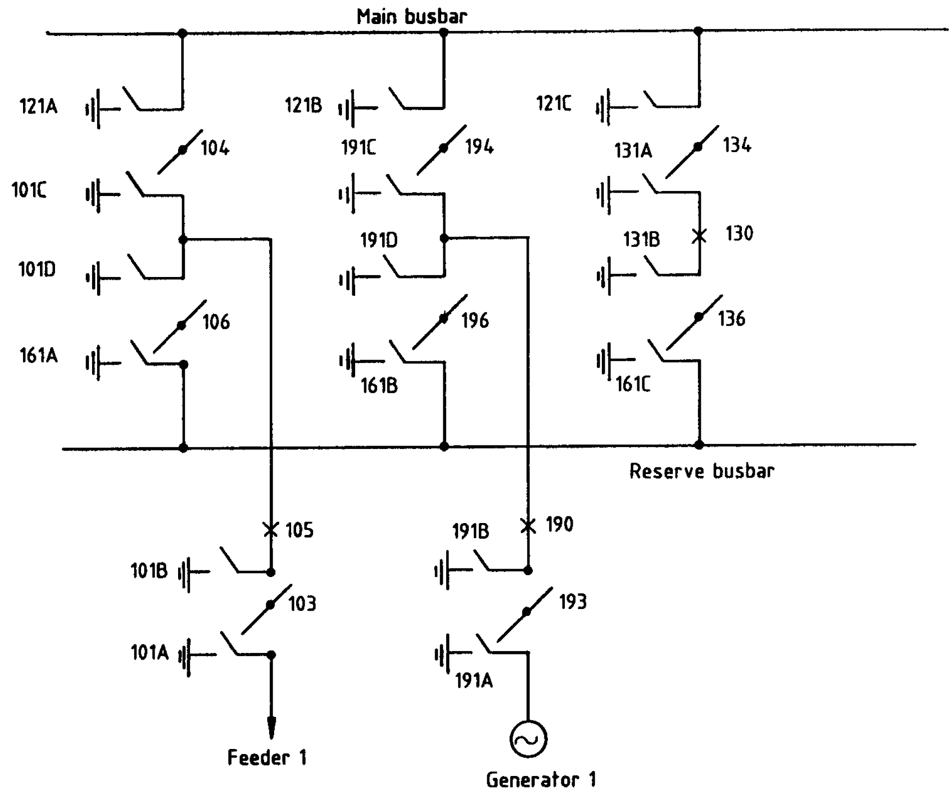


(a) Single busbar

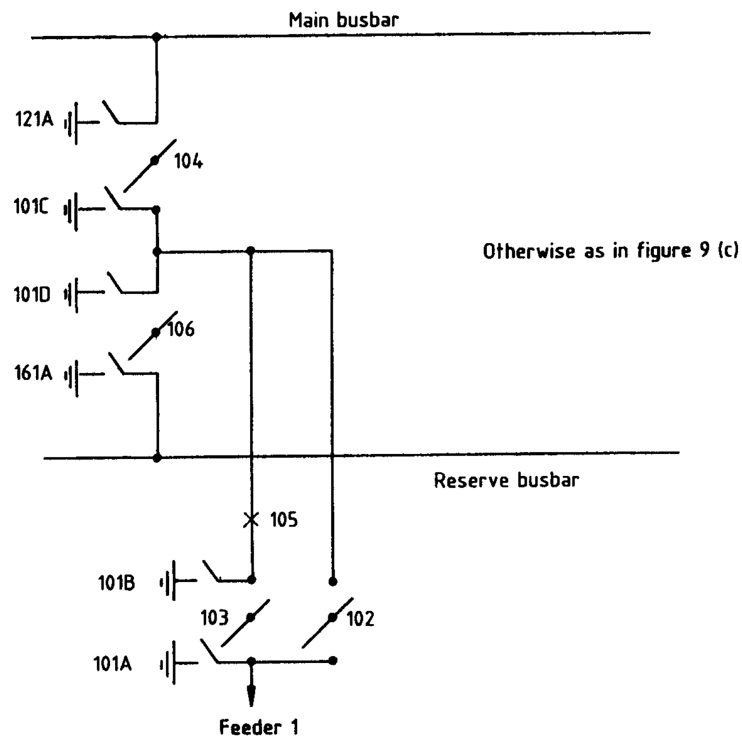


(b) Single busbar with bus section

Figure 9 — Equipment numbering system

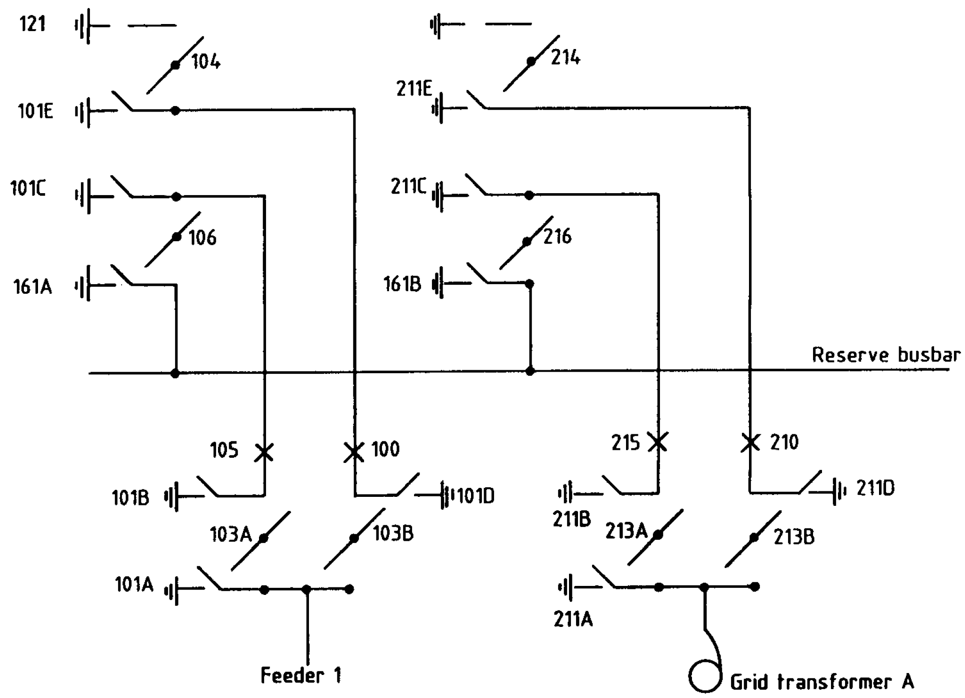


(c) Double busbar

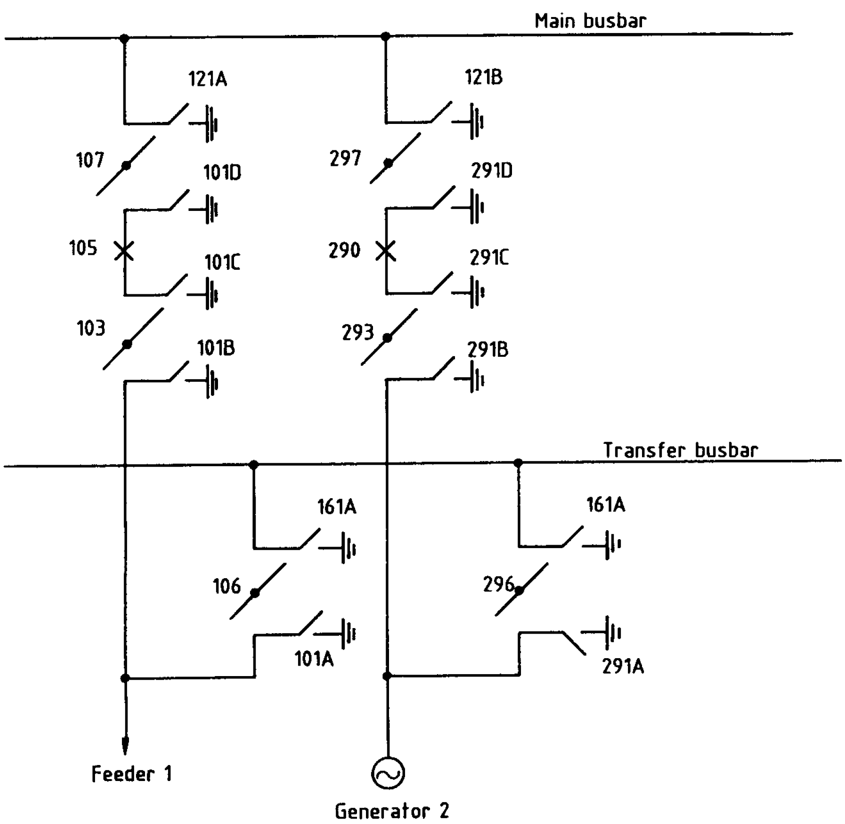


(d) Double busbar with feeder by-pass

Figure 9 — Equipment numbering system

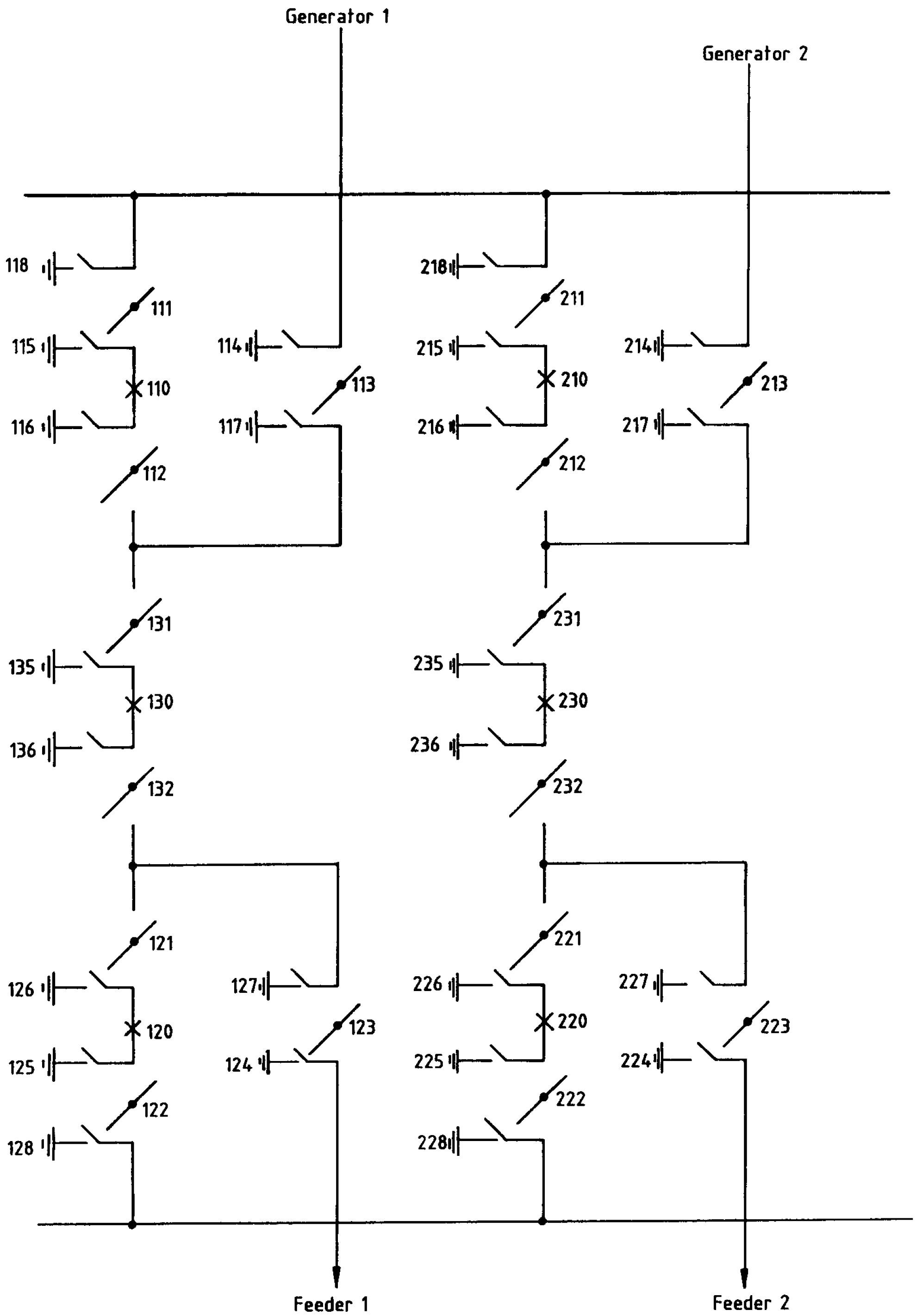


(e) Double busbar, double circuit-breaker



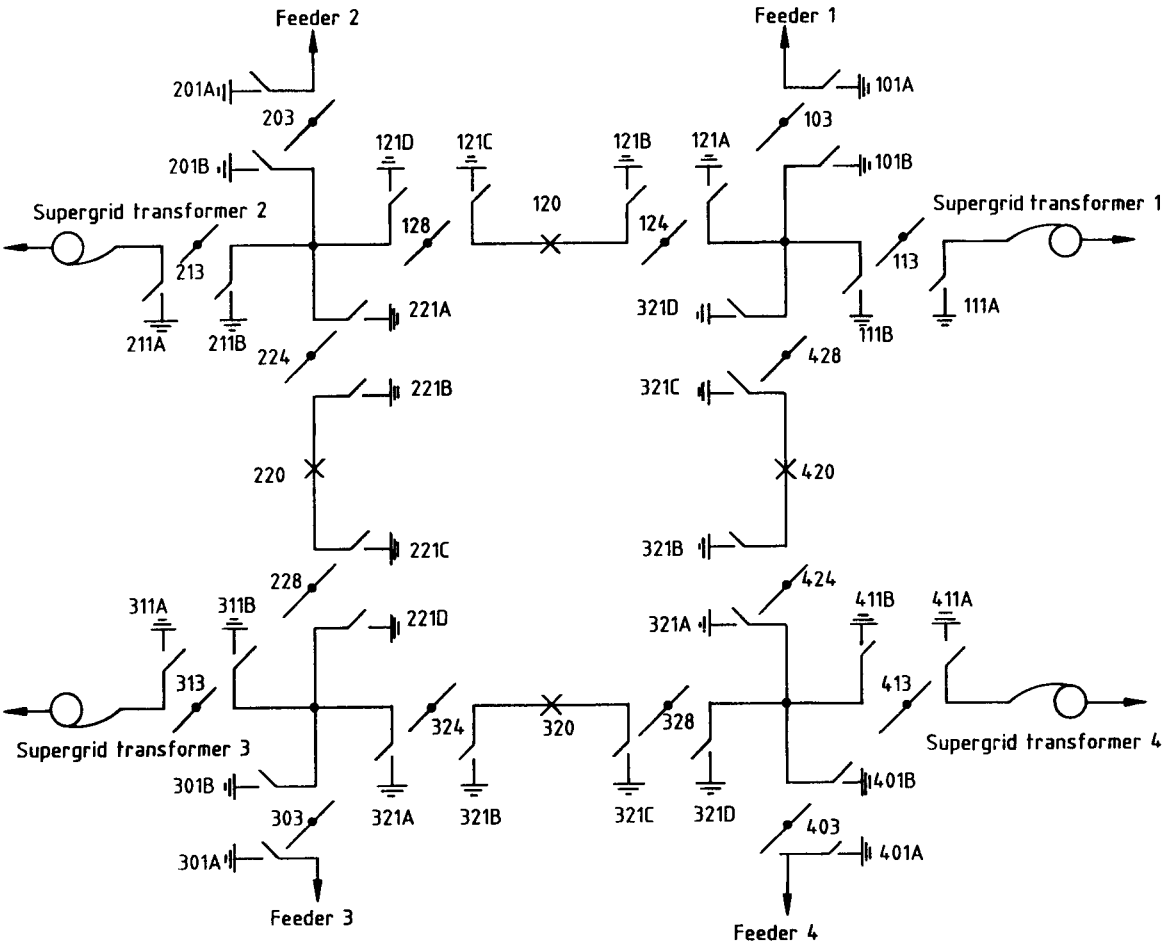
(f) Single busbar, transfer busbar

Figure 9 — Equipment numbering system



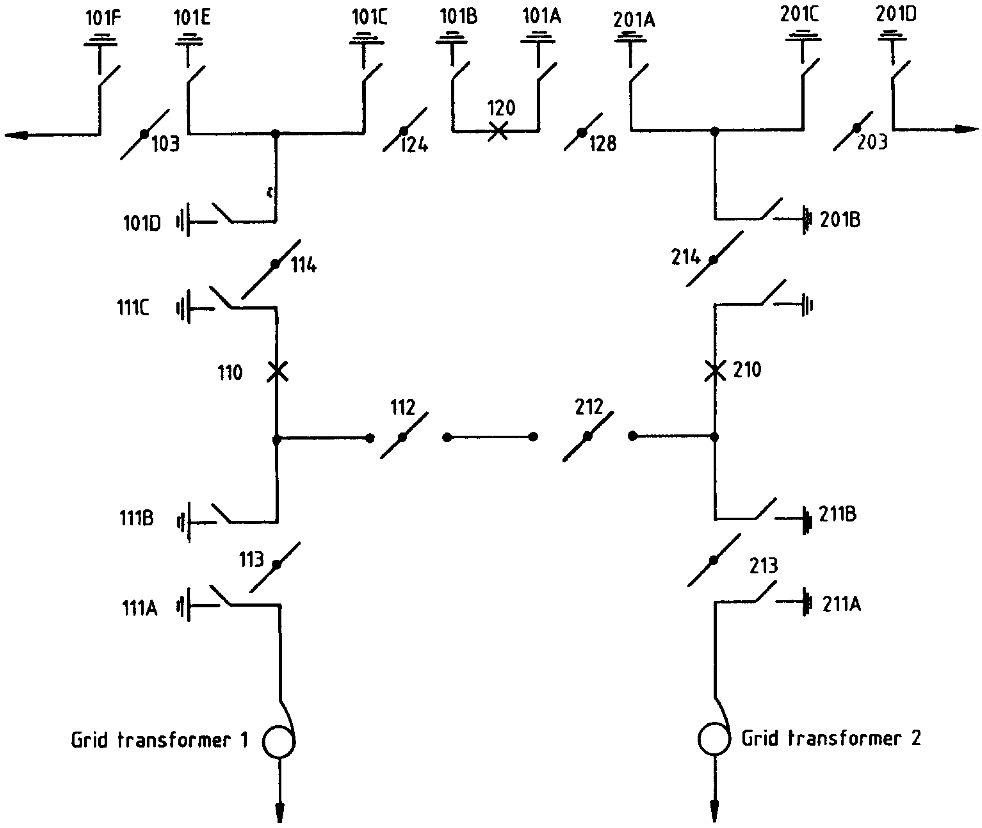
