EXTERNAL LIGHTING AND POWER DISTRIBUTION SYSTEM OF A PROPOSED RESIDENTIAL ESTATE

BY

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Declaration

I keji Lukman Oyewumi, declare that this work was done by me and has never been presented elsewhere for the award of a degree. I also hereby relinquish the copyright to the Federal University of Technology, Minna.

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DEDICATION

This project is dedicated to almighty Allah the most beneficent, the most merciful. And my lovely parents, Alhaji Prince R.A. Keji and Mrs. H.M. Keji for their love, care, affection and assistance since they born me to this world.

ACKNOWLEDGEMENT

I give special thanks to Almighty Allah for seeing me through my studies. And my parents for their moral and financial supports. To my siblings; brother Hafiz, brother Rasheed, Rafiat and Taofikat. Thank you so much, blood is thicker than water and I love you all.

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I will not stop but thank Julian Bello of Shell Concepts for her immeasurable assistance and input to the completion of this project and all the staff of Shell Concepts. My thanks also go to Engr. Musani of PHCN, Minna, for his professional advice.

Lastly, to all the people that have contributed one way or the other to my success, I say a big thank to you.

ABSTRACT

This project is a report on the external lighting and power distribution of a proposed residential estate. The purpose of the project is to design an external lighting within and outside the perimeter of the estate, to plan the power distribution system of the residential estate, to design the cable sizes for the lighting and power system and the illustration of the design on AutoCAD for easy interpretation.

Salient factors put into consideration are safety of the occupants of the apartments, comfort and convenience, prevention against faults and isolation of each apartment and installations for easy maintenance and fault detection. Other factors put into consideration are provision for future planned and unplanned loads while still reducing cost to the barest minimum.

The design can easily be interpreted and comprehended by Engineers and Technicians.

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Chapter One

INTRODUCTION

1.1 General Introduction

Building services engineering is the engineering of the internal environment and environmental impact of a building. It essentially brings ` and structures to life.

Building services engineers are responsible for the design, installation, operations and monitoring of the mechanical, electrical and public health systems required for the safe, comfortable and environmentally friendly operation of modern building.

- Communication lines, telephones and IT networks (ICT)
- Energy supply - gas, electricity and renewable sources
- Escalators and lifts
- Fire detection and protection
- Heating, ventilation and air conditioning (HVAC)
- Lightning protection
- Low voltage (LV) systems, distribution boards and switchgear
- Natural lighting and artificial lighting, and building facades
- Security and alarm systems
- Water , drainage and plumbing

Electrical service is one of the most important in Building engineering service. Electrical services provide utility and comfort to a building.

Engineering building services include design, electrical installation, power supply, security and fire prevention etc. The scope of this project is mainly about the external electrical installation service and power distribution system of a proposed residential estate.

Electricity or Power distribution is the final stage in the delivery (before retail) of electricity to end users. A distribution system's network carries electricity from the transmission system and delivers it to consumers. Typically, the network would include medium-voltage (less than 33 kV) power lines, electrical substations and pole-mounted transformers, low-voltage (less than 0.6 kV) distribution wiring and sometimes electricity meters [1].

The power distribution system design includes the planning of the power system from high voltage (HV) to low voltage (LV) and finally to the individual unit of the residential estate.

1.2 Project Motivation

With the incessant rise in power failures and fire outbreak in buildings in Nigeria, which is as a result of poor electrical service design, it has become a challenge for Electrical Engineers to provide electrical installations services and a power distribution system which are in compliance to IEE and other standard regulations. Also providing a simple and standard design which can easily be interpreted by Electricians and Technicians is a challenge.

These are what motivated me to embark on this project so as to correct these anomalies we have in our society and to minimise the cost of project maintenance which accrues as a result of bad planning and design.

This project has never been done in the department of Electrical/Computer Engineering, Federal University of Technology, Minna.

1.3 Aims and Objectives

The aim of this project is to design an external electrical installation and power distribution system of a proposed residential estate with 42 units of apartments and illustration in AutoCAD design. It is listed below:

- To design an external lighting for the residential estate
- To plan the power distribution system of the residential estate
- To design the cable sizes for the lighting and power distribution system
- To design to Institute of Electrical Engineering (IEE) regulation
- To illustrate the design on AutoCAD

1.4 Project Layout

This technical report is divided into five chapters;

Chapter one is general introduction: it discusses the meaning of the project work, the aims and objectives of the work, what motivated me to embark on the project work and what I want to achieve at the end of the project work.

Literature review is the second chapter. It contains the historical background of the project, theoretical background, previous work that has been done by other people and challenges encountered.

The external lighting and power distribution design is discussed, the cable size is calculated and the power equipment rating is chosen in chapter three.

Chapter 4 gives an explanatory note on system prevention, earthing, control and testing of installations.

Chapter five is the conclusion and recommendation part of the project report.

Chapter Two

LITERATURE REVIEW

2.1 HISTORICAL BACKGROUND

Electrical service design is an aspect of Electrical engineering that is being guided by different regulations and requirement. Although different countries have different regulations acceptable by international regulatory bodies, the most acceptable and most used is the British standard.

The Wiring Regulations were first issued in 1882 by the Society of Telegraph Engineers and of Electricians, consisting of four pages and 21 Regulations [2]. It shows requirements for electrical services design.

The first edition has requirement for:

i. **Isolation-Regulation 7**

> 7. Every switch or commutator used for turning the current on or off should be constructed so that when it is moved and left to itself it cannot permit of a permanent arc or of heating, and its stand should be made of slate, stoneware, or some other incombustible substance.

ii. **Mechanical protection and labelling-Regulation 17:**

> 17. Where wires are put out of sight, as beneath flooring, they should be thoroughly protected from mechanical injury, and their position should be indicated.

iii. **Periodic Inspection and Testing:**

In 1991, the Sixteenth Edition of the IEE Wiring Regulations was issued and in 1992, the Sixteenth Edition became a British Standard – BS 7671:1992 [2]

The UK National Committee responsible for BS 7671 is **JPEL/64**

J Joint IET/BSI Committee

P Power

EL Electrical

64 IEC designation for Committees dealing with low voltage electrical installations [2].

The timeline for wiring regulation for Electrical installation or BS7671 is shown below [2]:

Table 2.1: Timeline for electrical wiring regulation or BS7671

Edition	Title	Year
First Edition	Rules and Regulations for the Prevention of Fire Risks Arising from Electric Lighting	1882
Second Edition	"	1888
Third Edition	General Rules recommended for Wiring for the Supply of Electrical Energy	1897
Fourth Edition	"	1903
Fifth Edition	Wiring Rules	1907
Sixth Edition	"	1911
Seventh Edition	"	1916
Eighth Edition	Regulations for the Electrical Equipment of Buildings	1924
Ninth Edition	"	1927
Tenth Edition	"	1934

Eleventh Edition	"	1939
Twelfth Edition	"	1950
Thirteenth Edition	"	1955
Fourteenth Edition	"	1966
Fifteenth Edition	Regulations for Electrical Installations	1981
Sixteenth Edition	Requirements for Electrical Installations	1991
	BS 7671:1992, Requirements for Electrical Installations	1992
Seventeenth Edition	BS 7671:2008, Requirements for Electrical Installations	2008

2.2 THEORETICAL BACKGROUND

The BS7671:2008 and others explain the following [3, 4]:

i. Fundamentals requirements for safety

ii. Earthing

iii. Protection

iv. Isolation Switching and Control

v. Circuit design

vi. Inspection and Testing

vii. Electrical installations regulation in Special Locations

I] **Fundamentals requirements for safety:** It does not require a degree in electrical engineering to realize that electricity at *low* voltage can, if uncontrolled, present a serious threat of injury to persons or livestock, or damage to property by fire.

Clearly the type and arrangement of the equipment used, together with the quality of workmanship provided, will go a long way to minimizing danger. The following is a list of basic requirements

1. Use good workmanship.
2. Use approved materials and equipment.
3. Ensure that the correct type, size and current-carrying capacity of cables are chosen.
4. Ensure that equipment is suitable for the maximum power demanded of it.
5. Make sure that conductors are insulated, and sheathed or protected if necessary, or are placed in a position to prevent danger.
6. Joints and connections should be properly constructed to be mechanically and electrically sound.
7. Always provide overcurrent protection for every circuit in an installation (the protection for the whole installation is usually provided by the Distribution Network Operator [DNO]), and ensure that protective devices are suitably chosen for their location and the duty they have to perform.
8. Where there is a chance of metalwork becoming live owing to a fault, it should be earthed, and the circuit concerned should be protected by an overcurrent device or a residual current device (RCD).
9. Ensure that all necessary bonding of services is carried out.
10. Do not place a fuse, a switch or a circuit breaker, unless it is a linked switch or circuit breaker, in an earthed neutral conductor. The linked type must be arranged to break all the line conductors.
11. All single-pole switches must be wired in the line conductor only.
12. A readily accessible and effective means of isolation must be provided, so that all voltage may be cut off from an installation or any of its circuits.
13. All motors must have a readily accessible means of disconnection.

14. Ensure that any item of equipment which may normally need operating or attending by persons is accessible and easily operated.

15. Any equipment required to be installed in a situation exposed to weather or corrosion, or in explosive or volatile environments, should be of the correct type for such adverse conditions.

16. Before adding to or altering an installation, ensure that such work will not impair any part of the existing installation and that the existing is in a safe condition to accommodate the addition.

17. After completion of an installation or an alteration to an installation, the work must be inspected and tested to ensure, as far as reasonably practicable, that the fundamental requirements for safety have been met.

These requirements form the basis of the IEE Regulations. It is interesting to note that, whilst the Wiring Regulations are not statutory, they may be used to claim compliance with Statutory Regulations such as the Electricity at Work Regulations, the Health and Safety at Work of the Building Regulations [3].

II] **Earthing:** earth is the conductive mass of earth, whose electric potential at any point is conventionally taken as zero.

Hence, if we connect a voltmeter between the live conductor and earth, we may read 230V; the conductor is at 230 V, the earth at zero. The earth provides a path to complete the circuit. We would measure nothing at all if we connected our voltmeter between, say, the positive 12 V terminal of a car battery and earth, as in this case the earth plays no part in any circuit [3].

Contact with metalwork made live by a fault is clearly undesirable. One popular method of providing some measure of protection against the effects of such contact is by protective earthing, protective equipotential bonding and automatic disconnection in the event of a fault. This entails the bonding together and connection to earth of:

1. All metalwork associated with electrical apparatus and systems, termed exposed conductive parts. Examples include conduit, trunking and the metal cases of apparatus.
2. All metalwork liable to introduce a potential including earth potential, termed extraneous conductive parts. Examples are gas, oil and water pipes, structural steelwork, radiators, sinks and baths.

