TVET CERTIFICATE V in INDUSTRIAL ELECTRICITY

ELECTRICAL POWER DISTRIBUTION SYSTEM DESIGN

IELEP501 **Design electrical power distribution system**

Competence

Learning hours: 90

Credits: 9

Sector: Construction

Sub-sector: Electricity

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Purpose Statement

This particular module describes the skills, knowledge and attitude required to design electrical power distribution system. The electrician will be able to design the wiring diagram according to the site, elaborate technical specifications of the distribution line elements and estimate cost of the work. It applies to electricians working as distribution designer.

Elements of competence and performance criteria		Page No.
Learning Unit	**Performance Criteria**	
1. Carry out a site survey	1.1. Relevant collection of data from site	3
	1.2. Proper interpretation of data from site.	
	1.3. Proper layout of the site	
	1.4. Appropriate selection of wiring system	
2. Elaborate technical specifications	2.1. Accurate calculation of electrical design requirements	26
	2.2. Accurate calculation of mechanical design requirements	
	2.3. Proper specification of switching and protection equipment drawings	
	2.4. Proper elaboration of technical drawings	
3. Estimate cost	3.1. Precise determination of quantity of materials according to the wiring diagram and technical specifications.	59
	3.2. Relevant information on materials ‘cost	
	3.3. Relevant information of labour cost	
	3.4. Neat elaboration of cost report	

Total number of pages: 102

Learning Unit 1. Carry out a site survey

O. Introduction

Site surveys are inspections of an area where work is proposed, to gather information for a design or an estimate to complete the initial tasks required for an outdoor activity. It can determine a precise location, access, best orientation for the site and the location of obstacles.
The type of site survey and the best practices required depend on the nature of the project.

LO 1.1: Collect data from the site

Content/Topic1. Load assessment

Planning is necessary to design a system for optimum performance. While ensuring supply continuity, minimizing power losses, ensuring power quality, and obtaining trouble free operation by selecting appropriate sizing equipment based on surrounding influences.

Planning begins with assessing the predetermined energy demand for the facility.

Data required to be collected for power estimation include:

- List of Connections Loads and Locations
- Pattern of Loading (process variations)
- Separating Critical Load from Non-Critical Loads
- Loads with High Harmonics
- Inclusion of Future Growth Plans
- Utility Interfacing

A list of load locations and pattern of equipment loading will aid in assessing the load factor, demand factor, and diversity factor. Application of these factors is crucial in accurately estimating power requirements for any facility and designing distribution systems.

1.1 Different Types of Loads in power system

A device which taps electrical energy from the electric power system is called a **load on the system**.
The load may be resistive (e.g., electric lamp), inductive (e.g., induction motor), capacitive or some combination of them. The various types of loads on the power system are:

(i) Domestic load. Domestic load consists of lights, fans, refrigerators, heaters, television, small motors for pumping water etc. Most of the residential load occurs only for some hours during the day (i.e., 24 hours) e.g., lighting load occurs during night time and domestic appliance load occurs for only a few hours. For this reason, the load factor is low (10% to 12%).

(ii) Commercial load. Commercial load consists of lighting for shops, fans and electric appliances used in restaurants etc. This class of load occurs for more hours during the day as compared to the domestic load. The commercial load has seasonal variations due to the extensive use of air conditioners and space heaters.

(iii) Industrial load. Industrial load consists of load demand by industries. The magnitude of industrial load depends upon the type of industry. Thus small scale industry requires load up to 25 kW, medium scale industry between 25kW and 100 kW and large-scale industry requires load above 500 kW. Industrial loads are generally not weather dependent.

(iv) Municipal load. It consists of street lighting, power required for water supply and drainage purposes. Street lighting load is practically constant throughout the hours of the night. For water supply, water is pumped to overhead tanks by pumps driven by electric motors.
Pumping is carried out during the off-peak period, usually occurring during the night. This helps to improve the load factor of the power system.

(v) Irrigation load. This type of load is the electric power needed for pumps driven by motors to supply water to fields. Generally this type of load is supplied for 12 hours during night.

(vi) Traction load. This type of load includes tram cars, trolley buses, railways etc. This class of load has wide variation. During the morning hour, it reaches peak value because people have to go to their work place. After morning hours, the load starts decreasing and again rises during evening since the people start coming to their homes.

1.2 Types of electrical power supply

The conveyance of electric power from a power station to consumers' premises is known as **electric supply system.** An electric supply system consists of three principal components *viz*., **the power** station, the **transmission lines** and **the distribution system**.

Electric power is produced at the power stations which are located at favorable places, generally quite away from the consumers. It is then transmitted over large distances to load centres with the help of conductors known as transmission lines. Finally, it is distributed to a large number of small and big consumers through a distribution network.

- **Classification of electric supply system**
    - ✓ d.c. or a.c. system and
    - ✓ Overhead or underground system.

