# ENGINEERING STANDARD

# FOR

# ELECTRICAL SYSTEM DESIGN

# (INDUSTRIAL AND NON-INDUSTRIAL)

## CONTENTS :

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## APPENDICES:

## 0. INTRODUCTION

This Standard is written in two parts and 9 Appendices as described below:

| | |
|---|---|
| Part 1 | Electrical System Design Industrial |
| Part 2 | Electrical System Design Non-Industrial |

Appendices:

| | |
|---|---|
| Appendix A | Rotating Electric Machines |
| Appendix B | Switchgear and Controlgear |
| Appendix C | Transformers |
| Appendix D | Batteries, Chargers and UPS |
| Appendix E | Static Power Factor Correction Equipment |
| Appendix F | Heat Tracing |
| Appendix G | Lighting and Wiring |
| Appendix H | Power Cables |
| Appendix I | Earthing Bonding and Lightening Protection |

The above mentioned standards specifies the minimum requirement for electrical design in industrial and non-industrial installation and they should not prevent the designers from further considerations on subject matters.

# PART 1
# ELECTRICAL SYSTEM DESIGN
# INDUSTRIAL

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## 1. SCOPE

This recommendation covers the basic requirements to be considered in design of electrical systems in oil, gas, and petrochemical industries. It deals with planning, flexibility, selection of equipment, economic of design and hints to be taken care of in operation and maintenance. It describes criteria in selection of system voltage, fault consideration, and discusses the safety and protection of electrical system.

## 2. REFERENCES

**A)** The electrical system design shall in general comply with the IEC requirements, where other codes or standards are referenced to, it is understood that equivalent IEC recommendation shall be considered.

**B)** The following IPS shall be used for selection of equipment:

| | |
|---|---|
| IPS-M-EL-130 | "Electrical Rotating Machines" |
| IPS-M-EL-136 | "Direct Current Motors" |
| IPS-M-EL-138 | "Generators" |
| IPS-M-EL-140 | "Switchgear" |
| IPS-M-EL-142 | "Motor Starters" |
| IPS-M-EL-150 | "Power Transformers" |
| IPS-M-EL-155 | "Transformer Rectifiers" |
| IPS-M-EL-165 | "Low Voltage Industrial & Flameproof M.C.C." |
| IPS-M-EL-172 | "Batteries" |
| IPS-M-EL-174 | "Battery Chargers" |
| IPS-M-EL-176 | "Uninterrupted Power Supply (UPS)" |
| IPS-M-EL-180 | "Power Factor Improvement Capacitor" |
| IPS-M-EL-185 | "Remote Controls" |
| IPS-M-EL-220 | "Current Limiting Reactors" |
| IPS-M-EL-240 | "Low Voltage Industrial and Flameproof a.c. Switch Fuse Assembly" |
| IPS-M-EL-270 | "Cables and Wires" |
| IPS-M-EL-290 | "General Electric Items" |
| IPS-M-EL-190 | "Electrical Heat Tracing" |
| IPS-E-EL-110 | "Electrical Area Classification and Extent" |
| IPS-C-EL-115 | "Engineering Standards for Electric Equipment" |

## 3. UNITS

This Standard is based on International System of Units (SI), except where otherwise specified.

## 4. ENVIRONMENTAL AND SITE FACTORS

The following are the minimum typical information that shall be completed in conjunction with the environmental conditions before engineering work is proceeding on for ordering purpose:

**1)** Site elevation ........................................................................................................ m above sea level

**2)** Maximum air temperature ........................................................................................................ °C

**3)** Minimum air temperature ........................................................................................................ °C

**4)** Average relative humidity ........................................................................................ % (in a year)

**5)** Atmosphere: Saliferrous, dust corrosive and subject to dust storms with concentration of 70-1412 mg/m³, $H_2S$ may be present unless otherwise specified.

**6)** Lightning stormes: Isoceraunic level .................................................................................... storm-day/year

**7)** Earthquake zone .........................................................................................................................

**8)** Wind direction (where relevant) ........................................................................................................

**9)** Area classification (where explosive atmosphere shall prevail) ...................................................................

## 5. BASIC DESIGN CONSIDERATION

The basic consideration to electrical system design shall include the following:

### 5.1 General

#### 5.1.1 Safety

Safety takes to form: Safety to personnel, safety to materials, building and safety to electric equipment.

Safety to personnel involves no compromise, only the safest system can be considered. Safety to materials. Buildings and electric equipment may involve some compromise when safety of personnel is not jeopardized. For more information see also clauses 23 and 24.

#### 5.1.2 Continuity of service

The electrical system should be designed to isolate faults with a minimum of disturbance to the system and should feature to give the maximum dependability consistent with the plant requirements.

#### 5.1.3 First cost

The first cost of electric system shall not be the determining factor in design of plant.

#### 5.1.4 Simplicity of operation

Ease of operation is an important factor in the safe and reliable operation of a plant. Complicated and dangerous switching operations under emergency conditions shall be avoided.

#### 5.1.5 Voltage regulations

For some plant power system, voltage spread may be the determining factor of the distribution design. Poor regulation is detrimental to the life and the operation of electric equipment.

The voltage regulation of system shall not exceed ±5%.

#### 5.1.6 Plant expansion

Plant load generally increase, consideration of the plant voltages, rating of equipment, space for additional equipment and capacity for increased load must be included according to client requirements.

While the power capacity of a system is increased compatibility of fault level of existing installation shall be carefully scrutinized in conjunction with new available fault level.

## 5.2 Planning Guide for Distribution Design

With the above mentioned factors in mind, the following procedure is given to guide the engineer in the design of an electric system for any industrial plant.

**5.2.1** Obtain a general layout and mark it with the major loads at various locations and determine the approximate total plant load in horsepower, kilowatts, and kilo volt-amperes.

Estimate the lighting, air-conditioning, and other loads from known data.

**5.2.2** Determine the total connected load and calculate the maximum demand by using demand and diversity factors.

**5.2.3** Investigate unusual loads, such as the starting of large motors, or welding machines, and operating conditions such as boiler auxiliary motors, loads that must be kept in operation under all conditions, and loads that have a special duty cycle.

**5.2.4** Investigate the various types of distribution system and select the system or systems best suited to the requirements of the plant. Make a preliminary one line diagram of the power system.

**5.2.5** If power is to be purchased from the utility, obtain such information concerning the supply system or systems as: performance data, voltage available, voltage spread, type of systems available, method of system neutral grounding, and other data such as relaying, metering and the physical requirements of the equipment. The interrupting rating and momentary ratings of power circuit breakers should be obtained as well as the present and future short-circuit capabilities of the utility system at the point of service to the plant. Investigate the utility's power contract to determine if off-peak power at lower rates available, and any other requirements, such as power factor and demand clauses, that can influence power cost.

**5.2.6** If considering a generating station for an industrial plant, such items should be determined as : generating kva required including standby loads, generating voltage, and such features as relaying, metering, voltage regulating equipment, synchronizing equipment and grounding equipment. If parallel operation is contemplated, be sure to review this with the utility and obtain its requirements.

**5.2.7** A cost analysis may be required of the different voltage levels and various arrangements of equipment to justify and properly determine the voltage and equipment selected. The study should be made on the basis of installed cost including all the components in that section of the system.

**5.2.8** Check the calculations of short-circuit requirements to be sure that all breakers are of the correct rating. Review the selectivity of various protective devices to assure selectivity during load or fault disturbances.

**5.2.9** Calculate the voltage spread and voltage drop at various critical points.

**5.2.10** Determine the requirements of the various components of the electric distribution system with special attention given to special operating and equipment conditions.

**5.2.11** Review all applicable national and local Codes for requirements and restrictions.

**5.2.12** Check to see that the maximum safety features are incorporated in all parts of the system.

**5.2.13** Write specification on the equipment and include a one-line diagram as a part of the specifications.

**5.2.14** Obtain typical dimensions of equipment and make drawings of the entire system.

**5.2.15** Determine if the existing equipment is adequate to meet additional load requirements. Check such ratings as voltage, interrupting capacity, and current-carrying capacity.

**5.2.16** Determine the best method of connecting the new part of the power system with the existing system so as to have a minimum outage at minimum cost.

Naturally the above procedure will not automatically design the electric power system in itself; it must be used with good, sound, basic engineering judgment.

## 5.3 General Layout

A general layout of the plant should be available before the engineer can begin his study. This layout usually gives the location and the size of the proposed building or buildings in the initial particular project. The extent of the available layout gives the engineer an idea of the possible expansion of the plant in the future, and must be considered by the engineer in planning the electric distribution system.

## 5.4 Type of Circuit Arrangements

Load centers shall be employed as far as possible and the main busbars shall be fed from both sides.

## 5.5 Flexibility

Flexibility for expansion should be considered. In line with this, the engineer should strive for a system design that will permit reasonable expansion with minimum downtime to existing production.

## 5.6 System Reliability

The system shall be designed so that, when one fault occurs the operation of the system will not be jeopardized.

## 5.7 Selection of Equipment

The fundamental consideration in selecting equipment is to choose optimum equipment consistent with the requirements of the plant. Frequently it costs no more in the long run to use the best equipment available as it pays dividends in service continuity and lower maintenance. Some widely accepted principles are:

**5.7.1** Use metal enclosed for 400 volt indoor switchgear and metal clad for outdoor.

**5.7.2** Choose dry type transformers for indoor installations.

**5.7.3** Use factory assembled equipment for easier field installation and better coordination as far as possible.

### 5.7.4 Rating and sizing

**a)** The rating of equipment shall be as per IEC recommendation.
**b)** For sizing of equipment see Appendix "A" (Pages 76 and 77).

**5.7.5** Be sure equipment complies with requirement of pertinent hazard classification.

# 6. LOAD

## 6.1 Rating and Diversity Factors

**6.1.1** Electrical equipment shall be rated to carry continuously the maximum load associated with peak design production with an additional 10% contingency.

The ambient condition at which this rating applies shall be defined in equipment specifications and unless otherwise approved by client shall not be less than 40°C maximum air temperature at an altitude not exceeding 1000 m above see level.

**6.1.2** Assessment of maximum load requirements of an installation shall allow for diversity between various loads, drives or plants. The diversity factors used shall consider the coincidentally requiring peak demands and shall be based on similar installations whenever possible. The use of diversity factors shall result in "After Diversity Maximum Demands" (ADMD) being used for design purposes.

## 6.2 Types of Loads

### 6.2.1 Basic types

**a) Dynamic:** These are electric motors driving rotating equipment.

**b) Static:** These are non moving types of electrical equipment such as lighting, heating and supplies to rectifiers etc.

The bulk of the loads on the majority of installations comprise dynamic loads and the proportion of dynamic loads to static loads are generally high and varies under different circumstances.

### 6.2.2 Critical loads

These are loads of prime importance to the safety of the installation or the operational staff, and which require power to permit their safe shutdown in emergency. They shall have a second independent power source and be generally associated with no break supplies. In certain cases, a short supply break may be acceptable if this does not represent a hazard to safety.

### 6.2.3 Essential loads

These are loads whose loss would affect continuity of plant operation resulting in loss of revenue but would not result in an unsafe situation arising. Any decision to provide an alternative source of supply for these types of load shall be based on economic considerations as specified by client.

### 6.2.4 Non-essential loads

Non-essential loads are those which do not form an important component of a production or process plant and their disconnection is only of minimal or nuisance value. They usually form a small proportion of the total connected load and may have a single power source.

# 7. POWER SUPPLY SOURCES

## 7.1 General

The power supply system shall be designed to provide safe and economical operation. The safety aspects should cover both plant and personnel. Economic considerations shall cover capital and running costs and an assessment of the reliability and consequent availability of the system. The cost of improved power systems reliability should be weighed against the progressive potential loss incurred by loss of production.

All negotiations with public utilities shall be the sole responsibility of client.

### 7.1.1 Electrical import from a public utility

Where the principal sources of electrical power is selected to be from a public utility, the supply should be via duplicate feeders.

An exception to this may be permitted for economic reasons where low power loads are to be supplied from overhead lines and where a single feeder may be employed, provided that on-site standby generating equipment is available to meet the total load. Critical loads should always be provided for by on-site standby generating equipment which should only operate in the event of main supply failure.

### 7.1.2 On-site generation with no public utility connection

Where a site is offshore, or remote from a public utility network, or has a surplus of fuel or process energy, on-site generation will normally be selected as the principal source of power. The number and types of on-site generating sets shall depend on:

- **i)** The fuel source.
- **ii)** The nature of the process energy.
- **iii)** The process steam or other heat requirements, if any
- **iv)** The relationship between electric power requirements and the energy sources on any given site.

Unless otherwise agreed by client, a minimum of 3 generating sets, which may include an emergency generator to supply the critical loads, will be required on sites where there is no alternative electricity supply. The following criteria shall be satisfied:

**i)** There shall be sufficient generation to meet the "After Diversity Maximum Demand" (ADMD), when the largest single source of supply is out of service at peak demand times due to maintenance or any other reason.

**ii)** Generation shall be able to cater for the load requiring a supply after automatic load shedding (if provided) when the largest single source of supply is out of service and the second largest single source is coincidentally shut down due to unforeseen circumstances.

### 7.1.3 On site generation run in parallel with a public utility

Where on-site generation is selected to be the principal source of power and where a connection to a public utility is available, the public utility connection may serve.

- **i)** As a standby source of electric power.
- **ii)** A means of export of surplus electrical power.
- **iii)** A combination of both.

## 7.2 Emergency Power Supply Equipment

**7.2.1** Critical loads by definition require a high degree of reliability of supply. This reliability may be achieved by, in order of preference:

- **i)** Providing another source of energy, such as batteries.
- **ii)** Increasing the amount of normal supply generation equipment.
- **iii)** Ensuring a number of alternative supply feeds are available to the loads.
- **iv)** Providing local standby plant.

In cases where the provision of another source of energy is not practicable, the least cost of the remaining alternatives should normally be adopted bearing in mind the additional servicing and fuel requirements associated with standby generation.

**7.2.2** Critical loads shall be designed to cater for an additional unscheduled outage over and above that provided for normal supply. Thus, whereas the normal supply system design is based on being able to maintain the largest generator at peak demand times, the critical load supply system shall cater for maintenance of one unit coincidental to the unscheduled outage of the next largest generator.

**7.2.3** Where increased generating plant or local standby plant is selected to provide power to critical loads, it shall be either diesel engine or gas turbine driven generator set(s) each with its own dedicated fuel supply. Secure static power supplies may be selected depending on the nature of the critical loads being supplied and on fuel availability for generator sets. The emergency equipment shall be rated to have a spare capacity of 10%. The efficiency of operation of emergency equipment is not a significant factor but its ability to start reliably and supply the loads under emergency conditions is critical.

**7.2.4** Emergency generator sets shall be capable of starting and running when no alternative source of electrical a.c. power is available i.e., a black start capability. This shall be achieved by compressed air starting with air receivers being capable of six engine starts from one air charge, or by battery starting with a similar capability.

**7.2.5** It shall not be possible to connect emergency generators to a load greater than their rated capacity. They may however be required to operate in parallel with the normal supply for transfer or test purposes and shall always be provided with automatic starting and loading facilities. Manual facilities shall also be provided for regular testing purposes. Testing facilities should permit the loading of standby generator sets.

## 7.3 Primary Substation

**7.3.1** Generator circuits other than local emergency generators and public utility power intakes, shall be connected together at a common primary substation, the busbars of which are used as the main load distribution center. In certain cases, however, generators and public utility power intakes may be located at different points throughout the site, in which case there may be a number of primary substations which shall be interconnected on the site.

**7.3.2** The switchgear for primary substations shall comply with the requirements of IPS-M-EL-140.

**7.3.3** Busbar arrangements shall be selected to be cost effective, operationally flexible and safe. The following technical points shall be taken into account.

**i)** Operational flexibility to permit loads and power supplies to be effectively connected under schedule and unscheduled outages of circuits and busbar sections.

**ii)** Minimal switchgear per circuit and simple control and protection.

**iii)** Unscheduled loss of busbar sections shall not shut down the system beyond the level designed and provided for.

**iv)** Scheduled maintenance of busbars shall be possible without system shutdowns beyond those designed and provided for.

## 7.4 Synchronizing

**7.4.1** Synchronizing or check synchronizing equipment shall be provided wherever more than one source of power may be operated in parallel with another.

**7.4.2** The simples form of check synchronizing equipment shall comprise voltmeters and synchroscope to show the voltage and frequency differences between the two systems that need to be paralleled. A check synchronizing relay may be utilized to prevent operator maloperation, but in order to allow closing a power source on to a dead system, as is required under black start conditions, the check synchronizing relay shall have a means of manual or automatic disconnection.

**7.4.3** Synchronizing or check synchronizing facilities shall be fitted to busbar section and buscoupler circuit breakers only when it is possible to run the two systems feeding either section of a busbar completely segregated from the other. The number of circuit breakers provided with synchronizing or check synchronizing facilities shall be kept to a minimum. A similar logic shall be applied to public utility intake circuits. Alternatively, circuit breaker interlocking schemes shall be installed to preclude the possibility of paralleling two sources of power where synchronizing facilities are excluded.

Synchronizing facilities shall be provided at the primary power supply voltage and avoided at other voltages by use of appropriate circuit breaker interlocking.

## 7.5 Secondary Unit Substations

### 7.5.1 Application

Secondary unit substations form the heart of all industrial plant electrical distribution systems. They are used to step down the primary voltage to the utilization voltage at various load centers throughout the plant. Many factors must be considered when selecting and locating substations. Most important of these are:

**i)** Load grouping by KVA
**ii)** Voltage rating
**iii)** Service facilities
**iv)** Safety
**v)** Ambient conditions
**vi)** Continuity of service
**vii)** Aesthetic consideration
**viii)** Lightning protection requirements
**ix)** Space available
**x)** Outdoor vs. indoor location
**xi)** Plans for future expansion

### 7.5.2 Components of secondary unit substations

An articulated secondary unit substation consists of three basic components i.e.

- Incoming line section
- Transformer section
- Outgoing section

The design principle of which is similar to load centers.

## 8. LOAD-CENTER SYSTEMS

**8.1** A load-center system may be defined as one in which power is transmitted at voltages above 400 volts to unit substations located close to the centers of electric load. At these substations the voltage is stepped down to the utilization level and distributed by short secondary feeders to the points of use. The trend to this type of system has become very marked in recent years. An examination of the advantages listed below for the load-center system when compared to older systems will indicate why such a trend has come about.

**i)** Lower first cost.
**ii)** Reduced power losses.
**iii)** Improved voltage regulation.
**iv)** Increased flexibility.
**v)** Better continuity of service.
**vi)** Simplified engineering, planning, and purchasing.
**vii)** Lower field installation expense.

It should also be pointed out that a contributing factor to the increased use of load center system has been the development of air circuit breakers, metal-clad and metal-enclosed switchgear,and specially dry type transformers. These equipments have permitted the installation of the unit substations in buildings and close to the centers of loads without requiring expensive vaults to minimize fire hazards and danger to personnel.

## 9. SELECTION OF SYSTEM VOLTAGE

The selection of utilization distribution and transmission voltage levels is one of the most important consideration in power system design. System voltages usually affect the economics of equipment selection and plant expansion more than any other single factor; it behooves the power system engineer to consider carefully the problem when designing the distribution system.

### 9.1 Voltage Levels

The various voltage levels may be broadly defined as follows:

- Low voltage (LV): is defined as voltages below 1000 volt in a 3 phase 4 wire, 50 Hz system.

- Medium voltage (MV): is defined as voltages higher than 1000 volt up to and including 66 kV in a 3 phase, 3 wire, 50 Hz system.

- High voltage (HV): is defined as voltages higher than 66 kV in a 3 phase, 3 wire, 50 Hz system.

The low voltage is normally restricted for supplying to utilization equipment directly.

The medium voltage is used most frequently for distribution purposes and also is employed as utilization voltage particularly for motors rated 3.3, 6.6 and 11 kV.

The medium voltages above 20,000 volt and the high voltages are mainly used for power distribution and or transmission.

The most common voltages used in oil, gas and petrochemical industries are given below:

| | | | |
|---|---|---|---|
| 25 | volt | a.c. for inspection | 50 Hz |
| 110 | volt | single phase 2 wire | 50 Hz |
| 400/230 | volt | three phase 4 wire | 50 Hz |
| 6000 | volt | three phase 3 wire | 50 Hz |
| 10000 | volt | three phase 3 wire | 50 Hz |
| 20000 | volt | three phase 3 wire | 50 Hz |

**Note:**

**Under cerlan circumstances 11000 V and 33000 V may be utilized upon the approval of project management.**

### 9.2 The Factors Affecting System Voltage

**9.2.1** Service voltage available from utility.

**9.2.2** Load magnitude.

**9.2.3** Distance the power transmitted.

**9.2.4** Rating of utilization device.

**9.2.5** Safety.

### 9.3 System Voltage Variation

An ideal electric power system is one which will supply constant frequency and voltage at rated nameplate value to every piece of apparatus in the system. In modern power system frequency is a minor problem but it is impractical to design a power system which will deliver absolutely constant rated nameplate voltage to every piece of apparatus. Since this can not be attained what are the proper limits of voltage in an industrial plant?
This should be determined by the characteristics of the utilization apparatus.

### 9.3.1 Permissible voltage drop

Voltage drop in a distribution system is the difference at any instant between the voltages at the source and utilization and utilization ends of a feeder branch circuit or transformer voltage spread is the difference between the maximum and minimum voltages existing in any one voltage class system under specified steady state condition voltage regulation is a measure of the change in voltage between no load and full load in terms of the full load voltage.

$$\text{Percent regulation} = \frac{\text{(no load volt) - (full load volt)}}{\text{full load volts}} \times 100$$

The electrical power system shall be so designed to limit voltage drop (base on nominal voltage in the feeder cables to the following values:

| | |
|---|---|
| - Feeders to area sub-station | 1% |
| - Feeders from area sub-station | 1% |
| - Motor branch circuit (at full load) | 5% |
| - Power source to panel board | 2% |
| - Lighting circuits from panel board to last lighting fixture | 3% |
| - The maximum voltage drop in the motor feeder cable during motor starting | 15% |

For medium voltage motors the cable voltage drop at motor full load shall not exceed 3.25%.

### 9.3.2 Improvement of voltage conditions

If voltage condition must be improved the following are suggested lines of consideration:

- Changing circuit constants
- Changing the transformer taps

## 9.4 Motor Starting Voltage Drop

It is characteristic of most alternating-current motors that the current which they draw on starting is much higher than their normal running current. Synchronous and squirrel-cage induction motors starting on full voltage may draw a current as high as seven or eight times their full load running current. This sudden increase in the current drawn from the power system may result in excessive drop in voltage unless it is considered in the design of the system. The motor-starting KVA, imposed on the power-supply system, and the available motor torque are greatly affected by the method of starting used.

Table 1 gives a comparison or motor starting common methods.

Table 2 shows general effect of voltage variation on induction motor characteristics.

**TABLE 1 - COMPARISON OF MOTOR-STARTING METHODS***

| Type of Starter (Settings given are the more common for each type) | Motor <u>Terminal Voltage</u> Line Voltage | <u>Starting Torque</u> Full-Voltage Starting Torque | <u>Line Current</u> Full-Voltage Starting Current |
|---|---|---|---|
| Full-voltage starter | 1.0 | 1.0 | 1.0 |
| Auto transformer | | | |
| 80 percent tap | 0.80 | 0.64 | 0.88 |
| 65 percent tap | 0.65 | 0.42 | 0.46 |
| 50 percent tap | 0.50 | 0.25 | 0.30 |
| Resistor starter, single step (adjusted for motor voltage to be 80 percent of line voltage) | 0.80 | 0.64 | 0.80 |
| Reactor | | | |
| 50 percent tap | 0.50 | 0.25 | 0.50 |
| 45 percent tap | 0.45 | 0.20 | 0.45 |
| 37.5 percent tap | 0.375 | 0.14 | 0.375 |
| Part-winding starter (low-speed motors only) | | | |
| 75 percent winding | 1.0 | 0.75 | 0.75 |
| 50 percent winding | 1.0 | 0.50 | 0.50 |
| Star delta starter | 0.57 | 0.33 | 0.33 |

*** Notes:**

**1) For a line voltage not equal to the motor rated voltage multiply all values in the first column by the ratio:**

$$\left(\frac{\textbf{Actual Voltage}}{\textbf{Motor rated voltage}}\right)$$

**2) Multiply all values in the second column by the ratio:**

$$\left(\frac{\textbf{Actual Voltage}}{\textbf{Motor rated voltage}}\right)^2$$

**3) And multiply all values in the last column by the ratio:**

$$\left(\frac{\textbf{Actual Voltage}}{\textbf{Motor rated voltage}}\right)$$

**TABLE 2 - GENERAL EFFECT OF VOLTAGE VARIATION ON INDUCTION MOTOR CHARACTERISTICS**

| Characteristic | Voltage Variation | | |
|---|---|---|---|
| | **Function of Voltage** | **90 Percent Voltage** | **110 Percent Voltage** |
| Starting and maximum running torque | (Voltage) | Decreases 19% | Increase 21% |
| Synchronous speed | Constant | No Change | No Change |
| Percent Slup | 1/(Voltage) | Increase 20% | Decrease 17% |
| Full-Load Speed | (Synchronous Speed-Slip) | Decrease 1½ | Increase 1% |
| Etticiency | | | |
| Full Load | — | Decrease 2% | Increase 1/2-1% |
| 3/4 Load | — | Practically No Change | Practically No Change |
| 1/2 Load | — | Increase 1-2% | Decrease 1-2% |
| Power Factor | | | |
| Full Load | — | Increase 1% | Decrease 3% |
| 3/4 Load | — | Increase 2-3% | Decrease 4% |
| 1/2 Load | — | Increase 4-5% | Increase 5-6% |
| Full-Load Cuitent | | Increase 11% | Decrease 7% |
| Starting Current | Voltage | Decrease 10-12% | Increase 10-12% |
| Temperature Ruse Full Load | — | Increase 6-7°C | Decrease 1-2°C |
| Maximum Overload | (Voltage) | Decrease 19% | Increase 21% |
| Capacity | | | |
| Magnetic Noise-No Load in particular | | Decrease Slightly | Increase Slightly |

*** Note:**

**This data applies to motors of over 25 horsepower.**

## 10. POWER DISTRIBUTION SYSTEMS

### 10.1 General

**10.1.1** The distribution network shall be designed to carry continuously at least 110% of the 'After Diversity Maximum Demand' (ADMD) associated with peak design production at the maximum ambient conditions.

**10.1.2** The selected distribution arrangement shall have a degree of reliability consistent with the type of load being supplied, and with the power supply design philosophy which provides for coincidental maintenance and unscheduled outage of the largest component of on site generating plant or unscheduled outage of the largest feeder component of the power supply equipment.

## 10.2 Radial Systems

These system distribute power radially from the power source to the load and shall be used in single, duplicate or triplicate arrangements.

## 10.3 Single Radial

**10.3.1** The single radial system provide power to non-essential electrical loads or loads where alternative sources of energy are available such as standby generating plant.

**10.3.2** Each component of the single radial circuit shall be capable to supply 110% of the required electrical load. Transformers or other plant which includes forced cooling equipment shall not relay on the forced cooling arrangements to obtain the necessary rating.

## 10.4 Double Radial

**10.4.1** Critical and essential loads should be supplied by two or more identically rated radial system.

**10.4.2** In double radial systems, each circuit shall be capable of carrying a 110% of the ADMD and all busbars shall include bus-section switchgear. They shall be arranged to ensure that unscheduled outage of any component of the circuit would not result in loss of power supply after the faulty equipment has been disconnected from the system, the only exception to this is the bus-section switch.

**10.4.3** Double radially fed systems shall generally be operated in parallel with all bus-section switches closed.

**10.4.4** Where switchgear fault levels are found to be above the values outlined in 12.3 attention shall be given to operating with bus-section breakers open as opposed to purchasing higher fault level switchgear. Where an open bus-section breaker philosophy is being given attention, the need to restore rapidly the supplies to drives shall determine whether automatic closure of bus section circuit breakers(s) is to be employed. Schemes with auto-reclosure are covered in 10.7.

## 10.5 Triple Radial

**10.5.1** Critical and essential loads may be alternatively supplied by triple identically rated radial systems. These systems are preferred to double radial systems wherever there is an overall total cost advantage.

**10.5.2** Each circuit of triple fed radial systems shall be capable of providing 55% of the ADMD and all busbars shall be split into at least three sections with two bus-section switches. This will allow for the loss of any one of the three circuits, leaving the two healthy circuits still capable of providing 110% of the ADMD.

**10.5.3** Triple radial systems shall be provided where the power flow is relatively large. They shall generally be operated with only two circuits in parallel to reduce switchgear fault levels. The incoming circuit breaker on the third identically rated feeder shall be left open and automatically reclosed in order to restore rapidly full supplies to the load.

**Note:**

**For typical electrical distribution network see systems 1,2 and 3 which follow.**

## 10.6 Ring Fed Systems

**10.6.1** Power may be distributed from a primary or central substation to number of subsidiary load centers by using two primary cable feeds connected in a ring emerging from the source busbar and controlled by circuit breakers.

**10.6.2** Ring fed systems should normally duplicate only the primary cables to the load substation. They may however, duplicate the load substation transformers and the low voltage busbar by providing a low-voltage or secondary bus-section breaker.

**10.6.3** Ring fed systems may be operated with the ring closed or with it open at some point.

**10.6.4** Where the ring feed is operated closed, intermediate primary circuit breakers, including unit feeder protection, shall be provided at all vital or essential load centers on the ring, thereby ensuring fault clearance of only the unhealthy section of the ring. The whole of the ring circuit shall be fully rated to be capable of supplying 110% of the ADMD at all substations. Essential or critical loads may be supplied by ring systems if they are operated closed, their choice shall be based on the comparative reliability and cost as compared to the duplicate radial systems.

**10.6.5** Ring fed systems which are operated open shall not include circuit breakers on the ring. Fault clearance shall be achieved at the source substation and in that event power will be lost to all loads fed between the source and the open point on the ring.

In order that a fully section of the primary ring may be disconnected and repaired without power loss during the whole of the repair period, the ring shall include isolating means at every load substation. These ring dependent on availability, cost, and the need for rapid reconnection of load.

Open operated ring fed systems shall be permitted only to supply non-essential loads. Their choice shall be based on the comparative reliability and cost as compared with single radially fed systems with a non-automatic standby power supply back-up.

## 10.7 Automatic Transfer Schemes

**10.7.1** Automatic transfer schemes shall be given attention where there is a need to obtain a reliability level consistent with two or more sources of supply. Their use shall be economically justified when compared against other ways of providing duplication of power sources, and shall be limited to installations where there is a need to reduce switchgear short circuit levels either for reasons of cost or non-availability. All schemes shall only include load transfers that never parallel the preferred and emergency sources. Load transfer schemes may use circuit breakers, or on-load transfer switches/contactors.

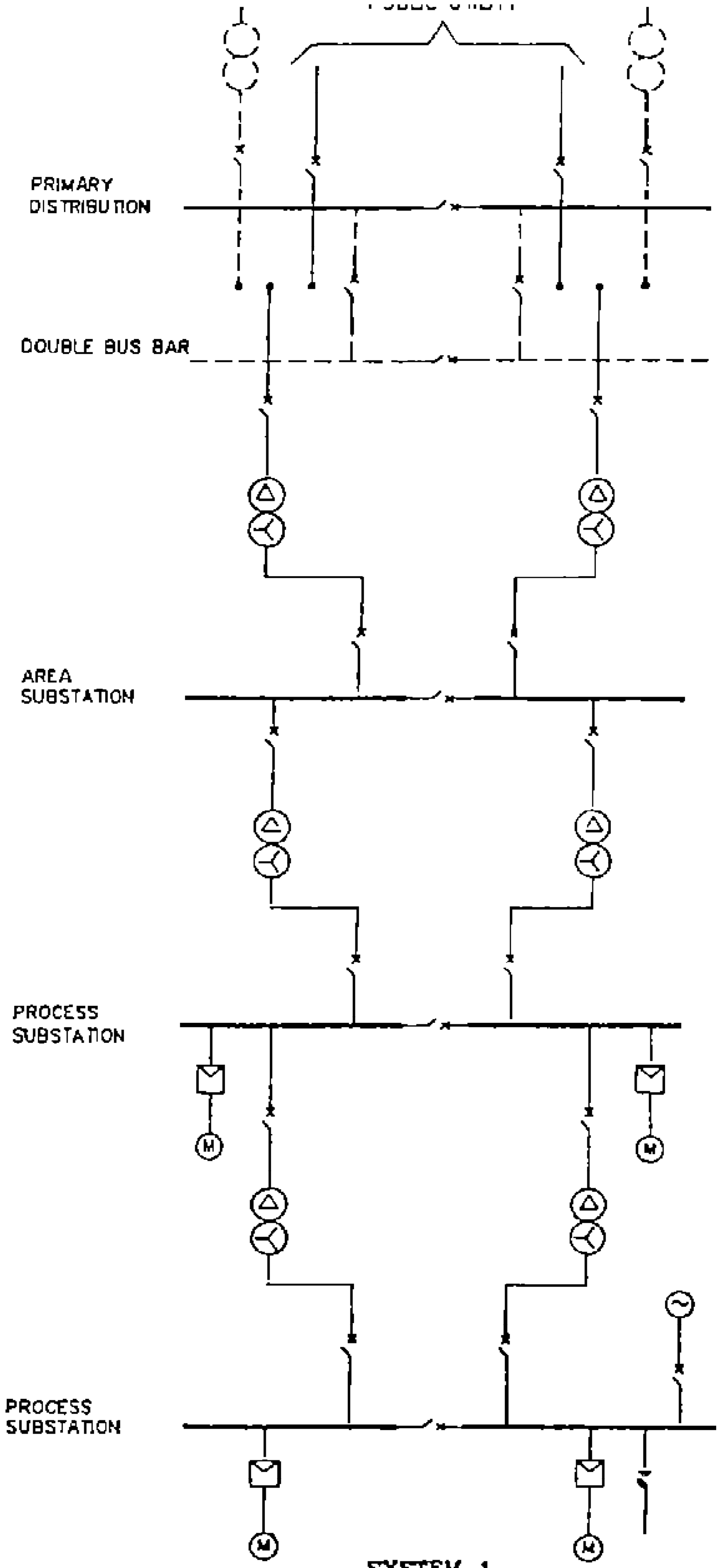
**10.7.2** Load transfer schemes may be applied to either static loads or induction motor loads or combination of the two. They shall not be used where synchronous motor loads are supplied. The load transfer shall be arranged so that the residual voltage of induction motors has decayed to less than 25% of the rated source voltage before the transfer is initiated. The rate of residual voltage decay shall be calculated and the complete transfer scheme shall be subject to approval by the client.

**10.7.3** Induction motors which are controlled by circuit breakers, or contactors of the d.c. controlled or a.c. controlled mechanically latched type shall include time delay undervoltage relaying. This relaying shall be set to trip the controller in typically 2 seconds or more on voltage dips to below 85% of the rated voltage. Transfer schemes associated with switchgear supplying these types of induction motor controllers shall be designed either to be capable of reaccelerating the motors within if the transfer taken place within the motor undervoltage tripping time, or time delaying the transfer to be in excess of the motor undervoltage tripping time.

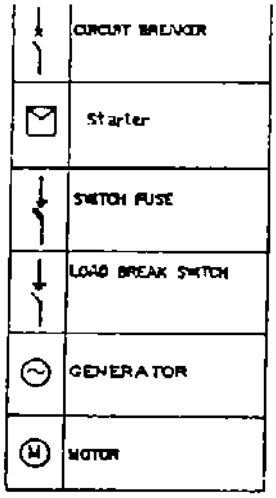
**10.7.4** Motors which are controlled by unlatched a.c., contactors will inherently disconnect from the supply on loss of voltage. Where it is required to restore power to these types of motor drives the auto-transfer schemes shall be supplemented by contactors control schemes which restart motors individually or in groups after a requisite time delay.

**10.7.5** Load transfer schemes for the startup, run and loading of a standby generator on to a busbar normally fed from a preferred a.c. source shall be initiated by time delayed undervoltage relaying set at 85% volts which shall trip the a.c. source and auto-start up the standby generator simultaneously. No transfer time delay is required in this case as standby generators take many seconds to be run up and loaded.

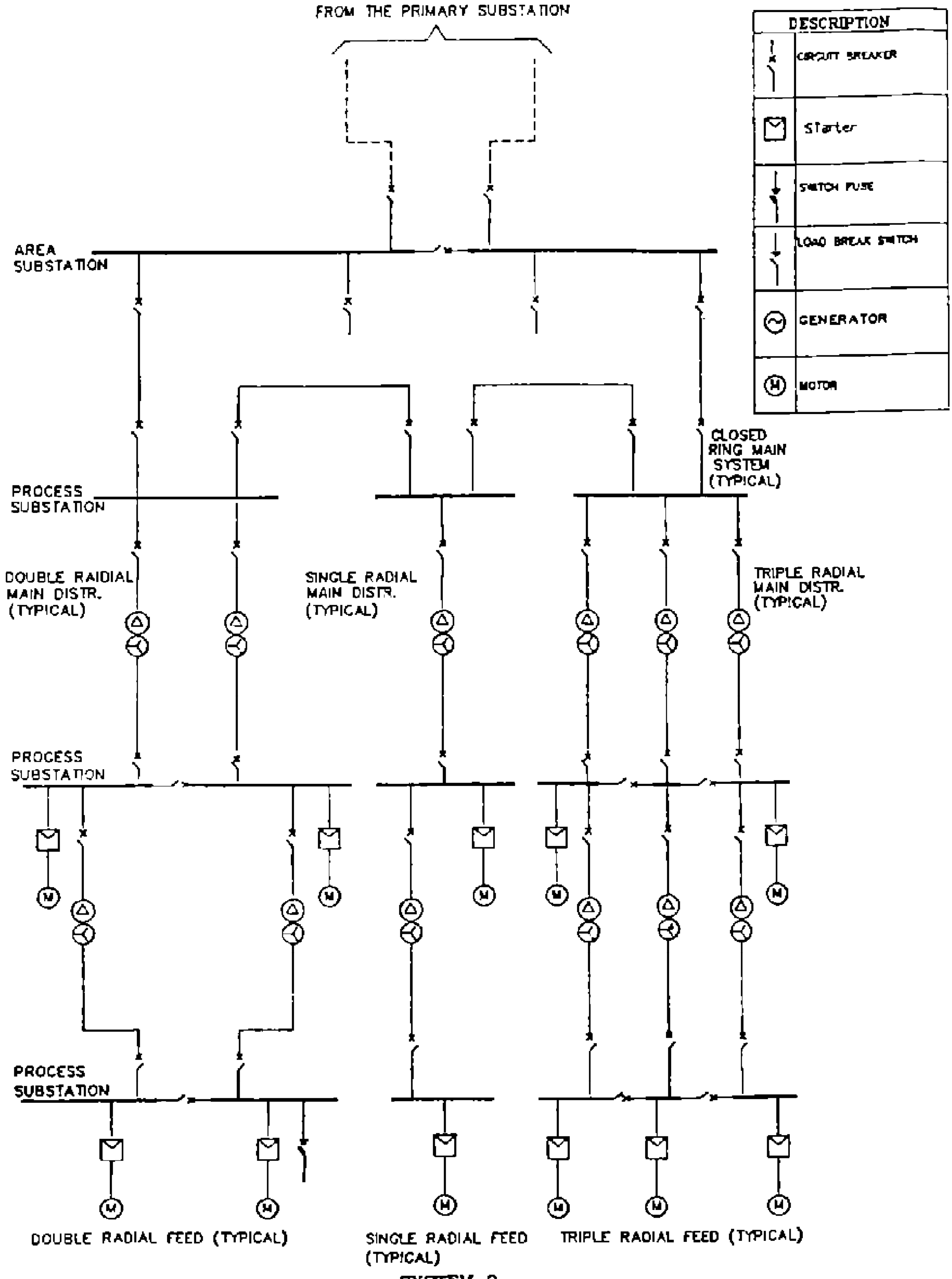
**10.7.6** Power system re-acceleration and re-start studies to determine the most technically acceptable and cost effective solution shall be carried out for each load transfer scheme considered and all such studies and their conclusions shall be subject to approval by the client.




SYSTEM 1
(DOUBLE RADIAL FEED DISTRIBUTION)

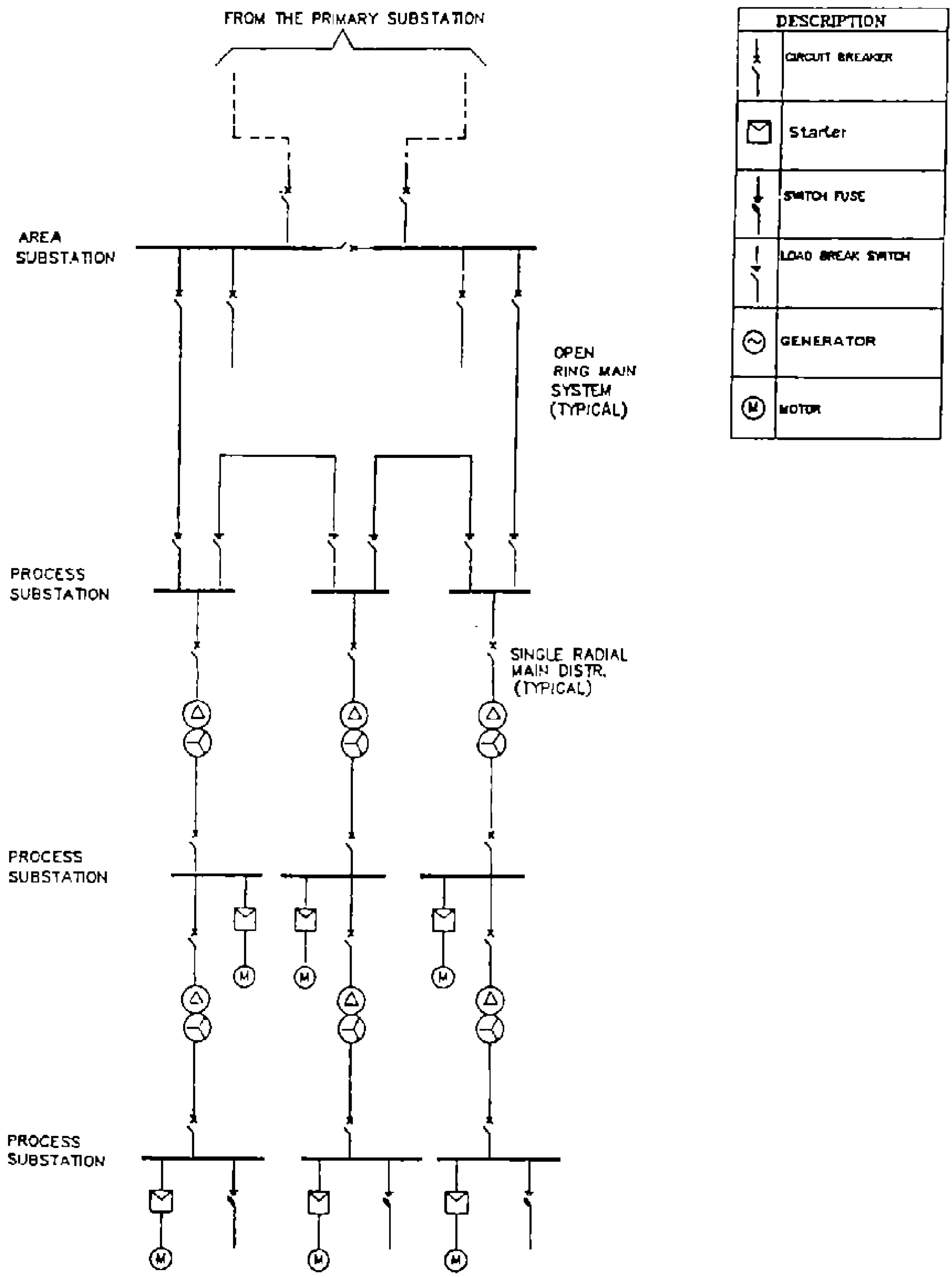



TYPICAL ELECTRICAL
DISTRIBUION NETWORKS




SYSTEM 2
(CLOSED RING MAIN DISTRIBUTION)

TYPICAL ELECTRICAL DISTRIBUION NETWORKS




SYSTEM 3
(OPEN RING MAIN DISTRIBUTION)

TYPICAL ELECTRICAL DISTRIBUION NETWORKS

## 11. POWER FACTOR IMPROVING EQUIPMENT

**11.1** Power factor improving equipment shall be provided on all installation where energy is imported from a public utility which applies a tariff penalty associated with low power factor energy provision.

**11.2** The equipment may be capacitors or synchronous motors depending on economics and suitability over the range of known operating condition.

**11.3** Where the public utility system is normally in parallel with on site generation, the generating equipment shall be designed and operated to supply the load kvar; this will avoid the need for power factor improving equipment to be installed for the normal parallel operating mode and will limit its provision to that required for standby (unparalleled operation alone).

**11.4** The amount of power factor equipment provided shall be such as to avoid any possibility of paying power factor penalties under the worst conceivable plant operating condition.

**11.5** Any power factor improving equipment provided either to reduce system losses (or to raise voltage levels alone) shall be subject to approval of client.

**11.6** Where synchronous motors are supplied for power factor improvement, they shall include constant power factor control equipment.

**Note:**

**In order to avoid risks of overvoltages or high transient torques, induction motors shall not be switched as a unit with their power factor improving capacitors, unless the capacitive current is less than the no load magnetisizing current of the associated induction motor.**

Correction can be applied in the form of individual, group or central compensation. Electricity supply authorities frequently stipulate a power factor Cos ≥ 0.9.

## 12. SIZING OF ELECTRICAL EQUIPMENT AND CABLES

### 12.1 Sizing of Electrical Equipment

**12.1.1** The sizing of the motors versus the driven machines shall generally be as follows:

- **a)** For pumps according and API 610.
- **b)** For compressors according to API 617.

**12.1.2** In radial and primary selective substation, the transformers shall be sized for the maximum simultaneous actual load of the connected switchgear plus about 20% spare capacity for future expansion.

While, in secondary selective substations, each transformer shall be sized such that, if any transformer is out of service, the remaining transformer can meet the combined maximum demand of the loads within its ONAN rating.

The KVA rating shall be chosen as far as possible accordingly to the standard sizes as per IEC 76 recommendation.

**12.1.3** Power factor at normal operating loads shall be maintained at 0.9. Power factor correction capacitors at all substations shall be provided.

**12.1.4** The lighting systems (street lighting, process area, buildings) shall be calculated according the illumination levels foreseen on the IPS-E-EL-115.

The street lighting and outdoor lighting systems shall be controlled by suitable relays actuated by photocells or timer clocks provided with manual override switch.

**12.1.5** The earthing protection system shall be designed to protect against indirect contacts (due to failure of insulation), electrostatic discharges and lightning. The system shall be designed according to IPS-E-EL-115/ standard specification, using green PVC insulated copper conductor for the purpose.

Earthing systems shall consist of networks installed around all major process units, buildings, structures, distribution centers, substations, etc.

Network shall consist of main cable loops, earthing electrodes and equipment conductors.

Equipment located remotely from the main earthing network may be earthed by means of individual conductors and earthing electrodes.

Earthing network resistance to ground shall not exceed 5 OHMS.

Separated earthing system shall be provided at each control building for instrument system.

## 12.2 Cable Sizing

**12.2.1** In cable sizing consideration shall be given both in normal services and short circuit conditions. The maximum permissible voltage drops. The cable protection (fuses circuit breakers and relays) the depth of laying. The soil thermal resistivity and grouping factors shall be carefully serutinized.

**12.2.2** The cable shall be sized to withstand without damage the maximum short circuit thermal stress for the full clearance time of the protective devices. The cable derating factors related to thermal limit, and laying conditions shall be to the IEC and or equivalent standards.

The current rating capacity of cables after being derated shall be as follows:

**12.2.3** The transformer feeder cables shall have a current carrying capacity equal to the transformer rated current in ONAF condition when applicable.

**12.2.4** Each switchgear feeder cables shall have a current carrying capacity equal to the rated current of connected transformers in ONAF conditions when applicable.

**12.2.5** The motor feeder cables shall be selected based on motor nameplate rating multiplied by a factor of 1.25 taking into account the cable derating factor as depth of installation soil thermal resistivity, grouping factor, soil temperature etc.

**12.2.6** Cables for other application not mentioned above shall have a current carrying capacity equal to the maximum current demand of duration not shorter than one hour.

**12.2.7** Minimum wire size for 6-6.6 KV, 10-11 KV cables shall be 50 mm².

**12.2.8** Minimum wire size for 400 volt motors shall be:

| | | | |
|---|---|---|---|
| 0 | to | 3.7kw | 4 mm² |
| 3.8 | to | 7.5kw | 6 mm² |
| 7.6 | to | 15 kw | 10 mm² |
| 15.1 | to | 22 kw | 16 mm² |
| 22.1 | to | 37 kw | 25 mm² |
| 37.1 | to | 55 kw | 35 mm² |
| 55.1 | to | 75 kw | 70 mm² |
| 75.1 | to | 90 kw | 95 mm² |
| 90.1 | to | 150 kw | 120 mm² |

**Note:**

**In each case voltage drop and voltage dip during starting should not exceed permissible values.**

**12.2.9** Minimum wire size for lighting and power circuits shall be 2.5 mm².

**12.2.10** Wire size for motor control shall be 2.5 mm².

### 12.2.11 Short-Circuit Rating

**i)** The short time maximum current carrying capacity shall take into account the current/time characteristics of the circuit protection device to ensure that cable do not suffer damage due to overheating under maximum through fault conditions.