The conductors used in such connections are called *protective, conductors*, and they can be further subdivided into:

1. Circuit protective conductors, for connecting exposed conductive parts to the main earthing terminal.
2. Main protective bonding conductors, for bonding together main incoming services, structural steelwork, etc.
3. Supplementary bonding conductors for bonding exposed conductive parts and extraneous conductive parts, when circuit disconnection times cannot be met, or in special locations, such as bathrooms, swimming pools, etc.

The effect of all this bonding is to create a zone in which all metalwork of different services and systems will, even under fault conditions, be at a substantially equal potential. If, added to this, there is a low-resistance earth return path; the protection should operate fast enough to prevent danger (IEE Regulations 411.3 to 411.6).

The resistance of such an earth return path will depend upon the system, whether TT, TN-S or TN-C-S

T: terre (French for earth) and meaning a direct connection to earth
N: neutral
C: combined
S: separate.

- A TT system has a direct connection of the supply source neutral to earth and a direct connection of the installation metalwork to earth. An example is an overhead line supply with earth electrodes, and the mass of earth as a return path
- A TN-S system has the supply source neutral directly connected to earth, the installation metalwork connected to the earthed neutral of the supply source via the lead sheath of the supply cable, and the neutral and protective conductors throughout the whole system performing separate functions
- A TN-C-S system is as the TN-S but the supply cable sheath is also the neutral, i.e. it forms a combined earth/neutral conductor known as a PEN (protective earthed neutral) conductor

In order to reduce the risk of serious electric shock, it is important to provide a path for earth fault currents to operate the circuit protection, and to endeavour to maintain all metalwork at a substantially equal potential. This is achieved by bonding together metalwork of electrical and non-electrical systems to earth. The path for earth fault currents would then be via the earth itself in TT systems or by a metallic return path in TN-S or TN-C-S systems [3].

III] PROTECTION: The meaning of the word 'protection', as used in the electrical Industry, is no different to that in everyday use. People protect themselves against personal or financial loss by means of insurance and from injury or discomfort by the use of the correct

protective clothing. They further protect their property by the installation of security measures such as locks and/or alarm systems. In the same way, electrical systems need:

1. to be protected against mechanical damage, the effects of the environment and electrical overcurrents; and

2. to be installed in such a fashion that persons and/or livestock are protected from the dangers that such an electrical installation may create.

Electrical installation should also be protected against overvoltage (caused by lightning or switching surges) and undervoltage (in the event of drop or loss in voltage).

IV] ISOLATION SWITCHING AND CONTROL: All installations, whether they are the whole or part, must have a means of isolation and switching for various reasons. These are:

1. To remove possible dangers associated with the installation/operation/testing of electrical installations.
2. To provide a means of functional switching and control.

The IEE Regulations make reference to:

1. Switching off for mechanical maintenance: The devices for this function should be manually operated and preferably located in the main supply circuit.
2. Emergency switching: The devices for this function should preferably be hand operated and be capable of interrupting the full load of the circuit concerned.
3. Functional switching: This is simply switching an item on or off to control its function, e.g. a light switch.
4. Fire fighters' switches: Clearly for the function of isolation in the event of a fire. They should be coloured red and be installed no more than 2.75 m above the ground with the OFF position at the top.

V <u>CIRCUIT DESIGN:</u> The requirements of IEE Regulations make it clear that circuits must be designed and the design data made readily available. In fact, this has always been the case with previous editions of the Regulations, but it has not been so clearly indicated [3].

Clearly, plunging into calculations of cable size is of little value unless the type of cable and the methods of installation are known. This, in turn, will depend on the installation's environment. At the same time, we would need to know whether the supply was single- or three-phase, the type of earthing arrangements, and so on.

Having ascertained all the necessary details, we can decide on an installation method, the type of cable, and how we will protect against electric shock and overcurrents. We would now be ready to begin the calculation part of the design procedure.

There are eight stages in such procedures they are;

1. Determine the design current I b.
2. Select the rating of the protection I n.
3. Select the relevant rating factors (CFs).
4. Divide I n by the relevant CFs to give tabulated cable current-carrying capacity I t.
5. Choose a cable size, to suit I t.
6. Check the voltage drop.
7. Check for shock risk constraints.
8. Check for thermal constraints.

VI] <u>TESTING AND INSPECTION:</u> Part 6 of the IEE Regulations gives details of testing and inspection requirements. Unfortunately, these requirements pre-suppose that the person carrying out the testing is in possession of all the design data, which is only likely to be the case on the larger commercial or industrial projects. It may be wise for the person who will eventually sign the test certificate to indicate that the test and inspection were carried out as far as was possible in the absence of any design or other information.

The Regulations initially call for a visual inspection, but some items such as correct connection of conductors, etc. can be done during the actual testing. A preferred sequence of tests is recommended, where relevant [2,3].

VII] SPECIAL LOCATION: The bulk of BS 7671 relates to typical, single- and three-phase, installations. There are, however, some special installations or locations that have particular requirements. Such locations may present the user/occupant with an increased risk of death or injuries from electric shock.

2.3 PREVIOUS WORK

Electrical services design and installation is like giving life to a building whilst designing to specifications. It involves both the internal and external design and installations. It conforms to a general rule which is the IEE regulation.

Most work that has been done in this department is mainly on internal services design of a building [6, 7].

This project work is the first of its kind in this department because it deals with the external services design and power distribution system of a proposed residential estate and to crown it, is in conformity to IEE regulations.

Chapter 3

LIGHTING AND POWER DISTRIBUTION DESIGN

3.1 LIGHTING DESIGN

External lighting provides an elegant, interesting environment at night as well as a safe and secure environment for people to move about.

The external lighting design would ensure that the following parameters are met:

- Highlighting building features and entrances
- Provision of appropriate lighting for pedestrians walkways between buildings and car park facilities
- Provision for appropriate lightings for roadways
- Compliance with all relevant all relevant lighting standards and occupational health and safety act
- Conformity with existing residential installations and control systems
- Maintainability of the installation

In the selection of the components making up an installation for external lighting, the following shall be assessed:

- Energy efficiency of the light fittings or luminaires
- Maintenance of the light fittings (easy access for any future need for spare part)
- Type of appropriate lamps
- The method for the control system

3.1.1 LIGHTING FIXTURES

Any lighting fixture or luminaire chosen would be from an international or national manufacturer which conforms to IEE standards or Standard Organization of Nigeria (SON).

The selection of luminaires shall be based on the following:

- Vandal resistance
- UV stability of component
- Resistance to corrosion
- Weather Proof
- Easy access for maintenance of lamps
- Energy management provision and control

3.1.2 TERMS USED IN ILLUMINATION

The following terms and laws are applied in lighting design:

a) *CANDELA:* - It is the unit of luminous intensity of a source. It is defined as 1/60th of the luminous intensity per $cm^2$of a blackbody radiator at the temperature of solidification of platinum (2045^oC). A source of one candela emits one lumen per steradian. The unit of solid angle is steradian (SP). The total flux emitted by it is 4π lumen.

b) *LUMINOUS FLUX, Ø:*- it is defined as the light energy radiated out per second from a body in the form of luminous light waves. It is called flux contained per unit solid angle of a source of one candela. The unit is lumen (lm). 1 Lumen = 0.0016 watt

c) *LUMINOUS INTENSITY, I:* - it is the flux radiated out per unit solid angle in a specified direction. It is the power of source of light energy. Also, it is solid flux density of a source of light in a given direction. The unit of luminous intensity is candela (cd). Luminous flux, I=$\emptyset/4\pi$.

d) *ILLUMINANCE, E:* - Illuminance is the amount of light falling on an area A of a surface. The unit of illuminance is <u>Lux</u>. Lux is the luminance flux per unit area of 1 square metre on a sphere of radius 1 metre.

Laws of illuminance

i. Illuminance, E is directly proportional to the luminous intensity, I of the source. $E \propto I$

ii. Illuminance, E of a surface is inversely proportional the square of the distance of the surface from the source. $E \propto 1/D^2$

iii. Cosine law or Lambert's law states that the illuminance, E on any surface is directly proportional to the cosine of the angle of incidence. $E = \cos\theta$. Combining the 3 laws: $E = (I\cos\theta)/D^2$

iv. Cosine cubed law: By substituting $H/\cos\theta$ for D, the equation $E = (I\cos\theta)/D^2$ becomes $E = (Icos^3\theta)/H^2$

e) *LUMINANCE, L:* -Luminance is the amount of light reflected from a surface. It is the measure of the brightness of a surface. It is defined as the luminous intensity per unit area.$L = I/A \ \ (cd/m^2)$

f) *UTILIZATION FACTOR, (UF):* - it is a measure of the effective usage of light output from a luminaire. It is the ratio of the actual light utilized to the actual light output emanating from the luminaire. It is also called the coefficient of utilization.

$$UF = \frac{lumen\ received\ on\ the\ working\ plane}{lumen\ emitted\ by\ the\ source}$$

g) *MAINTENANCE FACTOR, (MF):* - It is the ratio of the average illumination on the working plane after a specified period of use of a lighting installation to the average illumination obtained under the same conditions for a new installation. It is between 0.7 and 0.8. The reciprocal of maintenance factor is depreciation factor. $Depreciation\ factor = 1/MF$

h) *SPACE TO MOUNTING HEIGHT RATIO:* - Luminaire must be mounted at a reasonable height. Glare could be eliminated by the choice of a good height. Excessive height will increase maintenance cost and reduce the illuminance on the working plane or road surface [8]. Similarly correct spacing between each luminaire must be ensured. The *spacing height ratio* is a function of the type of light fitting and the illumination needed in a working environment. $space\ to\ height\ ratio = \frac{horizontal\ distance\ between\ two\ lamps}{mounting\ height\ of\ the\ lamps}$

i) *POLE SPACING:* - is the distance between two adjacent poles holding lighting fixtures. The optimum pole spacing is often considered to be the distance at which the maximum candlepower output from two luminaire meet on the ground.