Now-days, 3-phase, 3-wire a.c. system is universally adopted for ***generation*** and ***transmission*** of electric power as an economical proposition. However, distribution of electric power is done by 3-phase, 4-wire a.c. system.

The underground system is more expensive than the overhead system. Therefore, in our country, overhead system is mostly adopted for transmission and distribution of **electrical power.**

Various Voltage Levels in Distribution system

These voltage values, which are all 'line to line' values, are 66kV, 22kV, 11kV, 6.6kV and 400/230V. Some of these values are rarely used in public distribution networks but are common in private networks.

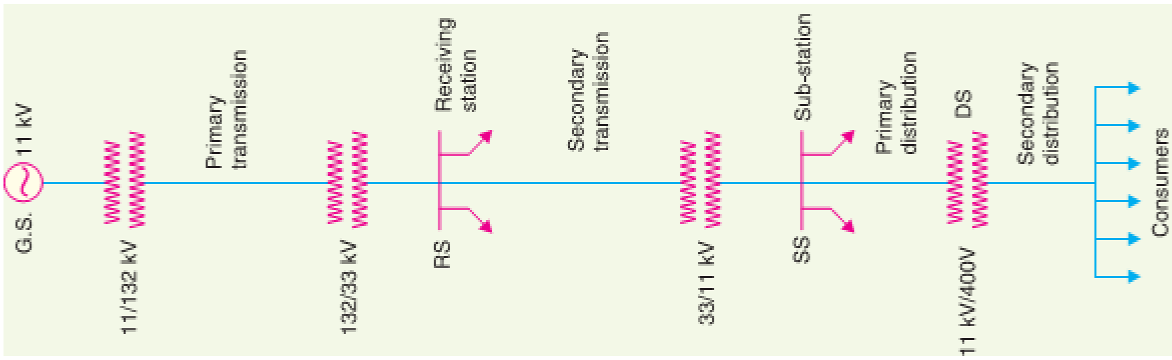


Fig 1. Electrical power supply system

Content/Topic 2. Distribution line route selection methodology

The route selected for a distribution line should be such that the length of the line should be minimum. However, the line route should also be as close to the road as possible in order to ensure easy maintenance.

While selecting the routes, natural obstacles e.g., hills, valleys, swamps or marshy places, rivers and thick forests are avoided as far as possible. The H.T. lines should also be kept as much away as possible from the residential area of villages, as a precaution for safety. The line should also be routed away from fire and chemical hazards, explosives, stores and away from play-grounds and cemetery.

1. Environmental and construction consideration

Environmental specifications depend on facility location for the distribution system design and equipment purchasing. Temperature and humidity are defining factors to determine distribution system equipment selection.

Construction of overhead power lines, especially in wilderness areas, may have significant environmental effects. Environmental studies for such projects may consider the effect of brush clearing, changed migration routes for migratory animals, possible access by predators and humans along transmission corridors, disturbances of fish habitat at stream crossings, and other effects.

2. Public/Social considerations.

1. Involuntary resettlement: The master plan may propose the construction of a new primary substation near an urban area. It may require somewhere around 50m^2 of land, to a maximum of about 200m^2. For this reason, prior consideration is necessary to avoid dense residential areas and farmlands when constructing the substation. The actual impacts will remain unclear until the site is decided, but since it is comparatively likely for the site to be selected near urban areas that have residences and farmlands, impacts are expected to a certain extent. There is also the possibility that land usage will be partially restricted due to the installation of the power distribution network and interconnected lines, necessary measures need to be taken, for example, to compensate for the impact on the land and agricultural products.

2. The poor, indigenous and ethnic people: As native settlements have been confirmed, due consideration needs to be given to prevent these areas from being selected as the sites of power facilities, as well as from social impacts on their traditional culture. At the present stage, there does not appear to be any system for designating areas such as native settlements, but it is necessary to confirm that no problems are foreseen.

3. Misdistribution of benefit and damage: Depending on the type and location of the planned facilities, the possibility of social inequality, such as in the access to public facilities, cannot be denied. A feeling of unfairness may also occur between electrified and un-electrified areas.

4. Cultural heritage: If there is a possibility of constructing a primary substation nears a designated cultural heritage, measures need to be taken to avert the construction of the primary substation or to divert distribution lines and interconnected lines away from the cultural heritage.

LO 1.2: Interpret data from the site

Content/Topic 1. Load assessment

Organizations use inventories to keep track of many items. An inventory of the uses of electricity will help to develop a baseline that will allow you to focus your energy management efforts upon the areas of greatest opportunity.

Making a list or inventory of all loads in a facility answers two important questions:

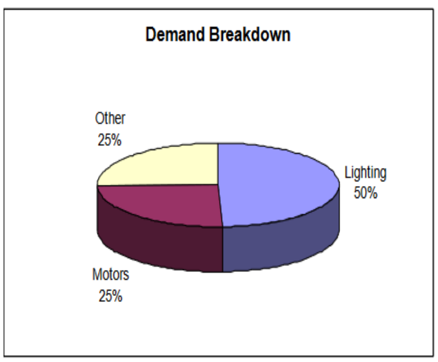
- Where is the electricity used?
- How much and how fast is electricity used in each category?

