NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

ELECTRICAL INSTALLATION OF AN AIRCRAFT SERVICE BUILDING

Graduation Project
EE-400

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Lefkoşa - 2001

TABLE OF CONTENTS

ACKNOWLEDGE

First of all I want to thank to Assist. Prof. Dr. Kadri Bürüncük who was supervisor of my project. With his endless knowledge I easily overcome many difficulties and learn a lot of thing about electrical installation. I think this knowledge will help me very much in my future life.

I also want to thank to all my friends, my family, and all my instructors because they never leave me alone and always try to help me during my education. If their helps was not with me I think I will not be in this situation now.

ABSTRACT

The electrical installation is I think the most important subject in electrical engineering. My project was electrical installation of an air craft service building and this project needs some backgraund knowledge about electrical installation knowledge.

This project consist the installation of lighting circuits and the installation of socket circuits. For both of them there are some regulations and we should use them in our work.

All project was drawed in Autocad so I improve my self in Autocad while I was doing the drawing parts of my installation project of the aircraft service building.

INTRODUCTION

This is a project about electrical installation. In this project we made the electrical installation of an aircraft service building. In my future life I want to be a good electric engineer so this project is really very useful for me. I learned how to deal with many problems and I think it will be more easy for me to solve the problems that I will be face to face in my future life. This project consists of three parts. The first one is lightning part. In this part we find the ideal lamps and ideal number of them for every floor and try to make a god distribution. The second part was installing the sockets and telephone plugs. We should distribute them in a correctly way to everyone who needs them can use them without any problem. The third part was making the electric scheme of the building. For me this was the hardest thing in my project and I believe that a good engineer should know it very good. This is where engineering starts.

CHAPTER 1: HISTORICAL REVIEW

1.1 Historical Review of Installation Work

As one might expect to find in the early beginnings of any industry, the application, and the methods of application, of electricity for lighting, heating and motive power was primitive in the extreme. Large-scale application of electrical energy was slow to develop. The first wide use of it was for lighting in houses, shops and offices. By the 1870s, electric lighting had advanced from being a curiosity to something with a definite practical future. Arc lamps were the first form of lighting, particularly for the illumination of main streets. When the incandescent-filament lamp appeared on the scene electric lighting took on such a prominence that it severely threatened the use of gas for this purpose. But it was not until cheap and reliable metal-filament lamps were produced that electric lighting found a place in every home in the land. Even then, because of the low power of these early filament lamps, shop windows continued for some time to be lighted externally by arc lamps suspended from the fronts of buildings.

The earliest application of electrical energy as an agent for motive power in industry is still electricity's greatest contribution to industrial expansion. The year 1900 has bean regarded as a time when industrialists awakened to the potential of the new form of power.

Electricity was first used in mining for pumping. In the iron and steel industry, by 1917, electric furnaces of both the arc and induction type were producing over 100,000 tons of ingot and castings. The first all-welded ship was constructed in 1920; and the other ship building processes were operated by electric motor power for punching, shearing, drilling machines and woodworking machinery.

The first electric motor drives in light industries were in the form of one motor-unit per line of shafting. Each motor was started once a day and continued to run throughout the whole working day in one direction at a constant speed. All the various machines driven from the shafting were started, stopped, reversed or changed in direction and speed by mechanical means. The development of integral electric drives, with provisions for starting, stopping and speed changes, led to the extensive use of the motor in small kilowatt ranges to drive an associated single machine, e.g. a lathe. One of the pioneers in the use of motors was the firm of Bruce Peebles, Edinburgh. The firm supplied, in the 1890s, a number of weatherproof, totally enclosed motors for quarries in Dumfriesshire, believed to be among the first of their type in Britain. The first electric winder ever built in Britain was supplied in 1905 to a Lanark oil concern. Railway electrification started as long ago as 1883, but it was not until long after the turn of this century that any major development took place.

Electrical installations in the early days were quite primitive and often dangerous. It is on record that in 1881, the installation in Hatfield House was carried out by an aristocratic amateur. That the installation was dangerous did not perturb visitors to the house who'... when the naked wires on the gallery ceiling broke into flame... nonchalantly threw up cushions to put out the fire and then went on with their conversation'...

Many names of the early electric pioneers survive today. Julius Sax began to make electric bells in 1855, and later supplied the telephone with which Queen Victoria spoke between Osborne, in the Isle of Wight, and Southampton in 1878. He founded one of the earliest purely electric manufacturing firms, which exists today and still makes bells and signaling equipment.

The General Electric Company had its origins in the 1880s, as a Company, which was able to supply every single item, which went to form a complete electrical installation. In addition it was guarantied that all the components offered for sale were technically suited to each other, were of adequate quality and were offered at an economic price.

Specializing in lighting, Falk Stadelmann & Co. Ltd began by marketing improved designs of oil lamps, then gas fittings, and ultimately electric lighting fittings.

Cable makers W. T. Glover & Co. were pioneers in the wire field. Glover was originally a designer of textile machinery, but by 1868 he was also making braided steel wires for the then fashionable crinolines. From this type of wire it was a natural step to the production of insulated conductors for electrical purposes. At the Crystal Palace Exhibition in 1885 he showed a great range of cables; he was also responsible for the wiring of the exhibition.

The well-known J. & P. firm (Johnson & Phillips) began with making telegraphic equipment, extended to generators and arc lamps, and then to power supply.

The coverings for the insulation of wires in the early days included textiles and gutta-percha. Progress in insulation provisions for cables was made when vulcanized rubber was introduced, and it is still used today. The first application of a lead sheath to rubber-insulated cables was made by Siemens Brothers. The manner in which we name cables was also a product of Siemens, whose early system was to give a cable a certain length related to a standard resistance of 0.1 ohm. Thus a No.90 cable in their catalogue was a cable of which 90 yards had a resistance of 0.1 ohm. Cable sizes were also generally known by the Standard Wire Gauge.

For many years ordinary VRI cables made up about 95 per cent of all installations. They were used first in wood casing, and then in conduit. Wood casing was a very early invention. It was introduced to separate conductors, this separation being considered a necessary safeguard against the two wires touching and so causing fire. Choosing a cable at the turn of the century was quite a task. From one catalogue alone, one could choose from fifty-eight sizes of wire, with no less than fourteen different grades of rubber insulation. The grades were described by such terms as light, high, medium or best insulation. Nowadays there are two grades of insulation: up to 600 V and 600 V/1,000 V. And the sizes of cables have been reduced to a more practicable seventeen.

During the 1890s the practice of using paper as an insulating material for cables was well established. One of the earliest makers was the company, which later became a member of the present-day BICC Group. The idea of using paper as an insulation material came from America to Britain where it formed part of the first wiring system for domestic premises. This was twin lead-sheathed cables. Bases for switches and other accessories associated with the system were of cast solder, to which the cable sheathing was wiped, and then all joints sealed with a compound. The compound was necessary because the paper insulation when dry tends to absorb moisture.

In 1911, the famous 'Henley Wiring System' came on the market. It comprised flat-twin cables with a lead-alloy sheath. Special junction boxes, if properly fixed, automatically effected good electrical continuity. The insulation was rubber. It became very popular. Indeed, it proved so easy to install that a lot of unqualified people appeared on the contracting scene as ‘electricians’. When it received the approval of the IEE Rules, it became an established wiring system and is still in use today.

At the time the lead-sheathed system made its first appearance, another rival wiring system also came onto the scene. This was the CTS system (cab-tyre sheathed). It arose out of the idea that if a rubber product could be used to stand up to the wear and tear of motor-car tyres on roads, then the material would well be applied to cover cables. The CTS name eventually gave way to TRS (tough-rubber sheath), when the rubber-sheathed cable system came into general use.

The main competitor to rubber as an insulating material appeared in the late 1930s. This material was PVC (polyvinyl chloride), a synthetic material which came from Germany. The material, though inferior to rubber so far as elastic properties were concerned, could withstand the effects of both oil and sunlight. During the Second World War PVC, used both as wire insulation and the protective sheath, became well established.

As experience increased with the use of TRS cables, it was made the basis of modified wiring systems. The first of these was the Callender farm-wiring system introduced in 1937. This was tough rubber sheathed cables with a semi-embedded braiding treated with a green-colored compound. This system combined the properties of ordinary TRS and HSOS (house-service overhead system) cables.

So far as conductor material was concerned, copper was the most widely used. But aluminium was also applied as a conductor material. Aluminium, which has excellent electrical properties, has been produced on a large commercial scale since about 1890. Overhead lines of aluminium were first installed in 1898. Rubber-insulated aluminium cables of 3/0.036 inch and 3/0.045 inch were made to the order of the British Aluminium Company and used in the early years of this century for the wiring of the staff quarters at Kinlochleven in Argyllshire. Despite the fact that lead and lead-alloy proved to be of great value in the sheathing of cables, aluminium was looked to for a sheath of, in particular, light weight. Many experiments were carried out before a reliable system of aluminium-sheathed cable could be put on the market.

Perhaps one of the most interesting systems of wiring to come into existence was the MICS (mineral-insulated copper-sheathed cable) which used compressed magnesium oxide as the insulation, and had a copper sheath and copper conductors. The cable was first developed in 1897 and was first produced in France. It has been made in Britain since 1937, first by Pyrotenax Ltd, and later by other firms. Mineral insulation has also been used with conductors and sheathing of aluminium.

One of the first suggestions for steel used for conduit was made in 1883. It was then called 'small iron tubes'. However, the first conduits were of bitumised paper. Steel for conduits did not appear on the wiring scene until about 1895. The revolution in conduit wiring dates from 1897, and is associated with the name 'Simplex' which is common enough today. It is said that the inventor, L. M. Waterhouse, got the idea of close-joint conduit by spending a sleepless night in a hotel bedroom staring at the bottom rail of his iron bedstead. In 1898 he began the production of light gauge close-joint conduits. A year later the screwed-conduit system was introduced.

Non-ferrous conduits were also a feature of the wiring scene. Heavy-gauge copper tubes were used for the wiring of the Rylands Library in Manchester in 1886. Aluminium conduit, though suggested during the 1920s, did not appear on the market until steel became a valuable material for munitions during the Second World War.

Insulated conduits also were used for many applications in installation work, and are still used to meet some particular installation conditions. The 'Gilflex' system, for instance, makes use of a PVC tube, which can be bent cold, compared with earlier material, which required the use of heat for bending.

Accessories for use with wiring systems were the subjects of many experiments; many interesting designs came onto the market for the electrician to use in his work. When lighting became popular, there arose a need for the individidual control of each lamp from its own control point. The 'branch switch' was used for this purpose. The term 'switch' came over to this country from America, from railway terms which indicated a railway 'point', where a train could be 'switched' from one set of tracks to another. The 'switch', so far as the electric circuit was concerned, thus came to mean a device, which could switch an electric current from one circuit to another.

It was Thomas Edison who, in addition to pioneering the incandescent lamp, gave much thought to the provision of branch switches in circuit wiring. The term 'branch' meant a tee off from a main cable to feed small current-using items. The earliest switches were of the ‘turn’ type, in which the contacts were wiped together in a rotary motion to make the circuit. The first switches were really crude efforts: made of wood and with no positive ON or OFF position. Indeed, it was usual practice to make an inefficient contact to produce an arc to 'dim' the lights! Needless to say, this misuse of the early switches, in conjunction with their wooden construction, led to many fires. But new materials were brought forward for switch construction such as slate, marble, and, later, porcelain. Movements were also made more positive with definite ON and OFF positions.

The 'turn' switch eventually gave way to the 'Tumbler' switch in popularity. It came into regular use about 1890. Where the name 'tumbler' originated is not clear; there are many sources, including the similarity of the switch action to the antics of Tumbler Pigeons. Many accessory names, which are household words to the electricians of today, appeared at the turn of the century: Verity's, McGeoch, Tucker and Crabtree. Further developments to produce the semi-recessed, the flush, the ac only, and the 'silent' switch proceeded apace. The switches of today are indeed of long and worthy pedigrees.

It was one thing to produce a lamp operated from electricity. It was quite another thing to devise a way in which the lamp could be held securely while current was flowing in its circuit. The first lamps were fitted with wire tails for joining to terminal screws. It was Thomas Edison who introduced, in 1880, the screw cap, which still bears his name. It is said he got the idea from the stoppers fitted to kerosene cans of the time. Like many another really good idea, it superseded all its competitive lamp holders and its use extended through America and Europe. In Britain, however, it was not popular. The bayonet-cap type of lamp-holder was introduced by the Edison & Swan Co. about 1886. The early type was soon improved to the lampholders we know today.

Ceiling roses, too, have an interesting history; some of the first types incorporated fuses. The first rose for direct attachment to conduit came out in the early 1900s, introduced by Dorman & Smith Ltd.

The first patent for a plug-and-socket was brought out by Lord Kelvin, a pioneer of electric wiring systems and wiring accessories. The accessory was used mainly for lamp loads at first, and so carried very small currents. However, domestic appliances were beginning to appear on the market, which meant that sockets had to carry heavier currents. Two popular items were irons and curling-tong heaters. Shuttered sockets were designed by Crompton in 1893. The modern shuttered type of socket appeared as a prototype in 1905, introduced by 'Diamond H'. Many sockets were individually fused, a practice which was later meet the extended to the provision of a fuse in the plug.

These fuses were, however, only a small piece of wire between two terminals and caused such a lot of trouble that in 1911 the Institution of Electrical Engineers banned their use. One firm, which came into existence with the socket-and-plug, was M.K. Electric Ltd. The initials were for 'Multi-Kontakt' and associated with a type of socket outlet, which eventually became the standard design for this accessory. It was Scholes, under the name of 'Wylex', who introduced a revolutionary design of plug-and-socket: a hollow circular earth pin and rectangular current-carrying pins. This was really the first attempt to 'polarise', or to differentiate between live, earth and neutral pins.

One of the earliest accessories to have a cartridge fuse incorporated in it was the plug produced by Dorman & Smith Ltd. The fuse actually formed one of the pins, and could be screwed in or out when replacement was necessary. It is a rather long cry from those pioneering days to the present system of standard socket-outlets and plugs.

Early fuses consisted of lead wires, lead being used because of its low melting point. Generally, devices which contained fuses were called 'cutouts', a term still used today for the item in the sequence of supply-control equipment entering a building. Once the idea caught on of providing protection for a circuit in the form of fuses, brains went to work to design fuses and fuse gear. Control gear first appeared encased in wood. But ironclad versions made their due appearance, particularly for industrial use during the nineties. They were usually called 'motor switches', and had their blades and contacts mounted on a slate panel. Among the first companies in the switchgear field were Bill & Co., Sanders & Co. and the MEM Co., whose 'Kantark' fuses are so well known today. In 1928 this Company introduced the ‘splitter’, which effected a useful economy in many of the smaller installations.

It was not until the 1930s that the distribution of electricity in buildings by means of bus bars came into fashion, though the system had been used as far back as about 1880, particularly for street mains. In 1935 the English Electric Co. introduced a bus bar trunking system designed to meet the needs of the motorcar industry. It provided the overhead distribution of electricity into which system individual machines could be tapped wherever required; this idea caught on and designs were produced and put onto the market by Marryat & Place, GEC and Ottermill.

Trunking came into fashion mainly because the larger sizes of conduit proved to be expensive and troublesome to install. One of the first trunking types to be produced was the 'spring conduit' of the Manchester firm of Key Engineering. They showed it for the first time at an electrical exhibition in 1908. It was semi-circular steel troughing with edges formed in such a way that they remained quite secure by a spring action after being pressed into contact. But it was not until about 1930 that the idea took root and is now established as a standard wiring system.

The story of electric wiring, its systems and accessories tells an important aspect in the history of industrial development and in the history of social progress. The inventiveness of the old electrical personalities, Compton, Swan, Edison, Kelvin and many others, is well worth noting; for it is from their brain-children that the present-day electrical contracting industry has evolved to become one of the most important sections of activity in electrical engineering. For those who are interested in details of the evolution and development of electric wiring systems and accessories, good reading can be found in the book by J. Mellanby: The History of Electric Wiring (MacDonald, London).

Any comparison of manufacturers catalogues of, say, ten years ago, with those of today will quickly reveal how development of both wiring systems and wiring accessories have changed, not only physically, in their design and appearance but in their ability to meet the demands made on them of modern electrical installations, both domestic and industrial. What were once innovations, such as dimmer switches, for instance, are now fairly commonplace where clients require more flexible control of domestic circuits. The new requirements of the Regulations for Electrical Installations will no doubt introduce more changes in wiring systems and accessories so that installations become safer to use with attendant reductions in the risk from electric shock and fire hazards. New developments in lighting, for instance, particularly during the last decade or so, herald changes in the approach to installation work. Innovative changes in space and water heating, using solar energy and heat pumps, will involve the electrician in situations which can offer exciting challenges in installation work, not least in keeping up with the new face of old technology. More and more is the work of the electrician becoming an area of activity where a thorough grasp of the technology involved is essential if one is to offer the client a safe, reliable and technically competent installation.

1.2 Historical Review of Wiring Installation

The history of the development of non-legal and statutory rules and regulations for the wiring of buildings is no less interesting than that of wiring systems and accessories. When electrical energy received an utilisation impetus from the invention of the incandescent lamp, many set themselves up as electricians or electrical wiremen. Others were gas plumbers who indulged in the installation of electrics as a matter of normal course. This was all very well: the contracting industry had to get started in some way, however ragged. But with so many amateurs troubles were bound to multiply. And they did. It was not long before arc lamps, sparking commutators, and badly insulated conductors contributed to fires. It was the insurance companies, which gave their attention to the fire risk inherent in the electrical installations of the 1880s. Foremost among these was the Phoenix Assurance Co., whose engineer, Mr. Heaphy, was told to investigate the situation and draw up a report on his findings.

The result was the Phoenix Rules of 1882. These Rules were produced just a few months after those of the American Board of Fire Underwriters who are credited with the issue of the first wiring rules in the world.

The Phoenix Rules were, however, the better set and went through many editions before revision was thought necessary. That these Rules contributed to a better standard of wiring, and introduced a high factor of safety in the electrical wiring and equipment of buildings, was indicated by a report in 1892, which showed the high incidence of electrical fires in the USA and the comparative freedom from fires of electrical origin in Britain.

Three months after the issue of the Phoenix Rules for wiring in 1882, the Society of Telegraph Engineers and Electricians (now the Institution of Electrical Engineers) issued the first edition of Rules and Regulations for the Prevention of Fire Risks arising from Electric lighting. These rules were drawn up by a committee of eighteen men, which included some of the famous names of the day: Lord Kelvin, Siemens and Crompton. The Rules, however, were subjected to some criticism. Compared with the Phoenix Rules they left much to be desired. But the Society was working on the basis of laying down a set of principles rather than, as Heaphy did, drawing up a guide or 'Code of Practice'. A second edition of the Society's Rules was issued in 1888. The third edition was issued in 1897 and entitled General Rules recommended for Wiring for the Supply of Electrical Energy.

The Rules have since been revised at fairly regular intervals as new developments and the results of experience can be written in for the considered attention of all those concerned with the electrical equipment of buildings. Basically the regulations were intended to act as a guide for electricians and others to provide a degree of safety in the use of electricity by inexperienced persons such as householders. The regulations were, and still are, not legal; that is, they cannot be enforced by the law of the land. Despite this apparent loophole, the regulations are accepted as a guide to the practice of installation work, which will ensure, at the very least, a minimum standard of work. The Institution of Electrical Engineers (IEE) was not alone in the insistence of good standards in electrical installation work. In 1905, the Electrical Trades Union, through the London District Committee, in a letter to the Phoenix Assurance Co., said '. . . they view with alarm the large extent to which bad work is now being carried out by electric light contractors . . .. As the carrying out of bad work is attended by fires and other risks, besides injuring the Trade, they respectfully ask you to . . uphold a higher standard of work'.

The legislation embodied in the Factory and Workshop Acts of 1901 and 1907 had a considerable influence on wiring practice. In the latter Act it was recognized for the first time that the generation, distribution and use of electricity in industrial premises could be dangerous. To control electricity in factories and other premises a draft set of Regulations was later to be incorporated into statutory requirements.

While the IEE and the statutory regulations were making their positions stronger, the British Standards Institution brought out, and is still issuing, Codes of Practice to provide what are regarded as guides to good practice. The position of the Statutory Regulations in this country is that they form the primary requirements, which must by law be satisfied. The IEE Regulations and Codes of Practice indicate supplementary requirements. However, it is accepted that if an installation is carried out in accordance with the IEE Wiring Regulations, then it generally fulfils the requirements of the Electricity Supply Regulations. This means that a supply authority can insist upon all electrical work to be carried out to the standard of the IEE Regulations, but cannot insist on a standard which is in excess of the IEE requirements.

The position of the IEE 'Regs', as they are popularly called, is that of being the installation engineer's 'bible'. Because the Regulations cover the whole field of installation work, and if they are complied with, it is certain that the resultant electrical installation will meet the requirements of all interested parties. There are, however, certain types of electrical installations, which require special attention to prevent fires and accidents. These include mines, cinemas, theatres, factories and places where there are exceptional risks.

The following list gives the principal regulations, which cover electricity supply and electrical installations:

Non-Statutory Regulations:

1.Institute of Electrical Engineers Regulations for Electrical Installations - This covers industrial and domestic electrical installation work in buildings.

2.The Institute of Petroleum Electrical Code, 1963- This indicates special safety requirements in the petroleum industry, including protection from lightning and static. It is supplementary to the IEE Regulations.

3.Factories Act, 1961. Memorandum by the Senior Electrical Inspector of Factories - Deals with installations in factories.

4.Explanatory Notes on the Electricity Supply Regulations, 1937 - These indicate the requirements governing the supply and use or electricity.

5.Hospital Technical Memoranda No.7 -Indicates the electrical services, supply and distribution in hospitals.

All electrical contractors are most particularly concerned with the various requirements laid down by Acts of Parliament (or by Orders and Regulations made thereunder) as to the method of installing electric lines and fittings in various premises, and as to their qualities and specifications.

Statutory Regulations:

1.Building (Scotland) Act, 1959 - Provides for minimum standards of construction and materials including electrical installations.

2.Building Standards (Scotland) Regulations, 1981 - Contains minimum requirements for electrical installations.

3.Electricity Supply Regulations, 1937 -Indicates the requirements governing the supply and use of electricity and deals with installations generally, subject to certain exemptions.

4.Electricity (Factories Act) Special Regulations, 1908 and 1944 - Deals with factory installations, installations on construction sites, and installations of non-domestic caravans such as mobile workshops. These Regulations come under the authority of the Health and Safety Commission.

5.Coal and other Mines (Electricity) Regulations, 1956 - Deals with coalmine installations.

6.Cinematograph (Safety) Regulations, 1952 Deals with installations in cinemas.

7.Quarries (Electricity) Regulations, 1956 -Deals with installations at quarry operations.

8.Agriculture (Stationary Machinery) Regulations, 1959 - Deals with agricultural and horticultural installations.

Though these Statutory Regulations are concerned with electrical safety in the respective type of installations listed, there are other Statutory Regulations, which are also concerned with electrical safety when equipment and appliances are being used. Included in these are the Electricity at Work Regulations, which came into force in 1990. They are stringent in their requirements that all electrical equipment used in schools, colleges, factories and other places of work is in a safe condition and must be subjected to regular testing by competent persons.

Because of the rather legal language in which many of the Statutory Regulations are written, a number of them are made the subject of Guides and Explanatory Notes so that the electrical contractor and his employees are better able to understand the requirements.

It should be noted that in addition to the above list, there are quite a number of Statutory Regulations, which deal with specific types of installations such as caravans and petrol stations. While it may seem that the electrician is completely surrounded by Regulations, it should be remembered that their purpose is to ensure not only the safety of the public, but work persons also. And it is also worth noting that in the UK the record for the lowest number of electrical accidents is among the best in the world.

It is a requirement of the current edition of the IEE Regulations for Electrical Installations that good workmanship and the use of approved materials contribute to the high level of safety provided in any electrical installation. The British Standards Institution (BSI) is the approved body for the preparation and issue of Standards for testing the quality of materials and their performance once they are installed in buildings. A typical Standard is BS 31 Steel Conduit and Fittings for Electrical Wiring. The BSI also issues Codes of Practice, which indicate acceptable standards of good practice and take the form of recommendations. These Codes contain the many years of practical experience of electrical contractors. Some of the Codes of interest to the practicing electrician include:

BS 1003: Electrical apparatus and associated equipment for use in explosive atmospheres of gas or vapour

BS 7375: Distribution of electricity on construction and building sites

BS 1018: Electric floor-warming systems for use with off-peak and similar supplies of electricity

Almost a century after the first Wiring Regulations were issued a complete revision was made in 1981 with the appearance of the 15th edition under the title Regulations for Electrical Installations. This edition differed from previous editions in its highly technical approach to the provision of electrical installations, based on the need for a high degree of quality of both materials and workmanship to ensure safety from fire, shock and bums. The technical content of the 15th edition of the Regulations placed a degree of responsibility on practicing electricians to become familiar with the electrical science principles and the technology which the installer must have in order to provide a client with an installation which is well designed and safe to use.

The 16th edition is now published with yet more changes and differences in approach from the 15th edition. The major changes include the smaller number of explanatory notes and fewer appendices. The 16th edition is also accompanied by a number of other publications: Guidance Notes and an On-site Guide. The Guidance Notes give detailed information on such topics as protection against electric shock, protection against overcurrent, initial and periodic testing and special installations and locations. The On-site Guide provides guidance on the construction of the smaller installation such as domestic, commercial and small three-phase installations without the need for the considerable amount of calculations, which the 15th edition required in the design of an installation. The Guide in fact offers information, which will ensure that an installation has a high degree of built-in safety without taking economic cost into consideration. The Guide also contains much need-to-know' information, thus making the technical aspects of an electrical installation more accessible to the practicing electrician.

In short, the new 16th edition of the Regulations still places responsibility on the electrician to fully understand the technical aspects of the work he carries out which is only to be expected from a skilled and qualified work person.

While the IEE Wiring Regulations have, since 1882, become a widely recognised standard for electrical installations, they have not had any legal status except when they are quoted for contractual purposes. With the creation of the Single Common Market and the harmonisation of, among many other things, electrical standards among the member countries of the Common Market, the Regulations, from 1992, have been given an enhanced status by being allotted a British standard number.

CHAPTER 2: ELECTRICAL MATERIALS

2.1 Conductors

In electrical work, a 'conductor' means a material which will allow the free passage of an electric current along it, and which presents negligible resistance to the current. If the conducting material has an extremely low resistance (e.g. a copper cable) there will, normally, be no effect when the conductor carries a current. If the conducting material has a significant resistance (e.g. iron wire) then the conductor will show the effects of an electric current passing through it, usually in the form of a rise in temperature to produce a heating effect. It should be remembered that the conduction of electric currents is offered not only by metals, but by liquids (e.g. water) and gases (e.g., neon). Conductors by nature differ so enormously from insulators in their degree of conduction that the materials which offer high resistance to an electric current are classed as insulators. Those materials which fall in between the two are classed as semiconductors (e.g. germanium).

Copper

This metal has been known to man since the beginning of recorded history. Copper was connected with the earliest electrical effects such as, for instance, that made by Galvani in 1786 when he noticed the curious behavior of frogs' legs hung by means of a copper hook from an iron railing (note here the two dissimilar metals). Gradually copper became known as an electrical material; its low resistance established it as a conductor. One of the first applications of copper as a conductor was for the purpose of signaling; afterwards the commercial generation of electricity looked to copper for electrical distribution. It has thus a prominent place and indeed is the first metal to come to mind when an electrical material is mentioned. As a point of interest, the stranded cable, as we know it today has an ancient forebear. Among several examples, a bronze cable was found in Pompeii (destroyed AD 79); it consisted of three cables, each composed of fifteen bronze wires twisted round each other.

Copper is a tough, slow-tarnishing and easily worked metal. Its high electrical conductivity marks it out for an almost exclusive use for wires and cables, contacts, and terminations. Copper for electrical purposes has a high degree of purity, at least 99.9 per cent. This degree of purity results in a conductivity value only slightly less than that of silver (106 to 100). As with all other pure metals, the electrical resistance of copper varies with temperature. Thus, when there is a rise in temperature, the resistance also increases. Copper is available as wire, bar, rod, tube, strip and plate. Copper is a soft metal; to strengthen it certain elements are added. For overhead lines, for instance, copper is required to have a high-tensile strength and is thus mixed with cadmium. Copper is also reinforced by making it surround a steel core, either solid or stranded.

Copper is the basis of many of the cuprous alloys found in electrical work. Bronze is an alloy of copper and tin. It is fairly hard and can be machined easily. When the bronze contains phosphorus, it is known as phosphor-bronze, which is used for spiral springs. Gunmetal (copper, tin and zinc) is used for terminals. Copper and zinc become brass, which is familiar as terminals, cable legs, screws and so on, where good conductivity is required coupled with resistance to wear. Copper oxidises slowly at ordinary temperatures, but rapidly at high temperatures; the oxide skin is not closely adherent and can be removed easily.

Aluminium

The use of aluminium in the electrical industry dates back to about the turn of this century when it was used for overhead-line conductors. But because in the early days no precautions were taken to prevent the corrosion, which occurs with, bimetallic junctions (e.g. copper cable to aluminium busbar) much trouble was experienced which discouraged the use of the metal. Generally speaking, aluminium and its alloys are used today for electrical purposes because of (a) weight; (b) resistance to corrosion; (c) economics (cheaper than copper); (d) ease of fabrication; (e) non-magnetic properties. Electrical applications include cable conductors, busbars, castings in switchgear, and cladding for switches. The conductor bars used in the rotor of squirrel-cage-induction ac motors are also of aluminium on account of the reduced weight afforded by the metal. Cable sheaths are available in aluminium. When used as conductors, the metal is either solid or stranded.

An oxide film is formed on the metal when exposed to the oxygen in the atmosphere. This film takes on the characteristics of an insulator, and is hard enough to withstand some considerable abrasion. The film also increases the corrosion-resisting properties of aluminium. Because of this film it is important to ensure that alt electrical contacts made with the metal are initially free from it; if it does form on surfaces to be mated, the film must be removed or broken before a good electrical contact can be made in a joint. Because the resistivity of aluminium is greater than that of copper, the cross-sectional area of the conductor for a given current-carrying capacity must be greater than that for a copper conductor.

Zinc

This metal is used mainly as a protective coating for steel and may be applied to the steel by either galvanising, sherardising or spraying. In electrical work it is found on switchgear components, conduit and fittings, resistance grids, channels, lighting fittings and wall brackets. Galvanizing is done by dipping iron or steel objects into molten metal after fluxing. Mixed with copper, the zinc forms the alloy brass. Sherardising is done by heating the steel or iron object to a certain temperature in zinc dust, to result in an amalgamation of the two metals, to form a zinc-iron alloy.

Lead

Lead is one of the oldest metals known to man. Lead is highly resistant to corrosion. So far as the electrical application of lead is concerned, apart from its use in primary and secondary cells, cable sheathing in lead was suggested as early as 1830-45. This period saw the quantity production of electrical conductors for inland telegraphs, and thoughts turned to the possibility of prolonging the life of the conductors: the earliest suggestions were that this could be done by encasing them in lead. Today lead is used extensively. Lead is not used pure; it is alloyed with such metals as tin, cadmium, antimony and copper. Its disadvantage is that it is very heavy; it is also soft, even though it is used to give insulated cables a degree of protection from mechanical damage. One of its principal properties is its resistance to the corrosive effects of water and acids. It has a low melting point; this fact is made use of in the production of solder, where it is alloyed with tin for cable-jointing work. Lead alloyed with tin and copper is used as white metal for machine bearings.

Nickel

This metal is used in conjunction with iron and chromium to form what is known as the resistive conductors used as heating elements for domestic and industrial beating appliances and equipment. The alloy stands up well to the effects of oxidation. Used with chromium only the alloy is non-magnetic; with iron it is slightly magnetic. It has a high electrical resistivity and low temperature coefficient. The most common alloy names are

Nichrome and Brightray and Pyromic. Pure nickel is found in wire and strip forms for wire leads in lamps, and woven resistance mats, where resistance to corrosion is essential.

Carbon

This material is used for motor brushes (slip-ring and commutator), resistors in radio work. It has a negative temperature characteristic in that its resistance decreases with an increase in temperature.

Ferrous metals

These metals are based on iron and used for the construction of many pieces of equipment found in the electrical field (switches, conduit, cable armouring, motor field-poles and so on). Because iron is a magnetic material, it is used where the magnetic effect of an electrical current is applied to perform some function (e.g. in an electric bell).

The choice of magnetic materials today is extremely wide. For practical purposes magnetic materials fall into two main classes: permanent (or hard) and temporary (or soft). Permanent magnetic materials include tungsten and chromium steel and cobalt steel: when magnetised they retain their magnetic properties for a long time. Cobalt-steel magnets are used for measuring instruments, telephone apparatus and small synchronous motors. Soft magnetic materials do not retain their magnetism for any appreciable time after the magnetising force has been withdrawn. In a laminated sheet form they are found in transformer cores and in machine poles and armatures and rotors. Silicon-iron is the most widely used material for cores.

Rare and precious metals

In general, precious metals are used either for thermocouples or contacts. Among the metals used are silver, gold, platinum, palladium and iridium. Sometimes they are used as pure metals, otherwise as an alloy within the above group or with iron and copper, where special characteristics are required. For instance, a silver-iron alloy contact has a good resistance to sticking and is used in circuits which are closed with a high inrush (e.g. magnetising currents associated with inductors, electromagnets and transformer). It is used also for small motor-starter contacts. The alloy maintains low contact resistance for very long periods. The following are some applications of rare and precious metals in contacts:
Circuit-breakers. Silver, silver-nickel, silver-tungsten.
Contactors. Silver, silver-tungsten. Relays. Silver, platinum, silver-nickel.