3.1.3 LIGHT SOURCES

The lamps for the lighting luminaire shall be appropriately selected from the following light sources:

a) Incadescent lamps

b) Discharge lamps

c) Mercury vapour discharge lamps

d) Sodium lamps

a) INCADESCENT LAMPS: - Tungsten filament lamp is also called incandescent lamp which is the ordinary bulb still commonly used at home today. It consist of a thin filament of thin tungsten inside a glass bulb when a current is passed through the filament, heat is generated and it is designed to reach a temperature at which it generates light energy as heat energy which means the filament glows or incandescence. A diagram of a tungsten filament is shown below.

b) *DISCHARGE LAMPS*: - A discharge lamp is a glass or quartz envelope containing two electrodes and a small quantity of gas at low pressure. The gas is excited and electrons are separated from the atoms. Positive ions move towards the cathode and electrons move towards anode. The ions further collide with neutral atoms knocking off electrons in the tube. As the current increases, resistance decreases. Hence, there is need to use a current limiting device called ballast in the current. This can be resistor (for a dc run lamp) or choke (for an ac run lamp). Discharge lamps are grouped into two kinds namely: Hot cathode and Cold cathode

c) *MERCURY VAPOUR LAMPS*: -It consists of an inner tube and outer one. The inner envelope may be of hard glass or quartz, while the outer one is made of ordinary glass. The space between them is evacuated to reduce heat loss through convection. The inner bulb holds the electrode. It also enclose argon gas some quantity of mercury. When the supply is switched on, discharge stars in the argon gas. As the temperature increases, mercury is vapourized, vapour pressure is increased and discharge starts in the mercury vapour. The lamp requires 2 or 3 minutes to achieve steady condition and the mercury gives out a light, the colour of which is modified as it passes the phosphor coated inside of the outer tube. The average efficiency is about 50 lumen/watt. It has a long life and ranges available are 80 watt to 1000 watt.

d) *SODIUM LAMPS:* - sodium discharge lamps are made of special glass which is resistant to the sodium vapour. The double glass container and high reactance leak transformer are designed to assist in ease of starting as the discharge lamp would not start the relatively low mains voltage. The inner glass contains neon in addition to metallic sodium at low pressure. Heat is produced by an initial neon discharge, at this stage a red light is emitted because of the neon gas. Due to the heated discharge, the sodium then begins to vapourise causing the colour of the discharge to change from red to yellow. It takes about 10 minutes for full light to be reached. The operating pressure is very low about 1mm Hg. It is the most efficient means as far known of converting electrical energy to light energy. The high pressure sodium lamp is an improvement on the low pressure sodium lamp. It has a high efficiency of about 150lumen/watt. The working pressure is about 250mm Hg. The working temperature is 1300^oC. the tube is made up of crystalline alumina.

3.1.4 TYPES OF LUMINAIRE

A luminaire normally consists of the lamp, reflector, control gear (including a photo-electric control switch), etc all included in a protective case with a glass or plastic lens. The type of luminaire which shall be used with the external lighting is the *TOP-POST LUMINAIRE.* This type of luminaire is mounted on a 3m to 12m (depending on location) painted galvanized steel pole. For a 3m to 4m luminaire height, the luminaire shape is a clear spherical lens.

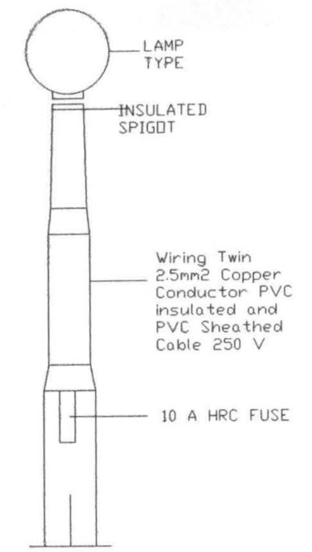


Fig 3.1.1: A Typical top-post luminaire

3.1.5 ILLUMINATION LEVEL

The illumination required depends upon the class of external lighting installations. An average well-lighted street will require illumination level between 8 and 15 lumen per square metre. Excellent illumination is considered when the distance apart is not more than 8 times the height of the luminaires.

Table 3.1: the recommended lighting level for external lighting

Area	Min. Average illuminance (lux)	Min. illuminance at any location
Service roads	10	4
Entrance and nodes	50	10
Shared roads and zones walk	10	5
Steps	10	5
Informal walk	5	2

Covered lighted ways	10-25	8

It has to be noted for compatibility with CCTV surveillance cameras, lighting should be as uniform as possible with a maximum lux of 10 Lux.

3.1.6 METHODS OF LIGHTING CALCULATION

The methods employed for lighting calculation are thus listed below:

a) Watts per square metre method

b) Lumen or light flux method

c) Point to point or inverse-square law method

Methods 1 and 2 shall not be discussed in this project because they are mostly used for internal design of a building.

Point to point method: This method is applicable where the illumination at a point due to one or more sources of light is required, the candle powers of the sources in the particular direction under consideration being known. The method is most employed in external calculations [6].

$$E = \frac{I\cos^3\theta}{H^2} \text{-------------------(1)}$$

The total luminance at a point P is given by:

$$L_p = \sum \frac{I_\theta}{H^2} \times (\beta, \theta)\cos^3\theta \text{----------(2)}$$

Finally, the absolute value of the luminance at a point is given by the relationship:

$$L_p = \frac{L_r \times a \times \emptyset_L \times q_o}{H^2} \text{ - - - - - - - - - - - - - - - - (3)}$$

Where;

L_r = The relative luminance at the point (lux)

a = Factor for the particular luminance in use, given on the iso-cd/m^2 diagram

$\emptyset_L$= The luminance flux of the lamp (lumen)

H = Mounting height of the lantern (metre)

It is possible to use the above equation to determine the value of luminance at various points on the surface of the road or walkways. When these values of luminance are connected, the result forms what is known as an Isoluminance or iso-cd/m^2 given on *Photometric Data Sheets* for light lanterns.

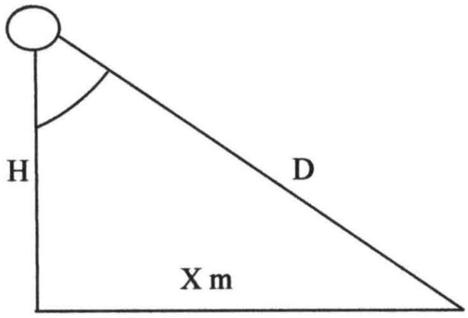
The lamps shall be located in the estate as shown in lighting layout on the drawing plan given. They are to be located at a distance not more than 8 times the mounting height of the lamp post for maximum result.

Using an average illuminance of 10 lux within the estate and a top post luminaire of about 3-4 metre high the luminous flux of the lantern to be used can thus be calculated from equation (1)

E = 10 lux

H= 4m

X = 4m



$D^2 = H^2 + X^2$

$D^2 = 4^2 + 4^2 = 32$

$\tan\theta = \frac{4}{4}, \theta = 45$

From equation 1 above the luminous intensity can thus be calculated

$E = \frac{I\cos^3\theta}{H^2}$

$I = \frac{(E \times H2)}{\cos^3\theta}$, $I = (10\times 4^2)/\cos^3 45$

I = 452.55 candela, but luminous flux $\varphi = 4\pi I$

Therefore, $\varphi = 4 \times \pi \times 452.55$

$\varphi = 5686.89\ lumen$

From the photometric data sheet in appendix 1, a 125 W MBF lamp will be used to achieve this value.

For the perimeter fencing light, the lamp post will be one with height of 7-8 metre.

$$D^2 = H^2 + X^2$$

$$D^2 = 7^2 + 8.3^2 = 118.6$$

$$\tan^{-1}\theta = \frac{8.3}{7}, \theta = 50$$

From equation 1 above the luminous intensity can thus be calculated

$$\mathrm{E} = \frac{Icos^3\theta}{H^2}$$

$$\mathrm{I} = \frac{(\mathrm{E} \times \mathrm{H2})}{cos^3\theta}, \mathrm{I} = (10\times 7^2)/cos^3 50$$

I = 1,845 candela, but luminous flux $\varphi = 4\pi I$

Therefore, $\varphi = 4 \times \pi \times 1845$

$$\varphi = 23{,}185\ lumen$$

From the photometric data sheet in appendix_, a 250 W SON T lamp will be chosen to achieve this effect.

3.1.7 POLE SPACING

Pole Spacing is the distance between two adjacent poles holding lighting fixtures. It is useful to consider the relative geometries involved. The angles and distances given in the following table could refer to either the cutoff angle (no light is emitted above this angle) or to the angle of maximum candlepower output of the luminaire. The optimum pole spacing is often considered to be the distance at which the maximum outputs from two luminaires meet on the ground. Other scenarios are possible, of course. The rows in the table have been calculated with either the angle or the value of X as the dependent variable, and the calculated values have been rounded off in most cases. The mounting height of the lighting luminaire above the ground, the horizontal spacing of one pole to the next, and the cutoff angle of the luminaire are all important issues in outdoor lighting design, just as much as is the choice of the luminaire, the lamp type, and the wattage. I give here a short table that relates some of the geometry of pole spacing relative to cutoff angle [10].

Table 3.2: Pole spacing geometry in relation to mounting height

Angle(θ)	X=H(tan θ)	D=$H/\cos\theta$	D^2	$1/D^2$	P.S = 2X(m) if H = 4m	P.S = 2X(m) if H = 7m
45	1.00	1.41	2.0	0.50	8	14
60	1.73	2.00	4.0	0.25	14	24
66	2.24	2.46	6.0	0.16	18	31
70	2.75	2.92	8.5	0.12	22	39
75	3.73	3.86	14.9	0.07	30	52
80	5.67	5.76	33	0.03	45	79
85	11.43	11.47	132	0.01	91	160
87.5	22.90	22.93	526	0.00	183	320

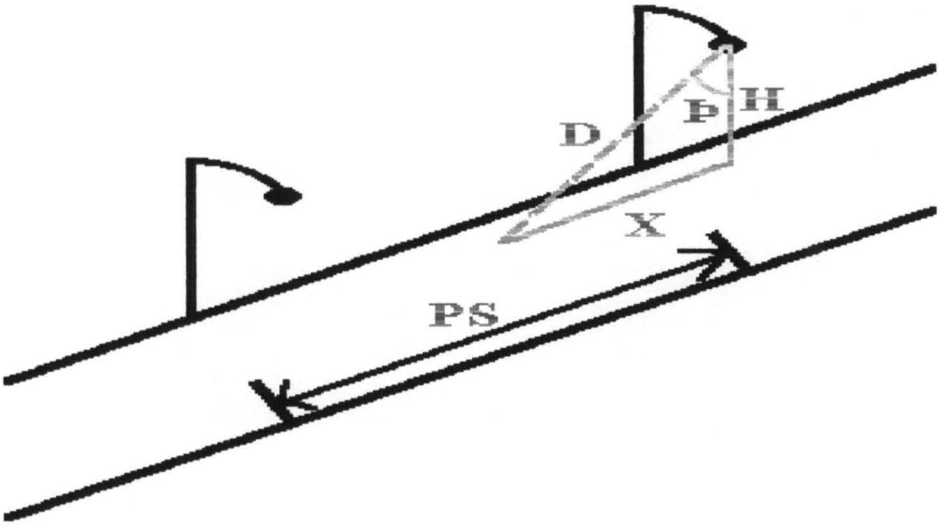


Fig 3.2: Pole spacing

At high cutoff angles, the X and D dimensions really stretch out, and the D^2 values show that there is little light left. There is no excuse for not having cutoff values be 80° to 82.5°. Any higher angles do not add anything to the effective light distribution, but they still do produce significant glare. In fact, cutoff angles in the range 75° to 80° appear to make the best sense. This still allows sufficient overlap of the beams from two adjacent fixtures. The key to designing a "good" lighting fixture is to get the maximum light output at an angle of say 65° to 70°, thus getting a good light throw out away from under the light fixture (avoiding a "hot spot" under the fixture), while at the same time getting a sharp cutoff at an angle of 75° to 80°.