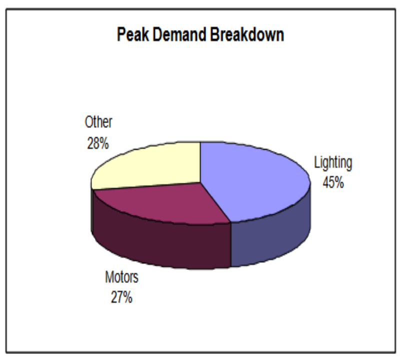
Often the process of identifying categories of use allows sources of waste to be easily identified, and this often leads to low cost savings opportunities. Identifying the high consumption loads lets you consider the best savings opportunities first. Because the inventory also quantifies the demand (or “how fast”) associated with each load or group of loads, it is invaluable in further interpretation of the demand profile.

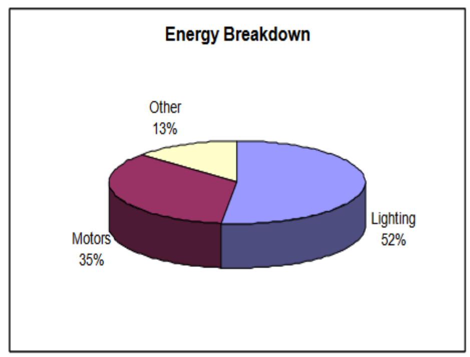
Sample Load Inventory Calculations

Data-entry Item	Units	Description
Quantity	(a number)	The quantity of this particular item.
Unit Load	kW	The load in kW for one of this particular load.
Total kW	kW	Quantity x Unit Load.
Hrs/Period	hours	The estimated hours of use per period
kWh/Period	kWh	Total kW x Hrs/Period
On - Peak	Yes/No	Is this load on during the peak period identified in the demand profile?
Diversity Factor (Div'ty Factor)	0 - 100%	That fraction of the total load that this particular item contributed to the peak demand.
Peak kW	kW	If the load is on peak, then this value equal to the Total kW x Diversity Factor

Finally, the load inventory data can be represented graphically to show the distribution of demand and energy consumption. The difference between the graphs reveals that any given load may have a greater impact upon demand or energy depending upon its size and mode of operation.







- ✓ **How to Compile a Load Inventory**

This section outlines a method for compiling a load inventory using a set of forms, samples of which are given in the next few pages and which are also included as worksheets at the end of this Section. Each form is accompanied by instructions for its use. In addition to these forms, a clipboard, pencil and calculator are required.

Instrumentation is not a necessity; a simple clip on ammeter is probably adequate in most situations.

STEP 1 To begin, three pieces of information are required:

A period of time on which the inventory will be based. Usually this would be a month corresponding to the utility billing period but it could also be a day, week or year. Select a period which is typical of operations in your facility.

The actual demand in kilowatts (kW) and the energy consumption in kilowatt-hours(kWh) for the period selected. If the period selected is a month, then this information is available from the utility bill.

If the facility demand is measured in kVA, then this will require a calculation based on the peak power factor to convert kVA to kW.

STEP 2
Identify each of the major categories of electricity use in the facility. This may require that you take a walk through and list categories as you notice them. When identifying the various categories of use, it is useful to consider both the type of electricity use and the activity in each area. Selecting categories with similar operation patterns is a good approach.

STEP 3
Guess the percentage of demand attributable to each category. This may be based on prior knowledge, a rough idea of the size of the loads, the size of the distribution wiring, etc. Also, use any information available from the demand profile when preparing this estimate.

STEP 4
Guess the percentage of energy used in each category. This should be based on occupancy, production, or other such factors relating to the intensity of use in each category.

STEP 5
Select the category of use in which the largest amount of demand and/or energy is used.

STEP 6
Only record nameplate and kW load information up to and including the Total kW. Each form is designed for a different type of information.

STEP 7
For each load, estimate the hours of operation for the period selected. Also indicate if this load is on during the peak demand period and/or at night. At this point, do not attempt to estimate the diversity factor.

STEP 8
Repeat Steps 6 and 7 for each category of use working down from the categories of highest energy use and demand to the lowest. If the estimated energy use and/or demand in a category is relatively small (less than 5%) then performing a detailed inventory is probably not worthwhile.

- ✓ **Types of power supply**

AC power supplies come in two varieties unregulated and regulated. Unregulated is the most basic type of power supply and does not have the ability to supply consistent voltage to a load, while regulated power supplies do and have many different design options.