**ii)** Unless required by local regulations and proved by client, the minimum cross-sectional area should be assessed from the following formula:

$$A = \frac{I\sqrt{t}}{k}\ mm^2$$

**Where:**

| | |
|---|---|
| *A* | = Cross sectional area of the conductor mm² |
| *I* | = Short circuit current (amps) |
| *t* | = Total fault clearance time (seconds) |
| *k* | = Constant dependent on the type of conductor, the insulations, and the initial and final temperatures. |

Values of k for various type of insulation in contact with copper conductors are given in Table 3.

**TABLE 3 - MAXIMUM PERMITTED CONDUCTOR TEMPERATURES AND VALUES OF K FOR VARIOUS INSULANTS (COPPER CONDUCTORS)**

| INSULATION TEMP. | CABLE TYPE | MAXIMUM WORKING $T_1$ °C | FINAL TEMP. AT END OF SHORT CIRCUIT $T_2$ °C | VALUE OF K FOR TEMP. $T_1$ AND $T_2$ |
|---|---|---|---|---|
| Paper | Up to 6.6 KV single | 80 | 160 | 108 |
| Paper | Core and multicore 1 KV and 15 KV single screened | 70 | 160 | 115 |
| Paper | 22 KV and 33 KV single Core and 3 Core | 65 | 160 | 118 |
| PVC | Up to 185 mm² | 70 | 150 | 109 |
| PVC | 240 mm² and above | 70 | 130 | 95 |
| EPR | All type | 85 | 220 | 134 |
| XLPE | All type | 90 | 250 | 143 |

**Note:**

**The values of k given in Table 1 assume that the cable is operating at its maximum current carrying capacity. If this is not the case, the true value may be determined from the formula:**

$$K = 228.6\, ln \sqrt{\frac{243.4 + T_2}{243.4 + T_1}}$$

**Where:**

| | |
|---|---|
| $T_1$ | = initial temperature of conductor (°C) |
| $T_2$ | = final temperature of conductor (°C) |
| *In* | = actual current of the conductor (A) |

**Note:**

**For more details about static power factor correction equipment see also IPS-M-EL-180.**

## 13. POWER SYSTEM FAULT CONSIDERATIONS

### 13.1 Fault Calculations

**13.1.1** The fault currents that flow as a result of short circuits shall be calculated at each system voltage for both three phase and phase to earth fault conditions. These calculated currents shall be used to select suitably rated switchgear and to allow the selection and setting of protective device to ensure that successful discriminatory fault clearance is achieved.

**13.1.2** The voltage disturbance sustained during the faults and after fault clearance shall also be ascertained to ensure that transient disturbances do not result in loss of supplies due to low voltages or overstressing of plant insulation due to high voltages.

**13.1.3** The calculation of fault currents shall include the fault current contribution from generators and from synchronous and induction motors. Both the a.c. symmetrical d.c. symmetrical component of fault currents shall be calculated at all system voltages. Public utility fault in feeds shall be obtained from the public utility concerned, and they shall exclude any decrement associated with fault duration, though maximum and minimum values consistent with annual load cycles shall be obtained.

**13.1.4** Positive sequence impedances shall be used for calculating balanced three phase faults. Positive, negative and zero sequence impedances shall be used for calculating unbalanced faults.

**13.1.5** Three phase balanced fault current calculations shall be carried out to obtain prospective circuit breaker ratings and shall include:

**i)** Asymmetric make capacity-expressed in peak amperes and calculated half a cycle after fault inception. Both a.c. and d.c. current decrements shall be included for the half cycle.

**ii)** Asymmetric break capability-expressed in rms amperes calculated at a time at which the breaker contacts are expected to part and allowing a maximum of 10 ms for instantaneous type protection operation. Both a.c. and d.c. decrements shall be included for the selected time.

**iii)** Symmetrical break capability-expressed in rms amperes calculated at a time as defined in item (ii) above. This assumes nil d.c. current component and shall allow for a.c. decrement for the selected time.

**13.1.6** Earth fault currents may be assumed to be no greater than the maximum phase fault currents for solidly earthed systems. On systems where the earth fault currents are limited by neutral earthing equipment, the currents may be assumed to include no decrement and shall be considered constant whatever the level of bonding between the conductor and the faulted phase.

**13.1.7** Both the a.c. and d.c. components of motor fault current contributions shall be calculated and included in calculation of prospective fault currents. At the instant of fault inspection the a.c. peak symmetrical component and the d.c. component shall be taken to be identical. Both values shall be taken as the peak direct-on-line starting current, this being dictated by the motor locked rotor reactance. Both these currents shall be taken to decay exponentially with time using a.c. and d.c. short circuit time constants respectively. The a.c. time constant shall be determined by using the ratio of the locked rotor reactance to the standstill rotor resistance. The d.c. time constant shall be determined by using the locked rotor reactance to the stator resistance ratio. In the case of faults not directly on the motor terminals, these time constants shall be modified to take account of external impedances to the point of fault.

**13.1.8** The calculation of individual fault current contributions shall be carried out for individual motors of significant rating on the power system. Generally motors with ratings greater than 500 kw should be treated in this way.

## 13.2 Equipment Fault Current Ratings

**13.2.1** All switchgear and distribution equipment on the power system shall be capable of carrying the prospective symmetrical fault currents for a specified short time duration of 1 or 3 seconds without deleterious effect. The choice between 1 and 3 second durations shall be dictated by availability, economics and fault current protection clearing times. Generally 3 second short time rating are preferred to avoid the necessity for rapid protection. The back-up fault current protection clearing times shall always be less than the equipment short time current rating.

**13.2.2** The closure of switchgear on to a balanced or unbalanced fault shall not result in shock load damage to healthy parts of the system as a result of peak asymmetrical make currents following.

**13.2.3** The selection of circuit breakers shall be dependent on the make and break duty which the breaker is required to cater for switching devices that may be closed on to fault shall have the necessary fault making capability.

**13.2.4** Plant protected by fault current limiting HBC type fuses need not be designed to sustain the prospective shock or thermal loads obtained by calculating system fault currents.

## 13.3 Methods of Limiting Fault Currents

**13.3.1** The power distribution system shall be designed to provide the required security and quality of supply with prospective fault levels within the capability of commonly available switchgear acceptable maximum short circuit symmetrical breaking current for various system voltages unless otherwise specified or approved by company are as follows:

**i)** Power systems with a voltage in excess of 1000 V shall be so designed that the rms value of the a.c. components of the short-circuit breaking current of the circuit breakers is to IEC 56 and or shall not exceed 25 KA.

**ii)** For power systems with a voltage less than 1000 volt, the rms value of the a.c. component of the short circuit breaking current of circuit breaken designed shall be IEC 157 and shall not exceed 50 KA.

If the power system design indicates prospective short circuit requirements exceeding the maximum circuit breaker rating given above, the following alternatives should be considered:

**i)** Increase the system reactances, provided this causes no other technical or commercial problem.

**ii)** Change the operating mode by operating with certain breakers open and provide auto-transfer facilities to reinstate the supply security and quality levels.

**iii)** Purchase switchgear and equipment to provide for the higher short circuit levels if these are available.

**iv)** Provide fault current limiting devices other than fuses.

**v)** Carry out any combination of the alternatives listed in items (i) to (iv) above.

**13.3.2** To have an idea of the short time withstand current for switchgear the following are to be considered:

**a)** All short circuit studies to be carried out in compliance with requirements of IEC standards.
**b)** The minimum short time withstand current for busbars shall be according to figures given in Table 1.
**c)** The minimum short time withstand current for low voltage busbars with explosion protection type Exd (EExd) shall be 15 KA.

**TABLE 1**

| RATED VOLTAGE | WITHSTAND CURRENT |
|---|---|
| 63-66 Kilo Volt | 20 KA (R.M.S.) |
| 33 Kilo Volt | 25 KA (R.M.S.) |
| 20 Kilo Volt | 25 KA (R.M.S.) |
| * 11 Kilo Volt | 25 KA (R.M.S.) |
| 6 Kilo Volt | 25 KA (R.M.S.) |
| * 3.3 Kilo Volt | 25 KA (R.M.S.) |
| 0.4 Kilo Volt | 50 KA (R.M.S.) |

**Note:**

**11 KV and 3.3 KV shall be used when unavoidable.**

### 13.4 Effects of Faults on Distribution Systems

Bolted three phase faults on the system will depress the voltage at the point of fault and downstream of the fault to zero. All locations between the sources of fault current and the fault will experience reduced voltages. This conditions will apply until the faulty section has been cleared at which stage voltages will be rapidly restored.

**13.4.1** The following effects of three phase fault applications and clearances shall be investigated:

**i)** Possible loss of synchronizm between parallel running synchronous machines. This would only be likely for dissimilar machines or for identical machines connected to the fault which are not electrically symmetrical.

**ii)** The possibility of motor contactors dropping out, and the consequential need to re-start the motors, either manually or automatically.

**iii)** Possible extinction of certain discharge lamps and the time for re-ignition. The provision of emergency lighting systems avoids the need to study this.

**iv)** Loss of electronic and control equipment supplies resulting in maloperation. The provision of d.c. or ’no break’ supplies for vital loads avoids the need to study this.

**v)** The extent of overvoltages on the system components resulting from fault clearance. This could cause unacceptable transient recovery voltages occurring for short periods which may have a destructive effect on electrical insulation.

## 14. SYSTEM PROTECTION AND COORDINATION

### 14.1 Introduction and Terms

#### Function of system protection

The function of system protection is to detect faults and to disconnect faulted parts of the system. It has also to limit. Over current and the effects of arcs due to fault.

#### Discrimination

Where there are two or more protection is series discrimination is generally called for. The protection scheme is said to embody discrimination when, in terms of direction of power flow, only the last protection device before the fault location operates.

**Back up protection**

In the event that a protection device fails the upstream protection device must operate (back protection).

**Grading of operating currents with time discrimination**

Grading of the operating current must also be observed when time discrimination is employed; that is the short circuit release of upstream circuit breaker must be set higher than that of downstream by a factor of at least 1.25 in order to allow for the spread of overcurrents definite time delay overcurrents releases.

See subclause 13.5 for more information.

## 14.2 General

The protective system should be such as to provide adequate safeguards against the effects of short circuits, overcurrent and earth-faults and sufficient discrimination to minimize system disturbances, due to faults on any part of the system.

Requirements for bus zone protection will be specified when necessary and the arrangements must be agreed.

Details are given below of the equipment that should generally be provided on each type of switch-gear assembly.

The arrangement to be such as to ensure that all circuit-breakers which have tripped on any fault, except undervoltage and overload can not be reclosed without manually resetting a master tripping relay.

Undervoltage protection should be of self resetting type unless the particular control system or process system dictates otherwise.

Motor overload protection should be of the manually reset type when associated with automatic control systems e.g. float control, pressure switch etc. otherwise it should be of resetting type.

In reading this standard the following two distinct nomenclatures have been used.

**a)** System "A" in which maximum use is made from industrial type switch and controlgear located in safe area.
**b)** System "B" in which use is made from explosion proof equipment located in potentially explosive atmosphere.

System "A" should be economically advantageous and is consequently preferred .

System "B" should only be used where extensions are necessary to established plant areas if retention of an existing. System "B" standard practices is required.

The use of a combination of system "A" and "B" may in particular cases be economical.

**I) Primary substation protection requirements**

20000 volt and (11000 volt)* incoming supplies:

All equipment to be agreed between the supply authority, the Company and other parties concerned.

• Sub-Section switches:

- Inverse definite minimum time limit over current and earth fault.

• Outgoing feeders

to 20000/6000 Volt, 20000/400 Volt, (11000/3300 Volt)*, and (11000/400 Volt)* Transformers:

- Inverse definite minimum time overcurrent (2 pole).
- Instantaneous earth fault.

- Instantaneous high set short circuit (2 pole) set to operate for 20000 volt and (11000 volt)* Fault only.
- Intertripping with remote end circuit breaker for duplicate supplies.

• Out going feeder to 20000 volt and (11000 volt)* Switch-board:

- Differential protection covering phase and earth faults.
- Inverse definite minimum time over current (2 pole).
- Inverse definite minimum time earth fault (1 pole).
- Intertripping with remote end circuit breakers on duplicate feeders.

• Motor starters (11000 volt)* and 6600 volt:

- Thermal or magnetic inverse definite minimum time limit overcurrent (2 pole).
- Instantaneous short circuit (2 pole).
- Instantaneous earth fault.
- Single phasing prevention.
- Motor stalling.
- Undervoltage time delayed adjustable between zero and five seconds. (voltage transformer connected on the circuit side).

**Note:**

**The above should preferably be incorporated in a single protection type relay.**

• Motor starters (11000 volt)* for (3300 volt)* motors with unit transformers:

As for 11000 volt motors stated above, but with the following additional protection:

- Transformer surge tripping
- Transformer gas alarm

The above mentioned requirements to be fitted to conservation type transformers 1500 KVA and above.

- Unrestricted earth fault instantaneous type using a current transformer in the (3300 volt)* Transformer neutral to trip (The 11000 volt)* circuit-breaker.

### II) Area and process plant sub-stations (3300 volt)*

#### a) system A

Incoming feeder from 20000/6000 volt, (11000/3300 volt transformers)*

- Instantaneous restricted earth fault

- Transformer surge tripping and transformer gas alarms, both filled to:

Conservation type transformers 1500 KVA and above.

- Intertripping with 20000 volt and (11000 volt)* circuit breaker as applicable.

- Sustain overload alarm (single phase thermal relay), 6000 volt or 3300 volt duplicate feeders to 6000 volt or 3300 volt switchboard:

- Inverse definite minimum time limit over current (2 pole) at sending end.

- Inverse definite minimum time limit earth fault (1 pole) at sending end.

- Instantaneous phase and earth fault protection of the pilot wire balanced type.

- 6000 volt (or 3300 volt)* feeders to 6000/400 or (3300/400)* transformers

- Inverse definite minimum time limit overcurrent (2 pole)

- High set instantaneous short circuit (2 pole) set to operate for 6000 volt or (3300 volt)* only.

- Instantaneous earth fault

- Inter tripping with remote end circuit breaker, other than by the use of circuit breaker auxiliary switches.

Motor starters 6000 volt and (3300 volt)* motors as for 11000 volt motor starters except that the motor stalling relay is to be omitted.

**Notes:**

**1) The use of high breaking current fuse protection in series with a circuit breaker must be agreed and it is essential that both switch-gear and motor manufacturer be fully informed, and all points agreed among all parties concerned.**

**2) * Indicates for conditions not avoidable.**

**b) System B**

In accordance with company/manufacturer agreed standards

**III) Generator protection**

Electrical protection requirement in this standard does not cover mechanical protective requirements of prime mover and it generally relates to machine rated above 2 MVA.

**IV) Generators shall be protected against the following internal faults:**

- Stator phase to phase
- Stator phase to earth
- rotor earth fault

In addition generator protective system shall consider the following abnormal conditions.

- Over current/overload/winding temperature
- Over voltage
- Unbalanced loading
- Motoring
- Loss of voltage

Field dide failure (above 15 MVA only), cooling water and air temperature detection.

Protection of generators below 1250 KVA rating

**1)** Protection should normally be provided by machine suppliers as part of total package and shall not be supplemented providing the following minimum requirements are met:

- Voltage sensitive overcurrent relays to detect phase faults.

- IDMTL earth fault relays for sets not normally run in parallel with other earth fault power sources.

Restricted earth fault high impedance relays internally looking on directionalized earth fault relays for set which are run in parallel with other earth fault power sources. In the latter event an IDMT earth fault relay energized from a C.T in the generator neutral shall be provided for system back up earth fault protection.

- Reverse power relay for generators which may be operated in parallel with other power sources.

- A means of indicating overcurrent or overload of emergency supply generators where these may be subjected to overload.

- Over current protection matched to the generator thermal characteristic for all self excited generators (normally portable).

- Where portable self excited generators are provided they shall all include phase and earth fault and reverse power protection to cover for the possibility of them ever being run in parallel with other power sources.

Protection and control circuits shall be segregated and fused to achieve perfect discrimination.

### 2) Special CT and VT Requirements

**a)** The primary rating of line CTs shall approximate 150% full load current of the generator. Neutral connection CTs shall have a primary rating at least equal to neutral resistance rating.

For generator earthed via a power transformer the neutral connected CT shall have a 1 to 1 ratio.

**b)** VTs for the AVR shall be two phase and exclusively used.

The same policy shall be adapted for VTs for synchronizing.

### V) Capacitors protection

- HRC fuses

- HRC fuses serve only as short circuit protection and do not provide adequate protection against overcurrent.

- Over current

Bimetal and secondary thermal relays are connected as thermal protection to capacitor banks of above 300 Kvar the tripping current of these relays should be set to 1.43 times the rated current of the capacitor (capacitor bank) protection by means of over current relays does not at the same time provide protection against over voltages.

All capacitor installation must be connected direct to a means of discharge without intervening isolators on fuse. Low voltage capacitors must discharge to a residual voltage <50 volt within one minute a maximum discharge time of 5 minute is stipulated for medium voltage.

When capacitors are connected in star the neutral point must not be directly earthed Earthing via surge arresters (blow out fuses) is permissible.

### VI) Line protection

The following protections are to be considered for lines as appropriate.

Fuse cut out
Over-current
Over-voltage
Undervoltage
Earth fault
Distance
Surge arresters (with counter)

**VII) Busbars protection**

Back up protection
Over Current
Distance
Differential
Frame leakage

### 14.3 Power System Coordination

Proper coordination of circuit interrupting devices is an essential but frequently overlooked phase of industrial power system design. On all but the simplest systems there will usually be at least two such devices in series between any fault or overload and the power source.

To minimize the effects of a fault on the system, these devices should be selective in operation so that the one nearest the fault on the source side will operate first and, if any device should fail to function, the next closest device on the source side should open the circuit.

In a properly coordinated power system the protective devices should be either preselected (as in the case of fuses and non-adjustable trip elements), or be capable of adjustment over the required range:

**i)** To operate on the minimum current that will permit them to distinguish between fault and load current.
**ii)** To function in the minimum time to permit selectivity with other devices in series with them.

Since the coordination requirements differ for each power system, all adjustable protective devices must be set by protection specialists in the field to achieve the desired coordination.

## 15. INSTRUMENTS AND METERS

Metering and instrumentation are essential to satisfactory plant operation. The amount required depending upon the size and complexity of the plant, as well as economic factors.

Instruments and meters are need to monitor plant operating conditions as well as for power billing purposes and for determination of production costs.

An instrument is defined as device for measuring the present value of the quantity under observation. Instruments may be either indicating or recording type.

A meter is defined as a device that measures and registers the integral of a quantity with respect to time. The term meter is also commonly used in a general sense as a suffix or as part of a compound word (e.g. voltmeter, frequency meter), even though these devices are classed as instruments.

The most common type instruments used in distribution system are as follows:

Ammeters, voltmeters wattmeters, varmeters, power factor meters, frequency meters, synchroscopes, elapse time meters, including portable and recording.

Among the meters which have application in distribution system watt-hour meters and demand meters are most common.

For more information reference to be made to IEC 51.

At least the following requirements to IEC 51 should be considered during design stage, all equipment must be connected on the circuit side of the circuit breaker or motor starter (voltmeters are excluded).

#### i) Incoming supply feeders

Instrument and metering to be in accordance with the supply authorities requirements and agreed by Company:

- Ammeter (with phase selector switch)
- Voltmeter (on incoming side of circuit breakers)
- Power factor meter
- Summation kilowatt recorder (mounted on bus section panel)

#### ii) Outgoing distribution feeders

6000 volt, 20000 volt and (33000 volt, 11000 volt)* ammeter.

Integrating wattmeter unless otherwise specified on 20000 volt and (11000 volt)* feeders.

#### iii) Motor starters medium voltage (11000 volt)* 6000 volt and (3300 volt)*

- Ammeter local/remote refer to VI below
- Integrating wattmeter unless otherwise specified on (11000 volt)* and 6000 volt motor

#### iv) Incoming feeders to 6000 volt, (3300 volt)* and 400 volt switch board ammeter, voltmeter (on supply side)

#### v) Motor starter 400 volt

Ammeter local remote refer to (VI) which follows:

**Note:**

**When voltage selection is unavoidable.**

#### vi) Ammeters for motors

Unless specified otherwise the provision of ammeters should comply with the following:

**Process area**

**a)** Ammeters should be provided for motors above 4 kW (5 HP) except for those driving motorized valves, cranes and winches, furnace fan without vane control and general ancillary equipment such as drinking water coolers, room ventilating fans air-conditioning units, etc.

**b)** Ammeters should be provided for motors of 4 kW (5 HP) and below only when such motors are not visible for the starting positions, when a change in noise level is not easily detachable, or when an ammeter provides adequate indication for essential process control to the exclusion of more expensive instrumentation.

**c)** Ammeters should be located adjacent to or be incorporated in the associated push button station.

**Other than process area**

**d)** Ammeters should be provided for motors of above 4 kW (5 HP) as stated under (a) above.

**e)** Ammeters should be provided for motors of 4 kW (5 HP) and below as stated under (b) above.

**f)** Ammeters should be located on the motor starter panel in the associated sub-station or switch house.

**Special cases**

**g)** In certain cases where supervisory control is exercised from a central control position, it may be necessary to have ammeter located at the central control position, typical cases are those of remotely controlled crude oil forwarding pumps and other process pumps driven through fluid coupling and transfer loading pumps having a wide range of duty horse power.

When such arrangements are required they will be specified and in view of distances sometimes involved details should be agreed.

**General**

**h)** Ammeters not located on motor starters panels should be operated from a current transformer mounted in the motor starter panel.

**i)** Scales should be selected so that full load current appears between 50% and 80% of full angular deflection. Full load motor current (design value) should be indicated by a red line on the scale.

**j)** Ammeters for motors should be capable of repeatedly withstanding the appropriate motor starting current without accuracy being impaired.

**vii) Maximum demand indicators, recorders and other instruments meters etc.**

When required to satisfy particular requirements, the installation of above will be specified.

**viii) Generators**

The following instruments and meters shall be provided at the relevant control locations for all generators:

- kW meter.
- Power factor meter.
- kVAr meter (excluding standby generators).
- Voltmeter and phase selector switch.
- Frequency meter.
- Elapsed time meter.
- kWh meter.
- Where remote monitoring of generator output is required, such as in main control room.
- Suitable transducers shall be provided at the generator switchgear to facilitate this.
- Syncronoscope when paralleling of two sources of power supply is required.

## 16. SECURITY LIGHTING

No plant security system is complete unless it has ample provision for lighting vulnerable areas, where employees enter and leave the plant, fences and boundaries and other particularly important points. Lighting of these areas is usually arranged to be independent of normal lighting circuits and may be used either continuously during the night hours or may be controlled for intermittent use automatically or by the plant security personnel.

Critical areas may be protected by providing ample lights to illuminate the area either by local fixtures or by floodlighting from more distant points, but sufficient units must be used to provide complete coverage.

Boundary lighting is often found to provide more useful illumination when asymmetrical fixtures are used and arranged so that the greater portion of the light output is spread along the boundary.

## 17. EARTHING (GROUNDING)

The subject of earthing (grounding) may be divided into two main parts. That is, the grounding of the system for electrical operating reasons and the grounding of non-current-carrying metal parts for safety to personnel.

The principal reasons for grounding an electric system are:

1) Safety of personnel
2) Keep transient overvoltages that may appear on a system minimum
3) Improve service reliability
4) Better system and equipment overcurrent protection
5) Readily locate and isolate circuits which have become accidentally grounded.
6) Improve lightning protection

Circuits are grounded for the purpose of limiting the voltages upon the circuit which might otherwise occur through exposure to lighting or other voltages higher than that for which the circuit is designed; or to limit the maximum potential to ground due to normal voltage.

Failure to provide proper grounding for electric equipment may be considered as the primary cause of many accidents which have resulted in the death of personnel and no system is complete unless adequate grounding connections have been made.

For details of earthing system reference to be made to IPS-E-EL-100 Appendix I.

## 18. STATION CONTROL SUPPLIES

### 18.1 General

Station control supplies:

As with all protection equipment which requires power supplies independent of normal C.T and V.T supplies, it is essential in the case of protection, signaling, and intertripping equipment to derive such supplies from a reliable source that is not dependent on normal mains supply which may fail at the instant of fault.

Present day policy is to provide 48 V (nominal) lead acid battery units to provide the auxiliary power supply requirements of protection and protection signaling equipment.

### 18.2 d.c. Supply

The use of d.c. supply for protection purposes is widespread as this supply has the merit of being already of high dependability d.c. voltages may be nominated also at 110 volt or 220 volt.

**Note:**

**110 volt is preferred value.**

Generally the 48 volt battery is used to power the solid state equipment and 110 and 220 volt supplies are used for tripping and control duties.

The station battery supplies are subject to variation -20% to +25% of nominal voltage and d.c./d.c. converter power supplies are usually employed to remove the effect of such variations where necessary. For more details for batteries, chargers and ups see IPS-M-EL-174 and IPS-M-EL-176.

### 18.3 Separate Batteries

In some places separate batteries are provided for protection purposes.

These batteries generally have lower voltage variation and because their use is restricted to protective equipment are not subject to the same levels of interference as station batteries.

Never the less it is common practice to employ d.c./d.c. convertor power supplies within the equipment being supplied from such a batteries.

### 18.4 Battery Selection

For type of battery chosen shall take into account the following:

- **i)** Existing installation if any
- **ii)** Capital costs and replacement costs
- **iii)** Required life
- **iv)** Size and weight
- **v)** Reliability
- **vi)** Robustness
- **vii)** Charging method
- **viii)** Temperature effect

**Note:**

**For more information see IPS-M-EL-174.**

## 19. SYSTEM ONE LINE DIAGRAM

A one line diagram is one which indicate by means of single lines and simplified symbols the course and component devices or parts of an electric circuit or system of circuits.

In the preparation of preliminary plans for a system or specification it is not necessary to show all details in complete form on a one line diagram. Some of the more important items to be included are as follows:

- **i)** Voltage, phase and frequency
- **ii)** The available fault level of system and (time)
- **iii)** The size, type and number of incoming and outgoing cables
- **iv)** The ratings, impedances and connections of the transformers
- **v)** The points at which power is metered (where applicable)
- **vi)** The amount and character of the load on all feeders

The following items if given special attention during preparation, ensure complete, accurate and lucid diagrams.

- **a)** Keep the diagram simple
- **b)** Avoid duplication
- **c)** Use of standard symbols
- **d)** Show all known facts

By the following list before releasing a diagram the omission of some of the more important details can be avoided:

- Rating and protection of devices.
- Ratio of current and potential transformers.
- Connection of transformer winding.
- Circuit breaker rating.

- Switch and fuse rating.
- Function of relays.
- Rating of motors and transformers.
- Size and type of transformers.
- Size and type of cables.

A statement should accompany this information stating whether or not the neutral of any apparatus connected to the source is grounded. If grounded the statement should specify whether the ground is solid or through an impedances, if the latter, the value of the impedances should be given.

**e)** Show future plans and extension where applicable.
**f)** Include correct title data.

## 20. DEVICE FUNCTION NUMBERS

While preparing single line diagrams. It is necessary to show the numbers indicating electrical instrument function.

The most common type of electrical/instrument function number which follow are extracted from:

IEEE Std. C 37.2 "Standard Electric Power System Device Function Numbers"

| | |
|---|---|
| 1 | Master element |
| 2 | Time-Delay starting or closing relay |
| 3 | Checking or interlocking relay |
| 4 | Master contactor |
| 5 | Stopping device |
| 6 | Starting circuit breaker |
| 7 | Reserved for future application |
| 8 | Control power disconnecting device |
| 9 | Reversing device |
| 10 | Unit sequence switch |
| 11 | Multifunction device |
| 12 | Overspeed device |
| 13 | Synchronous-Speed device |
| 14 | Underspeed device |
| 15 | Speed or frequency matching device |
| 16 | Reserved for future application |
| 17 | Shunting or discharge switch |
| 18 | Accelerating or decelerating device |
| 19 | Starting-To-Running transition contactor |
| 20 | Electrically operated valve |
| 21 | Distance relay |
| 22 | Equalizer circuit breaker |
| 23 | Temperature control device |
| 24 | Volts per herts relay |
| 25 | Synchronizing or synchronism check device |
| 26 | Apparatus thermal device |
| 27 | Undervoltage relay |
| 28 | Flame detector |
| 29 | Isolating contactor |
| 30 | Annunciator relay |

**(to be continued)**

| | |
|---|---|
| 31 | Separate excitation device |
| 32 | Directional power relay |
| 33 | Position switch |
| 34 | Master sequence device |
| 35 | Brush-Operating or slip-ring |
| | Short-Circuiting device |
| 36 | Polarity or polarizing voltage device |
| 37 | Undercurrent or underpower relay |
| 38 | Bearing protective device |
| 39 | Mechanical condition monitor |
| 40 | Field relay |
| 41 | Field circuit breaker |
| 42 | Running circuit breaker |
| 43 | Manual transfer or selector device |
| 44 | Unit sequence starting relay |
| 45 | Atmospheric condition monitor |
| 46 | Reverse-Phase or phase-balance current |
| | Relay |
| 47 | Phase-Sequence or phase balance voltage |
| | Relay |
| 48 | Incomplete sequence relay |
| 49 | Machine or transformer thermal relay |
| 50 | Instantaneous overcurrent or rate-of rise |
| | Relay |
| 51 | a.c. time overcurrent relay |
| 52 | a.c. circuit breaker |
| 53 | Exciter or d.c. generator relay |
| 54 | Turning gear engaging device |
| 55 | Power factor relay |
| 56 | Field application relay |
| 57 | Short-Circuiting or grounding device |
| 58 | Rectification failure relay |
| 59 | Overvoltage relay |
| 60 | Voltage or current balance relay |
| 61 | Density switch or sensor |
| 62 | Time-Delay stopping or opening relay |
| 63 | Pressure switch |
| 64 | Ground detector relay |
| 65 | Governor |
| 66 | Notching or jogging device |
| 67 | a.c. directional overcurrent relay |
| 68 | Blocking relay |
| 69 | Permissive control device |
| 70 | Rheostat |

**(to be continued)**

| | |
|---|---|
| 71 | Level switch |
| 72 | d.c. circuit breaker |
| 73 | Load-Resistor contactor |
| 74 | Alarm relay |
| 75 | Position changing mechanism |
| 76 | d.c. overcurrent relay |
| 77 | Telemetering device |
| 78 | Phase-Angle measuring or out-of-step |
| | Protective relay |
| 79 | a.c. reclosing relay |
| 80 | Flow switch |
| 81 | Frequency relay |
| 82 | d.c. reclosing relay |
| 83 | Automatic selective control or transfer |
| | Relay |
| 84 | Operating mechanism |
| 85 | Carrier or pilot-wire receiver relay |
| 86 | Lockout relay |
| 87 | Differential protective relay |
| 88 | Auxiliary motor or motor generator |
| 89 | Line switch (disconnecting switch) |
| 90 | Regulating device |
| 91 | Voltage directional relay |
| 92 | Voltage and power directional relay |
| 93 | Field-Changing contactor |
| 94 | Tripping or trip-free relay |
| 95 | Used only for specific application |
| 96 | Used only for specific application |
| 97 | Used only for specific application |
| 98 | Used only for specific application |
| 99 | Used only for specific application |

## 21. DRAWINGS AND SCHEDULES

Unless specified otherwise, the consultant responsible for the system design shall provide the following:

1) Plant layout diagram
2) Hazardous area classification (where applicable)
3) General single line diagram
4) Single line diagram for each substation
5) Relaying and metering diagrams
6) Coordination diagrams
7) Substation layouts
8) Cable runs and schedules (type, size and length)
9) Lighting layout
10) Earthing layout

**11)** Load flow analysis
**12)** Short circuit studies
**13)** Stability studies
**14)** Load shedding system

## 22. ALARMS, INDICATION AND COMMUNICATION SYSTEM

### 22.1 Plant Alarms

**22.1.1** Each substation and each on-site generator shall be provided with an alarm annunciation system. This shall comprise an alarm panel which shall collect together all the alarm conditions associated with that particular substation or generator. A common alarm shall be derived from each substation or generator alarm panel for transmission to an emergency control center.

**22.1.2** Each generator alarm panel shall have an alarm window associated with each separate alarm condition required.

**22.1.3** A window shall be provided on the substation alarm panel for each switchboard circuit breaker way which has protective relaying.

Where battery chargers are provided for closing and tripping supplies a window shall be provided on the substation alarm panel for each battery charger.

**22.1.4** Each alarm window of a substation alarm panel shall be operated by the combined alarm functions of the equipment the window is supposed to represent. For any circuit breaker each protective relay shall provide a contact into a common alarm circuit which shall operate the appropriate circuit breaker alarm window in the alarm panel. The alarms associated with a battery charger shall form a common alarm to operate the appropriate battery charger alarm window in the alarm panel.

For typical alarm system.

### 22.2 Fire Alarm

Fire alarm circuits, should be installed in a manner that will guarantee the least interruption from faults and changes in buildings or plant operations. Lines should be arranged to provide easy means of testing and of isolating portions of the system, in case of fault or changes without interference with the balance of the system.

### 22.3 Indications

**22.3.1** Local indication of status of circuit breakers on switchgear shall be as described on IPS-M-EL-140.

### 22.4 Plant Communication System

Any plan for the protection of a plant must include an adequate and reliable system of communication, both within the plant and to the associated utilities and emergency services which may be called upon in case of need. This can be accomplished in several ways; a principal one is by a completely self-contained and self-maintained inter-plant system of telephones, alarms, etc., and may include modern radio equipment as well.

## 23. SAFETY AND PLANT PROTECTION

### 23.1 Personnel Safety

There are listed below items which should be considered in order to provide safe working conditions for the personnel.

**1)** Interrupting devices should be able to function safely and properly under the most severe duty to which they may be exposed.

**2)** Protection should be provided against accidental contact with energized conductors by elevation, barriers, enclosures, and other similar equipment.

**3)** Disconnecting switches should not be operated while they are carrying currents, unless designed to do so. Suitable barriers should be provided between phases to confine accidental arcs unless adequate space separation is provided.

**4)** In many instances interlocks between the disconnecting switch and the power circuit breaker are desirable, so that the breaker in series must be opened first before the disconnects can be operated, thus preventing accidental opening of the disconnects under load.

**5)** Sufficient unobstructed room in any area containing electric apparatus must be provided for the operator to perform all necessary operations safely.

**6)** A sufficient number of exits with "panic-type" door features should be provided from any room containing electric apparatus such as a substation, control room or motor so that escape from this area can be easily effected in the event of failure of apparatus in the room.

**7)** A protective tagging procedure should be set up to give positive protection to men working on equipment. Such a procedure should be coordinated with the local utility for the common equipment.

**8)** Industrial plant electric systems should generally be designed so that all necessary work on circuits and equipment can be accomplished with the particular circuits and equipment de-energized.

**9)** All circuits should be marked in the switching station so as to be readily identified. Cables should be identified with suitable tags at both ends and in all manholes for the protection of men working on them.

**10)** Consider the fire and explosion hazard of oil-filled apparatus and whether such equipment is permitted by Codes. Wherever possible, substitute apparatus such as air circuit breakers, air load interrupter switches, and dry type transformers.

**11)** A fire crew should be formed of local employees who are familiar with the equipment and the hazards involved. This group should be trained in the proper procedures to follow in the event of fire in the electric apparatus, the proper use of the various types of extinguishers and methods of fire fighting.

### 23.2 Equipment Safety

Electrical interlocks : Safety interlocks can be arranged for almost any machine and any operating condition.

" An interlock is a device actuated by the operation of some other device with which it is directly associated to govern succeeding operations of the same or allied devices."

Interlocks have three general functions:

To assure personal safety
To protect equipment
And to coordinate complex operations

Adequate machinery guarding is of course basic to any organized safety program.

Human habits and practices in the interest of safety are difficult to establish and maintain, however interlocking of equipment either by manufacturer or by the user removes hazards and is a critical part of safe design and installation. As a general rule the starting point in determining the need for interlocking is to consider the past accident history of injury or major material damage, the question of whether the use of an interlocking device to prevent the injury should be considered.

It should be remembered that interlocking devices and their application go beyond protecting the point of operation during the normal work process. They can be used to restrict, access areas through gate operated controls or through other device such as castle interlock.

Interlocks can initiate visual or audible warnings or stop an operation or malfunction. Key type interlocks are often employed for access and sequence control.

If a visual warning is desirable flashing red light may be considered. Immediately, there is the problem of "burned out" light and the system is not "fail safe". Two lights in parallel offer redundancy and are generally acceptable.

In a series of process operations interlocks can be provided which will afford the necessary safety for operator and equipment in the event of failure of sequence timers or controllers.

The design and application of interlocks usually affect a critical safety function. It follows that they must be extensively tested and proved be convenient to use, have fail safe provisions and if applicable have detailed procedures to verify proper function.

## 24. HINTS ON PROTECTION OF PROPERTY AGAINST FIRE

A potential fire or explosion hazard is inherent with the use of nearly all electric apparatus and proper arrangement and protection of the equipment at the start will minimize if not eliminate serious property damage or interruption to production when insulation failures or breakdown occur.

The fire and explosion hazard of oil-insulated and compound-filled equipment is one of the most common hazards to safeguard against. Fires or explosions in oil insulated transformers occur infrequently, but where they do the results may be disastrous depending upon the arrangement of the equipment and the safeguards provided. The old practice of locating oil-filled transformers in the same room with an important switchgear assembly or other valuable apparatus should be avoided because a fire in the transformer will usually involve the other equipment increasing the damage and prolonging the interruption to production.

The National Electrical Code clearly outlines the installation requirements for transformers of all types. Oil-insulated transformers installed indoors must be installed in a vault of fire resistant construction if the total capacity exceeds 75 kVA.

Where a vault is required , adequate ventilation and drainage facilities are necessary to prevent overheating of the transformer and to drain away, to a safe place, any oil that may be released or expelled.

The cost of a vault may be eliminated, and a saving in space effected, by substituting dry type transformers in place of the oil insulated type. Dry-type sealed-tank nitrogen-filled transformers are considered fire and explosion resistant and need no special safeguards from this standpoint.

Where oil-insulated transformers are installed outdoors they should be located at least 8 meters away from combustible buildings or structures. They should not be located under important bridges, conveyors, tanks or similar structures where heat from a fire in the transformer may cause collapse of or serious damage to the structure. Facilities such as crushed stone-filled basins or drained concrete basins should be provided under the transformers to drain away and oil that may be expelled from them in time of trouble. Where a fire in one outdoor oil-insulated transformer is likely to involve other transformers in the same bank, a non-combustible barrier or wall is sometimes provided between adjacent transformers to confine the fire to the unit in which it started.

Permanently piped fire extinguishing $Co_2$ systems shall also be installed over large oil-insulated transformers or other oil-insulated apparatus where the value or importance of the apparatus and nearby equipment justifies this expense. These systems may be arranged to discharge either manually or automatically. One system employs water spray nozzles connected to a reliable and strong water supply.

The grouping together of a number of valuable or important cables or wires in trenches, cable boxes, junction boxes and manholes should be avoided, particularly if they have combustible insulation. This applies to both low, medium, and high-voltage installations, and lead sheathed cables as well. A failure in one cable or conductor can cause an arc that ignites the insulation on one cable and fire may destroy the entire group, or the arc can do extensive damage in the event of sustained arcing. Where it is necessary to group such cables together, they should be protected with a fireproof covering. The control circuits in power houses and substations should be arranged so that they will not be exposed to damage by arcing or fire. When possible, these wires should have asbestos or similar fire-resistive coverings.

An adequate supply of fire extinguishers should be provided on the premises, particularly in the vicinity of large quantities of electric apparatus. Extinguishers suitable for use on live electric apparatus are the vaporizing liquid, carbon dioxide, and dry chemical types.

Where insulating oil or compound is present in large quantities in power houses, substations, and motor rooms where there are many large motors present.

**Note:**

**For further information on fire protection see the following Standards:**

| | |
|---|---|
| **IPS-E-SF-260** | **Automatic detectors and fire alarm system** |
| **IPS-G-SF-126** | **Hand and wheel type fire extinguishers** |
| **IPS-E-SF-160** | **$Co_2$ gas fire extinguishing system** |

## 25. SPECIAL STUDIES

### 25.1 Load Flow Analysis

The objective of load flow analysis is to check voltage profile and circuit loading conditions under steady state conditions. Systematic routine solution of load flow problems are outlined as follows:

1) Mesh current method and connection matrices.
2) Nodal voltage method and connection matrices.
3) Application of nodal voltage method to the solution of power system load flow problem.
4) Direct methods involving inversion of the nodal admittance matrix.
5) Modification of the inverse of the nodal admittance metric.
6) Iterative methods
7) Tearing

**Note:**

**For detail information refer to:**
**Second edition of:**
**Electrical power system volume 2**
**By: A.E Guile University of Leeds England**
**W. Paterson Leeds Polytechnic England**

### 25.2 Short Circuit Studies

Refer to clause 12 under title power system fault consideration.

## 25.3 Stability Study of System

A synchronous power system has steady state stability if after a small slow disturbance it can regain and maintain synchronous speed; a small slow disturbance is taken to mean normal load fluctuation, including the action of automatic voltage regulators and turbine governors. A power system has transient stability if, after a large sudden disturbance it can regain and maintain synchronous speed: a large sudden disturbance is one caused by faults and switching. In order to develop the main principles simply it is assumed that the automatic voltage regulations and turbine governors are too slow to act during the period of the analysis. Dynamic stability refers to the case of transient stability where the regulations and governors are fast acting and are taken into account in the analysis.

The stability limit of the system is the maximum (Steady state) power which can be transformed through the system without loss of stability. The limits depends also on the magnitude, type and location of the disturbance. The stability factor is the ratio of the stability limit to the actual load-power transfer it can be shown that all the machines in a power exporting area can be reduced to an equivalent generator "G" and similarly that all the machines in a power importing area can be reduced to an equivalent synchronous motor 'M' the distribution or transmission system which connects these two areas is called interconnection (or tie line) the above two machine system can be reduced to one machine connected to an infinite busbar a constant voltage and constant frequency system.

Generally resistance will be neglected, relative to the inductive reactance of the system.

To analyze the transient and dynamic performance of power systems after large load changes and fault disturbances. These should be used to check:

a) The ability of the system to stay in synchronizm.
b) Induction motor stability after start.
c) Re-acceleration and re-start schemes.
d) The need and effectiveness of under frequency load shedding schemes.

They should also be used to consider the technical merit of:

e) Auto changeover schemes.
f) Parallel or open operation, or radial feeders.
g) Operation of fault limiting devices.
h) Insertion of switched reactors or capacitors, etc.

**Notes:**

**1) For load flow study,**
**2) Short circuit study,**
**3) Dynamic Stability**

**Reference can be made to:**

**Electrical transient analyzer program computer user guide:**

**Electrical transient analyzer**
**Computer user guide**
**Operation Technology Inc.**
**17870 Skypark circle suit 102 Irvine California 92714.**
**Fax: (714) 476-8814**
**Telephone (714 476-8117)**

# PART 2
# ELECTRICAL SYSTEM DESIGN
# NON-INDUSTRIAL

## CONTENTS :

PAGE No.

# 1. ELECTRICITY IN RESIDENTIAL AREAS

## 1.1 Introduction

Electricity makes a major contribution to living standards in every home by providing heating and motive power. Over the past decade the household applications of electricity have increased considerably and, as a result, the need for fully adequate and well planned electrical installations in homes is greater than ever before. Moreover, there are many homes in which the electrical installation is inadequate to meet the demand made upon it and, in many instances, modernization is urgently needed to handle the increases in electrical usage, however we have to economize in consumption of electrical energy.

## 1.2 Electrical Appliances in the Home

### 1.2.1 General

Electrical designer shall consider the electrical and electronic appliances deemed necessary for the housing under study.

The appliances shall be of recognized standard.

**1.2.2** Electric designer shall consider all necessary electrical appliances which may be used in kitchen and provide suitable electric outlet, for them, where gas supply is available installation of electrical cooker shall be avoided.

During the design, electrical points for ventilators shall not be over looked.

### 1.2.3 Living room

Adequate number of socket outlets for the television, video recorder and audio systems in addition to those needed including, table lamps shall be considered.

### 1.2.4 Bedroom

Again, adequate socket outlets are necessary for electric radio, bedside lights, and possibly a television.

### 1.2.5 Bathroom

The use of appliances in the bathroom is limited to an electric shaver. These must be operated through a special shaver socket outlet in which transformer is incorporated to isolate the socket from the mains supply. This eliminates the possibility of shock. Other socket outlets shall not be provided in the bathroom. In design of bathroom the installation of ventilation shall not be overlooked.

### 1.2.6 Garage and garden

Lighting and sockets shall be provided for garages and gardens socket for gardens shall be weatherproof under protected locations.

## 1.3 Lighting

Lighting in the home is used for two purposes ; for seeing and for effect. For visual tasks it is essential that the lighting is sufficient to prevent eye strain. Lighting for effect is decorative and is used to add interest to the home and enhance the appearance of the furnishings and decor. In winter-time, lighting provides the bonus of additional warmth because the energy used for lighting is released as heat.

Most home lighting needs are met by filament lamps of 40, 60, 100 and 150 W which have a working life of about 1000 hours.

Filament lamps include pearl lamps, which have a frosted finish inside the glass, and gives a softer light and suits most fittings. Mushroom lamps are more compact, and clear lamps are especially suited to glass fittings where they help give extra reflective sparkle.

Fluorescent lighting can be used for seeing or for decorative lighting. Fluorescent lamps, which give about four times the amount of light given by a filament bulb of the same wattage, are therefore more economical in use. Fluorescent lamps are also available in U shapes and circles.

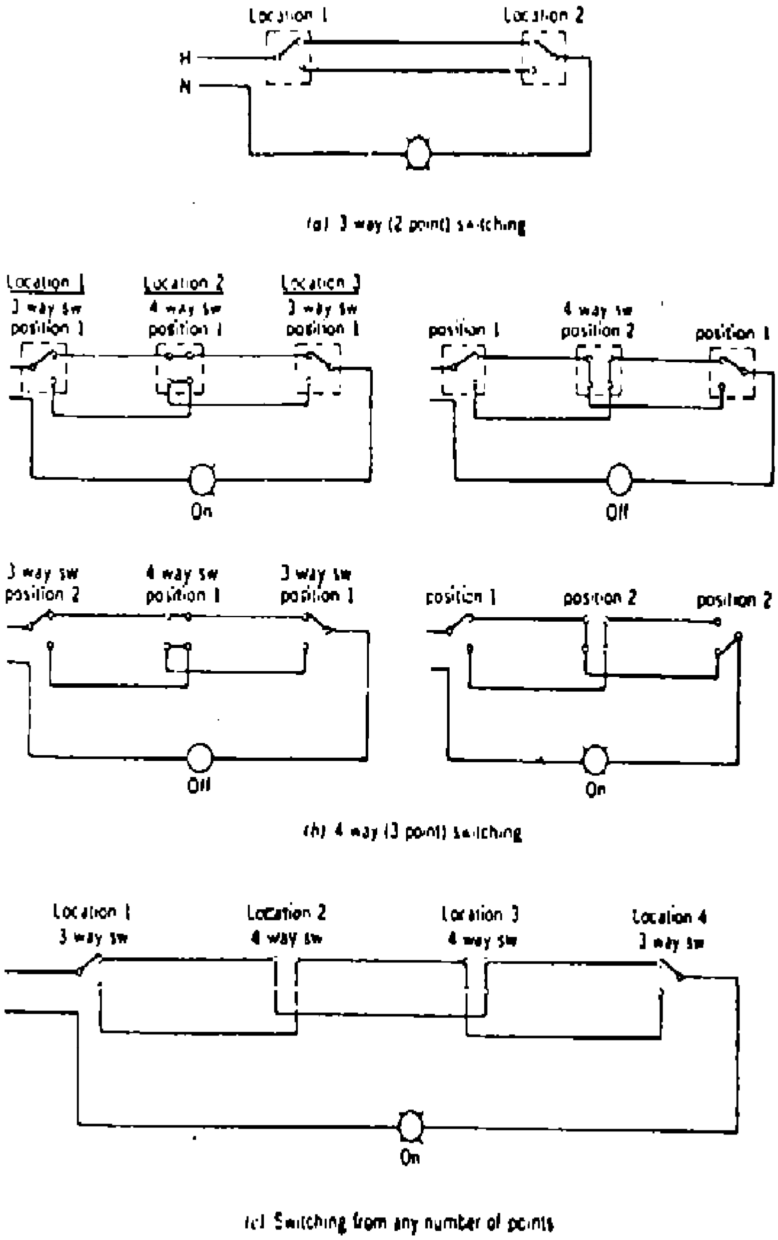
Complete fluorescent fitting can be used in many situations. Practical tube sizes range from miniature tubes 150 mm long up to 2400 mm.

As well as general lighting, focal decorative lighting may also be needed for effect. There are various designs of lighting fittings available, and wall and ceiling fittings are generally used in conjunction, together with free-standing table lamps or "spot lamps". Lighting control is normally by on/off switch , but dimmer and time control switches are available , assisting in both security and economy measures.

Exterior lighting is effective for security purposes, and may also be used to high light particular features of the home or garden.