(g) 1½ circuit-breaker

Figure 9 — Equipment numbering system



(h) Four switch mesh

Figure 9 — Equipment numbering system



NOTE The three switch mesh is as shown, for the one switch mesh omit 110 and 210.

(i) One or three switch mesh with by-pass

Figure 9 — Equipment numbering system

blank

Publication(s) referred to

NOTE See also Table 1.

BS 923, *Guide on high-voltage testing techniques.*

BS 2914, *Specification for surge diverters for alternating current power circuits.*

BS 4727, *Glossary of electrotechnical, power, telecommunication, electronics, lighting and colour terms.*

BS 4727-2, *Terms particular to power engineering.*

BS 4727: Group 06, *Switchgear and controlgear terminology (including fuse terminology).*

BS 5420, *Specification for degrees of protection of enclosures of switchgear and controlgear for voltages up to and including 1 000 V a.c. and 1 200 V d.c.*

BS 5622, *Guide for insulation co-ordination.*

BS 5622-1, *Terms, definitions, principles and rules.*

BS 5622-2, *Application guide.*

BS 6581, *Specification for common requirements for high-voltage switchgear and controlgear standards.*

BS 6626, *Code of practice for maintenance of electrical switchgear and controlgear for voltages above 650 V and up to and including 36 kV.*

CP 3, *Code of basic data for the design of buildings.*

CP 3 Chapter V, *Loading.*

CP 3-2, *Wind loads.*

CP 1013, *Earthing.*

PD 6499, *Guide to insulation co-ordination within low-voltage systems including clearances and creepage distances for equipment.*

PD 6519, *Guide to effects of current passing through the human body.*

PD 6519-1, *General aspects.*

EPRI EL3099, *Substation grounding scale tests*[3)].

IEEE 80, *Guide for safety in substation grounding*[4)].

[3)] Published by and available from Electric Power Research Institute, 1019 19th Street, Washington DC 98201, USA.

[4)] Published by and available from Institute of Electrical and Electronic Engineers, Service Centre, 445 Hoes Lane, Piscataway, New Jersey 088 54, USA.

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Tel: 020 8996 9000. Fax: 020 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: 020 8996 9001. Fax: 020 8996 7001.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre. Tel: 020 8996 7111. Fax: 020 8996 7048.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration. Tel: 020 8996 7002. Fax: 020 8996 7001.

Copyright

BSI
389 Chiswick High Road
London
W4 4AL