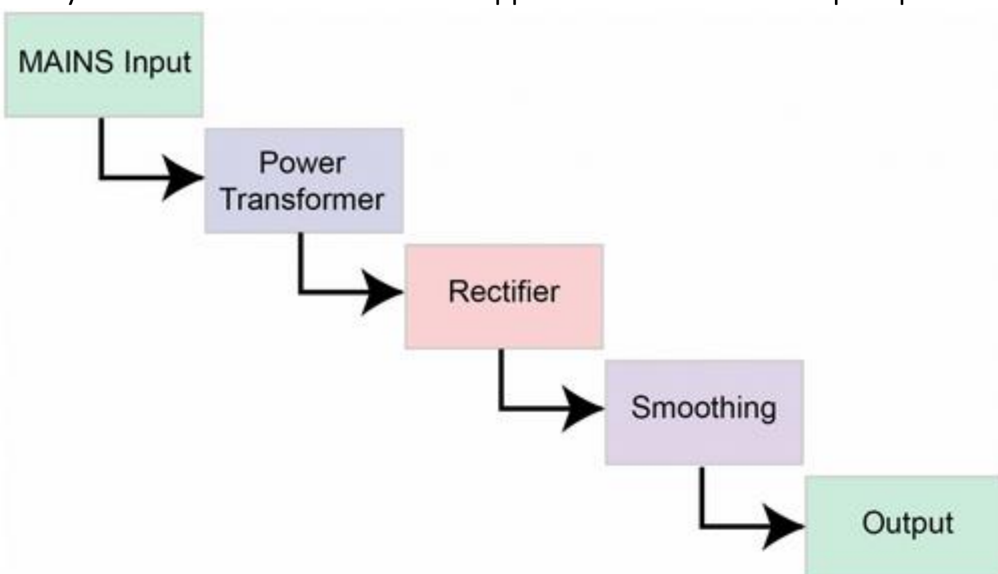
Linear converters are the least complex but also create the most heat, while switched converters are more intricate and cooler but create more noise. Batteries are typically switched converters. Each has advantages and drawbacks but which to use will be based mostly on the type of application and the conditions under which it will be run.

1. Unregulated Power Supply Theory

Because unregulated power supplies do not have voltage regulators built into them, they typically are designed to produce a specific voltage at a specific maximum output load current. These are typically the block wall chargers that turn AC into a small trickle of DC and are often used to power devices such as household electronics. They are the most common power adapters and are nicknamed a "wall wart".

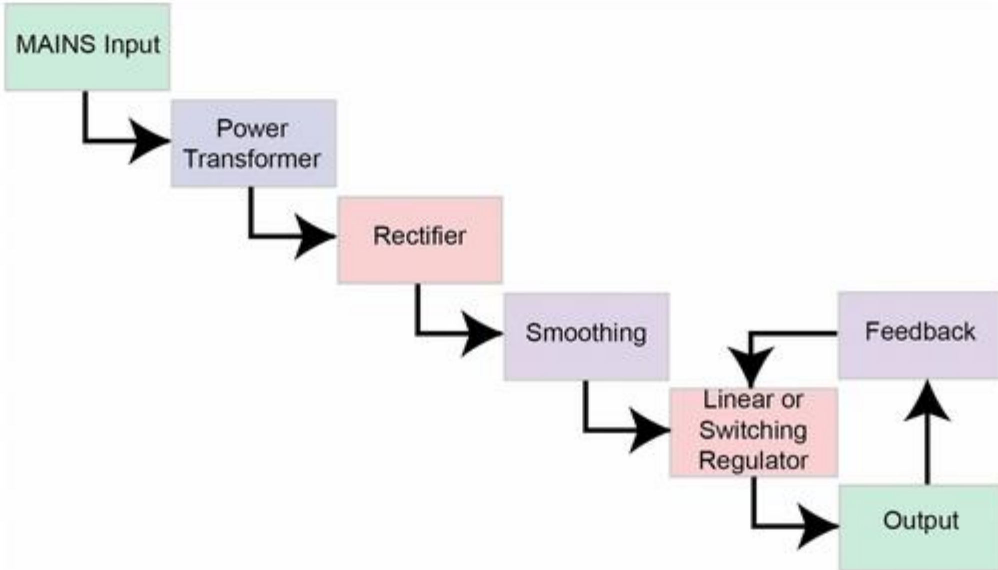
The DC voltage output is dependent on an internal voltage reduction transformer and should be matched as closely as possible to the current required by the load. Typically the output voltage will decrease as the current output to the load increases.

With an unregulated DC power supply, the voltage output varies with the size of the load. It typically consists of a rectifier and capacitor smoothing, but no regulation to steady the voltage. It may have safety circuits and would be best for applications that do not require precision.



2. Regulated Power Supply Theory

A regulated DC power supply is essentially an unregulated power supply with the addition of a voltage regulator. This allows the voltage to stay stable regardless of the amount of current consumed by the load, provided the predefined limits are not exceeded.



In regulated power supplies, a circuit continually samples a portion of the output voltage and adjusts the system to keep the output voltage at the required value. In many cases, additional circuitry is included to provide current or voltage limits, noise filtering, and output adjustments.