From the safety angle good lighting is vital to illuminate steps and other obstacles.

For typical multiple point switching of lighting system see Fig. 1 and for level of illumination at home see Table 1.




**a)** Shows control from two points , using 3- way switches.

**b)** Switching from three locations, using a 4 way switch in addition to the two 3-way switches of (a) above.

Note that complete control is accomplished from each location.

**c)** Switching from any number locations can be done by adding 4-way switches at each new location. Illustration is switching from 4 locations.

**MULTIPLE POINT SWITCHING**
**Fig. 1**

**TABLE 1 - LEVEL OF ILLUMINATION AT HOMES**

| AREA OF ACTIVITY | SERVICE ILLUMINANCE LUX |
|---|---|
| Bedrooms:<br>General<br>Bedhead | <br>50<br>200 |
| Bathrooms:<br>General<br>Shaving and make up | <br>100<br>500 |
| Living rooms:<br>General<br>Reading and sewing | <br>100<br>500 |
| Stair | 100 |
| Kitchen:<br>General<br>Working areas<br>Workroom<br>Nursery | <br>300<br>500<br>300<br>150 |
| Outdoor<br>Entrance exit | <br>30 |

## 1.4 Ventilation

Although thermal insulation is important there is still a need for adequate ventilation. Air change is essential in achieving a required comfort level. It also reduces condensation to a minimum. Levels of ventilation have to comply with Building Regulations, and are at present concerned with the window opening areas in relation to the floor area.

Houses and flats are often provided with internal bathrooms, and toilets. These need adequate ventilation which can be achieved by a ducted fan. These are delay switch controlled, and operate when the light is switched on, stopping approximately ten minutes after the light is switched off.

## 1.5 Heating

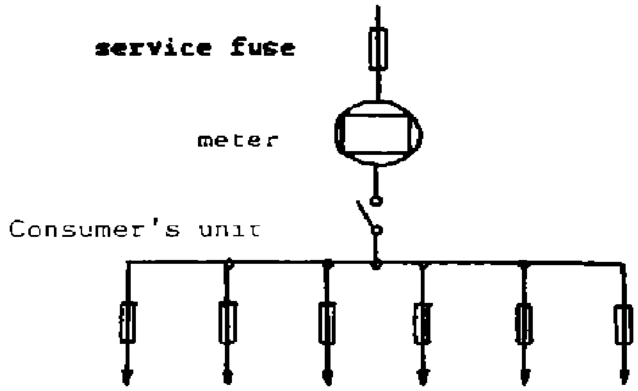
For heating of housing refer to standard IPS-E-AR-100.

## 1.6 Communications and Security

Provision should be made in the early stages of design for the installation of communications and security. These would include door bells, TV aerial points , telephone wiring, entry phones, intruder detector alarms, smoke detector and fire alarms.

## 1.7 General Consideration in Design

The supply enters the house at the service entry point , then passes through the house service cut-out which contains the main fuse and meter. In new properties these may be situated in special boxes on the exterior of the house, while in flats they may be communally sited for ease of reading by the Electricity Company staff. The distribution of electricity to all circuits in a house is controlled by a consumer's unit (Fig. 2), incorporating a main switch to isolate the supply. Each circuit inside the house, is connected to its own terminal, with a fuse or preferably miniature circuit breaker matched in rating to the circuit it protects.




**TYPICAL ARRANGEMENTS FOR FEEDING FINAL CIRCUITS IN A DOMESTIC SITUATION**
**Fig. 2**

Consideration should be given at the earliest stage to the prospective short circuit current at the origin of the installation. This is, in practical terms, the current which would flow if a short circuit occurred in the consumer’s main switch. The level and duration of this current is dependent upon the electricity network and fuse characteristics and therefore again , close liaison is necessary. The designer needs to satisfy himself that the main switch or consumer’s unit he propose to use will withstand the worst short circuit condition that could be imposed upon it and must therefore relate the data provided by the power authority with the manufacturer’s data.

In the event of a fault occurring in an installation, whether in an appliance or part of the wiring, it is essential that the faulty section be disconnected from the supply immediately, although the remainder of the system should remain in operation. This can be achieved by an adequate system of fuses or miniature circuit breakers, and by the provision of earthing.

### 1.7.1 Circuits for domestic installations

In selecting his consumer’s unit the designer should consider:

**a)** The adequacy of the main switch for the maximum demand of the installation.
**b)** The number of circuits required to be connected to it and their respective loadings.
**c)** The benefits to his installation and to the ultimate user of miniature circuit breakers rather than fuses.
**d)** The added safety provided by one or more residual current devices.
**e)** The desirability of providing at least one spare way for future needs.

The designer shall decide on rating of main switches.

The decision regarding the number of circuits is to some extent subjective but the following represents a typical selection:

**a)** Lighting circuit, ground floor.

**b)** Lighting circuit, first floor (although the total prospective load could be contained by one 5 A circuit, the consequences of a circuit failure plunging the whole dwelling into darkness should persuade the designer to use two circuits).

***c)** Immersion heater(s)(which must be on separate circuits, not connected to a ring main).

**d)** Kitchen/laundry area socket outlets.

**e)** Socket outlets ground floor.

**f)** Socket outlets-first floor. (where applicable)

***g)** Cooker circuit(s).

***h)** Electric shower unit.

***Note:**

**In rare cases.**

### 1.7.2 Domestic socket outlet circuits

The principle of the ring circuit recognizes that the total load in a given area is not likely to exceed 30 A, but that the location of small loads within that total is likely to be variable.

A domestic ring circuit may serve any number of socket within a floor area of 100 m². However consideration of the probable growth of electricity usage in future years makes the use of two or three ring circuits (ground floor, first floor and kitchen) highly desirable.

Table 2 gives, the number of socket outlets recommended in the new housing sphere, and the desirable minimum indicated by a reasonable consideration of the growth in ownership of appliances over the next few years.

Not only must the number and distribution of socket outlets provide for the appliances the householder may own, it must also provide for the fact that the positioning of furniture and the utilization of appliances varies from family to family with time. Flexible cords between sockets and appliance must always be as short as possible and never longer than 1.5-2 meters, from which it follows that a dual socket should be available within 1.5 meters of every point in a room at which a future occupier may wish to utilize an appliance or portable luminaire. Only the proposition of outlets to, at least, the level in Table 2 approaches this Standard.

It is not necessary for every socket outlet to be connected into a ring circuit.

Often it is not fully appreciated that an adequate number of socket outlets must be provided if an installation is to be safe under all conditions. Apart from the convenience of being able to use appliance in any required position, a reasonable number of socket outlets will eliminate lengths of trailing flex and other dangers.

**TABLE 2 - RECOMMENDED MINIMUM PROVISION OF SOCKET OUTLETS IN DOMESTIC PREMISES**

| PART OF THE HOME | RECOMMENDED NUMBER OF SOCKETS |
|---|---|
| Working kitchen | 4 - 8 |
| Dining room areas | 2 - 4 |
| Living rooms | 5 - 8 |
| Each other double bedroom | 2 - 4 |
| Each single bedroom | 2 - 3 |
| Hall or landing | 2 - 3 |
| Storage or garage | 1 - 2 |
| Total for typical 3 bed house | 18 - 32 |

### 1.7.3 Special precautions in bathrooms

Socket outlets are not permitted in bathrooms nor within 2.5 meters of a shower cubicle or bath in a bedroom. This is because the consequences of a shock when the person is wet, has bare feet or is in contact with earthed metal are far more likely to prove fatal than if the same shock were sustained elsewhere. For the same reason, lamp holders within 2.5 meters of a bath must be shrouded or totally enclosed and no fixed wall switches or heaters may be installed within reach of a person using a bath or shower. Pull cord switches are permissible and are indeed the preferred way of meeting the switching requirements of a bathroom.

### 1.7.4 Sockets for outdoor installations

Weatherproof socket outlets according to demand shall be provided outdoor where deemed necessary.

### 1.7.5 Bonding and earthing

Where PVC conduit is used for wiring, earthwire shall be accompanied throughout the conduit and bonded where necessary.

## 2. ELECTRICITY IN NON-RESIDENTIAL BUILDINGS

### 2.1 Supply and Distribution Considerations

In this section consideration is given to some of the special features and requirements of the installations in stores, office and leisure premises and other nondomestic medium sized installations.

While single phase 100 A services are adequate for the smaller shop or office unit, premises with a prospective maximum demand in excess of about 25 kW will be provided with a three phase 230/400 volt supply.

The service cable will be terminated in a cut-out located in agreement with the Electricity Authority where applicable. This should preferably be in a separate room away from stored materials, work areas etc., with adequate wall space for the meters, and the consumer's switchgear, together with access space for maintenance and alterations later. The switchboard will consist of a main fuse-switch or circuit breaker adequate in capacity for the installation, a busbar chamber and a number of circuit switch-fuses or circuit breakers which will in turn supply distribution. It is usually more economic to locate distribution boards as near as possible to the centers of the electrical load. Thus a building on three floors would have a distribution board on each floor fed by sub-main cables from the main switchboard.

Unless three-phase motors or other three-phase equipment are to be installed, the three phases of the supply should be segregated within the building. The lighting and all power circuits in any one area should be connected to the same phase so that the risk of 400 volt appearing between two adjacent outlets or pieces of equipment is minimized. Where, for good practical reasons, this separation cannot be achieved warning notices are required wherever two items of equipment connected to different phases are simultaneously accessible.

### 2.2 Circuits for Power-Using Equipment

The growth in the use of telecommunications equipment, office machinery and data transmission equipment means that almost every desk and work station may need access to such facilities. The trend away from small offices towards large flexible open-plan areas which can be replanned to suit changing needs makes the provision of such facilities somewhat more difficult. However, the recognition of these requirements at the design stage open the way to the installation of a network of floor trunking which, if laid in a 2 meter matrix, provides the flexibility the user will require in the future without the risks which follow the use of long trailing flexes. Floor and skirting trunking systems are available with two or three compartments so that circuits supplying socket outlets, telephones and data processing equipment can be carried along the same route. A wide variety of floor trunking systems are available which are adjustable to match the finished floor level and carpet or other floor finishes can be applied to them to render them without being obstructed.

General purpose power circuits in commercial premises will usually be wired on the ring circuit principle, an unlimited number of outlets within a 100 m² area being connected to a 30 A fuse or circuit breaker. However, this practice to connect sockets to a single ring should be exercised with care. The installation designer must be satisfied that the prospective demand on that circuit will not exceed the 30 A rating of the circuit protection.

## 3. LOAD INCREASE IN EXISTING SUPPLY SYSTEMS

In existing systems load increase can occur, e.g. due to extensions and modernization of dwellings or commercial premises.

The expected load is calculated using an annual rate of increase based on the present load and preceding development. Depending on the type of building development in the area of supply and the probable in filling of vacant spaces, growth rates of between 2 to 10% per year can arise.

Furthermore, without a general load increase due to alterations or change of consumers, local deviations of the load must be expected requiring a suitable extension to the system.

In order to fully estimate the future load ,it is necessary to study building plans and area utilization plans of the relevant area.

## 4. SUPPLY SYSTEMS IN BUILDINGS

For the estimation of loads for large building complexes the physical arrangement (vertical or horizontal) of the individual consumers and from this the distribution of load center within the building must be taken into consideration. Apart from consumer equipments spread across an area, e.g. light fittings and small appliances, mostly also concentrated loads (lifts, air conditioning equipment, or large kitchens) must be supplied.

For the consumer devices over area, often specific values per unit area (Watts/m²) are used. In the following some typical values are given which in real applications need to be verified because of the specific building or consumer situation:

| | |
|---|---|
| Lighting | 10 to 25 W/m² |
| air conditioning | 1 to 3 kW/equipment |
| office buildings | 100 W/m² |
| lifts | 10 to 50 kVA/lift |

In as much as installed power is indicated, the real load consumer values need to be estimated using diversity factors.

## 5. TOTAL LOAD

To plan the incoming supply of the system under consideration from a higher level of voltage or from a power station requires knowledge of the total load to be expected. The time related differing load peaks of individual system parts are taken into account when determining the total power requirements, it is necessary to take care of current demand and diversity factor explained in Tables 2 and 3 underheading of Maximum Demand and Diversity.

It is recommended that the estimated load values are compared with measured real values from time to time and deviations considered when planning extensions to the systems. This is of particular importance for long term development of public utility distribution systems.

## TABLE 3 - CURRENT DEMAND TO BE ASSUMED FOR POINTS OF UTILIZATION AND CURRENT-USING EQUIPMENT

| Point of utilization of current-using equipment | Current demand to be assumed |
|---|---|
| Socket-Outlets other than 2 A socket-outlets | Rated current |
| 2 A socket-outlets | At least 0.5 A |
| Lighting outlet | Current equivalent to the connected load, with a minimum of 100 W per outlet |
| Electric clock, electric shaver supply unit (complying with BS 3535), shaver socket-outlet (complying with BS 4573), bell transformer, and current-using equipment of a rating not greater than 5 VA | May be neglected |
| Household cooking appliance where applicable | The first 10 A of the rated current plus 30% of the remainder of the rated current plus 5 A if a socket-outlet is incorporated in the control unit |
| All other stationary equipment | Rated current, or normal current |

## TABLE 4 - ALLOWANCES FOR DIVERSITY

| PURPOSE OF FINAL CIRCUIT FED FROM CONDUCTORS OR SWITCHGEAR TO WHICH DIVERSITY APPLIES | TYPE OF PREMISES | | |
|---|---|---|---|
| | Individual household installations including individual dwellings of a block | Small shops, stores, offices and business premises | Small hotels, boarding houses, guest houses, etc. |
| 1. Lighting | 66% of total current demand | 90% of total current demand | 75% of total current demand |
| 2. Heating and power (but see 3 to 7 below) | 100% of total current demand up to 10 amperes +50% of any current demand in excess of 10 amperes | 100% f.l. of largest appliance +75% f.l. of remaining appliances | 100% f.l. of largest appliance +80% f.l. of 2nd largest appliance +60% f.l. of remaining appliance |
| 3. Cooking appliances where applicable | 10 amperes +30% f.l. of connected cooking appliances in excess of 10 amperes +5 amperes if socket-outlet incorporated in control unit | 100% f.l. of largest appliance +80% f.l. of 2nd largest appliance +60% f.l. of remaining appliance | 100% f.l. of largest appliance +80% f.l. of 2nd largest appliance +60% f.l. of remaining appliance |
| 4. Motors (other than lift motors which are subject to special consideration) | | 100% f.l. of largest motor +80% f.l. of 2nd largest motor +60% f.l. of remaining motors | 100% f.l. of largest motor +5% f.l. of remaining motor |
| 5. Water-heaters (thermostatiscally controlled) | Where applicable | No diversity allowable | |
| 6. Standard arrangement of final circuits | 100% of current demand of largest current +40% of current demand of every other circuit | 100% of current demand of largest circuit +50% of current demand of every other circuit | |
| 7. Socket-outlets other than those included in 6 above and stationary equipment other than those listed above | 100% of current demand of largest point of utilization +40% of current demand of every other point of utilization | 100% of current demand of largest point of utilization +75% of current demand of every other point of utilization | 100% of current demand of largest point of utilization +75% of current demand of every other point in main rooms (dining rooms, etc.) +40% of current demand of every other point of utilization |

**Note:**

♣ **It is important to ensure that the distribution boards etc. are of sufficient rating to take the total load connected to them without the application of any diversity.**

## 6. SYSTEM STANDBY SUPPLY PLANT

In supply systems for large buildings because of operational or economic reasons, a very high reliability of supply is required. Therefore standby power supplies are installed (diesel generators, static converters with battery back-up). Depending on the power demand which must be met by this plant this may influence the choice for type of plant and system arrangement. For the estimation of the load this means separation of important consumers, which must be supplied in the event of main supply failure, from consumers of non-essential loads for which supply from the general system will suffice.

## 7. PLANNING OF DISTRIBUTION SYSTEMS

### 7.1 General

Simple system configuration , clearly arranged operation conditions and flexibility in respect of extensions of the distribution system must be objectives for the planning. Only careful planning provides the foundation to be able to supply electrical energy reliably and economically.

When extending existing systems, firstly an analysis of the actual capacity and operational reliability of the system is required. Load-flow and short-circuit calculations will emphasis weak points in the system and give an initial indication where improvements must be made. In this evaluation not only improvements based on minimum requirements for voltage stability, load capacity and short-circuit safety, but future demand must also be considered.

Also in new installations or extensions of supply systems the functional arrangement of systems is of particular importance. The selection of system configuration is dependent on the load and also structural make-up of the area or building to be supplied. Systems which have grown over a long period have not always the optimum configuration, especially where the load situation has changed in the meantime. The simplification of system configuration as a basic for the economical development and reliable operation is, next to the system calculation, an important part of the system planning (system architecture). This requires the creative selection of several alternative solutions. Numerous local conditions together with individual experience and planning philosophy thereby influence the decisions of the planning engineer.

Because of this set of examples which follow cannot claim to be complete but can provide suggested methods for planning work on real projects.

All evaluations must be conducted for several extension stages according to the time-related progression of the load prognosis and the effect of the various improvement measures at differing times on the total cost. The evaluation of the cost situation can be carried out by using various methods of cost calculation (annuity method, cash assets method).

Criteria of variants which cannot be expressed as costs, e.g. updating with prospective technologies, clearly arranged system configurations etc. can best be determined from efficiency analysis.

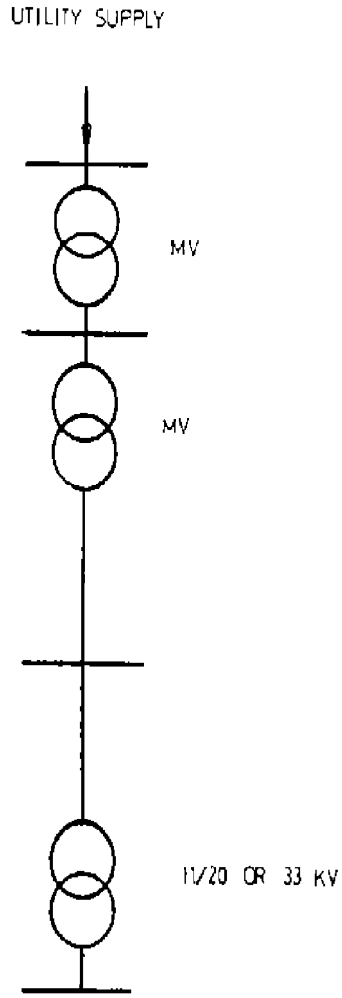
### 7.2 Selection of Distribution Voltage

In general the voltage levels of the low-voltage and medium-voltage systems are fixed for the utility supply authorities.

For the low-voltage system of the public supply, a uniform standard value of 230/400 Volt is recommended. Where a high proportion of load is in motors then in new installations 400 volt 3 phase is also employed.

The medium-voltage systems lying above the low-voltage systems must fulfill two main functions: It must be sufficiently powerful to transmit the high incoming power from the main substation (feeding from the high-voltage systems) and its component parts on the other hand transmit energy economically to numerous system substations and consumer stations. The optimum values for medium- voltage systems are the voltage levels of 11 and 20 kV or 33 kV as shown on Fig. 3 and are normally in use in oil industry.

In locations where there is a significant rising demand for power the selection of voltage levels in the medium-voltage systems forms a particularly important part of the network planning. Frequently because of the hitherto development, numerous voltage steps are found and because of several transformation steps additional costs for investment and losses are incurred. It must, however, be checked whether these voltages levels are adequate in the future for increasing demand or whether a higher voltage system should be used. In this aspect it must be assessed whether an existing intermediate voltage can be omitted partially or even completely or should be revised.




**LEVEL OF VOLTAGES**
**Fig. 3**

## 7.3 Low-Voltage Systems

### System Configuration and Types of Operation in the Public Supply

Whether an area is supplied via cables or overhead lines has to be decided in consideration of local conditions and the economics of these alternatives. In areas with low-load density an overhead line may be a cost effective solution. However, today also in rural areas load values are reached for which, together with an architectural point of view the establishment of a cable network or the changeover from overhead line to cable is economically justifiable.

Depending on load density and type of structural arrangement of buildings, differing system configurations result for the low-voltage cable system.

In a conventional low-voltage system of the public supply the cable runs (mains cable) follow the route of road. At road junctions the cables are joined in cable distribution cabinets (nodes). Substations should wherever possible feed into the load center and have a sufficient number of branches.

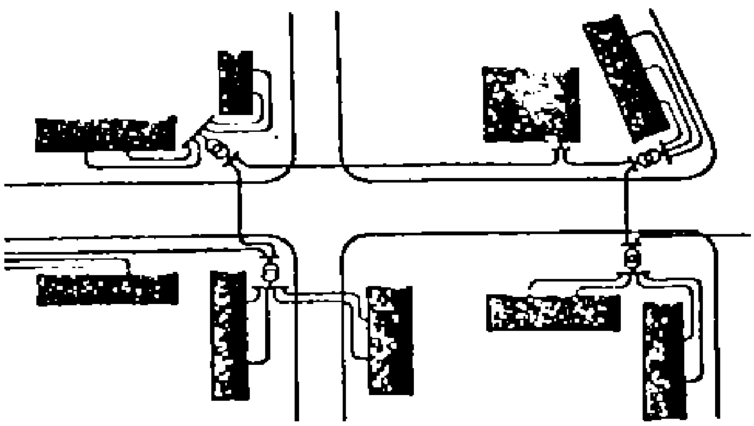
Dwellings are normally connected by means of a spur (service cable) from a branch or T-joint box or from a through-type joint box on the main supply cable. Service boxes have the advantage that no terminal points are required on the main cable. The through type joint boxes offer possibilities for changing connections in the event of a fault but also have disadvantages because of their numerous terminal points.

Whether cables in a road are installed on one side or both sides depend upon the width of the road, the specific cost of installation and on load density. Where buildings are openly spaced (great distances between houses, narrow roads) and hence low-load density, the installation of cable on one side of the road may suffice. In close spacing of houses and hence high-load density, installation of main cables on both sides is generally more favorable.

Low-voltage systems because of the simple and clearly operation are today mainly operated as radial systems. Each substation has its own area of supply. Changeover possibilities to other substation areas are mostly provided for in the distribution cabinets, which allow for full or part reserve in the rare event of a substation failure.

## 7.4 Extension of Low Voltage System

With increasing load density, the distance between substations is therefore reduced. The low-voltage system with high-load density becomes practically a pure connecting system (Fig. 4). The substations are operated without interlinking or possibility of reconnection. This type of system has advantages in very high-load density areas.



**LOW VOLTAGE CONNECTION NETWORK FOR A HOUSING ESTATE WITH HIGH-LOAD DENSITY**
**Fig. 4**

## 7.5 Selection of Transformers

Transformers used in substations of the public supply should have rated capacities from standard range. Since failures in transformers are very rare. It is sufficient to provide one transformer to each station only for heavy unit loads or very high load density e.g., industrial plant langer rated capacities are justified. Here also it may be necessary to consider as reserve a second or even several transformers.

### 7.6 Selection of Cables

In selection of cables the following parameters shall be fully considered:

**a)** Size of cable with an additional 25% in cross section.

**b)** Voltage drop with a maximum of %5.

**c)** Fault level at location of installation.

**d)** Cable grouping in accordance to schedule of methods of installation of cables (see Table 4A in Appendix 4 of IEE wiring Regulations 16th. Edition 1991).

**e)** Ambient temperature.

**f)** Test of voltage drop.

**g)** Test of short circuit.

## 8. HIGH RISE BUILDINGS

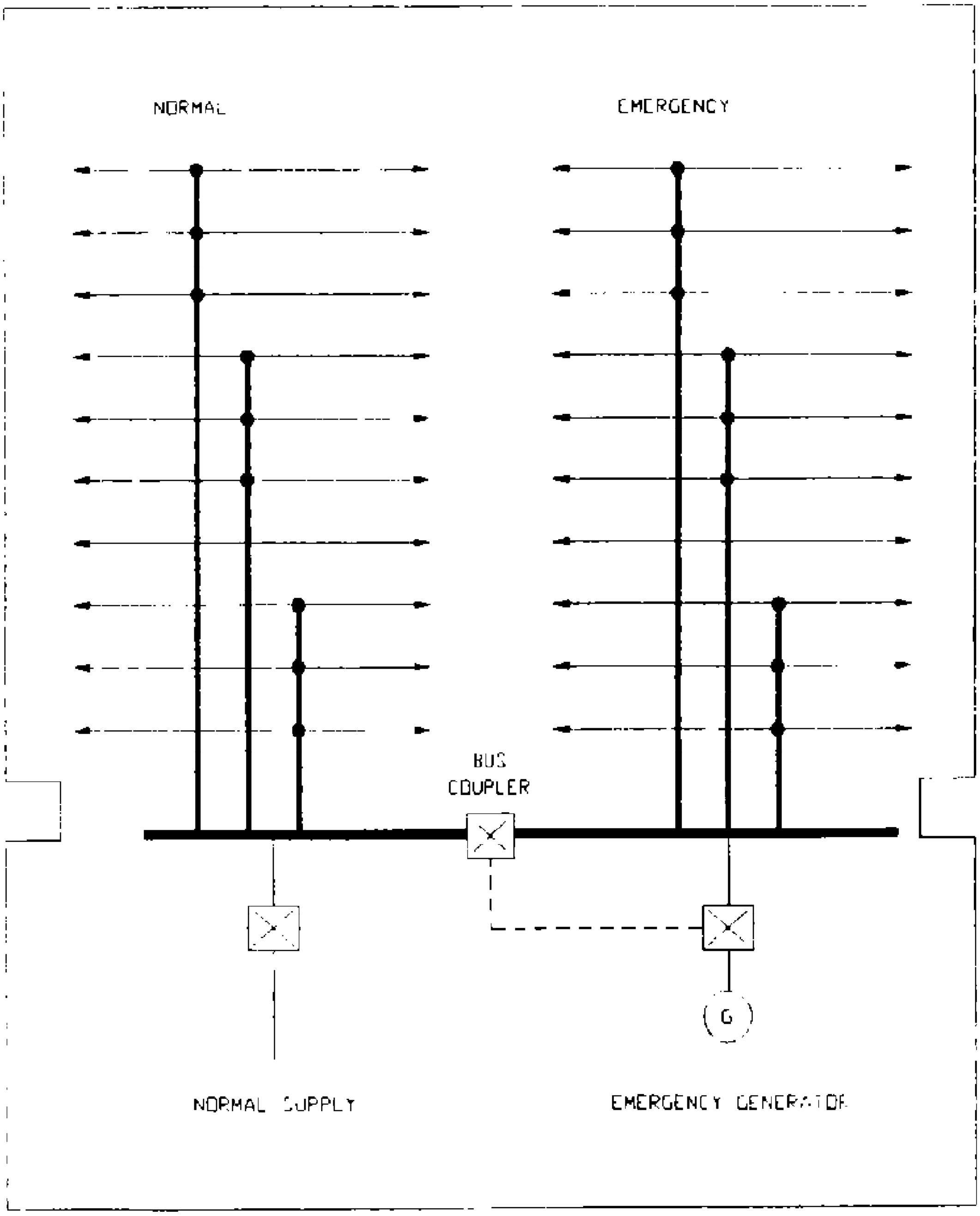
Power supply to different floors shall be via power cables. Alternatively bus trunking can be utilized upon approval.

If cables are used each floor shall be fed by one individual feeder.

Normal loads shall be supplied from normal supply bus and emergency load shall be supplied from emergency bus in normal conditions both buses are to be supplied from mains power supply, in case of mains power failure an emergency diesel generator shall be started via a suitable mains failure panel which opens the bus coupler and closes the emergency generator circuit breaker when frequency reaches 50 Hz on resumption of normal supply, Diesel engine shall stop and busbar coupler closed through properly designed interlocks see Fig. 5.

When requirement dictates power feeder shall be provided for:

**1)** Central cooling machinery
**2)** Ventilation
**3)** Smoke stack, fire pumps
**4)** Central power factor correction equipment
**5)** Lift(s)




**TYPICAL ELECTRICAL SYSTEM IN HIGH RISE BUILDING**
**Fig. 5**

# APPENDICES

## APPENDIX A
## ROTATING ELECTRIC MACHINES

## CONTENTS :

PAGE No.

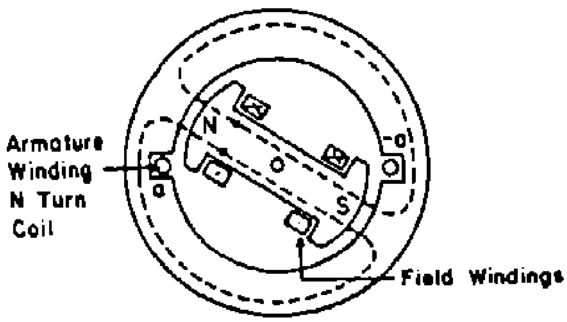
## 1. SYNCHRONOUS MACHINES

**1.1** The backbone of a utility system consists of a number of generating stations that are interconnected in a grid and operate in parallel. The largest single-unit electric machine for electric energy production is the synchronous machine. Generators with power ratings of several hundred to over a thousand megavolt-amperes (MVA) are fairly common in many utility systems. A synchronous machine provides a reliable and efficient means for energy conversion.

The operation of a synchronous generator is (like all other elctro-mechanical energy conversion devices) based on Faraday's law of electromagnetic induction. The term synchronous refers to the fact that this type of machine operates at speed proportional to the system frequency under normal conditions. Synchronous machines are capable of operating as motors, in which case the electric energy supplied at the armature terminals of the unit is converted into mechanical form. Another important function of this versatile machine is as a synchronous condenser where the unit is operated as a motor running without mechanical load and supplying or absorbing reactive power.

The term armature in rotating machinery refers to the machine part in which an alternating voltage is generated as a result of relative motion with respect to a magnetic flux field. In a synchronous machine, the armature winding is on the stator and the field winding is on the rotor, as shown in Fig. A1. The field is excited by direct current that is conducted through carbon brushes bearing on slip (or collector) rings. The d.c. source is called the exciter and is often mounted on the same shaft as the synchronous machine. Various excitation systems with a.c. exciters and solid-state rectifiers are used with large turbine generators. The main advantages of these systems include the elimination of cooling and maintenance problems associated with slip rings, commutators, and brushes. The pole faces are shaped such that the radial distribution of the air-gap flux density B is approximately sinusoidal.

The armature winding includes many coils. One coil is shown in Fig. A1 and has two coil sides (a and -a) placed in diametrically opposite slots on the inner periphery of the stator with conductors parallel to the shaft of the machine. The rotor is turned at a constant speed by a mechanical power source connected to its shaft. As a result, the flux wave-form sweeps by the coil sides a and -a. The induced voltage in the coil is a sinusoidal time function. It is evident that for each revolution of the two poles, the coil voltage passes through a complete cycle of values. The frequency of the voltage in cycles per second (Hertz) is the same as the rotor speed in revolutions per second. Thus a two-pole synchronous machine must revolve at 3000 r/min to produce a 50-Hz voltage, common in Iran. In systems requiring 60-Hz voltage, the two-pole machine runs at 3600 r/min.




**SIMPLIFIED SKETCH OF A SYNCHRONOUS MACHINE**
**Fig. A1**

### 1.1.1 P-pole machines

Many synchronous machines have more than two poles. A P-pole machines satisfies the following relation:

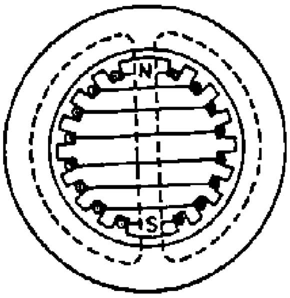
$$f = \frac{P_n}{120} \qquad \textbf{(Eq. 1)}$$

The frequency f is proportional to the speed in revolutions per minute. Note that P is the number of poles of the machine.

### 1.2 Cylindrical Versus Salient-pole Construction

Machines like the ones illustrated in Fig. A1 have rotors with salient poles. There is another type of rotor, which is shown in Fig. A2. The machine with such a rotor is called a cylindrical rotor or nonsalient-pole machine. The choice between the two designs (salient or nonsalient) for a specific application depends on the proposed prime mover. For hydroelectric generation, a salient-pole construction is employed. This is because hydraulic turbines run at relatively low speeds, and in this case, a large number of poles are required to produce the desired frequency, as indicated by Eq. 1.

On the other hand, steam and gas turbines perform better at relatively high speeds, and two or four-pole cylindrical rotor turbo-alternators are used in this case. This will avoid the use of protruding parts on the rotor, which at high speeds will give rise to dangerous mechanical stresses.




**CYLINDRICAL ROTOR TWO-POLE MACHINE**
**Fig. A2**

## 2. INDUCTION MOTORS

An induction machine is one in which alternating currents are supplied directly to stator windings and by transformer action (induction) to the rotor. The flow of power from stator to rotor is associated with a change of frequency, with an output being mechanical power transmitted to the load connected to the motor shaft. The induction motor is the most widely used motor in industrial and commercial utilization of electric energy. Reasons for the popularity of induction motors include simplicity, reliability, and low cost, combined with reasonable overload capacity, minimal service requirements, and good efficiency. The rotor of an induction motor may be one of two types. In the wound-rotor motor, distributed windings are employed with terminals connected to insulated slip rings mounted on the motor shaft. The second type is called the squirrel-cage rotor, where the windings are simply conducting bars embedded in the rotor and short-circuited at each end by conducting end rings. The rotor terminals are thus inaccessible in squirrel-cage construction, whereas the rotor terminals are made available through carbon brushes bearing on the slip rings for the wound-rotor construction.

The stator of a three-phase induction motor carries three sets of windings that are displaced by 120° in space to constitute a three-phase winding set.

The application of a three-phase voltage to the stator winding results in the appearance of a rotating magnetic field.

Three methods of motor starting is commonly:

**1)** Direct on line starting.
**2)** Star delta starting.
**3)** Auto-Transformer starting (Preferably Korndorffer Type).

Tables A1 and A2 are typical examples of low voltage and medium voltage induction motors with conventional rating and characteristics.

## TABLE A1 - LOW VOLTAGE MOTORS IEC STANDARD WITH CONVENTIONAL RATINGS AND CHARACTERISTICS

| Rated Output kW Air Temperature | | Starting Current = Times F.L. Current | η | | | cos ρ | | | |
|---|---|---|---|---|---|---|---|---|---|
| 40°C | | | 4/4 | 3/4 | 2/4 | 4/4 | 3/4 | 2/4 | Starting |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| ≤ 1.1 | | 4.7 | 0.73 | 0.73 | 0.70 | 0.81 | 0.75 | 0.65 | 0.70 |
| 1.5 | | 5 | 0.77 | 0.77 | 0.74 | 0.79 | 0.74 | 0.63 | 0.70 |
| 2.2 | | 5.2 | 0.78 | 0.78 | 0.75 | 0.81 | 0.75 | 0.65 | 0.63 |
| 3 | | 6 | 0.80 | 0.80 | 0.79 | 0.82 | 0.76 | 0.66 | 0.62 |
| 4 | | 6.3 | 0.83 | 0.83 | 0.82 | 0.82 | 0.77 | 0.67 | 0.62 |
| 5.5 | | 6.5 | 0.84 | 0.84 | 0.83 | 0.83 | 0.79 | 0.69 | 0.55 |
| 7.5 | | 6.5 | 0.85 | 0.85 | 0.84 | 0.85 | 0.81 | 0.73 | 0.55 |
| 9 | | 6.5 | 0.88 | 0.88 | 0.87 | 0.83 | 0.79 | 0.69 | 0.50 |
| 11 | | 6.5 | 0.88 | 0.88 | 0.87 | 0.83 | 0.79 | 0.69 | 0.50 |
| 15 | | 7 | 0.88 | 0.88 | 0.87 | 0.83 | 0.79 | 0.69 | 0.50 |
| 18.5 | | 7.2 | 0.90 | 0.90 | 0.89 | 0.83 | 0.79 | 0.69 | 0.45 |
| 22 | | 7.2 | 0.90 | 0.90 | 0.89 | 0.84 | 0.79 | 0.69 | 0.45 |
| 30 | | 7.5 | 0.91 | 0.91 | 0.90 | 0.85 | 0.80 | 0.70 | 0.40 |
| 37 | | 7 | 0.91 | 0.91 | 0.90 | 0.86 | 0.82 | 0.74 | 0.40 |
| 45 | | 7 | 0.92 | 0.92 | 0.91 | 0.86 | 0.82 | 0.74 | 0.40 |
| 55 | | 7 | 0.925 | 0.92 | 0.91 | 0.86 | 0.82 | 0.74 | 0.40 |
| 75 | | 7 | 0.935 | 0.93 | 0.92 | 0.86 | 0.83 | 0.75 | 0.38 |
| 90 | | 7 | 0.935 | 0.93 | 0.92 | 0.86 | 0.83 | 0.75 | 0.38 |
| 110 | | 7.5 | 0.935 | 0.93 | 0.92 | 0.86 | 0.83 | 0.75 | 0.37 |
| 132 | | 7.5 | 0.94 | 0.935 | 0.92 | 0.87 | 0.84 | 0.76 | 0.36 |
| 160 | | 7.5 | 0.94 | 0.935 | 0.92 | 0.87 | 0.84 | 0.77 | 0.35 |
| 200 | | 7.5 | 0.94 | 0.935 | 0.92 | 0.88 | 0.85 | 0.78 | 0.30 |
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**TABLE A2 - MEDIUM VOLTAGE MOTORS IEC STANDARD WITH CONVENTIONAL RATINGS AND CHARACTERISTICS**

| Rated Output kW Air Temperature | | Starting Current = Times F.L. Current | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | η | | | cos φ | | | |
| 40°C | 50°C | | 4/4 | 3/4 | 2/4 | 4/4 | 3/4 | 2/4 | Starting |
| 185 | 166 | 6 | 0.93 | 0.928 | 0.915 | 0.865 | 0.82 | 0.74 | 0.20 |
| 200 | 180 | 6 | 0.93 | 0.928 | 0.915 | 0.865 | 0.82 | 0.74 | 0.20 |
| 220 | 198 | 6 | 0.93 | 0.928 | 0.915 | 0.865 | 0.82 | 0.74 | 0.20 |
| 250 | 225 | 6 | 0.93 | 0.928 | 0.915 | 0.865 | 0.82 | 0.74 | 0.20 |
| 280 | 252 | 6 | 0.93 | 0.928 | 0.915 | 0.865 | 0.82 | 0.74 | 0.20 |
| 300 | 270 | 6 | 0.93 | 0.928 | 0.915 | 0.865 | 0.82 | 0.74 | 0.20 |
| 315 | 283 | 6 | 0.94 | 0.94 | 0.925 | 0.865 | 0.825 | 0.75 | 0.18 |
| 335 | 301 | 6 | 0.94 | 0.94 | 0.925 | 0.875 | 0.825 | 0.75 | 0.18 |
| 355 | 320 | 6 | 0.94 | 0.94 | 0.925 | 0.875 | 0.84 | 0.755 | 0.18 |
| 375 | 337 | 6 | 0.94 | 0.94 | 0.925 | 0.875 | 0.84 | 0.755 | 0.18 |
| 400 | 360 | 6 | 0.94 | 0.94 | 0.925 | 0.875 | 0.84 | 0.755 | 0.18 |
| 425 | 382 | 6 | 0.94 | 0.94 | 0.925 | 0.875 | 0.84 | 0.755 | 0.18 |
| 450 | 405 | 6 | 0.94 | 0.94 | 0.925 | 0.875 | 0.84 | 0.755 | 0.18 |
| 475 | 427 | 6 | 0.94 | 0.94 | 0.925 | 0.875 | 0.84 | 0.755 | 0.18 |
| 500 | 450 | 6 | 0.94 | 0.94 | 0.925 | 0.875 | 0.84 | 0.755 | 0.18 |
| 530 | 477 | 6 | 0.94 | 0.94 | 0.925 | 0.875 | 0.84 | 0.755 | 0.18 |
| 560 | 504 | 6 | 0.94 | 0.94 | 0.925 | 0.875 | 0.84 | 0.755 | 0.18 |
| 600 | 540 | 6 | 0.94 | 0.94 | 0.925 | 0.875 | 0.84 | 0.755 | 0.18 |
| 630 | 567 | 6 | 0.94 | 0.94 | 0.925 | 0.885 | 0.86 | 0.77 | 0.18 |
| 670 | 603 | 6 | 0.95 | 0.945 | 0.93 | 0.885 | 0.86 | 0.77 | 0.16 |
| 710 | 639 | 6 | 0.95 | 0.945 | 0.93 | 0.885 | 0.86 | 0.77 | 0.16 |
| 750 | 675 | 6 | 0.95 | 0.945 | 0.93 | 0.885 | 0.86 | 0.77 | 0.16 |
| 800 | 720 | 6 | 0.95 | 0.945 | 0.93 | 0.885 | 0.86 | 0.77 | 0.16 |
| 850 | 765 | 6 | 0.95 | 0.945 | 0.93 | 0.885 | 0.86 | 0.77 | 0.15 |
| 900 | 810 | 6 | 0.96 | 0.955 | 0.94 | 0.895 | 0.87 | 0.78 | 0.15 |
| 950 | 855 | 6 | 0.96 | 0.955 | 0.94 | 0.895 | 0.87 | 0.78 | 0.15 |
| 1000 | 900 | 6 | 0.96 | 0.955 | 0.94 | 0.895 | 0.87 | 0.78 | 0.15 |
| 1120 | 1008 | 6 | 0.96 | 0.955 | 0.94 | 0.895 | 0.87 | 0.78 | 0.15 |
| 1250 | 1125 | 6 | 0.96 | 0.955 | 0.94 | 0.895 | 0.87 | 0.78 | 0.15 |
| 1400 | 1260 | 6 | 0.96 | 0.955 | 0.94 | 0.895 | 0.87 | 0.78 | 0.15 |
| 1600 | 1440 | 6 | 0.96 | 0.955 | 0.94 | 0.895 | 0.87 | 0.78 | 0.16 |
| 1800 | 1620 | 6 | 0.96 | 0.955 | 0.94 | 0.895 | 0.87 | 0.78 | 0.16 |
| 2000 | 1800 | 6 | 0.96 | 0.955 | 0.94 | 0.895 | 0.87 | 0.78 | 0.16 |

## 3. RATING OF ELECTRICAL ROTATING MACHINES

The rating of a rotating machine implies the service conditions and loading conditions at which the machine can operate indefinitely. In general, the rating of a machine is also associated with warranties by the manufacturer for a certain period of time, although such warranties should be always obtained in written form. Rotating machines are rated in terms of output capabilities, as are most other types of rotating machines. The principal parameters used in rating a machine are listed on the nameplate of the machine. These generally include:

1) Output (Kilovolt-amperes in a generator; horsepower in a motor).
2) Terminal voltage, line to line.
3) Frequency (in case of a.c.).
4) Speed.
5) Current.
6) Power factor (in case of a.c.).
7) Temperature rise at rated kilovolt-ampere (or horsepower) output.
8) Service conditions.

The rating of a machine on its nameplate is its continuous, or indefinite, rating. For short periods of time, most rotating electric machines can operate at load conditions far exceeding these continuous, or steady-state, ratings. Ratings for shorter time periods, such as 1 h down to 1 min. are generally available from the manufacturer.

## 4. DESIGN SPECIFICATIONS

The first step in the design of a rotating machine is to specify its performance characteristics, or output parameters. These are generally based upon the machine's steady-state characteristics. Most rotating machines are categorized by these steady-state ratings and most machine catalogs describe their products on the basis of these ratings, known as continuous ratings. However, many other characteristics may be of importance in a specific application, such as:

### 4.1 Economic Factors

1) Initial cost.
2) Weight.
3) Mounting considerations, base, couplings, etc.
4) Efficient:
   a) At rated load.
   b) Over a certain duty cycle.
   c) Maximum.
   d) At a specific load.
5) Volume or space limitations.
6) Maintenance considerations; warranty.

### 4.2 Environmental Factors

1) Ambient temperature of environment.
2) Vibration environment:
   a) Load-induced vibration in motors.
   b) Coupling to load or drive machine.
   c) Number of bearings (one or two).

3) Corrosive influences.
4) Type of housing required;

   a) Open.
   b) Splash-proof; drip proof.
   c) Totally enclosed or hermetically sealed.

5) Type and amount of cooling:

   a) Shaft-mounted fan.
   b) External blower.
   c) Liquid cooling.
   d) Forced hydrogen.

6) Connected system voltage levels and phases.
7) Impedance and other characteristics of connected electrical system.

   a) Permissible fault current into system.
   b) Relay and fault protection,

8) Required machine protection, electrical and mechanical

### 4.3 Excitation Characteristics

1) Excitation source:

   a) Physical configuration.
   b) Voltage and volt-ampere rating.
   c) Transient response.

2) Voltage regulation: definition of expected load.
3) Excitation protective circuitry.

### 4.4 Means of Starting or Bringing Up to Speed

The above listings are given to serve as a guide in the design of a rotating machine. The use of these ancillary specifications depends upon the particular application, and some are of more significance than others. However, in designing or even purchasing a machine for a given application, most of these factors should be considered in the initial stages of the design or purchase.

## 5. PROTECTION CONSIDERATION

### 5.1 Generators Faults

#### 1) Stator faults

Stator faults involve the main current carrying conductors and must therefore be cleared quickly from the power system by a complete shut-down of the generator. They may be faults to earth, between phases or between turns of a phase, singly or in combination. The great danger from all faults is the possibility of damage to the laminations of the laminations of the stator core and stator windings due to the heat generated at the point of fault. If the damage so caused is other than superficial, the stator would have to be dismantled, the damaged laminations and windings replaced and the stator rebuilt, all of which is a lengthy and costly process.

Limitation of generator stator earth-fault current by means of resistance earthing is normal practice and serves, among other things, to minimize core burning.

Phase-to-phase faults and interturn faults are both less common than earth faults. It is relatively easy to provide protection for phase-to-phase faults, but interturn faults are, on the other hand more difficult to detect and protection is not usually provided. Generally speaking, interturn faults quickly involve contact with earth via the stator core and are then tripped by stator earth-fault protection.

### 2) Rotor faults

Rotor faults may be either to earth or between turns and may be caused by the severe mechanical and thermal stresses acting upon the winding insulation; these are aggravated by a variable load cycle.

The field system is not normally connected to earth so that a single earth fault does not give rise to any fault current. However, a second fault to earth would short circuit part of the field winding and thereby produce an asymmetrical field system, and unbalanced forces on the rotor. Such forces will cause excess pressure on bearings and shaft distortion, if not quickly removed.

Under the general heading of rotor faults can be included loss of excitation. This may be caused by an open circuit in the main field winding or a failure elsewhere in the excitation system.

Loss of excitation in a generator connected to a large interconnected power system results in a loss of synchronism and slightly increased generator speed, since the power input to the machine is unchanged. The machine behaves as an induction generator drawing its exciting current from the remainder of the system in the form of wattles current whose magnitude approximates to that of the full load rating of the machine. This may cause overheating of the stator winding and increased rotor losses due to the currents induced in the rotor body and damper winding. This condition should not be allowed to persist indefinitely and corrective action either to restore the field, or to off-load and shut-down the machine should be taken.

With generator outputs above half rated load, pole-slipping caused by weak field condition, would cause severe voltage variations which may, in turn, cause operation of the undervoltage protection on the boiler auxiliaries. The resultant operation of "loss of boiler firing" protection would then shut-down the generator unit. Other generators connected to the same busbar may also be caused to "swing" and system instability would result. Pole slipping may also result from insufficiently fast clearance of a system fault and require the tripping of the unit.

### 3) Mechanical conditions

The mechanical conditions requiring consideration are overspeed due to sudden loss of load, loss of drive due to prime mover failure and loss of condenser vacuum.

with modern large units it is essential to anticipate overspeed and take corrective action. Mechanical overspeed devices which operate on the steam stop valves are invariably fitted.

In the event of failure of the prime mover, a generator will continue to run synchronously drawing power from the system. This can sometimes lead to a dangerous mechanical condition if allowed to persist, although the condition is immediately obvious to the attendant.

Set having an internal combustion prime mover must be protected against engine failure, where, if the alternator continues to motor serious engine damage may result.

Vacuum failure (or low vacuum) detection is necessary to prevent a rise of condenser pressure which might lead to shattering of Internal Pressure casing and condensers.

#### 4) External faults

Turbo alternators must be protected against the effects of sustained external faults, for example faults of lines or busbars which are not cleared by the appropriate protection. The main condition of interest is that of an unsymmetrical fault producing negative phase sequence currents in the stator winding. The effect of these currents is to produce a field rotating in opposite sense to the d.c. field system producing a flux which cuts the rotor at twice the rotational frequency thereby inducing double frequency currents in the field system and the rotor body. These currents produce severe rotor heating and modern machines have a limited negative phase sequence current capability. Automatic tripping is therefore required for the higher negative phase sequence current conditions.

This capability limit applies to all modern hydrogen-cooled machines and many air-cooled machines, but some of the older air-cooled machines are designed to withstand full negative phase sequence currents continuously.

In large modern alternators, particularly those employing direct cooling of the stator and rotor conductors, the temperature rise caused by abnormally high stator currents is more rapid than in the less highly rated machines and the capability limit is therefore lower.