The result is then a nicely uniform distribution of light on the ground, out to a distance of at least six mounting heights from the pole, minimum glare, and no direct uplight [10].

3.1.8 CONTROL SYSTEM

The control system shall be a centralized one which will be connected to the sub-feeder pillars. The control system shall be an electronic control switch which has a light sensitive electronic device. The system is sensitive to darkness; once it is dark it switches ON and turns OFF when there is daylight. This control system is called a Light kiosk.

3.2.0 POWER DISTRIBUTION DESIGN

For any good installation, there must be proper design of the power circuits. This will be based on the facilities to be provided for in the each unit of the residential estate. The total power and current requirement will be calculated and based on this, the electrical installations to be used is selected. The following terms must be explained.

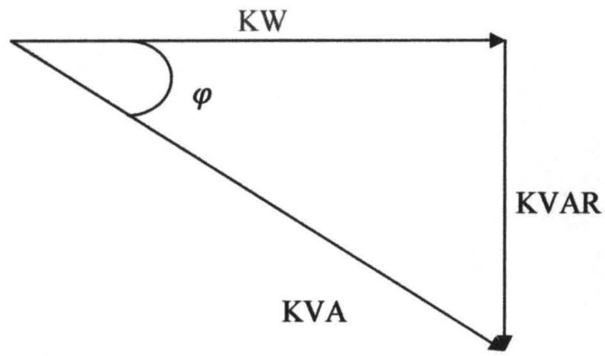
3.2.1 TERMS USED IN POWER DESIGN

The following terms used in power distribution design must be defined:

a) *DEMAND FACTOR:* - is the ratio of the maximum demand of a system, or part of a system, to the total connected load on the system, or part of the system under consideration. Demand factor is always less than one. Although feeder-circuit conductors should have an ampacity sufficient to carry the load, the ampacity of the feeder-circuit need not always be equal to the total of all loads on all branch-circuits connected to it.

b) *DIVERSITY FACTOR:* - is the ratio of the sum of the individual maximum demands of the various subdivisions of a system, or part of a system, to the maximum demand of the whole system, or part of the system, under consideration. Adding all connected loads would usually be impracticable and too costly, the reason being that the loads are unlikely to be used at together. The loads are thus diversified.

c) *POWER FACTOR:* - is defined as the ratio of real power to total apparent power. It may also be defined as the cosine of the angle of lead or lag. The real power is power expressed in watt while the apparent power is expressed in KVA. Thus power factor $PF = \frac{real\ power}{apparent\ power} = \frac{watt}{volt-ampere} = \cos\varphi$



d) *SINGLE-PHASE AND THREE-PHASE SUPPLY:* - the types of distribution system in Nigeria are: - (i) single phase, 2-wire system (ii) three phase, 3-wire system (iii) three phase, 4 wire systems. For residential purposes, the single phase, 2-wire system and three phases, 4-wire system is the most common.

For single-phase supply: $I = P/(V \times PF)$

For three-phase supply: $I = P/(\sqrt{3} \times V \times PF)$

Where, P = Load (Watt)

V = Supply voltage (240V for single phase and 415V for 3-phase)

PF = Power factor

3.2.2 ELECTRICAL POWER EQUIPMENTS

The following are power installations that will be used in the power design of the proposed residential estate.

a) *RING MAIN UNIT:* - is an electrical power machine that is used in a secondary distribution system. It is basically used for uninterrupted power supply. Alongside, it also protects the secondary side transformer from the occasional transient current. RMU has 3 numbers of switches (circuit breakers or isolators or LBS). It is used for either for 2 inputs with mechanical and electrical interlock and one outgoing to the load or 1 input with 2 outgoings output. Depending on the application and loading condition, a switch fuse or circuit breaker can be used to protect the transformer. The transformer connected to the switch fuse or circuit breaker is called T-OFF. In a common arrangement you have Load break switches on both the sides of your T off. Ring main Units come in standard ratings of 11/22/33 kV, 630/1250 A, 21 KA/3 secs. The Ring Main Unit (RMU) to be used will operate at the rated voltage (System highest voltage) of 12 kV and shall consist of two numbers of ring main switches and one number Tee-off fuse switch for control of 11 kV/L.T. transformers up to 1000 kVA.

b) *TRANSFORMER:* - a transformer is a static electrical machine that transforms electrical power in one circuit to another circuit at the same frequency. It can raise or lower the voltage in a circuit but with a corresponding decrease or increase in current. The physical basis of a transformer is mutual induction between two circuits linked by a common magnetic flux. In choosing the transformer for the design, the following was considered: -

(i) Primary and secondary voltage of transformer (available voltage)

(ii) Frequency (in Hz) and phases (three-phase)

(iii) KVA load (total load) and possible future additions

(iv) The type of wire system for the secondary voltage

The two types of transformers used in the design are the step-up and step-down transformers.

For a single phase transformer calculation:

$$kVA = \frac{Volts \times Amps}{1000}$$

For three phase transformer calculation:

$$kVA = \frac{1.73 \times Volts \times Amps}{1000}$$

c) *FEEDER PILLAR:* - is an electrical component of an electricity supply of a load (each unit of apartments), which provides a protective fuse or circuit breaker for each apartment. The low voltage feeder pillar comprises of the following units: (i) feeder pillar enclosure (ii) bus bars (iii) current transformers (iv) instrument panel (v) incoming units (vi) outgoing units

Both the incoming and outgoing units consists of 3 numbers true grip type insulated fuse carriers to provide a hinge action at the bottom contacts for circuit closing and to accommodate various ratings of 'J' slotted pattern HRC fuses

(BS88-5). The neutral phase is provided with detachable hinge bolted type solid link.

d) *LIGHTING KIOSK:* - is an electrical control switch used in external lighting design to turn ON or turn OFF. The type of kiosks to be used in the proposed estate shall be one that has a light-sensitive electronic circuit incorporated in it. It switches ON the lighting circuit automatically when it is dark and switches OFF when there is natural light (day). The lighting kiosk comprises of an incoming unit from the feeder pillar and an outgoing unit to the luminaires with protective fuses to isolate different circuit of the luminaires.

e) *ALTERNATIVE POWER GENERATOR:*- alternative generating sets are provided to serve as an alternative power source. The three-phase generator is to be connected to automatic power changeover equipment then to the main distribution panel.-

f) *SWITCHGEAR:* - is a general term covering switching and interrupting devices alone or their combination with other associated control, metering, protective and regulating equipment. Power switchgear is applied throughout the electric power system of the residential estate but is principally used for incoming line service and to control and protect load centers, transformers, panel boards and other secondary distribution equipment.

3.2.3 POWER LOAD

Table 3.3: The proposed residential estate comprises of the following units:

Section	Apartments
A	6
B	6
C	9
D	7
E	6
F	6
Total	40
Gate house	2
Water treatment plant	1

<u>Lighting luminaires</u>

13 numbers 2 X 250 W SON-T

18 numbers 1 X 125 W MBF

4 numbers 1 X 250 W SON-T Flood light

Total power of luminaires:

$$P = (2 \times 250 \times 13) + (125 \times 18) + (4 \times 250) = 9750\ W.$$

If P.F = 1. Then, Total power = 9750 VA

Given that the Power load for each apartment is P = 29,098 VA from the internal Electrical service design supplied: also the water treatment plant demands 7160 VA.

$I = \frac{P}{\sqrt{3} \times 400} = 42\ A$. A DB-rating of 60 A is chosen

From the lighting design;

Lighting Kiosk A (LKA)

LKA1 controls (4 X 125) W

LKA2 controls (3 X 125) W

LKA3 controls (3 X 2 X 250) W

LKA4 controls (4 X 2 X 250) W

Lighting Kiosk B

LKB1 controls (3 X 2 X 250) W

LKB2 controls (3 X 2 X 250) W

LKB3 controls (4 X 125) W

LKB4 controls (3 X 125) W

LKB5 controls (4 X 125) W

3.2.4 CHOOSING CABLE SIZE

The following steps are taken in designing the correct cable:

1. Determine the design current, I_b.

2. Select the rating of the protection, I_n.

3. Select the relevant rating factors (CFs).

4. Divide I_n by the relevant CFs to give tabulated cable current-carrying capacity I_t.

5. Choose a cable size, to suit I_t .

6. Check the voltage drop.

7. Check for shock risk constraints.

8. Check for thermal constraints.

Cable rating = $I_t = \frac{I_n}{C_a \times C_g \times C_i \times C_c}$ --3.2.1

Where:

$I_t = tabulated\ current\ capacity\ from\ Appendix\ 4\ of\ BS7671$

C denotes a correction factor as follows

$C_a = correction\ factor\ for\ ambient\ temperature$

$C_g = correction\ factor\ for\ grouping$

$C_i = correction\ factor\ for\ insulation$

$C_c = correction\ factor\ for\ rewirable\ fuse\ BS\ 3036$

Cable size from lighting kiosk to each lamp post

For LKA: P_{LKA}= $[(4\times 125) + (3 \times 125) + (3 \times 2 \times 250) + (4 \times 2 \times 250)]$ P_{LKA}= 4375 VA

$I_{LKA} = \frac{4375}{230} = 19.02$ A

From table 4D4A; a cable of size 2C X 1.5mm^2 should be chosen.

But because of voltage drop of the cable, a bigger size of cable shall be chosen.

Note: Voltage drop of the cables is discussed in section 3.2.5.

Cable size from feeder pillars to each unit of apartments

Given that I_n = 60 Amps (from the DB rating of each apartment)

From $I_t = \frac{I_n}{C_a \times C_g \times C_i \times C_c}$

Where: $C_a = 0.94$ (using an ambient temperature of 35^oC) from IEE regulation Table 4E41A: $I_t = \frac{60}{0.94} = 68.96\,A$

Cable size from each apartment to Feeder pillars is 4C× $16mm^2$ armoured PVC

Cable size from Main Feeder Pillar to Feeder Pillar (FP1)

Total load from section 1 (A1 to A6) with a DF of 0.6

$P_1 = 6 \times \sqrt{3} \times 400 \times 42 \times 0.6 = 104{,}754$VA

When connected to a three-phase supply,

$I_n = 104754/(\sqrt{3} \times 400)$

I_n= 151.20 Amp

From Table 4D4A: It = 4C X $50mm^2$ armoured cable is required.