3. Linear, Switched, or Battery-based

There are three subsets of regulated power supplies: linear, switched, and battery-based. Of the three basic regulated power supply designs, linear is the least complicated system, but switched and battery power have their advantages.

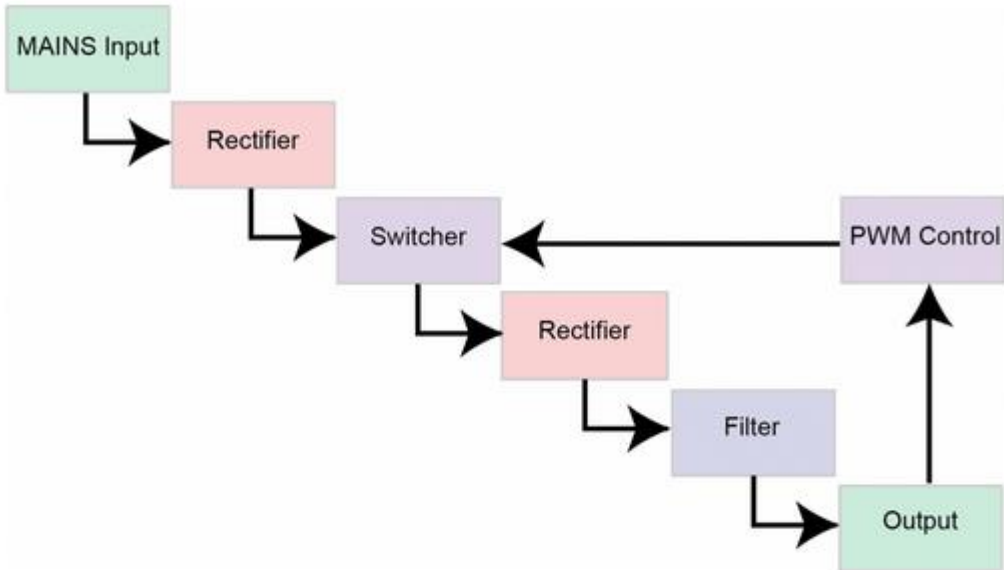
i. Linear Power Supply

Linear power supplies are used when precise regulation and the removal of noise is most important. While they are not the most efficient power source, they provide the best performance. The name is derived from the fact that they do not use a switch to regulate the voltage output.

Linear power supplies have been available for years and their use is widespread and reliable. They are also relatively noise-free and commercially available. The disadvantage to linear power supplies is that they require larger components, hence are larger and dissipate more heat than switched power supplies. Compared to switched power supplies and batteries, they are also less efficient, sometimes exhibiting only 50% efficiency.

ii. Switched Power Supply

Switched mode power supplies (SMPS) are more complicated to construct but have greater versatility in polarity and, if designed properly, can have an efficiency of 80% or more. Although they have more components, they are smaller and less expensive than linear power supplies.



One of the advantages of switched mode is that there is a smaller loss across the switch. Because SMPS operate at higher frequencies, they can radiate noise and interfere with other circuits. Interference suppression measures, such as shielding and following layout protocols, must be taken.

The advantages of a switched power supply is that they are typically small and lightweight, have a wide input voltage range and a higher output range, and are much more efficient than a linear supply. However, a SMPS has complex circuitry, can pollute the AC mains, is noisier, and operates at high frequencies requiring interference mitigation.

iii. Battery-based

Battery-based power is a third type of power supply and is essentially an energy storage unit. While there are a few advantages to battery-based power, such as not having to rely on a nearby power source and no noise to interfere with the electronics, in most applications using laser diodes, batteries are the least efficient method of powering the equipment. Most batteries are difficult to match the correct voltage to the load. Using a battery that can exceed the internal power dissipation of the driver or controller can damage your device.

Selecting a Power Supply

- When choosing a power supply, there are several requirements that need to be considered.
- The power requirements of the load or circuit, including voltage and current
- Safety features such as voltage and current limits to protect the load.
- Physical size and efficiency.
- Noise immunity of the system.

LO 1.3: Layout the site

Content/Topic1. Main parts of electrical power distribution line

In general, the ***distribution system*** is the electrical system between the sub-station fed by the transmission system and the consumers' meters.
It generally consists of three main parts namely, ***feeders, distributors*** and the ***Service mains.***

(i) Feeders. A feeder is a conductor which connects the sub-station (or localized generating station) to the area where power is to be distributed. Generally, no tappings are taken from the feeder so that current in it remains the same throughout. The main consideration in the design of a feeder is the current carrying capacity.

(ii) Distributor. A distributor is a conductor from which tappings are taken for supply to the consumers. In Fig. below, AB, BC, CD and DA are the distributors.

The current through a distributor is not constant because tappings are taken at various places along its length. While designing a distributor, voltage drop along its length is the main consideration since the statutory limit of voltage variations is ± 6% of rated value at the consumers' terminals.

(iii) Service mains. A service main is generally a small cable which connects the distributor to the consumers' terminals.