### 5.2 Motor Faults

In general it is necessary to protect a motor against abnormal running and fault conditions arising from:

**1)** Prolonged overloading as a result of the application of excessive mechanical load:

**2)** Single-phasing caused, for example, by the rupturing of a fuse or by the open circuiting of a connection in one phase of a three-phase motor. if one phase is open-circuited when the motor is running it will continue to run and provide power even though it is connected to what is, in effect, a single-phase supply. If the load on the motor is of the order of its rated output, the current drawn from the supply will be appreciably higher than the current for which the windings are designed and if the condition is allowed to persist, severe damage may be caused:

**3)** Short-circuits between phases or between phase and earth in the winding or its connections. Short-circuits may be caused by the chafing of connections, accidental shorting of the motor terminals or cable sealing ends or by cable faults:

**4)** Partial or complete collapse of voltage.

### 5.3 a.c. and d.c. Motor Protection

The protection of motor plant is based on the same essential considerations whether the motor is driven from an a.c. or a d.c. source. In some instances, for example, the thermal overload relay, a modified single-phase version is applied to the protection of d.c. motors.

Any dangerous or potentially dangerous condition in either an a.c. or a d.c. motor, its control or connections, must be detected and action taken automatically to disconnect the affected equipment. Such conditions are classified broadly as low or falling supply voltage and overloading beyond a predetermined safe value for an excessive time.

To these conditions must be added the open-circuiting of one phase of a three-phase a.c. motor and a short-circuit in either an a.c. or d.c. motor.

Many motors draw a starting current from the supply of several times their normal full-load current, and it is essential that the protection should be unresponsive to this starting surge provided that the motor current returns to its running value within the time determined by the design of the motor.

## 5.4 Neutral Grounding (Earthing)

For safety of personnel and to reduce over-voltages to ground, the generator neutral is often either grounded solidly or grounded through a resistor or reactor. When the neutral is grounded through a resistor or reactor properly selected in accordance with established power system practices, there are no special considerations required in the generator design or selection, unless the generator is to be operated in parallel with other power supplies. The neutral of a generator should not be solidly grounded unless the generator has been specifically designed for such operation. With the neutral solidly grounded, the maximum line-to-ground fault current may be excessive and in parallel systems excessive circulating harmonic currents may be present in the neutrals.

# APPENDIX B
# SWITCHGEAR AND CONTROLGEAR

## CONTENTS :

PAGE No.

SELECTION CRITERIA FOR LOW VOLTAGE SWITCHGEAR AND CONTROLGEAR

**SELECTION CRITERIA FOR M.V. SWITCHGEAR**

# SELECTION CRITERIA FOR LOW VOLTAGE SWITCHGEAR AND CONTROLGEAR

## 1. GENERAL

Low voltage switchgear and controlgear constitute the links between on the one hand the means of generation (generators), Transmission (cables or overhead lines) and voltage transformation (transformers of electric power, and on the other hand the consuming equipment such as motors, lighting, heating and air conditioning plant).

The selection criteria are grouped in four categories.

### 1.1 Current

- Rated current of busbar
- Rated current of infeeds
- Rated current of outgoing feeders
- Short circuit withstand capability of busbars

### 1.2 Nature of Protection and Installation

- Degree of protection to IEC 529
- Method of installation (against a wall, free standing)
- Number of operating faces
- Protective measure
- Enclosure material

### 1.3 Equipment Mounting

- Non withdrawable
- Removable (subassembly)
- Withdrawable

### 1.4 Application

Different possible application:

- Lighting and power distribution board
- Consumer unit
- Busbar trunking system
- Control system
- Power factor correction equipment
- Industrial distribution board
- Motor control
- Main switchgear
- Main distribution board

### 1.5 Applicable Standards

Low voltage switchgear and controlgear assembly shall be designed in accordance with all the applicable sections of these standards that are in effect at the time of publication of this Standard. The applicability of changes in standards that occur after the date of this Standard shall be verified.

**ISIRI (INSTITUTE OF STANDARDS AND INDUSTRIAL RESEARCHES OF IRAN)**

ISIRI 6 "Standard Voltage" (IEC 38)
ISIRI 9 "Standard Frequency" (IEC 242)

**IEC (INTERNATIONAL ELECTROTECHNICAL COMMISSION)**

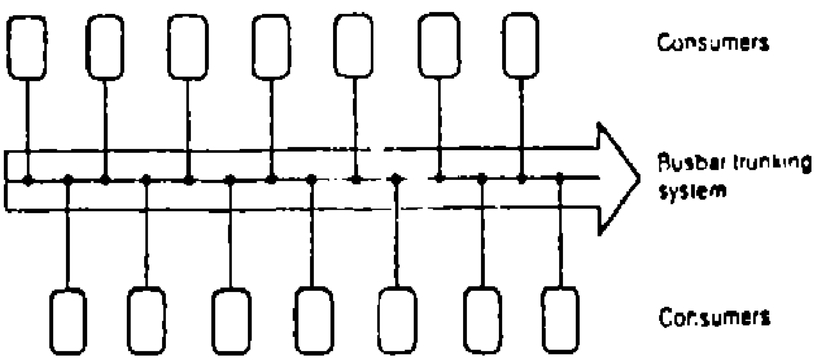
IEC 59 "Standard Current Rating"
IEC 79 "Electrical Apparatus for Explosive Gas Atmosphere"
IEC 157 "LV Distribution Switchgear"
IEC 158 "LV Controlgear for Industrial Use"
IEC 185 "Current Transformers"
IEC 186 "Voltage Transformers"
IEC 255 "Electrical Relays"
IEC 269 "LV Fuses with High Breaking Capacity"
IEC 292 "LV Motor Starter"
IEC 364 "Electric Installation of Buildings"
IEC 408 "Low Voltage Air-break Switches, Air-break Disconnector, Air Break Disconnectors and Fuse Combination Unit"
IEC 439 "Factory Built Assemblies of LV Switchgear and Controlgear"

## 2. EXAMPLES OF CONSTRUCTION

### 2.1 Busbar Trunking System

With "busbar trunking systems", the power is distributed through relatively long enclosed busbars, at up to about 400 A, to the immediate locality of the consuming equipments. The loads are connected to the busbars through tap-off boxes via fuses and short stub lines or cables. Busbar trunking systems (with tap-off units of various sizes and in various positions) are used to supply workshops, machines etc., in spatially extended factories and laboratories.

Tap-off units can be provided at practically any point in the busbar run, so that linear distribution systems are especially suitable for loads with frequently changeable locations. They are also used as rising mains in high buildings, where they feed the floor distribution boards see Fig. B1.

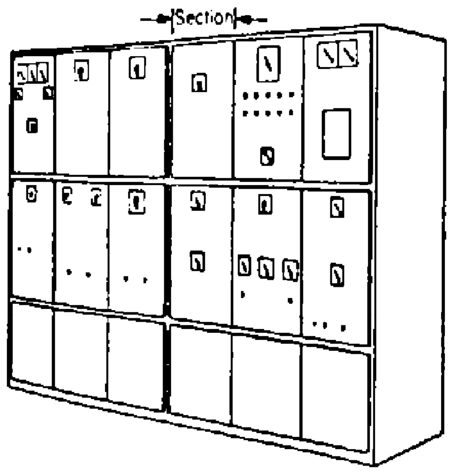



**BUSBAR TRUNKING SYSTEM (PRINCIPLE)**
**Fig. B1**

## 2.2 Cubicle Construction

The cubicle type of construction (Fig. B2) is enclosed on all sides, so that contact with live parts during operation is prevented. Installation is permissible in generally accessible operating areas. In most cases the cubicle construction has a height greater than 1 m (the standard height is 2.2 m) and is made up of a number of sections (panels). A group of sections (up to four) constitutes a transportable unit.

Cubicle construction is the most widely used nowadays, because of all the possible forms it represents the optimum for the user in regard to the protection of personnel and plant. In practice this type of construction is more often found with full-access doors, not as shown in the schematic drawing, with individual compartment doors. Behind individual compartment doors, items of equipment are mostly mounted in withdrawable units; with non-withdrawable units, full-height doors completely cover the fronts of the cubicles.

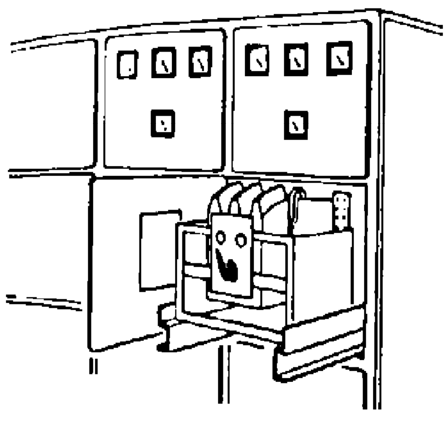



**CUBICLE CONSTRUCTION**
**Fig. B2**

## 2.3 Withdrawable Assembly

A withdrawable arrangement implies a pull-out or swing-out unit, in which a number of items of equipment are grouped and interconnected to form a functional entity.

The withdrawable arrangement (Fig. B3) is invariably associated with the totally enclosed cubicle construction. This is further divided into individual compartments for the withdrawable units (outgoing feeder unit, infeed or coupling unit) and in this way affords the best possible personal safety and operational security.

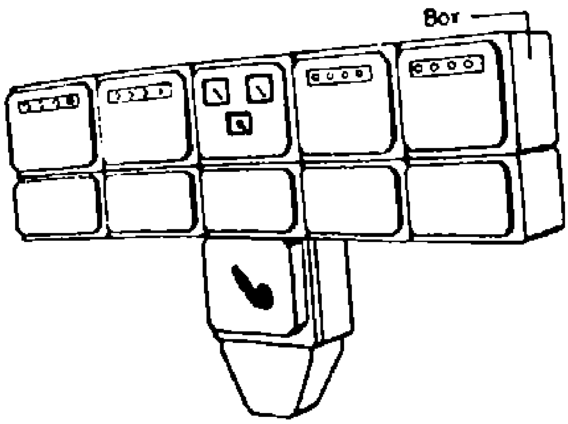


**WITHDRAWABLE ASSEMBLY**
**Fig. B3**

### 2.4 Box Type Construction

Box-type distribution boards (Fig. B4), made of insulating material, sheet steel, grey cast iron etc., consist of boxes securely assembled together and containing items of equipment such as busbars, fuses, switches and contactors. Contact with parts that may be live during operation is prevented. Distribution boards in this form can therefore be installed in generally accessible operating areas.

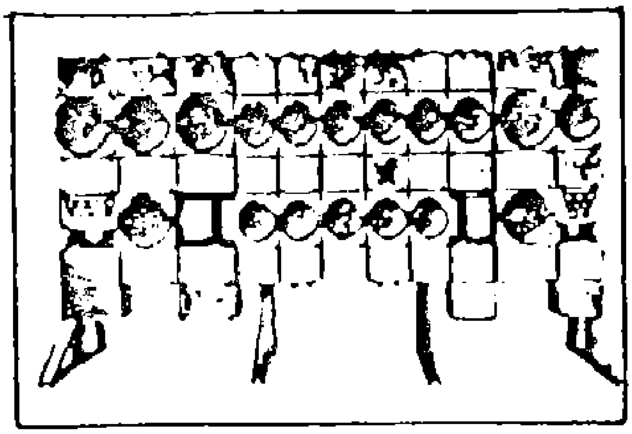
With the attachment of a protective cowl, and with an appropriate degree of protection for the boxes (minimum IP 55), this type of distribution board, unlike those described earlier, can be installed outdoors.




**BOX-TYPE CONSTRUCTION**
**Fig. B4**

### 2.5 Flameproof/Weatherproof Type Switch Fuse Assembly

For typical flameproof/weatherproof switch fuse assembly see Fig. B5.



**FLAMEPROOF/WEATHERPROOF TYPE, SWITCH-FUSE ASSEMBLY**
**Fig. B5**

# 3. RECOMMENDATION FOR SELECTION

## 3.1 Selection of Switchgear

The following are recommended for selection of switchgear:

- The highest current rating of the equipment up to 4000 Amps.
- Sheet steel as the enclosure material.
- A height of up to 2200 mm.
- Mounting methods for the equipment:
    - Fixed.
    - Removal.
    - Withdrawable.
- Short circuit withstand capability up to 176 KA peak.
- Enclosure protection up to IP 55.

## 3.2 Selection of Distribution Board

The following shall be considered in selection of distribution boards:

- Rated current of up to 2000 A.
- Various enclosure materials such as:
    - Grey Cast iron.
    - Insulating material.
    - Sheet steel.
- Height of individual boxes less than 1000 mm.
- Equipment items mainly fixed.
- Short circuit withstand capability up to 80 KA peak.
- Ingress protection up to IP 65.

A detailed description of the selected type with further technical data and ranges of equipment will be found in the following pages.

## 3.3 Short - Circuit Withstand Capability

The prospective short circuit current at the point of installation of the switchgear assembly or distribution board that is between the infeed transformer on one side and the cable connected loads on the other side must not exceed the short circuit withstand capability quoted for the product by the manufacturer. If necessary this requirement can be met by the interposition of a current limiting device.

Circuit breakers in accordance with the data sheet shall have normal current rating selected from the following ratings:

**630, 800, 1250, 1600, 2000, 2500, and 4000 ampere.**

The above mentioned figures shall be derated for maximum summer temperature i.e., 50°C where applicable.

Short circuit breaking and making rating current shall not be less than 50 KA and 150 KA respectively for a fault capacity of about 31 MVA for 1 second unless otherwise determined under different circumstances.

Where switchgear and controlgear assembly motor control centers are located in explosive hazardous areas they should be explosionproof, and the fault M.V.A should not exceed 15 M.V.A for one second.

### 3.4 Degree of Protection

Depending on the installation location and the surrounding conditions a switchgear and distribution board design should be chosen such that provides the necessary kind of protection against contact and against the ingress of foreign bodies and water. A list of ingress protection is given in IEC publication 529.

### 3.5 Insulated Enclosure

In certain distribution system design (up to busbar currents of 1000 A) there is a choice between metal and insulating material for the enclosure. The insulated enclosure offers full protection from corrosion and better protection against contact.

### 3.6 Protective Measures

All metal parts of switchgear assembly and distribution boards shall be provided with protective conductor (PE).

### 3.7 Selection of Apparatus According to Zone of Hazard

For selection of apparatus in hazardous area where circumstances dictate, the protection given in Table B1 may be applicable.

**TABLE B1 - SELECTION OF APPARATUS ACCORDING TO ZONE, GAS AND VAPOR RISKS**

| ZONE | TYPE OF PROTECTION |
|---|---|
| 0 | Ex "ia" (intrinsically safe) provide sparking contacts are protected.<br>Ex "S" (specially certified for zone "O") for special application |
| 1 | Any type of protection<br>Suitable for zone "O" and<br>Ex "d" (flammable enclosure)<br>Ex "ib" (intrinsically safe)<br>Ex "p" (pressurized enclosure)<br>Ex "e" (increased safety)<br>Ex "s" (specially certified) |
| 2 | Any type of protection<br>Suitable for zone "O" OR "1" and<br>Ex "e" (increased safety)<br>Ex "n" (type of protection "N")<br>Ex "O" (oil immersed apparatus) |

For list of standards of electrical apparatus in potentially explosive atmosphere see Table B2.

**TABLE B2 - STANDARDS FOR ELECTRICAL APPARATUS FOR POTENTIALLY EXPLOSIVE ATMOSPHERES**

| DESCRIPTION OF STANDARD | B.S.S No. | IEC AND EN No. |
|---|---|---|
| Flameproof enclosure "d" | BS 5501<br>PT. 5<br>(1977) | # IEC 79-1<br>PT. 1<br>(1971)<br>AMD 1 (1979)<br><br>IEC 79. 1A<br>(1975)<br>≡EN 50018 |
| Increased safety "e" | BS 5501<br>PT. 6<br>(1977) | # IEC 79.7<br>PT. 7<br>(1969) |
| Intrinsic safety "i"<br>(ia ib) | BS 5501<br>PT. 7<br>(1977) | IEC 79-11<br>PT. 11<br>(1984) |
| Encapsulation "M" | BS 5501<br>PT. 8<br>(1988) | ≡EN 50028 |
| Type of protection "N" (n) | BS 6941<br>(1988) | # IEC 79-15<br>PT. 15 |
| General requirements | BS 5501<br>PT. 1<br>(1977) | # IEC 79-0<br>PT. O<br>(1983)<br>≡EN 50014 |
| Oil immersion "O" | BS 5501<br>PT. 2<br>(1977) | # IEC 79-6<br>PT. 6<br>(1968) |
| Pressurized apparatus "P" | BS 5501<br>PT. 3<br>(1977) | # IEC 79-2<br>PT. 2<br>(1983)<br>≡EN 50016 |

**1) The symbols under description of standard, refer to B.S.S. They shall be preceded by "Ex" for IEC and "EEx" for EN Standards.**

**2) Legends**

**≡ stands for identical**
**# stands for related**

## 4. FEATURES TO BE CONSIDERED IN INSTALLATION, ACCESS, AND DELIVERY

### 4.1 Type of Installation

- On the floor against wall.
- On the floor free standing in the room.
- Fixed to a wall or a recess.
- Suspended from the ceiling.
- Mounted on a rack.

### 4.2 Nature of Access

- On one side or on two sides for operation.
- Front or back access for cable connections and alteration.
- Top or back access for modification to or installation of busbars.

### 4.3 Quoted Installation Dimension

- Height, width, and depth.

### 4.4 Delivery Facilities

- Height and width of doors.
- Lift dimensions.
- Where necessary lifting capability of cranes.

### 4.5 Special Requirements

Possible special requirements such as for example explosion protection, protection against hostile atmospheres, and earthquake should be considered within the scope of additional agreement between the manufacturer and user.

## SELECTION CRITERIA FOR M.V. SWITCHGEAR

## 1. STANDARDS

Design, rating, manufacture and testing of medium voltage switchgear shall be governed by International Electrotechnique Commission (IEC) recommendations and narrative. Whereby it should be noted that in Europe all national electrotechnical standards have been harmonized with the framework of the current IEC recommendations.

Where M.V. switchgears are used, they shall comply with the requirement of following IEC publications:

**IEC (INTERNATIONAL ELECTROTECHNICAL COMMISSION)**

| | |
|---|---|
| IEC 56 | "High Voltage Alternating Circuit Breaker" |
| IEC 129 | "Alternating Current Disconnectors" |
| IEC 185 | "Current Transformers" |
| IEC 186 | "Voltage Transformers" |
| IEC 265 | "High Voltage Switches" |
| IEC 282 | "High Voltage Fuses" |
| IEC 298 | "a.c. Metal Enclosed Switchgear and Controlgear (BS 5227) for Rated Voltages above 1 kV and Up to and Including 72.5 kV" |
| IEC 470 | "High Voltage Alternative Current Contactor" |
| IEC 694 | "Common Clauses for High Voltage Switchgear and Controlgear Standards" |

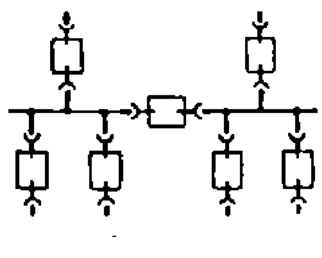
**Notes:**

**1) According to ISIRI No. 6 adapted from IEC 38 (1983) medium voltage is defined as voltages higher than 1000 volt up to and including 66 kV in a 3 phase 3 wire 50 Hz system.**

**2) See also sub-clause 1.5 of this Standard.**

## 2. BUSBARS

**2.1** Switchgear installations for normal service conditions shall be preferably equipped with single busbar systems. These are clean in their arrangement simple to operate, require relatively little space and are low in initial cost and operating expenses see Fig. B6.



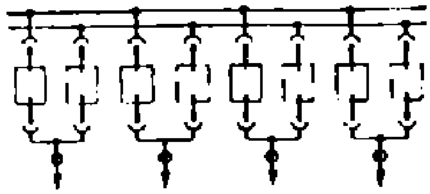
**SINGLE-BUSBAR WITH BUS-TIE BREAKER**
**Fig. B6**

**2.2** Double Busbar Switchgear and Controlgear (Switchboard)

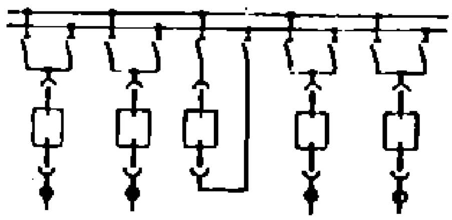
Double busbar switchgear and controlgear can offer advantages in the following:

- Operation with asynchronous feeders.
- Feeders with different degrees of importance to maintain operation during emergency conditions.

- Isolation of consumers with shock loading from the normal network.
- Balancing of feeders on two systems during operation.
- Access to busbars required during operation see Figs. B7 and B8.



**DOUBLE BUSBARS WITH DUAL FEEDER BREAKERS**
**Fig. B7**



**DOUBLE BUSBARS WITH SINGLE FEEDER BREAKER**
**Fig. B8**

### 2.3 Isolated Versus Insulated Busbars

To reduce the risk of internal arching in switchboards two basic preventive design measures are used:

**a)** Isolated busbar compartment that prevent the ingress of contamination and rodents.
**b)** Insulated busbars and tapping points.

Isolated busbar compartments with bare busbars offer the advantage of arc guidance under fault conditions and reduce the amount of inflammable material.

Insulated busbars allow for the reduction of internal spark over distance and demand less in terms of sealing the enclosure. No major differences in overall safety and or performance are known.

## 3. TYPES OF MEDIUM VOLTAGE SWITCHGEAR AND CONTROLGEAR

**3.1** IEC publication 298 subdivides metal enclosed switchgear and controlgear into three types.

**3.1.1** Metal-clad switchgear and controlgear.

**3.1.2** Compartmented switchgear and controlgear.

**3.1.3** Cubicle switchgear and controlgear.

For all of the above mentioned switchgear and controlgears the following rating terms may be used:

**a) Rated frequency**

The standard values of the rated frequency for three pole switchgear and controlgear are 50 hz or 60 hz.

**b) Rated normal current**

The rated normal current of a switching device is the rms value of the current which the switching device shall be able to carry continuously under specified condition of use and behavior. The values of rated normal current should be selected from the R 10 series specified in IEC publication 59.

**c) The rated voltage**

The rated voltage indicates the upper limit of the highest voltage of systems for which the switchgear and controlgear is intended. Standard values of rated voltages are given below:

**3.6 kV, 7.2 kV, 12 kV, 17.5 kV, 24 kV, 36 kV, 52 kV, 72.5 kV.**

## 4. CHOICE OF INTERRUPTERS

Depending on the switching duty in individual switchboard and feeder basically the following types of primary interrupters are used in the switchgear cubicles. All types of interrupters may be used in all types of cubicles.

### 4.1 Vacuum Circuit Breakers

Vacuum circuit breakers are recommended for all general purpose applications if high number of switching operations are anticipated (switching of m.v. motors), and limited maintenance is desired their use is indicated.

Examples of rated current at medium voltage are 630 A, 800 A, 1250 A, 1600 A, 2000 A, 2500 Amp, 3150 A, and 3600 A.

### 4.2 Minimum Oil Circuit Breakers

Minimum oil circuit breakers are time tested and reliable breakers for most applications for maximum ratings up to 4000 Amp rated current and 63 kA (rms) interruption current their use is recommended.

Minimum oil breakers are available in all common rating such as

**630, 1250, 1600, 2000, 2500, and 4000 Amps at various m.v. voltage.**

Examples of rated current at medium voltages are:

**630 A, 800 A, 1250 A, 1600 A, and 2000 A.**

### 4.3 SF 6 Circuit Breakers

Interrupting ability of SF 6 in comparison with air dates from 1953. This marks the beginning of intensive research into the special properties of the gas as an arch extinguishing medium as a dielectric and as a heat conductor which properties have facilated considerable increase in voltage and current rating in SF 6 circuit breakers relative air circuit breakers without restoring to extreme gas pressure or large numbers of break in series.

Examples of rated currents at medium voltages are as follows:

**630 A, 800 A, 1250 A, 1600 A, 2000 A, 2500 A, 3150 A, and 3600 A.**

### 4.4 Vacuum Contactors

Vacuum contactors are used for frequent switching operations in motors, transformers and capacitor bank feeders up to 400 Amp. They are reliable and compact device with maintenance free interrupters.

Since contactors cannot interrupt fault current they must always be used with current limiting fuses to protect the equipment connected.

# APPENDIX C
# TRANSFORMERS

## CONTENTS :

PAGE No.

## 1. REFERENCES

The latest issue of the following Standards including their latest amendments to be referred, while engineering transformer:

| | |
|---|---|
| IEC 38 | Standard Voltages |
| IEC 76.1 | Power Transformer : General |
| IEC 76.2 | Power Transformer Temperature Rise |
| IEC 76.3 | Power Transformers-Insulation Levels and Dielectric Tests |
| IEC 76.3.1 | Power Transformers-Insulation Levels and Dielectric Tests, External Clearances in Air |
| IEC 76.4 | Power Transformers-Tapping and Connections |
| IEC 76.5 | Power Transformers-Ability to Withstand Short Circuit |
| IEC 85 | Thermal Evaluation and Classification of Electrical Insulation |
| IEC 137 | Bushings for Alternating Voltages above 1000 V |
| IEC 214 | On-Load Tap Changers |
| IEC 227 | Polyvinyl Chloride Insulated Cables of Rated Voltages Up to and Including 450/750 V |
| IEC 296 | Specification for Unused Mineral Insulating Oils for Transformers and Switchgears |
| IEC 354 | Loading Guide for Oil-Immersed Transformers |
| IEC 529 | Degrees of Protection Provided by Enclosures (IP Code) |
| IEC 542 | Application Guide for On-Load Tap Changers |
| IEC 551 | Determination of Transformer and Reactor Sound Levels |
| IEC 606 | Guide to Power Transformers |
| IEC 726 | Dry-Type Power Transformers |
| BS 5493 | Code of Practice for Protective Coating of Iron and Steel Structures Against Corrosion |

## 2. SERVICE CONDITIONS

**2.1** Environmental conditions will be in accordance with Appendix A.

**2.2** The system supply voltage variations will be ±10% of rated value.

**2.3** The system frequency variation will be ±5% rated value.

## 3. GENERAL

### 3.1 Main Incoming Supply

Transformers required for the incoming supply. Associated with a local power supply authority and or company owned generating plant should be agreed and approved by all the parties concerned.

### 3.2 Distribution Transformers

**3.2.1** Transformers up to and including 1000 kVA rating should be of sealed type.

**3.2.2** Transformer in excess of 1000 kVA should be of conservative type.

**3.2.3** The impedance voltage of all transformers should be selected to meet the specified short circuit level on the lower voltage side but a value of 10% should not be exceeded unless otherwise agreed.

**3.2.4** Transformers should normally be of the oil immersed type using mineral oil complying with requirement of IEC publication 296.

In some instances the use of nonflammable synthetic insulating liquids may be desirable according to the type and insulation of the transformer. In the absence of IEC Standard covering synthetic insulating liquids, provision of the above must be agreed between Company, manufacturer and contractor.

## 3.3 Vector Group

Transformers should be provided in accordance with vector symbol Dy 5 or Dy 11. The installation of transformers to any other group should be subject to agreement.

## 3.4 Voltage Tapping

Unless otherwise specified the higher voltage winding of all transformers should be provided with a principal and four additional tappings for constant kVA to compensate for variations in the supply voltage of plus and minus 2½ and 5 percent unless agreed otherwise. Control should be by an externally operated off circuit tapping switch. Temperature rise requirement applicable to the principal tapping turn ratio should be such that, at full load, 0.85 power factor the secondary voltage equals the nominal system voltage.

## 3.5 Disconnecting Chambers and Termination

**3.5.1** Suitably insulated disconnecting chambers should be fitted to the higher and lower voltage sides to facilitate cable testing and safeguard transformer bushing.

When oil filled chambers are fitted they shall be separated from the main tank and provided with a drain plug or valve, and when deemed necessary according to climatic conditions be connected to a dehydrating breathing system, and be fitted with an oil filling gage.

Disconnecting chambers will not normally be required when associated with the low voltage system. When air insulated termination enclosure arrangement are considered the arrangement should be either phase segregated, or have all parts fully insulated with shrouds, and solid or taped insulation. The arrangement must also minimize adverse effects arising from breathing.

The above arrangement may preclude the necessity for a separate disconnection chamber by incorporating disconnecting links within the termination enclosure, and when cable size permits may preclude the necessity for cable links.

## 3.6 Neutral

**3.6.1** The neutral point on the lower voltage side of all distribution transformers should be brought out through an insulating bushing for connection to earth. The neutral should also be accessible for connection to a four wire system.

**3.6.2** For the purpose of restricted earth fault protection, provision should be made for a current transformer in the neutral, fitted so that both neutral and earth currents pass through it:

> **i)** When associated with medium voltage transformer secondary windings, and the neutral connection is only required for the purpose of earthing, the neutral current transformer should be accommodated in an oil filled compartment, having a removable access cover, external to the transformer main tank.
>
> The use of a weatherproof epoxy resin encapsulated type of current transformer, mounted on the transformer, or immediately adjacent to it, may be considered in some instances, but the complete arrangement, including the main and neutral connections must be agreed.
>
> **ii)** When associated with low voltage transformer secondary windings, and the neutral connection is required for the purpose of providing a four wire supply and for connection to earth, then the neutral current transformer may be accommodated (a) as described above for medium voltage transformer secondary winding (b) it can take the

form of a weatherproof epoxy resin encapsulated type and be mounted externally on or immediately adjacent to the transformer, or (c) it may be accommodated within the associated switchgear as part of the incoming supply controlling circuit breaker equipment.

**iii)** In all cases facilities should be provided to enable primary injection testing to be carried out by the provision of connecting points and removable links. Arrangements (ii) (b) and (c) are preferred for low voltage systems.

When arrangement (ii) (c) is adopted, connections must be made in the switchgear between the neutral busbar and main earth bar at each transformer neutral connection position, and a connection to earth should be made from the main earth bar from each of these positions.

When the neutral of only one transformer is involved on a switchgear a minimum of two connections between the neutral and earth bar and from the earth bar to earth must be made, one of which should be at the point where the transformer neutral connection is made to the neutral bar.

## 3.7 Method of Cooling

**3.7.1** Transformers are identified according to the cooling method employed. Letter symbols used in conjunction with cooling are given in Table C1.

**TABLE C1 - LETTER SYMBOLS**

| KIND OF COOLING MEDIUM | SYMBOL |
|---|---|
| Mineral oil or equivalent flammable synthetic insulating liquid | O |
| Non-Flammable synthetic insulating liquid | L |
| Gas | G |
| Water | W |
| Air | A |
| **KIND OF CIRCULATION** | |
| Natural | N |
| Forced (oil not directed) | F |
| Forced-Directed oil | D |

Transformers shall be identified by four symbols for each cooling method for which a rating is assigned by the manufacturer.

Dry-type transformers without protective enclosures are identified by two symbols only for the cooling medium that is in contact with the windings or the surface coating of windings with an overall coating (e.g. epoxy resin).

The order in which the symbols are used shall be as given in Table C2. Oblique strokes shall be used to separate the group symbols for different cooling methods.

**TABLE C2 - ORDER OF SYMBOLS**

| 1st LETTER | 2nd LETTER | 3rd LETTER | 4th LETTER |
|---|---|---|---|
| Indication the cooling medium that is in contact with the windings | | Indicating the cooling medium that is in contact with the external cooling system | |
| Kind of cooling medium | Kind of circulation | Kind of cooling medium | Kind of circulation |

For example, an oil-immersed transformer with forced-directed oil circulation and forced air circulation would be designated ODAF.

For oil-immersed transformers in which the alternatives of natural or forced cooling with non-directed oil flow are possible, typical designations are:

**ONAN/ONAF** **ONAN/OFAF**

The cooling method of a dry-type transformer without a protective enclosure or with a ventilated enclosure and with natural air cooling is designated by:

**AN**

For a dry-type transformer in a non-ventilated protective enclosure natural air cooling inside and outside the enclosure, the designation is:

**ANAN**

### 3.8 Weather Protection

**3.8.1** Detachable metal "sunshades" of adequate size, arranged to serve also as rain and snow shields, should be fitted above the disconnecting chambers and cable boxes. The above should preferably be provided by the manufacturer as an integral part of the transformer, but when dictated by circumstances may be omitted and added on site to supplement other protection according to the actual transformer location, if deemed to be necessary.

### 3.9 Transformer Sound Level

Transformer sound level shall follow the requirement of IEC publication No. 551

### 3.10 Earthing

Transformer shall be provided with at least one suitably sized earth terminal on the outside of transformer main frame or tank wall for connection to an external earthing grid. The earth connection shall consist of a brass or stainless bolt with nuts and washer at least size M8 and shall be located on the lower part of the transformer near the low voltage cable connection.

## 4. SELECTION

In selection of transformers, consideration shall be given to the following:

### 4.1 Characteristics Data

The rated quantities of a transformer such as rated power, rated ratio and rated impedance and voltage are decided by the requirement of system.

#### 4.1.1 Rated power

The rated power is decided on the basis of the maximum active power demand determined in the course of project planning or by measurement, usually with a reserve of power for the expected yearly rate of increase. The active power so determined is converted to the rated power by applying the expected power factor cost.

#### 4.1.2 Rated impedance voltage

A rated impedance voltage = 4% is preferred in distribution system in order to keep the voltage drop low.

For the higher power industrial systems, transformers with a rated impedance voltage of 6% are used in consideration of their influence on the short circuit stresses in the equipment.

#### 4.1.3 Transformer losses

Transformer losses can be divided into two categories as described below:

**a) No Load Losses**

The no losses arising from the continual magnetic flux reversal in the iron are practically constant at a constant voltage and independent of load.

**b) Load Losses**

The load losses consist of the RI losses in the windings and the losses due to stray fields and vary as the square of the load current.

### 4.2 Oil Immersed Transformers

Oil immersed transformers are used in installations in which structural measures required to deal with fire hazards can be applied economically and their use is not prohibited by any special regulation.

### 4.3 Resin Cast Transformers

Resin cast transformers are recognized as almost not combustible and self extinguishing, and can therefore be used in place of askarel immersed transformers in fire hazardous situations and in public and residential buildings.

### 4.4 Connections

Liquid cooled transformers normally have porcelain bushings with protection IP00 for the incoming and outgoing leads cables or busbars.

A high ingress protection can be achieved by means of terminal shrouds, with cable entry glands or plug and socket connections.

Resin cast transformers are provided with resin cast insulator for incoming lines and terminal of protection IP00 for outgoing lines higher protection grades can be achieved by means of sheet steel enclosures.

### 4.5 Effects of Altitude

Distribution transformer are suitable for operation at up to 1000 m above see level. At greater altitude the cooling properties deteriorate and the dielectric strength of the air reduced. Where the installation site, lies at an altitude, significantly greater than 1000 meters, the manufacturer should be consulted as capability of transformer.

The installation site should be free of ground water and the possibility of floods, and arranged as far as possible so that cooling is not impaired by solar radiation.

### 4.6 Indoor Installation

Liquid cooled transformers designed for indoor use may be installed only in covered premises which afford adequate protection against humidity.

The premises should have good access, so that equipment transport, operation, maintenance and fire fighting is possible without hindrance.

### 4.7 Outdoor Installation

Liquid cooled transformers can be installed outdoors so long as they have suitable bushings and an outdoor paint finish.

### 4.8 Use in Unusual Climates

Transformers designed with conservators should be fitted with dissicators for operation in warm damp tropical climates or in humid air close to the sea.

Resin cast transformers can in general be installed in any covered area so long as it is closed, since it is electrically unaffected by high humidity. Structural measures such as fire resistant partitions are not necessary with resin cast transformers. Outdoor installation is also possible in an enclosure affording protection to IP 23.

### 4.9 Accessories

The following accessories depending on requirements are normally provided on transformers:

1) Shut Off Valve
2) Filtering Valve
3) Drain Valve
4) Pocket Type Thermometer
5) Dial Type Thermometer
6) Buchholz Relay
7) Temperature Relay
8) Pressure Vent
9) Magnetic Oil Level Indications.
10) Temperature Monitoring System Complete With Tripping Unit in Case of Resin Cast Transformers.
11) Oil Conservative
12) Dessicator
13) Air Vent
14) Lifting Lugs
15) Connection Diagram Plate

## 5. SIZE OF TRANSFORMER SUBSTATIONS

The size of transformer substation is determined mainly by the dimensions of the transformer. To enable transformers of higher rating to be installed in the event of subsequent increase in power the building design of substations for transformers of up to 630 kVA rating is based on the dimensions of a 630 kVA transformers; with rating from 800 to 2500 kVA should be designed according to dimensions of 2500 kVA transformers.

For larger transformers manufacturer advise shall be sought.

### 5.1 Room Height

In transformer substation with operating facilities the height of operating room depends upon the height of transformer, the kind of ventilation the bushings and the clearances between live and earthed parts; the clear height of the operating room should be at least that of the transformer plus 500 mm.

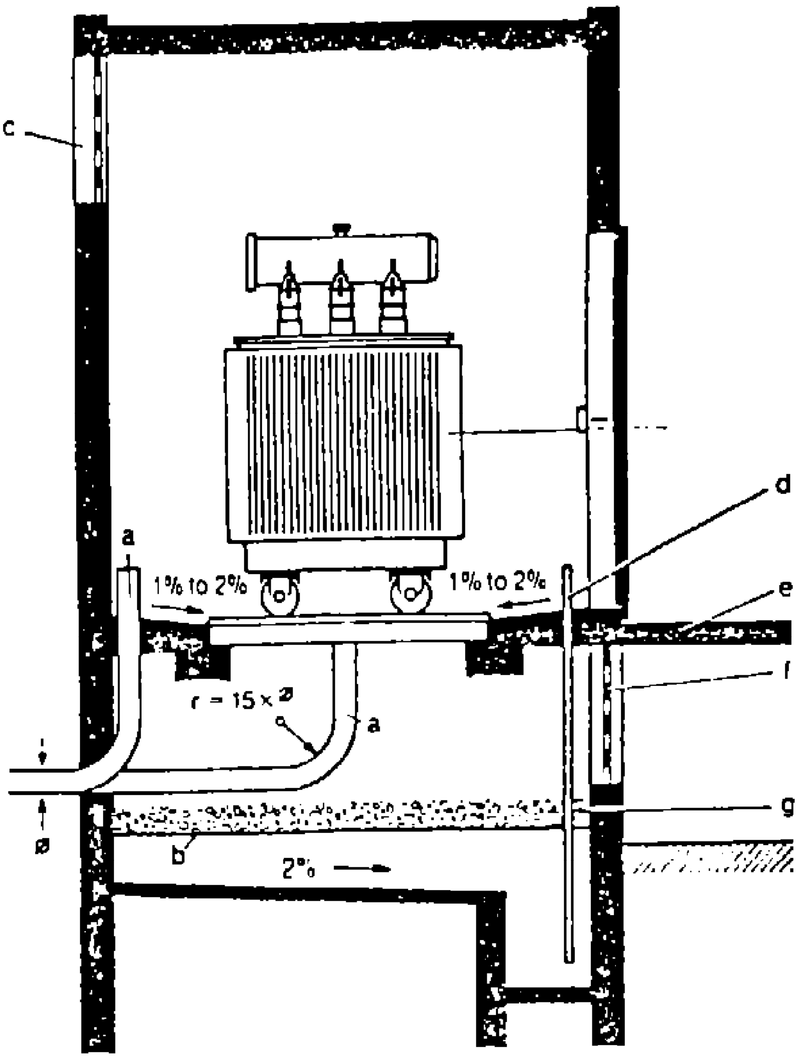
### 5.2 Width of Inspection Gangway

The length and width of transformer substation with operating facilities should be such that with transformers of up to 630 kVA rating there is an inspection gangway at least 70 cm wide on all sides and with rating from 800 to 2500 kVA at least 75 cm.

For larger transformers manufacturer drawings shall be referred.

### 5.3 Floor Design

The floor of a transformer substation may consists of a reinforced concrete slab with a central aperture, a mesh of reinforced concrete slab should be covered by a smooth cement finish with a slope of 1% to 2% towards the collection pit. If reinforced concrete or steel joists are used the floor can consist of grid plates, see Fig. C1.




**TYPICAL INDOOR INSTALLATION OF A LIQUID-COOLED TRANSFORMER**
**Fig. C1**

- **a** Cable conduit
- **b** Galvanized steel grid
- **c** Air outlet duct with grille
- **d** Pipe for oil pump
- **e** Ramp
- **f** Air inlet duct with grille
- **g** Gravel or stone chippings

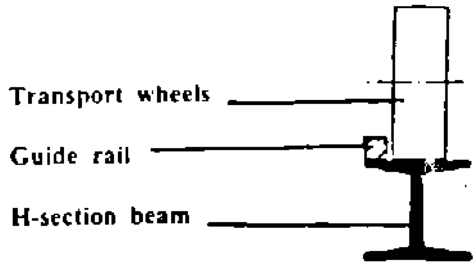
### 5.4 Rail for Transport Wheels

To guide the plain transport wheels, steel sections with 2 cm high lateral guide rails should be provided Fig. C2:

Transport wheels

Guide rail

H-section beam




**TYPICAL ARRANGEMENT OF RAILS FOR THE TRANSPORT WHEELS OF A TRANSFORMER**
**Fig. C2**

The castors can be set for transformer or longitudinal movement.

### 5.5 Protection of Ground Water

To avoid contamination of ground water, the following methods may be used to collect any escaping and possibly burning liquid from transformer.

#### 5.5.1 Collecting sump

For oil-immersed or synthetic-liquid-immersed transformers.

For a transformer of rated power up to 630 kVA a collecting sump large enough to accept the liquid contents of the transformer (about 0.7m³) may be placed in or under the transformer room. The floor can, if desired, be used as the collecting sump in conjunction with suitable thresholds in the ventilation and door openings.

Where several transformers of up to 630 kVA rating are installed in group, separate collecting sumps can be provided for each transformer, or a common sump (with a capacity of at least 0.7 m³) may be provided for the group.

#### 5.5.2 Collection pit

For a single transformer with a rated power of from 800 to 2500 kVA, a pit should be provided with a volume under the grid plates corresponding to the oil content of the transformer about 2 m³.

For a number of transformers from 800 to 2500 kVA rating instead of separate collection pits a common pit with a capacity of at least 2 m³ can be provided outside of transformer room if desired. Alternatively a number of small pit can be connected together to give a total capacity of at least 2 m³. A sump shall be provided in each pit to facilitate the pumping out of small quantities of oil or possible water.

Collection pits and the collection arrangements for a common pit should be covered with a layer of gravel or stone chippings at least 20 cm thick over a galvanized steel grid to prevent the spread of possible fire.

A collection pit is required for transformers installed outdoors to ensure that escaping oil can not seep into the ground it must have a capacity of at least 1.25 times the liquid contents of the transformer to allow for rain water etc. and should be regularly pumped out to prevent its filling with rain water over a period of time.

In view of absence of cooling and insulating liquid in cast resin transformers, collection arrangement and the provision associated with them are unnecessary.

## 5.6 Ventilation

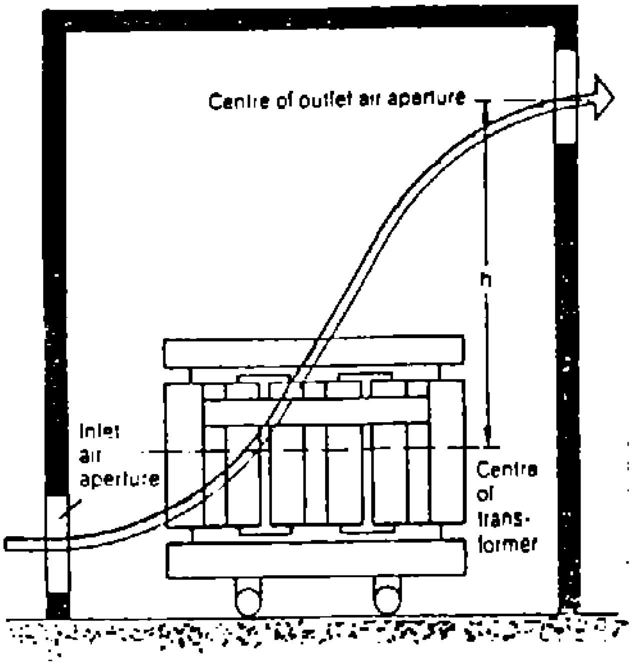
In designing buildings for naturally cooled transformer (ONAN) provision must be made for dissipating the heat losses of the transformers. For this purpose inlet and outlet air ducts must be provided.

The inlet air should be admitted at floor level or under the transformer (never above half the transformer height or half the tank height in the case of liquid cooled transformers) and the warm air let out at the top.

The air inlet and outlet if possible should be in opposite walls see Fig C3.

ARRANGEMENT OF AIR INLET AND OUTLET

h ≡ DIFFERENCE BETWEEN THE MID-HEIGHTS OF THE TRANSFORMER AND AIR OUTLET




**TYPICAL INDOOR INSTALLATION OF A RESIN-CAST TRANSFORMER**
**Fig. C3**

**Note:**

**When resin cast transformers are enclosed in protective housing forced ventilation is required.**

## 6. RECOMMENDED VALUES OF RATING

## 6.1 Rated Voltages

The rated voltages of transformer windings shall be selected from IEC publication 38. The following are most commonly used voltages in oil industry.

**230 V, 400 V, 3.3 KV, 6.6 KV, 20 KV, 33 KV, and 66 KV.**

## 6.2 Rated Ratios

- Most common voltage ratios are:

| | | | |
|---|---|---|---|
| **3.3 kV / 400 V,** | **6.6 kV / 400 V,** | **11 kV / 400V ,** | **20 kV / 400 V** |
| **11 kV / 3.3 kV,** | **33 KV / 11 kV,** | **66 kV or** | **63 kV / 6.6 kV** |
| **66 kV or 63 kV / 11 kV,** | **66 kV or** | **63 kV / 20 kV,** | **66 kV or 63 kV / 33 kV** |

## 6.3 Rated Impedance Voltage

Typical values of impedance voltage for transformers with two separate windings are given in Table C3.

**TABLE C3**

| IMPEDANCE VOLTAGE AT RATED CURRENT, GIVEN AS A PERCENTAGE OF THE RATED VOLTAGE OF THE WINDING TO WHICH THE VOLTAGE IS APPLIED | |
|---|---|
| RATED POWER kVA | IMPEDANCE VOLTAGE % |
| Up to 630 | 4.0 |
| 631 to 1250 | 5.0 |
| 1251 to 3150 | 6.25 |
| 3151 to 6300 | 7.15 |
| 6301 to 12500 | 8.35 |
| 12501 to 25000 | 10.0 |

## 6.4 Rated Short Circuit

Short circuit apparent power of the system which may be used in the absence of specification is given in Table C4.

**TABLE C4**

| HIGHEST SYSTEM VOLTAGE kV | SHORT- CIRCUIT APPARENT POWER MVA |
|---|---|
| 7.2, 12.17.5 and 24 | 500 |
| 36 | 1000 |
| 52 and 72.5 | 3000 |
| 100 and 123 | 6000 |
| 145 and 170 | 10000 |
| 245 | 20000 |

## 6.5 Rated Frequency

The rated frequency for design of transformers is 50 Hz, unless otherwise agreed.

## 6.6 Sizing

sizing of transformer shall be full load plus 20% extra.

## 7. PARALLEL OPERATION OF TRANSFORMERS

For satisfactory parallel operation on common busbar the following general condition must be fulfilled.

**7.1** Transformers to have the same vector group (phase angle number).

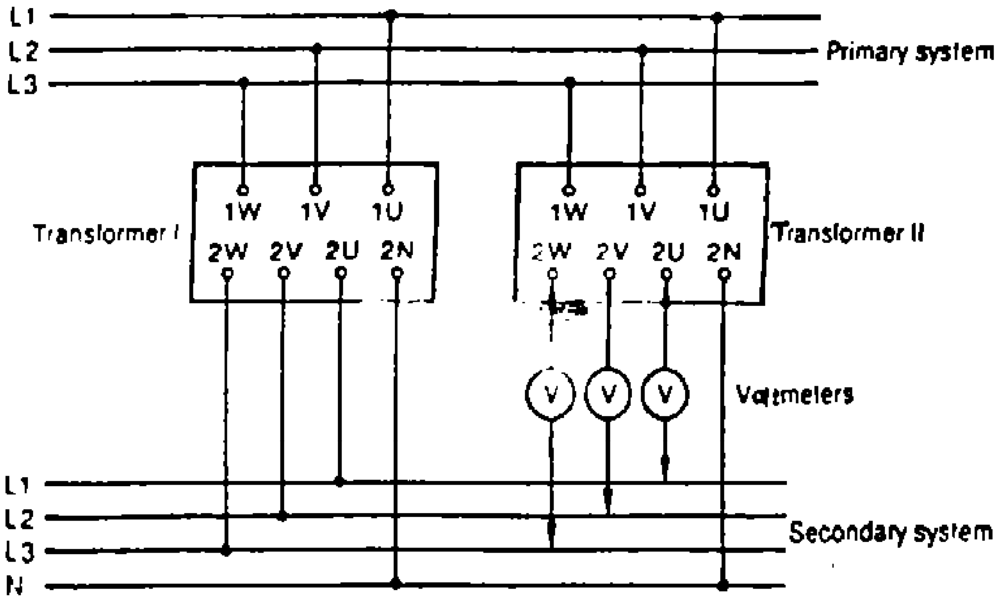
**7.2** Where windings have taps the tapping ranges of the transformers must be the same.

**7.3** Impedance voltages shall be nearly equal, if possible the transformer with the lower power rating should have the higher impedance voltage.