Relays. Silver, platinum, silver-nickel

Starters. Platinum, rhodium, silver, coin silver. Silver is used for the fuse-element in HRC fuses.

Mercury. This material is used almost exclusively for mercury switches. In a vapour form it is used in fluorescent lamps (low-pressure lamps) and in the high-pressure mercury-vapour lamp.

Semiconductors

Oxides of nickel, copper, iron, zinc and magnesium have high values of resistivity; they are neither conductors nor insulators, and are called semiconductors. Other examples are silicon and germanium. When treated in certain ways, these materials have the property of being able to pass a large current in one direction while restricting the flow of current to a negligible value in the other direction. The most important application for these materials is in the construction of rectifiers and transistors.

Conducting liquids

Among the liquids used to conduct electric currents are those used as electrolytes: sulphuric acid (lead-acid cells); sal ammoniac (Leclanche cells); copper sulphate (in simple cells); caustic potash (nickel-cadmium cells). When salts are introduced to water the liquid is used as a resistor.

Conducting gases

In electrical work, so far as the practical electrician is concerned, the conducting gases are, those used for electric discharge lamps: neon, vapour, sodium vapour, helium.

2.2 Insulators

An insulator is defined as a material, which offers an extremely high resistance to the passage of an electric current. Were it not for this property of some materials we would not be able to apply electrical energy to so many uses today. Some materials are better insulators than others. The resistivity of all insulating materials decreases with an increase in temperature. Because of this, a limit in the rise in temperature is imposed in the applications of insulating materials, otherwise the insulation would break down to cause a short circuit or leakage current to earth. The materials used for insulation purposes in electrical work are extremely varied and are of a most diverse nature. Because no single insulating material can be used extensively, different materials are combined to give the required properties of mechanical strength, adaptability and reliability. Solids, liquids and gases are to be found used as insulation.

Insulating materials arc grouped into classes:

Class A - Cotton, silk, paper and similar organic materials; impregnated or immersed in oil.

Class B - Mica, asbestos, and similar inorganic materials, generally found in a built-up form combined with cement binding cement. Also polyester enamel covering and glass-cloth and micanite.

Class C - Mica, porcelain glass quartz: and similar materials.

Class E - Polyvinyl acetal resin. Class H - Silicon-glass.

The following are some brief descriptions of some of the insulating materials more commonly found in electrical work.

Rubber

Used mainly for cable insulation. Cannot be used for high temperatures as it hardens. Generally used with sulphur (vulcanised rubber) and china clay. Has high insulation-resistance value.

Polyvinyl chloride (PVC)

This is a plastics material, which will tend to flow when used in high temperatures. Has a lower insulation-resistance value than rubber. Used for cable insulation and sheathing against mechanical damage.

Paper

Must be used in an impregnated form (resin or oil). Used for cable insulation. Impregnated with paraffin wax, paper is used for making capacitors. Different types are available: kraft, cotton, tissue, and pressboard.

Glass

Used for insulators (overhead lines). In glass fibre form it is used for cable insulation where high temperatures are present, or where areas are designated 'hazardous'. Requires a suitable impregnation (with silicone varnish) to fill the spaces between the glass fibres.

Mica

This material is used between the segments of commutators of de machines, and under slip rings of ac machines. Used where high temperatures are involved such as the heating elements of electric irons. It is a mineral, which is present in most granite-rock formations; generally produced in sheet and block form. Micanite is the name given to the large sheets built up from small mica splittings and can be found backed with paper, cotton fabric, silk or glass-cloth or varnishes. Forms include tubes and washers.

Ceramics

Used for overhead-line insulators and switchgear and transformer bushings as lead-ins for cables and conductors. Also found as switch-bases, and insulating beads for high-temperature insulation applications.

Bakelite

A very common synthetic material found in many aspects of electrical work (e.g. lamp holders, junction boxes), and used as a construction material for enclosing switches to be used with insulated wiring systems.

Insulating oil

This is a mineral oil used in transformers, and in oil-filled circuit-breakers where the arc drawn out when the contacts separate, is quenched by the oil. It is used to impregnate wood, paper and press-board. This oil breaks down when moisture is present.

Epoxide resin

This material is used extensively for 'potting' or encapsulating electronic items. In larger castings it is found as insulating bushings for switchgear and transformers.

Textiles

This group of insulating materials includes both natural (silk, cotton, and jute) and synthetic (nylon, Terylene). They are often found in tape form, for winding-wire coil insulation.

Gases

Air is the most important gas used for insulating purposes. Under certain conditions (humidity and dampness) it will break down. Nitrogen and hydrogen are used in electrical transformers and machines as both insulants and coolants.

Liquids

Mineral oil is the most common insulant in liquid form. Others include carbon tetrachloride, silicone fluids and varnishes. Semi-liquid materials include waxes, bitumens and some synthetic resins. Carbon tetrachloride is found as an arc-quencher in high-voltage cartridge type fuses on overhead lines. Silicone fluids are used in transformers and as dashpot damping liquids. Varnishes are used for thin insulation covering for winding wires in electromagnets. Waxes are generally used for impregnating capacitors and fibres where the operating temperatures are not high. Bitumens are used for filling cable-boxes; some are used in a paint form. Resins of a synthetic nature form the basis of the materials known as 'plastics' (polyethylene, polyvinyl chloride, melamine and polystyrene). Natural resins are used in varnishes, and as bonding media for mica and paper sheets hot-pressed to make boards.

2.3 Cables

The range of types of cables used in electrical work is very wide: from heavy lead-sheathed and armored paper-insulated cables to the domestic flexible cable used to connect a hair-drier to the supply. Lead, tough-rubber, PVC and other types of sheathed cables used for domestic and industrial wiring are generally placed under the heading of power cables. There are, however, other insulated copper conductors (they are sometimes aluminum) which, though by definitions are termed cables, are sometimes not regarded as such. Into this category fall for these rubber and PVC insulated conductors drawn into some form of conduit or trucking for domestic and factory wiring, and similar conductors employed for the wiring of electrical equipment. In addition, there are the various types of insulated flexible conductors including those used for portable appliances and pendant fittings.

The main group of cables is 'flexible cables', so termed to indicate that they consist of or more cores, each containing a group of wires, the diameters of the wires and the construction of the cable being such that they afford flexibility.

Single-core: These are natural or tinned copper wires. The insulating materials include butyl -rubber, silicon-rubber, and the more familiar PVC.

The synthetic rubbers are provided with braiding and are self-colored. The IEE Regulations recognize these insulating materials for twin-and multi-core flexible cables rather than for use as single conductors in conduit or trunking wiring systems. But that are available from the cable manufacturers for specific insulation requirements. Sizes vary from 1 to 36 mm squared (PVC) and 50 mm squared (synthetic rubbers).

Two-core: Two-core or 'twin' cables are flat or circular. The insulation and sheathing materials are those used for single-core cables. The circular cables require cotton filler threads to gain the circular shape. Flat cables have their two cores laid side by side.

Three-core: These cables are the same in all respects to single-and two-core cables except, of course, they carry three cores.

Composite cables: Composite cables are those which, in an addition to carrying the currency-carrying circuit conductors, also contains a circuit-protective conductor.

To summarize, the following group of cable types and applications are to be found in electrical work, and the electrician, at one time or another during his career, may be asked to install them.

Wiring cables: Switchboard wiring; domestic at workshop flexible cables and cords. Mainly copper conductors.

Power cables: Heavy cables, generally lead sheathed and armored; control cables for electrical equipment. Both copper and aluminum conductors.

Mining cables: In this field cables are used for trailing cables to supply equipment; shot-firing cables; roadway lighting; lift -shaft wiring; signaling, telephone and control cables. Adequate protection and fireproofing are features of cables for this application field.

Ship-wiring cables: These cables are generally lead-sheathed and armored, and mineral-insulated, metal-sheathed. Cables must comply with Lloyd's Rules and Regulations, and with Admiralty requirements.

Overhead cables: Bare, lightly-insulated and insulated conductors of copper, copper-vadmium and aluminum generally. Sometimes with steel core for added strength. For overhead distribution cables are PVC and in most cases comply with British Telecom requirements.

Communication cables: This group includes television down-leads and radio-relay cables; radio frequency cables; telephone cables.

Welding cables: These are flexible cables and heavy cords with either copper or aluminum conductors.

Electric-sign cables: PVC-and rubber-insulated cables for high-voltage discharge lamps able to withstand the high voltages.

Equipment wires: Special wires for use with instruments, often insulated with special materials such as silicon, rubber and irradiated polythene.

Appliance-wiring cables: This group includes high-temperature cables for electric radiators, cookers and so on. Insulation used includes nylon, asbestos and varnished cambric.

Heating cables: Cables for floor-warming, road-heating, soil-warming, ceiling-heating and similar applications.

Flexible cords: A flexible cord is defined as a flexible cable in which the csa of each conductor does not exceed 4 mm squared. The most common types of flexible cords are used in domestic and light industrial work. The diameter of each strand or wire varies from 0.21 to 0.31 mm. Flexible cord come in many sizes and types; for convenience they are groups as follows:

1) Twin-twisted: These consist of one single insulated stranded conductors twisted together to form a core-cable. Insulation used is vulcanized rubber and PVC. Color identification in red and black is often provided. The rubber is protected by a braiding of cotton, glazed-cotton, and rayon-barding and artificial silk. The PVC-insulated conductors are not provided with additional protection.

2) Three-core (twisted): Generally as two -twisted cords but with a third conductor colored green, for eating lighting fittings.

3) Three-core (circular): Generally as twin-core circular except that the third conductor is colored green and yellow for earthing purposes.

4) Four-care (circular): Generally as twin- core circular. Colors are brown and blue.

5) Parallel twin: :These are two stranded conductors laid together in parallel and insulated to form a uniform cable with rubber or PVC.

6) Twin-core (flat): This consists of two stranded conductors insulated with rubber, colored red and black. Lay side-by-side and braided with artificial silk.

7) High-temperature lighting, flexible cord: With the increasing use of filament lamps which produce very high temperatures, the temperature at the terminals of a lamp holder can reach 71 centigrade or more. In most instances the usual flexible insulators (rubber and PVC) are quite unsuitable and special flexible cords for lighting are now available. Conductors are generally of nickel-plated copper wires, each conductor being provided with two lapping of glass fiber. The braiding is also varnished with silicone. Cords are made in the twisted form (two-and three-core).

8) Flexible cables: These cables are made with stranded conductors, the diameters being 0.3, 0.4, 0.5, and 0.6 mm. They are generally used for trailing cables and similar applications where heavy currents up to 630 A are to be carried, for instance, to welding plant.

CHAPTER 3:ELECTRICAL SAFETY-PROTECTION-EARTHING

3.1 Electrical safety:

The most common method used today for the protection of human beings against the risk of electrical shock is either:

1) The use of insulation (screening live parts, and keeping live parts out of reach).

2) Ensuring, by means of earthing, that any metal in electrical installation, other than the conductor, is prevented from becoming electrically charged. Earthing basically provides a path of low resistance to earth for any current, which results from a fault between a live conductor and earthed metal.

The general mass of earth has always been regarded as a means of getting rid of unwanted currents, charges of electricity could be dissipated by conducting them to an electrode driven into the ground. A lighting discharge to earth illustrates this basic concept of earth as being a large 'drain' for electricity. Thus, every electrical installation, which has metal work, associated with it (either the wiring system, accessories or the appliances used) is connected to earth. Basically, this means if, say, the framework of an electric fire becomes 'live', the resultant current will, if the frame is earthed, flow through the frame, its associated circuit-protective conductor, and then to the general mass of earth. Earthing metalwork by means of a bonding conductor means that all metalwork will be at earth potential; or, no difference in potential can exist. And because a current will not flow unless there is a difference in potential, then that installation is said to be safe from the risk of electric shock.

Effective use of insulation is another method of ensuring that the amount of metalwork in an electrical installation, which could become live, is reduced to a minimum. The term 'double-insulated' means that not only are the live parts of an appliance insulated, but that the general construction is of some insulating material. A hair-dryer and an electric shaver are two items, which fall into this category.

Though the shock risk in every electrical installation is something with which every electrician must concern himself, there is also the increase in the number of fires caused, not only by faults in wiring, but also by defects in appliances. In order to start a fire there must be either be sustained heat or an electric spark of some kind. Sustained heating effects are often to be found in overloaded conductors, bad connections, loose-fitting contacts and so on. If the contacts of a switch are really bad, then arcing will occur which could start a fire in some nearby combustible material, such as blackboard, chipboard, sawdust and the like. The purpose of a fuse is to cut off the faulty circuit in the event of an excessive current flowing in the circuit. But fuse-protection is not always a guarantee that the circuit is safe from the risk. The wrong size of fuse, for instance 15 A wire instead of 5 A wire, will render the circuit dangerous.

Fires can also be caused by an eat-leakage current causing arcing between live metalwork and, say, a gas pipe. Again, fuses are not always of use in the protection of a circuit against the occurrence of fire. Residual-current devices (RCD) are often used instead of fuses to detect small fault currents and to isolate the faulty circuit from the supply.

To ensure a high degree of safety from shock-risk and fire risk, it is thus important that every electrical installation to be tested and inspected not only when it is new but at periodic intervals during its working life. Many electrical installations today are anything up to fifty years old. And often they have been extended and altered to such an extent that the original safety factors have been reduced to a point where amazement is expressed on why 'the place has not gone up in flames before this'. Insulation, used, as it is to prevent electricity from appearing where it is not wanted, often deteriorates with age. Old, hard and brittle insulation may, of course, give no trouble if left undisturbed and is in a dry situation. But the danger of shock- and fire risk - is ever present, for the cables may at some time be moved by electricians, plumbers, gas fitters and builders.

It is a recommendation of the IEE Regulations that every domestic installation be tested at intervals of five years or less. The Completion and Inspection Certificates in the IEE Regulations show the details required in every inspection. And not only should the electrical installation be tested, but all current-using appliances and apparatus used by the consumer.

The following are some of the points, which the inspecting electrician should look for:

1) Flexible cables not secure at plugs.

2) Frayed cables.

3) Cables without mechanical protection.

4) Use of unearthed metalwork.

5) Circuits over-fused.

6) Poor or broken earth connections, and especially sign of corrosion.

7) Unguarded elements of the radiant fires.

8) Unauthorized additions to final circuits resulting in overloaded circuit cables.

9) Unprotected or unearthed socket-outlets.

10) Appliances with earthing requirements being supplied from two-pin BC adaptors.

11) Bell-wire used to carry mains voltages.

12) Use of portable heating appliances in bathrooms.

13) Broken connectors, such as plugs.

14) Signs of heating at socket-outlet contacts.

The following are the requirements for electrical safety:

1) Ensuring that all conductors are sufficient in csa for the design load current of circuits.

2) All equipment, wiring systems and accessories must be appropriate to the working conditions.

3) All circuits are protected against overcurrent using devices, which have ratings appropriate to the current-carrying capacity of the conductors

4) All exposed conductive pans are connected together by means of CPCs.

5) All extraneous conductive parts are bonded together by means of main bonding conductors and supplementary bonding conductors are taken to the installation main earth terminal.

6) All control and over current protective devices are installed in the phase conductor.

7) All electrical equipment has the means for their control and isolation.

8) All joints and connections must be mechanically secure and electrically continuous and be accessible at all times.

9) No additions to existing installations should be made unless the existing conductors are sufficient in size to carry the extra loading.

10) All electrical conductors have to be installed with adequate protection against physical damage and be suitably insulated for the circuit voltage at which they are to operate.

11) In situations where a fault current to earth is not sufficient to operate an overcurrent device, an RCD must be installed.

12) All electrical equipment intended for use outside equipotent zone must be fed from socket-outlets incorporating an RCD.

13) The detailed inspection and testing of installation before they are connected to a mains supply, and at regular intervals there after.

3.2 Protection

In electrical work the term protection is applied to precautions to prevent damage to wiring systems and equipment, but also takes in more specific precautions against the occurrence of fire due to overcurrents flowing in circuits, and electric shock risks to human beings as a result, usually, of earth-leakage currents appearing in metalwork not directly associated with an electrical installation, such as hot and cold water pipes.

The initial design of any installation must take into account the potential effects on wiring system and equipment of environmental and working conditions. BS *5490* is a British Standard concerned with protection against mechanical, or physical, damage and gives full details of the Index of Protection Code to which all electrical equipment must conform. The Code is based on a numbering system with each number indicating the degree of protection offered.

The first characteristic numeral indicates the protection level offered to persons against contact with live or moving parts inside an enclosure and also the protection of the enclosure itself against the ingress of solid bodies, such as dust particles. The numbers range from 0 (no protection of equipment against the ingress of solid bodies and no protection against contact with live or moving parts) to 6 (complete protection).

The second characteristic numeral indicates the degree of protection of equipment against the ingress of liquid and ranges from 0 to 8. Thus an equipment with IP44 means that there is protection against objects of a thickness greater than 1.0 mm and against liquid splashed from any direction.

Mechanical damage

This term includes damage done to wiring systems, accessories and equipment by impact, vibration and collision, and damage due to corrosion. Typical examples of prevention include single-core conductors in conduit and trunking, the use of steel enclosures in industrial situations, the proper supporting of cables, the minimum bending radius for cables, the use of armoured cables when they are installed underground, and the supports required for conductors in a vertical run of conduit and trunking.

Some types of installation present greater risks of damage to equipment and cables than others, for example on a building or construction site and in a busy workshop. In general, the working conditions should be assessed at the design stage of an installation and, if they have not been foreseen, perhaps due to a change of activity in a particular area, further work may be needed to meet the new working conditions.

Electrical fires are caused by (a) a fault, defect or omission in the wiring, *(b)* faults or defects in appliances and *(c)* mal-operation or abuse of the electrical circuit (e.g. overloading). The electrical proportion of fire causation today is around the 20 per cent mark. The majority of installation fires are the result of insulation damage, that is, electrical faults accounting for nearly three-quarters of cables and flex fires. Another aspect of protection against the risk of fire is that many installations must be fireproof or flameproof. The definition of a flameproof unit is a device with an enclosure so designed and constructed that it will withstand an internal explosion of the particular gas for which it is certified, and also prevent any spark or flame from that explosion leaking out of the enclosure and igniting the surrounding atmosphere. In general, this protection is effected by wide-machined flanges, which damp or otherwise quench the flame in its passage across the metal, but at the same time allows the pressure generated by the explosion to be dissipated.

One important requirement in installations is the need to make good holes in floors, walls and ceilings for the passage of cables, conduit, trunking and ducts by using incombustible materials to prevent the spread of fire. In particular, the use of fire barriers are required in trunking.

It was not until some years after the First World War that it was realised there was a growing need for special measures where electrical energy was used in inflammable situations. Precautions were usually limited to the use of well-glass lighting fittings. Though equipment for use in mines was certified as flameproof, it was not common to find industrial gear designed specially to work with inflammable gases, vapours, solvents and dusts. With progress, based on the results of research and experience, a class of industrial flameproof gear eventually made its appearance and is now accepted for use in all hazardous areas.

There are two types of flameproof apparatus: (a) mining gear, which is used solely with armored cable or special flexible; and (b) industrial gear, which may be used with solid-drawn steel conduit, MIMS cables, aluminium-sheathed cables or armoured cables. Mining gear is known as 'Group I' gear and comes into contact with only one fire hazard: firedamp or methane. Industrial gear, on the other hand, may well be installed in situations where a wide range of explosive gases and liquids are present. Three types of industrial hazards are to be found: explosive gases and vapours inflammable liquids - and explosive dusts. The first two hazards are covered by what is called 'Group II' and 'Group III' apparatus. Explosive dusts may be of either metallic or organic origin. Of the former, magnesium, aluminium, silicon, zinc and ferro-manganese are hazards, which can be minimized by the installation of flameproof apparatus; the flanges of which are well greased before assembly. The appropriate British Standard Code of Practice is BS 5345 Electrical Apparatus and Associated Equipment for Use in Explosive Atmospheres of Gas or Vapour, other than Mining Applications.

All equipment certified as 'flameproof' carries a small outline of a crown with the letters Ex inside it. The equipment consists of two or more compartments. Each is separated from the other by integral barriers, which have insulated studs mounted therein to accommodate the electrical connection. Where weight is of importance, aluminium alloy is permitted. All glassware is of the toughened variety to provide additional strength. The glass is fitted to the apparatus with special cement. Certain types of gear, such as distribution boards, are provided with their own integral isolating switches, so that the replacement of fuses, maintenance, and so on, cannot be carried out while a circuit is live.

All conduit installations for hazardous areas must be carried out in solid-drawn 'Class B', with certified draw-boxes, and accessories. Couplers are to be of the flameproof type with a minimum thread length of 50 mm. All screwed joints, whether entering into switchgear, junction boxes or couplers, must be secured with a standard heavy locknut. This is done to ensure a tight and vibration-proof joint, which will not slacken during the life of the installation, and thus impair both continuity and flameproofness. The length of the thread on the conduit must be the same as the fitting plus sufficient for the locknut. Because of the exposed threads, running couplers are not recommended. Specially designed unions are manufactured which are flameproof and are designed to connect two conduits together or for securing conduit to an internally threaded entry.

Conduits of 20 and 25 mm can enter directly into a flameproof enclosure. Where exposed terminals are fitted, conduits above 25 mm must be sealed at the point of entry with compound. Where a conduit installation is subject to condensation, say, where it passes from an atmosphere containing one type of vapour to another, the system must be sectionalised to prevent the propagation of either condensated moisture or gas. Conduit stopper boxes, with two, three or four entries, must be used. They have a splayed, plugged filling spout in the cover so that the interior can be completely filled with compound.

When flexible, metal-sheathed or armoured cables are installed, certified cable glands must be used. Where paper-insulated cables are used, or in a situation where sealing is necessary, a cable-sealing box must be used, which has to be filled completely with compound.

The following are among the important installation points to be observed when installing flameproof systems and equipment. Flanges should be greased to prevent rusting. Special care is needed with aluminium-alloy flanges as the metal is ductile and is easily bent out of shape. All external bolts are made from special steel and have shrouded heads to prevent unauthorised interference; bolts of another type should not be fined as replacements. Though toughened glass is comparatively strong, it will not stand up to very rough treatment; a faulty glass will disintegrate easily when broken. Protective guards must always be in place. Conduit joints should always be painted over with a suitable paint to prevent rusting. Because earthing is of prime importance in a flameproof installation, it is essential to ensure that the resistance of the joints in a conduit installation, or in cable sheaths, is such as to prevent heating or a rise in voltage from the passage of a fault-current. Remember that standard flameproof gear is not necessarily weather proof, and should be shielded in some way from rain or other excessive moisture.

Being essentially a closed installation, a flameproof conduit system may suffer from condensation. Stopper boxes prevent the passage of moisture from one section to another. Draining of condensate from an installation should be carried out only by an authorised person. Alterations or modifications must never be made to certified flameproof gear. Because flexible metallic tubing is not recognised as flameproof, cables to movable motors (e.g. on slide-rails) should be of the armoured flexible cable type, with suitable cable-sealing boxes fitted at both ends. It is necessary to ensure that, as far as possible, contact between flameproof apparatus, conduit, or cables, and pipework carrying inflammable liquids should be avoided. If separation is not possible, the two should be effectively bonded together. When maintaining equipment in hazardous areas, care should be taken to ensure that circuits are dead before removing covers to gain access to terminals. Because flexible cables are a potential source of danger, they should he inspected frequently. All the equipment should be inspected and examined for mechanical faults, cracked glasses, deterioration of well-glass cement, slackened conduit joints and corrosion. Electrical tests should be carried out at regular intervals.

Corrosion

Wherever metal is used, there is often the attendant problem of corrosion and its prevention. There are two necessary conditions for corrosion:

(a) A susceptible metal and (b) a corrosive environment. Nearly all of the common metals corrode under most natural conditions. Little or no specific approach was made to the study of corrosion until the early years of the nineteenth century. Then it was discovered that corrosion was a natural electrochemical process or reaction by which a metal reverts in the presence of moisture to a more stable form usually of the type in which it is found in nature. It was Humphry Davy who suggested that protection against corrosion could result if the electrical condition of a metal and its surroundings were changed.

Corrosion is normally caused by the flow of direct electrical currents, which may be self-generated or imposed from an external source (e.g. an earth-leakage fault-current). Where direct current flows from a buried or submerged metal structure into the surrounding electrolyte (the sea or soil), no corrosion takes place. It is an interesting fact to record that where a pipe is buried in the soil there is a 'natural' potential of from -0.3V to -0.6 V between the pipe and the soil. In electrical installations, precautions against the occurrence of corrosion include:

a) The prevention of contact between two dissimilar metals (e.g. copper and aluminium).

b) The prohibition of soldering fluxes, which remain acidic or Corrosive at the completion of a soldering operation (e.g. cable joint).

c) The protection of cables, wiring systems and equipment against the corrosive action of water, oil and dampness, unless they are suitably designed to withstand these conditions.

d) The protection of metal sheaths of cables and metal conduit finings where they come into contact with lime, cement and plaster and certain hard woods (e.g. oak and beech).

e) The use of bituminised paints and PVC oversheathing on metallic surfaces liable to corrosion in service.

Dampness can affect conduit Systems both on the inside and externally. With enamel finishes, it is important that the enamel is preserved as intact as possible, particularly at the thread entry to fittings. Also, the breaking of the galvanising finishing on galvanised conduit presents a great risk of rusting simply because this type of conduit was specified to cope with damp or wet working conditions. Thus any breaks in the finish must be repaired with the use of a suitable paint to prevent rusting

Internal corrosion can occur in situations where the ambient temperature tends to fluctuate. Condensation thus occurs, even in what would otherwise be dry situations, and if the resulting condensate is not allowed to drain away out of the conduit run a build-up can occur. To deal with this problem, the drainage points are recommended in the form of conduit boxes either with holes drilled to allow condensate to drip out or else, say, using a tee box with the T-outlet plugged with a plug which can be removed at intervals.

Special care is needed in the choice of materials for clips and other fittings for bare aluminium-sheathed cables, and for aluminium conduit, because aluminium is not particularly stable in damp situations and especially when in contact with other metals. For instance, fixing an aluminium bulkhead luminaire with brass screws to an external wall can set up an electrolytic action between the fitting and the screws. Chromium-plated screws would be better in this situation.

While copper is fairly resistant to corrosion, there are situations in which the material will corrode. This is why MI copper-sheathed cables are provided with PVC-sheaths and clips are also covered with PVC.

Under-voltage

This is an electrical protection required by Regulation 552-4, and is a provision in the circuit of an electric motor to prevent automatic restarting after a stoppage of the motor due either to an excessive drop in the supply voltage, or a complete failure of the supply, where unexpected restarting of the motor might cause injury to an operator. These devices are found in dc motor starters (No-volt releases). In ac contactor starters failure of the supply stops the motor.

Overcurrents

Overcurrent protection is one of the requirements of Statutory and the IEE Regulations. IEE Regulation 130-03-01 states: 'Where necessary to prevent danger, every installation and every circuit thereof shall be protected against overcurrent by devices which (i) will operate automatically at values of current which are suitably related to the safe current ratings of the circuit, and (ii) are of adequate breaking capacity and, where appropriate, making capacity.

Transient overcurrents are due mainly to motor-starting currents and the inrush currents associated with such apparatus as capacitors, transformers and fluorescent lamp and other discharge lighting circuits. Sustained overcurrents are the result of indiscriminate additions to an existing circuit. Generally termed 'overloading', the additions cause current to flow, which is in excess of the current rating of the cables. Some transient currents can become sustained. Accidental single-phasing on three-phase induction motors means the loss of one phase caused by a fuse blowing in one of the lines; faulty operation of a contactor; or an open-circuit in one of the motor windings. Contactor faults and fuse blowing are frequent. When single phasing occurs, the motor, in order to produce its designed performance characteristics, finds that it must draw more current from the supply. With normal motor designs, a 5 per cent imbalance in supply voltage can lead to a 15-20 per cent increase in the current in one phase on full load. This fault condition is very dangerous and can cause damage to the motor and inconvenience to the user (unless, of course, the motor circuit has been provided with adequate protection which disconnects it from the supply). The main problem associated with single-phasing is that because in practice the majority of small and medium-phasing induction motors operate on no more than 50-80 per cent full load, they will continue to run in a single-phased condition. Single-phasing stator damage is characterised by signs of uneven overheating. If an attempt is made to start the motor with a single-phase condition, damage will occur to the squirrel-cage rotor in the form of localized overheating caused by high induced rotor-bar currents in positions corresponding to the number of poles in the stator winding.

Short-circuit currents

A short-circuit occurs for any of the following reasons

1. Incorrect connection during the initial installation or after a modification.

2. Failure of the insulation of cables or equipment.

3. Excessive arcing leading to a phase-to-phase or phase-to-earth short.

4. Disconnection of a cable or wire leading to a phase-to-phase or phase-to-earth short.

The energy of the short-circuit, which can be taken as a link between points of differing potentials of negligible resistance or impedance, is fed from the point of supply, usually via the h.v. /l.v. transformer. This energy is dissipated in the complete distribution system as I^2R losses. The sub-division of this energy is in proportion to the resistance and reactance of the various items in the system or circuit, e.g., h.v. reactance, transformer reactance, and busbar and cable resistance and reactance. The value of the maximum short-circuit at any point in the installation can be calculated, provided the following data are known:

1. The high-voltage MVA rating.

2. The transformer rating and its percentage impedance.

3. The total resistance and reactance of the busbar and cables up to the point of the installation where the value of the theoretical fault current is required.

The items which have the greatest influence on the value of the fault are:

1. The percentage impedance and current rating of the transformer and the secondary circuit ohmic resistance.

2. The remaining items affect the fault current by usually less than 20 per cent. These can be taken into account or omitted at discretion.

For example, a 415 V, three-phase transformer of 750 kVA and a 4.75 per cent impedance (this value is standard for the majority of transformers conforming to the Electricity Boards' T.L. Specification) will have a full-load current of 1050 A at unity power factor. The 4.75 per cent impedance means that if the secondary terminals of the transformer were bolted together and the primary voltage was reduced to 4.75 per cent of its rated voltage, then the rated secondary full-load current of the transformer would flow in the short-circuited connection. Thus, when full voltage is applied, the short-circuit will be:

rated current x 100/4.75,

which in the above transformer will be

1050 x 21 = 22 kA (r.m.s.).

If a cable resistance of 0.01 ohm per phase is added, the fault current will be reduced to about -14 kA.

This value of the fault current is the symmetrical fault level in amperes (r.m.s.) and causes the thermal damage to equipment. The asymmetrical fault current depends on the inductance of the circuit and the point on the sine wave at which the fault occurs. This peak current, under the worst conditions can reach twice the symmetrical fault current peak value or 2 x 1.414 = 2.828 x r.m.s. symmetrical value. In the example given above the worst asymmetrical current would be 62 kA (peak).

The asymmetrical short-circuit current is responsible for the mechanical damage which results from the high oscillating mechanical forces (proportional to I^2) set up between two conductors which are adjacent and parallel to each other. For example, if the initial peak current on a 31 MVA system is about 110 kA, this would mean a force in kg per mm run of busbars, assuming a 76 mm spacing between conductors, of about 100 kgf, which is either repelling or attracting depending upon the direction of the currents at the instant of short circuit.

In summary, when a short-circuit fault occurs, for any given supply voltage, two main factors will be seen to control the severity of the fault. These are the magnitude and the power factor of the fault current. In this connection, two terms are worthy of note: prospective and actual values of fault current.

The 'prospective' level of fault current is the r.m.s. symmetrical current that would flow in a circuit due to the nominal applied voltage when a short-circuiting link of negligible impedance replaces the designed circuitry. In other words, it corresponds to a circuit condition of zero fault impedance. In a similar manner, the prospective value of power factor is assumed to obtain with zero fault-impedance.

The actual current, however, can never exceed the prospective value and usually it is considerably less. Almost any fault has some impedance, to which must be added the impedances and resistances, which exist in the circuit. These additional elements usually combine to limit the actual fault current to about 30 per cent or less the full prospective value; they also raise the actual short-circuit power factor to a value which approaches unity. The effect of a low power factor can be serious, because in such a circuit condition, there will be a considerable amount of stored energy to be dissipated during the time taken to clear the fault.

Protection by fuses

The fuse offers a means of protection against overcurrents. In its basic form, the first consists of a short length of suitable material, often in the form of a wire, which has a very small cross-sectional area compared with that of its associated circuit conductors. When a current flows which is greater than the current rating of the wire, the wire will get hot and, eventually, melt. This occurs because its resistance per 'unit length is much greater than that of its associated circuit conductors (so giving greater power loss and heat), and because this increased beat is concentrated in the smaller volume of the material.

Fuse terminology

The following terms are used in connection with fuses:

Current rating. This is a current, less than the minimum fusing current, stated by the manufacturer as the current that the first will carry continuously without deterioration. The current rating is chosen in consideration of the temperature rise while the fuse element carries the specified current. Because a fuse is a thermal device, the ambient temperature in which it operates is very important. Where fuses are used in high-temperature situations, a derating of the assigned current rating may be necessary for ambient temperatures of 35^0C and above.

Applied voltage. It is important that the applied voltage of a circuit does not exceed the voltage rating of any fuse used for its protection. This is because a fuse is particularly voltage-sensitive immediately before and after it operates to break the circuit current. The rated voltage is that assigned to the fuse by the manufacturer to indicate the nominal system voltage with which the fuse may normally be associated. It is important to note that the voltage rating of a fuse may not apply equally to both a.c. and d.c. circuits.

Breaking capacity rating. This is a prospective current stated by the manufacturer as the greatest prospective current that may be associated with the fuse under prescribed conditions of voltage and power factor or time constant. Fuses of different breaking-capacity ratings are available according to the several categories listed in British Standards. The category of duty assigned to a fuse should take into account the prospective current and the transient behavior of the circuit during short-circuit conditions (for instance, the degree of asymmetry in the a.c circuits).