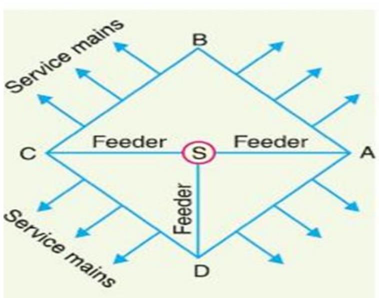


Fig2. Distributors

Content/Topic2: Location of electrical power distribution line equipment

1. Location of feeder

Power stations may be located near a fuel source, at a dam site (to take advantage of renewable energy sources), and are often located away from heavily populated areas. The electric power which is generated is stepped up to a higher voltage at which it connects to the electric power transmission net.

2. Electrical substation location

An electrical substation is a subsidiary station of an electricity generation, transmission and distribution system where voltage is transformed from high to low or the reverse using transformers. Electric power may flow through several substations between generating plant and consumer, and may be changed in voltage in several steps.
A substation that has a step-up transformer increases the voltage while decreasing the current, while a step-down transformer decreases the voltage while increasing the current for domestic and commercial distribution. Substations may be on the surface in fenced enclosures underground, or located in special-purpose buildings.

3. Service entrance, service entrance equipment

The equipment needed at the point where electrical service enters a building. Refers to equipment related to the point of entry for electrical service, not electrical equipment at a building's service entrance. This equipment normally consists of the main junction box, circuit breakers and/or fuses, and any additional equipment located between the main junction and the service drop, including meters.

Service entrance equipment is rated by size, and its size is a measure of the total current capacity of the equipment. Older homes typically have 100 amp service; newer homes commonly offer twice this capacity. Service entrance equipment size for commercial establishments may be measured in thousands of amps.

4. Location of poles

The following policies detail location and set back requirements for poles near roads:

- ✓ Guidelines for placement of power poles within road reserves in built up areas
- ✓ Placement of distribution poles along roads with speed limits not exceeding 70 kmh.
- ✓ Placement of rigid distribution poles along roads with speed limits exceeding 70 kmh.
- ✓ Placement of frangible distribution poles along roads with speed limits exceeding 70 kmh.

As well as meeting the requirements of the Code, poles should be installed according to the following guidelines:

1) Maximum number of customer services: In order to minimize costs, poles should be positioned so as to maximize the number of customers serviced from one pole.

2) Street lighting: distribution poles are used to carry streetlights. Therefore, they should be positioned to take into Account Street lighting design requirements.

3) Future extensions: In order to minimize future costs, consideration should be given to the likelihood/possibility of extensions to the existing/proposed distribution network (for example requirements for “tee-offs”, ground/aerial stays etc.)

4) Customer service poles: consideration should also be given to any advantage that may be achieved by positioning poles on the side of a street that will minimize the number of customer service poles required when service connections are run across the road.

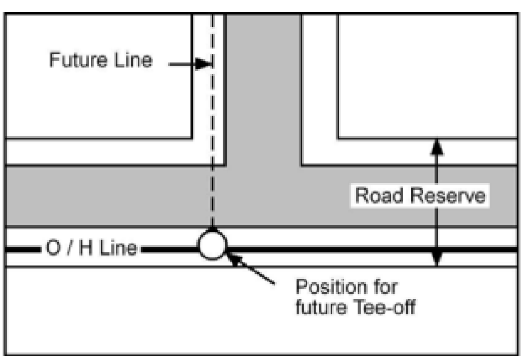


Fig.3 show Customer service poles

5) Vegetation clearing: it is important to minimize the impact Western Power's assets have on the environment. Therefore, consideration should be given to positioning poles on the side of the road that will minimize the need for vegetation-clearing.

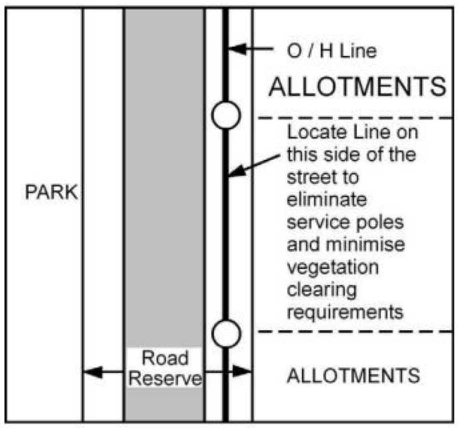


Fig.4 show Vegetation clearing

6) Deviation stays: stays can restrict land use and obstruct pedestrian traffic. Therefore, conductor deviation angles should be avoided or installed in a way that eliminates or reduces the need for deviation stays.

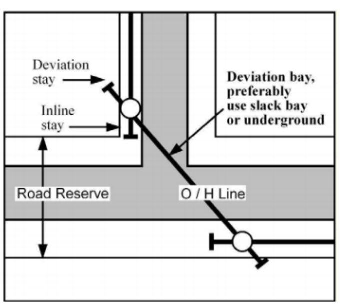


Fig.5 shows Deviation stays

7) **No conductors inside property:** In built-up areas it is not acceptable for new overhead power lines to be located inside property boundaries.