**Notes:**

**1) In all cases of parallel operation it must be ensured that non of the transformers is unduly overloaded.**

**2) The 2N terminals of the transformers to be parallel should be connected to the N busbar of the system and corresponding terminal and phase conductor checked with volt meter. With the correct connection there should be no deflection on the voltmeter(s) see Fig. C4.**




**CHECKING THE PHASE CORRESPONDENCE OF DISTRIBUTION TRANSFORMER**
**Fig. C4**

**3) Division of load with equal ratios**

**With equal rated transformation ratios the total load is divided between the parallel connected transformers in proportion to their rated power, and in inverse proportion to their rated impedance voltages.**

## 8. ENVIRONMENTAL CONDITIONS

**8.1** Site elevation .................... m above sea level.

**8.2** Maximum air temperature ........................... °C.

**8.3** Minimum air temperature ............................ °C.

**8.4** Average relative humidity ........................% ( in a year).

**8.5** Atmosphere:

Saliferrous, dust corrosive and subject to dust storms with concentration of 70-1412 mg/m³, $H_2S$ may be present.

**8.6** Lightning storm: Isoceraunic level ......... storm-day/year.

**8.7** Earthquake zone ........... local earthquake zone.

**Note:**

**Blanks to be filled by client.**

# APPENDIX D
# BATTERIES, CHARGERS AND UPS

## CONTENTS :

PAGE No.

## 1. BATTERIES

Vented or sealed, lead acid or nickel Cadmium batteries are amongst the principal types in widespread use, and it is important that the specified, owner and operator are aware of the significant, albeit subtle differences between them. These ranges from price to reliability, from convenience to safety and from the understood to the unknown. Perhaps the main characteristics can be summarized by the Table D1 with all numerical values quoted here, substantial variations can be found from different suppliers at different times and different places.

**TABLE D1 - BATTERY CHARACTERISTICS COMPARISON**

| CRITERIA | LEAD ACID | | NICKEL CADMIUM | |
|---|---|---|---|---|
| | VENTED | SEALED | VENTED | SEALED |
| Price (%) | 100 | 120 | 200 | 400 |
| Life (years) | 10 | 10 | 20 | 15 |
| Maintenance (months) | 6 | negligible | 12 | negligible |
| Size (%) | 100 | 50 | 150 | 100 |
| Life reduction(%) at 35°C | 50 | not available | 20 | not available |

## 2. RECTIFIERS AND INVERTERS

The introduction of sophisticated automatic control and solid state power electronics has done much to make the UPS an ubiquitous convenient tool of widespread popularity. However, these are also the very characteristics which easily baffle the purchaser of the UPS and lead to an inferior model being selected.

The attributes that solid electronics has brought to the UPS field include:

- close voltage regulation, e.g. ±1 %
- close frequency regulation, e.g. ±0.1 %
- excellent transient response, e.g. 3% voltage for 100% load change
- reliability, e.g. MTBF of 100,000 hr.

However, several ill-effects tend also to be introduced. The principal ones include:

- harmonic interference to the supply
- harmonics induced on the output
- acoustic noise, e.g. 50 to 85 dBA.

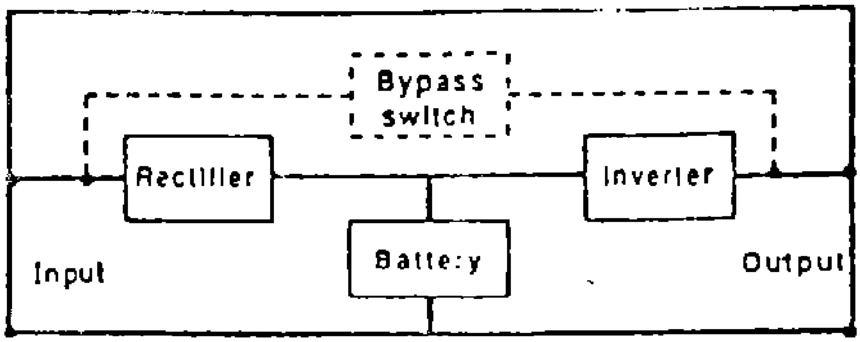
All these characteristics can be specified to values covering a very wide range, and the temptation to overspecify must be balanced against the quite significant affect this will have on initial costs. These costs can be affected over a 3:1 range for smaller UPS's and 1.5:1 range for larger ones.

Interference imposed by a UPS upon the incoming mains can typically be 5% for total harmonic distortion and this can be significant for large installations.

## 3. CHANGEOVER SWITCHES

Where an alternative a.c. back-up supply is used, a changeover switch is often provided. It may use mechanical or solid state electronic technology. For some applications-computers and perhaps remote control-the speed of changeover is important and even when this is in the millisecond range it can be dangerously misleading to describe it as negligible. While the introduction of a changeover switch in smaller simpler configurations is seen as an unnecessary additional complication, in other cases its advantages are significant. These include a reduction in power consumptions, an automatic guard against rectifier failure, facilitation of UPS maintenance and an improvement of protection co-ordination.

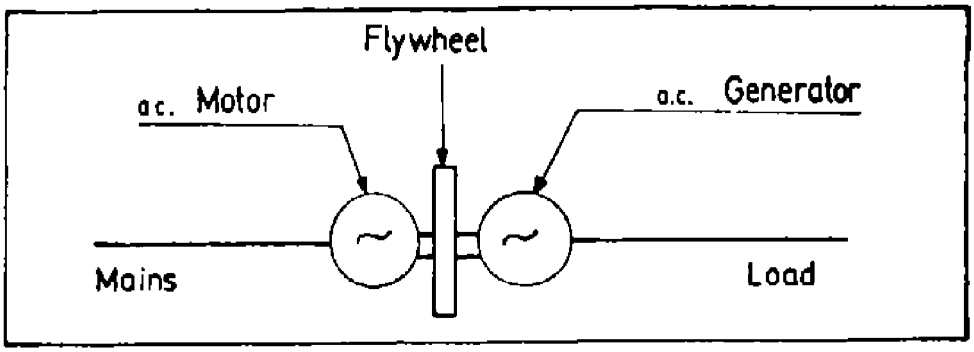
A manual bypass switch is sometimes considered an adequate low-cost alternative where just the maintenance attribute is relevant. Typical bypass switch is shown in Fig. D1.



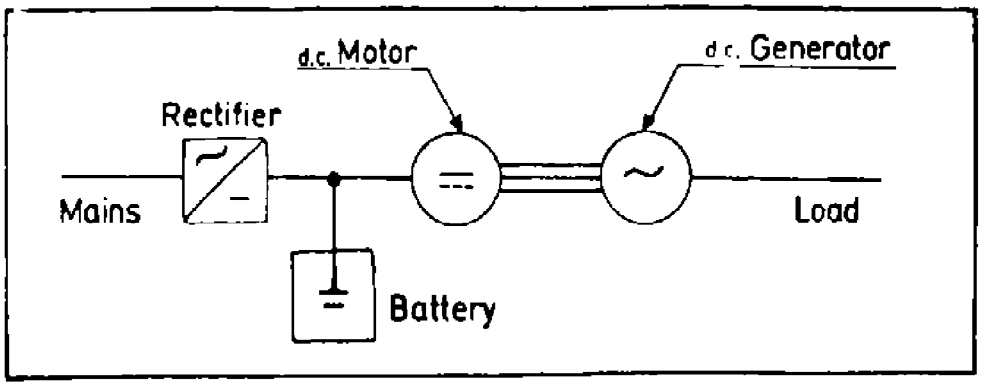

**UNINTERRUPTIBLE POWER SUPPLY**
**Fig. D1**

## 4. REVIEW OF GENERAL TYPES OF UPS SYSTEMS

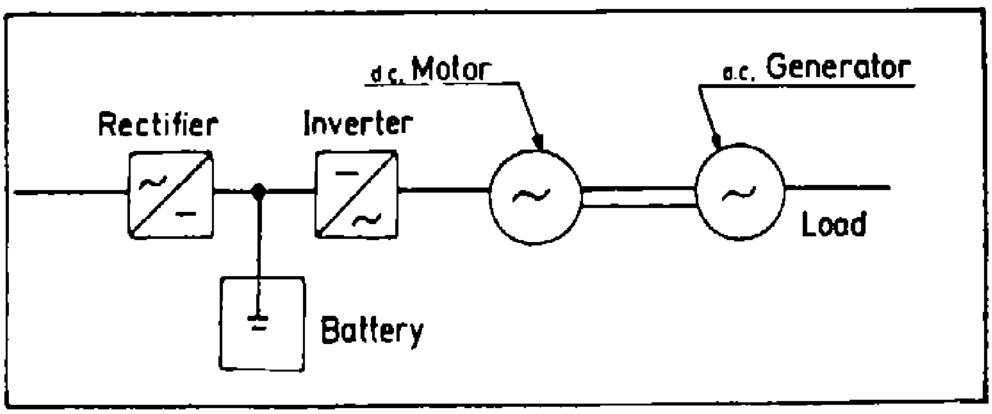
When it is essential that electrical supplies to standby load be maintained without interruption, a UPS must be employed. Virtually by definition, all UPS must have a means of storing energy when the mains supply is available and a means of drawing upon this stored energy when the mains supply is not available. Where the standby load requires an a.c. voltage supply a number of differing types of UPS are currently available. Generally the UPS a.c. output is produced using either a rotating, machine (rotary UPS) or a semiconductor based inverter (static UPS). For static UPS and some rotary UPS, batteries provide the energy source during mains failure. However, the use of rotating machines allows other energy sources such as the rotational energy from flywheels or prime movers to be used. See Fig. D2 (a), (b), (c).




a) Flywheel rotary UPS




b) Battery supported rotary UPS (d.c. motor)




c) Battery supported rotary UPS (a.c. motor)
Fig. D2

## 5. ENVIRONMENTAL FACTORS

A UPS installation may typically be expected to give twenty or more years trouble-free operation. However a number of undesirable characteristics tend to emerge over such a timescale, some sooner some later, and some as a result of post-installation changing expectations as to how it ought to behave. These can be costly or even impractical to alter other than by replacement of the equipment.

Undesirable characteristics include the venting of corrosive and/or hazardous gases, the often-ignored considerable acoustic noise and to the less obvious line-borne electrical noise.

Quite clearly we live in times of rising expectations regarding such matters of quality of performance. Furthermore it is often by no means clear to the designer just what the most appropriate design standard for such environmental factors should be. Any tendency towards an "if in doubt, leave it out" approach at the specification stage needs to be resisted; otherwise a tenderer may well incline to the lowest costs option as his primary guide. Where necessary, a better aim would be, where no appreciable cost nor an exclusion from manufacturer’s available product lines is incurred, to over-specify in such areas.

One example of such trends is move towards lower-maintenance safer batteries, by specifying sealed units. As seen in the Table No. 1 this incurs little extra initial cost, in any case offset by reduced maintenance, and as the trend continues the price differential may close still further.

Another example is safety. Familiarity with motor car-like batteries may tempt staff into forgetting that the terminals can be at dangerously voltages. Installations are now readily available which:

**a)** Place groups of cells into compartments such that step voltages of over 110 V are not exceeded, and
**b)** include doors, perhaps of wire mesh, which are interlocked to disconnect voltages above a safe level when opened.

## 6. CENTRALIZED AND DECENTRALIZED UPS

Where static or rotary UPS are used it must be decided whether loads are supported by individual UPS (decentralized approach) or from a single busbar supplied from a number of parallel operated UPS (centralized approach). Generally the falling cost, weight and space per kVA of static and rotary UPS tend to favor a centralized approach which by comparison with a decentralized approach allows the total installed UPS rating to be minimized while allowing n+1 redundancy and maintainability to be economically incorporated. Technically the centralized approach is quite acceptable provided the interactive effect of separate loads (e.g., waveform distortion and fault clearing) is resolved.

## 7. ELECTROMAGNETIC INTERFERENCE IN UPS DISTRIBUTION SYSTEM

In addition to providing short term support in the event of mains failure, UPS which operate in an on-line mode act as a barrier, effectively isolating the protected system from mains borne disturbances. In certain installations this may be their primary function. However, this important function of the UPS can be completely negated if the design of the UPS distribution system allows electromagnetic coupling with the mains system. Cabling running from the UPS to the uninterruptible loads should therefore be run segregated from mains cable where possible. The need for cable screening should also be examined. The greater is the extent of the cabling in the UPS distribution system the greater the likelihood of electromagnetic compatibility (EMC) problems. The temptation to support extended system such as security and fire detection from the same source as is used for computers and telecommunications should be avoided.

Other aspects such as the design of system earthing and the EMC polluting effects of UPS load should also be considered at the design stage.

## 8. IMPLEMENTATION OF UPS

The implementation will generally follow the same stages as that of the project of which it is a part. Such stages may include a conceptual study, a feasibility study and an outline design leading to a procurement specification. Where these are undertaken by an independent consultant, the manufacturer's views might only be injected at the end of these stages.

It is important that these views are taken into consideration before the main decisions at each stage are effectively frozen. For instance, typically the energy transfer efficiency at full load is some 90% and thus a heat dissipation of 10% should be allowed for in the installation design.

It has been said that 70% of the decisions have been taken by the feasibility study stage and it would be a poor design that had not allowed for currently available performance specification values. For large UPS's incorporated in major building installations, it will thus be worth considering what is involved in these separate stages. The first is the conceptual stage. Here basic questions are dealt with, like.

**a)** is a UPS really needed, in preference to alternatives;
**b)** is it needed for small computer loads, emergency lighting or a more extensive portion of the load;
**c)** what are the space and maintenance cost implications?

Second is the feasibility stage where an initial assessment is made of performance needs, integration into the supply-load network, cost-benefit analyses of various size options, location, environmental impact, etc.

The third stage covers design and specification leading to a quotation, which may then be accepted for the fourth, or provision (supply and installation) stage. Finally tests if may be necessary, especially for larger installations. A set of artificial small and full-loads may be needed to simulate the real full load, should that not be available at this stage. Alternatively if factory acceptance tests were judged adequate, this stage may become routine. In either case it is good practice to set down a list of the tests, the acceptance values, and the measured values.

With the increasing cost of maintenance and an increasing realization that this is largely determined at the design stage, greater emphasis is being placed upon life cycle costing.

The owner an operator need to be made aware that although a UPS grossly reduces the probability of a black-out (or even a brown-out), it does not absolutely eliminate it. The residual risk may be worth quantifying.

## 9. UPS SYSTEM FAULT DISCRIMINATION

The fault clearing performance of any UPS fed system which supplies more than one load should be examined at the design stage because achieving the required performance can influence both UPS and system design. In particular the time to clear short circuit feeder faults by protective devices should be assessed and compared with tolerances acceptable to connected equipment. While the fault is present on the system the volts of the faulted phase or phases will be negligible and therefore effectively constitutes a supply interruption. For certain computer based systems supply interruptions of more than 10-20 ms can adversely affect their operation. Therefore, protective feeder devices such as circuit breakers of fuses should be selected such that total fault clearance times of 10-20 ms can be achieved. In practice this means that in view of available circuit breaker and fuse characteristics the maximum feeder load which may be connected is determined by the fault current which the UPS may deliver. The lower the fault level the lower the maximum feeder rating.

For standard static UPS fault levels are typically limited to 150-200% of full load current. Maximum feeder ratings using standard fuse and switchgear are as a result limited to 10-15% of full load current level if fault clearance times of 10-20 ms are required.

An important point to note is that in UPS systems where fault levels are important and rotary UPS appear attractive ensure that adequate discrimination between the feeder protection and the UPS output protection can be achieved. For certain rotary UPS, fault clearance times of greater than 10 ms May cause the UPS to trip. A single feeder fault would then cause total collapse of the system.

## 10. NON-LINEAR LOADING

It is a common requirement imposed by manufacturers of computer and telecommunications systems that total harmonic distortion (THD) of the supply voltage waveform should not exceed 5-10%. The same equipment is also often responsible for distorting the voltage waveform because of the highly non-linear load currents they draw from the supply source. In general the UPS industry guarantees a voltage THD of less than 5% only on the basis of a linear load. Achieving a 5% voltage THD on a non-linear load can often result in uprating or the application of filters.

## APPENDIX E
## STATIC POWER FACTOR CORRECTION EQUIPMENT

## CONTENTS :

PAGE No.

## 1. ALTERNATING CURRENT POWER CONCEPTS

Active or real power flows in one direction from the generator source to the load where it is converted into another form of energy usually mechanical external to the circuit. Reactive or apparent power flows to and fro, and remains within the electric circuits without performing useful work.

Lagging reactive power from a magnetic field is opposite in time, phase to leading reactive power from an electrostatic field and when the two are present in equal quantities at the load end of the circuit no reactive power flows between generator and the load.

When the leading and lagging reactive power flows are unequal the difference will flow between the generator and the load. The term power factor is the mathematical ratio of active to total current. Most utilization devices require two components of current.

**a)** magnetizing current (reactive current);
**b)** power producing current (active current).

These two components of current are vectorially at right angles to each other and the total current can be determined from the expression:

***(total current)² = (active current)² + (reactive current)²***

$$(\text{total current})^2 = (\text{active current})^2 + (\text{reactive current})^2$$

At a common voltage point, Kva and kw are proportional to current, therefore:

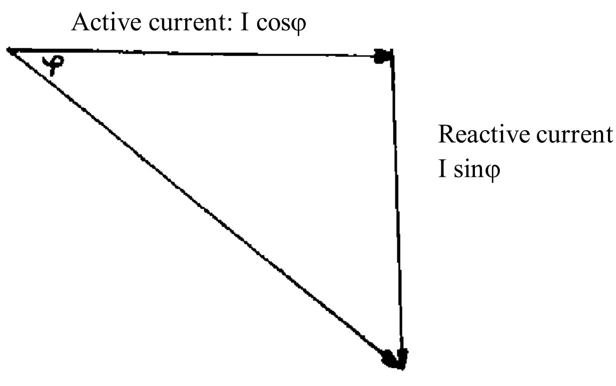
$$(V1)^2 = (V1\cos\varphi)^2 + (V1\sin\varphi)^2$$

$$(Kva)^2 = (Kw)^2 + (K\,var.)^2$$

Power factor can be expressed as ratio of active current to the total current. In more useful form it is the ratio of "Kw" to the total "Kva" thus:

$$Power\ factor = \frac{Kw}{Kva}$$

From the right triangle relationship in Fig. E1:




$$Kw = Kva\cos\varphi$$

$$Thus\ P.F. = \frac{Kw}{Kva} \quad \cos\varphi$$

**Fig. E1**

The angle ρ is known as the power factor angle. Power factor is the cosine of that angle usually expressed as a percent.

## 2. LEADING AND LAGGING POWER FACTOR

Power factor may be lagging or leading depending on the direction of both kilowatt and magnetizing kilovar flow.

From the stand point of an industrial load which requires kilowatts its power factor is "lagging", if it requires kilovars and leading, it supplies kilovars. Thus an induction motor has a lagging power factor because its magnetizing kilovars must be supplied by other kilovar sources. On the other hand a capacitor or an over excited synchronous motor can supply magnetizing kilovars and therefore these have leading factors. Thus in effect leading kilovars balance lagging kilovars. Incancedent lamps require no kilovars and therefore have unity power factor that is neither lagging nor leading.

## 3. POWER FACTOR IMPROVEMENT BENEFITS

All the benefits provided by power factor improvement, stems from the reduction of magnetizing kilovars. This reduction results in:

- lower purchased power cost;
- increased system capacity;
- voltage improvement and;
- lower system losses.

Maximum benefits are obtained when capacitors on synchronous motors are located at the load where the low power factor exists.

### 3.1 Power Cost Saving

The rate structures of many utility companies include power factor clauses which result in increased power cost when the power factor is below a specified level.

Power factor may be the monthly average or it may be measured at time of maximum kilowatt demand or during normal demand.

The daily load chart will show how much improvement in power factor can be obtained during each period and permit a calculation of the power bill savings based on the particular power factor clause.

### 3.2 Increase in System Capacity

When the reactive current in a circuit is reduced the total current is also reduced, thus if a capacitor is connected to a lagging power factor load, the total or line current is reduced i.e., certain amount of current has been released the same release of system capacity can be obtained whenever a cable, transformer, or generator is loaded at a low power factor.

Since system capacity can be increased by additional distribution facilities, as well by power factor improvement, with capacitors or synchronous machines, the installed costs of alternate equipment must be compared.

In many cases the cost comparison will be in favor of adding of capacitors. In those cases where the costs are equal the addition of capacitors may be warranted because of other benefits such as reduced losses and voltage improvement.

### 3.3 Improvement in Voltage Condition

Although it is not usually economical to improve power factor solely to improve system voltage, the voltage improvement is a significant benefit. Since circuit current is reduced when the power factor is improved the voltage drop is also reduced.

The amount of reduction depends on the reactance of the circuit as well as the magnitude of power factor of the load.

### 3.4 Decrease in Power Losses

The reduction in electric losses due to power factor improvement can result in a considerable annual gross return (of as much as 15% of investment in power factor improvement) losses are proportional to the total current squared.

Since total current varies inversely as the power factor. The reduction in losses is inversely proportional to the square of the power factor:

$$\textit{Loss reduction} = \textit{Original loss} \left[ 1 - \left( \frac{\text{original PF}}{\text{improved PF}} \right)^2 \right]$$

This equation assumes that the kilowatt load remains the same. If kilowatt load is increased to take advantage of the released system capacity the loss reduction will not be as great .

## 4. GENERATION AND CONSUMPTION OF REACTIVE POWER

Most apparatus connected to a power supply network, not only requires active power, but also a certain amount of reactive power. Magnetic fields in motors and transformers are maintained by reactive current. Series inductance in transmission lines implies consumption of reactive power. Reactors, fluorescent lamp and all inductive circuits on the whole require a certain amount of reactive power to work. Approximate reactive power requirements for different components are given in Table E1.

Reactive power may be generated by means of rotating compensators or synchronous generators or capacitors as follows:

#### a) Rotating compensators

**I) Synchronous generators** at power stations produce reactive power at a relatively low cost, but at the expense of their ability to produce active power. With regard to transmission problems, it is generally considered preferable to produce reactive power by using generators situated centrally in the networks.

**II) Synchronous condensers** are situated at certain feed points in power supply networks. These machines are continuously variable within wide limits to generate as well as to consume reactive power. Due to high initial costs and losses, synchronous condenser are solely motivated where their voltage regulating and stabilizing effects are necessary.

**III) Synchronous motors** can be overexcited for the purpose of producing reactive power. However, due to small synchronous motors being much more expensive, when compared to normal asynchronous motors, they are seldom used.

#### b) Capacitors

As opposed to the rotating machines, the capacitor is a device with no moving parts, which generates reactive power. By series and parallel connecting an adequate number of units, banks for any output and voltage can be designed. Low voltage capacitor banks, i.e., banks for 660 V system voltage and below, are normally built up from three-phase units. Unit output varies between 2 and 130 kvar approximately. Thus, the size of low voltage plant may vary considerably, from one single unit, giving a few kvar only, to several parallel connected units with a total output of more than 1000 kvar.

Capacitors are, by comparison, the simplest and cheapest means of relieving the load of transformers, supply networks and industrial distribution system. Investments in equipment for power factor correction are today generally made in capacitors. New dielectric materials have made it possible to increase output per unit and to reduce losses considerably, thus making compensation by means of capacitors more profitable in comparison with rotating compensators.

**TABLE E1 - APPROXIMATE REACTIVE POWER REQUIREMENTS**

| Component | Reactive power requirement |
|---|---|
| Transformers | approx. 0.05 Kvar/kVA |
| Induction motors | 0.5 - 0.9 kvar/kW |
| Fluorescent lamps | approx. 2 kvar/kW |
| Transmission lines | 20 - 50 kvar/kW |

## 5. DETERMINATION OF CAPACITOR OUTPUT

Table E2 is a power factor correction table to simplify the calculation involved in determining the capacitor size necessary to improve the power factor of a given load from original to desired value.

### Example 1:

Assume that a 700 kVA load has a 65 per cent power factor. It is desired to improve the power factor to 92% using Table E2 determine the following:

### Solution:

From Table E2 the correction factor can be found at intersection of lines from 65% (horizontal) and from 92% vertical to be 74% .

**The 700 kVA load at 65% P.F. is equal to 700 × 65% = 455 kw**

**Capacitor size = 455 (correction factor) = 455 × (74%) = 366.7 kvar**

The nearest standard size shall be selected.

## TABLE E2 - POWER-FACTOR CORRECTION

| Reactive Factor | Orig. Power Factor % | Correcting Factor: Desired Power Factor, % | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 |
| 0.800 | 60 | 0.584 | 0.610 | 0.636 | 0.662 | 0.688 | 0.714 | 0.741 | 0.767 | 0.794 | 0.822 | 0.850 | 0.878 | 0.905 | 0.939 | 0.971 | 1.005 | 1.043 | 1.083 | 1.311 | 1.192 | 1.334 |
| 0.791 | 61 | 0.549 | 0.575 | 0.601 | 0.627 | 0.653 | 0.676 | 0.706 | 0.732 | 0.759 | 0.787 | 0.815 | 0.843 | 0.870 | 0.904 | 0.936 | 0.970 | 1.008 | 1.048 | 1.096 | 1.157 | 1.299 |
| 0.785 | 62 | 0.515 | 0.541 | 0.567 | 0.593 | 0.619 | 0.645 | 0.672 | 0.698 | 0.725 | 0.753 | 0.781 | 0.809 | 0.836 | 0.870 | 0.902 | 0.936 | 0.974 | 1.014 | 1.062 | 1.123 | 1.265 |
| 0.776 | 63 | 0.483 | 0.509 | 0.535 | 0.561 | 0.587 | 0.613 | 0.640 | 0.666 | 0.693 | 0.721 | 0.749 | 0.777 | 0.804 | 0.838 | 0.870 | 0.904 | 0.942 | 0.982 | 1.030 | 1.091 | 1.233 |
| 0.768 | 64 | 0.450 | 0.476 | 0.502 | 0.528 | 0.554 | 0.580 | 0.607 | 0.633 | 0.660 | 0.688 | 0.716 | 0.744 | 0.771 | 0.805 | 0.837 | 0.871 | 0.909 | 0.949 | 0.997 | 1.058 | 1.200 |
| 0.759 | 65 | 0.419 | 0.445 | 0.471 | 0.479 | 0.523 | 0.549 | 0.576 | 0.602 | 0.629 | 0.657 | 0.685 | 0.713 | 0.740 | 0.774 | 0.806 | 0.840 | 0.878 | 0.918 | 0.966 | 1.027 | 1.169 |
| 0.751 | 66 | 0.388 | 0.414 | 0.440 | 0.466 | 0.492 | 0.518 | 0.545 | 0.571 | 0.598 | 0.626 | 0.654 | 0.682 | 0.709 | 0.743 | 0.775 | 0.809 | 0.847 | 0.887 | 0.935 | 0.996 | 1.138 |
| 0.744 | 67 | 0.358 | 0.384 | 0.410 | 0.436 | 0.462 | 0.488 | 0.515 | 0.541 | 0.568 | 0.596 | 0.624 | 0.652 | 0.679 | 0.713 | 0.745 | 0.779 | 0.817 | 0.857 | 0.905 | 0.966 | 1.108 |
| 0.733 | 68 | 0.329 | 0.355 | 0.381 | 0.407 | 0.433 | 0.459 | 0.486 | 0.512 | 0.539 | 0.567 | 0.595 | 0.623 | 0.650 | 0.684 | 0.716 | 0.750 | 0.788 | 0.828 | 0.876 | 0.937 | 1.079 |
| 0.725 | 69 | 0.299 | 0.325 | 0.351 | 0.377 | 0.403 | 0.429 | 0.456 | 0.482 | 0.509 | 0.537 | 0.565 | 0.593 | 0.620 | 0.654 | 0.686 | 0.720 | 0.758 | 0.798 | 0.840 | 0.907 | 1.049 |
| 0.714 | 70 | 0.270 | 0.296 | 0.322 | 0.348 | 0.374 | 0.400 | 0.427 | 0.453 | 0.480 | 0.508 | 0.536 | 0.564 | 0.591 | 0.625 | 0.657 | 0.691 | 0.729 | 0.769 | 0.811 | 0.878 | 1.020 |
| 0.704 | 71 | 0.242 | 0.268 | 0.294 | 0.320 | 0.346 | 0.372 | 0.399 | 0.425 | 0.452 | 0.480 | 0.508 | 0.536 | 0.563 | 0.597 | 0.629 | 0.663 | 0.700 | 0.741 | 0.783 | 0.850 | 0.992 |
| 0.694 | 72 | 0.213 | 0.239 | 0.265 | 0.291 | 0.317 | 0.343 | 0.370 | 0.396 | 0.423 | 0.451 | 0.479 | 0.507 | 0.534 | 0.568 | 0.600 | 0.634 | 0.672 | 0.712 | 0.754 | 0.821 | 0.963 |
| 0.682 | 73 | 0.186 | 0.212 | 0.238 | 0.264 | 0.290 | 0.316 | 0.343 | 0.369 | 0.396 | 0.424 | 0.452 | 0.480 | 0.507 | 0.541 | 0.573 | 0.607 | 0.645 | 0.685 | 0.727 | 0.794 | 0.936 |
| 0.673 | 74 | 0.159 | 0.185 | 0.211 | 0.237 | 0.263 | 0.289 | 0.316 | 0.342 | 0.369 | 0.397 | 0.425 | 0.453 | 0.480 | 0.514 | 0.546 | 0.580 | 0.618 | 0.658 | 0.700 | 0.767 | 0.909 |
| 0.661 | 75 | 0.132 | 0.158 | 0.184 | 0.210 | 0.236 | 0.262 | 0.289 | 0.315 | 0.342 | 0.370 | 0.398 | 0.426 | 0.453 | 0.487 | 0.519 | 0.553 | 0.591 | 0.631 | 0.673 | 0.740 | 0.882 |
| 0.650 | 76 | 0.105 | 0.131 | 0.157 | 0.183 | 0.209 | 0.235 | 0.262 | 0.288 | 0.315 | 0.343 | 0.371 | 0.399 | 0.426 | 0.460 | 0.492 | 0.526 | 0.564 | 0.604 | 0.652 | 0.713 | 0.855 |
| 0.637 | 77 | 0.079 | 0.105 | 0.131 | 0.157 | 0.183 | 0.209 | 0.236 | 0.262 | 0.289 | 0.317 | 0.345 | 0.373 | 0.400 | 0.434 | 0.466 | 0.500 | 0.538 | 0.578 | 0.620 | 0.687 | 0.829 |
| 0.626 | 78 | 0.053 | 0.079 | 0.105 | 0.131 | 0.157 | 0.183 | 0.210 | 0.236 | 0.263 | 0.291 | 0.319 | 0.347 | 0.374 | 0.408 | 0.440 | 0.474 | 0.512 | 0.552 | 0.594 | 0.661 | 0.803 |
| 0.613 | 79 | 0.026 | 0.052 | 0.078 | 0.104 | 0.130 | 0.156 | 0.183 | 0.209 | 0.236 | 0.264 | 0.292 | 0.320 | 0.347 | 0.381 | 0.413 | 0.447 | 0.485 | 0.525 | 0.567 | 0.634 | 0.776 |
| 0.600 | 80 | 0.000 | 0.026 | 0.052 | 0.078 | 0.104 | 0.130 | 0.157 | 0.183 | 0.210 | 0.238 | 0.266 | 0.294 | 0.321 | 0.355 | 0.387 | 0.421 | 0.459 | 0.499 | 0.541 | 0.608 | 0.750 |
| 0.588 | 81 | | 0.000 | 0.026 | 0.052 | 0.078 | 0.104 | 0.131 | 0.157 | 0.184 | 0.212 | 0.240 | 0.268 | 0.295 | 0.329 | 0.361 | 0.395 | 0.433 | 0.473 | 0.515 | 0.582 | 0.724 |
| 0.572 | 82 | | | 0.000 | 0.026 | 0.052 | 0.078 | 0.105 | 0.131 | 0.158 | 0.186 | 0.214 | 0.242 | 0.269 | 0.303 | 0.335 | 0.369 | 0.407 | 0.447 | 0.489 | 0.556 | 0.698 |
| 0.559 | 83 | | | | 0.000 | 0.026 | 0.052 | 0.079 | 0.105 | 0.132 | 0.160 | 0.188 | 0.216 | 0.243 | 0.277 | 0.309 | 0.343 | 0.381 | 0.421 | 0.463 | 0.530 | 0.672 |
| 0.543 | 84 | | | | | 0.000 | 0.026 | 0.053 | 0.079 | 0.106 | 0.134 | 0.162 | 0.190 | 0.217 | 0.251 | 0.283 | 0.317 | 0.355 | 0.395 | 0.437 | 0.504 | 0.646 |
| 0.529 | 85 | | | | | | 0.000 | 0.027 | 0.053 | 0.080 | 0.108 | 0.136 | 0.164 | 0.191 | 0.225 | 0.257 | 0.291 | 0.329 | 0.369 | 0.417 | 0.478 | 0.620 |
| 0.510 | 86 | | | | | | | 0.000 | 0.026 | 0.053 | 0.081 | 0.109 | 0.137 | 0.167 | 0.198 | 0.230 | 0.265 | 0.301 | 0.342 | 0.390 | 0.451 | 0.593 |
| 0.497 | 87 | | | | | | | | 0.000 | 0.027 | 0.055 | 0.083 | 0.111 | 0.141 | 0.172 | 0.204 | 0.239 | 0.275 | 0.316 | 0.364 | 0.425 | 0.567 |
| 0.475 | 88 | | | | | | | | | 0.000 | 0.028 | 0.056 | 0.083 | 0.113 | 0.144 | 0.176 | 0.211 | 0.247 | 0.288 | 0.336 | 0.397 | 0.540 |
| 0.455 | 89 | | | | | | | | | | 0.000 | 0.028 | 0.055 | 0.086 | 0.117 | 0.149 | 0.183 | 0.221 | 0.262 | 0.309 | 0.370 | 0.512 |
| 0.443 | 90 | | | | | | | | | | | 0.000 | 0.028 | 0.058 | 0.089 | 0.121 | 0.155 | 0.193 | 0.234 | 0.281 | 0.342 | 0.484 |
| 0.427 | 91 | | | | | | | | | | | | 0.000 | 0.030 | 0.061 | 0.093 | 0.127 | 0.165 | 0.206 | 0.253 | 0.314 | 0.456 |
| 0.392 | 92 | | | | | | | | | | | | | 0.000 | 0.031 | 0.063 | 0.097 | 0.135 | 0.176 | 0.223 | 0.284 | 0.426 |
| 0.386 | 93 | | | | | | | | | | | | | | 0.000 | 0.032 | 0.066 | 0.104 | 0.145 | 0.192 | 0.253 | 0.395 |
| 0.341 | 94 | | | | | | | | | | | | | | | 0.000 | 0.035 | 0.072 | 0.113 | 0.160 | 0.221 | 0.363 |
| 0.327 | 95 | | | | | | | | | | | | | | | | 0.000 | 0.036 | 0.078 | 0.125 | 0.186 | 0.328 |
| 0.280 | 96 | | | | | | | | | | | | | | | | | 0.000 | 0.041 | 0.089 | 0.150 | 0.292 |
| 0.242 | 97 | | | | | | | | | | | | | | | | | | 0.000 | 0.048 | 0.109 | 0.251 |
| 0.199 | 98 | | | | | | | | | | | | | | | | | | | 0.000 | 0.061 | 0.203 |
| 0.137 | 99 | | | | | | | | | | | | | | | | | | | | 0.000 | 0.142 |

## 6. CAPACITOR LOCATIONS

When the required reactive power is determined, the next question is where to install the capacitors. The location, of course, depends on the object and the motive for compensating. To state clear directions for location and distribution is difficult, however the following general rules should be considered.

**6.1** Place the capacitors as close as possible to the load for compensation. The largest profit from reduced losses and the highest voltage increase are thereby obtained.

**6.2** At first hand, install capacitors which make it possible to postpone an immediate or imminent extension of the existing plant or network.

**6.3** Aim at covering the reactive minimum load by fixed capacitors, to reduce the cost of installation (switchgear etc.). The minimum load is usually 20-30 per cent of the maximum load. The remainder is supplied by automatically switched capacitors.

**6.4** Allocate the reactive power on more than one bank or step, if switching of the capacitors causes too high voltage fluctuations. Normally, fluctuations not exceeding 2% are acceptable at one switching in/out per hour, 3% at one switching in/out per 24 hours and 5% at seasonal switching.

The advantage of allocating the reactive power on more than one bank must be weighed against the fact that the price per kvar increases with decreasing bank size. A schematic diagram of different capacitor location is shown in Fig. E2.

## 7. TYPE OF COMPENSATION

### 7.1 Central Compensation

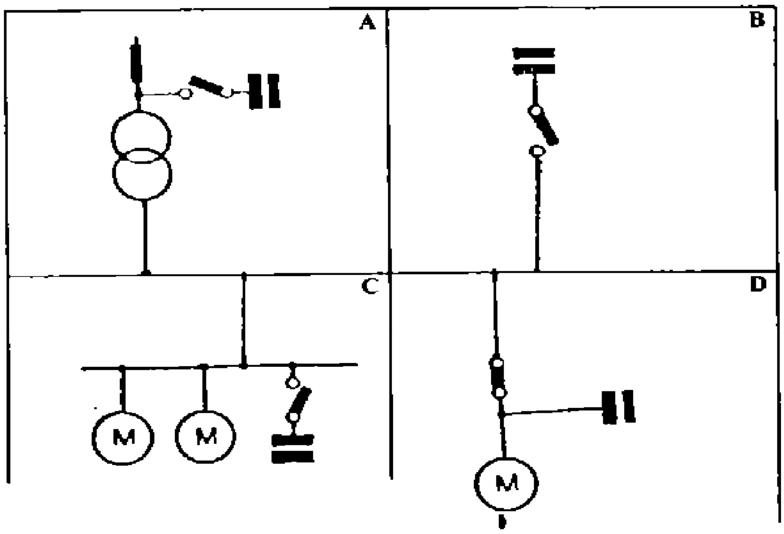
When the main purpose is to reduce reactive power purchase, due to power supplier's tariffs, central compensation is preferable. Reactive loading condition within a plant are not affected if compensation is made on the high voltage side (alternative A). When made on the low voltage side (alternative B), the transformer is relieved. Cost of installation on the high voltage and the low voltage side respectively and the possible need for relieving the transformer will thus determine where to install the capacitors. At a fluctuating reactive load automatic low voltage capacitors with the capacitor output split into a number of steps, may be preferable.

### 7.2 Group Compensation

Group compensation (alternative C) instead of central compensation is preferable if sufficiently large capacitors can be utilized. In addition to what is obtained at central compensation,load on cables is reduced and losses decrease. Reduced losses often make group compensation more profitable than central compensation.

### 7.3 Individual Compensation

The special advantage with individual compensation (alternative D) is that existing switching and protective devices for the machine to be compensated can also be utilized for switching and protection of the capacitors. The costs are thereby limited solely to purchasing the capacitors. Another advantage is gained by the capacitor being automatically switched in and out, in step with the load. However, this signifies that individual compensation is solely motivated for apparatus and machines which have a very good load factor. Large machines with a good load factor are always suitable for individual compensation. Small machines require small capacitors and the prices per kvar increases as the size of capacitor decreases. Thus cost of installation for individual compensation must be compared with that of group or central compensation. The lower losses at individual compensation must, of course, be considered.




A Central compensation on the high voltage side
B Central compensation on the low voltage side
C Group compensation
D Individual compensation

**SCHEMATIC DIAGRAM OF DIFFERENT Pf CORRECTION ALTERNATIVES**
**Fig. E2**

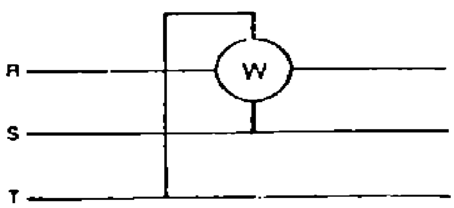
### 7.4 Measurement of Reactive Power and Power Factor

Where no permanent meters are installed for measuring reactive power and power factor, measurement can be carried out easily, by using a wattmeter and clip-on power-factor meter. When the load is symmetrical a single-phase wattmeter is used, connected as shown in Fig. E3, i.e., the current is measured in one phase and the voltage between the two other phases.

When no power-factor meter is available, the power-factor may be calculated if reactive and active power are measured first:

$$\cos \varphi = \frac{1}{\sqrt{1 + \left(\frac{Q}{P}\right)^2}}$$

At unsymmetrical load the two-wattmeter method can be used determining the power-factor. The calculation is ade from the formulas below, where ($P_1$) and ($P_2$) are the active powers for the two wattmeters.




**SINGLE-PHASE MEASUREMENT OF REACTIVE POWER**
**Fig. E3**

## 8. AUTOMATIC CAPACITOR BANKS

The majority of industrial plants work in one or two shifts, weekends and holidays being free. This signifies that plants with central or group compensation are often overcompensated during periods of low-load, if they are not fitted with automatic regulation of reactive power.

If the capacitor output is fixed when the load decreases, total (apparent) load will be capacitive at low active load, i.e., the plant will generate reactive power to the power supply network. See top of Fig. E4, (S) decreases to (S') .Sometimes the power supplier prescribes that reactive power may not be fed out into the network during off-peak load periods.

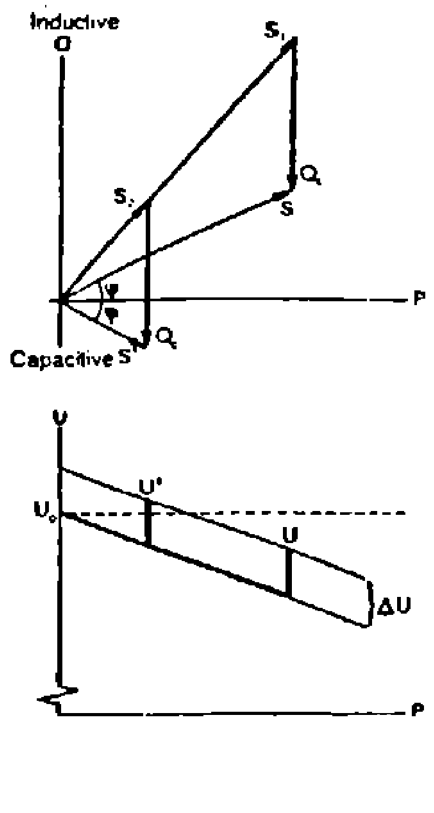
The voltage increase caused by the capacitors is usually an advantage for loaded networks. With decreasing load the voltage drop decreases and consequently the voltage increase. See bottom of figure; U increases to (U') the capacitors still produce the same voltage increase ( $\Delta U$) and the system voltage may thus be unacceptably high.

In order to avoid the above disadvantages, equipment for group or central compensation is often provided with automatic regulation, switching capacitors in and out in step with the load.

These automatic regulators can be designed with one or several steps. However plants do not require several steps, if the load remains stable during a work shift. When large load fluctuations exist, it may be suitable to use an automatic bank having several steps.

Switching of the capacitors is regulated by a power-factor relay keeping the power-factor at the setting value. Automatic low voltage banks may be installed in cubicles or they may be delivered as complete banks with capacitors, power-factor relay, fuses and breakers in one enclosed unit.

The automatic banks with division into several steps make it possible to keep a smooth and high power-factor with a fluctuating load.




**THE EFFECT OF A CAPACITOR AT LOW AND HIGH LOADS**
**Fig. E4**

## 9. POWER-FACTOR CORRECTION CUBICLE

Power factor correction cubicles are designed to provide either a separate free standing arrangement or alternatively an integral extension to an existing low voltage switchgear assembly. Each arrangement may provide the following:

- Automatic control of power factor.
- Direct connection to switchgear assembly without cabling.
- Various sizes of unit in 50 kvar steps.
- Each capacitor section individually controlled and protected.
- No volt feature in control relay disconnects capacitors in event of power failure.
- Low loss environmentaly safe capacitors.

**Note:**

**For more information on installation of capacitors on electric circuits refer to article 460 National Electrical code.**

## APPENDIX F
## HEAT TRACING

## CONTENTS :

PAGE No.

# 1. DESIGN OF ESH SYSTEMS

## 1.1 General Requirements

**1.1.1** The ESH system should generally be designed in accordance with BS 6351: Part 2.

**1.1.2** Calculations should be made to ascertain the heating requirements of each zone or zones associated with a particular part of the plant or process, either:

**a)** to maintain the pipe, vessel or other container, and the material within at the required temperature, or
**b)** to raise the temperature of the material to the desired value within a prescribed time.

**1.1.3** The information required for the above calculations is listed in BS 6351: Part 2, Clause 6.3, items (a) to (m) inclusive.

## 1.2 Selection of Heating Devices

**1.2.1** Devices should be selected to achieve the most cost effective design for the application under consideration, taking account of both capital and revenue expenditure.

**1.2.2** The heating devices should comply with BS 6351: Part 1 and should be of the appropriate grade in accordance with Tables 1 and 2 of that document.

**1.2.3** All devices should satisfy the type tests in BS 6351: Part 1, Clause 8.1.

**1.2.4** ESH devices for indoor application in non-hazardous areas may be selected from the grades listed in the tables contained in BS 6351: Part 1 in accordance with the location with respect to the possibility of exposure to moisture or mechanical damage.

**1.2.5** ESH devices for indoor application in hazardous areas may be specified in accordance with BS 6351: Part 2, Tables 3 and 4, taking into account their location in respect of exposure to moisture or mechanical damage.

**1.2.6** ESH devices for outdoor application in either hazardous or non-hazardous areas should be specified as grade 22 as contained in BS 6351: Part 2, Table 1- Service Categories.

**1.2.7** For temperature maintenance duties a stabilized design is preferred, i.e. a design which will stabilize under all conditions that may be reasonably foreseen, including empty pipe and no-flow conditions at a temperature below the maximum withstand temperature of the ESH device, the maximum withstand temperature of the workpiece and its contents, and the hazardous area temperature classification, if any.

**1.2.8** Where economically justified, e.g., for short heater lengths, frost protection, low process temperature, the use of self limiting ESH devices is preferred.

**1.2.9** In hazardous areas, for site assembled and connected heating tapes/cables, tape/cable units and surface heating units, all items of the assembly e.g., tapes/cables, junction boxes etc., shall be certified or have component approval by a recognized Certifying Authority for the apparatus group and temperature classification relevant to the hazardous area classification, in accordance with the applicable requirements of BS 4683, BS 5501 or BS 6941.

**1.2.10** Factory completed heating/tap cable units and surface heating units installed in hazardous areas shall be certified by a recognized certifying authority as complying with the requirements of BS 4683, BS 5501 or BS 6941 for relevant apparatus group and temperature class.

**1.2.11** The ESH device maximum withstand temperature shall exceed the maximum workpiece, i.e. pipe or vessel, temperature under all foreseeable conditions of operation, including steam cleaning during maintenance, otherwise irreparable heater damage may result.

**1.2.12** Where practicable, heating tapes/cables on horizontal pipe runs should be selected to runs straight, without spiraling. Straight runs of tape should be installed on the bottom quadrants of such pipe runs, at 45 degrees to the horizontal, to avoid the possibility of being immersed in any water which may gather at the bottom of the pipe insulation.

## 1.3 System Protection

**1.3.1** The minimum requirements for the protection of ESH devices in the event of faults are specified in BS 6351: Part 2, Tables 2, 3 and 4.

**1.3.2** Overcurrent protection shall be provided on all devices. This may be either a fuse or a miniature circuit breaker. The overcurrent settings should ensure that tripping does not occur when switching on the device at minimum ambient temperature and a cold workpiece.

**1.3.3** Residual current protection, with trip indication, shall be provided on all devices in hazardous areas and on devices in non-hazardous areas liable by location to be mechanically damaged.

**1.3.4** On devices for temperature maintenance on lines or vessels containing material which would set solid if the heating is lost under 'no-flow' conditions, e.g. bitumen lines, overcurrent and RCD operation alarm shall be provided at a manned location. Consideration should also be given to the provision of a spare heating device.

**1.3.5** On short heating circuits, involving low capacitance currents, the preferred RCD setting is 30 mA operating in 30 m. sec. on longer lines with larger capacitance currents, the setting of the RCD should not exceed 100 mA operating in 100 m. sec.

**1.3.6** All protection and isolating devices should have the position of the contacts clearly indicated.

## 1.4 System Temperature Control

**1.4.1** ESH systems of a stabilized design are preferred wherever practicable, e.g. in systems designed for temperature maintenance only. With a stabilized design an overtemperature controller should not be necessary. However BS 6351: Part 2 recommends that the designed heat (power) input makes allowance for low supply voltage and high resistance tolerances, together with an additional 10% allowance. This could result in a higher stabilized temperature than required even at minimum ambient and product temperature. The installation of a temperature controller should be considered for energy conservation and to reduce running cost.

**1.4.2** The same considerations in 1.4.1 apply to ESH designs incorporating self-limiting ESH devices.

**1.4.3** On non-stabilized designs of systems in non-hazardous areas a temperature controller only needs to be fitted to each zone in the event that overheating would result in damage to the ESH device or the materials being heated. However, the installation of a temperature controller should be considered to reduce running costs.

**1.4.4** On non-stabilized systems in hazardous areas the installation of two temperature controllers to each heating zone is essential. One controller should be used for over-temperature control. The second controller is a standby to the first for over-temperature control, but whilst the first is operationally serviceable, it may be used at a lower temperature setting for process control or to reduce running costs. In zone 1 hazardous areas the over-temperature controller should be a lock-out type and fitted with an alarm and fail to safety.