Rated minimum fusing current. This is the current, which will cause the fuse to operate in a specified time under prescribed conditions.

Fusing factor. This is the ratio, greater than unity, of the rating minimum fusing current to the current rating.

A fuse, which carries its rated current, does not suffer any deterioration. However, if the current carried approaches the rated minimum fusing current, it will eventually reach a temperature at which its fuse element will begin to melt. A fuse is not intended to be run at currents between the values given for prolonged periods; if this does happen the characteristics of the fuse will change.

Let-through energy. This is the specific energy to which a protected circuit is subjected during the pre-arcing time.

Rewirable fuses

The rewirable fuse is a simple device. It consists of a short length of wire, generally of tinned copper. The current at which the wire will melt depends on the length of the wire and its cross-sectional area. If it is very short, the beat generated (I^2R watts) will be conducted away from the wire by the contacts or securing screws. Also, if the wire is open to the atmosphere, it will cool much more quickly than if it was surrounded by a thermal insulator such as an asbestos sleeve. In view of these and other factors, the rewirable fuse is a device with a number of variables, which affect its performance; any one, or all, of these can differ between similar fuses. Though the rewirable fuse is cheap, involving only the replacement of the fuse-element, it has a number of disadvantages and limitations:

1. The fuse element is always at a fairly high temperature when in use. This leads to oxidisation of the element material, which is a form of corrosion, and results in a reduction in the cross-sectional area of the element, so that it fuses at a current lower than its rating. Fuses, which carry their rated current for long periods generally, require replacement at two-yearly periods, otherwise nuisance blowing will be experienced on the circuit.

2. It is very easy for an inexperienced person to replace a blown fuse element with a wire of incorrect size or type.

3. When a fault occurs on a circuit, the time for the fuse to blow may be as long as several seconds, during which time considerable electrical and physical damage may occur to the circuit conductors and the equipment being protected.

4. The calibration of a rewirable fuse can never be accurate, which fact renders this type of fuse unsuitable for circuits, which require descriminative protection.

5. Lack of discrimination means that it is possible in certain circuit conditions for a 15 A-rated fuse-element to melt before a 10 A-rated element. Also, the type is not capable of discriminating between a transient high current (e.g., motor starting current) and a continuous fault current.

6. Owing to the fact that intense heat must be generated in the fuse-element before it can perform its protective action, there is an associated fire risk. Also in this context, should the fault current be particularly high, though the wire breaks, an arc may still be maintained by the circuit voltage and flow through the air and metallic vapour. The rewirable fuse has thus a low rupturing capacity, which is the product of the maximum current, which the fuse will interrupt, and the supply voltage. The capacity is measured in kVA. Generally a limit of 5000 kVA is placed on rewirable fuses.

Semi-enclosed or rewirable fuses are not regarded as devices, which will offer closely, controlled protection, particularly where important circuits are concerned. As seen from the above, they cannot be guaranteed as to their performance, which is why their use is penalised in the IEE Wiring Regulations.

Cartridge fuses

The cartridge fuse was developed to overcome the disadvantages of the rewirable type of fuse, particularly because with the increasing use of electricity, the energy flowing in circuits was growing larger. The main trouble with the rewirable fuse was oxidation and premature failure even when carrying normal load currents, causing interruptions in supply and loss of production in factories. Thus the fully enclosed or cartidge fuse came into existence. Non-deterioration of the fuse-element was, and stilt is, one of the most valuable features of this type of fuse. The advantage also of the cartidge fuse is that its rating is accurately known. However, it is also more expensive to replace than the rewirable type and it is also unsuitable for really high values of fault current.

It finds common application for domestic and small industrial loads. As house-service cutout fuselinks (BS 88), they are used by Supply Authorities as services fuses. Ferrule-cap fuselinks (BS 1361) are used in domestic 250 V consumer control units, switchfuses and switch splitters. The domestic cartidge fuselinks (BS 1361) were designed for use specifically in 13 A fused rectangular-pin plugs. Domestic cartidge fuselinks (BS 646) are for use specifically in 15 A, round-pin plugs where the load taken from a 15 A socket-outlet is small (e.g. radio, TV or table lamp), in relation to the 15 A fuse which protects the circuit at the distribution board. In addition, there are other cartridge fuses for particular applications (e.g. in fluorescent fittings). All these cartridge fuses are so designed that they cannot be interchanged except within their own group.

Essentially the cartridge fuse is a ceramic barrel containing the fuse element. The barrel is filled with a non-fusible sand, which helps to quench the resultant arc produced when the element melts.

The short-time characteristics of the HRC fuse enable it to take care of short-circuit conditions when used to protect motor circuits. Tests have shown that HRC fuses have a short-circuit fusing time as low as 0.0013 second. On large ratings they will open circuit in less than 0.02 second. HRC fuses are discriminating, which means that they are able to distinguish between a high starting current taken by a motor (which lasts only a matter of seconds) and a high fault or overload current (which lasts longer).

Selection of fuses

The selection of a particular fuse for circuit-protection duty should never be a casual matter.The important factors to be considered are:

1. The Voltage Rating of the fuse which should be not less than the highest voltage obtainable between the conductors of the circuit.

2. Ampere Rating of the fuse should be suitable for the circuit and the type of apparatus to be protected

3. The Service Conditions. These fall into two categories. First, the ambient temperature that will affect the operational characteristics of the fuse. In high ambient temperatures the current-ratings of fuses should be reduced to ensure that the total temperature does not exceed the permitted values calculated for materials and insulation. The total temperature varies with fuse size and application and it is thus advisable for

advice to be sought from manufacturers regarding the derating factors to be used. Secondly, an altitude of 1000 meters will result in the derating of a fuse.

Protection by circuit-breakers

There are few industrial power switching requirements which cannot be dealt with by standard circuit-breakers. And for the smaller-rated loads such as commercial and domestic installations, the moulded-case and miniature circuit-breakers are finding an increasing role to play for both the control and protection of circuits. Essentially, switchgear links the various elements of an electrical system together to provide normal operational facilities and permit the immediate disconnection of faulty apparatus and circuits. To do this it must be able to perform some or all of the following duties without damage to itself or other equipment and without danger to personnel:

1. Carry full-load currents continuously.

2. Withstand normal and possible abnormal system voltages.

3. Open and close the circuit on no-load.

4. Make and break on normal operating currents.

5. Make short-circuit currents.

6. Break short-circuit currents.

Of the different switching devices available, all must perform (1) and (2); the isolating switch is normally designed to perform (3) although certain types can perform (4); the circuit-breaker must perform (3), (4), (5) and (6).

The actual making or breaking of the circuit takes place at the contacts; these must be able to carry continuously the full-load current of the circuit without excessive temperature rise, i.e. they must have a very low contact resistance; they must also be able to pass, in a fraction of a second, from the state in which they carry a short-circuit current with a negligible volt drop to the state in which they can withstand full system voltage across them. This rapid change can only be effected as a result of the arc that takes place when current-carrying contacts are separated. The main problem in switch, circuit-breaker or fuse design is the proper control of this arc. But other important associated problems are the provision of adequate insulation, the countering of the high mechanical forces due to short-circuit currents, and the devising of suitable operating mechanisms for rapidly closing and opening the contacts. The most arduous duty is the interrupting of short-circuit currents.

In the medium voltage range (up to 660 V) oil-and air-break circuit-breakers are available. For applications at 3.3 kV, 6.6 kV and 11 kV, oil-break, air-break and (for some special applications at 11 kV) air-blast circuit-breakers are also available. The several factors which affect the selection of the right circuit-breaker for a particular application include: service voltage and load current; the type of duty; environment of the installation; ancillaries and other features required. BS 116 and BS 936 contain extensive appendices, which gives guidance on the selection of circuit-breakers. They also contain details of methods, which should be used to determine the symmetrical fault current; BS 116 also gives guidance on the calculation of asymmetrical fault current. BS 162 Electrical Power Switch gear and Associated Apparatus coordinates requirements of circuit-breakers and those of associated apparatus and provides information on general matters appertaining to switchgear.

Circuit-breakers must not he allowed to carry current in excess of their rated normal current as they normally have little, if any, overload capacity. An approximate assessment of symmetrical fault currents to be anticipated on systems supplied through transformers can be made by neglecting the impedance on the supply side of the transformers. The formula used is:

$$\text{Fault MVA} = \frac{\text{transformer rated kVA}}{\text{\% impedance of the transformer} \times 10}$$

Allowance has also to be made for the fault contribution of rotating machinery. It is desirable to take advantage of the reduction in fault current, which can occur on medium-voltage Systems due to the impedance of all connections.

Various types of operating mechanisms are used in circuit-breakers. Manual unassisted mechanisms are not recommended for use in 11 kV and 6.6 kV installations where the fault levels exceed 150 MVA. Where manual mechanisms are required, it is necessary to ensure that the design incorporates features such as instantaneous trip and trip-free features, which can add greatly to the safety with which circuit-breakers can cope with their fault-making duty. For a manual spring-operated arrangement, an operating handle is provided whereby a spring is charged and released in one stroke. A charged spring closes the circuit-breaker, the energy of the spring having been checked on short-circuit tests, thus ensuring safe closing of the circuit-breaker during fault conditions. The hand-charged spring arrangement is similar, except that the charging of the spring is carried out manually and the closing of the circuit-breaker is carried out by a separate action to release the charged spring. In the spring motor-wound arrangement, manual charging is dispensed with.

Amongst the service conditions which must be taken into account when considering the choice of suitable equipment are the temperatures and climatic circumstances under which it is intended to operate. For instance, when circuit-breakers are installed in places subject to abnormally low temperatures, a suitable low-freeze oil should be selected not only for the breaker itself but also for the overcurrent dashpots. To prevent the oil from freezing, heaters are sometimes built into the circuit-breaker tanks. Special low-temperature greases may be required to maintain the correct functioning of mechanical parts. On the other hand, where the maximum temperature exceeds 40^0C, or the average ambient over a 24-hour period exceeds 35^0C, derating of the standard circuit-breaker may be necessary.

Where excessive dust exists, as in steel millis, cement works and boiler houses, special precautions may be necessary and the breaker may be required to be enclosed in a recognised enclosure. In general, oil circuit-breakers, because they tend to be totally enclosed, are more tolerant of dusty and dirty locations than are their air-break counterparts. Application outdoors involves equipment specifically designed for outdoor use or, alternatively, the application of indoor equipment within weatherproof enclosures.

Moulded case circuit-breakers

The moulded case circuit-breaker is designed to provide circuit protection for medium-voltage distribution systems. It is defined as an air-break circuit-breaker, designed to have no provision for maintenance, having a supporting and enclosing housing of moulded insulating material forming an integral part of the unit. It is capable of making, carrying and breaking currents under specified abnormal circuit conditions such as those of short-circuit. The usual current ratings are from10-1200 A up to 600 V in single-, double-, or triple-pole units with a breaking capacity of up to 50kA (r.m.s.) at power factors of 0.25 to 0.4 .

The breakers were developed because of the advantages they had over ordinary switches and fuses in the control and protection of circuits and apparatus They have a repeatable non-destructive performance, safety in operation under fault conditions, and, in the case of the triple-pole circuit-breaker, simultaneous opening of all three phases, even under a single-phase fault to earth. All breakers have, as a standard feature, the ability to disconnect automatically under overload conditions, usually up to 8-10 times the rated current via bimetal overcurrent trips in each pole. An essential feature of all moulded-case circuit-breakers is the quick-make-and-break operation of the contacts, independent of operating personnel, and a high contact pressure; both these features are essential if high fault currents are to be switched safely.

The function of the breaker trip elements is to trip the operating mechanism in the event of a prolonged overload or short circuit. To accomplish this, a thermal-magnetic trip action is normally provided. The thermal trip action is achieved through the use of a bimetal heated by the load current. On a sustained overload, the bimetal will deflect, causing the operating mechanism to trip. Because bimetals are responsive to the heat generated by the current flow, they allow a long time delay on light overloads and have a faster response on heavier overloads. Magnetic trip action is achieved through the use of a simple electromagnet in series with the load current and thermal device. This provides instantaneous tripping when the current reaches too high a value for the thermal trip element to provide sufficiently rapid tripping.

Miniature circuit-breakers

These devices are in many ways similar to the moulded-case breakers. The dividing line between the two types of breaker is drawn on a basis of current rating and short-circuit capacity. The m.c.b. has found an increasing role for final circuit protection in domestic and commercial installations. It offers these circuits better protection, and a better fire risk protection, particularly when overload conditions are being considered, than the fuse alternative.

Discrimination

The term discrimination is applied to a circuit condition, under the circumstances of an excess-current flow, where, for example, one fuse blows before another. If the blown fuse is the 'minor' fuse in the circuit, then the other, the 'major' device has discriminated with the minor unit. In practice, if two fuses appear to have discriminated with each other, the criterion of discrimination is, however, not merely that one is open-circuited and the other is not. It is essential for the unblown fuse to continue to give satisfactory service after the fault has been removed and the minor fuse replaced.

Discrimination may be defined as 'the ability of fuses and circuit-breakers to interrupt the supply to a faulty circuit without interfering with the source of supply to the remaining healthy circuits in the system'. This requires that a larger fuse nearer to the source of supply will remain unaffected by fault currents, which would cause a smaller fuse, further from the source of supply, to operate.

In practice, fairly good discrimination, as required by Regulation 533-01-06 can be achieved between different fuse ratings when the prospective current of the circuit is small and the fuse operates in more than approximately 0.02 second. If, however, the prospective current is large, resulting in operating times of less than 0.1 second, discrimination will be more difficult and a ratio of not less than 2:1 between major and minor fuses may become necessary. Reference to standard time/current curves will enable a fairly close approximation of discrimination to be made for operating times of not less than 0.02 second.

In practice, too, it is often the case that a system of circuits contains protection offered by HRC fuses, semi-enclosed fuses, and circuit-breakers; circuits are also protected by one type only or two or more m combination. In these circumstances the advice of fuse manufacturers should be sought. Where circuit-breakers and HRC fuses are used, either as one means of protection or in combination, it is a relatively simple matter to choose ratings to achieve discrimination by referring to standard curves issued by the manufacturers.

Relays

The overcurrent protective relay has been a common means of protection against excess currents for large and small systems for many years and is now finding new applications. With the ever-growing size of electrical power systems and the increasing use of interconnection, it is often difficult to secure the really accurate and discriminative disconnection of the supply when circuit conditions become unhealthy. Relays are used in association with circuit-breakers which are tripped by a series-connected, direct acting, overcurrent trip oil. This device is electromagnetic in operation and consists of either an electromagnet and armature, or a solenoid with a central plunger. The coil of the electromagnet (or the solenoid) consists of a few turns of conductor connected in series with the main circuit. The armature (or plunger) is arranged to operate the circuit-breaker trip mechanism. The operating current of such a device is usually adjustable by means of variation of either the magnetic gap or a restraining spring.

Some items of electrical equipment, such as transformers, can carry an overload for a short time without damage; this time will decrease with heavier overloads. The overload trip coil, in consequence, is required to impose a time delay between the incidence of an overload and the tripping of the circuit-breaker, this time delay being arranged to decrease with increasing current, i.e., an inverse-time characteristic. One method of obtaining this characteristic is by means of an oil dashpot.

The disadvantage of the direct-acting overload trip-coil is that it has to carry the main circuit current and it must also be capable of carrying, without damage, short-circuit currents. Instead, the direct-acting overload device can be arranged to operate via a current-transformer. This method has advantages where it is necessary to insulate the trip device from the main circuit. In addition, since a current-transformer will saturate on heavy over-current, it is possible to obtain overload settings which are lower than those obtainable with a series connected coil; this is because the saturation of the current-transformer relieves the coil of the overload trip device from the stresses due to short-circuit currents. When current-transformer operation is used, it is possible to obtain a time lag on overloads by means of a time-limit fuse. This fuse is connected across the trip coil, and consequently the overload trip device is prevented from operating until the fuse melts due to a current in excess of its rating. The thermal characteristic of the fuse provides a satisfactory time lag for overload currents.

Perhaps the most familiar relay is the induction-type overcurrent relay It consists of an operating coil which is tapped, the tappings being brought out to a plug bridge; the tappings correspond to different current settings. A closed secondary winding is wound on upper and lower magnets. The fluxes produced by the primary (operating coil) and secondary windings are separated in phase and space and produce a torque, as in the shaded-pole induction disc motor. The disc experiences a torque, which depends on the current, and will move against a restraining spring provided the current, is large enough. The time of travel is adjustable by means of a stop, which adjusts the distance of disc travel to contacts connected to the trip coil of the associated circuit-breaker.

The thermal relay is suitable for the protection against serious overload of such items of equipment as motors and transformers. The relay has a relatively slow action, due to the thermal lag. But this can be an advantage where a time lag is needed in the circuit. The relay will therefore not operate on momentary overloads such as occur during motor starting. An advantage is that the overload is integrated over a period of time, since the heating action is continuous due to the fact that the relay does not reset immediately load is removed, but only recovers gradually as the bimetal cools down.

The thermal relay action is not suitable for coping with short-circuit currents, which must be interrupted as quickly as possible. Some types of relay incorporate an instantaneous high-set element which operates immediately a predetermined value of current is exceeded, as represented by short-circuit conditions.

The use of relays for the protection of motors is becoming common place. Overload protection is arranged to carry the starting current for the starting period without tripping. In the case of direct-on-line starting, the initial starting current may be as high as 8 x F.L., and the starting period as long as 25 seconds. Under these conditions the protection is usually by means of thermal relays. Instantaneous high-set over-current devices are recommended for short-circuit currents.

Protection for cables

Cables require protection against excess currents, from small overloads to the highest values of short-circuit currents. The introduction of plastics in recent years has resulted in cables insulated and sheathed with such materials being more sensitive to overcurrent conditions than rubber-compounds, paper and mineral insulation. The HRC fuse can provide short-circuit protection up to the highest values of fault currents and, in addition, limit the fault energy so as to keep the fault damage to a minimum.

The zone in which protection is probably most difficult to provide is at the low-overload/long-time region. Investigations have proved that PVC-insulated cables are able to withstand currents not exceeding 150 percent of their rating for 4 hours when installed in air. Most other forms of cable in common use have a higher withstand value than this; the implication in this is that an overcurrent protective device which will protect PVC and similar cables will, within reason, be satisfactory for other types.

Protection for apparatus

When a capacitor is switched into a circuit, a heavy inrush of current results and to ensure that fuses do not blow unnecessarily in these circumstances higher rated fuses are required in the circuit. In general, if the fuses fitted are rated at 125-150 per cent of the capacitor rating, nuisance blowing of the fuses will be avoided. Transformer and fluorescent lighting circuits may also require higher rated fuselinks to deal with the inrush currents associated with this class of gear. Fuselinks with a rating about 50 per cent greater than the normal current of the apparatus to be protected are usually found to be satisfactory

The use of semi-conductor devices for rectification and for system control purposes has increased rapidly in recent years, with specific problems in their protection. The result has been the introduction of specialised ranges of fuses. The semi-conductor device has a low thermal withstand compared with its rating and is, therefore, capable only of accepting a comparatively small input of fault energy. Protection must be capable of rapid operation and provide a high degree of energy limitation. The special HRC fuse is the only protective device at present capable of being matched to a semi-conductor. When such a fuse does blow, it is extremely important that it is replaced with a fuselink of exactly the same make and type. Published data are available which discuss the various types of basic circuitry at present in use.

3.3 Earthing

An efficient earthing arrangement is an essential part of every electrical installation and system to guard against the effects of leakage currents, shortcircuits, static charges and lightning discharges. The basic reason for earthing is to prevent or minimise the risk of shock to human beings and livestock, and to reduce the risk of fire hazard. The earthing arrangement provides a low-resistance discharge path for currents, which would otherwise prove injurious or fatal to any person touching the metalwork associated with the faulty circuit. The prevention of electric shock risk in installations is a matter, which has been given close attention in these past few years, particularly since the rapid increase in the use of electricity for an ever-widening range of applications.

Electric shock

An electric shock is dangerous only when the current through the body reaches a certain minimum value. The degree of danger is dependent not only on the current but also on the time for which it flows. A low current for a long time can easily prove just as dangerous as a high current for a relatively brief period. The applied voltage is in itself only important in producing this minimum current through the resistance of the body. In human beings, the resistance between hand and hand, or between hand and foot, can be as low as 500 ohms. If the body is immersed in a conducting liquid (e.g. as in a bath) the resistance may be as low as 200 ohms. In the case of a person with a body resistance of 500 ohms, with a 240 V supply the resulting current would be

480 mA, or 1.2 A in the more extreme case. However, much smaller currents are lethal, It has been estimated that about 3 mA is sufficient for a shock to be felt, with a tingling sensation. Between 10 mA and 15 mA, a tightening of the muscles is experienced and there is difficulty in releasing any object being gripped. Acute discomfort is felt at this current level. Between 25 mA and 30mA the dangerous level is reached, with the extension of muscular tightening, particularly to the thoracic muscles. An over 50 mA result in fibrillation of the heart which is generally lethal if immediate specialist attention is not given. Fibrillation of the heart is due to irregular contraction of the heart muscles.

The object of earthing, as understood by the IEE Regulations, is, so far as is possible, to reduce the amount of current available for passage through the human body in the event of the occurrence of an earth-leakage current in an installation.

It has been proved that more than 25 per cent of alt electrical deaths are the result of a failure or lack of earthing.

Lightning protection

Lightning discharges can generate large amounts of heat and release considerable mechanical forces, both due to the large currents involved. The recommendations for the protection of structures against lightning are contained in BS Code of Practice 6651 (Protection of Structures Against Lightning). The object of such a protective system is to lead away the very high transient values of voltage and current into the earth where they are safely dissipated. Thus a protective system, to be effective, should be solid and permanent. Two main factors are considered in determining whether a structure should be given protection against lightning discharges:

1. Whether it is located in an area where lightning is prevalent and whether, because of its height and/or its exposed position, it is most likely to be struck.

2. Whether it is one to which damage is likely to be serious by virtue of its use, contents, importance or interest (e.g. expolsives factory, church monument, railway station, spire, radio mast, wire fence, etc.).

It is explained in BS Code of Practice 6651 that the 'zone of protection' of a single vertical conductor fixed to a structure is considered to be a cone with an apex at the highest point of the conductor and a base of radius equal to the height. This means that a conductor 30 meters high will protect that part of the structure which comes within a cone extending to 60 meters in diameter at ground level Care is therefore necessary in ensuring that the whole of a structure or building falls within the protective zone; if it does not, two down conductors must be run to provide two protective zones within which the whole structure is contained. All metallic objects and projections, such as metallic vent pipes and guttering, should be bonded to form part of the air-termination network. All down conductors should be cross-bonded.

The use of multiple electrodes is common. Rule 5 of the Phoenix Fire Office Rules states:

Earth connections and number. The earth connection should be made either by means of a copper plate buried in damp earth, or by means of the tubular earth system, or by connection to the water mains (not nowadays recommended). The number of connections should be in proportion to the ground area of the building, and there are few structures where less than two are necessary ... Church spires, high towers, factory chimneys having two down conductors should have two earths which may be interconnected.

All the component parts of a lightning-protective system should be either castings of leaded gunmetal, copper, naval brass or wrought phosphor bronze, or sheet copper or phosphor bronze. Steel, suitably protected from corrosion, may be used in special cases where tensile or compressive strength is needed.

Air terminations constitute that part of dice system which distributes discharges into, or collects discharges from, the atmosphere. Roof conductors are generally of soft annealed copper strip and interconnect the various air terminations. Down conductors, between earth and the air terminations, are also of soft-annealed copper strip. Test points are joints in down conductors, bonds, earth leads, which allow resistance tests to be made. The earth terminations are those parts of the system designed to collect discharges from, or distribute charges into, the general mass of earth. Down conductors are secured to the face of the structure by 'holdfasts' made from gunmetal The 'building-in' type is used for new structures; a caulking type is used for existing structures.

With a lightning protection system, the resistance to earth need not be less than 10 ohms. But in the case of important buildings, seven ohms is the maximum resistance. Because the effectiveness of a lightning conductor is dependent on its connection with moist earth, a poor earth connection may render the whole system useless The 'Hedges' patent tubular earth provides a permanent and efficient earth connection, which is inexpensive, simple in construction and easy to install. These earths, when driven firmly into the soil, do not lose their efficiency by changes in the soil due to drainage; they have a constant resistance by reason of their being kept in contact with moist soil by watering arrangements provided at ground level. In addition, tubular or rod earths are easier to install than plate earths, because the latter require excavation.

Lightning conductors should have as few joints as possible. If these are necessary, other than at the testing-clamp or the earth-electrode clamping points, flat tape should be tinned, soldered and riveted; rod should be screw-jointed.

All lightning protective systems should he examined and tested by a competent engineer after completion, alteration and extension. A routine inspection and test should be made once a year and any defects remedied. In the case of a structure containing explosives or other inflammable materials, the inspection and test should be made every six months. The tests should include the resistance to earth and earth continuity. The methods of testing are similar to those described in the IEE Regulations, though tests for earth-resistance of earth electrodes require definite distances to be observed.

Anti-static earthing

'Static', which is a shortened term for 'static electric discharge' has been the subject of increasing concern in recent years partly due to the increasing use of highly insulating materials (various plastics and textile fibres).

Earthing practice

1. Direct Earthing

The term 'direct earthing' means connection to an earth electrode, of some recognised type, and reliance on the effectiveness of overcurrent protective devices for protection against shock and fire hazards in the event of an earth fault. If non-current-carrying metalwork is protected by direct earthing, under fault conditions a potential difference will exist between the metalwork and the general mass of earth to which the earth electrode is connected. This potential will persist until the protective device comes into operation. The value of this potential difference depends on the line voltage, the substation or supply transformer earth resistance, the line resistance, the fault resistance and finally, the earth resistance at the installation. Direct earth connections are made with electrodes in the soil at the consumer's premises. A further method of effecting connection to earth is that which makes use of the metallic sheaths of underground cables. But such sheaths are more generally used to provide a direct metallic connection for the return of earth-fault current to the neutral of the supply system rather than as a means of direct connection to earth.

The earth electrode, the means by which a connection with the general mass of earth is made, can take a number of forms, and can appear either as a single connection or as a network of multiple electrodes. Each type of electrode has its own advantages and disadvantages.

The design of an earth electrode system takes into consideration its resistance to ensure that this is of such a value that sufficient current will pass to earth to operate the protective system. It must also be designed to accommodate thermally the maximum fault current during the time it takes for the protective device to clear the fault. In designing for a specific ohmic resistance, the resistivity of the soil is perhaps the most important factor, although it is a variable one.

The current rating or fault-current capacity of earth electrodes must be adequate for the 'fault-current/time-delay' characteristic of the system under the worst possible conditions. Undue heating of the electrode, which would dry out the adjacent soil and increase the earth resistance, must be avoided. Calculated short-time ratings for earth electrodes of various types are available from electrode manufacturers. These ratings are based on the short-time current rating of the associated protective devices and a maximum temperature, which will not cause damage to the earth connections or to the equipment with which they may be in contact.

In general soils have a negative temperature coefficient of resistance. Sustained current loadings result in an initial decrease in electrode resistance and a consequent rise in the earth-fault current for a given applied voltage. However, as the moisture in the soil is driven away from the soil/electrode interface, the resistance rises rapidly and will ultimately approach infinity if the temperature rise is sufficient. This occurs in the region of 100^0C and results in the complete failure of the electrode.

The current density of the electrode is found by:

$$\text{Current density} = \frac{I}{A} = \frac{92 \times 10^3}{\sqrt{t}}$$

where I = short-circuit fault current; A = area (in cm^2); t = time in seconds (duration of the fault current).

The formula assumes a temperature rise of 120^0C, over an ambient temperature of 25^0C, and the use of high-conductivity copper. The formula does not allow for any dissipation of heat into the ground or into the air.

Under fault conditions, the earth electrode is raised to a potential with respect to the earth surrounding it. This can be calculated from the prospective fault current and the earth resistance of the electrode. It results in the existence of voltages in soil around the electrode, which may harm telephone and pilot cables (whose cores are substantially at earth potential) owing to the voltage to which the sheaths of such cables are raised. The voltage gradient at the surface of the ground may also constitute a danger to life, especially where cattle and livestock are concerned. In rural areas, for instance, it is not uncommon for the earth-path resistance to be such that faults are not cleared within a short period of time and animals which congregate near the areas in which current carrying electrodes are installed are liable to receive fatal shocks. The same trouble occurs on farms where earth electrodes are sometimes used for individual appliances. The maximum voltage gradient over a span of 2 meters to a 25 mm diameter pipe electrode is reduced from 85 per cent of the total electrode potential when the top of the electrode is at ground level to 20 per cent and 5 per cent when the electrode is buried at 30 cm and 100 cm respectively. Thus, in areas where livestock are allowed to roam it is recommended that electrodes be buried with their tops well below the surface of the soil.

Corrosion of electrodes due to oxidation and direct chemical attack is sometimes a problem to be considered. Bare copper acquires a protective oxide film under normal atmospheric conditions which does not result in any progressive wasting away of the metal. It does, however, tend to increase the resistance of joints at contact surfaces. It is thus important to ensure that all contact surfaces in copper work, such as at test links, be carefully prepared so that good electrical connections are made. Test links should be bolted up tightly. Electrodes should not be installed in ground, which is contaminated by corrosive chemicals. If copper conductors must be run in an atmosphere containing hydrogen sulphide, or laid in ground liable to contamination by corrosive chemicals, they should be protected by a covering of PVC adhesive tape or a wrapping of some other suitable material, up to the point of connection with the earth electrode. Electrolytic corrosion will occur in addition to the other forms of attack if dissimilar metals are in contact and exposed to the action of moisture. Bolts and rivets used for making connections in copper work should be of either brass or copper. Uninsulated copper should not be run in direct contact with ferrous metals. Contact between bare copper and the lead sheath or armouring of cables should be avoided, especially underground. If it is impossible to avoid the connection of dissimilar metals, these should be protected by painting with a moisture-resisting bituminous paint or compound, or by wrapping with PVC tape, to exclude all moisture.

The following are the types of electrodes used to make contact with the general mass of earth:

a) Plates. These are generally made from copper, zinc, steel or cast iron, and may be solid or the lattice type. Because of their mass, they tend to be costly. With the steel or cast-iron types care must he taken to ensure that the termination of the earthing lead to the plate is water-proofed to prevent cathodic action taking place at the joint, If this happens, the conductor will eventually become detached from the plate and render the electrode practically useless. Plates are usually installed on edge in a hole in the ground about 2-3 meters deep, which is subsequently refilled with soil. Because one plate electrode is seldom sufficient to obtain a low-resistance earth connection, the cost of excavation associated with this type of electrode can be considerable. In addition, due to the plates being installed relatively near the surface of the ground, the resistance value is liable to flucuate throughout the year due to the seasonal changes in the water content of the soil. To increase the area of contact between the plate and the surrounding ground, a layer of charcoal can be interposed. Coke, which is sometimes used as an alternative to charcoal, often has a high sulphur content, which can lead to serious corrosion and even complete destruction of the copper. The use of hygroscopic salts such as calcium chloride to keep the soil in a moist condition around the electrode can also lead to corrosion.

b) Rods. In general rod electrodes have many advantages over other types of electrode in that they are less costly to install. They do not require much space, are convenient to test and do not create large voltage gradients because the earth-fault current is dissipated vertically. Deeply installed electrodes are not subject to seasonal resistance changes. There are several types of rod electrodes. The solid copper rod gives excellent conductivity and is highly resistant to corrosion. But it tends to be expensive and, being relatively soft, is not ideally suited for driving deep into heavy soils because it is likely to bend if it comes up against a large rock. Rods made from galvanised steel are inexpensive and remain rigid when being installed. However, the life of galvanised steel in acidic soils is short. Another disadvantage is that the copper earthing lead connection to the rod must be protected to prevent the ingress of moisture. Because the conductivity of steel is much less than that of copper, difficulties may arise, particularly under heavy fault current conditions when the temperature of the electrode wilt rise and therefore its inherent resistance. This will tend to dry out the surrounding soil, increasing its resistivity value and resulting in a general increase in the earth resistance of the electrode. In fact, in very severe fault conditions, the resistance of the rod may rise so rapidly and to such an extent that protective equipment may fail to operate.

The bimetallic rod has a steel core and a copper exterior and offers the best alternative to either the copper or steel rod. The steel core gives the necessary rigidity while the copper exterior offers good conductivity and resistance to corrosion. In the extensible type of steel-cored rod, and rods made from bard-drawn copper, steel driving caps are used to avoid splaying the rod end as it is being driven into the soil. The first rod is also provided with a pointed steel tip. The extensible rods are fitted with bronze screwed couplings. Rods should be installed by means of a power driven hammer fitted with a special head. Although rods should be driven vertically into the ground, an angle not exceeding 60° to the vertical is recommended in order to avoid rock or other buried obstruction.

c) Strip. Copper strip is used where the soil is shallow and overlies rock. It should be buried in a trench to a depth of not less than 50 cm and should not be used where there is a possibility of the ground being disturbed (e.g. on farmland). The strip electrode is most effective if buried in ditches under hedgerows where the bacteriological action arising from the decay of vegetation maintains a low soil resistivity.

d) Earths mat. These consist of copper wire buried in trenches up to one meter deep. The mat can be laid out either linearly or in 'star' form and terminated at the down lead from the transformer or other items of equipment to be earthed. The total length of conductor used can often exceed 100 meters. The cost of trenching alone can be expensive. Often scrap overhead line conductor was used but because of the increasing amount of aluminium now being used, scrap copper conductor is scarce. The most common areas where this system is still used are where rock is present near the surface of the soil, making deep excavation impracticable. As with plate electrodes, this method of earthing is subject to seasonal changes in resistance. Also, there is the danger of voltage gradients being created by earth faults along the lengths of buried conductor, causing a risk to livestock.

e) Cable sheaths. These form a metallic return path and are provided by the supply undertaking. They are particularly useful where an extensive underground cable system is available; the combination of sheath and armouring forms a most effective earth electrode. In most cases the resistance to earth of such a system is less than one ohm. Cable sheaths are, however, more used to provide a direct metallic connection for the return of fault current to the neutral of a supply system rather than as a means of direct connection with earth; this, even though such cables are served with the gradual deterioration of the final jute or hessian serving.