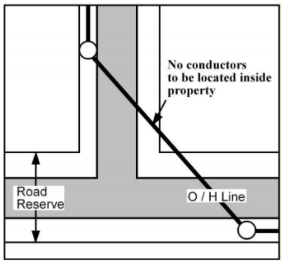


Fig.6 shows No conductors inside

8) Compliance with ENA C (b) 1, Section 9: bare overhead power lines can be built only on the 2.7m alignment in areas zoned for building setbacks of 6m, or in areas with special dispensation setbacks of 3m. If zoning allows properties to be built along the front property boundary, bare overhead line construction should not be used. The distance between a building and the closest conductor could be reduced to 1.3m as a result of blowout caused by strong wind. The required minimum clearance from the wall is 1.5m and from the window it is 2.1m.

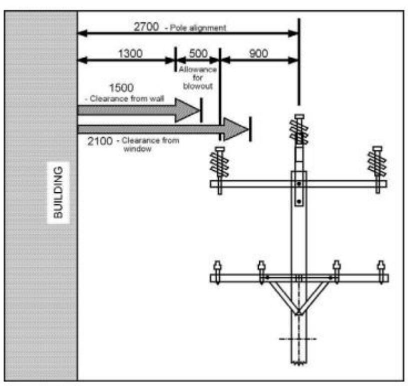


Fig.7 shows Compliance with ENA

LO 1.4: Select wiring system

Content/Topic1. Classification of Distribution Systems

A distribution system may be classified according to;

1. Nature of current. According to nature of current, distribution system may be classified as:

- d.c. distribution system
- A.c. distribution system

2. Type of construction. According to type of construction, distribution system may be classified as;

- overhead system
- Underground system. The overhead system is generally employed for distribution as it is 5 to 10 times cheaper than the equivalent underground system.

In general, the underground system is used at places where overhead construction is impracticable or prohibited by the local laws.

3. Scheme of connection. According to scheme of connection**,** the distribution system may be classified as:

- Radial system
- Ring main system
- Inter-connected system.

Now-a-days electrical energy is generated, transmitted and distributed in the form of alternating current.
One important reason for the widespread use of alternating current in preference to direct current is the fact that alternating voltage can be conveniently changed in magnitude by means of a transformer.
Transformer has made it possible to transmit a.c. power at high voltage and utilise it at a safe potential.
High transmission and distribution voltages have greatly reduced the current in the conductors and the resulting line losses.

The **a.c. distribution system** is classified into;

(i) Primary distribution system and
(ii) Secondary distribution system.

Primary distribution system.

It is that part of a.c. distribution system which operates at voltages somewhat higher than general utilization and handles large blocks of electrical energy than the average low-voltage consumer uses.
The voltage used for primary distribution depends upon the amount of power to be conveyed and the distance of the substation required to be fed.
The most commonly used primary distribution voltages are 11 kV, 6·6 kV and 3·3 kV. Due to economic considerations, primary distribution is carried out by 3-phase, 3-wire system.

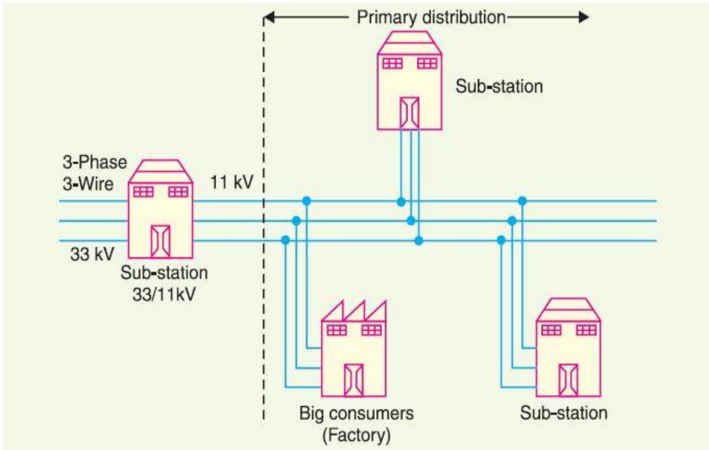


Fig.8 Shows a typical primary distribution system.

Secondary distribution system.

It is that part of a.c. distribution system which includes the range of voltages at which the ultimate consumer utilizes the electrical energy delivered to him.
The secondary distribution employs 400/230 V, 3-phase, 4-wire system.