Cable size from Main Feeder Pillar to Feeder Pillar (FP2)

Total load from section 2 (B1 to B6) + water treatment house + 1 gatehouse + Lighting kiosk A (LKA):

$P_2 = (7 \times 42 \times \sqrt{3} \times 400) + [7160 + (\sqrt{3} \times 42 \times 400)] + (4375 \times 0.6)$

$P_2 = 203{,}689 + 29{,}098 + (2625) + (7160)$ VA

$P_2 = (206{,}599 \times 0.7) + 9785$

$P_2 = 154{,}404$ VA

When connected to a three phase supply,

I_n = 154,404 / ($\sqrt{3} \times 400$)

I_n = 222.86 A

From Table 4D4A: of IEE, cable size $I_t = 4C\ X\ 95mm^2$ armoured cable is required.

<u>Cable size from Main Feeder Pillar to Feeder Pillar (FP3)</u>

Total load for section 3 (C1 to C9) + LKB with DF of 0.6

$P_3 = 9 \times 42 \times \sqrt{3} \times 400 \times 0.6 + (4375 \times 0.6)$= 159,757 VA

When connected to a three phase supply,

I_n = 159,757/ ($\sqrt{3} \times 400$)

$I_n = 230.59A$

From Table 4D4A: of IEE, cable size $I_t = 4C\ X\ 95mm^2$ armoured cable is required.

<u>Cable size from Main Feeder Pillar to Feeder Pillar (FP4)</u>

Total load for section 4 (D4 to D7 and E1 to E6) with a DF of 0.6

$P_4 = 10 \times 42 \times \sqrt{3} \times 400 \times 0.6$= 174,590 VA

When connected to a three phase supply,

I_n = 174,590/($\sqrt{3} \times 400$)

I_n= 252 A

From Table 4D4A of IEE, cable size $I_t = 4C\ X\ 120mm^2$ armoured cable is required.

<u>Cable size from Main Feeder Pillar to Feeder Pillar (FP5)</u>

Total load for section 5 (F1 to F6) + (D1 to D3) + gatehouse and DF of 0.6:

P_5= (10 × √3 × 400 × 42 × 0.6) VA

P_5 = 174,590 A

I_n = 174,590/(√3 × 400)

I_n= 252 A

From Table 4D4A of IEE, cable size, $= 4C \times 120mm^2$ armored cable is required.

Cable size from Transformer LV to Main Feeder Pillar (MFP)

FP1 + FP2 + FP3 + FP4 + FP5 with a DF of 0.55

P_T = (104,754VA + 154,404 VA + 159,757 VA + 174,590 VA + 174,590)

$Total\ power = 768{,}095VA \times 0.50$

I_n = 384,047.5 VA / (√3 × 400),

I_n= 554.3 A

From Table 9D1 of IEE, cable size $I_t = 4nos$ ×1C×400mm^2 non-armoured cable is required.

3.2.5 VOLTAGE DROP

The resistance of a conductor increases as the length increases and/or the cross-sectional area decreases. Associated with an increased resistance is a drop in voltage, which means that a load at the end of a long thin cable will not have the full supply voltage available.

The IEE Regulations require that the voltage drop *V* should not be so excessive that equipment does not function safely. They further indicate that the following percentages of the nominal voltage at the *origin* of the circuit will satisfy. This means that:

	LV Lighting (3%)	LV Power (5%)
230 V	single-phase 6.9 V	11.5 V
400 V	three-phase 12 V	20 V

Using the formula $V_c = \frac{mV \times I_b \times L}{1000}$

$$L = (V_c \times 1000)/(mV \times I_b)$$

The maximum allowable distance of each cable from Table 4D2B is thus calculated:

For <u>4C× 16mm² armoured PVC</u>, voltage drop/ampere/metre = 2.8mV, therefore maximum allowable distance of cable from FP;

$L = (V_c \times 1000)/(mV \times I_b)$.

$$L = \frac{20\ X 1000}{2.8\ X\ 60}$$

$$L = 119\ m$$

For <u>$4C \times 50mm^2$</u> armoured cable, voltage drop/ampere/metre = 0.81mV, therefore maximum allowable distance of cable from MFP to FP1;

$$L = (20\ X\ 1000)/(0.81\ X\ 119.511)$$

$$L = 209\ metre.$$

For $\underline{4C \times 95mm^2}$ armoured cable, voltage drop/ampere/metre = 0.42mV, therefore maximum allowable distance of cable from MFP to FP2;

$$L = \frac{20\ X\ 1000}{0.42\ X\ 222.86}$$

$$L = 21\ metre$$

For $\underline{4C \times 95mm^2}$ armoured cable, voltage drop/ampere/metre = 0.42mV, therefore maximum allowable distance of cable from MFP to FP4;

$L = (20\ X\ 1000)/(0.42\ X\ 199.19$, L = 240 metre and from MFP to FP5;

$$L = \frac{20\ X\ 1000}{0.42\ X\ 205.5}$$

$$L = 232\ metre.$$

For $\underline{4C \times 120mm^2}$ armoured cable, voltage drop/ampere/metre = 0.40mV, therefore maximum allowable distance of cable from MFP to FP4,

$$L = \frac{20\ X\ 1000}{0.40\ X\ 252.99}$$

$$L = 198\ metre$$

The maximum allowable distance from MFP to FP5;

$$L = \frac{20\ X\ 1000}{0.40\ X\ 252} = 198\ \text{metre}$$

For $\underline{4nos \times 1C \times 400mm^2}$ single core cable, voltage drop/ampere/metre = 0.24mV, therefore maximum allowable distance of cable from Transformer to MFP;

$$L = \frac{20\ X\ 1000}{0.24\ X\ 554.9}$$

$$L = 150\ metre$$

3.2.6 CABLE TERMINATION

A termination for an insulated power cable must provide certain basic electrical and mechanical functions. These essential functions include the following:

1) Electrically connect the insulated cable conductor to electric equipment, bus or insulated conductor.
2) Physically protect and support the end of the cable conductor, insulation, shielding system, and overall jacket, sheath or armor of the cable.
3) Effectively control electrical stresses to provide both internal and external dielectric strength to meet desired insulation levels for the cable system.

The current-carrying capacity requirements are the controlling factors in the selection of the proper type and size of connector or lug to be used. Variations in these components are related, in turn, to the base material used to make up the conductor within the cable, the type of termination used, and the requirements of the electric system. Some common terminations include:

- Taped terminations
- Armor termination
- Potheads
- Preassembled terminators

3.2.7 GROUNDING OF CABLE SYSTEM

For safety and reliable operation, the shields and metallic sheaths of power cables must be grounded. Without such grounding, shields would operate at potential considerably above ground. Thus they would be hazardous to touch, and would incur rapid degradation of the jacket or other material intervening between shield and ground.

Multiple grounding rather than two-end grounding is simply the best [8]. This limits possible shield damage to only the faulted section.

3.2.8 CHOOSING ELECTRICAL POWER EQUIPMENTS

Based on the calculations and parameters discussed in the previous sections, the following ratings of electrical power equipments shall be chosen.

Ring Main Unit RMU): RMU is connected between H.V and L.V side. RMU have 3 nos of switches (Circuit Breakers or Isolators or LBS), it is used for two inputs with mechanical or electrical interlock and one outgoing to the load. Either one input with two outgoings. RMU used for redundancy feeder's purpose in the estate shall have the following ratings:

i. Nominal voltage---11kV
ii. System highest voltage-----------------------------------12kV
iii. System frequency/Phases-------------------------------50Hz/3-phase
iv. Method of Earthing-----------------------through resistance of 4.75Ω
v. Short time withstand current---------------------------20 kA rms

Transformer: The transformer shall be chosen based on the total power load of the residential estate. FP1 + FP2 + FP3 + FP4 + FP5

$P_{FP} = (104{,}754\text{VA} + 154{,}404\ \text{VA} + 159{,}757\ \text{VA} + 174{,}590\ \text{VA} + 174{,}590)$

$P_{FP} = 768{,}095VA$

By using a diversity factor of 0.50

Total Power = $768{,}095VA \times 0.50$

$P_T = 384{,}047.5\ VA$

Adding 20% contingency for unplanned load growth and planned load.

20% of 384,047.5 VA = 76,809.5 VA

Total load = $384{,}047.5 + 76{,}809.5 = 460{,}857\ VA$

KVA rating = $\frac{460{,}857}{1000} = 460.857\ KVA$

Therefore the transformer chosen shall be a 500KVA, 3-phase, 50-Hz oil-filled transformer.

Feeder Pillars: there are two types of feeder pillars to be used in the distribution system; main feeder pillar or main distribution panel and sub-feeder pillars. There will be one main feeder pillar and five sub feeder pillars in the estate.

Table 3.4: Technical data for feeder pillars

Description	2 in 6 out	2 in 10 out
Rated Operational voltage	440V	440V
Rated Insulation voltage	690V	690V
Rated Current	1600A	800A
Incoming units Current rating/no of units	800A/2	400A/2
Outgoing units Current rating/no of units	400A/6	63A/10
Current transformer	800/5A	400/5A
Degree of protection	IP 33*	IP 33*

- EA Tech Specs 37-2 (LV Distribution Fuse board)
- IEC 60439-1 (LV Switchgear and control gear assemblies)
- IEC 60269-1 (LV Fuses)

Alternative Power Generator: Based on the total connected load, a 500KVA, 3-phase, 50-Hz generating set is required to provide an alternative to the public source. The generator will be connected to an automatic power changeover equipment or ATS. This equipment must be provided to start the engine of the stand-by generator and transfer the supply connections from the public supply. A typical ATS circuit is shown below.

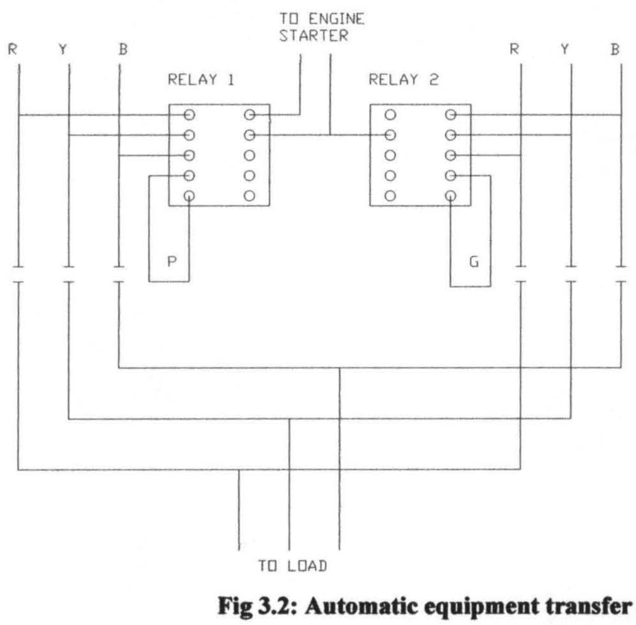


Fig 3.2: Automatic equipment transfer switching

Relay 1: Voltage sensitive

Relay 2: Voltage and frequency sensitive

Coil P: Powered from regular source

Coil G: Powered from emergency source

A voltage sensitive relay is connected to the main power source. This relay (transfer switch) activates the control cycle when the correct speed, a set of contactors is energized to disconnect the load from its normal supply and connect to the generator output.