In rural areas with overhead distribution, there is a problem, for any direct metallic return path must consist of an additional conductor. This, when provided, is known as a continuous earth wire. The disadvantage, apart from the cost of the extra conductor and its installation, is that an open-circuited earth wire could remain undetected for a long time. The earth wire is connected at the source of supply to the neutral and to the low-voltage distribution earth electrode.

2. Protective multiple earthing

This form of earthing is popularly known by the abbreviation PME. It is an extremely reliable system and is being used increasingly in this country. Basically the system uses the neutral of the incoming supply as the earth point. In this way all circuit protective conductors connect all the protected metalwork in an installation to this common point: the main earthing terminal. All line-to-earth faults are convened to line-to-neutral faults, the intention being to ensure that sufficient current flows under the fault conditions to bring overcurrent protective devices into operation.

There are two main hazards associated with PME. The first is that owing to the increased earth-fault currents, which are encouraged to flow, there is an enhanced fire risk during the time it takes for the protective device to operate. Also, with this method of earthing it is essential to ensure that the neutral conductor cannot rise to a dangerous potential relative to earth. This is because the interconnection of neutral and protected metalwork would automatically extend the resultant shock risk to all the protected metalwork on every installation connected to this particular supply distribution network. As a result of these hazards, stringent requirements are laid down to cover the use of PME on any particular distribution system. In accordance with the new system of earthing arrangements identified by the IEE Regulations, PME is officially known as TN-C-S. Three points of interest might be mentioned here. First, the neutral conductor must be earthed at a number of points on the system, and the maximum resistance from neutral to earth must not exceed 10 ohms. In addition, an earth electrode at each consumer's installation is recommended, Secondly, so far as the consumer is concerned, there must be no fusible cutout, single-pole switch, removable link or automatic circuit- breaker in any neutral conductor in the installation. Thirdly, the neutral conductor at any point must be made of the same material and be at least of equal cross-sectional area as the phase conductor at that point.

PME can he applied to a consumer's installation only if the supply authority's feeder is multiple earthed. This restricts PME to new distribution networks, though conversions from old systems can be made at a certain cost, which varies according to the type of consumer. The supply authority has to obtain permission in accordance with the provisions laid down by the Minister of Energy and Secretary of State for Scotland British Telecom approval must also be obtained for each and every PME installation, and is required since it was once thought that the flow of currents from PME neutrals to the general mass of earth could cause interference with and/or corrosion of their equipment. In practice, however, no such problems have occurred although the board still retains its right to approve or otherwise a proposed PME installation.

Should a break occur in a neutral conductor of a PME system, the conductor will become live with respect to earth on both sides of the break, the actual voltage distribution depending on the relative values of the load and the earth electrode resistances of the two sections of the neutral distributor. All earthed metalwork on every installation supplied from this particular distribution system would become live. High-resistance joints on the neutral can also have a similar effect, the degree of danger in all cases being goverened by the values of the connected load and the various earth electrode resistances. Trouble on a neutral conductor may go undetected for some considerable time, some of the only symptoms being reduced voltages on appliances, lights, etc., and slight to severe shocks from earthed metalwork. Overhead-line distribution systems are, of course, particularly prone so far as broken or discontinuous neutral conductors are concerned.

The aspect of earthed concentric wiring is important in the context of PME. For PME systems, the conventional four-core (three phases and neutral) armoured cable can be replaced by a three-core metallic sheathed and armoured cable where the sheath and armour are used for the earthed neutral. For consumer wiring, the sheath-return concentric cable, in which the sheath acts as both the neutral and earth conductor, is a logical extension of the PME principle and is covered by IEE Regulations Section 546. The main advantage of sheath-return wiring is that a separate CPC is not required. This is because the chances of a complete disconnection of the earth neutral conductor without breaking the included phase conductors is remote.

Sheath return usually means that mineral-insulated cable is used. While the cost of MI cable is slightly higher than other types of cable (including any necessary conduit) this is offset considerably by the saving in labour resulting from ease of handling, the small diameter, and the reduced amount of chasing work required. Sheath-return wiring can result in savings in installed cost of about 30 per cent compared with a conventional direct-earthed system using plastic insulated cable in black-enameled screwed conduit.

For single-phase supplies, single-core MI sheath-return cables are used. Twin-core cables are used for two-way switching. Multi-core cables are used from multi-switch points and rising mains to junction boxes where a number of separate outlets are situated close together. Since the outer sheath of the MI cable is used for both neutral and earth connections, care has to be taken at terminations which are made with pot-type seals and glands into switchgear and terminal boxes at which sockets, ceiling roses, etc., are fined. Duplicate bonding is used to ensure that the contact remains good at all times. A special seal, with an earth-bonding lead, is used.

3. Circuit-protective conductors

The circuit-protective conductor (CPC) is defined as, 'a protective conductor connecting exposed conductive pans of equipment to the main earthing terminal' The IEE Regulations go into some considerable detail to identity the specific requirements which CPCs must satisfy, if they are to perform their function in the context of ensuring that should an earth fault occur, the resulting current is carried for the time it takes for the associated circuit overcurrent protective device to operate.

IEE Regulations Section 543, and specifically Regulation 543-02-02, indicate the following types of circuit protective conductor, which are generally recognised. All these types of conductor are regarded as being normally dormant (that is, they do not carry current) until a fault to earth occurs.

a) Conductor contained in a sheathed cable, known as a composite cable. In this cable, the sheath can be of metal, rubber, or PVC; the conductors are the circuit conductors and the CPC (e.g. 2.5 mm^2 twin with CPC). The conductor is either single-strand or multi-stranded, depending on the size of the circuit conductors. And it is uninsulated. If the sheath is of metal, the conductor is always single-stranded. Inspection of samples of cables will reveal that the cross-sectional area of CPCs in metal-sheathed cables is less than their counterparts in insulated-sheathed cables; this is because the metal sheath and conductor are in parallel and together constitute a conducting path of very low resistance.

Where these CPCs are made off at, say, a switch position or ceiling rose, they should be insulated with a green-coloured sleeve.

b) Conductor in a flexible cable or flexible cord. The requirement is that the CPC should have a cross-sectional area equal to that of the largest associated circuit conductor in the cable or cord. The colour of the CPC, which is insulated in this case, is green and yellow.

c) The separate CPC. The requirement in this case is that the CPC should have a cross-sectional area not less than the appropriate value. The minimum size is 2.5 mm^2, but in practice the size depends on the size of the associated circuit conductors. The reason for this is that if the circuit conductors are rated to carry I amperes, then the CPC should be able to carry a similar current, in the event of an earth fault, for sufficient time to allow a fuse to blow or a circuit-breaker to open. The resistance of a CPC of a material other than copper should not exceed that of the associated copper conductor. Additional requirements for the separate CPC are that it shall be insulated and coloured green.

d) Metal sheath of MICS CABLE. Where the sheath of MICS cable is used as a CPC, the effective cross-sectional area of the sheath should be not less than one-half of the largest current-carrying conductor, subject to a minimum of 2.5 mm^2 .This requirement is not applicable to MICS cables used in earthed concentric wiring systems.

e) Conduits, ducting, trunking. Wiring systems, which comprise metalwork, such as conduit, trunking, and ducting, are used as the CPC of an installation. The requirement here is that the resistance of the CPC should not he more than twice that of the largest current-carrying conductor of the circuit. All joints must be mechanically sound and be electrically continuous.

4. Additional Requirements

a) Extraneous Metalwork. The IEE Regulation recommend that extraneous fixed metalwork be bonded and earthed. This is particularly important where exposed metalwork of all apparatus, which is required by the Regulations to be earthed, might come into contact with extraneous fixed metalwork. Two solutions are offered: the bonding of such metalwork, or its segregation. The latter course is often very difficult to achieve and appreciable voltage differences may arise between points of contact. The extraneous fixed metalwork includes baths and exposed metal pipes, radiators, sinks and tanks, where there are no metal-to-metal joints of negligible resistance; structural steelwork; and the framework of mobile equipment on which electrical apparatus is mounted, such as cranes and lifts.

b) Bathrooms. Additional precautions are required to be taken to prevent risk of shock in bathrooms; these places are usually associated with dampness and condensation from steam. A bathroom is regarded as any room containing a fixed bath or shower. First, all parts of a lamp holder likely to be touched by a person replacing a lamp shall be constructed of, or shrouded in, insulating material and, for BC lamp holders, should be fined with a protective shield of insulating material. The Regulations strongly recommend that lighting fittings should be of a totally enclosed type. Switches or other means of control should be located so that they cannot be touched by a person using a fixed bath or shower. This means location of the control switch either outside the room itself, or be ceiling-mounted with an insulating cord for its operation. No stationary appliances are allowed in the room, unless the heating elements cannot he touched. There should be no provision for socket-outlets, except to supply an electric shaver from a unit complying with BS 3052.

c) Bell and similar circuits. Where a bell or similar circuit is energised from a public supply by means of a double-wound transformer, the secondary circuit, the core of the transformers, and the metal casing if any, should be connected to earth.

d)Portable appliances. To reduce the risk of electric shock when portable appliances are used, the appliance is often supplied with a reduced voltage. A double-wound transformer reduces the mains voltage to a suitable level. The secondary winding has one point earthed so that should a fault to earth occur on the appliance the shock received will be virtually harmless. Another method of protecting the user of a portable appliance from electric shock is to provide the appliance with automatic protection. In the event of an earth-fault the supply is automatically disconnected from the appliance.

Protective methods

Insulation. Measures to prevent dangerous voltages occurring on exposed metalwork of electrical equipment are divided into three classes: earthed equipment; protective insulation; extra-low voltage (less than 50 V to earth). The second class (protective insulation) is sub-divided into all-insulated equipment and double-insulated equipment. All-insulated equipment is recognised by the majority of Regulations and Specifications as an alternative to earthing. The principles of design of all-insulated equipment are simple and therefore difficult to abuse. It is the only protective measure that will meet all the requirements of safety. The advent in recent years of modern reinforced plastics has met all the practical requirements of strength, stability and incombustibility.

The Factories Act Memorandum on the Electricity Regulations, Regulation 21, covers the precautions to be taken either by earthing or other suitable means to prevent any metal other than a conductor from becoming electrically charged. The Memorandum recognises the possibility of providing apparatus with covers and handles of insulating material, which should also be incombustible and mechanically strong, as an alternative to earthing. The recent advances in plastics technology have made available reinforced incombustible plastics and polycarbonate material which will withstand mechanical damage better than many of the average metal enclosures supplied for equipment today.

A British Standards Memorandum sates.

If the outside of the protective case is made entirely of insulating material, to a satisfactory standard, no further protection is necessary.

In general, it is accepted, despite the IEE Regulations' emphasis on the earthing of metalwork, that insulation is a better and more effective method than earthing for medium voltage installations.

The insulation necessary for the proper functioning of electrical equipment and for basic protection against electric shock is known as 'functional' insulation. 'Protective' insulation is provided externally to the functional insulation. With 'double' insulation, accessible metal parts are separated from live pans by both functional and protective insulation. With 'all-insulated' equipment, all conductive pans are safely and permanently covered with a substantially continuous cover of insulating material. A good example of 'all-insulation' is a PVC-sheathed cable. The basic principles of all ‘totally-insulated’ equipment are that the protective insulation must not be penetrated by conducting parts, however small, which could assist a voltage path to the outside of the enclosure in the event of a fault. In addition, it must be impossible for inactive conductive parts inside the totally insulated component or enclosure to be connected to an earth conductor.

Double-insulated equipment is marked with the internationally recognised symbol for Class II equipment: two concentric squares. An additional label is also affixed, approved by the H.M. Senior Electrical Factory Inspector, to draw attention to the characteristics of the equipment. It states:

The metal mounting plate and other con current carrying metal parts are not connected to earth, and therefore earthing terminals are not provided.

Fuses are recognised by the 16th Edition of the IEE Wiring Regulations as having a pan to play in the disconnection of circuits on which an earth fault occurs. Of necessity, fault currents in excess of the fusing factors of the fuses are required before the device will operate and this requirement itself presents problems, not least the rise in voltage on protected metalwork, which occurs while the fuse operated. A number of Tables in the IEE Regulations are specifically concerned with the maximum values of earth fault loop impedance for circuits supplying (a) socket outlets and (b) fixed equipment. In each of these cases, the disconnection times are, respectively, 0.4 second and 5 seconds. Recognising that the fusing characteristics of different types of fuses vary, even among devices of the same rating, the Regulations offer detailed information regarding the maximum values of earth loop impedance which are not to be exceeded if the disconnection of the faulty circuit is to be achieved in less than the stated times for disconnection.

Fuses, however, do not provide a wholly satisfactory answer to the problem of increasing the safety factor in respect of electric shock from earth-leakage currents. For example, take a 40 A metal sub distribution hoard protected by 40 A HRC fuses with a fusing factor of 1.5. The metal case is caroled by a steel-wire4rnoured cable direct to the consumer's earthing lead. The earth loop test at 3 times the rated current of the circuit gives an impedance of 2 ohms and the circuit protective conductor is satisfactory at one ohm. If an earth-fault of negligible impedance occurs (at 240 V) then a current of 120 A flows. This current through the 1-ohm CPC impedance will raise the potential of the steel enclosure of the board to 120 V above the consumer's main earth potential for the time taken for the fuse to blow, about 20 seconds.

Any increase in the earth leakage impedance due to a partial earth fault or arcing will cause a lower current to flow for a longer time. If the total earth-loop impedance, including the impedance of the partial earth fault, is 3 ohms, the fault current will be 80 A. And the board metal enclosure will rise to 80 V above earth for more than four minutes while the fuse melts. During this time a person could receive a dangerous or fatal shock on touching the board metalwork.

Fuses do not provide sensitive protection, whether or not they are of the semi-enclosed type of cartridge fuses with fusing factors which exceed 1.5. The rapid cut-off of earth fault current, which is desirable for protection against serious electric shock, can be achieved only with earth-fault loops of much lower impedances now called for by the IEE

Regulations. Indeed, lower impedance values are advised for industrial premises, in which the maximum earth-fault loop impedance should be equal to:

$$\frac{\text{phase-to-neutral voltage}}{\text{minimum fusing current x 2}} \text{ ohms}$$

Fuses are insensitive devices because they must operate above the full-load current of the protected circuit, and also have an appreciable time lag even on higher currents.

Circuit-breakers. Over current circuit-breakers, like fuses, do not altogether provide a satisfactory protection against earth-leakage currents, The IEE Regulations, however, recognise that these protective devices offer some degree of protection; and in view of the low tripping factors of these devices they are in many ways better than fuses. It is generally accepted that protection can be provided by overcurrent circuit-breakers in situations where the level of earth fault current available to operate the device exceeds 1.5 times the tripping current of the device.

E.L.V supplies. Equipment in which extra-low voltage supplies are used have the disadvantage that, to achieve modern power requirements, impracticably high currents are involved and applications are restricted to control circuits, small portable tools, lighting circuits and the like. Virtually complete safety from shock to earth, however, can be provided by limiting the voltage to earth to a non-lethal value. A large number of supplies at 55 V or less to earth have been proved to be almost free from electrical accidents. E.L.V. systems should be used wherever practicable for socket outlets and in dangerous situations. The cost involved in purchasing low-voltage appliances, and the problems raised by increased loading, limit the use of E. L.V. voltages to a small proportion of the instances in which protection is required.

Earth-monitoring devices and portable equipment. For applications such as the protection of portable equipment where (due to the use of flexible or trailing leads) the reliability of the circuit protective conductor may by suspect, direct methods of protection are required. The use of E.L.V. supplies is not always practicable. If an earth fault occurs whilst an appliance is being handled, neither a fuse nor an overcurrent circuit-breaker may operate quickly enough to protect the user. If the actual fault current is only of the order of three times the fuse retiring (a good rule of thumb limit) the fuse can easily take a matter of ten seconds or so to blow - a time delay which may welt have fatal consequences. Again, if the circuit of an appliance becomes completely open-circuited, an earth fault on an appliance may leave its casing alive at a voltage to earth which is almost equal to the phase-to-neutral voltage of the supply. This condition is by no means uncommon with portable and transportable equipment where the earthing conductor of the flexible cable may break or come adrift from its terminal. Special risks arise when the appliance is held in the hand.

Earth-monitoring devices are designed to ensure that earth connections to particular pans of an installation exist during the time it is energised. A small current is made to flow round a circuit consisting of the earth and pilot conductors and the trip coil of a circuit-breaker. The trip is prevented from operating while the coil is energised. But as soon as the monitoring circuit is opened, the circuit-breaker is tripped. Earth monitoring requires an additional conductor and special socket-outlets; installation costs are thereby increased. The system is insensitive to appreciable impedances in the monitoring circuits and completely so to resistance or open-circuit in the earth path before the monitored circuit.

The use of the 'Butcher' system of protection for portable appliances involves a centre-tapped isolating transformer and a voltage operated earth-leakage circuit-breaker. Socket outlets are supplied at 240 V. The advantage of this method of protection is that if an earth fault occurs (even if it is only due to someone touching a live conductor) the earth-leakage current must return to the transformer via the trip coil of the circuit-breaker. Hence, provided that the operating current of the trip coil is below the lethal limit of body current, it is theoretically impossible to receive a lethal shock from any of the socket outlets supplied from the isolating transformer.

Earth-leakage circuit-breakers. Earth-leakage and earth-fault protection are systems of protection arranged to disconnect the supply automatically from an installation or circuit when the earth-leakage or earth-fault current exceed predetermined values. Similarly, protection is offered when the voltage between non-current-carrying metalwork of the installation and earth rises above a predetermined value. Such a system may be made to operate more rapidly and at lower values of leakage or fault current than one depending on overcurrent protective devices such as fuses, thermal trips etc. Automatic protection is therefore used where the impedance of the earth-fault loop limits the current flowing in it to a value less than three times the current rating of the fuse of 1.5 times the overcurrent setting of the circuit-breaker.

Earth-leakage or earth-fault protection is generally effected by means of a device known as an earth-leakage circuit-breaker (ELCB). There are two types; (i) the fault-voltage and (ii) the residual-current.

i) Fault-voltage operated ELCBs are units designed to be directly responsive to fault voltages appearing on protected metalwork. Their primary function is to give protection against earth-leakage shock risk. If the only connection to earth is through the ELCB, leakage currents of as low as 50 mA will produce immediate circuit isolation. The fault-voltage ELCB depends for its operation on a voltage which, existing between the apparatus to be protected and the general mass of earth, is itself dependent not only on the circuit-breaker, but also on earth-electrode resistance. Depending on design, the units trip at 24 V to earth with a 200-ohm earth electrode, or 40 V with a 500-ohm earth electrode. The ELCBs are instantaneous in operation. The normal operating time is less than one cycle.

The unit consists of an operating or trip coil, which is connected between a reference earth-electrode and the protected metalwork of the installation. Any fault current, which appears in the metalwork, will flow through the coil to energise it and trip the circuit-breaker to isolate the faulty circuit from the supply. In present-day practice, there are two conditions in which the fault-voltage ELCB may function:

1.The trip coil is connected between an earth-electrode and the metal to be protected, which are not otherwise connected with earth.

2.The trip coil is connected in earth-electrode with the metal to be protected, which is in addition unavoidably connected directly with earth, e.g. a metallic water-pipe system.

In making the earth connection, care is taken to ensure that the earth electrode of the ELCB is at least 2 meters away from any buried metalwork, or the consumer's earth electrode, if one is installed. As far as possible, the operating coil of the unit should carry any fault current, which occurs, and not by-pass it by means of another path. The effect of 'parallel' earth connection is to deprive the operating coil of the necessary current which is required to trip the circuit-breaker.

Units are generally provided with a test switch. The primary purpose of this switch is to prove the existence of an adequate earth path. Failure of the unit to trip indicates potentially dangerous conditions in the installation such as excessive earth-electrode resistance or a broken earth lead. The test switch also checks that the sensitivity of the tripping mechanism is correct. The switch, generally a push-button, connects a high-ohmic value resistance in series with the live conductor and the operating coil to allow sufficient current to flow to operate the circuit-breaker.

The fault-voltage ELCB is susceptible to nuisance tripping, because it is not selective in operation and will trip out if the installation metalwork becomes live, irrespective of the source of the leakage current. This gives rise to several problems. It is virtually impossible to sub-divide large installations, because of the difficulty in isolating sections of installation metalwork associated with individual earth-leakage circuit-breakers. This difficulty applies with equal force to the parallel condition of a number of installations in the same building, such as is encountered with flats. Even when the dwellings are quite separate, trouble has been encountered with a common water pipe transmitting faults from one house to another.

This particular disadvantage may lead to another difficulty if the installation on which a fault occurs does not have adequate earth-fault protection. The leakage current from the first dwelling may then flow to earth through the trip coil of the fault-voltage ELCB in the second earth through the trip coil of the fault-voltage ELCB in the second dwelling. One effect of this fault condition is a bum-out of the trip coil.

The protection offered by the fault-voltage ELCB is ideally suited to the small country-cottage installation: relatively remote from other dwellings, with poor earthing facilities and without a piped water supply. The most awkward problem associated with these units is finding a suitable location for the reference earth electrode. It must be located outside the resistance area of any metallic pipes or gas pipes or any other metalwork associated with the installation. This problem has recently become particularly acute in recent years with the cross bonding of water pipes to the electrical earth-continuity system, which automatically results from the installation of immersion heaters in household hot-water tanks.

ii)A residual-current ELCE is a device consisting of a transformer having opposed windings, which carry the incoming and outgoing current of the load. In a healthy circuit, where the values of current in the windings are equal, their magnetic effects cancel out in the transformer core. A fault causes an out-of-balance circuit condition and creates an effective magnetic flux in the core which links with the turns of a secondary winding and induces an emf in it. The secondary winding is permanently connected to the trip coil of the circuit breaker. When the circulating current reaches a pre-determined value, it pulls out the release latch to open the main contacts which are normally held closed against strong springs.

In contrast to the fault-voltage ELCB, this type can he used to provide discriminative protection for individual circuits. In practice, the normal order of sensitivity ranges from about one ampere out-of-balance, for a 15 A unit, up to about 3 A out-of-balance for a 60 A unit.

These units are also known as 'low-sensitivity units' to distinguish them from the 'high-sensitivity units'. The latter units operate within 1/25 of a heart cycle and can detect a fault current of 30 mA to earth or less. The operating time is in the region of 30 milliseconds. Certain units are available which do not require an earth connection; they rely for their operation on the actual fault current to earth through a person's body. The rapid time of operation, however, ensures that no electrical accident occurs.

One fault found with these high-sensitivity units is that they are also susceptible to what is called nuisance tripping. This occurs because the units can detect very low currents of the order of 25-30 mA, which are often found as normal leakage current from, say, cooker boiling plates and immersion elements.

Regulation 413-02-16 indicates that a residual current device shall be used only where the product of its operating current in amperes and the earth-loop impedance in ohms does not exceed 50. Where such a unit is used, the consumer's earthing terminal shall be connected to a suitable earth electrode. It is recommended that the operating current of a residual-current device should not exceed 2 per cent of the normal rates current of the circuit. Operating currents less than 500 mA is not regarded as necessary unless the value of earth-loop impedance is such that a lower operating current is essential.

However, residual-current devices of 30 mA sensitivity are coming into general use because of their reliability, the simplicity of their installation, and their low cost. They are generally recommended because they are considered effective in providing more positive protection. They are also suitable for earthing installations having loop impedances of 80 ohms or less, and are regarded as being effective in reducing fire risks.

Devices of below 500 mA sensitivity fail into two broad groups: those requiring electrical amplification, and those using a combination of permanent and electro-magnetic fields. The latter are independent of the electrical supply for their operation. The electrically amplified types have a wide range of loadings and interruption ratings. Primary windings are not necessary: the load cables are simply taken through an aperture in the core of the transformer. The magnetically assisted types depend on delicate tripping mechanisms and are therefore subject to the effects of vibration and shock. They require primary windings, which tends to limit their load capacity and makes them vulnerable to thermal and magnetic stresses when they are subjected to high fault currents. They are satisfactory where conditions are not unduly dangerous.

Response times of 30 to 50 ms are common to most sensitive relays and the maximum shock severity that can be experienced on metalwork protected by these units is well within the limits of safety prescribed by the International Labour Office (500 mA-sec at 50 mA, to 50 mA-sec at 600 mA).

High-sensitivity units are particularly recommended for protection in laundries, boiler-houses and for electrically heated food-trolleys as used in hospitals. They are also ideal for preventing the ignition of concentrations of explosive vapours by sparking along earth-fault paths and at the same time avoid the sudden interruption of the supply to an operating theatre while an operation is in progress. Circuits to operating theatres are fed from an isolating transformer with a 40-ohm resistor, having its mid-point earthed, connected across the output terminals. This limits the maximum earth-fault current and energy to small values. And the supply need not be interrupted until it can be manually discontinued, without danger or inconvenience to the patient and operating staff, to enable the fault to be removed. Healthy and dangerous conditions are indicated by the use of indicating lamps (coloured green and red respectively).

Earth testing

IEE Regulations requires that tests he made on every installation to ensure that the earthing arrangement provided for that installation is effective and offers the users of the installation a satisfactory degree of protection against earth-leakage currents. The following are the individual tests prescribed by the Regulations.

Circuit-protective conductors

Regulation 713-02-01 requires that every circuit-protective conductor (CPC) be tested to verify that it is electrically sound and correctly connected. The IEE Regulations Guidance Notes on inspection and testing give details on the recognised means used to test the CPC. For each final circuit, the CPC forms part of the earth-loop impedance path, its purpose being to connect all exposed conductive parts in the circuit to the main earth terminal. The CPC can take a number of forms. If metallic conduit or trunking is used, the usual figure for ohmic resistance of one meter length is 5 milliohms/m.

Generally if the total earth-loop impedance (Z_s) for a particular final circuit is within the maximum Z_s limits, the CPC is then regarded as being satisfactory. However, some testing specifications for large installations do require a separate test of each CPC to be carried out. The following descriptions of such tests refer to a.c. installations.

Reduced a.c. test. In certain circumstances, the testing equipment in the a.c. test described above is not always available and it is often necessary to use hand-testers, which deliver a low value of test current at the frequency of the mains supply. After allowing for the resistance of the test lead, a value for impedance of 0.5 ohm maximum should be obtained where the CPC, or part of it, is made from steel conduit. If the CPC is in whole or in part made of copper, copper-alloy or aluminium, the maximum value is one ohm.

Direct current. Where it is not convenient to use a.c. for the test, d.c. may be used instead. Before the d.c. is applied, an inspection must be made to ensure that no inductor is incorporated in the length of the CPC. Subject to the requirements of the total earth-loop impedance, the maximum values for impedance for the CPC should be 0.5 ohm (if of steel) or one ohm (if of copper, copper-alloy or aluminium).

The resistance of an earth-continuity conductor, which contains imperfect joints, varies with the test current. It is therefore recommended that a d.c. resistance test for quality be made, first at low current, secondly with high current, and finally with low current. The low-current tests should be made with an instrument delivering not more than 200 mA into one ohm; the high-current test should be made at 10 A or such higher current as is practicable. The open-circuit voltage of the test set should be less than 30 V. Any substantial variations in the readings (say 25 per cent) will indicate faulty joints in the conductor; these should be rectified. If the values obtained are within the variation limit, no further test of the CPC is necessary.

Residual current devices

IEE Regulation 713-12-01 requires that where an RCD provides protection against indirect contact, the unit must have its effectiveness tested by the simulation of a fault condition. This test is independent of the unit's own test facility. The latter is designed for use by the consumer who is advised to ensure that the RCD trips when a test current, provided by an internal resistor, is applied to the trip-coil of the unit. Thus, on pressing the 'Test' button the unit should trip immediately. If it does not it may indicate that a fault exists and the unit should not be used with its associated socket-outlet, particularly if the outlet is to be used for outdoor equipment.

The RCD has a normal tripping current of 30 mA and an operating time not exceeding 40 ms at a test current of 150 mA.

RCD testers are commercially available, which allow a range of tripping currents to be applied to the unit, from 10 mA upwards. In general the lower the tripping current the longer will be the time of disconnection.

It should be noted that a double pole RCD is required for caravans and caravan sites and for agricultural and horticultural installations where socket-outlets are designed for equipment to be used other than 'that essential to the welfare of livestock'.

Earth-electrode resistance area

The general mass of earth is used in electrical work to maintain the potential of any part of a system at a definite value with respect to earth (usually taken as zero volts). It also allows a current to flow in the event of a fault to earth, so that protective gear will operate to isolate the faulty circuit. One particular aspect of the earth electrode resistance area is that its resistance is by no means constant. It varies with the amount of moisture in the soil and is therefore subject to seasonal and other changes. As the general mass of earth forms part of the earth-fault loop path, it is essential at times to know its actual value of resistance, and particularly of that area within the vicinity of the earth electrode. The effective resistance area of an earth electrode extends for some distance around the actual electrode; but the surface voltage dies away very rapidly as the distance from the electrode increases . The basic method of measuring the earth-electrode resistance is to pass current into the soil via the electrode and to measure the voltage needed to produce this current.

The type of soil largely determines its resistivity. The ability of the soil to conduct currents is essentially electrolytic in nature, and is therefore affected by moisture in the soil and by the chemical compositon and concentration of salts dissolved in the contained water. Grain size and distribution, and closeness of packing are also contributory factors, since these control the manner in which moisture is held in the soil. Many of these factors vary locally. The following table shows some typical values of soil resistivity.

Table of soil-resistivity values

Type of soil	Approximate value in ohm-cm
Marshy ground	200 to 350
Loam and clay	400 to 15,000
Chalk	6000 to 40,000
Sand	9000 to 800,000
Peat	5000 to 50,000
Sandy gravel	5000 to 50,000
Rock	100,000 upwards

When the site of an earth electrode is to be considered, the following types of soil are recommended, in order of preference:

1. Wet marshy ground, which is not too well drained.

2. Clay, loamy soil, arable land, clayey soil, and clayey soil mixed with small quantities of sand.

3. Clay and loam mixed with varying proportions of sand, gravel, and stones.

4. Damp and wet sand, peat.

Dry sand, gravel, chalk, limestone, whinstone, granite and any very stony ground should be avoided, as should all locations where virgin rock is very close to the surface.

Chemical treatment of the soil is sometimes used to improve its conductivity Common salt is very suitable for this purpose. Calcium chloride, sodium carbonate and other substances are also beneficial, but before any chemical treatment is applied it should be verified that no corrosive actions would be set up, particularly on the earth electrode.

Either a hand-operated tester or a mains-energised double-wound transformer can be used, the latter requiring an ammeter and a high-resistance voltmeter. The former method gives a direct reading in ohms on the instrument scale; the latter method requires a calculation in the form:

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

The procedure is the same in each case. An auxiliary electrode is driven into the ground at a distance of about 30 meters away from the electrode under test (the consumer's electrode). A third electrode is driven midway between them. To ensure that the resistance area of the first two electrodes do not overlap, the third electrode is moved 6 meters farther from, and nearer to, the electrode under test. The three tests should give similar results, the average value being taken as the mean resistance of the earth electrode.

One disadvantage of using the simple method of earth electrode resistance measurement is that the effects of emfs (owing to electrolytic action in the soil) have to be taken into account when testing. Also, there is the possibility of stray earth currents being leakages from local distribution systems. Because of this it is usual to use a commercial instrument, the Megger earth tester being a typical example.

Earth-fault loop impedance

Regulation 113-11-01 stipulates that where earth-leakage relies on the operation of overcurrent devices, an earth-loop impedance test should be carried out to prove the effectiveness of the installation's earthing arrangement. Although the supply authority makes its own earth-loop impedance tests, the electrical contractor is still required to carry out his own tests. The tests carried out by a supply authority will not absolve the contractor from his legal responsibilities for the safe and effective operation of protection equipment which he may install as part of a wiring installation. This applies both to new installations and extensions to existing installations. Earth-loop impedance tests must be carried out on all extension work of major importance to ensure that the earth-continuity path right back to the consumer's earthing terminal is effective and will enable the protective equipment to operate under fault conditions.

Phase-earth loop test. This test closely simulates the condition which would arise should an earth- fault occurs. The instruments used for the test create an artificial fault to earth between the 'me and earth conductors, and the fault current, which is limited by a resistor or some other means, is allowed to flow for a very short period. During this time, there is a voltage drop across the limiting device, the magnitude of which depends on the value of the earth loop. The voltage drop is used to operate an instrument movement, with an associated scale calibrated in ohms. The contribution of the consumer's earhing conductor should be not more than one ohm. This is to ensure that the voltage drop across any two Points on the conductor is kept to a low value and, under fault conditions there will be no danger to any person touching it at the time of the test.

The testers, which are commercially available, include both digital readouts and analogue scales, and incorporate indications of the circuit condition (correct polarity and a proven earth connection). The readings are in ohms and represent the earth-loop impedance (Z_s). Once a reading is obtained, reference must be made to IEE Regulations Tables 41B1 to 41D, which give the maximum values of Z_s which refer to: (a) the type of overcurrent device used to protect the circuit and (b) the rating of the device. Reference should also be made to any previous test reading to see whether any increase in Z_s has occurred in the meantime. Any increase may indicate a deteriorating condition in the CPC or earthing lead and should be investigated immediately. The values of Z_s indicated in the Tables are maximum values which must not be exceeded if the relevant circuits are to be disconnected within the disconnection times stated.