**1.4.5** Over-temperature control sensors should be located in the zone where it is estimated that the maximum temperature will occur, if practicable.

**1.4.6** Where required, air temperature thermostats should be sited in the most exposed position for each zone. For frost protection systems a setting of 6°C is recommended to allow for thermostat tolerance.

**1.4.7** All temperature sensors within a zone should be located where they are unaffected by heating from an adjacent zone.

**1.4.8** Over-temperature sensors should be located not more than 100 mm from the heating cable or tape.

**1.4.9** The temperature sensors should also be located away from heat sinks, e.g., pipe supports or valves, within the zone.

**1.4.10** All contactors associated with the control system should have the position of the contacts clearly indicated.

### 1.5 Basic Design Requirements of ESH

For a particular application there are some basic design requirements which may limit the choice of the ESH device. These are as follows:

**1.5.1** The grade of the ESH device has to be equal to or better than the minimum specified for the service category in the appropriate Tables 2, 3 or 4 of BS 6351: Part 2: 1983.

**1.5.2** The maximum withstand temperature of the ESH device has to be equal to or better than the maximum possible work piece temperature (which may be greater than the normal operating temperature).

**1.5.3** The ESH device has to be suitable for operation in the environmental conditions specified, in Appendix A for example a corrosive atmosphere, or a low ambient temperature.

**1.5.4** The ESH device has to be suitable for use in the hazardous area if applicable.

## 2. POWER SYSTEM

The power system for an electric heat tracing system consists of power source, distribution transformers and the heat tracer distribution system.

### 2.1 Power Sources

Since the power source is a key factor in the overall design of an electric heat tracing system it is recommended that voltage levels and physical distribution to be determined in the early stages of the design.

Generally the power source is 3 phase 4 wire 400 volt or single phase 230 volt, 50 Hz.

### 2.2 Distribution Transformers

The kilo-volt ampere ratings of the distribution transformers should be based on the total rated operating load plus expected spare capacity. A power system may require several distribution transformers depending on the magnitude and physical distribution of the heat tracing loads.

### 2.3 Heat Tracing Distribution System

The physical location of the distribution system which services heat tracing should be considered in relation to the piping system when developing the distribution system. It is recommend to locate distribution boards in non-hazardous areas when practical.

For contactor and circuit-breaker selection consideration of both start-up and normal operating current is recommended. The selection of the distribution board enclosure is based on the environment and area classifications. For process control each heat tracing circuit should be connected to an individual circuit protection device.

The minimum size of branch circuit conductor and overcurrent protective devices should be sized at 125% of the heat tracing circuit full load current. Circuit protection devices may be mounted in the same enclosure as temperature controllers and alarms.

All enclosures should have the specific system identification, clearly marked on the outside and the circuit directories should be easily accessible.

## 3. WIRING SYSTEMS

### 3.1 Design

The regulations, codes and standards applicable to conventional electrical distribution systems and wiring systems apply equally to the design and installation of those for electric surface heating. The whole of any installation is required to be in conformity with the sixteenth edition of the Institution of Electrical Engineers Regulations for the Electrical Installations. Clause 25 of BS 5345: Part 1: 1976 gives an outline of the requirements for wiring systems in hazardous areas.

Electric surface heating systems may, however, exhibit characteristics which influence the design of wiring systems, such as the following:

**a)** Protective devices require to be rated to allow for any inrush current to the ESH device when cold. The wiring system may be required to be rated for this condition rather than for the normal circuit current.

**b)** Special wiring methods may be required to allow for vibrations and movements due to expansion or contraction of the heated equipment.

**c)** Electric surface heating is frequently installed in areas having unusual environmental conditions or requirements.

**d)** ESH systems frequently have discrete heating zones which require an electrical supply remote from the main distribution source and early consideration should be given to feeder cable sizing.

**e)** Approval of ESH systems for use in hazardous areas may require the protective devices in the wiring system to have specified characteristics.

### 3.2 Type of ESH Device

The following types of ESH device may be used according to specific requirements:

**a)** Heating cable.
**b)** Heating cable unit.
**c)** Heating tape.
**d)** Heating tape unit.

The most common type of ESH are:

***1)** Self limiting.
***2)** Zonal constant wattage parallel heater.
***3)** Mineral insulated copper sheath cables with copper conductors to BS 6207 (1987). Other types of cable should be to an agreed specification.

*** For details see IPS-M-EL-190.**

### 3.3 Grounding (Earthing) Considerations

**3.3.1** Every effort should be made to provide an effective ground path from the outer metallic covering of the heating cable to the power distribution system.

**3.3.2** In applications where the primary ground path is dependent on the metallic sheath, the chemical resistance of the metallic sheath should be considered if exposure to corrosive vapors or liquids might occur.

## 3.4 Ground Fault Protection

Even though properly applied, standard fuses and circuit breakers are inadequate protection in many instances against arcing ground faults, because they are not sufficiently sensitive to detect the resulting ground-fault currents.

For this reason, ground-fault equipment protective devices of a nominal 230 V, alternating current, 50 Hz, 30 mA trip type to immediately open the circuit if arcing should occur, are recommended for piping systems in classified areas requiring a high degree of maintenance, or which may be exposed to physical abuse or corrosive atmospheres. Such ground-fault devices should also be considered for applications where an effective ground path cannot be achieved. Types of piping that may not provide an effective ground path are plastic pipe, stainless steel pipe, painted pipe, or highly oxidized pipe.

Clause 22 of BS 5345 Part 1 (1976) gives requirements for earthing in hazardous areas.

## 3.5 Control and Monitoring

A control system generally monitors only a single point on the piping system therefore, the overall performance is highly dependent on the integrity of the thermal-insulation system, heat-tracing design, and installation. A wide range of control and monitoring schemes exist for pipe tracing systems, the simplest being a manual switch without an alarm to a sophisticated solid-state multi-mode control scheme with temperature, current, or continuity alarms.

### 3.5.1 Mechanical controllers

The mechanical controller utilizes the expansion of a fluid within a local bulb or bulb and capillary to actuate electrical contacts through a bellows or a similar coupling device. The bulb and capillary should be of materials suitable for the atmosphere in which they are to be used. Flexible armor that offers mechanical protection for the capillary is recommended. Mechanical controllers are rugged; however, the short sensing element is not easily grouped or panel mounted, and field calibration is cumbersome.

### 3.5.2 Electronic controllers

Electronic controllers, using resistance temperature detectors (rtd), thermistors, or thermocouples are capable of being located several hundred meters away from the heated pipes and are often panel mounted and located for easy maintenance access. Those controllers take a sensor signal through an electronic process to switch and electromechanical relay or solidstate device. Field calibration is similar to standard process instruments.

### 3.5.3 Applications

Freeze-protection systems should only require a simple ambient air sensing control system; however, because of energy conservation, pipe sensing with mechanical thermostats may be considered.

Normal process temperature applications, as a minimum, require pipesensing mechanical thermostats, and alarm functions, may be required. When conditions and job specifications require it, electronic controls may be utilized. Process applications where the temperature should be controlled within a narrow band and which require an electronic type of controller may be grouped in a common cabinet to serve a portion of the heat-tracing system. Such systems usually have high and low-temperature alarms and continuity alarms. Some applications, especially in classified environments, require special controller enclosures and may require high temperature cut-out controllers or thermostats. Consideration should be given to grouping the controllers outside the classified area, if possible. When selecting a control and monitoring scheme, attention should be given to the overall end result and degree of control required in order to specify the minimum control system to perform the function.

### 3.5.4 Location of controllers

Where possible, temperature controllers should be located outside congested or inaccessible areas so as to make them more convenient for calibration and maintenance.

### 3.5.5 Location of sensors

Proper location of the temperature sensor on the piping or mechanical equipment will ensure accurate temperature control. The sensor should be positioned at a point which is representative of the design temperature.

The following conditions should be considered in relation to the location of the temperature sensor:

**1)** Where two or more electric heating cables meet or join, the sensors should be mounted 1 m to 1.5 from the junction.

**2)** If an electric heating cable circuit includes both piping and any in-line heat sinks or heat sources, the sensor should be located on a section of pipe in the system approximately 1 m to 1.5 m from the in-line equipment.

**3)** The temperature sensor should be located so as to avoid direct temperature effects of its associated heating cable or any adjacent heating cable.

**4)** The temperature sensitivity of plastic materials may warrant both a control and overlimit thermostat. The control thermostat sensor should be located at least 90° along the circumference from the heating cable. The overlimit thermostat sensor should be located on or immediately adjacent to the heater with a set point at the material maximum allowable temperature, minus a safety margin.

### 3.5.6 Alarm consideration

The primary function of an alarm system is to alert operating personnel that the heating system may be operating outside its design range and should be checked for possible corrective action. The type and complexity of the alarm systems will depend upon the critical nature of the heating system and the plant operating procedures. The various alarm systems and their functions are described as follows:

#### 1) Circuit Alarm

A circuit continuity alarm is used to detect loss of current or voltage to each heating circuit. The alarm is designed in a variety of styles and includes (but is not limited to) the following devices:

**a)** Current sensing device to monitor the heating cable current and signal and alarm if the current drops below a preset minimum while the temperature switch is closed (usually on series-type heating cables).

**b)** Voltage sensitive device to monitor voltage at the end of the heating circuit (usually on parallel-type heating cables).

#### 2) Temperature Alarms

The following descriptions are of various temperature alarm:

#### a) Low Temperature Alarm.

The alarm indicates that the piping system temperature has fallen below a set minimum and subsequent cooling may be beyond acceptable operating design criteria. The alarm is incorporated with a temperature controller or is furnished as a separate device.

**b) High Temperature Alarm**

The alarm indicates that the piping system temperature has exceeded a set maximum and subsequent heating may be beyond acceptable operating design criteria. As indicated above, the alarm is incorporated with a temperature controller, or is furnished as a separate device.

**c) Data-logging System**

A temperature alarm is also incorporated in data-logging equipment.

**3) Other Available Alarms**

Other available alarms include (but are not limited to) the following devices:

**a) Auxiliary contact alarm**

The alarm is used to indicate when a contactor is closed and power is being supplied to the heating system.

It can provide a functional check for the operator to ensure proper operation of the contactor, but will not ensure proper operation of the heating circuit if a secondary contactor has an open circuit.

**b) Ground-fault equipment protective devices**

Devices with a nominal 230 V alternating current, 30 mA trip are also available with alarm contacts. This device monitors the electrical circuit's ground leakage current.

If the total circuit's leakage exceeds 30 mA, the device will trip, indicating a failure and interruption of power to the circuit.

**c) Switch-Actuated Alarm**

The alarm is usually initiated by an auxiliary contact on the temperature controller.

**d) Current Sensing Apparatus**

The apparatus consists of a thermostat bypass switch and an ammeter, or current-sensitive relays and alarms.

## 3.6 Typical Heat Tracing Installation

For typical heat tracing installation see Fig. F1 to F4 which show the schematic diagrams for typical ESH.

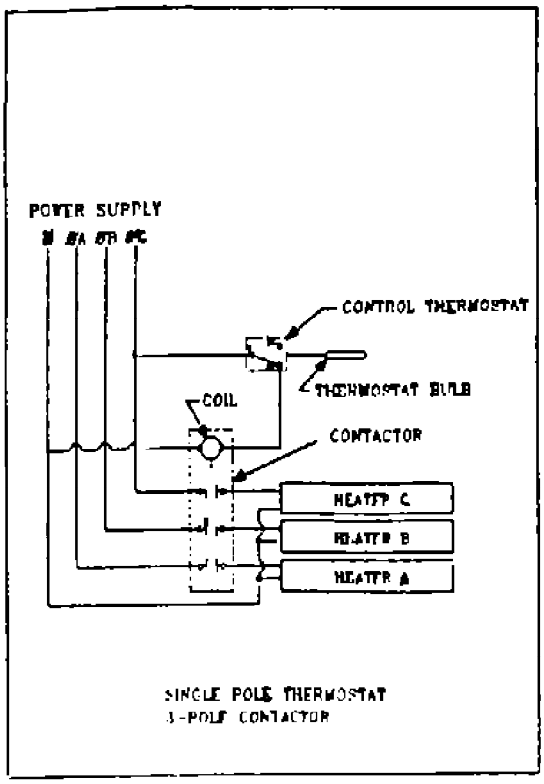



Fig. F1

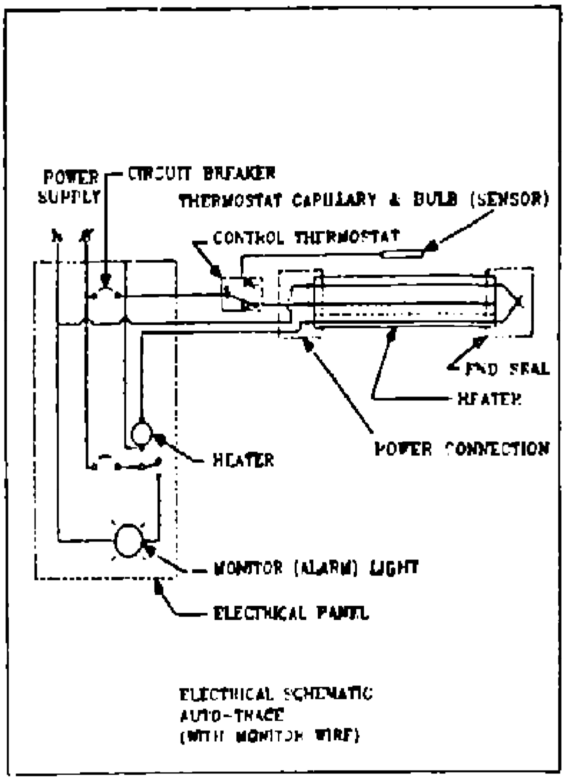



Fig. F2

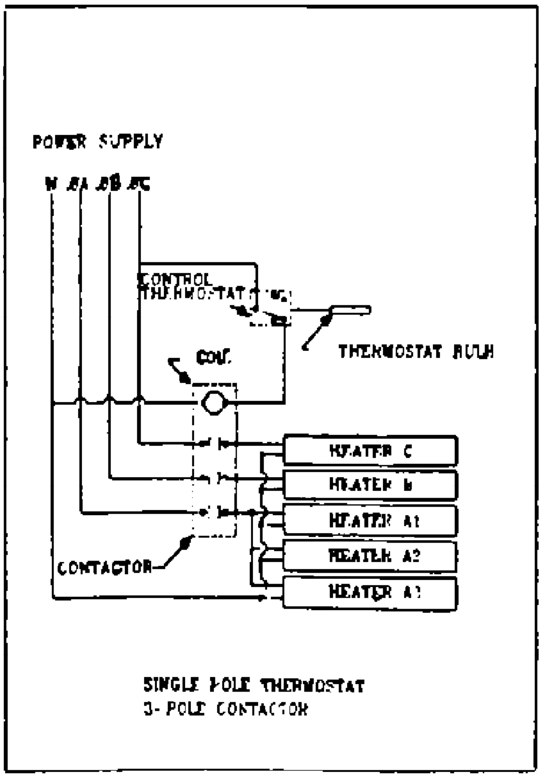



Fig. F3

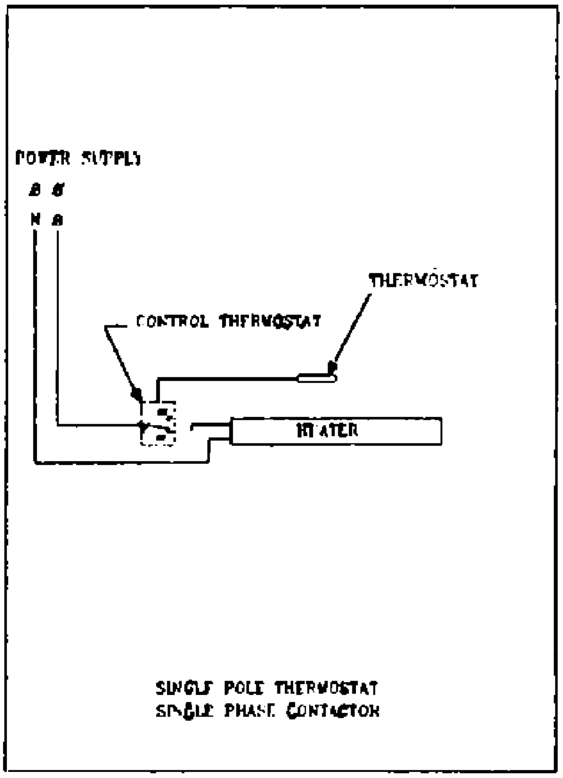



Fig. F4

**SCHEMATIC DIAGRAMS FOR TYPICAL HEAT TRACING INSTALLATION**

## 4. THERMAL INSULATION AND HEAT-LOSS CONSIDERATIONS

The primary function of thermal insulation is to reduce the rate of heat transfer from a surface which is operating at a temperature other than ambient. This reduction of energy loss can:

1) Reduce operating expenses
2) Improve system performance
3) Increase system output capability

Prior to any heat-loss analysis for an electrically-traced pipe or vessel, a review of the selection of the insulation system is recommended. The principle areas for consideration are;

1) Selection of an insulation material
2) Selection of a weather barrier
3) Selection of the economic insulation thickness
4) Selection of the proper insulation size

### 4.1 Selection of an Insulation Material

The important aspects to be considered when selecting an insulation material are:

1) Thermal characteristics
2) Mechanical properties
3) Chemical compatibility
4) Moisture resistance
5) Personnel safety characteristics
6) Fire resistance
7) Cost

Insulation materials available are:

1) Expanded Silica
2) Mineral fiber
3) Cellular glass
4) Urethane
5) Fiberglass
6)* Calcium Silicate
7) Isocyanurate

*** Note:**

**Calcium silicate insulation is most commonly used in oil industry.**

#### 4.1.1 Environmental conditions

a) Site elevation: ______________ meters above sea level.

b) Maximum ambient air temperature: _________ degree centigrade.
(Bare metal directly exposed to the sun can at times reach a surface temperature of ______ degree centigrade.

c) Minimum air temperature: ________ degree centigrade.

d) Relative humidity: _____ percent.

e) Atmosphere : saliferrous, dusty corrosive and subject to dust storms with concentration of 70 - 1412 mg/cubic meter, $H_2S$ may be present, unless otherwise specified.

**f)** Lightning storm isoceraunic level : ______ storm days/year.

**g)** Maximum intensity of earthquake ________ richters.

**Note:**

**Blanks to be filled by client.**

## 4.2 Selection of a Weather Barrier

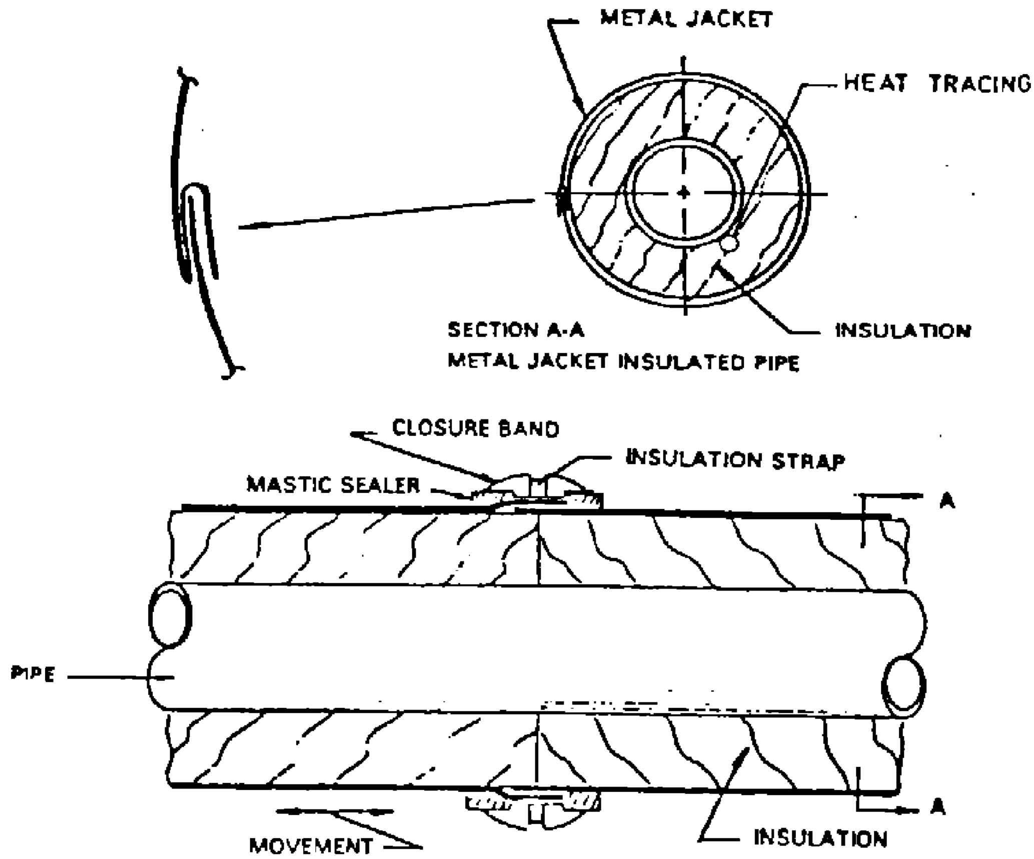
Proper operation of an electrically-traced system depends upon the insulation being dry. Electric tracing normally has insufficient heat output to dry wet insulation. Some insulation materials, even though removed from the piping and force-dried, never regain their initial integrity after once being wet.

Straight piping may be weather protected with either metal jacketing, polymeric, or a mastic system. When metal jacketing is used, it should be smooth with formed, modified "S" longitudinal joints. The circumferential end joints should be sealed with closure bands and supplied with sealant on the outer edge or where they overlap (see Fig. F5).

Jacketing which is overlapped or otherwise closed without sealant is not effective as a barrier to moisture. A single unsealed joint can allow a considerable amount of water to leak into the insulation during a rainstorm.

The type of weather barrier used should, at minimum, be based on a consideration of:

**1)** Effectiveness in excluding moisture
**2)** Corrosive nature of chemicals in the area
**3)** Fire-protection requirements
**4)** Cost




**THERMAL INSULATION WEATHER-BARRIER INSTALLATION**
**Fig. F5**

### 4.3 Temperature Class Markings

A temperature identification number (T-class) should be used when it has been demonstrated that the maximum sheath temperatures under the design conditions of on wind and maximum design ambient are predictable. The identification number should correspond to the maximum sheath temperature, except where the maximum sheath temperature falls between the temperature identification numbers, then the next higher temperature identification number is used (see ANSI/NFPA 70-1989) Section 500-2 (b).

## 5. DRAWINGS

### 5.1 Design Information, Drawings and Documents

So as to ensure a workable heat-tracing design, the design function should be furnished with up-to-date piping information and should be notified of any revisions of items and drawings that pertain to the heat-tracing system.

Any or all of the following may be applicable:

1) Thermal design parameters
2) System flow diagram
3) Equipment layout drawings (plans, sections, etc.)
4) Pipe drawings (plans, isometrics, line lists, etc.)
5) Piping specifications
6) Thermal insulation specifications
7) Equipment detail drawings (pumps, valves, strainers, etc.)
8) Electrical drawings (one-lines. elementaries, etc.)
9) Bill of materials
10) Electrical equipment specifications
11) Equipment installation and instruction manuals
12) Equipment details
13) Thermal insulation schedules
14) Area classification drawings
15) Ignition temperature of gas or vapor involved
16) Process procedures which would cause elevated pipe temperatures, that is, steam out or exothermic reactions

### 5.2 Isometric or Heater-Configuration Line Lists and Load Charts

Each heater circuit should be shown on a drawing depicting its physical location, configuration, and relevant data for the heating cable and its piping system.

The drawing or data sheets should include the following information:

1) Piping system designation
2) Pipe size
3) Piping location or line number
4) Heating cable designation or circuit number
5) Heating cable number
6) Heating cable characteristics such as:

   a) Heat-up parameters (when required)
   b) Maximum process temperature
   c) Temperature to be maintained
   d) Minimum ambient temperature and required heat-up time

**e)** Voltage
**f)** Current
**g)** Watts, total
**h)** Watts, per unit length
**i)** Length of heating cable
**j)** Maximum sheath temperature (when required)

**7)** Thermal insulation type, nominal size, and thickness
**8)** Area classification

The drawing should also indicate the power distribution panel number or designation, and the alarm and control equipment designation, and set points.

## 6. EXPLOSIVE ATMOSPHERE APPLICATIONS

### 6.1 Basic Requirements

Applications in this category must satisfy a number of interrelated safety standards and codes of practice in the design, installation and maintenance of Electric Trace Heating Systems. Primarily, Section 3 of BS 6351 Part 1 1983 in addition to those specified in section 2 of the same standard i.e. "Electrical Surface Heating", together with related requirements to BS 4683 "Electrical Apparatus for Explosive Atmospheres" and BS 5501 "Electrical Apparatus for Potentially Explosive Atmospheres" (in line with European Standards and eventually to replace BS 4683) covering the design, construction and installation of orthodox electrical apparatus, are the controlling standards. Related codes of practice are contained in BS 6351 and BS 5345, Which describe, amongst other things, various categories of hazard. Unlike design practice applied in the specification and design of orthodox electrical apparatus, the design limits for electric surface heating units depend on a number of interdependent factors, including process temperature, the limiting temperature of the material or "T" classification is given in (BS 4683: Part 1).

# APPENDIX G
# LIGHTING AND WIRING

## CONTENTS :

PAGE No.

# 1. GENERAL

- The modern petroleum, gas and petrochemical plants are highly automated continuous process operations.

- Each unit is controlled from a local control room by one or two operators.

A central control room may be used instead of unit control rooms to operate several process units. It is apparent that there are very few people in modern plant. - The seeing tasks in the process units are reduced to very basic operations such as turning a valve, starting or stopping a pump, taking a sample or just walking through a unit to sense some disorder. More critical seeing task require supplementary local illumination.

- Most modern continuous process plants have preventive maintenance programs scheduled during daytime shifts. When unusual maintenance is required at night portable illumination may be necessary.

- Many areas requires illumination only for safe movement of personal.

- Most process involves elevated temperatures and pressures and are designed for the continuous flow of vapor, liquid or solid from one vessel to another, many of these materials are highly toxic and highly flammable; for these reasons most process streams are contained entirely within closed piping systems and vessels for which outdoor luminaries are appropriate.

## 1.1 Classified Areas

- Some areas may be exposed to the release of flammable gases, vapors or dusts. IEC 79 requires that these areas must be classified and sets forth requirements for the type of protection to be considered for luminaire that may be installed.

- Classification of an area within a plant must be made prior to selection of equipment.

Refer to: IPS E-EL-110.

Luminaries must be approved for the Zone, class, group and ignition temperature of atmosphere in which they are to be installed. Improper application of a lighting unit in hazardous area can result in fire and or explosion.

## 1.2 Corrosive Areas

- A variety of corrosive chemicals is generally present in each plant. The usual methods to protect against these are to use metals that resist attack, special surface preparation, epoxy finishes polyvinyl chloride coatings or non-metallic paints in addition to these protections against the corrosive conditions, it is quite common to hosedown an area.

- Further outdoor plants are exposed to the elements of rain, snow, fog high humidity and salt-laden sea air. Luminaires should be selected that are protected against the pertinent corrosive elements.

# 2. STANDARDS AND RECOMMENDATIONS

- Requirements for lighting and wiring shall conform to accepted standards and regulations however the following are described as useful information and guidance:

| | |
|---|---|
| BS 1853<br>(IEC 81) | "Tubular Fluorescent Lamps for General Lighting Service" |
| BS 4533<br>(IEC 598) | "Luminaires" |

| | |
|---|---|
| BS 4580 (IEC 817) | "Specification for Steel Conduit and Fittings with Metric Threads of ISO form for Electrical Installations" |
| BS 4727 (IEC 50) | "Glossary of Terms Particular to Lighting and Colors" |
| BS 5225 | "Photometric Data for Luminaires" |
| BS 5266 | "Emergency Lighting" |
| BS 5489 | "Road Lighting" |
| BS 5971 (IEC 432) | "Specification for Safety of Tungsten Filament Lamp for Domestic and Similar General Purpose" |
| BS 6004 (IEC 227) | "Specification for PVC Insulated Cable non Armored for Electric Power and Lighting" |
| BS 6007 (IEC 245) | "Specification for Rubber Insulated Cable for Electric Power and Lighting" |
| BS 6207 (IEC 702.1) | "Specification for Mineral Insulated Copper Sheathed Cables with Copper Conductors" |
| BS 6346 | "Specification for PVC Insulated Cables for Electricity Supply" |
| BS 6387 | "Specification for Performance Requirements for Cables Required to Maintain Circuit Integrity under Fire Conditions" |

- API Recommended Practice 540 second Edition. (Recommended practice for electrical installation in Petroleum Processing Plant.)

**- IEE Regulations**

IEE wiring regulations for Electrical Installation 16th Edition, 1991 is a very useful publication for electrical installations in non explosive atmospheres.

## 3. ELECTRIC SUPPLY

### 3.1 Normal Supply

- All lighting should be supplied at single phase and neutral voltage from three phase four wire and/or single phase and neutral feeders from the low voltage distribution boards. The normally operating lighting load should be balanced within practical limits; across three phases at all main distribution boards.

### 3.2 Emergency Supply

**3.2.1** Where failure of the normal electricity supply to essential lighting involves danger to personnel and/or plant operation an alternative supply should be provided.

**3.2.2** The alternative supply should generally be from a turbine or engine driven generator set arranged for automatic starting upon failure of the normal electric supply. Schemes for providing an alternative supply by other means depending upon requirements shall be considered.

**3.2.3** The emergency supply for lighting may also serve process instrumentation and any other essential equipment. Attention should be paid to the requirement of the emergency supplies for instrumentation.

**3.2.4** An emergency alternative supply may be arranged to serve an individual plant or plants as appropriate.

**3.2.5** Details of the complete emergency supply scheme should be agreed.

## 4. LEVEL OF ILLUMINATION

**4.1** Illumination should generally conform to the requirements of Illumination Engineering Society (IES).

Illumination currently recommended in publications of Illumination Engineering Society for the petroleum, chemical and petrochemical plants are given in Table G1.

## TABLE G1 - ILLUMINANCES CURRENTLY RECOMMENDED FOR THE PETROLEUM, CHEMICAL AND PETROCHEMICAL INDUSTRY

| AREA OR ACTIVITY | ILLUMINANCE LUX | ELEVATION MILLIMETER |
|---|---|---|
| **I PROCESS AREAS** | | |
| A) General process units | | |
| Pump rows, valves, manifolds | 50 | Ground |
| Heat exchangers | 30 | Ground |
| Maintenance platforms | 10 | Floor |
| Operating platforms | 50 | Floor |
| Cooling towers (equipment areas) | 50 | Ground |
| Furnaces | 30 | Ground |
| Ladders and stairs (inactive) | 30 | Floor |
| Ladders and stairs (active) | 50 | Floor |
| Gage glasses | 50 | Eye level |
| Instruments (on process units) | 50 | Eye level |
| Compressor houses | 200 | Floor |
| Separators | 50 | Top of bay |
| General area | 10 | Ground |
| B) Control rooms and houses | | |
| Ordinary control house | 300 | Floor |
| Instrument panel | 300 | 1700 |
| Console | 300 | 760 |
| Back of panel | 100 | 760 |
| Central control house | 500 | Floor |
| Instrument | 500 | 1700 |
| Back of pane | 100 | 900 |
| C) Specialty process units | | |
| Conveyors | 20 | Surface |
| Conveyor transfer points | 50 | Surface |
| **II NONPROCESS AREA** | | |
| A) Loading, unloading, and cooling water | | |
| pump houses, Pump area | 50 | Ground |
| General control area | 150 | Floor |
| Control panel | 200 | 1100 |
| B) Boiler and air compressor plants | | |
| Indoor | 200 | Floor |
| Outdoor equipment 50 | 50 | Ground |
| C) Tank fields (where lighting is required) | | |
| Ladders and stairs | 5 | Floor |
| Gaging area | 10 | Ground |
| Manifold area | 5 | Floor |
| D) Loading racks | | |
| General area | 50 | Floor |
| Tank car | 100 | Point |
| Tank trucks, loading point | 100 | Point |
| E) Tanker dock facilities | | |

**(to be continued)**

**TABLE G1 - (continued)**

| | | |
|---|---|---|
| F) Electrical substations and switch yards[d] | | |
| Outdoor switch yards | 20 | Ground |
| General substation (outdoor) | 20 | Ground |
| Substation operating aisles | 150 | Floor |
| General substation (indoor) | 50 | Floor |
| Switch racks | 50 | 1200 |
| G) Plantroad lighting (where lighting is required[d]) | | |
| Frequent use (trucking) | 4 | Ground |
| Infrequent use | 2 | Ground |
| H) Plant parking lots[d] | 1 | Ground |
| I) Aircraft obstruction lighting[e] | | |
| **III BUILDINGS[d]** | | |
| A) Offices | 500 | |
| B) Laboratories | | |
| Qualitative, quantitative and physical test | 500 | 900 |
| Research, experimental | 500 | 900 |
| Pilot plant, process and specialty | 300 | Floor |
| Glassware, washrooms | 300 | 900 |
| Fume hoods | 300 | 900 |
| Stock rooms | 150 | Floor |
| C) Warehouses and stock rooms[d] | | |
| Indoor bulk storage | 50 | Floor |
| Outdoor bulk storage | 5 | Ground |
| Large bin storage | 50 | 760 |
| Small bin storage | 100 | 760 |
| Small parts storage | 200 | 760 |
| Counter tops | 300 | 1200 |
| D) Repair shop[d] | | |
| Large fabrication | 200 | Floor |
| Bench and machine work | 500 | 760 |
| Craneway, aisles | 150 | Floor |
| Small machine | 300 | 760 |
| Sheet metal | 200 | 760 |
| Electrical | 200 | 760 |
| Instrument | 300 | 760 |
| E) Change house[d] | | |
| Locker room, shower | 100 | Floor |
| Lavatory | 100 | Floor |
| F) Clock house and entrance gatehouse[d] | | |
| Card rack and clock area | 100 | Floor |
| Entrance gate, inspection | 150 | Floor |
| General | 50 | Floor |

**(to be continued)**

**TABLE G1 - (continued)**

| | | |
|---|---|---|
| G) Cafeteria | | |
| Eating | 300 | 760 |
| Serving area | 300 | 900 |
| Food preparation | 300 | 900 |
| General, halls, etc. | 100 | Floor |
| H) Garage and firehouse | | |
| Storage and minor repairs | 100 | Floor |
| I) First aid room[d] | 700 | 760 |

**Notes:**

**a) These illumination values are recommended practice to be considered in the design of new facilities.**

**b) Indicates vertical illumination.**

**c) Refer to port authority for required navigational lights.**

**d) Illuminance may be different from those recommended for other industries because of the nature of area.**

**e) Refer to local aviation authority for requirements of obstruction lighting and marking.**

**4.2** Illumination from the emergency lighting system should be designed to permit safety of movement for personnel particularly from elevated platforms etc., in addition to that required at control positions. Details of the above should be agreed in conjunction with Clause 4.2, and Clause 6.2 Para. (VI).

## 5. ISOLATION AND CONTROL

### 5.1 Means of Isolation

A complete means of isolation should be included on distribution feeder system to lighting distribution board, street lighting etc., except those wholly situated in and wholly serving sub-circuits, installation, apparatus etc., within safe areas. The complete means of isolation should preferably be by an isolating switch, with locking off facilities having the requisite number of poles to include the neutral. System wholly within "safe areas" may include a bolted type neutral link instead of having the means of isolation incorporated in the isolating switch.

### 5.2 Final Sub-Circuits

**i)** Final sub-circuits should be taken from switch and fuse units mounted to form one or more unit type distribution switchboards. Refer to(V) below.

**ii)** Switch and fuse units in "Safe Areas" serving circuits and apparatus wholly within " Safe Areas" should be equipped with single pole switches, single pole fuses and neutral link.

Switch and fuse units in "Safe Areas" serving circuits and apparatus in zones 1 and 2 areas should be equipped with double pole switches, single pole fuses and neutral link.

**iii)** Switch and fuse units in zones 1 and 2 areas serving circuits and apparatus in zones 1, 2 and Safe Areas should be equipped with double pole switches, single pole fuses and neutral link.

**iv)** The switches incorporated in the switch and fuse units referred to under (i), (ii) and (iii) above should be suitable for locking in the OFF position.

**v)** Consideration will be given to the use in "Safe Areas" of fused distribution boards for final sub-circuits wholly in " Safe Areas".

**vi)** Emergency lighting installations should be entirely independent from the normal system, and sub-circuits should be taken direct from the generator, or a central distribution box, without additional control switches or fuses. Details should be agreed in conjunction with Clauses 4.2 and 5.2.

### 5.3 Control

**i)** Control of all lighting should preferably be from the distribution switchboards, or an appropriate occupied control location. The installation of individual control switches mounted adjacent to the lighting under control should be restricted to those places where it is essential.

**ii)** Street lighting and essential area lighting should be automatically controlled from a light sensitive device incorporating a manual over-ride control.

## 6. TYPES OF LAMPS AND FITTINGS

**6.1** The use of fluorescent types of lighting is preferred, supplemented if necessary in local areas by tungsten filament types or Quartz Halogen where there is a space limitation. Sodium type lamps are not normally permitted due to fire risk, and their use must be avoided. High pressure mercury vapor lamps shall be used for extension lighting, street lighting, flood lighting and interior lighting industrial especially high bay workshops.

**6.2** If lamps that are adversely affected by transient voltage disturbances are used in working areas, they must be adequately interspersed with lamps that are not so affected.

**6.3** In the selection of types of lamps consideration should be given to the likelihood of producing undesirable color distortion.

**6.4** The number of types of lamps and fittings should be a minimum.

**6.5** In the selection of lamps and fittings consideration should be given to ensuring maximum lamp life and the minimum likelihood of internal moisture accumulation(i.e., effects of vibration, operating temperature, breathing).

**6.6** All exposed lighting fittings should be of weatherproof construction.

**Note:**

**For characteristics and application of various light sources see Table G2.**

## LIGHT SOURCES

### TABLE G2 - THE PRINCIPAL LIGHT SOURCES FOR GENERAL LIGHTING PURPOSES AND THEIR CHARACTERISTICS

| Types / Characteristics | General Lighting Service Incandescent Lamps | Fluorescent Lamps | High-Pressure Mercury-Vapor Lamps |
|---|---|---|---|
| Working principle | Light produced by radiation from a tungsten filament heated to about 2600°C. Vaporization of the tungsten is reduced by filling the bulb with gas, blackening of the bulb is avoided in tungsten-halogen lamps | UV radiation from a discharge between heated electrodes in mercury vapor at low pressure excites phosphors on the inside of the glass tube to produce visible light. The light color depends on the combination of phosphors | Light is produced by a discharge in mercury vapor, pure or with additives (halogens), in a quartz tube at an operating pressure of a few bars. The protecting glass bulb can also be coated with phosphors |
| Luminous efficacy | About 8 to 20 lm/W, depending on power | About 30 to 94 lm/W, depending on light color and power consumption, including ballast unit | About 34 to 92 lm/W depending on type and power, including ballast unit |
| Useful life | Standard lamps generally 1000 h. Special lamps usually less | Standard lamps generally 7500 h | 6000 to 9000 h depending on type |
| Life color, color rendering (CR) | Warm white yellow-red region of spectrum emphs | Various types for daylight, neutral white, warm white and special colors | Generally neutral white or daylight |
| Luminance | Up to about 2000 cd/cm² with clear bulbs | About 4.0 to 1.5 cd/cm² depending on type | About 4 to 23 cd/cm² for ellipsoidal phosphor-coated bulbs, 530 to 1600 cd/cm² for lamps with clear bulbs |
| Temperature dependence of luminous flux | The luminous flux is strongly dependent on the filament temperature, but practically unaffected by the ambient temperature | Standard lamps are designed for 20°C amalgam lamps for 40°C. At other temperatures the pressure alters and the light output drops | Ambient temperature has practically no effect on luminous flux |
| Light ripple | At powers above 40 W and supply frequency 50 Hz or greater the light ripple is not noticeable in practice | Luminous-flux ripple (at twice supply frequency), limited by phosphors, generally not objectionable in practice. Stroboscopic effects alleviated by appropriate circuits | Ripple greater than with fluorescent lamps. Can be alleviated by appropriate circuits |
| Requirements for mains operation | Mains operation possible without special measures (also on d.c.) | Standard lamps require starter and ballast unit (inductor), and usually power-factor-correction capacitor. Recently developed electronic ballast units | For all types, ballast unit (inductor) for some metal-halide vapor lamps, a starter or high-voltage ignition device is also necessary |
| Switching-on and start-up behavior | Full luminous flux immediately on switching on. In rush current up to 14 times rated current | Almost full luminous flux on striking pre-heating current before striking (a few seconds) about twice rated current | Full luminous flux not until 1 to 4 minutes after switching on. Starting current 1.5 to 1.7 times rated current |
| Application area | All-round application by virtue of wide range of powers and small dimensions Domestic lighting Directional lighting | Universally applicable for general lighting purposes | Exterior lighting, street lighting, sports grounds and floodlighting. Interior lighting industrial, especially high-bay workshops |

**Note:**

**1 Lux ≡ 1 candela/m²**

**1 Candela ≡ one lumen. per steradian**

## 7. ARRANGEMENT AND ACCESSIBILITY

### 7.1 Control Rooms

Lighting should be provided at the front and rear of all control panels and the arrangement should preclude the likelihood of inconvenience due to failure of a single sub-circuit or phase. Schemes for front of panel and control desk illumination should be agreed.

### 7.2 Plants and General Areas

**i)** The arrangement of lighting fittings on final sub-circuits should avoid a complete area of darkness should any one sub-circuit be isolated.

**ii)** Fittings should, wherever possible, be mounted from structural steelwork installed for other purposes, except when this may adversely affect the lighting fitting due, for example, to vibration. Individual poles, etc., provided for the purpose of mounting, fittings must be of adequate strength to permit access for maintenance as detailed under (iii) below.

**iii)** Fittings should be located as far as possible to permit safe access from portable ladders.

**iv)** Floodlights should be mounted when necessary on metal or concrete masts equipped with permanent access ladders and a platform.

## 8. WIRING AND CABLING

Installation should normally be carried out using the following types of copper conductor cables subject to being entirely suitable for the environment.

**i)** Mineral insulated cables with a rated voltage not exceeding 750 volt in accordance with IEC standard No. 702 (BS 6207).

**ii)** Polyvinyl chloride insulated cables(unarmored) of rated voltages up to and including 450/750 volt according to IEC 227(BS 6004.

**iii)** Polyvinyl chloride insulated cables for electricity supply: pvc/pvc, 600/1000 volt according to BS 6346.

**iv)** Polyvinyl chloride insulated cables for electricity supply (Armored cables): pvc/pvc/sw/pvc 600/1000 volt according to BS 6346.

**v)** Polyvinyl chloride insulated cables for electricity supply (Armored cables): pvc/lc/pvc/sw/pvc 600/1000 volt according to OCMA-43 adopted to BS 6346. vi) Cross linked polyethylene insulated power cable 600/1000 volt according to IEC 502.

**vii)** Cross linked polyethylene insulated power cables steel tape armored 600/1000 volt according to IEC publication No. 502.

**viii)** Where cables required to maintain circuit integrity under fire conditions. They should comply with the requirements of BS 6387.

- Type (i) cables to be used for electric lighting, small power and instrument installation in all Zone 1 and Zone 2 hazardous area in above ground surface installations.

- Type (ii) cable should only be used in conduits. The use of conduit should normally be restricted to installations inside administration, workshop laboratory and similar type of buildings in other areas when the use of conduit is essential, e.g., due to space limitations, galvanized heavy gage solid drawn conduit complying with BS 4568 should be employed in conjunction with appropriate galvanized fittings.

- Type (iii) and (iv) cables should only be used if agreed and this will only normally be considered if the whole route is within safe areas and there is no likelihood of hydrocarbon spillage or ground contamination.

- The use of rubber insulated cables should be avoided where climatic and other environments are likely to cause deterioration of the rubber.

## 9. INSTALLATION OF WIRING AND CABLING

Above mentioned surface wiring and cabling should be supported by cleating to structures etc., or laid on cable trays protected against corrosion.

Cable routing should be such that the maximum degree of protection against accidental damage due for example to the use of ladders and slings during maintenance work, is afforded by running cables along the inside of channels and beams so that the webs of the steel work provide protection.

Underground cable distribution to street and area lighting should make maximum use of looping type boxes at each offtake point and the boxes should preferably be accommodated within the supporting column: The use of underground tee type joint boxes should be minimized.

# APPENDIX H
# POWER CABLES

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## TABLES :



## FIGURES :

## 1. REFERENCES

The following standard may be referred to while engineering the cable installations for different cases:

**IEC (INTERNATIONAL ELECTROTECHNICAL COMMISSION)**

| | |
|---|---|
| IEC 38 | "Standard Voltages" |
| IEC 50 (461) | "International Electrotechnical Vocabulary: Electric Cables" |
| IEC 55 | "Paper Insulated Metal Sheathed Cables for Rated Voltages up to 18/30 kV (with Copper or Aluminum Conductors and Excluding Gas Pressure and Oil Filled Cables)" |
| IEC 92-350 | "Electric Installation on Ships: Low Voltage Shipboard Power Cables, General Construction and Test Requirements: 0.6/1 kV" |
| IEC 173 | "Colors of the Cores of Flexible Cables and Cores" |
| IEC 183 | "Guide to the Selection of High Voltage Cables" |
| IEC 227 Part 1 to 6 | "Polyvinyl Chloride Insulated Cables of Rated and Including 450/750 V" |
| IEC 228 | "Conductors of Insulated Cables" |
| IEC 229 | "Tests on Cable Oversheaths which have Special Protective Function and Are Applied by Extrusion" |
| IEC 230 | "Impulse Tests on Cables and their Accessories" |
| IEC 245 Parts 1 to 6 | "Rubber Insulated Cables of Rated Voltages up to and including 450/750 V" |
| IEC 247 | "Measurement of Relative Permitivity, Dielectric Dissipation Factor and d.c. resistivity of Insulating Liquids" |
| IEC 287 | "Calculation of the Continuous Rating of Cables (100% Load Factor)" |
| IEC 331 | "Fire Resisting Characteristics of Electric Cables" |
| IEC 332 | "Tests on Electric Cables under Fire Conditions" |
| IEC 364-5-523 | "Chapter 52 : Wiring System Section 523 Current Carrying Capacities " |
| IEC 446 | "Identification of Insulated and Bare Conductors by Colors" |
| IEC 502 | "Extruded Solid Dielectric Insulated Power Cables for Rated Voltages from 1 kV to 30 kV" |
| IEC 540 | "Test Methods for Insulations and Sheaths of Electric Cables and Cords(Elastomeric and Termoplastic Compounds)" |
| IEC 702 | "Mineral Insulated Cables with a Rated Voltage not Exceeding 750 V" |
| IEC 724 | "Guide to the Short Circuit Temperature Limits of Electric Cables with a Rated Voltage not Exceeding 0.6/1.0 kV" |
| IEC 811 | "Common Test Methods for Insulating and Sheathing Materials of Electric Cables" |
| IEC 840 | "Test for Power Cables With Extruded Insulation for Rated Voltages above 30 kV Um = 36 kV up to 150 kV (Um = 170 kV)" |
| IEC 885 | "Electrical Test Method for Electric Cables (for up to and Including 450/750 V)" |

**BSI** **(BRITISH STANDARDS INSTITUTION)**

BS 4579 "Specification for Performance of Mechanical and Compression Joints in Electrical Cable and Wire Connections Part 1 Compression Joints in Copper Conductors"

BS 6724 "Specification for Armored Cables for Electricity Supply Having Thermosetting Insulation with Low Emission of Smoke and Corrosive Gases when Affected by Fire"

**VDE** **(VERBAND DEUTSCHER ELECTROTECHNICKER)**

VDE 0291 "Compound for use in Cable Accessories Casting Resinous Compound before Cure and in Cure State"

**EEMUA** **(THE ENGINEERING EQUIPMENT AND MATERIAL USER ASSOCIATION)**

Publication No. 133 "Specification for Underground Armored Cable Protected Against Solvent Penetration and Corrosive Attack"

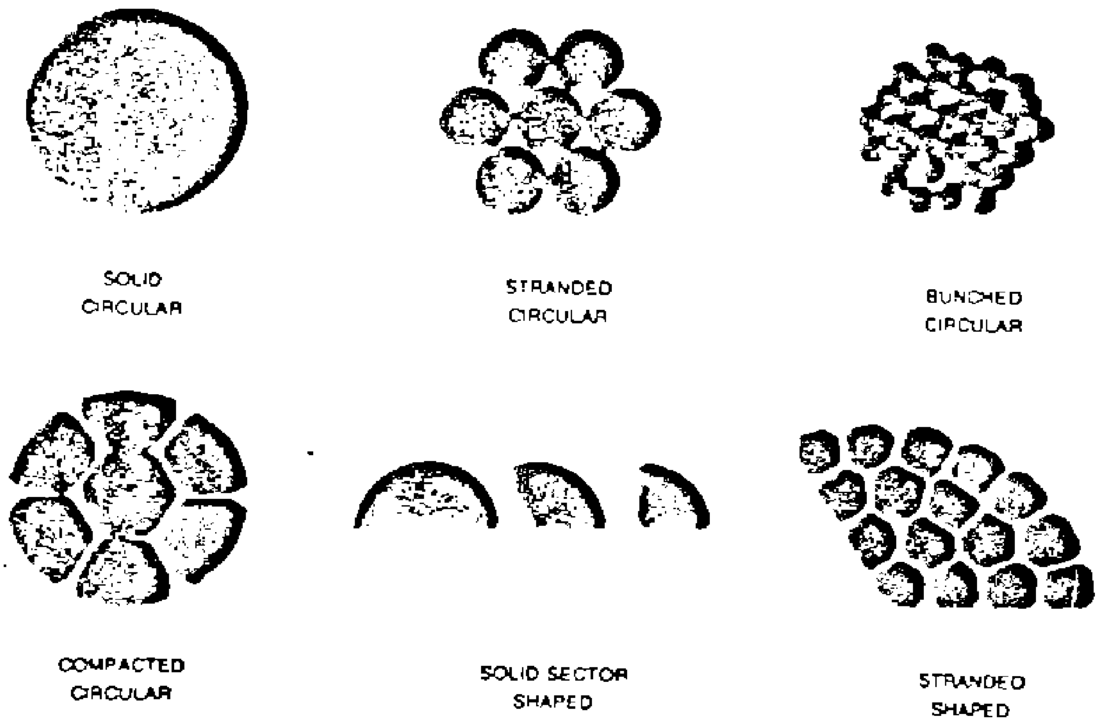
## 2. UNITS

This Standard is based on International System of Units (SI), except where otherwise specified.