CHAPTER 4

SYSTEM AND EQUIPMENT PROTECTION

4.1 PROTECTION

The system and equipment protective devices guard the power system from the ever present threat of damage caused by *mechanical damage*, *over currents* and *transient overvoltage* that can result in equipment loss and system failure.

4.1.1 PROTECTION AGAINST *MECHANICAL DAMAGE*

These are some of the ways of preventing mechanical damage by physical impact and the like:

i) Cable construction: A cable comprises one or more conductors each covered with an insulating material. This insulation provides protection from shock by contact with live parts and prevents the passage of leakage currents between conductors. Clearly, insulation is very important and in itself should be protected from damage. This may be achieved by covering the insulated conductors with a protective sheathing during manufacture, or by enclosing them in conduit or trunking at the installation stage. The type of sheathing chosen and/or the installation method will depend on the environment in which the cable is to be installed.

ii) Protection against corrosion: Mechanical damage to cable sheaths and metalwork of wiring systems can occur through corrosion, and hence care must be taken to choose corrosion-resistant materials and to avoid contact between dissimilar metals in damp situations.

iii) Protection against thermal effects: This is the subject of Chapter 42 of the IEE Regulations. Basically, it requires common-sense decisions regarding the placing of fixed equipments, such that surrounding materials are not at risk from damage by heat. Added to these requirements is the need to protect persons from burns by guarding parts of equipment liable to exceed temperatures listed in Table 42.1 of the Regulations [3].

iv Polyvinyl chloride: PVC is a thermoplastic polymer widely used in electrical installation work for cable insulation, conduit and trunking. General purpose PVC is manufactured to the British Standard BS 6746. PVC in its raw state is a white powder; it is only after the addition

of plasticizers and stabilizers that it acquires the form that we are familiar with.

Other mechanical damage protection includes protection against ingress of solid objects, liquid and impact.

4.1.2 PROTECTION AGAINST OVERCURRENT AND TRANSIENT VOLTAGE

The following are the available protective device which is use against overcurrent and transient voltage in the power design:

i. Re-wirable fuses (BS 3036)
ii. High Breaking capacity fuse (HBC)
iii. Miniature circuit breaker (M.C.B)
iv. Earth leakage circuit breaker (E.L.C.B)
v. Isolating transformer

i. ***Rewirable fuses BS3036***: This type of fuse is inserted in a circuit being protected and the size of the fuse wire is such that it matches the rating of the protected circuit. The function of the fuse element is to melt, whenever there is excess current, thereby disconnecting the circuit from the power supply.

ii. ***High rupturing capacity fuse (HRC):*** This type of fuse is known technically as Cartridge fuses (HBC BS 88 and BS 1361 and cartridge fuse BS 1362). The fuse is mounted between to end caps which form the terminals of the complete fuse links. The wire is surrounded by closely packed granular filler and the hole is contained in a solid casing. When the wire melts or blows, the energy is absorbed by the granular filler.

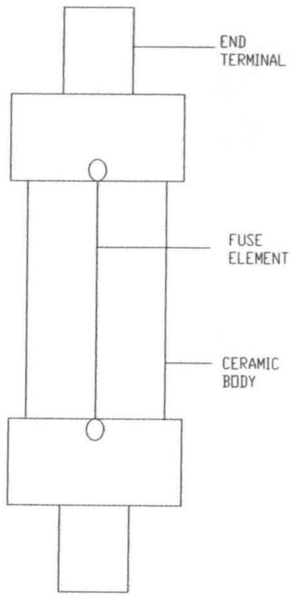


Figure 4.1: A typical cartridge fuse

a) *Class H fuses*: they are renewable or non-renewable and are generally of zinc-link construction. They are rated and sized up to 600 A at either 250 V or less or 600 v or less. These fuse have no interrupting ratings but have been tested for ac of 10,000 A [10].

b) *Class K high-interrupting-capacity fuses*:- these fuses are identical to class h fuses. However, they have a high interrupting fault-current level of labeled ratings, which may be 50,000, 100,000,200,000 A rms. They ae available in two subclasses: RK1 and RK5.

c) *Class J current-limiting fuses*:- these fuses are manufactured in ratings up to 600 A and in specified dimensions which are non interchangeable with class H and K fuses. They are labeled as current-limiting. There are no 250 or less rating; all are labeled 600 V or less and may be used only in fuse holders of suitable class J dimensions [10]. They have a 200,000 A rms interrupting rating.

d) *Class L current-limiting fuses*:- these are labeled fuses with current ratings in excess of 600 A. Their ratings range from 601 to 6000 A rms, all at 600V or less. There is no 250 size. They have an interrupting rating of 200,000 A rms and will safely interrupt any overcurrent up to this value.

iii) **Miniature circuit breaker (M.C.B)**:- A M.C.B has similar ratings like a cartridge fuse nd is about the same physical size. It differs from the fuse in the sense that it consists of no melting element. M.C.B are either magnetic or thermal type.

iv) **Earth leakage circuit breaker (E.L.C.B)**:- The ELCB is a device used to disconnect a circuit from supply, when an earth fault occurs. There are two types of ELCB in use i.e Current operated type and Voltage operated type.

4.1.3 FUSE SELECTION

For fuse selection to correspond to standards, the following must be put into consideration:

- Current rating
- Voltage rating
- Frequency rating
- Interruption rating

- Maximum peak let through and clearing thermal energy

4.2 EARTHING

In order to reduce the risk of serious electric shock, it is important to provide a path for earth fault currents to operate the circuit protection, and to endeavour to maintain all metalwork at a substantially equal potential. This is achieved by bonding together metalwork of electrical and non-electrical systems to earth. The path for earth fault currents would then be via the earth itself in TT systems or by a metallic return path in TN-S or TN-C-S systems.

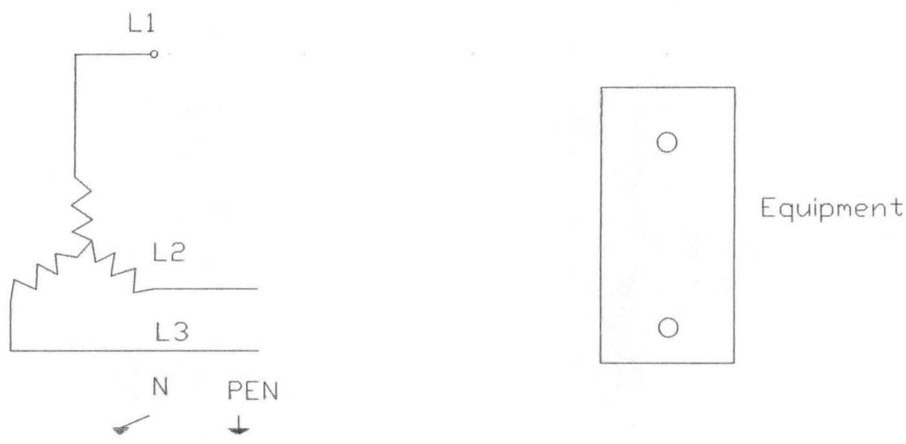


Fig 4.2: A TN-C Earthing system (Combined Neutral and Earth throughout)

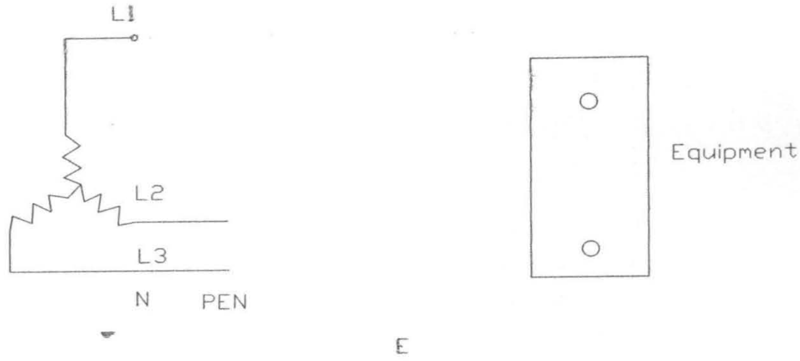


Fig 4.3: A TN-S Earthing system (Combined Neutral and Earth separated)

4.2.1 REASONS OF EARTHING

The following are the reasons of earthing:

i. To maintain the potential of any part of the system at a definite value with respect to earth.

ii. To allow current to flow to earth in the event of a fault, so that the protective gear will operate to isolate the fault current.

iii. To ensure that, in the event of a fault, apparatus normally "dead" cannot reach a dangerous potential with respect to earth (the earth is taken as a no volt potential)

4.2.2 EARTH ELECTRODE RESISTANCE

Earth electrodes are usually of solid copper or copper-clad carbon steel, the latter being used for the larger-diameter rods with extension facilities. These facilities comprise: a thread at each end of the rod to enable a coupler to be used for connection of the next rod; a steel cap to protect the thread from damage when the rod is being driven in; a steel driving tip; and a clamp for the connection of an earth tape or conductor.

The choice of length and diameter of such a rod will, as previously mentioned, depend on the soil conditions. For example, a long thick electrode is used for earth with little moisture retention. Generally, a 1–2 m rod, 16 mm in diameter, will give a relatively low resistance.

If we were to place an electrode in the earth and then measure the resistance between the electrode and points at increasingly larger distance from it, we would notice that the resistance increased with distance until a point was reached (usually around 2.5 m) beyond which no increase in resistance was noticed. The resistance area around the electrode is particularly important with regard to the voltage at the surface of the ground. For a 2 m rod, with its top at ground level, 80–90% of the voltage appearing at the electrode under fault conditions is dropped across the earth in the first 2.5 to 3 m.

In addition to the earth conductors, the following are used as earth continuity conductors or circuit protection conductors.

- Metallic reinforcement of concrete structures.
- Metal pipes
- Metal conduits
- Metallic sheath of cables

These will have resistance in parallel wit the earth electrode resistance.