Before a test is made, the instrument should be 'proved' by using a calibration unit, which will ensure that it reads correctly during the test. It is also recommended that the serial number and type or model used for the test should be recorded, so that future tests made by the same tester will produce readings which are correlated.

CHAPTER 4 : CIRCUIT CONTROL DEVICES

4.1 Circuit Conditions-Contacts

All electrical circuits are required to have some means whereby they can be energised and disconnected from their supply source. This is done by switches, of which there is a very wide variety of types available. A 'switch' is defined as a mechanical device capable of making, carrying and breaking current under normal circuit conditions, which may include specified overload conditions. Switches in domestic installations are familiar devices used to control the supply to lighting, cooker and water-heating circuits. Socket-outlets may have switches incorporated. In a consumer unit, the main switch isolates the whole installation from the supply.

Certain types of circuit controls do not qualify as switches. These include thermostats for water-heaters and heating equipment, and touch switches, or electronic switches. Some switches are used as isolators, which are designed to disconnect a circuit usually when the circuit has no current flowing in it.

Some switches are operated by an electromagnet; these include contactors used for switching heating loads, large lighting loads and are also incorporated in motor starters. A more specialised type of electromagnet-operated device is the relay.

Although circuit-breakers tend to be regarded as devices used for protection of circuits against overcurrent (overload and short-circuit), they also perform a duty as switches.

Circuit conditions

Every electrical circuit has its own characteristics, which means that it will show some peculiar electrical property depending on the type of load connected to it. For instance, a circuit which has a purely resistive load (a resistor used as a lamp filament, or heater element) will show a current, which rises when the circuit is first switched on and then falls as the element reaches its normal operating condition. This means that the switch or other circuit-control device must at least be able to break the full-load current taken by the resistor. This applies particularly if the circuit has a dc supply. If, however, the supply is ac, when the switch contacts separate there may be a small arc drawn out between the contacts. This characteristic is even more noticeable when the resistor is in the form of a coil (e.g. in a firebar element). This effect is caused by the electrical property, which a coil has in an ac circuit. It is called the 'inductive effect' .

If, instead of a resistive conductor wound in the form of a coil, a low-resistance conductor is wound round a soft-iron core, the item is then known as a 'choke' or inductor, and the circuit is said to have 'inductive characteristics', which lead to switching problems. A fluorescent circuit is an inductive circuit, as is a motor circuit.

If the circuit has a capacitor included in it, it will also show certain characteristics, which may be shown as arcing between switch contacts as they separate. The most pronounced effects of the inclusion of an inductor or a capacitor in a circuit is seen when an ac supply is used. However, small capacitors are often used connected across switch contacts to absorb the sparking caused by contact separation. Used in this way they are sometimes called 'radio-interference suppressors' (e.g. in fluorescent lamp switch starters)

Thus, before a circuit-control device is chosen the circuit to be controlled must be studied so that the device can handle, without damage to itself or the associated circuit wiring, the conditions in the circuit when it is connected or disconnected from its supply. The sections in this chapter, which follow, indicate the type of control for a circuit which various devices offer.

Contacts

There is in existence an extremely wide range of electrical-contact types used to control the flow of an electric current in a circuit. The action of any pair or pairs of contacts is (a) to 'make', to allow the current to flow, and (b) to 'break', to prevent the current flow. When this action is contained in a specially designed wiring accessory or apparatus it becomes one of the many forms of devices used to control circuits: switches, contactors, circuit-breakers and the like.

The basic requirements of any pair of contacts are (a) low resistance of the contact material and (b) low resistance between the two contact surfaces when they meet to make the circuit.

When these requirements are satisfied, the two main factors, which lead to switch troubles, are very much reduced. Though one can choose a low-resistance contact material (e.g. copper), one cannot always control the amount of pressure required to keep the two contact surfaces closed sufficiently to reduce what is called 'contact resistance'. A switch, for instance, which is operated many times, will eventually reach a state when its springs become weakened, with the result that pressure of the contacts is lost to such an extent that heat is generated and a breakdown of the switch follows.

The higher the resistance of contact material the more heat (I^2R walls) there will be when a current passes along it. The second factor involved in the design of switch contacts is the amount of pressure needed to keep the two contact surfaces together. All circuit-control devices, which meet the relevant specifications of the BSI, are tested very rigorously to ensure that they stand up to more wear and tear than they would meet with in normal use. Even so, most contact troubles met with in practice involving the use of circuit-control devices can be traced to insufficient contact pressures.

The material most often used for contacts is copper; this is because it is available in commercial quantities and it has a very low resistance. The terminals associated with the contacts, to which cables and wires are attached, are most often made from brass or phosphor bronze. These two metals are much harder than copper and so can withstand a certain amount of rough handling with screwdrivers when wiring is being carried out.

The insulating materials used in circuit-control devices include vitrified ceramic (for the bases of switches), bakelite (for switch covers and cases), nylon and mica (for carrying the moving contacts of switches), and insulating oil (used in oil-break circuit-breakers)

In many circuit-control devices silver is used, either as a contact facing, or as the contact itself. The material has a resistance lower than that of copper; it also has high heat-dissipation characteristics and is, for this application, economical to use. Motor-control switches sometimes have contacts of silver-cadmium oxide to reduce the tendency to weld together with heat.

Liquid mercury is also used in special switches called mercury switches. This material has a low contact resistance and a high load-carrying capacity, and can be used in situations with ambient temperatures from about - 17 to
204 ^{0}C.

Because the contacts are the bean of the circuit-control device; it follows that their surfaces must be kept clean at all times. Cleaning fluids are available for this purpose. Other maintenance points are the periodic tightening up of conductor terminals and connections, and ensuring that springs have not weakened through use, or that cam surfaces have not become worn.

There are two classes of duty for circuit-control devices: (a) light current and (b) heavy current. Into the first class fall generally lighting switches, relays and bell pushes; the second class includes contactors and circuit-breakers.

4.2 Switches and switch fuses

A switch is a device for controlling a circuit or pan of a circuit. The control function consists of energising an electrical circuit, or in isolating it from the supply. The type of switch generally indicates the form, which this control takes. For instance, a single-pole switch (usually called 'one-way') controls the live pole of a supply. A double pole switch controls two poles.

A common type of switch in use today is the micro-gap with a rating of 5 A, to control lighting circuits. Switches with a 15 A rating are also used to control circuits, which carry heavier currents on both power (socket-outlet) and lighting arrangements.

Switches are designed for use on dc and/or ac. In a dc circuit, when the switch contacts separate, an arc tends to be drawn out between the separating surfaces. This arc is extinguished only when the contacts are far enough apart and when the breaking movement is quick.

Investigation of a dc switch will indicate the length of the gap required when the switch is open. Compare this gap with the gap length on an ac-only switch; it will be found that the latter is very much smaller. The reason for this is that ac tends to be what is called 'self-extinguishing'. In an ac circuit, during the time taken for the contacts to open, the voltage, which is alternating, varies between zero and a maximum. It is at the zero position of the alternating voltage that the arc drawn between the parting contacts of an ac only switch is extinguished - and it does not establish itself again in normal circuit conditions. Thus, a switch designed for use only on an ac system need have only a small gap and, furthermore, the con-tact movement does not require to he operated so rapidly as is the case with dc switches.

Quick-make-and-break switches are used for de circuits. Quick-make, slow-break switches are recommended for ac circuits, particularly where the load is an inductive one, for instance where fluorescent lamps are being used.

The most common lighting circuits are controlled by using one-way and two-way switches, double-pole switches and intermediate switches.

The single-pole, one-way switch provides the ON and OFF control of a circuit from one position only. When the switch is closed, the lamp is on; when the switch is open, the lamp is off. One-way switches are mounted with the word 'TOP', which appears on the back of the switch plate, at the top. This is to ensure that when the switch rocker is in the up position, the circuit is disconnected from the supply. The switch is, of course, connected in the phase conductor only.

. The double-pole switch is used in any situation where the voltage of the neutral conductor of a supply system is likely to rise an appreciable amount above earth potential: use of the double-pole switch means that a two-wire circuit can be completely isolated from the supply. The usual application is for the main control of sub-circuits and for the local control of cookers, water-heaters, wall-mounted radiators, and other fixed current using apparatus. The double-pole switch is often used for the 'master' control of circuits, the switch being operated by a 'secret key' attachment, and in consumer units for the complete isolation of an electrical installation from the supply.

The two-way switch is basically a single-pole changeover switch offering two alternative routes for the passage of the circuit current. These switches are sometimes known as 'landing' switches from the days when their application in the electrical installation was virtually limited to 'one in the hall, and one on the landing upstairs'

Though the two-way switch is still used extensively for stair lighting, it is also to be found wherever it is necessary to have one or more lights controlled from any one of two positions. They are nowadays to be found in bedrooms (door and bedside), long halls (at each end) and particularly in any room with two entry doors (one at each door).

In design, the switch has four terminals, two of which are permanently connected together inside the switch by a small copper bar on what is called the 'bar' side. One of the bar terminals is blanked off to form a non-separable contact. The switch feed is taken to the other open terminal on the bar side. The two other terminals are connected to the 'strapping wires'. Two-way switches are used in pairs, interconnected so that the switch wire of the light circuit is taken from the open terminal on the bar side of the second switch.

The intermediate switch offers control of a circuit from any one of three positions, the other two positions being at the two two-way switches with which the intermediate switch is most often used. The intermediate wiring circuit is basically a two-way circuit in which the strapping wires are cross connected by the two ON positions of the intermediate switch. There are two different kinds of intermediate switch, one of which is in common use. It is thus advisable to check the type with an ohmmeter, or bell-and-battery set, because the method of connecting up differs. Shows the two common forms of connection made within each type of switch.

The application of the intermediate switch in electrical installations has so far been very limited. But there is no reason why it should not be used more extensively. Long halls, corridors and passageways with many doors are stilt wired up for two-way control. For reasonable convenience the light or lights should be controlled from every door and entrance. Thus, the user of this type of circuit can make his way through a house, switching on lights before him, and switching off behind him without have to grope about in the dark.

Two or more intermediate switches can be inter-connected into the basic two-way circuit to offer control from an almost unlimited number of positions.

The switch fuse is often found as the 'main switch', near the supply-intake position. It is a unit in which the main switch (for installation control) and the main fuses (for the protection of the installation) are combined. In all instances, the switch of the switch fuse cannot be operated when the cover is open, nor can the cover be removed or opened while the switch fuse is closed. The switch fuse, which usually controls a separate distribution board, is of the double or triple-pole type, depending on the supply system.

Double and triple-pole switches are found in metal-clad units called isolators. An example is the fireman's emergency switch, painted red and found beside high-voltage gas-discharge lamps such as neons. Isolators are also used to isolate the supply from motors, and heating and non-portable appliances.

The consumer control unit is the most common means used to isolate a complete domestic installation from the supply. It incorporates a double-pole switch and a 'live' busbar to which the final circuits' protection are connected, and either semi-closed fuses, cartridge fuses, or miniature circuit-breakers, the latter becoming increasingly popular because of their definite action in the event of overloading and circuit faults, coupled with safety in their operation. Although originally intended for domestic installations, these units are being used in commercial and industrial installations where small lighting and power loads are involved.

The extremely wide range of switchgear types available today can be found in makers' trade literature, study of which is advised so as to become familiar with what is offered for use in electrical installations.

All circuit-control devices, whether switches or other types, must conform to the relevant BS specifications, which thus ensure a minimum guarantee of quality and suitability for use.

4.3 Circuit-breakers

The circuit-breakers can be regarded as a switch, which can be opened automatically by means of a 'tripping' device. It is, however, more than this

Whereas a switch is capable of making and breaking a current not greatly in excess of its rated normal current, the circuit-breaker can make and break a circuit, particularly in abnormal conditions such as the occasion of a short-circuit in an installation. It thus disconnects automatically a faulty circuit.

A circuit-breaker is selected for a particular duty, taking into consideration the following. (a) the normal current it will have to carry and (b) the amount of current which the supply will feed into the circuit fault, which current the circuit-breaker will have to interrupt without damage to itself.

The circuit-breaker generally has a mechanism which, when in the closed position, holds the contacts together. The contacts are separated when the release mechanism of the circuit-breaker is operated by hand or automatically by magnetic means. The circuit-breaker with magnetic 'tripping' (the term used to indicate the opening of the device) employs a solenoid, which is an air cooled coil. In the hollow of the coil is located an iron cylinder attached to a trip mechanism consisting of a series of pivoted links. When the circuit-breaker is closed, the main current passes through the solenoid. When the circuit rises above a certain value (due to an overload or a fault), the cylinder moves within the solenoid to cause the attached linkage to collapse and, in turn, separate the circuit-breaker contacts.

Circuit-breakers are used in many installations in place of fuses because of a number of definite advantages. First, in the event of an overload or fault all poles of the circuit are positively disconnected. The devices are also capable of remote control by push buttons, by under-voltage release coils, or by earth-leakage trip coils. The over-current setting of the circuit-breakers can be adjusted to suit the load conditions of the circuit to be controlled. Time-lag devices can also be introduced so that the time taken for tripping can be delayed because, in some instances, a fault can clear itself, and so avoid the need for a circuit-breaker to disconnect not only the faulty circuit, but other healthy circuits which may be associated with it. The time-lag facility is also useful in motor circuits, to allow the circuit-breaker to stay closed while the motor takes the high initial starting current during the run-up to attain its normal speed. After they have tripped, circuit-breakers can be closed immediately without loss of time. Circuit-breaker contacts separate either in air or in insulating oil.

In certain circumstances, circuit-breakers must be used with 'back-up' protection, which involves the provision of HBC (high breaking capacity) fuses in the main circuit-breaker circuit. In this instance, an extremely heavy overcurrent, such as is caused by a short circuit, is handled by the fuses, to leave the circuit-breaker to deal with the overcurrents caused by overloads

In increasing use for modern electrical installations is the miniature circuit-breaker (MCB). It is used as an alternative to the fuse, and has certain advantages: it can be reset or reclosed easily; it gives a close degree of small overcurrent protection (the tripping factor is 1.1); it will trip on a small sustained overcurrent, but not on a harmless transient overcurrent such as a switching surge. For all applications the MCB tends to give much better overall protection against both fire and shock risks than can be obtained with the use of normal HBC or rewirable fuses. Miniature circuit-breakers are available in distribution-board units for final circuit protection.

One main disadvantage of the MCB is the initial cost, although it has the long-term advantage. There is also tendency for the tripping mechanism to stick or become sluggish in operation after long periods of inaction It is recommended that the MCB be tripped at frequent intervals to 'ease the springs' and so ensure that it performs its prescribed duty with no damage either to itself or to the circuit it protects.

Contactor

When a switching device has one or more switches in the form of pivoted contact arms, which are actuated automatically by an electromagnet, the device is known as a contactor. The coil of the electromagnet is energised by a small current, which is just sufficient to hold the pivoted contact arm against the magnet core, and in turn so hold the contacts (fixed and moving) together. Contactors are used in an extremely wide range of applications.

They fall into two general types: (a) 'maintained' and (b) 'latched-in'. In the first type, the contact arm is maintained in position by the electromagnet. In the latched-in type, the contact arm is retained in the closed position by mechanical means.

Contact design and material depend on the size, rating and application of the contactor. Contactors with double-break contacts usually have silver cadmium-oxide contacts to provide low contact-resistance, improve arc interruption and anti- welding characteristics. Large contactors with single-break contacts use copper contacts for economy.Usually single-break contacts are designed with a wiping action to remove the copper-oxide film which readily forms on the copper tips. Since copper oxide is not a good conductor, it must be eliminated in this way for good continuity.

When the contacts open, an arc is drawn between them. The longer the arc remains, the more the contact material is consumed, and so the shorter is the contact life. The arc can be extinguished by two means: long contact travel, or by use of arc interrupters.

The typical arc interrupter is called a 'blow-out' coil. This uses magnetic means to force the arc and its products away from the surfaces of the contacts, thus lengthening and weakening the arc so that it is eventually extinguished.

Contactors are used to control heating loads, and are often used in conjunction with time switches and thermostats, which close or open the electromagnet current as required. With the contactor, a small current (for the electromagnet) can be used to control a relatively large current in another circuit.

Thermostat

The thermostat is used to control an electric heating appliance or apparatus so that a definite temperature is maintained. It is, therefore, a switch, which operates with a change in temperature and is used in the temperature control of rooms, water-heaters, irons, cooker ovens and toasters. It maintains a temperature within defined limits by switching off the appliance when a higher temperature is attained, and switching it on again when a lower temperature has been reached.

The methods used to operate the switch contacts of a thermostat include the expansion of a metal rod, expansion of a liquid or a gas or the bending of a bimetallic strip. Applications of these methods are, respectively, water-heaters, ovens and irons. The illustrations show the basic elements of each type of thermostat.

The speed of response of a thermostat to a change in temperature depends to a large extent on the material used to convey the heat, called the controller. A thermostat whose thermally sensitive elements are directly opposed to the heat transfer medium will respond faster than one whose elements are shielded by a housing. Liquid-filled systems respond more quickly than gas-filled systems.

4.4 Special switches

With the extensive use of electricity today, it is not surprising to find that there is a great variety of switches and other circuit-control devices with special applications. It is possible to indicate here only some of the most common types.

Three-heat switch

This type of switch is most often associated with the grill-plate of an electric cooker, though it is also used for the heat control of boiling plates The circuit controlled by the switch consists of two elements of equal resistance. The three-heat switch then offers low, medium and high heat values by its three positions.

The three-heat switch is essentially a rotary or turn switch. The positions are OFF, LOW, MEDIUM, HIGH. The switches are available as a single-pole type (four terminals) or a double-pole type (five terminals).

Time switch

As indicated by its definition, the time switch introduces a time element' into an electrical circuit, so that automatic control of the circuit is available at predetermined times. Time switches fall into two general groups: spring-driven and motor-driven. The former uses a mechanism similar to that found in clocks The latter group uses as the driving unit a small electric (synchronous) motor whose speed is constant and varies only with the 50 Hz frequency of the mains supply. Similar motors are used in electric clocks.

There are many applications for time switches: shop-window lighting, driveway lighting, street lighting, staircase lighting in multi-tenanted buildings and heating loads, the latter being switched on during 'off-peak' periods when a cheaper tariff is available.

The time-switch control of lighting circuits is often found in such particular applications as poultry houses, where banks of switches control the lighting to simulate summer-daylight conditions and so introduce a 'longer-day'. The same technique is also used in horticulture, to hasten the growth of seedlings and plants, particularly during off-season periods of the year.

For normal work, the contacts (either single- or double-pole) are silvered copper, or entirely silver. For heavy currents, mercury-contact time switches are used.

Mercury switch

This is basically a sealed glass tube with a small amount of liquid mercury inside it. The leads are fused into the glass. When the tube is tilted, mercury flows over a second terminal (the first being in permanent contact with the mercury). Thus, contact is made to make the circuit. Mercury switches are made in a very wide variety of types, each type being designed with a particular duty and application in mind.

Switches of this type have many advantages: low force required to operate them, low contact-resistance, high load-carrying capacity, low cost, and a long life because of the 'no wear' characteristic of the contacts. It is also relatively insensitive to ambient temperature conditions; a range from -4°C to over 204 ^{0}C has been specified for some switches. Because the glass is hermetically sealed, the mercury switch is effectively immune to dust, oil and condensation, and can be used where corrosive fumes are present.

Contact connections to the switch are made through flexible leads, or 'pigtails', attached to the embedded electrodes or contacts. Some switches are filled with a reducing gas to keep the surface of the mercury pool free from tarnish.

Because glass is used as the switch container, the contacts are always visible for inspection; and mercury tends to resist heat and arc effects. The materials used for the contacts include tungsten, iron or iron alloys (e.g. nickel-iron) and mercury pools.

Mercury switches are operated by a tilting motion; the method of mounting a switch depends on its application, shape of the actuating member, and the motion produced by it. In the case of a single-throw switch, the glass tube is tilted from the horizontal. Mountings include bimetallic strips, cams and rotating levers. A time-lag element can be introduced by restricting the flow of mercury from one position to another; this is done by a wall placed inside the tube. The wall contains a hole, the diameter of which determines the amount of rime-delay.

Rotary switch

The rotary or turn switch offers the facility of controlling a large number of circuits from a local position by using one switch. The three-heat switch is one of the most common examples of the rotary switch. Others include the switches used on switchboards in conjunction with ammeters and voltmeters on three-phase systems to indicate phase-to-phase currents and voltages.

Many banks of contacts can be fitted to a rotary switch so that complete control of circuits is available. Generally the currents are not large: 15 A is the usual limit.

Micro-gap switch

This switch derives its type name from the fact that when its contacts (usually silver) are open they are separated by an extremely small gap: anything up to 3 mm. As indicated earlier in the section on contacts, such switches can be used only on ac circuits. They have many applications apart from 'ac only' lighting circuits.

Thermostats using a 'snap-acting' bimetallic element are in effect micro-gap switches and are to be found in the temperature control of irons, toasters, and cooker heating elements. One industrial application is where a motor overheats and a bimetallic, snap-acting device will switch off the energising current to stop the motor and so protect its winding.

The snap action is always positive in these switches, no matter how rapidly or how gently the force is applied to the operating button. The button can be moved by a plunger, a leaf spring, or a roller and a lever.

Starter switch

Starter switches are used for starting fluorescent lamps. The glow-type starter switch consists of two separated bimetallic contact strips contained in a glass bulb filled with helium gas. The contacts are connected to the fluorescent lamp filaments. When the circuit-control switch is closed, the mains voltage appears across the two contact strips. This voltage is sufficient to cause a small gas discharge. The heat generated by the discharge affects the bimetallic contact strips, which bend forward to meet each other. When they make contact, the current flows through the fluorescent lamp filaments to heat them. The gas-discharge glow in the starter switch now disappears. After a few seconds the bimetallic contact strips cool down and separate. This sudden interruption of the circuit causes a high-voltage surge to appear across the ends of the main lamp electrodes to start the gas discharge.

The voltage which now appears across the contact strips in the starter switch is, during running conditions, insufficient to cause further discharge in the helium gas, and so the contacts remain open while the main lamp is burning.

Two-way-and-off switch

This is a single-pole changeover switch with an OFF position. It is to be found in hotels, ships and hospitals where it is required to have two lamps in circuit while so arranging their control that both cannot be used at the same time.

The two-way-and-off switch can be used as a dimmer control, when in one ON position of the switch only one lamp is lit; in the other ON position, two lamps are connected in series to give a 'dim' light. Other lamp-control arrangements are available when this type of switch is used with other types such as the two-way.

Series-parallel switch

This is a three-position switch with an OFF position when the switch knob or dolly is central. The switch is used to control two points, or two groups of points. In one ON position, the lamp or lamps are connected in series (dim). In the other ON position, the lamp or lamps are connected in parallel (bright). These switches are to be found in hotel corridors, hospital wards and in railway carriages.

Low-voltage contacts

The most common type of low-voltage contact is the bell push, which is operated by the direct pressure of a finger on a push-button: the contacts are copper or brass. One is fixed to the base of the bell push, the other is fixed at one terminal end, its other free end being raised. Pressure on the push-button depresses the contact's free end to complete the circuit. The contacts are usually natural copper, though they are sometimes given a coating of non-oxidisable metal. Other low-voltage contacts use steel springs and phosphor-bronze springs, and are associated with various alarm circuits: burglar, fire, frost, water-level and smoke-density.

Relay

The most common relay is a switch operated by an electromagnet. It consists of an iron-cored coil and a pivoted armature. When the coil is energised, one end of the armature is attracted to the electromagnet and the other end presses two or more contacts together; contacts may also be opened by this movement of the armature.

Relays are either normally closed (NC) or normally open (NO). In the first type, when the coil is energised the contacts are open; the contacts close when the coil is de-energised. In the NO relay, the contacts are closed when the coil is energised, and open when it is de-energised. In effect, the relay is an automatic switch.

Relays are normally designed to operate when a very small current flows in the coil. Thus, a small current can be made to switch a larger current on or off, just as a contactor functions from a distant point (remote control). They are also used in bell and telephone systems, and have a wide application in industry.

Other types of relays use a solenoid for their operation. In this instance a plunger is attracted when a predetermined value of current flows in the coil. A time-lag element can be introduced by the addition of an oil- or air-dashpot to delay the movement of the plunger.

Induction and impedance relays operate by the movement of a pivoted disc in the field of an electromagnet; the protective device (usually a circuit-breaker) with which these types are associated is operated by small contacts on the moving disc which, when they close, trip the circuit-breaker. They are used in the protective systems for supply systems, motors, generators and transformers.

The thermal relay consists of a bimetallic strip, which heats up when the operating or circuit current flows through it or through an adjacent heating coil. The bending of the strip causes the contacts to either make or break.

Fireman's switch

This switch is used to isolate high-voltage lighting circuits usually found on the exterior walls of buildings, such as neon signs. The switch, which is painted red, is mounted on the outside of the building adjacent to the sign lamps. A label Fireman's switch' is required to be mounted close to the switch. The OFF position of the switch is at the top and there must be a catch (spring-loaded) to prevent its inadvertent return to the ON position. The mounting height should be not more than 2.75 m from ground level.

Emergency switching

This is a requirement of the Wiring Regulations. The switches take the form of large mushroom-head buttons, which can be knocked in the event of an emergency, say, in a workshop. The switch then disconnects the circuit or machine.

General requirements

Directly operated switches are not allowed in bathrooms or shower rooms where switches are within reach of a person in contact with the bath or shower. Pull-cord switches are recommended in these situations.

When time switches are being connected up, it is essential to ensure that a CPC is also connected to the earth terminal provided. From time to time the consumer may need to make adjustments to the switch settings, thus coming into contact with metal parts such as the switch-operating levers. Correct use of the earthing terminal will prevent shock risks.

All lighting switches must be connected m the phase conductor only and the correct colour coding of the connecting wires is required by the Wiring Regulations. Any exposed metalwork (such as a metal switch plate) must be earthed. The switch must be of an adequate current rating. If they are used for inductive loads such as fluorescent circuits, they must be fully rated for the value of inductive current taken. If they are not, then they must not carry any more than half their rating, e.g. 2.5 A in the case of a 5 A-rated switch.

Where switches are used as isolators for motor circuits, they should be located close to the motor position. If this is not possible, the switch handle should be able to be padlocked in the OFF position so that work can be carried out without fear of the circuit becoming live.

CHAPTER 5: SUPPLY DISTRIBUTION AND CONTROL

5.1 Supply Distribution

With few exceptions, the types of electricity supply normally available are alternating current single-phase-two-wire, and three-phase-four-wire. In large factories involved in certain kinds of processes as steel mills, the internal works supplies for much of the rotating plant is dc. Direct current supplies outside industry are rarely available from a supply company, although they are, of course, in wide use of emergency lighting, battery charging and similar applications where the power requirement involved is small. Where the amount of power is large as in metal refining, the voltage is small (e.g. 10 V) and the current is correspondingly is large (e.g. 10,000 A). The dc system in general use until the gradual changeover to ac supplies was the three-wire system. This consisted of a dc generator supplying a voltage of 500 V between two outer conductors known respectively as the 'positive outer' and the ' negative outer'. A middle wire, generally of smaller cross-sectional area, was earthed and thus provided a voltage of 250 V between any of the outer conductors and the neutral or mid-wire. Thus, a 500 V motor could be supplied across the outers, while a domestic requirement of 250 V was met by connecting the mid-wire and the positive or negative-outers. This two-voltage facility was developed from the older single-voltage systems evolved before the turn of this century.

The ac systems came into their own because it was found possible to transmit large amounts of ac electrical power over long distances provided high voltage was used. AC is generated in the power station usually at 25,000 V. This generated voltage is transformed by generator-transformers to transmission-line voltages of 132, 275 and 400 kV. The transmission line from apart of what is known as the NATIONAL GRID, which is an interconnected system of conductors (overhead lines and underground cables), which carry electrical power to points of use. All these points, the transmission voltage is reduced by transformers to 33 kV and 11 kV for large consumers. The voltage is further reduced to 415/240 V for small consumers.

The single phase, 240V, 50 Hz systems is the normal supply for small dwellings, and other single-occupier premises where the load demand is relatively small. The three-phase systems derived from a star-connected winding of a transformer, the star point being earthed. From this point a fourth conductor, the neutral, is taken to form a three-phase, four-wire system.

The voltage between any phase conductor and the neutral is 240 V. This system is the normal supply for commercial and industrial premises of medium size: schools, hotels, blocks of flats, hospitals and the like. The lighting and heating circuits of individual tenements in blocks of flats are normally supplied from low-voltage circuits derived from this system, the load across the three phases being balanced as far as practicable. High-voltage three phase supplies are fed to very large consumers where total electrical load exceeds 100 kW. The voltages are either 11 or 33 kV. The consumer is offered a cheaper tariff if he takes a higher voltage. A balance-load on a three-phase system is usually available only where three-phase motors are used. Heating loads, in most instances, can be connected across three phases and the neutral conductor omitted unless required for control purposes.

Cable sizes are dictated by the amount of electrical power to be carried. If a large power is to be taken to a consumer, high-voltage cable is use, to reduce the current and so the cross-sectional area csa of the cable conductors. Because of the high voltage, however, the cable must be of necessity cost more to insulate. Despite this, there are sound economic reasons for carrying as much power as possible at a high voltage, leaving the larger csa cables to carry larger currents associated with individual circuits in an installation at low and medium voltages. The main economic reason is to reduce the amount of power loss in a conductor. There is also the important aspect of the loss in voltage along the length of the conductor as it caries the load current.

Underground cables are used where there is a visual objection to overhead lines to where it would not be convenient to use lines. Both paper and PVC insulated cables are used, with copper and aluminum conductors. The latter has now come into favor because it costs less than copper and has its lightweight requires a smaller cable-laying labor force. Copper conductors are stranded. Aluminum conductors are found in both stranded and solid forms. Belted cables are cheaper than careened types and are used for systems up to 11 kV.

Protection of underground cables against mechanical damage is provided for by steel-wire or steel-tape armoring. Steel-tape armoring cables are cheaper in first cost than the wired-armored types, but the bending radius is less and they cannot be left 'bright', that is, with the jute serving removed to present a clean appearance n surface work. Also, tape armoring cannot be taken over plumbed or cone gland to the Armour clamp as in wire-armored cables.

There are three methods of laying underground cables: direct lying, draw-in and solid. The direct-laying method involves the cable being placed in a trench and then covered with soil. In most instances, the cable is protected in wood planks, bricks, tiles or concrete slabs. Such cables should be armored, though if the risk of mechanical damage is small, bare-sheath cables can be used. Subsidence of the soil is an important factor in the installation of buried cables. And if the soil contains harmful chemicals, precautions must be taken to prevent the cable from being damaged by corrosion and electrolysis. Direct lying is cheap, but replacement or renewal of the cable involves completely new excavation, which could be costly in the long terms. In the draw-in system, a line of conduits is glazed stoneware, cement or concrete. The tubes can be of earthenware or iron. After the ducts are laid, the cables are pulled into position from manholes or brick pits. Armoring is not necessary, but the cables are usually given a covering of Hessian tape or use to protect them while drawing in. Ducts are usually multi-compartmented. In the solid system, the cable is laid in thronging in an open trench. The toughing is then covered with a bituminous compound, and the trench filled in.

5.2 Overhead Lines

The cheapest method of carrying power is by overhead line, particularly where light loads are concerned, as might be the case in a farm installation. Overhead line poles for low-and medium-voltage services are of wood, generally 8m in length some 7 m out of the ground. There are regulations, which govern the minimum lengths of span and minimum heights above ground for consumers' overhead wiring between buildings. In ordinary ground, the erection of poles presents no difficulty. The pole should be dug as narrow as possible in the direction of line. The pole should be positioned in one corner of the hole, so that in two directions it bears against undisturbed soil. Preferably, the butt of the pole should rest on a few inches of concrete or hard core, and be well rammed. In loose ground, cross-braces are necessary below ground level to present a larger area to the yielding soil.

Copper, owing to its high electrical conductivity, being second only to silver, and because it has good mechanical properties and resistance to corrosion, has for long been the most commonly used conductor for overhead lines. One limitation to its use is the excessive sag that is necessary on long spans. In such instances, conductors with a higher tensile strength are used e.g.- a composite conductor employing copper or aluminum strands round a steel wire; or a conductor of cadmium-copper alloy. Overhead lines are subject to the requirements of the Overhead Lines Regulations, where a public supply is being carried. A conductor must have a breaking load at least 560 kg. Thus the minimum size for a copper conductor is 8 SWG. The minimum permissible size of service line must be such as to have an actual breaking load of not less than 370 kg.

Conductors may be bare, or insulated PBJ, VR or PVC. Line conductors are attached to insulators carried on supports of wood, iron, steel, or reinforced concrete. All wooden supports other oak or hardwood cross-arm must be impregnated with creosote. Two forms of insulators are used; the pin-type and the disk insulator for tension positions.

5.3 Supply control

It is a requirement of the Wiring Regulations that every consumer's installation shall be Adequately controlled by switchgear which is readily accessible to the consumer and which shall incorporate:

1) Protection against electric shock.

2) Protection against over current.

3) Isolation and switching

The type and size of main switchgear to be installed depends on the type of premises and anticipated load. For the average domestic premises, the service cable (underground) is two-core and PILC- or PVC-insulated. This is suitable for a load of about 20 kW at 240V, single phase and 25 mm squared csa; it is sufficient for the electrical requirements of most households. Industrial installations, unless they are very small workshops, are provided with three phases, four-wire services, usually 415V between phases, higher voltages are supplied where the load is large. The size of cable for an industrial load must cater for any future additions to the load or extensions to the factory. It is usual practice to install cables of sufficient capacity with appropriate switchgear; to save additional installation expense and outage time at a later date extensions are projected.