## 3. GENERAL

### 3.1 Conductors

The most common type of metal used in cable industry are copper, cadmium copper, aluminum lead alloy and galvanized mild steel, which their electrical and mechanical properties are given in Table H1. The most common type conductor cross section shapes are given in Fig. H1.




**CONDUCTOR CROSS SECTIONS**
**Fig. H1**

## 3.2 Insulations

Amongst insulations which are used in cable manufacturing, the following are well known:

Polyethylene, Polypropylen, Polyvinil Chloride, Ethylene Propylene rubber, Chlorosulphonated, Polyethylene, Silicon Rubber, Cross linked Polyethylene and Impregnated paper.

For chemical, electrical and mechanical properties of above mentioned insulations see Tables H2, H3 and H4.

### TABLE H1 - ELECTRICAL AND MECHANICAL PROPERTIES OF METALS

| PROPERTY | COPPER | | | CADMIUM COPPER | ALUMINUM | | | LEAD ALLOY | GALVANIZED MILD STEEL WIRE |
|---|---|---|---|---|---|---|---|---|---|
| | Annealed | Hard Drawn | Tinned | Hard Drawn | Solid Extruded HO | Drawn H68 | Aerial H9 | E | |
| Electrical Resistivity @20°C (n Ωm) | 17.241 | 17.77 | 17.4 | 21.6 | 28.03 | 28.26 | 28.26 | 214 | 218 |
| Temperature Coefficient of Resistance | 0.00393 | 0.00381 | 0.00393 | 0.0031 | 0.00403 | 0.00403 | 0.00403 | 0.0040 | 0.0045 |
| Melting Point (°C) | 1083 | 1083 | 1083 | 1078 | 658 | 658 | 658 | 327 | 1527 |
| Thermal Conductivity (W/m°C) | 380 | 380 | 380 | 300 | 200 | 200 | 200 | 35 | 45 |
| Specific Heat Capacity @20°C (L/kg.K) | 387 | 387 | 387 | 385 | 900 | 900 | 900 | 129 | 450 |
| Coefficient of Linear Expansion (per °C × $10^{-6}$) | 17 | 17 | 17 | 17 | 23 | 23 | 23 | 29 | 12 |
| Density @20°C (kg/$m^3$) | 8890 | 8890 | 8890 | 8945 | 2703 | 2703 | 2703 | 11370 | 7780 |
| Tensile Strength (MPa) | 250 | 405 - 460 | 250 | 570 - 650 | 90 | 120 - 205 | 151 - 183 | 23 | 340 - 500 |
| Approximate Elongation at Break (%) | 15 - 30 | 3 | 15 - 30 | 3 | 30 | 2 | 2 | — | 10 |
| Modulus of Elasticity (GPa) | 117 | 124 | 117 | 124 | 68 | 68 | 68 | — | 193 |

### TABLE H2 - CHEMICAL PROPERTIES OF INSULATIONS

| Material | Resistance to | | | | | Low Flame Protection | Combustion Products | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ozone | Weather | Water | Oil | Solvents | | Low Smoke | Low Toxicity | Low Acidity |
| Polyethylene (PE) | M | G | E | P | G | P | G | E | E |
| Polypropylene (PP) | M | G | E | M | G | P | G | E | E |
| Polyvinyl Chloride (PVC) | E | G | G | G | M | G | P | P | P |
| Ethylene Propylene Rubber (EPR) | E | E | E | M | M | P | E | E | E |
| Chloro Sulphonated Polyethylene (CSP) | G | G | G | G | G | G | P | P | P |
| Chlorinated Polyethylene (CPE) | G | G | G | G | G | G | P | P | P |
| Silicone Rubber (SR) | E | E | E | G | G | P | M | G | E |
| Crosslinked Polyethylene (XLPE) | M | G | E | M | G | P | G | G | G |
| Impregnated Paper | — | — | — | — | — | P | P | M | M |

**P ≡ Poor, M ≡ Moderate, G ≡ Good & E ≡ Excellent**

**TABLE H3 - ELECTRICAL PROPERTIES OF INSULATIONS**

| Material | Dielectric Constant @50 Hz & 20°C | Loss Factor Tan δ @50 Hz & 20°C | Volume Resistivity @20°C Ωm |
|---|---|---|---|
| Polyethylene (PE) | 2.3 | 0.0001 | $10^{16}$ |
| Polypropylene (PP) | 2.5 | 0.0005 | $10^{16}$ |
| Polyvinyl Chloride (PVC) | 5 | 0.07 | $10^{12}$ |
| Ethylene Propylene Rubber (EPR) | 3 | 0.008 | $10^{13}$ |
| Chloro Sulphonated Polyethylene (CSP) | 4 | 0.01 | $10^{12}$ |
| Chlorinated Polyethylene (CPE) | 4 | 0.01 | $10^{12}$ |
| Silicone Rubber (SR) | 3 | 0.01 | $10^{12}$ |
| Crosslinked Polyethylene (XLPE) | 2.5 | 0.0008 | $10^{14}$ |
| Impregnated Paper | 3.5 | 0.004 | $10^{13}$ |

**TABLE H4 - MECHANICAL PROPERTIES OF INSULATIONS**

| Material | Flexibility | | Wear Resistance | Cut Resistance | Deformation Resistance at 150°C | Tensile Strength @20°C MPa | Aging Resistance at | | |
|---|---|---|---|---|---|---|---|---|---|
| | 20°C | -10°C | | | | | 180°C | 120°C | 150°C |
| Polyethylene (PE) | G | G | G | G | P | 10 - 14 | P | P | P |
| Polypropylene (PP) | G | G | E | G | M | 30 - 40 | M | P | P |
| Polyvinyl Chloride (PVC) | E | P | G | G | P | 10 - 14 | P | P | P |
| Ethylene Propylene Rubber (EPR) | E | E | M | M | E | 6 - 10 | G | G | P |
| Chloro Sulphonated Polyethylene (CSP) R-CPE-90 | E | E | G | M | E | 8 - 12 | G | M | P |
| Chlorinated Polyethylene (CPE) R-CPE-90 | E | E | G | G | E | 8 - 12 | G | M | P |
| Silicone Rubber (SR) | E | E | P | P | E | 5 - 10 | E | G | M |
| Crosslinked Polyethylene (XLPE) | G | G | G | G | G | 12 - 16 | G | M | P |
| Impregnated Paper | — | — | — | — | — | — | G | M | P |

**P ≡ Poor, M ≡ Moderate, G ≡ Good & E ≡ Excellent**

## 3.3 Sheathing

The most common use of sheathing compounds are given in Table 5 where in minimum installation temperature and maximum operating temperature are shown.

**TABLE H5 - TEMPERATURE LIMITS FOR SHEATHING COMPOUNDS**

| Material | Minimum Installation Temperature °C | Maximum Operating Temperature °C |
|---|---|---|
| Polyethylene (PE)high density (hdpe) | -40 | 70 |
| Polypropylene(PP) | -10 | 80 |
| Polyolefin (PO) | -20 | 90 |
| Polyvinyl chloride (PVC) | 05 | 75 |
| Chloro sulphonate polyethylene (CSP) | -20 | 90 |
| Polychloroprene (PVP) | -20 | 85 |
| Chlorinated polyethylene (CPE) | -20 | 90 |
| Ethyl methyl acrylate (EMA) | -40 | 90 |
| Polyamide (PA) | -40 | 80 |
| Polyurethane (PU) | -40 | 90 |

## 3.4 Color Coding

Color coding of individual cable cores and wiring conductors shall be as follows:

| | |
|---|---|
| **phase conductors:** | **Red - Yellow - Blue** |
| **neutral:** | **Black** |
| **d.c. positive conductors:** | **Red** |
| **d.c. negative conductors:** | **Black** |
| **control conductors cables:** | **White*** |
| **(7 core cables and larger)** | |
| **Earthing conductors:** | **Green/Yellow** |

***Note:**

**Each core of multicore control cable shall be numbered along its length.**

## 4. SELECTION OF CABLE

There are four main requirements in selecting cables. Three are technical and one economic, viz:

- current carrying capacity;
- short circuit temperature limit;
- voltage drop;
- economic cross sectional area of conductor.

The minimum cable size will be the smallest conductor which satisfies all three technical requirements. With experience, it will generally become apparent which of the above requirements will predominate in the various types of installations.

## 4.1 Current Carrying Capacity

When a current flows through a conductor the thermal output of the cable is due to ohmic losses in the conductor and if the conductor is carrying alternating current ohmic losses also occur in any metallic coverings.

Dielectric losses can, and do, occur but are normally negligible. The working temperature of the conductor must be controlled, otherwise deterioration of the insulation can occur. Expansion of the metallic and organic components of the cable also require control.

The cable losses have to be dissipated through an external path to the surroundings. The heat flow is the sum of all the losses generated in the cable. To reach the surroundings the heat generated must overcome the thermal resistances within the cable and the thermal resistance of the ground if buried direct; the thermal resistance of the space between cable and duct, the duct wall and ground if in underground ducts or the external thermal resistance in air.

Where a cable is installed in thermal insulation the additional resistance must be taken into account, with consequent lowering of the current carrying capacity.

### 4.1.1 Conductor losses

Heat is generated by the joule or $I^2$ R effect where I is the current and R is the a.c. resistance taking into account skin effect and proximity effect.

### 4.1.2 Sheath and screen losses

#### i) Single core cables

It is normal practice to bond and earth the screens or sheaths of single core cables near the ends of each run and at each joint position. Losses are made up of eddy currents and circulating currents. Eddy currents are generally very small but circulating currents can be of a much larger magnitude and are at their lowest when the cables are run in close trefoil.

Circulating currents can be eliminated by earthing with single point end bonding or mid point bonding. Both these methods of earthing are suitable for short lengths only, say less than 500 meters. Under fault conditions voltages sometimes in the thousands of volts can be induced.

For long cable runs a cross bonding method can be used to reduce screen or sheath circulating current to a low and insignificant value.

Before departing from the normal practice of bonding the screens or sheaths of single core cables at each end and at joint positions the cost effectiveness, electrical performance and safety of the alternative methods of earthing must be investigated.

#### ii) Three core cables

Sheath and screen losses of three core cables are due to eddy currents alone and are acceptably small.

### 4.1.3 Armor losses

#### i) Single core cables

Armoring is seldom applied to single core cables. If the armoring is a non ferrous material it will act as a supplementary conductor to the sheath or screen with consequent eddy current and circulating current losses. If the armoring is magnetic, hysteresis losses can be unacceptably high.

#### ii) Three core cables

Armor losses in the three core cables are generally restricted to eddy currents and small hysteresis losses and are usually acceptably low.

## 4.2 Short-Circuit Ratings

It happens frequently that the conductor size necessary for an installation is dictated by its ability to carry short-circuit rather than sustained current. During a short-circuit there is a sudden inrush of current for a few cycles followed by a steadier flow for a short period until the protection operates, normally between 0.2 and 3 seconds. During this period the current falls off slightly due to the increase in conductor resistance with temperature but for calculation purposes it is assumed to remain steady.

At the commencement of the short circuit the cable may be operating at its maximum permissible continuous temperature and the increase in temperature caused by the short circuit is a main factor in deriving acceptable ratings. However, the current may be 20 or more times greater than the sustained current and it produces thermomechanical and electromagnetic forces proportional to the square of the current. The stresses induced may themselves impose an operating limit unless they can be contained adequately by the whole installation. This requires checks on cable design, joints, terminations and installation conditions.

The graphs in Figs. H2 to H8 enable a suitable cable to be selected from the symmetrical fault level and fault duration.

When cables are connected to a system with a potentially high fault current consideration must be given to electromagnetic forces of repulsion which can cause damage to the cable and fixings.

Table H6 shows temperature limits of insulations under following column:

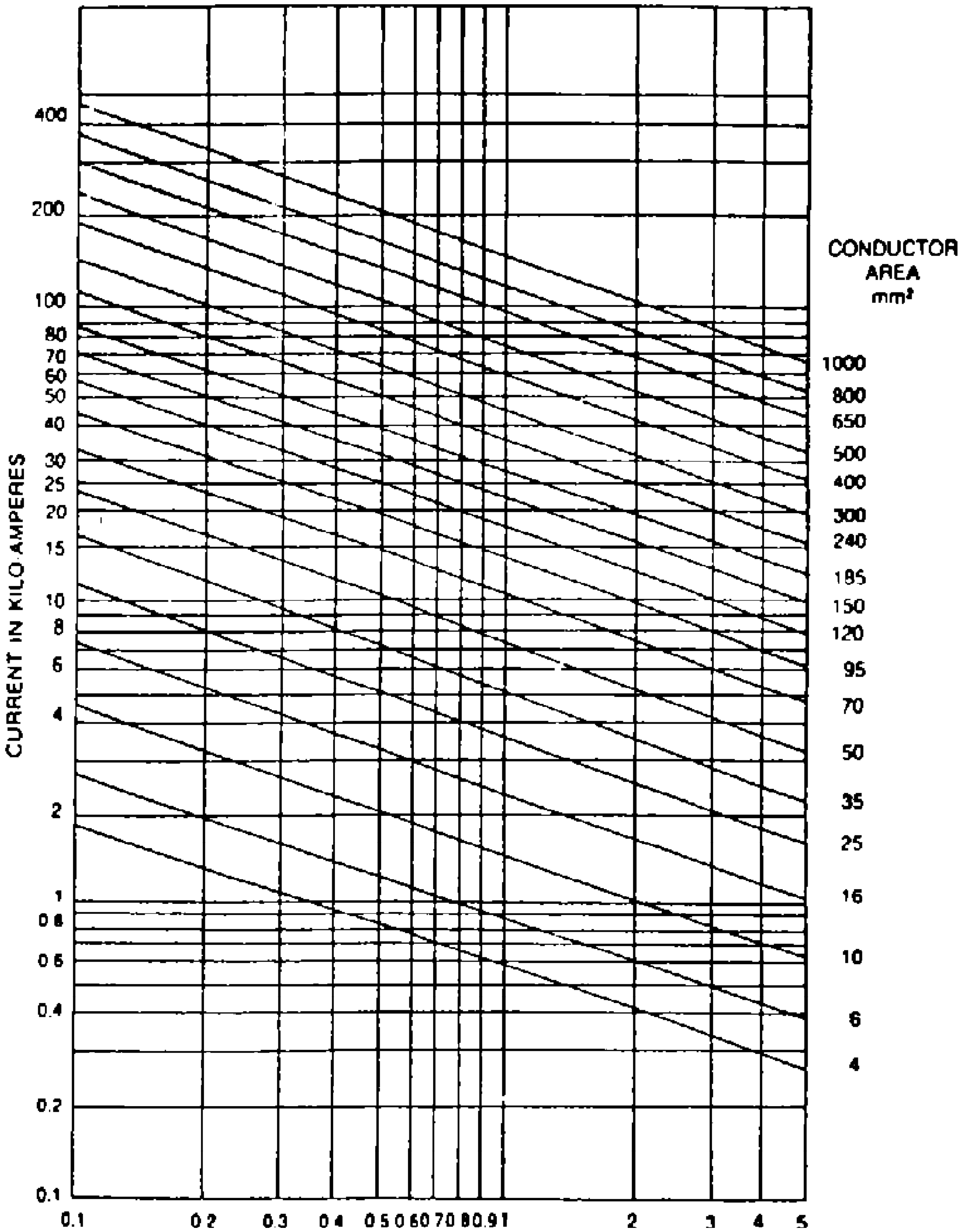
**a)** Minimum installation temperature.
**b)** Maximum continuous operating temperature.
**c)** Maximum temperature at short circuit.

Table H7 shows the minimum installation temperature and maximum operating temperature of the sheathing compound.

**TABLE H6 - MAXIMUM CONDUCTOR TEMPERATURES**

| Insulation | Voltage kV | Type | Cable Laid Direct in Ground or in Air | | Cable Laid in Ducts | | Emergency Operating Temperature °C |
|---|---|---|---|---|---|---|---|
| | | | Arm °C | Unarm °C | Arm °C | Unarm °C | |
| Impregnated Paper | 0.6/1 to 3 8/6.6 | Single core | | 80 | | 70 | |
| | | Multicore belted | 80 | 80 | 80 | 70 | |
| | 6.35/11 | Single core | | 70 | | 60 | |
| | | Multicore belted | 65 | 65 | 65 | 60 | |
| | | Multicore screened | 70 | 70 | 70 | 60 | |
| | 12.7/22 | Single core | | 65 | | 60 | |
| | 19/33 | Multicore screened | 65 | 65 | 65 | 60 | |
| XLPE, EPR, CSP, CPE, EMA | 0.6/1 | Single core and multicore | 90 | 90 | 90 | 90 | 130 |
| XPLE | 1.9/3.3 to 38/66 | Single core and multicore with Cu wire screen | 90 | 90 | 90 | 90 | 105 |
| EPR | 1.9/3.3 to 38/66 | | 90 | 90 | 90 | 90 | 130 |
| XPLE and EPR | 1.9/3.3 to 38/66 | With copper tape screen | 90 | 90 | 90 | 90 | 90 |
| PVC | 0.6/1 | Single core and multicore | 75 | 75 | 75 | 75 | |

COPPER CONDUCTORS




DURATION OF SHORT CIRCUIT IN SECONDS

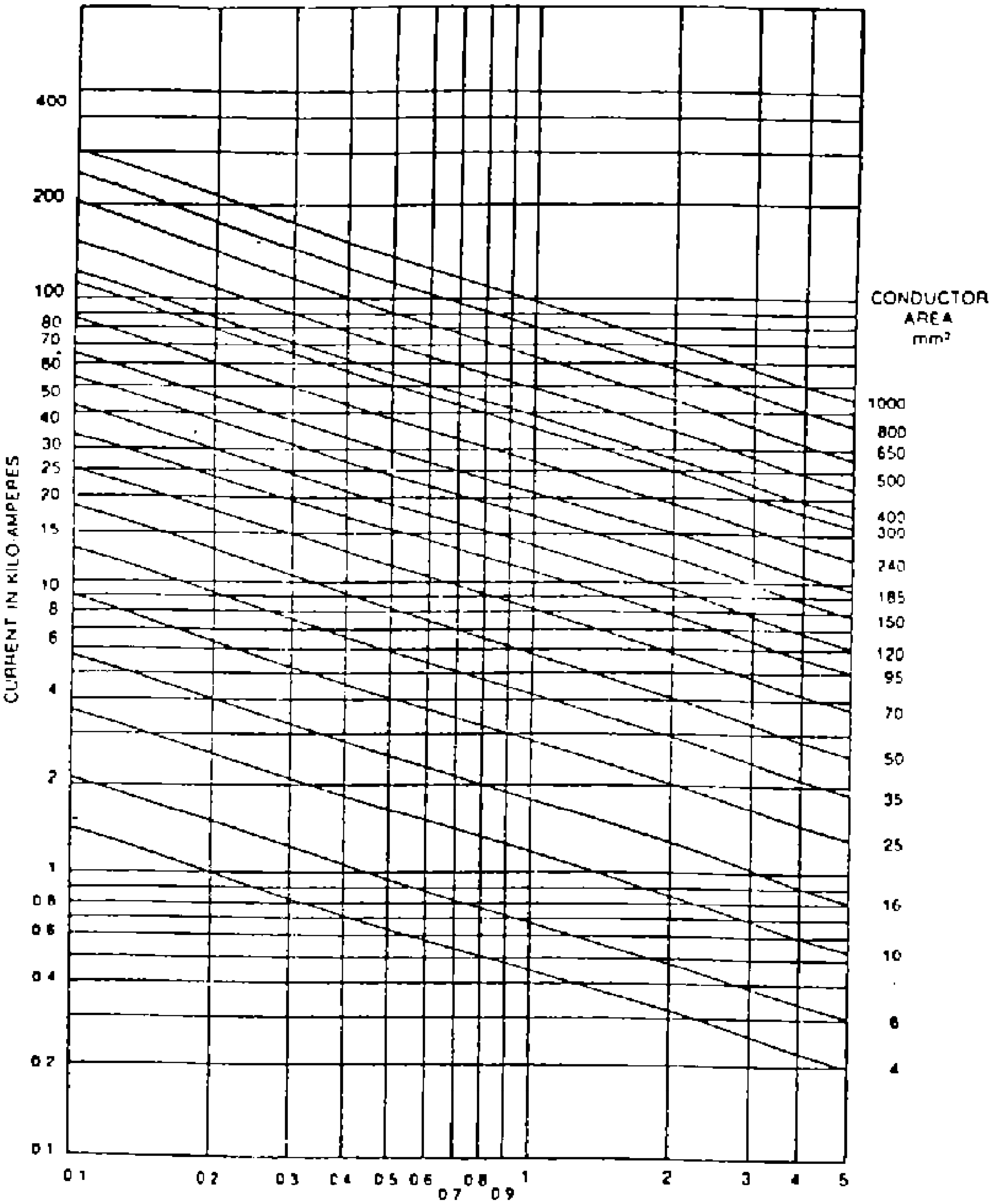
SHORT CIRCUIT RATINGS FOR XLPE, EPR, CPE AND CSP INSULATED CABLES HAVING COPPER CONDUCTORS

Fig. H2

**Note:**

**Cables are assumed to be at the maximum conductor temperature of 90°C, prior to short circuit. Conductor temperature after short circuit is 250°C.**

COPPER CONDUCTORS



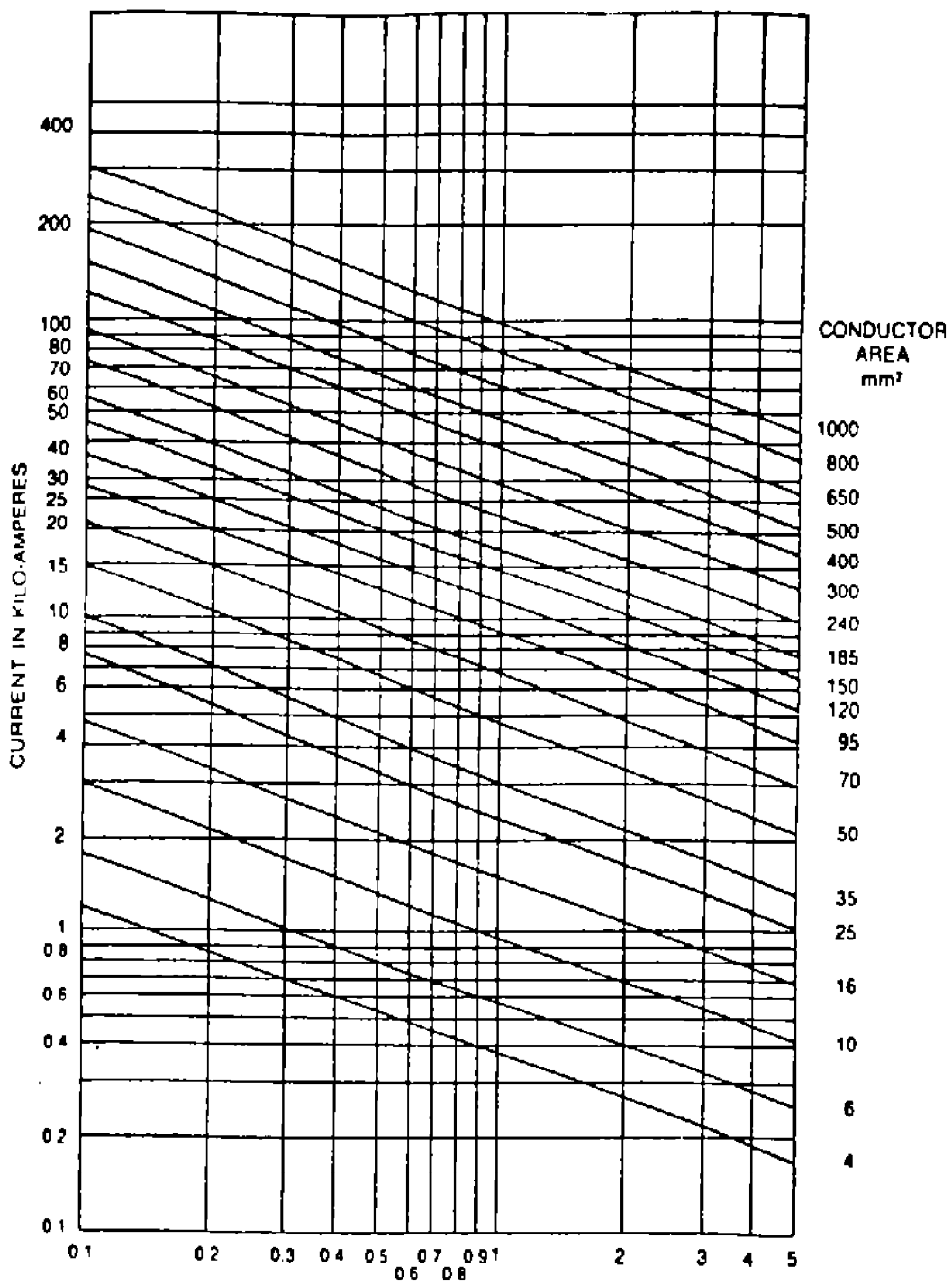

DURATION OF SHORT CIRCUIT IN SECONDS

**SHORT CIRCUIT RATINGS FOR PVC INSULATED CABLES HAVING COPPER CONDUCTORS**
**Fig. H3**

**Note:**

**Cables are assumed to be at the maximum conductor temperature of 75°C, prior to short circuit. Conductor temperature after short circuit is 140°C to 160°C.**

ALUMINUM CONDUCTORS



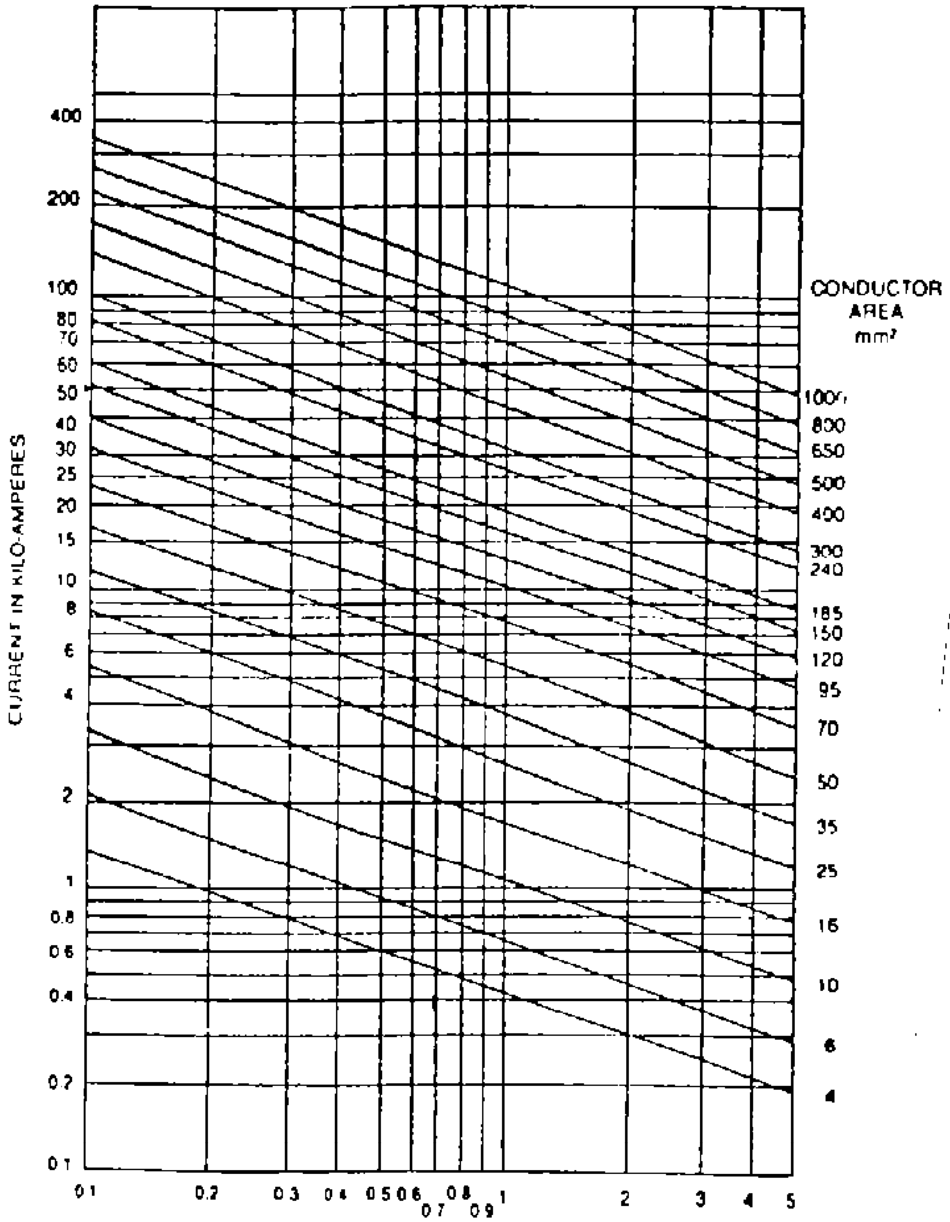

DURATION OF SHORT CIRCUIT IN SECONDS

**SHORT CIRCUIT RATINGS FOR PVC INSULATED CABLES HAVING ALUMINUM CONDUCTORS**
**Fig. H4**

**Note:**

**Cables are assumed to be at the maximum conductor temperature of 75°C, prior to short circuit. Conductor temperature after short circuit is 250°C.**

**COPPER CONDUCTORS**




**DURATION OF SHORT CIRCUIT IN SECONDS**

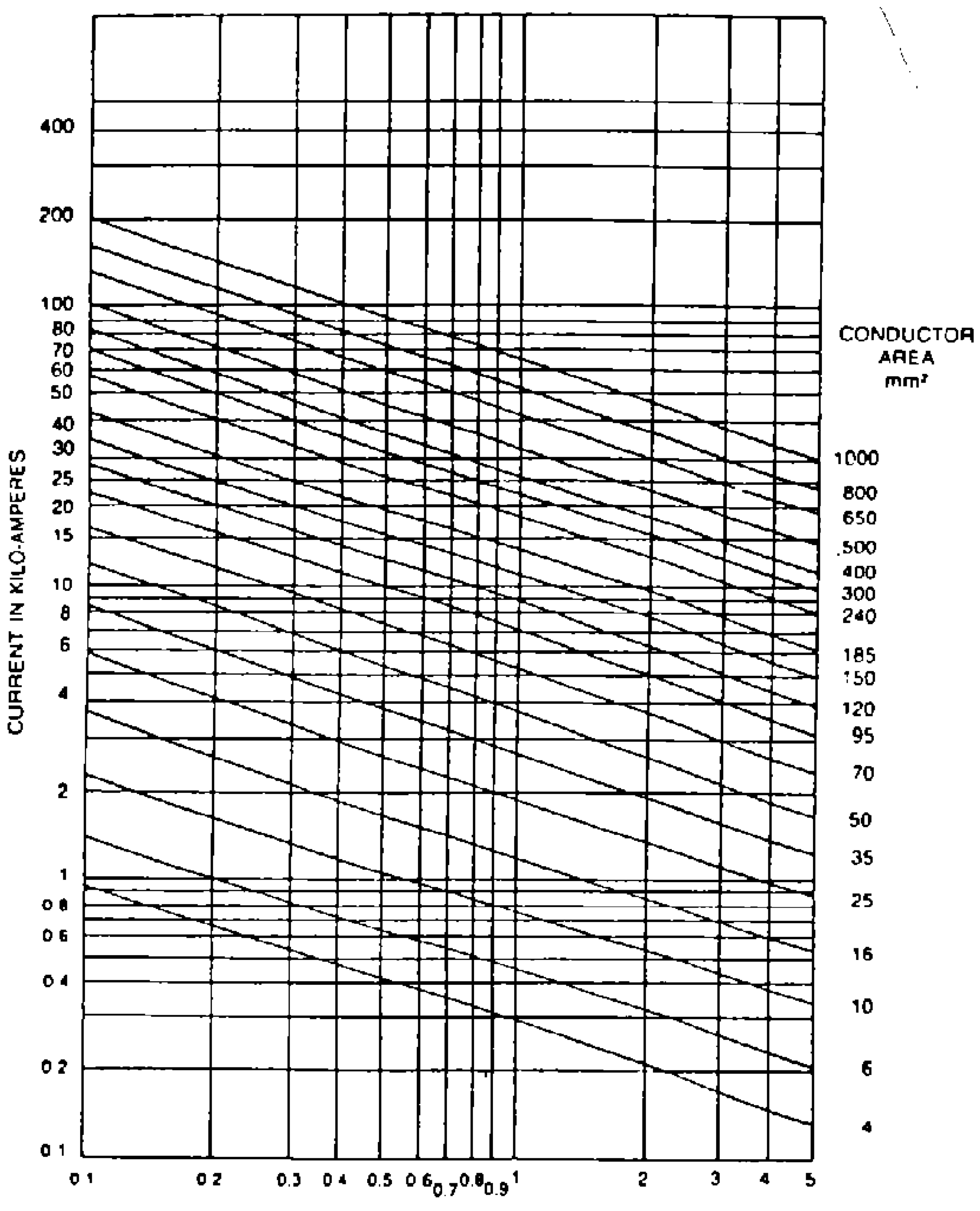
**SHORT CIRCUIT RATINGS FOR PAPER INSULATED CABLES HAVING COPPER CONDUCTORS**
**Fig. H5**

**Note:**

**The graph is for cables up to and including 3.8/6.6 kV. For voltages above this, up to and including 19/38 kV, multiply the current obtained by 1.1.**

**Cables are assumed to be at maximum conductor temperature prior to short circuit. Conductor temperatures after short circuit is 250°C.**

## ALUMINUM CONDUCTORS



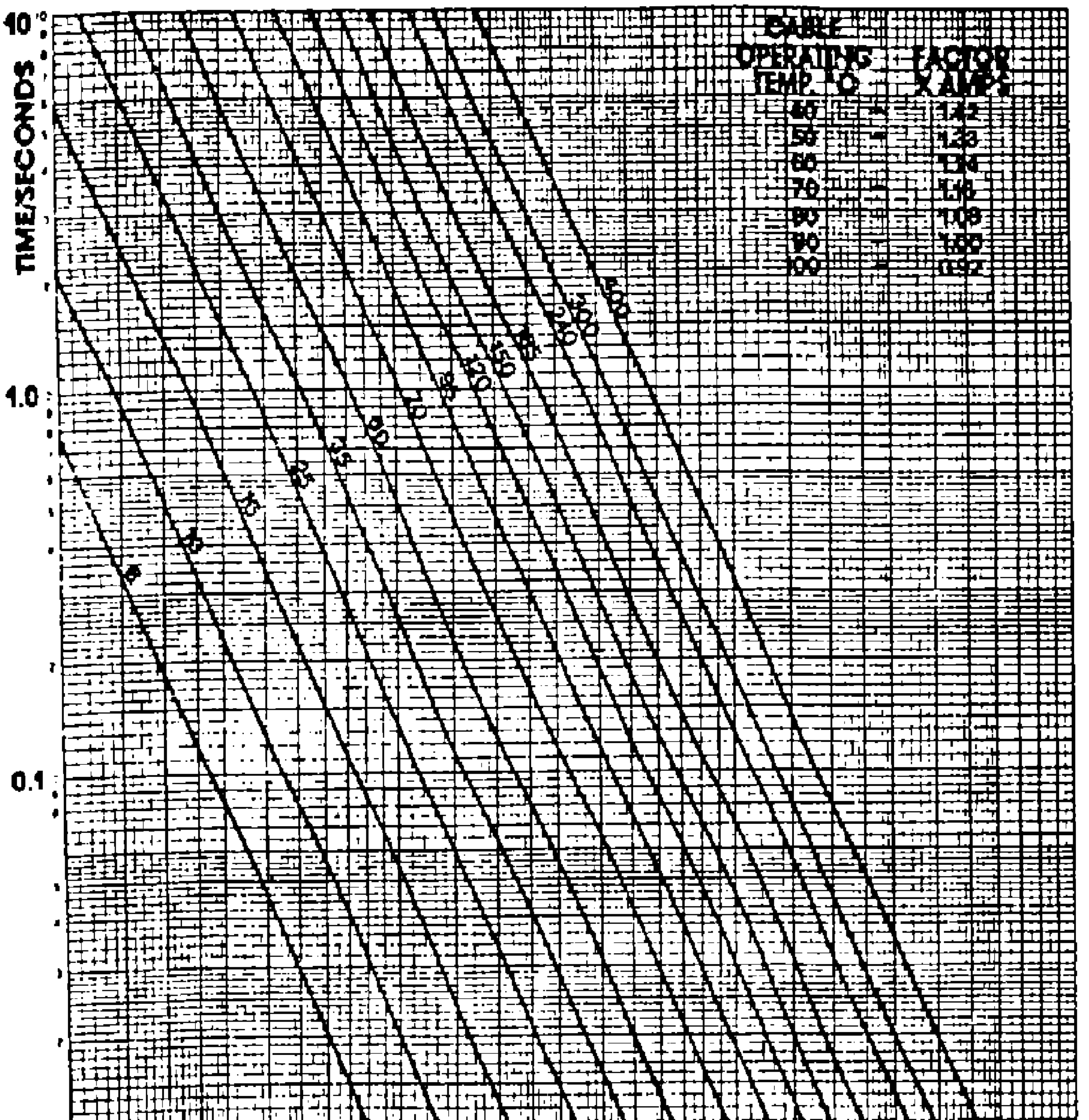

DURATION OF SHORT CIRCUIT IN SECONDS

**SHORT CIRCUIT RATINGS FOR XLPE, EPR, CPE AND CSP INSULATED CABLES HAVING ALUMINUM CONDUCTORS**
**Fig. H6**

**Note:**

**Cables are assumed to be at the maximum conductor temperature of 90°C, prior to short circuit. Conductor temperature after short circuit is 250°C.**

SHORT CIRCUIT CAPACITY PVC SERVED MI CABLE
UPPER LIMIT SHEATH TEMPERATURE 200°C




SHORT CIRCUIT RMS AMPERES

SHORT CIRCUIT CURRENT VERSUS TIME FOR VARIOUS SIZES OF CABLES
Fig. H7

**TABLE H7 - TEMPERATURE LIMITS OF INSULATIONS**

| Material | Minimum Installation Temperature °C | Maximum Continuous Operating Temperature °C | Maximum Temperature at Short Circuit °C |
|---|---|---|---|
| Polyethylene (PE) | -70 | 70 | 130 |
| Polypropylene (PP) | -10 | 80 | 150 |
| Polyvinyl Chloride (PVC) | -5 | 75 | 140/160 |
| Ethylene Propylene Rubber (EPR) | -30 | 90 | 250 |
| Chloro Sulphonated Polyethylene (CSP) | -20 | 90 | 250 |
| Chlorinated Polyethylene (CPE) | -20 | 90 | 250 |
| Silicone Rubber (SR) | -55 | 150 | 350 |
| Crosslinked Polyethylene (XLPE) | -70 | 90 | 250 |
| Impregnated Paper | 0 | 65 - 80 | 250 |

### 4.3 Voltage Drop

Voltage drop in individual cables are given in the unit milivolt per ampere per meter length of cable they are derived from the following formulae:

for single phase circuits $mv = 2z$
for three phase circuit $mv = \sqrt{3}z$

where

mv = volt drop in milivolts per meter length of cable and
z = impedance per conductor per kilometre of cable at maximum operating temperature in ohms.

### 4.4 Economic Cross Sectional Area of Conductor

The economic cross sectional area of conductor is that which results in the minimum annual cost which is the combination of the capital changes and the cost of the losses.

## 5. SINGLE CORE CABLES IN THREE-PHASE SYSTEMS

### 5.1 Arrangement of the Cables

If two busbars are to be connected by means of several parallel systems of single-core cables, the inductivity of the parallel cables carrying the same phase should be the same for all of them, if possible, as this is a prerequisite for an even distribution of the current between them.

The distribution of the current is most irregular, if the cables of one phase are grouped together and installed side by side. It is better to bundle three cables carrying three phases together in systems and to keep the distances between those in one system smaller than the distance between the systems.

A completely even distribution of the current is obtained only with three core cables as with these the inductive influence on neighboring cables under normal operating conditions is cut out due to the even lay of the cores.

The distance between two systems of single-core cables should be about twice as large as the distance between the cables of one system. The phase sequence within a system is of great importance also. Depending on the number of three-phase systems the following phase sequence is recommended:

**RYB BYR RYB BYR and so on.**

With this arrangement the inductivities of the parallel cables in one phase are nearly equal, those of the phases R, Y and B, however, differ from each other. But this is less detrimental than different inductivities in the parallel cables carrying the same phase. The arrangement RYB, RYB, RYB ....in unfavorable in so far as here not only the phase inductivities RYB, but also the inductivities of the parallel cables of one phase differ.

The cables of the same phase should not be placed side by side, but on different levels, if they are laid on racks. The vertical distance between racks should not be less than 300 mm. Two systems whose phase sequences oppose each other may be laid on the same rack also, if the space is sufficient:

**RYB BYR**
**RYB BYR**
**RYB BYR and so on.**

With this arrangement the inductivity of the parallel cables is nearly the same for all of them. The inductivities of the three phases, however, are different, but this is of no importance, as such connections are short in most cases. With one system only the trefoil formation:

**B**
**R Y**

will cause the phase inductivity to be equal. With several systems in trefoil formation it is advisable to arrange the cables as follows:

**B B B B**
**R Y Y R R Y Y R and so on.**

Trefoil formation of several systems above each other is not recommended, as in this case the inductivities of the parallel cables differ considerably.

With single-core cables care has also to be taken that they are properly fastened at short distances, in order to prevent them from being shifted about by the dynamic forces of an asymmetric short circuit current. With cables laid directly in the ground there is no such problem.

## 5.2 Earthing

Voltages, which are directly proportional to the conductor current, the frequency, the coefficient of mutual induction between conductor and metal sheath and to the length of the cable, are induced in the metal sheath of single-core cables if these are operated in a.c. or three-phase systems. With the usual method of installation, i.e. connecting the metal sheaths across the joints and interconnecting and earthing them at the terminations, the induced voltages cause currents to flow in the metal sheaths. These in turn cause additional losses and thus a reduction in the current carrying capacity if the cables are operated in a.c. or three-phase systems, as compared with d.c. operation. We have to take into account the reduced current rating due to the additional losses in the metal sheaths.

Non-magnetic armor or screens (e.g., with single-core PVC cables) also cause such additional losses if they are earthed in the normal way at both ends.

If for economic reasons or with regard to the current carrying capacity of the cable these additional losses are to be avoided,then the metal sheaths or screens of the cables, or the terminations connected to them, may be earthed at one end only. At the other end the sealing ends are to be mounted isolated. The consequence is, however, that the induced voltages between metal sheaths (screens) and earth at the free end are at their peak value, reaching $\sqrt{3}$ times the value of the induced voltages between the free ends of the metal sheaths (screens) of a three-phase system. In order to keep these voltages, which are proportional to the length of the cable, within the permissible range, cable connections earthed at one end only have to be kept short (generally below 500 m), or the induced voltages have to be broken up by installing joints in which sheath or screen are interrupted and earthed at one end of each section only.

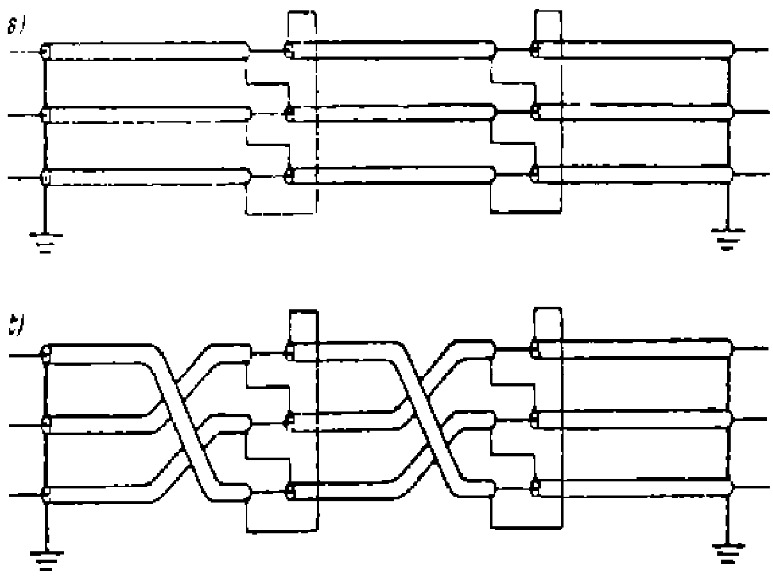
Apart from the higher cost of installation the one-sided earthing of the sheaths or screens has other disadvantages also. The earthing is impaired and there is no earth connection between two stations connected by the cables; under certain conditions this will necessitate additional expenditure on earthing these. The reduction factor for the inductive influence is worsened, as the induced current in the sheaths is suppressed. The induced voltages, which may appear at the free end of the sheaths in the event of a fault or during switching operations, are of particular importance.

## 5.3 Cross-Bonding of the Sheaths, Transposition of the Cables

There is another method of suppressing the induced current in the sheaths apart from a residual current:

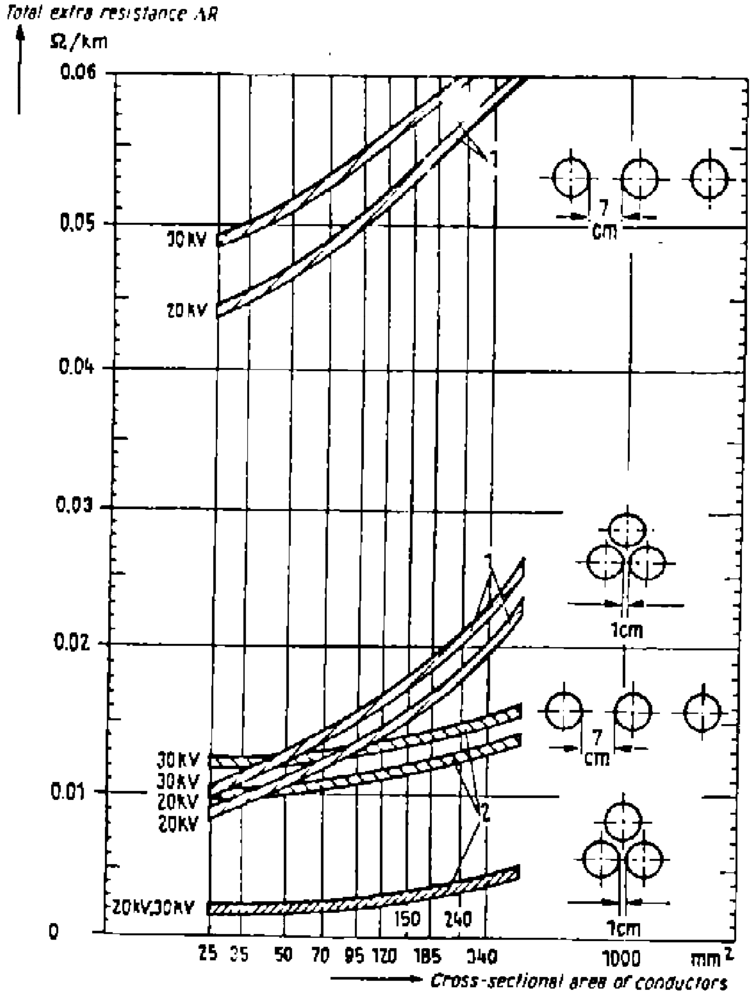
The metallic continuity of the sheaths is interrupted in the joints and corresponds in a cycle as shown in Figs.(H8 a and b). This corresponds to a transposition of the sheaths, similar to the transposition of asymmetrically arranged overhead lines. In addition the cables themselves may be transposed. By these methods the earthing conditions are not impaired and the dangers of high induced voltages at the free ends are avoided. Only the reduction factor for the inductive influence is worsened.

Earthing at one end only, as well as cross-bonding of the sheaths or transposition are at present employed with extra high tension cables only, due to the high cost of installation and of specially constructed joint boxes as well as of the additional maintenance required.