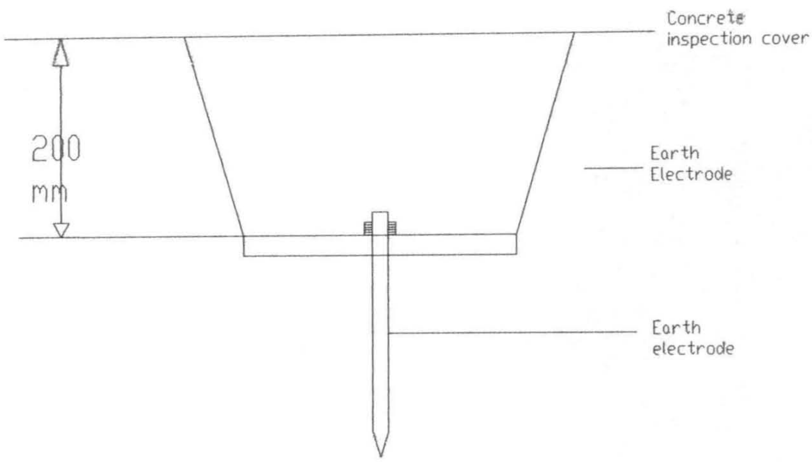


Fig 4.4: Earth Electrode installation

The figure below is graph of voltage distribution at surface of the ground due to the rod electrode.

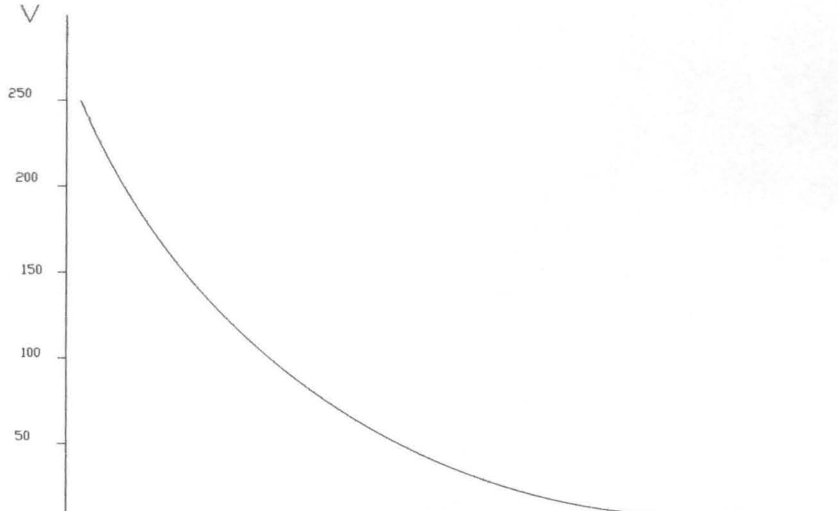


Fig 4.5: Voltage distribution at surface of the ground due to the rod electrode

4.2.3 SIZING PROTECTIVE CONDUCTORS

In order to prevent overheating of the protective conductor during a fault, the cross sectional

area of a protective conductor(s) shall be not less than that determined by the adiabatic formula as follows:

$S = (\sqrt{I^2 t})/k$, or alternatively arranged as $S = \frac{\sqrt{I^2 t}}{k}$

Where, S is nominal cross-sectional area of conductors in mm^2

I is the value of fault current in amperes (rms for a.c.) for a fault of negligible impedance.

T is the operating time of the disconnecting device in seconds, corresponding to the fault current. It is found from the protective device characteristic curve.

K is a factor taking account of the resistivity, temperature coefficient and heat capacity of the conductor material, and the appropriate initial and final temperatures, see Tables 54.2 to 54.6 of BS 7671.

4.3. TESTING AND MEASUREMENT

The IEE regulation attaches much importance to periodic inspection and testing. Test and measurement are carried out on an electrical installation for these main reasons;

i. To ensure that the electrical installations is free from faults and it conforms with IEE regulation
ii. To diagnose the cause of failure and to locate the exact position off the breakdown.
iii. To ensure that an installation remains in good working condition through out its lifetime.

4.3.1TEST OF NEW INSTALLATIONS

Having designed our installation, selected the appropriate materials and equipment, and installed the system, it now remains to put it into service. However, before this happens, the installation must be tested and inspected to ensure that it complies, as far as is practicable, with the IEE Regulations given in part 6. A preferred sequence of tests is recommended, where relevant, and is as follows:

1. Continuity of protective conductors

2. Continuity of ring final circuit conductors

3. Insulation resistance

4. Protection by SELV or PELV or electrical separation

5. Protection by barriers and enclosures provided during erection

6. Insulation of non-conducting floors and walls

7. Polarity

8. Earth electrode resistance

9. Earth fault loop impedance

10. Additional protection

11. Prospective fault current (PFC)

12. Check of phase sequence

13. Functional testing

14. Verification of voltage drop.

Note: Not all the tests will be relevant

Continuity of protective conductors: All protective conductors, including main protective and supplementary bonding conductors, must be tested for continuity using a low-reading ohmmeter.

For main protective bonding conductors there is no single fixed value of resistance above which the conductor would be deemed unsuitable. Each measured value, if indeed it is measurable for very short lengths, should be compared with the relevant value for a particular conductor length and size. Such values are shown in the table below:

Table 4.2: comparison of conductor size to resistance

Conductor Size (mm^2)	Resistance ($m\Omega/m$)
1.0	18.1
1.5	12.1
2.5	7.41
4.0	4.61
6.0	4.61
10.0	1.83
16.0	1.15
25.0	0.727
35.0	0.524

Earth loop impedance: This is the resistance of the part of fault current from the live-conductor connection of the equipment or appliance to the metal conductive parts along the EEC to the consumer's earthing lead and hence to the consumer's earth electrode. From here to the part continues to the general mass and to the PHCN earth electrode connected to the neutral of the supply transformer, though the transformer winding and along the supply line through the consumer's wiring back to the fault. The path is the line neutral loop.

Earth testing instrument: These instruments are used for testing the resistance of the earth-electrode resistance area. The principle involved in testing is passed through the electrode under tests and the earth to a distance auxiliary electrode. The potential is resistance is obtained by dividing the voltage reading thus obtained the current flowing in the circuit measured between the electrodes under test and a center potential electrode. The resistance is obtained by dividing the voltage reading thus obtained the current flowing in the circuit.

Chapter Five

CONCLUSION AND RECOMMENDATION

The external lighting and power distribution design of a proposed residential estate was carried out bearing in a mind the financial capability of the client, the safety and easy maintainability of the apartments and installations in the estate.

Other salient points considered in the design is the careful selection of lighting luminaires, fuses and circuit breakers to isolate individual units of the estate incase of faults. Compliance to IEE regulations and other accepted regulations was strongly adhered to.

With this write-up, I strongly believed that the construction and technical aspect can be carried can be easily carried out. An explanatory illustration of the design is provided on AutoCAD drawings for careful and proper implementation by the technicians.

It is evident that the residential apartments are safe from fire outbreak and other electrical dangers. All cables, fuses and installations to be used were calculated to specifications in accordance to IEE standards.

No additional temporary or permanent electrical installations should be made except with the consent of an expert.

I sincerely welcome advice, constructive criticism and suggestions in the implementation of the design and consultancy services in general for the promotion of Electrical Engineering in Nigeria.

REFERENCES

[1] www.wikipedia.com: Electricity distribution (Sakspower single wire ground return electrification) 1949.

[2] John Elliot, senior Engineer, IET " IET standards and compliance"

[3] Brian Scaddar IEng, MIET: 17th Edition, IEE wiring regulations Explained and Illustrated. 8th edition.

[4] Darrell Locke IEng, MIEE AGBSE, Electrical Contractor Association: Guide to the wiring regulations: 17th edition IEE wiring regulations. (C) 2008, John Wiley and sons Ltd, West Sussex.

[5] Geoff Cronshew: "The 17th Edition: a brief overview IEE wiring matters, Summer 2007"

[6] Engr (Prof.) Oria Usifo, Electrical Networks Design and Installations in buildings: 2nd edition, Fredorus, Benin City.

[7] J.K Gupta: Utilization of Electro-Power.

[8] IEEE (1976): IEEE Recommended Practice for electric Power Distribution for Industrial Plants.

[9] Odesola Micheal Oluremi (2001): Electrical Service Design of a hostel block.

[10] International Dark-Sky Association: "Basic Lighting Laws and Pole Spacing Geometry" Information sheet #78.

[11] UNSW Design and Construction requirement Rev 4.1 (2004). Page 7.

Appendix 1

WINDSOR HERITAGE LIMITED Tel 0800 845 845 31/10/10

Lamp flux data and depreciation factors for use with DW Windsor photometric data

For maintained illuminance: Initial flux x appropriate lamp lumen maintenance factor

Lamp type and wattage	Initial flux (Klumens)	Lumen Depreciation (maintenance factor)				Data supplied by
		4400 Hrs	6600Hrs	8800Hrs	13000Hrs	
50w SON E	3.5	0.94	0.92	0.89	n/a	Osram
70w SON E	5.6	0.94	0.92	0.89	n/a	Osram
100w SON E+	9.5	0.97	0.95	0.94	0.9	Osram
150w SON E	15.5	0.96	0.93	0.9	n/a	Osram
150w SON E+	16.75	0.97	0.95	0.94	0.9	Osram
150w SON E DL	12	0.87	0.8	0.76	n/a	Osram
250w SON E	28	0.95	0.93	0.9	n/a	Osram
250w SON E+	31.75	0.97	0.95	0.94	0.9	Osram
250w SON E DL	22	0.87	0.8	0.76	n/a	Osram
50w SON T	4.5	0.97	0.95	0.94	0.9	Osram
70w SON T	5.9	0.95	0.93	0.89	0.9	Osram
70w SON T+	6.6	0.97	0.95	0.94	0.9	Osram
100w SON T+	10	0.97	0.95	0.94	0.9	Osram
150w SON T	15.75	0.95	0.93	0.9	n/a	Osram
150w SON T+	17.5	0.98	0.95	0.94	0.9	Osram
150w SON T DL	12.5	0.87	0.8	0.76	n/a	Osram
250w SON T	28	0.95	0.93	0.9	n/a	Osram
250w SON T+	33	0.98	0.95	0.94	0.9	Osram
250w SON T DL	23	0.87	0.8	0.76	n/a	Osram
50w MBF	1.9	0.9	0.86	0.82	0.79	Osram
50w MBF DL	2	0.9	0.86	0.82	0.79	Osram
50w MBF SDL	1.6	0.9	0.86	0.82	0.79	Osram
80w MBF	3.8	0.9	0.86	0.82	0.79	Osram
80w MBF DL	4	0.9	0.86	0.82	0.79	Osram
80w MBF SDL	3.4	0.9	0.86	0.82	0.79	Osram
125w MBF	6.2	0.9	0.86	0.82	0.79	Osram
125w MBF DL	6.5	0.9	0.86	0.82	0.79	Osram
125w MBF SDL	5.7	0.9	0.86	0.82	0.79	Osram
250w MBF	13	0.9	0.86	0.82	0.79	Osram
250w MBF DL	14	0.9	0.86	0.82	0.79	Osram
70w HQI Clear	5.04	0.78	0.72	0.69	0.62	Venture
100w HQI Clear	8.1	0.81	0.75	0.71	0.64	Venture
150w HQI Clear	13.5	0.81	0.75	0.71	0.64	Venture
250w HQI Clear	23.6	0.75	0.69	0.65	n/a	Venture
42w CFL	3200	0.87	0.84	0.82	n/a	Phillips
35w CDM-T	3200	0.87	0.80	n/a	n/a	Phillips
70w CDM-T	6300	0.87	0.80	n/a	n/a	Phillips
150w CDM-T	13500	0.87	0.80	n/a	n/a	Phillips

Venture lamps: The rated life is determined when 50% of the lamps initially installed are still burning.