The location of the switchgear of a medium-voltage installation is at the main switchboard. This is situated in a substation or in a separate room on the premises to which any authorized persons have access and which is always kept clean and dry. The

Switchgear, fusegear and circuit breakers should have adequate breaking capacity current obtainable from the supply system. For medium-sized installations, the switchgear is in the form of manually operate switch fuses. These units are available as metal clad, double- or triple-pole and neutral switches with HRC fuses. Capacities are up to 300A, and can safely handle faulty currents up to 25MVA at voltages up to 660V ac. Large industrial loads are handled by circuit-breakers which, of course, incorporate the facilities for handling large amounts of short-circuit automatically. A typical switchboard for a large installation usually consists of a main circuit breaker with a bus bar chamber from which are fed the various sub circuits of the installations, each having its own small-rated circuit breaker. It is a requirement of the IEE Wiring Regulations that all switchgear be labeled to identify their functions and the circuits they control. In addition, switches controlling emergency services such as fire alarms, firemen's' lifts and sprinkler systems should be distinctively marked, for example, by painting them red.

The memorandum by the Senior Inspector of Factories indicates the adequate passageways should be allowed to give access to al switchboards. Adequate means must also be provided for isolating the equipment to allow access for maintenance and other purposes. Where more than one phase is brought into a building, as in the case of industrial loads, special precautions must be taken to avoid the risk of shock. The Regulations insist that all live terminals between which low voltage exists should be shrouded with an insulating material or be enclosed in earthed metal. Single-phase distribution boards, which are connected to different phases, must be 2 m apart from each other.

The position of distribution fuse boards is important, and should be near the electrical center of the load they are intended to serve. This reduces of the cost circuit cables, though the length between the supply-intake position and particular distribution board should be taken into consideration so that the volt drop does not exceed the permitted maximum of 4 % of the nominal voltage of the supply.

Sub-main distribution in industrial premises is generally by cables or by busbar trunking systems. For machine shops and other parts of a factory where alterations in machines layout may occur frequently, the plug-in tap-off system is recommended. Separate sub-mains should be installed for special electrical services such as passenger and goods lifts and ventilating systems. Sub-main circuits should not be run within lift shafts. In small domestic and commercial installations, the distribution board is at the meter position. With the usual two-pan tariff, one-meter records the energy used for lighting, heating and cooking, and only one main control switch or switch fuse is necessary. If a different tariff is applied, for example, for peak-off loads, a separate meter and switch must be provided. The off-peak loads are controlled by time switches and contractors.

HAPTER 6: FINAL CIRCUITS

A final circuit is defined as 'A circuit connected directly to current-using equipment, to a socket-outlet or socket-outlets or other outlet points for the connection of such quipment.' In addition, the regulations require that where an installation comprises more an one final circuit, each circuit shall be connected to a separate way in a distribution oard. They also require that the wiring of each final circuit shall be electrically separate rom that of every other final circuit. To facilitate disconnection of each final circuit for esting, the neutral conductors shall be connected at the distribution board in the same order as that in which the live conductors are connected to the fuses or circuit-breakers.

Final circuits make up the greater part of electrical installations and can vary from a pair of 1 mm^2 cables feeding one lamp, to a heavy three-core PILC cable feeding a large motor from a circuit-breaker located at a factory switchboard. The main important regulation which applies to final circuits is No.27 of the Electricity Supply Regulations: 'All conductors and apparatus must be of sufficient size and power for the work they are called on to do, and so constructed, installed and protected as to prevent danger.'

There are five general groups of final circuits:

1. Rated at not more than 16A.

2. Rated over 16A.

3. Rated over 16A but confined to feeding 13A socket-outlets with fused plugs.

4. Circuits feeding fluorescent and other discharge lamps.

5. Circuits feeding motors.

An industrial installation may have all five types; a domestic installation may have only 1, 2 and 3. Whatever the type of installation and the uses to which electrical energy is put, it is essential that some significant element of planning be introduced at any early stage in the design of an installation. Before indicating the factors, which are involved in the choice of final circuit types, a few brief notes on planning aspects will be relevant.

6.1 Installation Planning

a) Domestic installations seem to be the simplest to plan, but there are a number of points, which are worth considering. And though these might seem obvious at first sight, a close survey of existing installations will reveal rather too many lapses in efficient planning, even for a dwelling house. For example, a room which can be entered from two points should be wired for two-way switching; a two-landing staircase should be wired for intermediate switching; and a large house should have two or more lighting circuits. A note in an older edition of the IEE Regulations is still relevant: in the interests of good planning ills undesirable that the whole of the fixed lighting of an installation should be supplied from one final sub circuit The reason for this is not far to seek. If an installation has two lighting circuits and one circuit fails, the house is not plunged into darkness. It is often a good point to consider a slight 'overlap' of lighting circuits: to wire one lighting point from one circuit within the wiring area of the other circuit. If this is done, there should be a note to this effect displayed at the distribution board.

The lighting in houses should be regarded as an important aspect of interior decoration, as well as supplying lighting on a purely functional basis. In living rooms and bedrooms, wall-mounted fittings can be used, controlled by multi-point switches at the entrance doors. Thought should be given to the provision of 13A socket-outlets for supplying table and standard lamps. The use of local lighting over working surfaces in kitchens is an aspect of good planning. External lighting should not be overlooked, either to light up the front and back doors or to light the way to outhouses such as detached garages, coal stores and greenhouses. In very large houses, driveway lighting may have to be considered.

To facilitate the interchange of fittings and appliances throughout the house, it is recommended that 13A three-pin socket-outlets to BS 1363 should be used exclusively. Where it might be inconvenient to withdraw plugs from the associated socket-outlets when appliances are out of use, switched socket-outlets should be used. Because the past few years have seen a rapid increase in the use of electrical appliances, it is essential that an ample number of socket-outlets be provided, and situated wherever there might arise the need for an electrical outlet The table below shows the provision of socket-outlets, both the desirable number and the minimum provision that can be considered as acceptable:

Part of dwelling	*Desirable provision*	*Minimum provision*
Working area of a kitchen	4	4
Dining area	2	1
Living area	5	3
First (or only) double bedroom	3	2
Other double bedrooms	2	2
Single bedrooms	2	2
Hall or landing	1	1
Store/workshop/garage	1	—
	20	15
Single study-bedrooms	2	2
Single bed-sitting rooms in family dwellings	3	3
Single bed-sitting rooms in self-contained bed-sitting room dwellings	5	5

It can thus be seen that the average house should have an adequate number of socket-outlets. In the living room, there should be a two-gang socket-outlet on each side of the fireplace. Additional socket-outlets should be located less than 2 m from the opposite corners of the room, where they are least likely to he hidden by furniture, In bedrooms, at least a single socket-outlet should be provided at each side of a bed; two-gang units can be used to good advantage (e.g. to supply a bedside lamp and an electric blanket). Additionally, there should be socket-outlets for dressing-table lamps, a heating appliance or a portable television set.

The kitchen probably places the greatest demand on the electrical service. Outlets are required for such varied appliances as washing machines, refrigerators, waste-disposal units, food mixers, can-openers, flat irons, coffee percolators and toasters. As far as possible, the outlets should be located above working surfaces and two-gang units are recommended.

In the dining room, small plate-warmers may be required. In halls and on landings the outlet is generally used for a vacuum cleaner or floor polisher, and perhaps a ball heater. No provision is made for the use of portable appliances in a room containing a fixed bath or shower. However, an electric shaver unit to BS 3052 may be installed out of reach of a person in the bath or shower. Additionally, a bathroom heater (of the enclosed-element type) or towel rail should be permanently connected through a fixed control switch out of reach of the bath or shower position.

b) Commercial installations are often difficult to design because frequently the buildings are built as basic shells with the final requirements for lighting and other circuits not known until the office tenants sign their leases. The lighting in such buildings is general, special, and building services'. The general lighting is supplied by a flexible wiring system which will allow for a specific area in a new building to be sectioned or partitioned off into smaller areas for offices, stores and the like. Special lighting may include external lighting, wall points, etc. The service lighting is that associated with lifts, corridors, stairs, and landings and is usually the responsibility of the landlord. Where a tenant's specific lighting requirements are not known when the building is being erected, the lighting outlets are laid out on a 'grid' system, in which the outlet points are sited at regular intervals usually related to the module of the building (that is, the basic size, multiples of which are used in the construction of the building). Generally, about 3 m are allowed between outlets. Outlets may be left on the ceiling for ceiling switches. They may also be fined on structural columns or on the ceiling along the line of future corridors from which extensions to switch positions can be made on future partitions.

The provision of adequate socket-outlets is a particular problem, for should the electrical load increase (e.g. an office may go over to all-electric typewriters or install a computer or data-processing system), it is often difficult to extend or alter an inflexible installation. Thus, the electrical services provisions should allow for the possibility of installing new outlets or revising the positions of existing outlets without difficulty or serious disturbance to the building and its occupants. Where a tenant's requirements for socket-outlets are not known, it is usual practice to install one socket-outlet on the external wall in each building bay and make provision for spur connections to two further outlets to be installed on internal partitions as may be required. Only a limited number of bays, not more than three, should be connected to each ring circuit.

c) Industrial premises require lighting installations, which cater for the intensity of lighting required for the process to be carried out. In addition, local lighting at reduced voltages is often a requirement on machines or for portable inspection lamps. The lighting installation within the factory area should be wired with a system, which will allow for extensive alteration and significant addition with ease of maintenance and rewiring when necessary.

d) Special types of premises include hospitals, theatres, cinemas, hotels, schools and buildings of historic interest. Some of these, such as hospitals, have specific codes of practice laid down by the Ministry of Health. In places of entertainment, secondary lighting installations are required.

6.2 Circuit Ratings

Circuits rated under 16A

A final circuit rated at not more than 16A may feed an unlimited number of points provided that the total 'current demand' does not exceed 16A. They include 15, 13, 5 and 2A socket-outlets, lighting outlets, stationary appliances and certain loads which may be neglected because their current demand is negligible (e.g. clocks, bell-transformers, electric shaver supply units), provided that their rating is not greater than 5VA. No diversity is allowed on final circuits. The current rating of the cable must not be exceeded. An important point to note is that if a cable size must be increased to avoid excessive voltage drop in the circuit, the rating of the fuse or circuit-breaker protecting the circuit must not be increased correspondingly. The same condition would apply if the ambient temperature of a cable were to be taken into consideration. The reason for this is that the larger cables are not being chosen for the current that they can carry under favourable circuit conditions, but to provide for the special conditions in which they are being installed. The lighting circuits of domestic installations are rated at 5A. Industrial lighting circuits are usually rated at 15/16A because of the higher wattage of the lamps used.

Circuits rated over 16A

With two exceptions, circuits rated at over 16A should not serve more than one point. The exceptions are circuits, which feed 13A socket-outlets, and cooker circuits. Final circuits for cooking appliances are assessed for current demand as follows

The first 10A of the total rated current of the connected cooking appliances, plus 30% of the remainder of the total rated current of the connected cooking appliances, plus 5A, if the cooker control unit has a socket-outlet.

Thus, a cooker with a total load of 11kW at 240V (46A) would in fact be supplied by cables rated to carry about 26A, depending on the distance the cooker is away from the distribution board. If a large cooker, which exceeds 30A, is to be installed in domestic premises, and where the protection is offered by fuses, a supply service of more than the normal 60A rating may be required. In this instance, the supply authority should be consulted. Water-heater circuits are terminated in a 20A double-pole isolating switch, fitted with an earthing terminal and a neon pilot lamp.

Circuits rated for 13A socket-outlets

Final circuits which supply 13A socket-outlets with fused plugs and 13A fused (switched or unswitched) connection units are provided by two types of circuit: ring and radial. Ring circuits serve a maximum floor area of 100 m^2 derived from a 30A protective device. Radial circuits serving a maximum area of 50 m^2 are also protected by a 30A device, while if the area served is no more than 20 m^2 a 20A device provides the protection. The following is a summary of the requirements relating to 13A socket-outlet circuits:

Each socket-outlet of a two-gang or multiple socket-outlet is to be counted as one socket-outlet.

Stationary appliances, permanently connected to a radial or ring circuit, must be protected by a fuse not exceeding 13A rating and controlled by a switch or a circuit-breaker.

It is important to realise that the conductor sizes recommended for ring circuits are minima. They must be increased if necessary where circuits are installed in groups, or in conditions of high ambient temperature, taking into consideration the class of excess-current protection provided.

The method of properly connecting circuit conductors of a ring circuit involves correct polarity and security of the terminals.

Except where a ring circuit is run throughout in metallic conduit, ducts or trunking, the CPC shall be run in the form of a ring, having both ends connected to earth at the distribution board (or its equivalent).

The total number of spurs shall not exceed the total number of socket-outlets and stationary appliances connected directly to the ring.

Fused spurs from ring circuits must be connected through fused spur boxes, and the rating of the fuse must not exceed the current rating of the cable forming the spur, and in any event must not exceed 13A.

One socket-outlet or one two-gang socket outlet unit, or one stationary appliance fed from a connection unit, can be connected to each non-fused spur.

Circuits feeding motors

Final circuits, which supply motors, require careful consideration. In particular, cables which carry the starting, accelerating and load currents of a motor must be rated at least to the full-load current rating of the motor If, however, the motor is subjected to frequent starting and stopping, the csa of the cables should be increased to cater for the consequent increase in conductor temperature. More than one motor may be connected to a 16A final circuit, provided that the aggregate hill-load rating of the motors does not exceed 16A. If a motor takes more than 16A hill-load current, it should be fed from its own final circuit.

Cooker circuits

These are derived from (usually) a 30 A or 32 A way, but can be higher depending on the kW rating of the cooker. The control units need not have a socket-outlet incorporated in them, but if one is provided the protective device must be able to disconnect the circuit in the event of a fault within 0.4 second (it would he 5 seconds otherwise). The control unit must be located within 2 m of the appliance (this also applies to 'split-level' cooking appliances).

Water-heater circuits

Generally derived from a 15 A or 16 A way, the circuit must incorporate a double-pole switch (usually of 20 A rating), with an additional switch recommended in close proximity to the immerser unit which should be connected by using heat-resisting flexible cable or cord.

6.3 Choosing cable sizes

The selection of the size of a cable to carry a load current involves the consideration of the rating and type of the protective device, the ambient temperature and whether other cables are run alongside the cable (grouping). There are many situations in which cables can find themselves being overheated. The more obvious are the conditions set up when overcurrents are carried due to overloading and when a short-circuit occurs. Others include the increase in temperature when a number of current carrying cables are bunched together, for instance in conduit and trunking, which is a situation in which each cable contributes its heat to that of others and which, because of tile enclosed situation, produces an environment, which can quickly lead to the deterioration of the cable insulation (particularly when PVC is involved) and lead to a possible source of fire. At about 80 ^{0}C, PVC becomes very son, so that a conductor can 'migrate' or travel through the insulation and eventually make contact with earthed metalwork. This produces a shock-risk situation, with an increase in the leakage current which could prove fatal if the installation earthing arrangement is faulty.Eventually, when the insulation breaks down completely, a short-circuit occurs and the circuit is now dependent on the ability of the over-current protection device to operate to disconnect the circuit from its supply. As is probably realised, the time of operation of the protective device is crucial: a semi-enclosed fuse will take longer to operate than would a miniature circuit-breaker. In some circumstances, particularly where PVC insulated cables are used, the time taken by a semi-enclosed fuse to operate may be long enough for the cables to burn out and create a fire hazard.

Another problem, which has occurred in recent years, concerns the use of thermal insulation in buildings, with cables being installed in conditions where the natural heat produced by even their normal load currents cannot be dissipated easily. The IEE Regulations recognise the fact that, in these circumstances, the ratings of cables have to be reduced quite considerably. These classifications are used in the tables, which give the current-carrying capacities of cables. The installation conditions include 'enclosed (e.g. in conduit, trunking and ducts); 'open and clipped direct' (e.g. clipped to a wall, to a cable tray, embedded direct in plaster which is not thermally-insulating, and suspended from a catenary wire); 'defined conditions', which include cables in free air; and cables 'in enclosed trenches'.

From this, it can be seen and appreciated that the selection of a cable to feed a circuit is now required to be undertaken with a number of factors to be considered carefully. Situations which were formerly taken for granted must now be investigated so that the cable is installed in the best conditions which will allow the cable to carry its load current with the safety of the user of the installation in mind.

The IEE Regulations require that the choice of a cable for a particular circuit must have due regard for a number of factors, and not just the circuit current. These factors include:

a) the ambient temperature in which the cable is installed;

b) the installation condition, e.g. whether grouped or bunched with other current-carrying cables, enclosed or installed open';

c) whether the cable is surrounded by or in contact with thermal insulating material;

d) whether the circuit is protected by semi-enclosed (rewirable) fuses to BS 3036.

The method of choosing the correct size of conductor for a particular load condition, as recommended by the IEE Regulations, is based on the rating of the overcurrent protective device. All factors affecting the cable in its installed condition are applied as divisors to the rating of the device. In general, the size of every bare conductor or cable conductor shall be such that the drop in voltage from the origin of the installation to any point in that installation does not exceed 4% of the nominal voltage when the conductors are carrying the full load current. It should be noted that conductors of large cross-sectional area have different volt drops per ampere per meter for ac circuits than those operating from dc supplies. This is because of the reactance inherent in conductors carrying ac.

The following process for working out the correct size of cables is as follows:

1. First find the load current of the circuit (I_B).

2. Determine the correction factor for the ambient temperature, which of course does not include the heat generated in the cable itself, but is more concerned with the maximum temperature of the medium through which the cable runs.

3. Determine the correction factor for grouping.

4. Determine the correction factor if the cable is in contact with or is surrounded by thermal insulation material. Two factors are given: 0.75 if only one side of the cable is in contact with the material (e.g. a cable clipped to the side of a joist) and 0.5 if the cable is completely surrounded by the material.

5. Select the rating of the overcurrent device. If this is offering what used to be called 'close' protection, the correction factor is 1. If, however, protection is by means of a semi-enclosed fuse, the factor is 0.725. The rating of the device must at least equal the load current.

6. Determine the size of the circuit conductor by calculating its current rating.

7. Check that the volt drop does not exceed the maximum permissible allowed.

If I_z represents the current rating of the conductor and I_n the rating of the protective device, then

$$I_z = \frac{I_n}{C_g \times C_a \times C_i \times C_f} \text{ amperes}$$

Where C_g is the factor for grouping;

C_a is the factor for ambient temperature;

C_i is the factor for thermal insulation (0.5 if cable is surrounded and 0.75 if the insulation is in contact with only one side of the cable;

C_f is the factor for the overcurrent device. This factor is 1 for all devices except semi-enclosed fuses, when the factor is 0.725.

6.4 Lighting Circuits

Final circuits

Electrical apparatus is connected by cables to the electricity supply, and to the associated protective and controlling devices (usually fuses and switches). This arrangement of cables is known as a circuit and circuits which connect current, using apparatus to the consumer unit or distribution board, are called final circuits.

Lighting final circuits

One of the earliest commercial uses for electricity was for the lighting of premises; indeed, some of the early installations had only lighting installed, as the number of electrical appliances were few.

The simplest lighting circuit is one lamp controlled by one switch and is known as a one-way circuit. The circuit commences at the protective device in the consumer unit, which is connected to the phase conductor of the supply. From here it goes to the switch controlling the circuit and from there to the lamp. From the lamp the cable returns to the consumer unit where it is connected to the neutral terminal of the consumer unit, so completing the circuit.

Two-way lighting circuits

For independent control from two positions, for example on a staircase, two-way switches are required. These switches have three terminals, one of which is called the common and is marked with a letter C; the other two arc called the strappers and are usually marked L1 and L2 respectively. The neutral conductor is taken to the lamp position. From the other side of the lamp, a conductor known as the switch wire is taken to the common of the second switch, and the two switches are linked by a pair of conductors known as the strappers. From the common of the first switch, a conductor known as the switch feed is taken to the phase.

With the switches in the positions shown in drawing (a); the current travels from the common of the first switch across the switch contacts to L2. From L2 it travels along the L2 strapper to the L2 terminal of the second switch; here it cannot go any further because the contacts of the second switch are open, so that the lamp does not light.

To make the lamp light, it would be necessary for someone to operate switch one so that the common is in contact with L1, as shown in drawing (b), or to operate switch two so that its common was in contact with L2. Either of these actions would complete the circuit and the lamp would light.

Intermediate lighting circuits

If it is desired to have control from three or more positions, intermediate type switches are necessary as well as the two two-way switches. Intermediate switches have four terminals and although the switch action of different makes of switch end up with the same results, the connections vary, so it is advisable to check the switch action before connecting up.The intermediate switches should be connect to the two strapping cables. This means that the circuit must always start and finish with the two-way switches. When using the commonest type of intermediate switch for three-way control, the circuit is wired as shown. The switch action in position one is shown with the solid line, and in position two with the dotted line. Operation of the two-way switches is carried out as normal and the lamp can be turned on or off from any of the three positions.

In another often used type, the L1 strappers from the two-way switches are connected into the nearest of the top terminals, but the L2 strappers are taken into the furthest of the bottom terminals (i.e. the cables are crossed over).

Conversion of a one-way circuit into a two-way circuit

On occasions, the electrician is called upon to make alterations to existing circuits. One of the more popular requests is to make a one-way circuit into a two-way.The conversion can be carried out quite simply by running a piece of three core and CPC cable from the existing switch position to the new position.

Methods of wiring lighting circuits

The loop-in method of wiring

For circuits wired in single core PVC insulated cable and are suitable for wiring carried out in conduit wiring systems. Much of the wiring done today, however, is carried out in composite cables such as PVC insulated, PVC sheathed, twin and earth cable. The technique used for this type of cable is essentially different for that of the singles cables, and the first method we are going to look at is the loop-in method.

This is probably the most common method of wiring domestic premises in use today. All the connections are made at the electrical accessories. A cable containing phase neutral and CPC conductors is run from the consumer unit to the first lighting point; a second cable is run down to the switch position. The connections are made inside the ceiling rose at the terminals provided and it should be noted that it is a requirement of the IEE Wiring Regulations that the phase terminal in the ceiling rose shall be shrouded. The reason for this is that, even with the switch in the off position, this terminal is still live until the power is switched off at the consumer unit.

If a further lighting point is required, an additional cable is run from the first lighting point to the new position. The phase, neutral and CPC conductors are connected into the corresponding connections on the first ceiling rose. At the new position, another ceiling rose is fitted and a cable taken down to the new switch position. The connections at the second position arc made off in exactly the same way as before. This procedure is known as looping in and out of the accessories, hence the name loop-in system. If any of the current carrying conductors are coloured black, then they must be identified with a red sleeve or piece of red tape, both at the ceiling rose and at the switch.

The joint box method of wiring

There are a number of different types of joint box, but the most popular pattern consists of a circular moulded plastic box in which is fixed four or more brass pillar terminals.

The joint box is sired in a position as near to the center of the area to be wired as possible, and fixed with wood screws to a suitable timber bearer nailed between the floor or ceiling joists. A composite cable, which contains the phase, neutral and CPC conductors, is run from the consumer unit and terminated in the joint box. Care should be taken to see that the cable sheath enters into the joint box, so no conductors are exposed on the outside. The CPC conductor is bare in composite cables, so it will be necessary to insulate this from the other cables in the joint box. This is done by fitting over it a plastic sleeving, coloured green and yellow in accordance with the IEE Wiring Regulations. To complete the circuit, further cables are run from the light position and the switch position.

IEE Regulations concerning lighting circuits

We have already seen a number of the regulations applicable to the installation of lighting circuits; however, there are several other points, which must be noted.

- Where conductors or flexibles enter a luminaire, as, for example, when a bulkhead fitting or batten lampholder is used, the conductors should be able to withstand any heat likely to be encountered, or sleeved with heat resistant sleeving.
- A ceiling rose, unless specially designed for the purpose, should have only one flexible cord.
- The flexible cord used to make up a pendant (the ceiling rose, flex and lampholder assembly) should be capable of withstanding any heat that is likely 7 -to be present in normal use.
- Where a flexible cord supports or partly supports a luminaire, the maximum mass supported shall nor exceed the values.
- A ceiling rose shall not be used on a voltage exceeding 250 V.
- Parts of lampholders, installed within 2.5 m of a fixed bath or shower, shall be constructed or shrouded in insulating material. Bayonet-type (B22) lampholders shall be fitted with a protective shield to BS 5042 (Home Office skirt), or a totally enclosed luminaire installed.
- Lighting switches shall be installed, so as to be normally inaccessible to persons using a fixed bath or shower.
- For circuits supplying equipment in a room containing a fixed bath or shower that can be touched at the same time as exposed conductive or extraneous conductive parts, the protective device shall disconnect the circuit within 0.4 of a second.
- For circuits on TN or TT systems, where an Edison screw lampholder is being used, the outer contact shall be connected to the neutral conductor.
- Final circuits for discharge lighting (this includes fluorescent luminaires) shall be

capable of carrying the total steady current, viz the lamp's associated gear and its harmonic currents. Where this information is not available, the demand in volt-amperes can be worked out by multiplying the rated lamp watts by 1.8. This is based on the assumption that the power factor is not less than 0.85 lagging.

- Semi-conductors may be used for functional switching (not isolators) provided that they comply with sections 512 and 537 of the Regulations.
- When installing lighting circuits, the current is equivalent to the connected load with a minimum of 100 W per lampholder. It should be noted, however, that diversity can be applied to lighting.

CHAPTER 7: SPECIAL INSTALATIONS

Though the bulk of electrical installation work carried out in this country does not involve the consideration of special factors in the context of the wiring systems, accessories and the equipment to be used in an installation, there are some types of installation conditions which call for special consideration. These conditions create the need for what are called in this chapter 'special installations', which tend to fall out with the general run of installations and require their special and particular requirements to be satisfied. These special installations are dealt with in the IEE Regulations in a rather general way and the electrician must therefore consult other sources of information as to installation procedures, techniques and recommended types of equipment. These sources include BS Codes of Practice and manufacturers' instructions, and IEE Regulations.

7.1 Damp Situations

In general terms a 'damp situation' is one in which moisture is either permanently present, or intermittently present to such an extent as to be likely to impair the effectiveness of an installation conforming to the requirements for ordinary situations. These situations create a hazard from electric shock (particularly from surface leakage over otherwise healthy insulation) and the risks, which attend a gradual deterioration of the metalwork of the installation as the result of corrosion.

The IEE Regulations require that every cable installed in a damp situation, and where it is exposed to rain, dripping water, condensed water, and accumulations of water, shall be of a type designed to withstand these conditions. In addition all metal sheaths and armour of cables, metal conduit, ducts or trunking, and clips and their fixings, shall be of corrosion-resisting material. In particular, they should not be placed in contact with other metals with which they are liable to set up electrolytic action. If steel conduit is involved in such damp installations, it must be of heavy gauge. Conduit threads should be painted over with a bituminous paint immediately after erection Cables, which are armoured and destined for installation in a damp situation, are required to have further protection in the form of an overall PVC sheath.

Even though an installation is not classed as 'damp', there may occasionally arise a situation, which could place it in this category. This is one result of condensation, which, though it might occur intermittently, may well appear in the form of a considerable quantity of condensate. Condensation exists where there is a difference in temperature, for instance, where equipment is installed inside a room in which the ambient temperature is high, the equipment being controlled by switchgear outside the room in a lower ambient temperature. If the switchgear and the equipment are connected by trunking or conduit, then condensation is likely to occur. It will also occur where a room has a high ambient temperature during the day and where the temperature subsequently falls when the room is unoccupied during the night.

Generally, whenever dampness, whatever its source, is present, galvanised or sherardised metalwork is recommended. In addition, site conditions may be such that fixing accessories and materials may also he required to withstand any corrosive action that might occur. If conduit is used, drip points should be provided so that water can drip away. Long runs of conduit should be slightly off level to allow any accumulated condensate to run to a drain point at the lowest level.

The problem of condensation occurs frequently in cold-store installations and around refrigeration plant. Switchgear and other control equipment should be installed outside the cold rooms in a position some reasonable distance away from blasts of cold air and clear of door openings where changes in temperature are likely to occur. Cables of the MICS and lead-sheathed types should be glanded into totally enclosed lighting fittings and run into the cold chambers on wood battens. Cable entries into cold rooms should be sealed with some bituminous material. It is important to recognise that working PVC cables in low temperatures will injure the cables. At temperatures below $0^{\circ}C$, PVC has a 'cold-shatter' characteristic and may crack if hit sharply. There is also a warning note regarding the use of cables with bituminous-compounded beddings or servings.

7.2 Corrosion

Wherever metal is used there is the attendant problem of corrosion. Two conditions are necessary for corrosion: a susceptible metal and a corrosive environment. Nearly all of the common metals in use today corrode under most natural conditions; the bulk of all anti-corrosive measures have thus been attempts either to isolate the metal from its environment, or to changing the environment chemically to render it less corrosive In installation work, the problems of corrosion tend to be more acute in certain types of installation. Chemical works, salt works, cow byres and other ammonia-affected areas, all require special consideration in their design and the work executed to produce the installation. Corrosion, in a normal installation condition, may affect earth connections.

The corrosion of metals in contact with soil or water is an electrochemical reaction; that is, the corrosion reaction involves both the chemical change (e.g., from iron to rust) and a flow of electric current. It is this principle, which is used in the dry cell, where the corrosion of the zinc case provides the cell's electrical output. The current flows from the metal into the soil or water (called the electrolyte) at the anode and then from the electrolyte into the metal at the cathode. Corrosion occurs at the point where the current flows from tile metal into tile electrolyte. Every metal develops its own particular electrode potential when placed in an electrolyte or similar medium. If two different metals are coupled together in the same electrolyte, tile difference between their potentials will be sufficient to produce a current of electricity. The metal with the more negative potential will suffer corrosion. It follows that the more compatible the metals are, the less will be the rate of progress of any corrosive action which takes place between them, because the amount of potential difference between them is reduced.

In general there is a 'natural' potential of -0.3 to - 0.6 V between a buried mass of metal and its surrounding soil. This potential is measured by using a very-high-resistance voltmeter and a device called a half-cell, which consists of a copper rod immersed in saturated copper sulphate solution contained in a plastic tube which has a porous plug at the bottom for making contact with the soil as near as possible to the buried mass. Certain areas of the mass surface will act as anodes (where the current leaves the metal) and these will corrode. The areas, which act as cathodes (where the current enters the metal) do not corrode. This sub-division in the areas of the surface of the buried mass is due to the fact that the areas assume the roles of anodes and cathodes depending upon variations in the metal itself, its surface treatment and the electrolyte.

The corrosion of a metal can be diminished by reducing the amount of current that flows from it into the surrounding medium or electrolyte. Painting or otherwise coating the metal will increase the electrical resistance of both anodes and cathodes. But if the coating has flaws or holes in it, then the current concentrates at these points and deep pitting will occur. The corrosion current can also be reduced by lowering the electrical potential difference between the anodes and the cathodes either by controlling the purity of the electrolyte or by adding inhibitors to it.

Because only the anodes corrode, corrosion can be prevented by current flowing into them from an introduced external anode so as to cause the whole of the buried structure to become a cathode. This is the principle of cathodic protection. The method can be used only where the introduced anode can be accommodated within the electrolyte that surrounds the buried metal, and the soil or water must be present in bulk.

The method is widely employed as a corrosion preventive measure on underground metalwork. Two basic techniques are used to give cathodic protection: (i) the sacrificial anode system; (ii) the impressed current system.

In the first method , a mass of base metal, such as magnesium, is buried in the electrolyte and connected electrically to the structure to be protected. The natural difference in potential between the structure metal, usually steel, and the magnesium causes a current to flow from the magnesium (the new anode) through the electrolyte to the steel, which is the new cathode. The anode gradually corrodes and is thus called a 'sacrificial anode'. In practice a closely controlled magnesium-alloy is used. The main factors which govern the degree of protection, and the current output from the galvanic cell so formed by the protective system, are the surface area, volume and shape of the anodes used, the resistivity of the electrolyte and the surface area of the exposed metal being protected. The sacrificial anode system is common in congested areas since the low potentials generated by the galvanic system virtually eliminate the possibility of corrosion arising on adjacent metal structures on account of stray current. The system also needs no external electrical supply and is to a great extent self regulating in output, which latter will vary according to the resistivity of the surrounding medium (e.g., in wet or dry weather conditions). The anodes need periodical renewal. In reasonable soil conditions, the life of an anode may be up to 15 years.

The second method of protection, the impressed-current system, uses a conventionally generated direct current from rotating machinery or via a transformer/rectifier unit. The negative side of the supply is connected to the structure to be protected; the positive side is fed to an 'anode ground-bed' usually formed from high-quality graphite impregnated by resin, wax or linseed oil, silicon iron or scrap iron or steel. The buried structure then

becomes the cathode. The anode may, but need not, corrode. Silicon-iron and graphite anode ground-beds are semi-inert and have a very long life. Scrap iron or scrap steel beds go into solution quite rapidly and disintegrate at the rate of about
10 kg/Ampere/year.

The metalwork associated with electrical installations, which may require cathodic protection include supporting lattice structures, armoured cables with rotted servings, metal pipes containing cables, and general structural steelwork.

Another aspect of corrosion may not be too familiar to installation installers. This concerns the continuous exposure of PVC-insulated cables to temperatures above 115°C that may cause the formation of corrosive products, which can attack conductors and other metalwork. Generally, the precautions to prevent the occurrence of corrosion in normal installations include:

1. The prevention of contact between two dissimilar metals (e.g. copper and aluminium), particularly where dampness is likely to be present.

2. The protection of cables, wiring Systems and equipment against the corrosive action of water, oil, and dampness, unless they are designed to withstand these conditions.

3. The protection of metal sheaths of cables and metal-conduit fittings where they come into contact with lime, plaster, cement and certain hardwoods such as beech and oak.