**SINGLE-CORE CABLE SYSTEM IN FLAT FORMATION WITH SCREENS CROSS-BONDED AND CONDUCTORS CYCLICALLY TRANSPOSED**

**Fig. H8**




**TOTAL EXTRA RESISTANCE ∆R OF VARIOUS TYPES OF MEDIUM VOLTAGE CABLES AS A FUNCTION OF THE C.S.A. OF THE CONDUCTORS**

**Fig. H9**

**Notes:**

**1) Aluminum-sheathed cables.**

**2) Single-core plastic cables.**

## 6. PROTECTION OF CABLES

### 6.1 Protection Against Overcurrents

**Rule:**

Cables must be protected by overcurrent protective devices against excessive temperature rise, which can be caused both by overloads in the course of operation and by short circuit.

### Overcurrent Protection Devices:

Overcurrent protective devices protect either against overload and short circuit or against one of these conditions only (Table H8).

### Disposition:

Overcurrent protection devices for protection against overload and/or short circuit must be provided at the input to every circuit and at every point where the current-carrying capacity or the short-circuit carrying capacity is reduced e.g., a reduction in the cross-sectional areas or different laying conditions.

**TABLE H8 - APPLICATION OF OVERCURRENT PROTECTION DEVICES**

| OVERCURRENT PROTECTION DEVICE | OVERLOAD PROTECTION | SHORT-CIRCUIT PROTECTION |
|---|---|---|
| H.R.C. fuses | × | × |
| Back-Up fuses for equipment protection | | × |
| Line-Protection circuit breakers | × | × |
| Circuit breaker with delayed and instantaneous overcurrent releases | × | × |
| Thermal-Delay releases in conjunction with switchgear | | × |
| Instantaneous overcurrent releases in conjunction with switchgear | | × |
| Thermistor-Type protection e.g. in motor circuits | | × |

**Note:**

× **Denotes suitability.**

## 6.2 Fire Protection

**6.2.1** In general a cable can be described as fire resistant when it complies with the severe test in IEC 331 in which the middle portion of a sample of cable l200 mm long is supported by two metal rings 300 mm apart and exposed to the flame from a tube type gas burner at 750°C for 3 hours. Simultaneously the rated voltage of the cable is applied continuously throughout the test period. Furthermore, not less than 12 hours after the flame has been extinguished, the cable is re-energized. No electrical failure must occur under these conditions.

There are many customer variations of this test in which the time and temperature are treated as variables. Test temperatures of l000°C are now common to simulate hydrocarbon fires. The cable is also subjected to impact during the test to simulate falling debris and application of a water deluge after the gas flame has been extinguished to simulate fire fighting.

**6.2.2** For protection of fire specialist advice is necessary and when such consideration apply cables with suit- able characteristic should be employed. BS 6724 recommends armored cables for electricity supply, having thermosetting insulation with low emission for smoke and corrosive gases when affected by fire.

**6.2.3** Cables clipped direct may be bare MICC to withstand fire.

**Notes:**

**1) Cables with specially fire-resistant or fire-retardant constructions. either to keep important circuits in operation or to restrict the spread of fire, are of importance as also is the use of materials with low emission of acid gases and smoke in fires.**

**2) Cables for offshore oil installations generally follow the same pattern as for cables in ships.**

## 6.3 Environmental Protection

There are many installations where conditions are much more onerous than normal, and some brief note for protection of cables against hostile environments are useful.

Amongst hostile environment the following could be mentioned:

- Refineries and chemical plants
- Termites and rodents
- Exposure to mechanical damage
- Solar radiation

### 6.3.l Oil refineries and chemical plants

**I)** Polymeric and elastomeric cables are not compatible with hydrocarbon oils and organic solvents. Such solvent particularly at elevated temperatures are absorbed by the insulation and sheathing material leading to swelling and resultant damage.

Semi-conductive components on high voltage cables may lose their conductive properties. It follows therefore that where polymeric and elastomeric cables are used in locations where exposure to hydrocarbon oils and organic solvents is likely, a lead sheath is required. The most satisfactory protection for the lead sheath would be a high density polyethylene sheath with steel wire armor.

**II)** For casual contact with oil spills a CSP sheath can be used. It is worthwhile to mention that.

**III)** Because the PVC insulated, wire armored, PVC oversheathed cable design, as used in general industry, has good ability to withstand a broad range of hostile environment, it is also the cable mainly used in oil and petrochemical plants.

An important difference, however, is that. If such cables are buried in ground containing hydrocarbons, these materials may pass through the oversheath and into the center of the cable and the hydrocarbons could be transmitted into fire risk areas. It is sometimes necessary, therefore, to incorporate a metallic sheath over the inner sheath. In the UK. a lead sheath is used with steel wire armor over it. In North America, an aluminum sheath with PVC oversheath and no armor is often preferred. Cables with XLPE or EPR insulation are also protected similarly.

Specifications for such cables are issued by individual oil companies and in the UK by the Engineering Equipment and Materials Users Association (EEMUA) under publication No. 133.

### 6.3.2 Termites, and rodents

Special constructions are necessary to resist termites as all cables with normal finishes are susceptible to their attack. If cables are installed in locations where termite attack is likely, protection may take the form of one of the following:

**i)** Two brass tapes, the upper one overlapping the gap in the lower one, may be incorporated into cable finish. In the case of armored cable the brass tapes may be applied under the bedding of the armor. For unarmored cable the brass tapes can be applied over the normal PVC or other extruded sheath followed by a PVC sheath over the brass tapes.

**ii)** A nylon jacket may be applied over the PVC or other extruded sheath followed by a sacrificial layer of extruded PVC over the nylon to protect it from damage during installation.

Chemical treatment of the backfill is no longer recommended because of damage to the environment and the health risk.

#### 6.3.3 Exposure to mechanical damage

**i) Slight exposure to impact and to tensile stresses**

The application of a high density polyethylene sheath can give appreciable added mechanical protection to cables with the normal PVC sheath. This method is suitable for single and multicore cables.

**ii) Moderate exposure to impact and to tensile stresses**

Single core cables can be armored with non-ferrous armor wire, usually hard drawn aluminum.

Double steel tape armor or a single layer of galvanized steel wire armor is recommended for multicore cables. The steel wire is necessary if there is likely to be a moderate tensile stress applied to the cable during pulling in or during service. Both steel tape and steel wire armored cables offer good protection against rugged installation conditions.

**iii) Severe exposure to impact and tensile stresses**

The double wire armor finish offers a very high level of protection against mechanical damage whether it be impact or longitudinal tensile stress such as in subsidence areas and submarine installations on an uneven sea floor.

#### 6.3.4 Exposure to ultra violet radiation

Cables shall have special materials to prevent ultra violet degradation when exposed to sunlight. To be sure the correct material is used it is necessary to state at time of enquiry and ordering that the cable will be exposed to sun-light.

#### 6.3.5 Exposure to solar radiation

In location with intense solar radiation plastic-insulated cables must be protected against direct radiation. Upward cable runs or cable racks must be provided with covers or sunshades. It is important that the air circulation shall not be impeded in any way.

## 7. USEFUL GUIDES IN ENGINEERING OF CABLE WORKS

### 7.l Minimum Installation Bending Radii

In absence of manufacturing data in conjunction with bending radii Tables H.1 to H.5 can be used. The radii quoted in these tables are in accordance with British Standards or for cables not covered by British Standards represent accepted practice.

**Symbols:**

do = cable overall diameter or the major axis for flat cables

### 7.1.1 General wiring cables

**TABLE H9.1 - CABLES FOR FIXED WIRING**

| INSULATION | CONDUCTORS | CONSTRUCTION | OVERALL DIAMETER (mm) | MINIMUM RADIUS |
|---|---|---|---|---|
| PVC or rubber | Aluminum solid circular or stranded | Unarmored | Up to l0<br>10 - 25<br>Above 25 | 3 do<br>4 do<br>6 do |
| | | Armored | Any | 6 do |
| Mineral | Copper | | Any | 6 do |

**TABLE H9.2 - PVC AND EPR INSULATED CABLES FOR INSTALLATION IN SHIPS OR PLATFORMS**

| VOLTAGE | CONSTRUCTION | DIAMETER mm | MINIMUM RADIUS |
|---|---|---|---|
| 150/240 V<br>440/750 V<br>600/1000 V | Unarmored | UP to 10<br>10 to 25<br>Above 25 | 3 do<br>4 do<br>6 do |
| 150/240 V<br>440/750 V<br>600/1000 V | Armored | Any | 6 do |
| 150/240 V<br>440/750 V<br>600/1000 V | Shaped conductor | Any | 8 do |
| 1.9/3.3 kV<br>3.3/3.3 kV | Unarmored<br>Unscreened | Any | 6 do |
| 1.9/3.3 kV to<br>6.35/11 kV | Unarmored<br>Armored | Any | 8 do<br>12 do |

### 7.1.2 Distribution cable

**TABLE H9.3 - PAPER INSULATED CABLES**

| VOLTAGE | MINIMUM RADIUS | | | |
|---|---|---|---|---|
| | SINGLE | MULTICORE | ADJACENT TO JOINTS AND TERMINATIONS | |
| | | | WITHOUT FORMER | WITH FORMER |
| Up to and including 6.35/11 kV | 15 do | 12 do | | |
| Above 6.35/11 kV and up to and including 12.7/22 kV | 18 do | 15 do | | |
| 19/33 kV single-core | 21 do | 18 do | 20 do | 15 do |
| 19/33 kV 3-core screened | 21 do | 18 do | 15 do | 12 do |
| 19/33 kV 3-core SL | 21 do | 18 do | 15 do | 12 do |
| 19/33 kV cores of SL | 21 do | | 20 do | 15 do |

**TABLE H9.4 - PVC AND XLPE INSULATED CABLES FOR 6.6-33 kV**

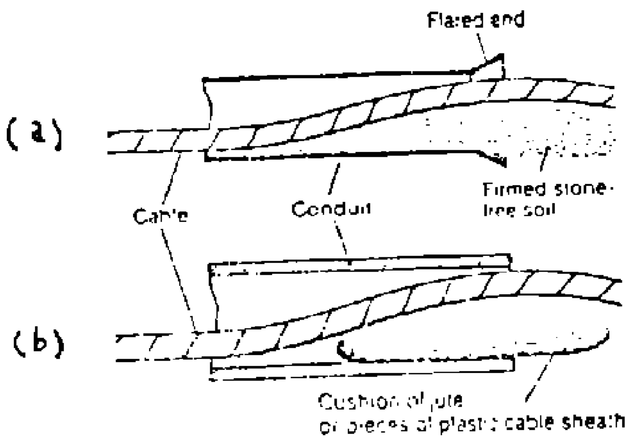
| CONDUCTOR | CONSTRUCTION | OVERALL DIAMETER (mm) | MINIMUM RADIUS |
|---|---|---|---|
| Solid aluminum or stranded copper | Armored or unarmored | Any | 8 do |

**TABLE H9.5 - XLPE INSULATED CABLES FOR 6.6-33 kV**

| TYPE OF CABLE | MINIMUM RADIUS | |
|---|---|---|
| | DURING LAYING | ADJACENT TO JOINTS OR TERMINATIONS |
| Single core | | |
| (a) Unarmored | 20 do | 15 do |
| (b) Armored | 20 do | 12 do |
| Three core | | |
| (a) Unarmored | 15 do | 12 do |
| (b) Armored | 12 do | 10 do |

## 7.2 Protection of Cables at Pipe Exit

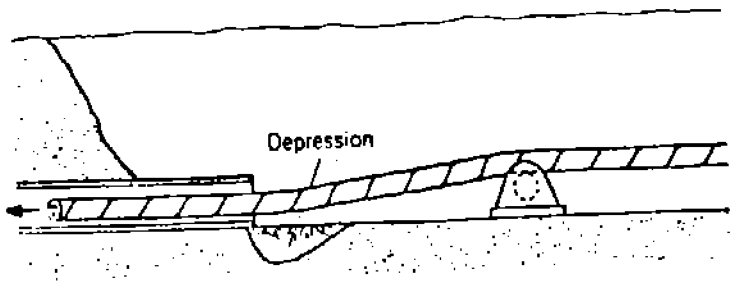
A cushion of jute or pieces of plastic cable sheath or firmed stone free soil shall be provided for protection of cables at pipe exit, similar to those shown in Fig. H10 (a and b).




**UNDER-PADDING OF CABLES AT THE END OF A PIPE**
**Fig. H10**

## 7.3 Inserting of Cables into a Pipe or Duct Block Section

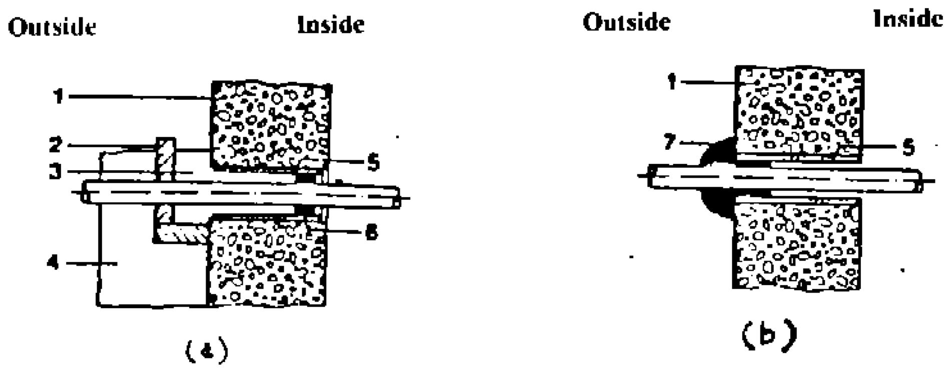
Fig. H11 shows method of inserting a cable into a pipe or duct-block section. Attention is drawn to use of the roller and provision of depression to facilitate cable pulling.




**INSERTING A CABLE INTO A PIPE OR DUCT-BLOCK SECTION**
**Fig. H11**

## 7.4 Typical Wall Lead Through

Fig. H12 (a and b) shows typical wall lead through, and the required sealing.

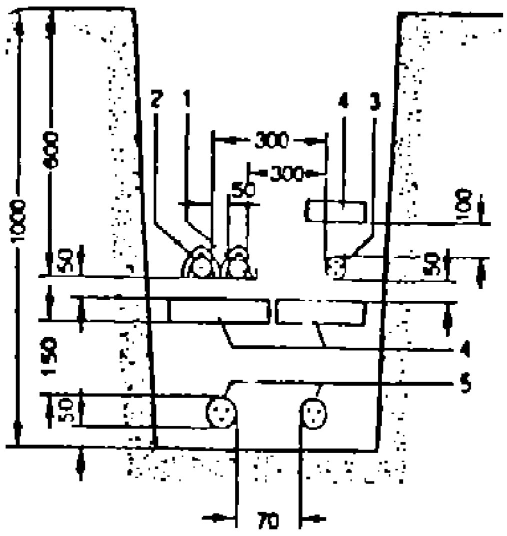



**TYPICAL WALL LEAD-THROUGH**
**Fig. H12**

**1) Wall**
**2) Bricks or clay moldings**
**3) Sealing compound**
**4) Sand barrier**
**5) Plastic, concrete or steel pipe**
**6) Seal of unimpregnated jute, bitumenized binding or plastic strip**
**7) Resilient plastic compound**

## 7.5 Minimum Clearances and Laying Depth in a Cable Trench

Fig. H13 shows minimum clearances and laying depth in a cable trench in which LV, MV, control cable and telecommunication cables are laid.




**MINIMUM CLEARANCES AND LAYING DEPTHS IN A CABLE TRENCH**
**Fig. H13**

**1) Communications cable**
**2) Control cable**
**3) Power cable up to 0.6/1 kV**
**4) Cover plates, or bricks**
**5) Power cables > 0.6/1 Kv**

**Dimensions in mm**

## 8. SUBMARINE CABLES

## 8.1 General

Submarine cables are used in three basic types of installation :

**a)** river or short route crossings which are generally relatively shallow water installations.

**b)** between platforms, platforms and sea-bed modules or between shore and a platform in an offshore oil or gas field: these cables are currently laid in depths not exceeding 200 m but it is anticipated that much deeper installations will be required in the future.

**c)** major submarine cable installations, coast to coast, often laid in deep water and crossing shipping routes and fishing zones; these cables are generally required for bulk power transfer in a high voltage either a.c. or d.c. transmission scheme.

Submarine cables are usually subject to much more onerous installation and service conditions than an equivalent land cable and it is necessary to design each cable to withstand the environmental conditions pervailing on the specific route. Subject to certain restrictions, paper insulated solid type cables, oil-filled cables, gas-filled cables and polymeric cables are all suitable for submarine power cable installations. Polymeric and thermoplastic insulated cables are used for control and instrumentation and appropriate action has to be taken in the design and manufacture of the cable to attain the required mechanical characteristics.

## 8.2 Cables for River Crossings

Cables routes for river crossings are generally short and cross relatively shallow water. The length of cable required can often be delivered to site as a continuous length on a despatch drum. Normal methods of installation include laying the cable from a barge into a pre-cut trench and mounting the drum on jacks on one shore and floating the cable across the river on inflatable bags. Installation of the cable is therefore a relatively simple operation which does not involve excessive bending or tension. The cable design is the most similar to land cable practice of all the different types of submarine cable. However, it is considered prudent to improve the mechanical security of the cable by applying slightly thicker lead and anticorrosion sheaths and to increase the diameter of the armor wires. If the cable is to be laid across the river at the entrance to a port, it is recommended that the cable be buried to a depth of at least 1 m. A cheaper but less effective alternative is to protect a surface-laid cable by laying bags of concrete around it.

Should the cable be considered liable to damage due to shipping activities, an alternative solution to direct burial of the cable is to entrench a suitable pipe into the river bed and then pull in the selected type of cable.

## 8.3 Requirements for Long Cable Lengths Laid in Deep Water

Any cable to be laid on the sea bed should have the characteristics given below, the relevant importance of each particular characteristic being dependent on the depth of water and length of cable route.

**a)** The cable must have a high electrical factor of safety as repair operations are generally expensive and the loss of service before repairs can be completed is often a serious embarrassment to the utility concerned.

**b)** The cable should be designed to reduce transmission losses to a minimum as submarine cable routes are generally long and the operating power losses are therefore significant in the overall economics of the system.

**c)** The cable should preferably be supplied in the continuous length necessary to permit a continuous laying operation without the need to insert joints while at sea. Proven designs of flexible joints are available to permit drum length of cable to be jointed together, either during manufacture or prior to loading the continuous cable length onto the laying vessel.

**d)** The cable must withstand, without deterioration, the severe bending under tension, twisting and coiling which may occur during the manufacture and installation programs.

**e)** The cable must also withstand, without deformation, the external water pressure at the deepest part of the route.

**f)** The cable, and where appropriate the terminal equipment, must be designed to ensure that only a limited length of cable is affected by water ingress if the metal sheath is damaged when in service.

**g)** The armor must be sufficiently robust to resist impact damage and severance of the cable if fouled by a ship’s anchor or fishing gear.

**h)** For deep water installations, the cable must be reasonably torque balanced to avoid uncontrolled twisting as it is lowered to the sea bed.

**i)** The weight of the cable in water must be sufficient to inhibit movement on the sea bed under the influence of tidal currents. Movement would cause abrasion and fatigue damage to the cable.

**j)** The cable must be adequately protected from all corrosion hazards.

**k)** All cable components must have adequate flexural fatigue life.

**l)** All paper insulated and some polymeric insulated cables are required to be watertight along their complete lengths. Water ingress impairs the electric strength of these cables.

### 8.4 Requirements for Cable to be Buried

The requirements for cable laid on the sea bed also largely apply to cables which are to be buried. The bending characteristics of the cable as it passes through the burial device may need further consideration, and the friction of the serving against rollers and skid plates has to be taken into account. It is essential that information be provided on the length of the proposed route, the nature and contour of the sea bed, tidal currents, temperatures etc. before a provisional cable design can be prepared for the proposed installation. Sufficient information can often be obtained from naval charts to enable a tentative cable design to be prepared to complete a feasibility study but in most cases it is necessary to carry out a hydrographic survey before the cable design can be finalized.

### 8.5 a.c. Cable Schemes

Submarine cable schemes are normally a.c. schemes as land transmission and distribution system usually operate on a.c. As in the case of land cable circuits, the use of 3-core cables up to and including l50 kV is preferred to single-core cables provided that they can meet the required rating. 3-core cables also offer savings in both cable and installation costs as only two cables compared with four for a 3-phase scheme need be installed when security of supply is required if one cable is damaged. There is a limit, however, to the length of 3-core cable that can be laid and the cost of inserting flexible joints into very long cable lengths has to be taken into account.

If a 3-core submarine cable is damaged externally. e.g., by a ship's anchor or trawling gear, all three cores are liable to be affected. It would therefore be necessary to install two 3-core cables from the outset. Preferably separated by 250 m or more to obtain reasonable security of supply. In 3-core solid type cable installations (i.e. for circuits up to 33 kV rating) single lead type cables are sometimes preferred, particularly for deep water installations.

For major a.c. power schemes it will probably be necessary to use single-core cables as 3-core cables will be unable to meet the rating. In this case the cables are spaced far apart so that the risk of more than one cable being damaged in a single incident is minimized. The installation of four single-core cables for one circuit, or one spare cable for two or three circuits, would be expected to provide reasonable assurance of continuity of supply.

However, widely spaced single-core magnetically armored cables give rise to high sheath losses. These losses can be reduced substantially by the use of non-magnetic armor in conjunction with an outer concentric conductor, although this solution increases the initial cost of the cables.

## 9. RESIN FILLED JOINTS AND TERMINATIONS

**9.1** Resin Filled Joints are now the most common form of joint on 600/1000 V polymeric cables. The resin is a solid setting medium which gives mechanical protection for the joint by adhering to the various components within the joint, and provides waterproof encapsulation. The resin also provides the electrical insulation between phases and phase to earth.

**9.2** Although several resin systems have been investigated, only two are now in popular use these are acrylic and polyurethane systems. Both are supplied in packs of two or more components which are mixed just prior to pouring into the joint shell. The resin then cures or sets into the hard encapsulation within ¼ to 3 hours (depending on different make) at normal ambient temperature. Summary of the characteristics of cast resins important for their application are given in Table H10.

**9.3** Both acrylic and polyurethane resins are successful as a low voltage joint medium but acrylic resins have advantages during mixing. Acrylic resins are generally easier to mix and unlike polyurethane resins are unaffected by moisture during curing.

Some polyurethane resin can cause skin irritation and inhalation of the fumes given off during curing should be avoided. Acrylic resins have no health hazards but are generally more expensive than polyurethane system.

**TABLE H10 - SUMMARY OF THE CHARACTERISTICS OF CAST RESINS**

| CAST RESIN | PROTOLIN 51 | PROTOLIN 72 | PROTOLIN 80 | PROTOLIN 84 |
|---|---|---|---|---|
| Regulation | VDE 0291 Part 2 | VDE 0291 Part 2 | VDE 0291 Part 2 | VDE 0291 Part 2 |
| Base | Polyurethane | Polyurethane elastified | Polyurethane elastified | Polyurethane |
| Packaging | Resin and hardener in two-part tins or in two-part bag | Resin and hardener in two-part tins | Resin and bardener in two-part tins or in two-part bag | Resin and bardener in two-part tins |
| Hardening time | 1 to 3 hrs | 1 to 3 hrs | ¼ to 2 hrs | ¼ to 2 hrs |
| Shelf life | 24 months | 24 months | 24 months | 24 months |
| Application | Joints for 3.6/6 kV PVC cables<br>Transition joints for 6/10 kV cables | Indoor sealing ends for medium-voltage PVC cables - rubber and thermoplastic sheathed cables | Low-voltage accessories for<br>- PVC-XLPE cables<br>- mass impregnated<br>- rubber and thermo- cables<br>Transition joints 20 kV<br>Mechanically stressed accessories and resinfiller for joint tubes | Low-voltage accessories for<br>- PVC cables<br>- mass impregnated<br>- rubber and thermoplastic sheathed cables<br>Mechanically stressed accessories and resin filler for joint tubes |
| Special notes | For abnormally high-ambient temperatures or for very large filling volumes PROTOLIN 51 H must be used as it has longer hardening time | For PVC insulation good adhesion to insulation is achieved; XLPE cables require a bedding of tapes | Very good adhesion and therefore good tightness of sealing to XLPE cables | PROTOLIN 84 is less elastic but is less costly |

**9.4** The use of resin systems on paper insulated cables has been extended to 22 kV for both joints and terminations where the resin provides the primary insulation between phases and phase to earth.

**9.5** Terminations use the same principle of box filled with resin which seals the crutch of the cable. Stress control on screened paper insulated cable is effected by antimonial lead wire applied at the screen termination.

**9.6** Resin is also used as the primary insulation on polymeric cables up to 22 kV.

**9.7** For 33 kV polymeric cables, the resin continues to provide protection against mechanical damage and moisture ingress, but insulation is provided by self amalgamating tapes: typically polisobutylene or EPR based. The insulating layer is parallel in the center of the joint and tapers down to the screen terminations. A semiconducting layer is then provided by self amalgamating tapes, producing stress relief by means of a stress cone. Metallic screening is reinstated with a neated copper wire.

## 10. COMMON CONDUCTOR SIZES

The common normal cross section and diameter of conductors for PVC, PE, XLPE and EPR cables are given in Table H11. For comparison of cross sectional areas of conductors to metric, British and U.S. Standards see Table H12.

**TABLE H11 - THE COMMON NOMINAL CROSS SECTION AND DIAMETERS OF CONDUCTORS**

| Nominal cross-section of conductor ($mm^2$) | Fictitious conductor diameter derived from nominal cross-section ($d_L$) (mm∅) |
|---|---|
| 4 | 2.3 |
| 6 | 2.8 |
| 10 | 3.6 |
| 16 | 4.5 |
| 25 | 5.6 |
| 35 | 6.7 |
| 50 | 8.0 |
| 70 | 9.4 |
| 95 | 11.0 |
| 120 | 12.4 |
| 150 | 13.8 |
| 185 | 15.3 |
| 240 | 17.5 |
| 300 | 19.5 |
| 400 | 22.6 |
| 500 | 25.2 |
| 630 | 28.3 |
| 800 | 31.9 |
| 1000 | 35.7 |

## TABLE H12 - COMPARISON OF CROSS-SECTIONAL AREAS TO METRIC, BRITISH AND U.S. STANDARDS

| British Standards[1]) BS | | | Metric Cross-sectional Areas[2]) (in line with VDE) | American Wire Gauge | |
|---|---|---|---|---|---|
| C.S.A. of Conductor sq. inch | Number and Diameter of Strands inch | Equivalent Metric C.S.A. $mm^2$ | Cross-sectional Area $mm^2$ | Equivalent Metric C.S.A. $mm^2$ | AWG or MCM |
| | 3/.020 | | | | |
| .001 | or | 0.65 | | 0.653 | 19 AWG |
| | | | 0.75 | | |
| | 1/.036 | | | | |
| | | | | 0.823 | 18 |
| .0015 | 1/.044 | 0.97 | | 1.04 | 17 |
| .0020 | 3/.029 | 1.29 | | 1.31 | 16 |
| | | | 1.5 | | |
| | 3/.036 | | | 1.65 | 15 |
| .003 | or | 1.94 | | 2.08 | 14 |
| | 1/.064 | | | | |
| | | | 2.5 | | |
| | | | | 2.62 | 13 |
| .0045 | 7/.029 | 2.90 | | | |
| .0050 | 1/.083 | 3.23 | | 3.31 | 12 |
| | | | 4.0 | | |
| .007 | 7/.036 | 4.52 | | 4.17 | 11 |
| .008 | 1/.103 | 5.16 | | 5.26 | 10 |
| | | | 6.0 | | |
| .01 | 7/.044 | 6.45 | | 6.63 | 9 |
| .013 | 1/.128 | 8.39 | | 8.37 | 8 |
| .0145 | 7/.052 | 9.35 | | | |
| | | | 10.0 | 10.55 | 7 |
| .020 | 1/.160 | 12.90 | | 13.30 | 6 |
| .0225 | 7/.064 | 14.52 | | | |
| | | | 16.0 | 16.77 | 5 |
| | 19/.044 | | | | |
| .03 | | | | | |
| | or | 19.35 | | 21.15 | 4 |
| .04 | 1/.192 | | 25.0 | 26.67 | 3 |
| | 19/.052 | 25.81 | | 33.63 | 2 |
| | | | 35.0 | | |
| .06 | 19/.064 | 38.71 | | | |
| | | | | 42.41 | 1 |
| | | | 50.0 | 53.48 | 1/0 |
| .10 | 19/.083 | 64.52 | | 67.43 | 2/0 |
| | | | 70.0 | | |
| | | | | 85.03 | 3/0 |
| | | | 95.0 | | |
| .15 | 37/.072 | 96.77 | | | |
| | | | | 107.20 | 4/0 |
| | | | 120.0 | | |
| .2 | 37/.083 | 129.03 | | 126.64 | 250 MCM |
| | | | 150.0 | | |
| .25 | 37/.093 | 161.25 | | 152.00 | 300 |
| | | | 185.0 | | |
| .3 | 37/.103 | 193.55 | | 202.71 | 400 |
| | | | 240.0 | 253.35 | 500 |
| .4 | 61/.093 | 258.06 | | | |
| | | | | 304.00 | 600 |
| | | | 300.0 | | |
| .5 | 61./103 | 322.58 | | 354.71 | 700 |
| .6 | 91/.093 | 387.00 | 400.0 | 405.35 | 800 |
| .75 | 91/.103 | 483.87 | 500.0 | 506.71 | 1000 |
| 1.0 | 127/.103 | 645.00 | 625.0 | | |

[1]) The range of metric cross-sectional areas acc. to I.E.C. Publ. 228 was introduced in British Standards in 1970 [2]) Acc. to I.E.C. Publ. 228

# APPENDIX I
# EARTHING BONDING AND LIGHTENING PROTECTION

## CONTENTS :

PAGE No.



## FIGURES :

## 1. GENERAL

Earthing implies the establishment of an electrically continuous path between a conducting body and the conductive mass of the earth.

Bonding implies the provision of an electrically continuous connection between exposed conductor parts and or extend-neous conductive bodies such that they are all at a substantially equal potential.

## 2. STANDARDS

Requirements for earthing and bonding should conform at least to following IEC 364.3.

| | |
|---|---|
| BS 5958 | "Code of Practice for Control of Undesirable Static Electricity" |
| Part 1 | "General Consideration" |
| Part 2 | "Recommendation for Particular Industrial Situation" |
| BS 6656 | "Code of Practice for Protection of Structures Against Lighting" |

## 3. TYPE OF EARTHING SYSTEMS

The following types of system earthing are taken into account in this standard:

**Notes:**

**1) Figures IA to IE show examples of commonly used three phase systems.**
**2) The codes used have the following meanings:**

- **First letter - Relationship of the power system to earth.**

  **T ≡ direct connection of one point to earth**

  **I ≡ all live parts isolated from earth on one point connected to earth through an impedance.**

- **Second letter - Relationship of the exposed conductive parts of the installation to earth.**

  **T ≡ direct electrical connection of exposed conductive parts to earth independently of the earthing of any point of power system.**

  **N ≡ direct electrical connection of the exposed conductive parts to the earthed point of the power system (in a.c. systems the earthed point is normally the neutral point)**

- **Subsequent letter(s) if any arrangements of neutral and protective conductors:**

  **S ≡ neutral and protective functions provided by separate conductors;**

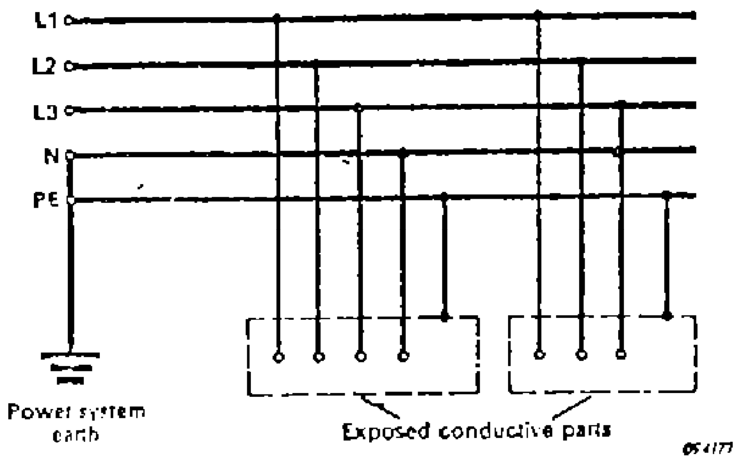
  **C ≡ neutral and protective functions combined in a single conductor (PEN conductor)**

### 3.1 TN System

TN power systems have one point directly earthed, the exposed conductive parts of the installation being connected to that point by protective conductors.

Three types of TN system are recognized, according to the arrangement of neutral and protective conductors as follows:

TN-S System: having separate neutral and protective conductors throughout the system see Fig. 1.




**TN-SYSTEM. SEPARATE NEUTRAL AND PROTECTIVE CONDUCTORS THROUGHOUT SYSTEM**
**Fig. 1**

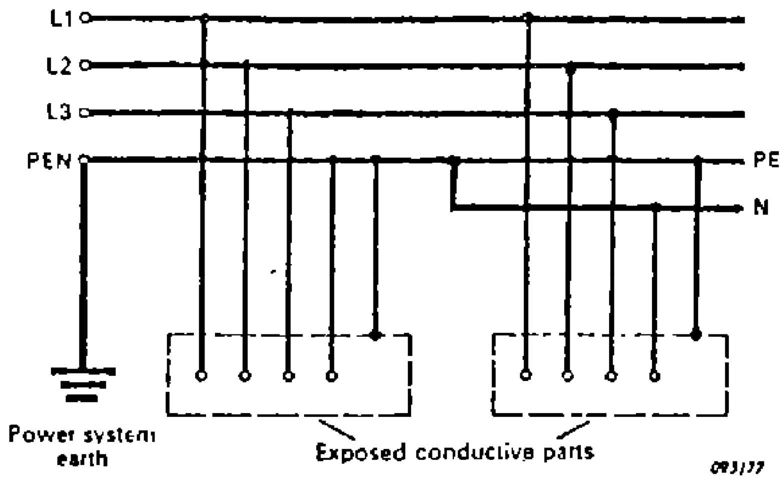
**TN-C-S system** In which neutral and protective functions are combined in a single conduction in a part of the system. See Fig. 2.

**TN-C system** In which neutral and protective functions are combined in a single conductor throughout the system. See Fig. 3.

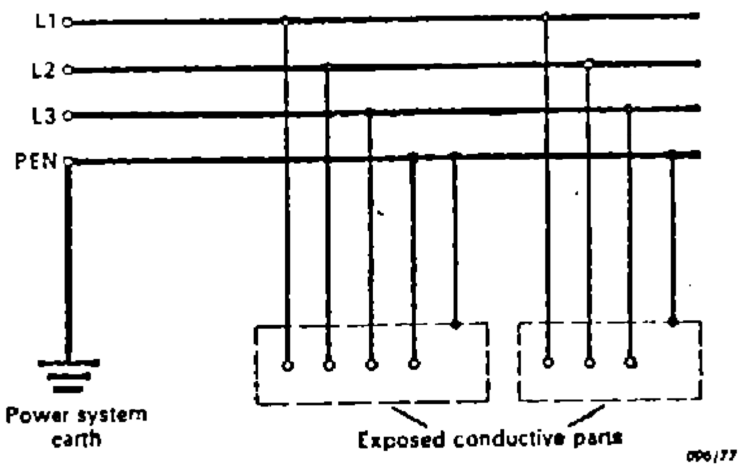
**Note:**

**Earthing system type "TN" to IEC 364.3 Amendment 1 is preferred system.**

**When there is demand for use of other types permission of client shall be obtained.**




**TN-C-S SYSTEM. NEUTRAL AND PROTECTIVE FUNCTIONS COMBINED IN A SINGLE CONDUCTOR IN A PART OF THE SYSTEM.**
**Fig. 2**

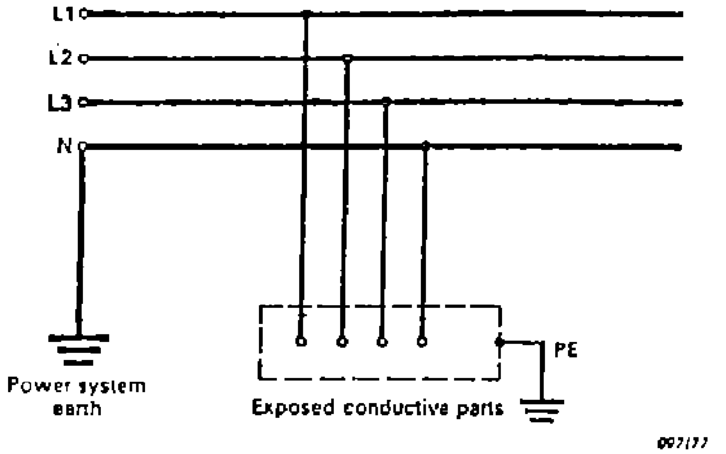



**TN-C SYSTEM. NEUTRAL AND PROTECTIVE FUNCTIONS COMBINED IN A SINGLE CONDUCTOR THROUGHOUT SYSTEM**

**Fig. 3**

## 3.2 TT System

The TT power system has one point directly earthed, the exposed conductive parts of the installation being connected to earth electrodes electrically independent of the earth electrodes of the power system. See Fig. 4.

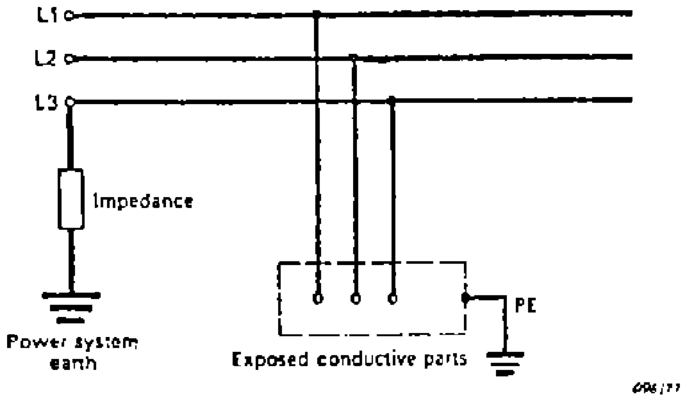



**TT SYSTEM**

**Fig. 4**

## 3.3 IT System

The IT power system has no direct connection between live parts and earth, the exposed conductive parts of the electrical installation being earthed. See Fig. 5.



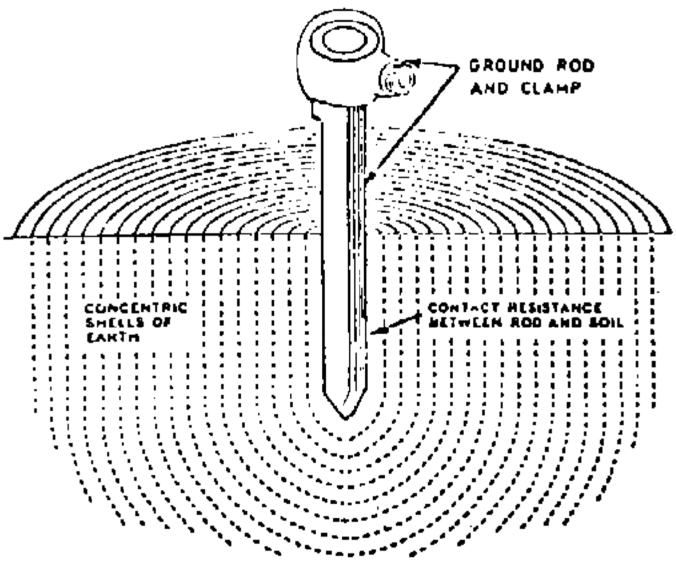

**IT SYSTEM**
**Fig. 5**

## 4. ASPECTS OF SOLID EARTHING

Details for earthing and bonding has been fully explained in IP Electrical Safety Code, Model Code of Safe Practice Part I section a, the following are general aspects of solid earthing which shall not be overlooked while an earthing system is designed.

### 4.1 Effect of Soil on Resistance

It cannot be assumed that all connections to the earth will have the same characteristics, because the electrical conductance of soil is largely determined by the chemical ingredients and the amount of moisture in the soil. Fig. 6 shows how the resistance of a ground connection is dependent mainly upon the type of soil surrounding an electrode.




**RESISTIVE COMPONENTS OF EARTH ELECTRODE**
**Fig. 6**

This is pictured as cylindrical shell of earth of equal thickness. Assuming soil of uniform resistivity, the greatest resistance is in the shell immediately surrounding the electrode which has smallest cross section of soil at right angle to the flow of current through the soil. Each succeeding shell has increased cross section and therefore lower resistance. At a distance of 2.5 to 3 meters from the rod, the area of the path is so large that the resistance of successive shells is almost negligible compared to that of the shell immediately surrounding the rod.

Measurement shows that considerable (say 90 percent) of the total electrical resistance surrounding an electrode is generally within a radius of less than 3 meters from the electrode.

### 4.2 Effect of Moisture on Soil

The moisture content in the soil is of great importance. A variation of a few percent in moisture will make a marked difference in the effectiveness of a ground connection made with electrode of a given size. This is especially for moisture contents below 20 percent.

For example experimental tests made with red clay soil indicated that with only 10 percent moisture contents the resistivity was over 30 times that of the same soil having a moisture content of about 20 percent.

For values over 20 percent the resistivity is not affected too much but below 20 percent .The resistivity increases rapidly with a decrease in moisture contents.

### 4.3 Effect of Temperature

In localities where the winter seasons are very severe and earth freezes to a considerable depth below the surface, and below "0" degree centigrades, the water in the soil freezes and this causes a tremendous increase in the temperature coefficient of resistivity for the soil. This coefficient is negative, and as temperature goes down the resistivity rises and resistance of the ground connection is increased.

Grounding electrodes which are not driven below the frost line in such localities will show a great variation in resistance throughout the seasons of year. Even when driven below the frost line there is some variation. Since the upper soil when frozen has the effect of shortening the active length of the rod, consequently for grounds which must function throughout the year depth is important so that protection will be obtained at all times.

### 4.4 Effect of Depth

The depth of the grounding electrode is an important factor in electrical performance. Driven electrodes should be long enough to reach the permanent moisture level of the soil.

Failure to reach the moisture may result not only in high resistance but also may cause large variations of resistance during changes of seasons. The most common length of driven electrodes is about 2.5 meters. Longer rods are necessary at times.

### 4.5 Effect of Size of Electrode

Very little change in resistance would result from using large diameter electrodes. Mainly the soil surrounding the electrode and not the diameter determines the resistance.

Experience shows that the difference in resistance is so small between driven electrodes of all diameters used commercially that the question of diameter is practically a negligible factor, in so far as the electrical resistance is concerned.

A good rule is to select a diameter of driven electrode large and strong enough to be driven into the soil without bending or otherwise damaging the rod.

### 4.6 Application of Plates

These are generally made from either copper, zinc, steel or cast iron. Since they are fairly bulky the initial cost particularly of zinc and copper types tends to be high. With the steel or cast iron versions great care should be taken to completely mask the termination of the copper conductor at the plate with some waterproof material. This is to prevent cathodic action occurring at the joint, which could cause the conductor to become detached from the plate and render the electrode practically useless.

The plates are usually installed on edge in a hole in the ground approximately 2-3 m. deep, which is subsequently refilled with soil. As one plate electrode is seldom sufficient to obtain a low resistance earth, the cost of excavation alone can be considerable, also being installed relatively near the surface the resistance value can fluctuate throughout the year due to the seasonal change in the water content of the soil.

### 4.7 Use of Coke Pit

The coke pit method of earthing is not as common today as, say, 20 years ago, although it is still used to some extent by the Coal and Gas Boards. The system comprises a cast iron pipe serving as the electrode placed centrally in a pit, usually about 2.5 meters deep, which is subsequently back-filled with crushed coke. The reason for using coke is, of course, to lower the earth resistance around the pipe, coke having a low resistivity value.

Although this lowers the resistance reading whilst the system is being tested under heavy fault conditions, the magnitude of the fields set up around the pipe can extend beyond the perimeter of the pit. The current density inside the pit reaches a point where it cannot be contained, and the soil surrounding it has to dissipate the fault current. Since the resistivity of this soil is invariably greater than that of the coke, the earth resistance of the pipe may rise at an inopportune time.

Other disadvantages of this system are similar to those of the Plate Type electrodes, in that excavation costs are considerable, they are subject to seasonal resistance variation and again the joint between the copper conductor from the equipment to the iron pipe must be fully waterproofed to prevent cathodic action.

### 4.8 Use of BI-metallic Rods

This type of electrode, having a steel core and a copper exterior, offers the best alternative to the types discussed above, in that the steel core gives the necessary rigidity while the copper exterior gives good conductivity.

It is important that the copper and steel should be molecularly bonded together to prevent the copper sheath from stripping or splitting when the rod is driven into the ground.

### 4.9 Rod Separation

When earthing rods are installed it is important that the distance between them should be such that their resistance areas do not overlap under fault conditions as this will impede the flow of current to earth. In practice a minimum separating distance is generally accepted to be once times the depth of the electrode, although, if space permits, this should preferably be one and a half times the separating distance.

## 5. BONDING

In order to minimize the risk of dangerous potential difference occurring between adjacent exposed metal work, it is necessary to bond together the main metallic services at a point as close as practicable to the point of entry to the premises and provide supplementary bonding at locations of special risk.

Protective (bonding) conductors must be connected from the main earth bar to the gas, water and other metallic services using reliable mechanical clamps.

These conductors shall have cross sectional areas not less than half the cross sectional of the earthing conductor of the installation, subject to a minimum of 6 mm² colored green, yellow and shall be labeled:

"Safety Electric Connection: Do not remove" (For protective multiple earthing (PME) see clause 574-2 of IEE Regulations).

## 6. LIGHTENING PROTECTION

The protection of buildings and their installations against lightning is an inexact science because the behavior of lightning is unpredictable and subject to all manner of external variables. What is known is that lightning discharges can take the form of electric currents of up to 200000 A and that a series of discharges may last for up to a second, causing grave thermal, mechanical and electrical consequences.

Overhead lines, particularly in exposed locations, are equipped with a variety of arc gap and surge divertor devices designed to facilitate the safe discharge of any lightning strike to earth before it causes damage to terminations, plant, or other equipment.

Owners of private overhead lines which may be prone to lightning strikes would be well advised to consult the local Electricity Authority engineers whose knowledge of the locality and its risks will prove invaluable.

Since, in general, lightning from a storm cloud will discharge to the nearest prominent feature of the landscape, it follows that high or isolated structures such as tall chimneys are most likely to need protection from such effects. The principle of lightning protection of such structures is the provision of one or more metallic air terminations above the highest point of the structure, and connected directly to earth via copper down conductors connected to rods driven into the ground.

It is essential that metallic conduits, cables and other structures forming part of an electrical installation do not come into fortuitous contact nor run in close proximity to any part of the lightning protection installation.

Authoritative guidance on the assessment of the need for, and the principles and practice of the installation of, lightning protection is contained in BS 6651 to which reference should be made whenever this topic is under consideration.

## 7. STATIC ELECTRICITY

Static electricity occurs frequently in industrial and domestic situations and, for certain special applications, e.g. paint spraying, can be deliberately generated. Unintentional and undesirable static electricity can be a source of shock, fire and accident and while having no direct relationship with the electrical installation, is often mistaken for 'leakage' from adjacent wiring.

Static electricity can occur in situations remote from electrical supplies. In simplified terms, it is most likely to occur when two dissimilar insulating materials are separated, creating a potential between them. The effect is enhanced, for reasons not yet fully understood, if the contact between the two materials involves rubbing. One of the more common manifestations of static electricity occurs therefore when a person's dry shoes rub along a synthetic fibre floor covering, giving rise to a static charge on the wearer. Only when the person concerned comes into contact with earthed metal, e.g., a handrail, does he become aware of the electrostatic charge which is at that instant dissipated. In industry, static electricity can be created in any process involving the transmission of powder or suspended particles passing along insulated pipes or channels.

The hazards of static electricity, whether to human beings or in industrial processes, occur in the discharge of the stored energy. This can, in certain circumstances, give rise to sparks which in turn can create fire or explosion hazards.

The basic approach to the prevention of hazards from unwanted static electricity is to connect all conductors together and to earth by electrical paths which will allow the relaxation of stored charges. This can in extreme cases be an elaborate and necessarily costly process, but one which will avoid the even more costly consequences of resulting incidents.

One of the more frequently encountered and disturbing manifestations of static electricity is that which occurs in offices and similar carpeted areas. The combination of synthetic carpets, man-made footwear and dry atmospheric conditions contribute to the creation of static electrical charges on people moving around the area. The individual only becomes aware of the charge, however, if he comes into contact with some earthed metal before static electricity has been dissipated. The effect can in extreme cases, be a visible spark and a sensation of momentary shock.

Erroneously, these symptoms are sometimes attributed to the electrical installation, leading to unnecessary and misdirected alarm.

The precautions against this problem include the use of floor coverings treated to increase their conductivity or containing a proportion of natural fibres which have the same effect. The wearing of leather soled footwear also reduces the likelihood of a static charge persisting, as does an increase in the humidity of the air in the area, where this is practicable.

Where special circumstances make the avoidance of static electric shocks particularly important, reference should be made to BS 5958 for general advice and to BS 2050 and BS 5451 for specifications for conducting flooring materials and footwear respectively.