Venture lamps are rated on a burning cycle of 10 hours per start.

Osram lamp data is based on 11 hours on and 1 off with laboratory switching

Maintenance factors are derived from bi-polar charts and due to scale cannot be guaranteed

Luminaire Maintenance Factors

Luminaire rating	Ingress protection factor IP5			Ingress protection factor IP6		
Pollution category	High	Medium	Low	High	Medium	Low
Maintenance at 12 months	0.89	0.90	0.92	0.91	0.92	0.93
Maintenance at 18 months	0.87	0.88	0.91	0.90	0.91	0.92
Maintenance at 24 months	0.84	0.86	0.90	0.88	0.89	0.91
Maintenance at 36 months	0.76	0.82	0.88	0.83	0.87	0.90

High pollution occurs in the centre of large urban areas and in heavy industrial areas

Medium pollution occurs in semi-urban, residential and light industrial areas

Low pollution occurs in rural areas

Appendix 2

TABLE 4B

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 8 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 appliances
3. Cooking appliances	10 amperes + 30% f.l. of connected cooking appliances in excess of 10 amperes + 5 amperes if socket-outlet incorporated in unit	100% f.l. of largest appliance + 80% f.l. of 2nd largest appliance + 60% f.l. of remaining appliances	100% f.l. of largest appliance + 80% f.l. of 2nd largest appliance + 60% f.l. of remaining appliances
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 + 50% f.l. of remaining motors
5. Water-heaters (instantaneous type)*	100% f.l. of largest appliance + 100% f.l. of 2nd largest appliance + 25% f.l. of remaining appliances	100% f.l. of largest appliance + 100% f.l. of 2nd largest appliance + 25% f.l. of remaining appliances	100% f.l. of largest appliance + 100% f.l. of 2nd largest appliance + 25% f.l. of remaining appliances
6. Water heaters (thermostatically controlled)	no diversity allowable‡		
7. Floor warming installations	no diversity allowable‡		
8. Thermal storage space heating installations	no diversity allowable‡		
9. Standard arrangements of final circuits in accordance with Appendix 5	100% of current demand of largest circuit + 40% of current demand of every other circuit	100% of current demand of largest circuit + 50% of current demand of every other circuit	
10. Socket outlets other than those included in 9 above and stationary equipment other than those listed above	100% of current demand of largest point of utilisation + 40% of current demand of every other point of utilisation	100% of current demand of largest point of utilisation + 75% of current demand of every other point of utilisation	100% of current demand of largest point of utilisation + 75% of current demand of every point in main rooms (dining rooms, etc) + 40% of current demand of every other point of utilisation

+ For blocks of residential dwellings, large hotels, large commercial premises, and factories, the allowances are to be assessed by a competent person.

* For the purpose of this Table an instantaneous water-heater is deemed to be a water-heater of any loading which heats water only while the tap is turned on and therefore uses electricity intermittently.

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

TABLE 4D1A

Single-core pvc-insulated cables, non-armoured, with or without sheath (COPPER CONDUCTORS)

BS 6004
BS 6231
BS 6346

CURRENT-CARRYING CAPACITY (amperes):

Ambient temperature: 30 °C
Conductor operating temperature: 70 °C

Conductor cross-sectional area	Reference Method 4 (enclosed in conduit in thermally insulating wall etc.)		Reference Method 3 (enclosed in conduit on a wall or in trunking etc.)		Reference Method 1 (clipped direct)		Reference Method 11 (on a perforated cable tray horizontal or vertical)		Reference Method 12 (free air)		
									Horizontal flat spaced	Vertical flat spaced	Trefoil
	2 cables, single-phase a.c. or d.c.	3 or 4 cables, three-phase a.c.	2 cables, single-phase a.c. or d.c.	3 or 4 cables, three-phase a.c.	2 cables, single-phase a.c. or d.c. flat and touching	3 or 4 cables, three-phase a.c. flat and touching or trefoil	2 cables, single-phase a.c. or d.c. flat and touching	3 or 4 cables, three-phase a.c. flat and touching or trefoil	2 cables, single-phase a.c. or d.c. or 3 cables three-phase a.c.	2 cables, single-phase a.c. or d.c. or 3 cables three-phase a.c.	3 cables trefoil, three phase a.c.
1	2	3	4	5	6	7	8	9	10	11	12
(mm²)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
1	11	10.5	13.5	12	15.5	14	-	-	-	-	-
1.5	14.5	13.5	17.5	15.5	20	18	-	-	-	-	-
2.5	19.5	18	24	21	27	25	-	-	-	-	-
4	26	24	32	28	37	33	-	-	-	-	-
6	34	31	41	36	47	43	-	-	-	-	-
10	46	42	57	50	65	59	-	-	-	-	-
16	61	56	76	68	87	79	-	-	-	-	-
25	80	73	101	89	114	104	126	112	146	130	110
35	99	89	125	110	141	129	156	141	181	162	137
50	119	108	151	134	182	167	191	172	219	197	167
70	151	136	192	171	234	214	246	223	281	254	216
95	182	164	232	207	284	261	300	273	341	311	264
120	210	188	269	239	330	303	349	318	396	362	308
150	240	216	300	262	381	349	404	369	456	419	356
185	273	245	341	296	436	400	463	424	521	480	409
240	320	286	400	346	515	472	549	504	615	569	485
300	367	328	458	394	594	545	635	584	709	659	561
400	-	-	546	467	694	634	732	679	852	795	656
500	-	-	626	533	792	723	835	778	982	920	749
630	-	-	720	611	904	826	953	892	1138	1070	855
800	-	-	-	-	1030	943	1086	1020	1265	1188	971
1000	-	-	-	-	1154	1058	1216	1149	1420	1337	1079

NOTES:

1. Where the conductor is to be protected by a semi-enclosed fuse to BS 3036, see item 6.2 of the preface to this appendix.
2. The current-carrying capacities in columns 2 to 5 are also applicable to flexible cables to BS 6004 table 1(c) and to 90 °C heat resisting pvc cables to BS 6231 tables 8 and 9 where the cables are used in fixed installations.

Appendix 3

62

COPPER CONDUCTORS

TABLE 4D2A

Multicore pvc-insulated cables, non-armoured (COPPER CONDUCTORS)

BS 6004
BS 6346
BS 7629

CURRENT-CARRYING CAPACITY (amperes):

Ambient temperature: 30 °C
Conductor operating temperature: 70 °C

Conductor cross-sectional area	Reference Method 4 (enclosed in an insulated wall, etc.)		Reference Method 3 (enclosed in conduit on a wall or ceiling, or in trunking)		Reference Method 1 (clipped direct)		Reference Method 11 (on a perforated cable tray) or Reference Method 13 (free air)	
	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.	1 two-core cable*, single-phase a.c. or d.c.	1 three-core cable* or 1 four-core cable, three-phase a.c.
1	2	3	4	5	6	7	8	9
(mm²)	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
[illegible]	11	10	13	11.5	15	13.5	17	14.5
1.5	14	13	16.5	15	19.5	17.5	22	18.5
2.5	18.5	17.5	23	20	27	24	30	25
4	25	23	30	27	36	32	40	34
6	32	29	38	34	46	41	51	43
10	43	39	52	46	63	57	70	60
16	57	52	69	62	85	76	94	80
25	75	68	90	80	112	96	119	101
35	92	83	111	99	138	119	148	126
50	110	99	133	118	168	144	180	153
70	139	125	168	149	213	184	232	196
95	167	150	201	179	258	223	282	238
120	192	172	232	206	299	259	328	276
150	219	196	258	225	344	299	379	319
185	248	223	294	255	392	341	434	364
240	291	261	344	297	461	403	514	430
300	334	298	394	339	530	464	593	497
400	-	-	470	402	634	557	715	597

NOTES:

1. Where the conductor is to be protected by a semi-enclosed fuse to BS 3036, see item 6.[illegible] of the preface to this appendix.
2. Circular conductors are assumed for sizes up to and including 16 mm². Values for larger sizes relate to shaped conductors and may safely be applied to circular conductors.
3. Cables to BS 7629 are rated for a conductor operating temperature of 70 °C and are therefore included in this table, although the material used for the cable insulation is not pvc.
4. * With or without a protective conductor.

TABLE 4D2B

VOLTAGE DROP (per ampere per metre): Conductor operating temperature: 70 °C

Conductor cross-sectional area	Two-core cable, d.c.	Two-core cable, single-phase a.c.			Three- or four-core cable, three-phase a.c.		
1	2	3			4		
(mm²)	(mV/A/m)	(mV/A/m)			(mV/A/m)		
1	44	44			38		
1.5	29	29			25		
2.5	18	18			15		
4	11	11			9.5		
6	7.3	7.3			6.4		
10	4.4	4.4			3.8		
16	2.8	2.8			2.4		
		r	x	z	r	x	z
25	1.75	1.75	0.170	1.75	1.50	0.145	1.50
35	1.25	1.25	0.165	1.25	1.10	0.145	1.10
50	0.93	0.93	0.165	0.94	0.80	0.140	0.81
70	0.63	0.63	0.160	0.65	0.55	0.140	0.57
95	0.46	0.47	0.155	0.50	0.41	0.135	0.43
120	0.36	0.38	0.155	0.41	0.33	0.135	0.35
150	0.29	0.30	0.155	0.34	0.26	0.130	0.29
185	0.23	0.25	0.150	0.29	0.21	0.130	0.25
240	0.180	0.190	0.150	0.24	0.165	0.130	0.21
300	0.145	0.155	0.145	0.21	0.135	0.130	0.185
		0.115	0.145	0.185	0.100	0.125	0.160