4. The use of bituminised paints and PVC over sheathing on metallic surfaces liable to corrosion in service.

7.3 Installation In Hazardous Areas

Flameproof installations

There are three main types of hazard to be considered: explosive gases and vapours, flammable liquids, and explosive dusts. Flammable liquids produce explosive vapours in greater or lesser degree according to their temperature. A liquid, which is safe at normal temperatures, may become heated to its flashpoint, above which temperature it is necessary to install flameproof equipment. Where flammable organic dusts (such as cork, sugar and flour) or metallic dusts (such as magnesium, aluminium, titanium and zirconium) are liable to be present, the electrical equipment used should be of the dust-proof type (Type 'V' in BS 587). Similar precautions should be taken where explosives such as cordite and gunpowder are involved.

For the purpose of specification, flammable gases and vapours met with in industry lassified in groups, as follows:

Group I - Gases encountered in coal-mining such as methane (firedamp)

Group II - Various gases commonly found in industry, such as blast-furnace gas, ropane,butane, pentane, ammonia, amylacetate and carbon monoxide, etc.

Group III -Coal gas (town's gas), coke-oven gas, etc.

Group IV -Acetylene, hydrogen, etc.

Generally, Group I is referred to as applying to the mining industry. Group II usually efers to the petroleum industry and processes involving the use of cellulose solvents.

Equipment, which is classed as 'flameproof', can withstand an internal explosion of he particular gas for which it is certified. It will also prevent any spark or flame from that explosion leaking out of the enclosure and igniting the surrounding atmosphere. In general, his is effected by wide machined flanges, which damp or otherwise quench the flame in its assage across the metal, but at the same time allow the pressure generated by the explosion to be dissipated. There are two types of apparatus: (i) mining gear which is solely used with armoured cable or special mining type flexible cables; (ii) industrial gear, which may be used with solid-drawn conduit, MICS cable, aluminium-sheathed cable or armoured cable.

All flameproof gear is certified and consists of two or more compartments, generally constructed in either grey or malleable iron. Each compartment is separated one from the other by integral barriers having insulated studs mounted therein to accommodate the electrical connection. Where weight is important, certain articles are made in aluminium alloy. All glassware is of the toughened variety to give added strength. The glass is fitted to he item with special cement. Certain types of gear, such as distribution boards, are provided with their own integral isolating switches, so that the replacement of fuses, maintenance, and so on, cannot be carried out while the circuit is live.

All conduit installations for hazardous areas must be carried out in solid-drawn 'Class B' equipment, with certified draw-boxes and accessories. Couplers are to be of the flameproof type with a minimum length of 5cm. All screwed joints, whether entering into switchgear, junction boxes or couplers, must be secured with a standard heavy lock nut. This is done to ensure a tight and vibration-proof joint, which will not slacken during the life of the installation, and thus impair both continuity and flame-proofing. The length of the thread on the conduit must be the same as the fining plus sufficient for the lock nut. Because of the exposed threads, running couplers are not recommended. Specially designed unions are manufactured which are flameproof and are intended to connect two conduits together or for securing conduit to an internally threaded entry.

Conduit of 20 mm diameter and 25 mm diameter can enter directly into a flameproof enclosure. Where exposed terminals are fined, conduits above 25 mm must be sealed with compound at the point of entry. Where a conduit installation is subjected to condensation, say, where it passes from an atmosphere containing one type of vapour to another, the system must be sectionalised to prevent the propagation of either condensated moisture or gases. Conduit stopper boxes, with two, three or four entries must be used. They have a splayed, plugged filling spout in the cover so that the interior can be completely filled with compound.

When flexible, metal-sheathed or armoured cables are installed, certified cable glands must be used. Where paper-insulated cables are used, or in a situation where sealing is necessary, a cable-sealing box must be used, which has to be filled completely with compound.

The following are among the important installation points to be observed when installing flameproof systems and equipment. Flanges should be greased to prevent rusting. Special care is needed with aluminium-alloy flanges as the metal is ductile and is easily bent out of shape. All external bolts are made from special steel and have shrouded heads to prevent unauthorised interference; bolts of another type should not be fitted as replacements. Though toughened glass is comparatively strong, it will not stand up to very rough treatment; a faulty glass will disintegrate easily when broken. Protective guards must always be in place. Conduit joints should always be painted over with a suitable paint to prevent rusting. Because earthing is of prime importance in a flame-proof installation, it is essential to ensure that the resistance of the joints in a conduit installation, or in cable sheaths, is such as to prevent heating or a rise in voltage from the passage of a fault-current. Standard flameproof gear is not necessarily weatherproof, and should be shielded from rain or other excessive moisture.

Being essentially a closed installation, a flameproof conduit system may suffer from condensation. Stopper boxes prevent the passage of moisture from one section to another. Draining of condensate from an installation should be carried out only by an authorised person. Alterations or modifications must never be made to certified flameproof gear. Because flexible metallic conduit is not recognized as flameproof cables to movable motors (e.g. on slide rails) should be of the armoured flexible cable type, with suitable cable-sealing boxes fitted at both ends. It is necessary to ensure that, as far as possible, contact between flameproof apparatus, conduit, or cables, and pipe work carrying inflammable liquids should be avoided. If separation is not possible, the two should be effectively bonded together. When 'maintaining equipment in hazardous areas, care should be taken to ensure that circuits are dead before removing covers to gain access to terminals. Because flexible cables are a potential source of danger, they should be inspected frequently. All the equipment should be examined for mechanical faults, cracked glasses, deterioration of well-glass cement, slackened conduit joints and corrosion. Electrical tests should be carried out at regular intervals.

The definition of a 'flameproof enclosure' for electrical apparatus is:
one that will withstand, without injury, any explosion of the prescribed flammable gas that may occur within it under practical conditions of operation within the rating of the apparatus (and recognised overloads, if any), as will ignite the prescribed inflammable gas which may be present in the surrounding atmosphere.

As might be expected, there are a number of statutory regulations, which are concerned with safety in hazardous areas, the areas being classed in three divisions:

Division 0: An area of enclosed space within which any flammable or explosive substance, whether gas, vapour or volatile liquid is continuously present in concentration within the lower and upper limits of flammability.

Division 1: An area within which any flammable or explosive substance, whether gas, vapour or volatile liquid is processed, handled, or stored, and where during normal operations an explosive or ignitable concentration is likely to occur in sufficient quantity to produce a hazard.

Division 2: An area within which any flammable or explosive substance, whether gas, vapour or volatile liquid, although processed or stored, is so well under the conditions of control that the production (or release) of an explosive or ignitable concentration in sufficient quantity to constitute a hazard is only likely under abnormal conditions.

An area, which falls into the category of Division2 is sometimes known as a 'remotely dangerous area'. If an area contains the conditions as described in Division 0, then electrical equipment is totally excluded from the area. Hut if such equipment is necessary in the area, it is possible to introduce special measures to reduce the risk, such as pressurisation or the use of intrinsically-safe equipment. The definition of the latter term (intrinsically-safe) is.'

1. Applied to a circuit, the term denotes that any electrical sparking that may occur in normal working under the conditions specified by the Certifying Authority, and with the prescribed components, is incapable of causing an ignition of the prescribed flammable gas or vapour; or

2. Applied to apparatus, the term denotes that it is so constructed that when installed and operated under the conditions specified by the Certifying Authority, any electrical sparking that may occur in normal working, either in the apparatus or in the circuit associated therewith, is incapable of causing an ignition of the prescribed flammable gas or vapour.

If there is any risk in a Division 1 area, the use is recommended of flameproof or intrinsically safe equipment.

CHAPTER 8: BUILDING SERVICES

While the electrical contractor's interest in a contract tends to be centered on the provision of a power-fed electrical installation which meets the requirements of the client's specification, there are other services with which he may be involved; these are outlined in general in this chapter. The extent to which these services are part of the overall electrical provision of a client's premises depends on the function of the building or buildings. When new buildings are being considered, the client or owner considers the extent to which additional services (e.g. radio and TV aerials, public-address systems, fire-alarms, clocks, telephones) are required. There is of course the difficulty and cost incurred if these are installed after the main building is completed. The disturbance to decorations is an expected result of inadequate planning and adds further expense, which can be avoided in the initial stages of the electrical provisions.

Multi-tenanted office blocks require really detailed planning for the provision of adequate socket outlets for mains-operated machines, and for bell and telephone circuits with outlets placed in all possible strategic positions which will appear 'right' irrespective of alterations in sectional wall positions, changes in the positions of desk and other office furniture, or changes in the functions of rooms. Separate metering for different tenants may also have to be considered.

Industrial premises have their work areas reasonably stable once the machinery and equipment is installed. Even so, the systems of secondary electrical services have to be considered in the event of possible foreseeable changes.

Domestic premises present the least number of problems where the provision of services is required. However, it is conman nowadays to cater for door-bells, radio and TV aerials and rant' points, and telephone companies' telephones. Boarding houses and hotels may require extended bell-call Systems, and extension phones connected to a small private exchange switchboard.

Premises, which comprise a number of buildings, may require outdoor lighting, flood-lighting provisions, or road lighting.

8.1 Clock Systems

These clock systems are used where a number of clocks throughout a building are required to show the same time, or else used to operate time-recorders for stamping timeds which indicate when work has been started or finished.

Most clocks found in small installations are independent units, run by a synchronous tor fed from mains voltage. Impulse-clock systems are independent of mains and operate m extra-low voltage supplies. The master clock is the name given to the primary unit, ich controls all other clocks in the installation. It is pendulum-operated and has an pulse transmitter, which transmits electrical impulses of alternate polarity at one-minute ervals over a two-wire circuit to the subsidiary or 'slave' clocks. The slave clocks have ovements, which accept these impulses and alter their clock hands accordingly.

The mechanism of one type of master clock consists of a pendulum of half-seconds at operated by an electrically wound spring through a dead-beat escapement. At each e-minute interval, while a small synchronous motor is rewinding the main spring, an pulse is transmitted to the subsidiary clocks. The mains arc. supply is transformed to 48 for operating the synchronous motor and again reduced and rectified to provide 24 V d.c. r the transmitted impulses. Should the mains supply be interrupted for any reason, the ain spring has a sufficient reserve to operate the escapement movement and hands for out 10 hours, though no impulses will be transmitted to the subsidiary clocks. The ovement of a subsidiary clock is a one-minute polarised movement with a rotating mature, and incorporates a flywheel to render the hands 'dead-beat'.

The usual master-and-slave installation can cater for up to 60 clocks. To add clocks to e system, it is only necessary to connect a clock in parallel with the remainder. The clock ad and the connecting cables should total a certain value of resistance so that the farthest-way clock has sufficient voltage at its terminals.

The impulse current is around 220 mA. In series-impulse clock systems, the voltage equired for the installation is calculated as the total resistance of the clocks plus the line esistance multiplied by the impulse Current of 220 mA, i.e., $(R_2 + R_1) \times 0.22$ A = voltage equired. Sixty volts is the recommended maximum. Should the required operating voltage e above this, the installation should be sub-divided. As it is occasionally required to emove a clock from a series system, 'shorting-blocks' are provided.

.2 Sound Distribution Systems

Sound-distribution Systems consist essentially of loudspeakers permanently installed n suitable positions in buildings or in open spaces associated with buildings - They are essentially part of the telecommunications Systems of buildings. The currents, which operate such systems, are derived from a microphone, gramophone, radio receiver or other device, or from a wire broadcasting service. These currents are of a very small order and so require to be amplified to values suitable for the operation of loudspeakers. Sound-distribution systems are found in schools, theatres and cinemas, churches, meeting halls, factories, offices and department stores, hotels and clubs, hospitals, railway stations and sports grounds. Though these systems generally operate from mains supplies, some systems, or parts thereof, operate from batteries or from mains-supplied rectified current, producing low voltages.

8.3 Personnel call Systems

These systems are used in private dwellings, hotels, schools, factories and other premises where it is required to attract the attention of individuals to a situation or circumstance. The simplest system is where a person is called to a particular position by a caller. In a private house, the householder is called to the door. A bellpush or similar device is fitted at each such position and an indicator provided to show which push has been operated. A bell or buzzer is used to provide the sound, which will attract attention to the call. Bellpushes can be of the wall-mounted, table or pendant type; the contact points are of a metal, which gives long service without becoming pitted or corroded. If the bellpush is to be installed outside, protection against the ingress of moisture must be provided.

Indicators are installed in a central position in the building. In large premises, such as hotels and factories, the indicator board is located in a room in which some person is always in attendance, e.g., kitchen or reception office. The use of lamps is necessary where the sound of bells must be either objectionable or useless, e.g., in hospitals at night or in noisy workshops. Hand-setting indicators should be mounted at a height convenient for access and visibility.

Multiple-call systems are used in very large hotels where the call points are too many to be indicated conveniently on a single indicator board or panel. Pushes are fitted at each call point, but the circuits are grouped to serve a corridor or floor. Each group gives the indication in a central service room. In these systems, arrangements must be made to have attendants on duty in corridors or floors to deal with the calls. Multiple-call systems use indicators, which have to be reset by the attendant.

Time-bell systems are common in schools and factories to indicate the beginning or ıd of a time or period (e.g., break, class change, etc.). These systems usually have one or /o pushes or other switches connected in parallel and a number of bells throughout the uilding, which are also connected in parallel. The bells can be controlled from a clock ystem, to eliminate the human element required with bell pushes.

The burglar-alarm system is also a call system. The switches in this case are sets of ɔntacts mounted at doors and windows. There are two circuit types; open-circuit and osed circuit. The first type requires contacts to close to energise the bell circuit. In the osed circuit type, all contacts are closed. A series relay with normally open contacts is nergised by a circulating current. When a contact set is opened, this current ceases to flow, e-energises the relay and closes the relay contacts to ring an alarm bell. Some alarm ystems operate from photoelectric cells, which work when an invisible light beam is roken. The large plate-glass windows of jewelers' shops often have a series length of very iin wire, which, if broken when the window is smashed in or a hole cut in it, will bring the elay into operation to ring a bell. In certain systems today, no bell rings, but a buzzer and ght indication circuit is wired from the protected building and terminated at a nearby olice station. Thus the intruder is not warned, and the police have the opportunity of atching the burglar red-handed.

The open-circuit system is seldom used because it can be interfered with. For ıstance, a cut in a wire will render the complete system inoperative, whereas such a break ı the series circuit of a circulating-current (closed-circuit) system will immediately set an larm-bell ringing. Supplies are sometimes from the mains, but in this instance a standby-attery supply is provided in the event of a power failure. Alarm bells are often installed in place inaccessible to unauthorised persons, and outside the building.

Another type of call alarm system is the watchman's supervisory service. It is esigned to provide a recorded indication of the visits of watchmen or guards to different eans of a building in the course of the duty round. The system uses a clock movement of ne impulse, synchronous-time controlled a.c. or 8-day clockwork type installed at each ontact station throughout the building. Each station has a box with a bell push operated by ne insertion of a special key. Operation of the contacts energises an electromagnetically-perated marker which records the time of the visit on a paper marked off in hours. In some systems, an alarm is given after a predetermined time if the watchman fails to 'clock in' at any contact station.

Luminous call systems are used instead of bells. These Systems use colour lights, which summon staff to fulfill a service duty. They are largely used in hospitals and hotels. When the bell push is pressed in any position in the building, a small lamp lights in a duty room to indicate the general area from which the call has come. Alternatively, a lamp outside the call room lights and remains so until an attendant extinguishes it by operating a reset push located just outside the room. Some systems incorporate a single-stroke bell. Call and indicating circuitry is also incorporated in lift systems.

8.4 Fire-Alarm Circuits

A fire-alarm is defined as 'an arrangement of call points, detectors, sounders and other equipment for the transmission and indication of alarm and supervisory signals, for the testing of circuits, and where required, for the operation of auxiliary services' Section 37(7) of the Factories Act of 1937 states: where in any factory... more than 20 persons are employed... effective provision shall be made for giving warning in case of fire, which shall be clearly audible throughout the building.

A fire-alarm system consists of a number of press-buttons or call-points, which operate bells, sirens or hooters, generally known as 'sounders'. Manually operated call-points are effective only if there are persons present to give an alarm. But if protection from fire is required when the premises are unoccupied, as at night and during weekends or during holiday periods, then automatic call-points are necessary. On very large premises, additional circuitry is included in fire-alarm systems to give an indication of the location of the fire, so that firemen can go directly to the fire and allow staff to leave the building by safe routes which by-pass the fire area.

The closed-circuit type of system is used so that circuit failure or breakage will at once be indicated by an audible alarm. Manual call-points consist of a pair of contacts kept together by a thin sheet of glass, which, if broken, in the event of a fire, or maliciously, will cause the contacts to separate and, through a relay, energise a bell or alarm circuit. All call-points are required to be coloured red. The method of operation (e.g., 'Fire Alarm: in case of fire, break glass') must be clearly indicated either on the point itself or on a label beside it.

Automatic call-points are known as 'detectors' and are heat-sensitive, which means that they are sensitive to a rise in the ambient temperature of a room. They come into operation at a predetermined temperature (e.g., $80^{\circ}C$).

There are two types of heat detector. The more common type is the 'point' detector, which, as its name suggests, is relatively small. The other type is the 'line' detector, which has a long continuous sensitive detecting element extending over a large area of ceiling. The sensing elements used in heat detectors include:

1. Metal strips, rods, wires or coils, which expand when heated.

2. Fusible alloys.

3. Conductors whose electrical resistance changes with a rise in the ambient temperature.

4. Hollow tubes containing a fluid, which expands on heating and applies the resultant pressure to a diaphragm.

5. Thermocouples.

Some detectors ate of the light-sensitive type: photoelectric cells which operate when a beam of light illuminating the cells is scattered and absorbed by smoke particles. Heat and smoke detectors are liable to give false alarms in certain conditions:

a) Heat detectors. False alarms may be caused by abnormal increases in temperature due to space heating equipment, industrial processes and sunshine.

b) Smoke detectors. False alarms may be caused by smoke and other fumes, dusts, fibers and steam produced by normal processes and activities, or by passing road vehicles. Those detectors, which use a beam of light to illuminate a photoelectric cell, may also give false alarms if the beam is accidentally obstructed.

Automatic call-points are sometimes designed to give an alarm and also to bring into operation an auxiliary fire service, such as a sprinkler system. Other examples of such services are the closing of windows and the closing of the covers of tanks, which contain inflammable liquids.

Some means of giving an audible warning of fire is a statutory obligation in certain premises under the Offices, Shops and Railway Premises Act, 1963. Normally for these premises, an automatic fire alarm system must also be capable of manual operation, but this may not be necessary if the fire risk is low.

In a large installation a visual indicator panel (enunciator board) sited in a position agreed with the local Fire Authority, is normally incorporated in the system. All circuits to which detectors are fitted are connected to it. Each circuit is connected to a separate enunciator, so that when a detector actuates, it indicates on the board the area in which the fire has occurred. The panels are also provided with test facilities, by means of which the circuits can be tested and certain faults indicated. With some systems, faults are indicated automatically.

Warning devices included bells, sirens, hooters or whistles; they may be arranged to give either local or general alarms. In either case, the warning should sound continuously once a detector has operated, until the Fire Brigade arrives. An external audible warning device is recommended for mounting near to the visual indicating panel. The device should indicate which building is involved, this being particularly necessary for premises, which comprise several buildings. In hospitals, department stores and other places where a general internal alarm is not thought desirable, an alarm may be given at a manned central point only and warning passed by telephone or light signal to other parts of the premises.

The object of an automatic fire-alarm system is to call the fire brigade. The most effective and reliable means of satisfying this requirement is the provision of a signal, which is automatically transmitted to the local fire brigade, through a direct-line connection. The line can be continuously monitored so that an immediate alarm is given as soon as a fault develops; regular testing can be arranged.

Some methods use an auto-dialling unit at the protected premises, which connects alarm calls in the form of a pre-recorded message, either via the public '911' emergency call service to the appropriate fire-control room, or direct via the automatic telephone system to a pre-selected telephone number. This method is cheaper than the direct-line method, but is less reliable. It for some reason, connection to the appropriate fire-control point is not achieved at the first attempt, it is possible for an alarm call to be lost. Also, this system cannot be continuously monitored for faults because it is not permanently connected to the point where the alarm calls are received.

Recommendations on wiring and equipment used are set out in BS Code of Practice BS 5839, which also includes recommendations on suitable power supplies.

The following bibliography contains information on fire alarm systems:

Rules for Automatic Fire Alarms - Fire Offices' Committee

BS 3116 - Heat Sensitive Detectors for Automatic Fire Alarm Systems in Buildings

Automatic Fire Detection and Alarm Systems -Fire Protection Association. Fixed Fire Extinguishing Equipment in Buildings - Fire Protection Association

The IEE Regulations recognise fire-alarm circuits as 'Category 3' circuits, in that fire-alarm circuits, for reasons of security, should be segregated from each other as well as completely separated from any other wiring. Mains-voltage circuits (Category 1) for sounders, battery-charging and other auxiliary circuits in a fire-alarm system should also be completely separated from other (Category 2) circuits in the same fire-alarm system. If Category 3 (fire-alarm) circuits are wired in MIC's cable, the cable may be laid in a common trunking or channel, but must not be drawn into a common duct or conduit.

8.5 Radio and TV

The erection of aerials for the reception of radio and TV broadcasts is usually undertaken by the specialist. In buildings, which consist of blocks of flats, communal pick-up services are provided, being fed from a communal pre-amplifier. This unit is installed as near as possible to the aerial site so that any interference picked up by the intervening feeder is reduced to a minimum. The contractor's interest in these Services is mainly confined to the provision of conduit or socket-outlet facilities. In a multi-point television installation, Up to twenty receiver points may be connected to one cable, which is looped through the socket-outlets.

8.6 Telephone Systems

These systems are either internal or are connected to the public telephone facilities. All installations, which have public connections, are subject to the supervision and approval of the telephone companies whose engineers normally undertake the final connecting-up. The electrical contractor is generally required to install conduit or trunking to facilitate the wiring of the building for telephone outlets. In large buildings a main switchboard is installed to receive incoming calls, which are then switched to the required extension phone. There are two types of private installations: PMBX (private manual branch exchange) and PABX (private automatic branch exchange).

In the PMBX system, each extension phone is wired to the main switchboard and connection is made by sockets called jacks. There are certain disadvantages associated with nis system, which usually requires an additional internal phone system.

In the PABX system, all incoming calls are terminated at the manual switchboard and re answered by the telephone operator. All extension to extension calls are set up utomatically and direct out dialing on certain extensions is possible. All extension phones an call the operator who can identify the extension on a lamp-per-line basis. Direct access o the local Fire Brigade can be incorporated in the system, a special code being allocated or this purpose. A cordless switchboard (PMBX 4) is a more recent development of the PABX system. It has a switchboard with a translucent screen or lamp signaling. It enables he operator to supervise and connect all calls with full control given by a few levers and eys. When a call is transferred to an extension it disappears from the switchboard and is hen under the full control of the extension; this is a feature not available with the older pproved system known as PABX 3.

CHAPTER 9 : ILLUMINATION

9.1 Some Kinds of Lamps

Filament lamps

Filament lamps fall into a group of light-producing devices called 'incandescent'. They give light as a result of heating a filament conductor to a very high temperature. In 1860, Sir Joseph Swan produced the first lamp using carbonised paper strip. Later, carbonised filaments made from silk were used. Until 1900, carbon-filament lamps enjoyed an undisputed field of use. Then the metal-filament lamp appeared and by 1910 it had superseded the carbon lamp. The carbon lamps, which are made today, have a limited application: for lamp resistances (battery-charging), and radiant-heat apparatus. The modern carbon lamp has a filament of Swedish filter paper, which is dissolved in zinc chloride solution. The resultant viscous solution is squirted slowly through a fine die into a jar of acidified alcohol. Tough cellulose threads are the result. They are wound on formers, which are packed into a crucible filled with finely powdered graphite. The crucibles are then baked in a furnace at 1400°C when the cellulose threads become pure carbon. The temperature limit for a carbon filament is about 1800°C. The light output is low, at about 3.6 lumens per watt (lm/W).

The tungsten-filament lamp first appeared about 1910 and has since been the main incandescent lamp in use. It operates at a temperature of about 2300°C and has a light output of about 8 lm/W. The first lamp to use a tungsten filament had the air evacuated from the glass bulb the so called vacuum lamp. Later, the bulb was filled with argon and nitrogen which are inert gases and do not support combustion. This development enabled the filament to be operated at a higher temperature without the undue evaporation of the filament, which tends to take place in a vacuum. The operating temperature of the gas-filled lamp is about 2700°C. The light output is in the region of 12 lm/W. The early lamps had a single-coil filament. Later the coiled-coil lamp was produced, that is, the coiled filament was itself formed into a coil. The light output of this lamp is about 14 lm/W. The main advantages of the coiled-coil lamp are (a) the filament has a more compact formation and (b) the beat losses due to convection currents in the gas are reduced, so giving a higher light output efficiency.

Tungsten has a resistance, which increases with temperature. The resistance when cold is about 6 per cent of that when operating at normal temperature. This means that when the lamp is switched on, a current of about fourteen times the running current flows. The increase in the temperature of the filament is rapid, however, and the current surge does not harm the filament. The resistance of the filament increases as rapidly and has a stabilising effect on the power consumed.

There are many types of metal-filament lamps available today. Signal lamps are small and are used on indication boards to show the flow of chemicals, the passage of trains past a given point, and the energising of a circuit in a definite sequence. Spot and flood lamps are made from pressed glass and are internally mirrored to radiate a defined beam of light. The flood lamp has a relatively broad beam and is used for outdoor illumination such as gardens, monuments, parks and sports grounds. The spot lamp has a narrow beam and is found in shop windows and showcases. They are also used to highlight an object, which has a general illumination. Thermal -radiation lamps are used in piglet and chicken rearing. They are hard-glass bulbs and are internally mirrored for use for short-periods at a time. They are also to be found in bathrooms, and in industry for drying processes (e.g. stove enameling).

Discharge lamps

The discharge lamp consists of a glass tube containing a gas. At each end of the tube there is an electrode. If a sufficiently high voltage is applied across these electrodes a discharge takes place between them. The gas now becomes an electrical conductor and light is produced. The colour of the light produced by a discharge lamp depends on the gas in the tube: Neon - red; mercury vapour - bluish-white; helium - ivory; sodium vapour - yellow.

There are a number of electric-discharge lamps available today, each of which has a particular application or advantage over another.

Low-pressure mercury-vapour

This lamp is popularly known as the 'fluorescent' lamp. It consists of a glass tube filled with mercury vapour at a low pressure. The electrodes are located at the ends of the tube. When the lamp is switched on, an arc-discharge excites a barely-visible radiation, the greater part of which consists of ultra-violet radiation. The interior wall of the tube is coated with a fluorescent powder, which transforms the ultra-violet radiation into visible radiation or light. The type of light, that is the colour range, is determined by the omposition of the fluorescent powder. An important aspect of the gas-discharge lamp is hat the discharge has a 'negative resistance characteristic'. This means that when the emperature of the gas or vapour rises, its resistance decreases and will thus tend to draw an ever-increasing current from the supply. The current is limited to a predetermined value by he insertion in the circuit, in series with the lamp, of a limiting resistor or choke (inductor).

There are two types of fluorescent lamp: the hot-cathode and the cold-cathode.

The hot-cathode lamp is the more common type, familiar in tube lengths of 2.5, 1.7, 1.3 m and down to 30 cm. In this type, the electrodes are heated and the voltage of operation is low or medium voltage. To assist starting, the mercury vapour is mixed with a small quantity of argon gas. The light produced varies from 30 to 35 lm/W. The colours available from the lamp include a near-daylight and a colour-corrected light for use where colours (of wool, paints, etc.) must be seen correctly. The practical application of the lamp includes the lighting of shops, homes, factories, streets, ships, transport ~uses and trains), tunnels, coalmines and caravans. The auxiliary equipment associated with the hot-cathode lamp includes.

1. The choke, which supplies a high initial voltage on starting (caused by the interruption of the lamp's inductive circuit), and also limits the current in the lamp when it is operating.

2. The starter.

3. The capacitor, which is fitted to correct or improve the power factor of the circuit by neutralising the inductive effect of the choke.

There are a number of methods used to start fluorescent lamp circuits.

The methods fall into two general groups." those which use a switch (sometimes called a 'glow' starter) and those, which do not use a switching arrangement but rely on an autotransformer to produce the high voltage, needed to start the lamps. With the glow-starter, it is important to use the correct type for the size of lamp. Although 'universal' starter switches are available, it must be remembered that they are not in fact suitable for all sizes.

The semi-resonant start circuit has the usual choke or inductor replaced by a specially wound transformer and is used for starting fluorescent lamps in cold temperatures. Current flows through the primary coil to one cathode of the lamp and thence through the secondary coil, which is wound in opposition to it. A large capacitor is connected between the secondary and the second cathode of the lamp. The starting current quickly heats up the cathodes and as the circuit is mainly capacitive; this current leads the mains voltage. Because the primary and secondary windings are in opposition, the voltage across the lamp is increased and causes the lamp to strike.

The glow-start switch consists of two-separated bimetallic contact strips contained in a small glass bulb filled with helium gas. The contacts are connected in series with the lamp electrodes. When the circuit-control switch is closed, the mains voltage appears across the two contacts and results in a small gas discharge. The heat generated by the discharge effects the bimetallic strips, which bend forward to meet each other. When they make contact, current flows through the lamp electrodes to heat them. The gas discharge in the bulb ceases and the strips begin to cool down. When they separate, a high voltage appears between the electrodes and the main gas discharge is started. The voltage, which now appears across the contacts in the bulb, is, during running conditions, insufficient to cause further discharge in the helium gas, and so the contacts remain open while the lamp is burning.

The instant-start or 'quick-start' method of starling fluorescent lamps consists of an autotransformer connected across the tube. Two tappings provide a small current for heating each of the electrodes. When the electrodes become hot (usually in a fraction of a second) the tube strikes. The striking or discharge is caused by the very small currents flowing from the cathodes to an external earthed strip, which runs down the length of the tube, providing a conducting path. A normal choke is used, but only for current-limiting purposes, since there is no interruption of the current on starting.

The cold-cathode lamp uses a high voltage (about 5kV) for its operation. For general lighting purposes, they are familiar as fluorescent tubes of about 2.5 cm in diameter, straight, curved or bent to take a certain form. The power consumption is generally about 24W per meter length. The current taken is of the order of milliamperes.

Cold-cathode neon lamp

The 'domestic' type of this lamp is the small 'pygmy' lamp, which operates on mains voltage and produces a dull-red glow. Very small lamps are used as indicating lights on wiring accessories (e.g. socket-outlets and switch positions) and on control panels, where space is at a premium and the small filament lamp cannot be accommodated. The fact that these tiny neons take an insignificant current and do not beat up is another factor in their favour for signalling and indication purposes. Neons are now popular for showing up switch Positions in a dark room.

The more familiar lamp of the neon-discharge type is used for sign and display lighting. As the electrodes (or cathodes) are not heated, a high voltage is used for both starting and operation of the lamp. This voltage is obtained from a double wound transformer, which transforms the mains at 240V to 5000V to earth (this is the maximum voltage to earth allowed for such circuits, though values of 10kV may be applied to tubes from a transformer with an earthed and center-tapped secondary winding). Most high-voltage neon lamps Consist of short lengths of glass tube bent to form a particular shape or letter and connected in series.

Sodium-vapour lamp

This lamp gives an orange light and is used mainly for street and road lighting, and on airfields. The lamp is the most efficient producer of light, but because of its single-colour characteristic it gives many items an inferior colour quality (everything looks yellow or grey to black). The lamp consists of a long glass tube, usually bent into a U-shape. The tube contains a mixture of argon and neon gases, with particles of solid sodium. The lamp is operated from an autotransformer, which raises the mains voltage to about 350-400V. When the circuit-control switch is made, the tube gives off an initial reddish glow, the result of the discharge through the neon-argon gas. The heat of the discharge vaporises the sodium and after about ten minutes or so, the vapour fills the tube. The colour of the light emitted changes from the neon red to orange. Because the sodium is at a very lo pressure, it will not vaporise if the tube is cooled in any way. To prevent this, the tube is enclosed in a double-glass jacket, with an evacuated space, which conserves the tube's heat. When in operation the running voltage falls to between 100 and 150V, depending on lamp size. The transformer used has a high leakage reactance so that no current-limiting device is needed, such as in other discharge-lamp circuits. Because of the danger of the sodium vapour condensing on the electrodes of the lamp when it is cooling down after being switched off, these lamps are usually designed for operation in a horizontal or near-horizontal position. Lamp sizes vary from 45 to 200W, the latter being a recent development in a corrugated ιear form instead of the more familiar U-shape. The lamp circuit has a power-factor ›rrection capacitor to improve its overall power-factor. The lamp will start immediately ıether it is hot or cold. Care is necessary in disposing of used sodium lamps, because etallic sodium may burn if it comes into contact with moisture or water.

High-pressure mercury-vapour lamp

This type of lamp is used for street and road lighting, floodlighting and lightining dustrial premises. The light emitted is bluish-green in colour. There are several types of PMV lamp. They are classed according to the loading per centimeter of arc length. The mp consists of an inner bulb or lamp proper made of special silicate glass to withstand the gh temperature of the arc, surrounded by an outer glass bulb. This arrangement prevents e loss of heat from the inner bulb and also the emission of unwanted ultra-violet diation. The space between the two bulbs is either evacuated or filled with an inert gas. ıe inner bulb has sealed into it three electrodes, the main electrodes at each end and a ird, or starting electrode, adjacent to one of the main electrodes. The lamp contains a tiny obule of liquid mercury and argon gas at low pressure. The starting electrode is connected the main electrode farthest from it by a high resistance of the order of 50k-ohms. The ectrodes are special electron-emitting cathodes, coated with oxide. When the circuit- ›ntrol switch is made, the mains voltage appears across the tip of the starting electrode ıd its adjacent main electrode. A discharge takes place through the argon gas. The heat ›m this discharge gradually vaporises the mercury globules. The vapour carries the scharge along the lamp tube until the main discharge takes place between the main lamp ectrodes. The lamp takes about five minutes to reach its full light output. The current ken by the discharge is limited by a choke connected in series with the lamp. The circuit provided with a power-factor correction capacitor. As the lamp heats up, the internal essure increases to about 20 atmospheres in the larger sizes of lamp with a loading of)0W/cm of arc length. After switching off, these lamps will not restart until they have ›oled down. The lamps are operated in a vertical or horizontal position, depending on pe. The suffixes V, H and U (universal) are used to indicate the method of mounting.

Special lamps

There are special lamps available for particular duties. One such is a recent ›velopment: the quartz-iodine lamp, in which iodine vapour is used to control the rate of evaporation of the filament material, thus prolonging its life. This type of lamp is smaller than other types of filament lamp though the problem of heat dissipation is greatly increased. Usually the metal housing of the lamp fitting is of finned construction, and the terminal chamber for cable entry is partially separated from the main housing. The main application of this lamp is for floodlighting. The reflectors used are protected by toughened glass, because there can be a considerable difference in temperature between the edge and the center.

Another lamp is the super high-pressure mercury vapour. It has a very high efficiency and is of very small size. A 70W lamp is less than 5 cm long and has an efficiency of about 40 lm/W. The light produced is almost white. The arc tube is of quartz and is cooled by being placed in a jacket containing running water.

Flash lamps of the xenon-gas type are used for photographic work and for the stroboscopic illuminators used for investigation and test purposes. The discharge through the gas is produced by a large capacitor discharging its held charge; the resultant light produced is extremely bright and white.

The mercury/tungsten blended lamp consists of a quartz mercury discharge tube with a series-connected tungsten filament which acts both as a light source and as a ballast-resistance controlling the current in the discharge tube and making it independent of external gear. The combination of blue-green light from the mercury discharge and the reddish-yellow light from the tungsten produces a better colour than the mercury-vapour lamp alone. This lamp has a very long life.

Practical aspects of lighting

Though many aspects of lighting or illumination are the special concern of the qualified lighting engineer, there are some, which also affect, either directly or indirectly, the electrician. These aspects are dealt with in the following sections.

Ambient temperature of lamps

The recent development in lamp sizes and the increase in ratings used in domestic, commercial and industrial installations has led to problems resulting from the heat generated by these lamps. If a 1000W lamp is operated in an ambient temperature of 25°C, the temperature rise can be greater than 60°C. This means that if the lighting point is a pendant, the flexible cord will be in an ambient temperature of 85°C. It has always been accepted that, owing to such high temperatures near the lamp-holders, embitterment of the insulation of the cord will occur, with consequent shortening of the life of the cord. The trend in recent years has been to manufacture lamps smaller in size than that of the equivalent wattage previously made, so that it has become possible to use a higher wattage lamp in an existing type of fining. For instance, whereas in the past temperatures in enclosed fittings may have been as high as 80°C or so, it is now possible for temperatures to be as high as 130°C and even more where the ambient temperature is also high.

The IEE Regulations have recognised this problem of heat from lamps and now recommend that the choice of a flexible cord for a particular lighting duty should be based, not only on current rating, but on the ambient temperature likely to he encountered at a lighting point. Certain new heat-resisting materials are now available.

Conductors for very high temperatures are now nickel-plated copper, instead of the usual tinned-copper; some conductors are natural copper and are associated with thermoplastic insulating materials such as polythene and polyvinyl chloride (PVC). The greatest advances have been made with insulating materials. Natural rubber is now limited to use where the temperatures do not exceed 65°C. Above this limit the rubber becomes hard and the life of a cord may be as little as a year or so. Inspection of rubber insulation, which has become hard during service, has shown that it may still function as an insulator provided the cable is not fixed.

Polyethylene (polythene) has many electrical properties. But it is a thermoplastic material and deforms seriously under pressure and excessive heat. At about 110°C there is a sharp melting point when severe flow may take place with consequential electrical failure. This type of cable is not used in lamp finings. PVC has excellent age-resisting properties, but has a low maximum operating temperature of 70°C. This type is also not used for lamp fittings, unless the ventilation is adequate.

Butyl-rubber insulation is suitable for lamp fittings where higher ambient temperatures are prevalent. The maximum permitted operatig temperature is 85°C. At this temperature, the cable has a long life. At higher temperatures the insulation deteriorates rapidly. Around 130°C it turns to powder. Silicone rubber can be operated continuously at 150°C, and is used for many of the enclosed lamp fittings installed at the present time. The physical properties of this type of insulation are such that a suitable protection is necessary and a heat-resisting braid is normal for this purpose. Glass braiding with a heat-resisting lacquer is an excellent finish, but makes an expensive cable. An alternative is terylene braiding, which is considered ideally suitable for many lamp fittings. Another good heat-resistant type of finish is an impregnated glass lapping with an impregnated glass braid. The temperature of operation of this type of cable may be as high as 180°C. For enclosed lamp fittings, where temperatures of this order are obtained, this cable is a suitable answer. installations, are chlorosulphonated polyethylene (CPS or 'Hypalon') and PVC

Two sheathing materials, which are used widely in /nitrile rubber (NCR/PVC) generally known as HOFR insulants. These materials are both vulcanisable rubbers and besides having good weathering, solvent and oil resistance, are flame retardant. They may be compounded so as to be used over an insulated conductor operating at 85°C. Another new product, which appears suitable, particularly for insulation, is ethylene propylene rubber. The age-resistance of this material is proving excellent and may well prove to be a common material in the near future.

The effect of voltage drop

The voltage applied to a lamp is reduced if the actual voltage at the lamp terminals is lower than the rated lamp voltage. Generally, the reduction in light output is more rapid than the reduction of the wattage. It is therefore not economical to run lamps at less than the rated voltage. Another aspect of reduced voltage at the lamp terminals is that financial loss can be experienced in addition to less light being available. Over-volting a lamp by 5 per cent (e.g. a 230V lamp on 242V) halves its life, as the filament is operated at a higher than normal temperature and vaporises more rapidly. On the other hand, under-volting a lamp lengthens its life but reduces its light output without a corresponding reduction in the wattage consumed. Electricity, in effect, is being run to waste.

Voltage drop can also occur as a result of the lighting cables being too small for the current carried. This situation may arise when old wiring is allowed to supply new lamp fittings, which contain lamps with higher wattage ratings. In fact, in many modern commercial and industrial premises it is often found that with high-wattage lamps being used and long circuit runs, cables larger than the usual 1, 1.5 and 2.5 mm^2 are necessary.

Faults in discharge lamps

Because of their associated circuitry, containing components such as starters, chokes and capacitors, and transformers, discharge lamps may fail or fault, to show certain symptoms which can be useful in any diagnosis by the electrician sent to investigate the fault. The following is summarised information on different lamp types.

Mercury lamps. One of the first points to note about these lamps is that they require up to 5 minutes to cool before re-ignition can take place. In factory situations lamps are often extinguished because of voltage 'dips'. If a lamp fails to reignite after cooling, the ballast should be checked for over-heating and continuity. If the lamp is nearing the end of its life it will fail to re-strike and should be replaced. If the lamp delivers a poor light output, the choke should be checked for continuity. In some circuits, parallel chokes are used and their currents should be equal. However, one type of 700W circuit uses dissimilar chokes. Some types of lamp may suffer from 'thermal shock' as the result of cold water, e.g. rain, falling onto the hot glass envelopes. Cracked lamps (perhaps the result of damage in transit) will operate until the internal pressure falls to atmospheric when the arc tube will fail. Excessive pressure used when screwing lamps in their holders also produces faults resulting in eventual lamp failure. If the tight output is unstable, a possible cause could be poor contact in the lampholder (look for signs or arcing on the cap center contact).

Low-pressure sodium lamps. The output voltage from the lamp transformer is important and should be in the region of 480V for most types of lamp (650V for the 135W and 150W SOX lamp). An unstable light output indicates the lamp is nearing the end of its life and should be replaced. Starter switches are a source of trouble and should be changed (on the 60W and 200W linear lamps). Voltages should be checked at the lampholders but note that this technique will not apply to switch-start circuits because volts will only appear intermittently as the switch operates and this could generate peak voltages of up to 1.5kV, which will not register on a meter.

Compact-source iodide. If this type of lamp does not light check for the supply voltage appearing at the lampholder terminals. If no volts are indicated this could mean an open-circuit choke or capacitor. The relay should vibrate on closing the starter switch. It should be noted that the starting circuit produces pulses of up to 9kV and cannot be properly tested except with special equipment. Poor light output could indicate the lamp nearing the end of its life. In the case of the 400W lamp, the choke might be short-circuited; in the 1000W lamp circuit, one of the three parallel chokes could be open-circuited.

Linear metal halide (MBIL). If the lamp does not work, the transformer output should be tested (Note: the transformer open-circuit volts are well over 1kV). The c6ntinuity of the transformer winding and leads should be checked, as also should the lampholder for loose connections.

Metal halide (MBI and MBJF). Initial checks for failure of the lamp to operate should be made for open-circuit in the ballast. The open-circuit voltage of the choke is about 570V. The capacitor function is important; in the 400W twin-choke type of circuit, if the voltage at the lampholder is low (it should be just over 400V), the capacitor could be open-circuited. Note that a safety thermal cutout is used in ballast-type lamps; this could be open-circuited with a high ambient temperature condition, and after running with a failed lamp. Nearly half an hour must be allowed for resetting before trying another lamp. In the 400W choke ignitor circuit, the cable length between the choke and the lamp should not exceed 33 m.

9.2 Maintenance

Immediately a lighting installation is put into service it begins to deteriorate. A film of dust or dirt begins to reduce the transparency or reflecting power of all the exposed surfaces of lamps, fittings, and the walls and ceiling of a room. This process, if unchecked, may result in the level of illumination falling very low in a comparatively short time. Only thorough and periodic cleaning of lighting equipment and attention to room decorations can maintain the performance of the installation at a reasonably high average value. Generally, a maintenance factor is applied. The general figure is 0.8. This means that in planning the amount of illumination required for a particular installation, the light in lumens must be divided by 0.8 to allow for a decrease in light output caused by dust, etc. Very dirty situations may have a maintenance factor of 0.6 applied to them.

Maintenance of lighting installations also involves the replacement of lamps, which have either failed or have suffered reductions in their light output.Labour costs generally determine whether such lamps should be replaced individually as they fail, or by group replacement.

Planning lighting installations

Though the efficient planning of a lighting installation is the job of the lighting engineer, the electrician is sometimes called on to advise in the lighting requirements of small premises. Once the decision for lighting has been made, and the type of lamp and fitting settled, the remainder of the initial planning is largely a matter of simple mathematics in conjunction with the 'lumen method of design. This is based on theory and the practical results obtained in experimental rooms in which all the factors which effect illumination were variable at wilt. The mounting height of fittings can be settled within close limits, for they are mounted either directly on the ceiling or suspended from it. Generally, it is usual to adopt a rectangular layout of the light sources, the fittings being spaced at equal distances apart in each direction whenever possible.

The number of lumens required on the working plane is equal to the product of the area of the working plane in square feet and the lumen/ft^2 desired. The lumens provided by the lamps must, however, be greater than this figure to allow for depreciation of the installation owing to dust and dirt on the lamps and their fittings. The following formula is generally used:

$$F = \frac{E \times A}{C \times M}$$

where F = the lumens required per lamp

E = the average lm/m^2 required in service

A = area per fitting in square feet

C = coefficient of utilisation

M = maintenance factor.

The coefficient of utilisation represents the proportion of the light emitted by the lamp that actually reaches the working plane, and is dependent on the size of the room, height of the fittings, colour of the walls and ceiling, and the type of fitting used. An average value is about 0.6. The maintenance factor is taken on average as 0.8.

Up to a point, the eyes function better the more light they receive. Beyond that point glare supervenes. At least 150 lm/m^2 should be provided for adequate visual performance on rough or unskilled work. Up to 1,500 lm/m^2 should be provided for difficult or fine work.

Light measurements The instrument used to measure the amount of tight falling on a surface is the photoelectric photometer. This consists of a photoelectric cell made up of a layer of selenium coated onto a steel base-plate. A film of gold is formed over the selenium and is so thin that any light, which falls on the cell, will penetrate the gold layer to release electrons inside the selenium. These electrons then flow to the gold layer giving it a negative charge. The cell is coupled to a sensitive micro-ammeter whose scale is marked off in lm/m^2. The greater the amount of light falling on the cell the greater will be the voltage (lm/m^2) recorded.

Economic factors or light sources

Because lamps are consumable devices, both the initial and replacement lamp costs are treated as running costs, and not as overhead charges. For comparative purposes, costs are calculated on a lumen-hour basis:

$$C = \frac{1{,}000}{F}\left(\left(\frac{C_l}{h}\right) + (C_e \times P)\right)$$

Where C= total running cost in pence per million lumen-hours

C_l = total cost of all lamps in pence

C_e = cost of current in pence per unit (kWh)

F = total lumen output of all lamps

h = lamp life in thousands of hours

P = total lighting wattage.

When calculating C_e allowance must be made for any kilowatt or maximum demand charges, divided by the estimated annual burning hours.

9.3 Light control

Most sources radiate light in all directions, and are too brilliant to be viewed comfortably. The light must therefore be controlled to direct it where it is required and to soften its brilliance. All substances absorb some of the light which strikes or passes through them All substance also reflect some of the light falling on them, or transmit it, or both. Reflection of light may be of three kinds:

a) Specular reflection. When light strikes a mirror-like surface it is reflected at the same angle and in the same plane as it strikes. The type of reflection is much used for the precise control of light, e.g. car headlamps, silvered shop-window reflectors. Accidental specular reflection is generally unwanted, e.g. lighting fittings reflected in glossy table tops. A mirror-like surface can took dark even though a great deal of tight is striking it, and vice versa. Its appearance depends only on what is mirrored in its surface from the particular viewpoint concerned. The streakiness sometimes obtained from specular reflection is avoided by breaking up the reflector surface by ripples, flutes or dimples, by giving it a 'satin' finish, by using a pearl (or otherwise obscured) type of lamp, or by using a moulded or lightly frosted glass cover to the lamp fitting.

b) Diffuse reflection. This is the reflection obtained from a perfectly matt surface, the distribution of the reflected tight being independent of the direction of the incident light. The distribution of reflected light follows the cosine law, i.e. the intensity in any direction is proportional to the cosine of the angle between that direction and the perpendicular to the surface. A surface having this characteristic appears equally bright whatever the direction of view. White blotting paper and whitewash are nearly perfect diffuse reflectors. Diffuse reflection is useless for the precise control of light, but it can be used to reflect light in a general direction.

c) Spread reflection. Depolished metals and satin-finished mirrored surfaces have reflection characteristics between secular and diffuse. Vitreous and synthetic enamels are widely used for the reflecting surfaces of lighting fittings. Vitreous enamel is the more hard-wearing.

Stroboscopic effects. When discharge lamps operate on alternating current systems, their light output varies in each cycle and this produces certain effects. These are rarely very troublesome, but it is sometimes necessary to take certain precautions to minimize them. The cyclic variation in the light output is not normally perceptible with Lamps operating on a 50 Hz (cycles per second) supply, since it occurs at twice the frequency of the mains. However, it can give rise to stroboscopic effects where the true speed of rotating machinery or other objects is not immediately apparent and they can appear to be, lowed down or even stationary. The means of overcoming this stroboscopic effect are easy to provide in circuitry, and should be used where there is any possibility that accidents may result from misjudgment of machine speed.

Apart from the stroboscopic effect, this flicker from tubular fluorescent lamps may be a source of optical annoyance. This flicker arises from half-wave rectification in the lamps or from the random movement of hot spots on the lamp electrodes. Flicker is also apparent at the extreme ends of fluorescent lamps and is caused by the fact that a small pan of the discharge emits radiation only during one-half of a complete cycle. This fluctuation, which occurs at mains frequency, may be overcome by fitting opaque shields over the lamp ends, or by other methods, which screen the ends of the lamp from direct view.

One method used to eliminate or minimize stroboscopic effect is the connection of every second lamp in a pair of fluorescents in series with a capacitor, to change the phase of the second lamp's circuit. The circuit is usually known as a lead/lag circuit. Another method is to use banks of fluorescent lamps supplied from a three-phase four-wire supply, where each bank of lamps is connected to each phase wire and neutral to give a balanced three-phase lighting load.

Operation of fluorescents on dc supplies. By omitting the power-factor correction capacitor and inserting a suitable current-limiting resistor in the circuit instead of a choke, fluorescent lamps can be operated on de supplies. A polarity-reversing switch is necessary in the circuit so that the lamp can be operated as required to prevent the tube darkening at one end. For caravans and mobile stores, and buses having 12V dc supplies, there are available transistor circuits for 'mini-lamps'. The most important point to observe in this type of circuit is that the polarity is correct, otherwise damage to the transistor may result. Similarly, for emergency supplies there has been developed a range of invertors, convening 11OV or 220V dc supply from an emergency battery to 220V 50/60 Hz ac. These invertors have no moving parts and require no maintenance.

Emergency lighting. Emergency lighting is lighting which is provided as supplementary to the main lighting provisions of a building. This provision is essential in buildings where work is in progress or where large numbers of people are gathered, in, for example, a theatre. Again, an emergency supply is essential in hospitals, particularly for those services (operating theatres, blood banks, etc.), which depend on electricity. The risk of accident is particularly great in industrial premises. Moreover, many industrial processes require that certain precautions, such as closing valves, opening switches or starting standby equipment, be taken whenever the mains supply fails. In buildings where large numbers of the public gather, emergency lighting is necessary to ensure that the people can leave the building safely. In particular, lighting is needed on stairways and at exit points.

CHAPTER 10:PRACTICAL APPLICATION

10.1: Technical Work of the Installation

This service building consists of five floors, and in all floors there are some rooms.

a) Cellar Floor:

In the left side, the building has a very big depot, which there are 24 (2x80W) waterproof fluorescents. These fluorescents are controlled by 6 switches. In this depot we also use 2 socket rings each has 6 (1x13A) waterproof sockets. Far from these we also put 4 telephone plugs to make the communication of this part with others. For the stairs which goes to the ground floor we use 2 (1x40W) waterproof fluorescents and to control these fluorescents we use 1 switch. The feedings of these lamps and sockets are made by the panel 'BDT1' which is in this depot. This panel is feeding by the main panel of the cellar which is called 'BDT'

In the right side, the building has two stairs, each has 2 (1x40W) waterproof fluorescents which are controlled by separately a switch. Here there is a long pathway which has 8 (1x40W) waterproof fluorescents controlled by two switches. In this pathway there are two sockets each (1x13A) waterproof, which are feeding by a ring circuit. And there is one telephone plug. Here also there is an eating room for the personnel. This room is illuminated by 4 (1x40W) waterproof fluorescents, which are controlled by a switch. This room has also a telephone plug and a socket plug (1x13A) waterproof, which is feeding by a ring circuit. In the right side of this room there is the personnel room for small rests. In this room we use a (1x40W) waterproof fluorescent and for controlling this lamp we use a switch. Again in the right side of this room there is a small depot. We use same things in this depot that we use in the personnel room. In the opposite side there is one more small depot and near it there is the electric room. For their illumination we use same things: one (1x40W) waterproof fluorescent and a switch to control them. But in electric room there are three panels. One of them is feeding the lamps and sockets in the right side of the cellar whose name is 'BDT2'. The other is the main panel for cellar whose name is 'BDT' and it is feeding 'BDT1' and 'BDT2'. The third one is the main panel of the whole building which is feeding all main floor panels and its name is 'ADT'. In the left side of these rooms there is a depot and we use 2 (1x80W) waterproof fluorescents in it and for controlling this lamp we use one switch. We also use a socket (1x13A) waterproof in this room which is feeding by a ring circuit. In the opposite side of this depot. there is one depot more with same lamps and switches but instead of ring circuit we use radial circuits (1x13A) waterproof. This is because of the regulations says that we can't use ring circuit where the area of place is more than $100m^2$. In the right side of this depot there are two rooms. One for women wearing and one for men wearing. The room for women wearing is a little small than men wearing room so we use a (1x80W) waterproof fluorescent in this room and we use 2 (1x80W) waterproof fluorescents in men wearing room. Both has separately one switch to control the lamps. The up side of the right place is all depots and have totally 5 (1x80W) waterproof fluorescents and 4 (2x80W) waterproof fluorescents. To control these lamps we use 4 switches. In this part there are also two sockets (1x13A) waterproof feeding by a radial circuit. In these depots there are two telephone plugs too.

b) Ground Floor:

This is the floor which technicians will make the service and repairing of the plane. Because of this here we made some calculations for ideal light distribution. These calculations are explained in Chapter 10.2 in details.

In the lower part of this floor according to our calculations we use 16 (250W) high pressure mercury vapor lamp. These lamps are joint to the second floors ground. We use high pressure mercury vapor lamps (HPMVL) instead of high pressure sodium vapor lamp (HPSVL) because HPMVL light is more white than the HPSVL and in this kind buildings white light is better than yellow one. The other reason that we choose HPMVL is its lumen is nearly twice better than HPSVL. In this part there was also two sockets (1x13A) which are feeding by radial circuits. And there are two telephone plugs. And there is some stairs here to go down. To illuminate these stairs we use one (1x40w) fluorescent and for control this lamp we use a switch. There is also one more switch to control the lamp in the stairs to go down. In the lower right part there is the information office. This office has 5 (4x20W) fluorescent lamps and they are controlling by one switch. In this part there is also three sockets which two of them are (1x13A) and one of them is (2x13A).These sockets are feeding by a ring circuit. Because here is the information office there are two telephone plugs here. In this corner there is the stairs for going up and down. This stairs are illuminated by 2 (1x40W) fluorescents. These fluorescents are controlled by one switch.

But there is one switch more there to control the lamps of stairs for going down. In the opposite side of the stairs there are three rooms which two of them is depot and one of them is electric room. They all have separately (2x40W) fluorescents and for controlling each has a switch. But in the electric room we have two panels. One of them is feeding some of the lights and sockets in this floor and its name is 'ZDT1'. The other one is the main panel of ground floor and its name is 'ZDT'. ,

The right part of the building will be used for making small repairs of the plain parts. After calculations we found that we should put here 22 (2x40W) fluorescents. They are controlling by six switches. From this six switch three of them is in up side and three of them is in the down side. In this part there are also three sockets (1x13A). They are feeding by a radial circuit. And also there are two telephone plugs in this part.

The middle part is the part where planes will be . The lamps of this part is joint to the roof. Again after calculations we found that we should put 29 (400W) HPMVL to this part. To control these lamps we use eight heater switches. Four of them was in the left side and four of them was in the right side.

In the left upper side there is a small place. In this place there are 2(2x40W) fluorescents which are controlled by a switch. In this part there is a stair which is going to the cellar floor. This stairs are illuminated by a (1x40W) fluorescent and controlled by a switch. There is one more switch here to control the lamp in this stairs which is going down. In the left part of the building there are two telephone plugs and three sockets (1x13A) which is feeding by a radial circuit. IN this part there is also a panel which feeds some of the lamps and sockets in this floor whose name is 'ZDT2'.

c) First Floor:

This floor is the office floor. In the lower part there is a office. This office has 3 (2x40W)fluorescents and for controlling it a switch. This office has two telephone plugs and 2 (2x13A) sockets. These sockets are feeding by a ring circuit. In the right side of this office there is a place for making tea or coffee. This room has a (2x40W) fluorescent which is controlling by a switch. In this room there are two (1x13A)sockets feeding by a ring circuit. And there is a telephone plug. The right side of this room there is the stairs. These stairs are illuminated by 2 (1x40W) fluorescent and they are controlling by a switch. But there is one more switch here and it is for controlling the lamps for downstairs. In this floor there is a pathway which has 5 (4x20W) fluorescent and controlled by a switch. This pathway has also 2 (2x13A)sockets which are feeding by ring circuit. In the opposite side of the stairs there are two rooms. One of them is a depot and the other is electric room. Each has separately (2x40W) fluorescent and a switch to control the lamps. But the electric room has the main panel of the first floor which is called '1DT'. Near this rooms there is the women toilet and the men toilet. The women toilet is illuminated by a (2x40W) fluorescent and the men toilet is illuminated by 2 (2x40W) fluorescents. Each of them is controlled separately by a switch. In the right side the first two offices are same. So the installation of them are same. They are both illuminated by 4(2x40W) fluorescents, and controlled by a switch. Both have 3 (2x13A) sockets which are feeding by a ring circuit. And they both have separately three telephone plugs. The last office in this part is a little big than the others. This office has 6 (2x40W) fluorescents and controlled by two switches. In this office there are 3(2x13A) sockets which are feeding by a ring circuit. And this office has three telephone plugs.

d) Second Floor:

The second floor is again a office floor. The lower left room is a meeting room. This room has 12 (2x40W) fluorescents and they are controlling by three switches. In this room there are 4 (2x13A) sockets which are feeding by a ring circuit. In this room there are also three telephone plugs. The next four rooms are offices and they are nearly same. All have separately 6 (2x40W) fluorescents, each controlled by two switches. In these rooms each have 3 (2x13A) sockets which are feeding by ring circuits, and each have three telephone plugs. The office near them is a little smaller. This office has 4 (2x40W) fluorescents, controlled by a switch. This office has 2 (2x13A) sockets which are feed by ring circuits, and two telephone plugs. In the lower part of these offices there is a pathway. This pathway has 5 (4x20W) fluorescent and they are controlled by a switch. In the left side of this pathway there is a room for making tea or coffee. This room has a (2x40W) fluorescent, and controlled by a switch. This room has a (2x13A) socket feeding by a ring circuit, and a telephone plug. Near this room there is the stairs. The stairs are illuminated with 2 (1x40W) fluorescent, and controlled by a switch. But there is one more switch here for controlling the lamps of downstairs. In front of this stairs there is the second pathway. This pathway has 5 (4x20W) fluorescents and controlled by a switch. This pathway has also a (1x13A) socket, feed by a ring circuit. In the opposite side of the stairs there are two rooms. One of them is a depot and the other is electric room. Each has separately (2x40W) fluorescent and a switch to control the lamps. But in depot there is a (1x13A) socket feed by a ring circuit, and the electric room has the second floors main panel which is called '2DT'. Near this rooms there is the women toilet and the men toilet. The women toilet is illuminated by a (2x40W) fluorescent and the men toilet is illuminated by 2 (2x40W) fluorescents. Each of them is controlled separately by a switch. In the right side the first two offices are same. So the installation of them are same. They are both illuminated by 4(2x40W) fluorescents, and controlled by a switch. Both have 3 (2x13A) sockets which are feeding by a ring circuit. And they both have separately three telephone plugs. The last office in this part is a little big than the others. This office has 6 (2x40W) fluorescents and controlled by two switches. In this office there are 3(2x13A) sockets which are feeding by a ring circuit. And this office has three telephone plugs.

e) Third Floor:

We can divide this floor in to two parts. The up side and the down side. In the up side there are 8 (2x40W) fluorescents and they are controlled by two switches. This part has 2 (1x13A) sockets, feed by a ring circuit. The lower part has 7 (2x40W) fluorescents, and are controlled by two switches. Also this part has 2 (1x13A) sockets and are feed by a ring circuit too, and this part has a telephone plug. In the middle this floor has its main panel whose name is 'TDT'.

10.2: Illumination Calculations

For the ground floor we made some illumination calculations. Here I will show the formulas that I used and the calculations

Z: Number of lamps

ØT: Total needed lumen

ØL: The lamps lumen

k: Section index (According to place dimensions)

a: Length

b: Width

h: Height of lamp to the working place

H: Height of lamp to the floor

.**h1:** The height of working place to the floor

E: Needed light level (Will be selected from the table)

A: Area of the section that will be illuminated

.**d:** The factor of becoming dirty of the place (Will be selected from the table)

η:The factor of place illumination activity (Will be selected from the table)

For the right part:

.a=7.3 m b=23.7 m H=3 m h1=1m E=250 lux

∅L= For 40W fluorescent 2100 lm

η ceiling=0.8 η wall=0.5 η ground=0.3

h=H-h1 h=3-1 h=2m

$$k=\frac{a \times b}{h \times (a \times b)} \qquad k=\frac{7.3 \times 23.7}{2 \times (7.3 + 23.7)} \qquad k=2.8$$

For k=2.8 η=0.578

A=a x b A=7.3 x 23.7 A=173m^2

.d=1.25

$$\varnothing T=\frac{E \times A \times d}{\eta} \qquad \varnothing T=\frac{250 \times 173 \times 1.25}{0.578} \qquad \varnothing T=93533.7 \text{ lm}$$

$$Z = \frac{\varnothing T}{\varnothing L} \qquad Z = \frac{93533}{2100} \qquad Z = 44$$

$$E = \frac{\varnothing L \times Z \times \eta}{.d \times A} \qquad E = \frac{2100 \times 44 \times 0.578}{1.25 \times 173} \qquad E = 247 \text{ lux}$$

For down part:

.a=38.5 m b=6 m H=6 m h1=1m E=250 lux

ØL= For 250W high pressure mercury vapor lamp 13000 lm

η ceiling=0.8 η wall=0.5 η ground=0.3

h=H-h1 h=6-1 h=5m

$$k = \frac{a \times b}{h \times (a \times b)} \qquad k = \frac{38.5 \times 6}{5 \times (38.5 + 6)} \qquad k = 1$$

For k=1 η=0.36

A=a x b A=38.5 x 6 A=231m^2

.d=1.25

$$\varnothing T = \frac{E \times A \times d}{\eta} \qquad \varnothing T = \frac{250 \times 231 \times 1.25}{0.36} \qquad \varnothing T = 200520 \text{ lm}$$

$$Z = \frac{\varnothing T}{\varnothing L} \qquad Z = \frac{200520}{13000} \qquad Z = 16$$

$$E = \frac{\varnothing L \times Z \times \eta}{.d \times A} \qquad E = \frac{13000 \times 16 \times 0.36}{1.25 \times 231} \qquad E = 259 \text{ lux}$$

For middle part:

.a=42.6 m b=23.7 m H=9 m h1=1m E=250 lux

∅L= For 400W high pressure mercury vapor lamp 22000 lm

η ceiling=0.8 η wall=0.5 η ground=0.3

h=H-h1 h=9-1 h=8m

$$k = \frac{a \times b}{h \times (a \times b)} \qquad k = \frac{42.6 \times 23.7}{8 \times (42.6 + 23.7)} \qquad k = 1.9$$

For k=1.9 η=0.498

A=a x b A=42.6 x 23.7 A=1009m^2

.d=1.25

$$\varnothing T = \frac{E \times A \times d}{\eta} \qquad \varnothing T = \frac{250 \times 1009 \times 1.25}{0.498} \qquad \varnothing T = 633157.6 \text{ lm}$$

$$Z = \frac{\varnothing T}{\varnothing L} \qquad Z = \frac{633157}{22000} \qquad Z = 29$$

$$E = \frac{\varnothing L \times Z \times \eta}{.d \times A} \qquad E = \frac{22000 \times 29 \times 0.498}{1.25 \times 1009} \qquad E = 252 \text{ lux}$$

10.3: Cost of Electric Installation of This Building

The list below shows the cost of the electrical installation of this building.

S.No	Type of the work	N. units	Cost/Unit	Total
1	2x80W w/proof flo. Circuit	28 times	112500000 TL	3150000000 TL
2	1x80W w/proof flo. Circuit	12 times	98000000 TL	1176000000 TL
3	2x40W flo. Circuit	125 times	93750000 TL	11718750000TL
4	1x40W w/proof flo. Circuit	26 times	90000000 TL	2340000000 TL
5	4x20W flo. Circuit	20 times	112500000 TL	2250000000 TL
6	1x13A w/proof plug circuit	19 times	50000000 TL	950000000 TL
7	1x13A plug circuit	21 times	19500000 TL	409000000 TL
8	2x13A plug circuit	40 times	23200000 TL	928000000 TL
9	Telephone plug circuit	59 times	21200000 TL	1250800000 TL
10	400W HPMVL circuit	29 times	139500000 TL	4045500000 TL
11	250W HPMVL circuit	16 times	139500000 TL	2232000000 TL
12	3x6 ways 250A MCCB	1 times	1500000000 TL	1500000000 TL
13	3x4 ways 3x100A MCB	7 times	212000000 TL	1484000000 TL
14	3x6 ways 3x100A MCB	2 times	230000000 TL	460000000 TL

15	3x250A MCCB+ELCB	1 times	800000000 TL	800000000 TL
16	3x100A MCCB	2 times	185000000 TL	370000000 TL
17	3x63A MCCB	2 times	175000000 TL	350000000 TL
18	1x63A MCCB	1 times	85000000 TL	85000000 TL
19	$(4x150+70)mm^2$ cable	40 m	46440000 TL	1857600000 TL
20	$(4x35+16)mm^2$ cable	10 m	14550000 TL	145500000 TL
21	$(4x16+6)mm^2$ cable	140 m	4950000 TL	693000000 TL
22	$(2x16+6)mm^2$ cable	20 m	4300000 TL	86000000 TL

Total= 38.028.165.000 TL

CONCLUSION

For the electrical engineering the most important topic of all is electrical installation for me. Because of I was thinking in this way I chose a project about electrical installation.

I saw that, while working in the topic of electrical installation everyone, technicians or engineers should be very carefull because a small mistake can cause big damages. After finishing my project I felt my self that I learned a lot of things about electrical installation.

First of all in practical life if I face such an installation project, I have some knowledge about the topic. I learned that an engineer should know both illumination and installation and also should have the ability to work both in site work and the office.

REFERANCES

The list below is the references that I use while making my project.

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