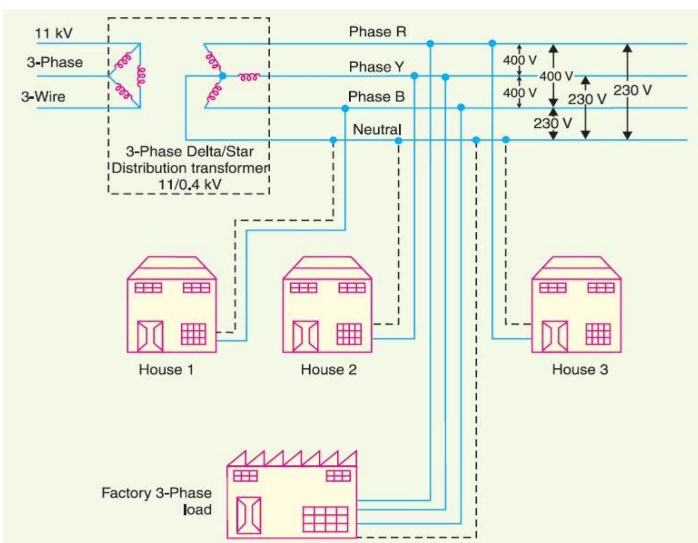


Fig.9 shows a typical secondary distribution system.

The primary distribution circuit delivers power to various substations, called **distribution substations**
The substations are situated near the consumers' localities and contain step-down transformers. At each distribution substation, the voltage is stepped down to 400V and power is delivered by 3-phase, 4-wire a.c. system.
The voltage between any two phases is 400 V and between any phase and neutral is 230 V. The single phase domestic loads are connected between any one phase and the neutral, whereas 3-phase 400 V motor loads are connected across 3-phase lines directly.

2. D.C. Distribution

It is a common knowledge that electric power is almost exclusively generated, transmitted and distributed as a.c.

However, for certain applications, d.c supply is absolutely necessary. For instance, d.c supply is required for the operation of **variable speed machinery** (i.e. d.c motors), **for electrochemical work** and **for congested areas** where storage battery reserves are necessary.

For this purpose, a.c. power is converted into d.c power at the substation by using converting machinery e.g., mercury arc rectifiers, rotary converters and motor-generator sets.

The d.c supply from the substation may be obtained in the form of

(i) 2-wire or

(ii) 3-wire for distribution

2-wire d.c system.

As the name implies, this system of distribution consists of two wires.

One is the outgoing or positive wire and the other is the return or negative wire. The loads such as lamps, motors etc. are connected in parallel between the two wires as shown in ***Fig.10.a*** This system is never used for transmission purposes due to low efficiency but may be employed for distribution of d.c. power.

3-wire d.c system.

It consists of two outers and a middle or neutral wire which is earthed at the substation. The voltage between the outers is twice the voltage between either outer or neutral wire as shown in ***Fig.10.b.***

The principal advantage of this system is that it makes available two voltages at the consumer terminals viz., V between any outer and the neutral and 2V between the outers. Loads requiring high voltage (e.g., motors) are connected across the outers, whereas lamps and heating circuits requiring less voltage are connected between either outer and the neutral

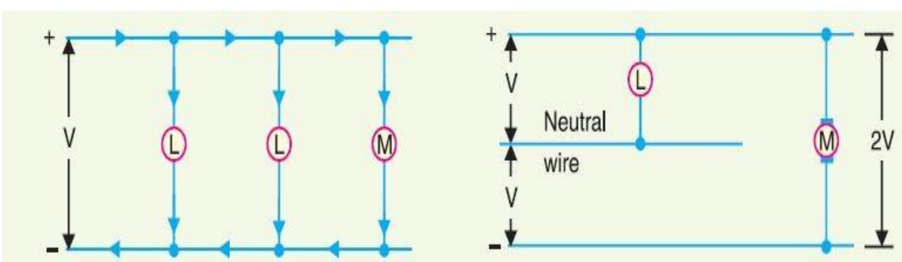


Fig. 10.a.2-wire d.c. system *Fig. 10.b.3-wire d.c. system*

2. Overhead versus Underground System

The distribution system can be overhead or underground.

Overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution transformers in addition to the conductors***.***

The underground system uses conduits, cables and manholes under the surface of streets and sidewalks.
The choice between overhead and underground system depends upon a number of widely differing factors such as:

- ✓ **Public safety**: The underground system is safer than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.
- ✓ **Initial cost**: The underground system is more expensive due to the high cost of trenching, conduits, cables, manholes and other special equipment. The initial cost of an underground system may be five to ten times than that of an overhead system.

- ✓ **Flexibility***:* The overhead system is much more flexible than the underground system.

- ✓ **Faults:** The chances of faults in underground system are very rare as the cables are laid underground and are generally provided with better insulation.

- ✓ **Appearance**: The general appearance of an underground system is better as all the distribution lines are invisible. This factor is exerting considerable public pressure on electric supply companies to switch over to underground system.

- ✓ **Fault location and repairs**: In general, there are little chances of faults in an underground system. However, if a fault does occur, it is difficult to locate and repair on this system. On an overhead system, the conductors are visible and easily accessible so that fault locations and repairs can be easily made.

- ✓ **Current carrying capacity and voltage drop:** An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section. On the other hand, underground cable conductor has much lower inductive reactance than that of an overhead conductor because of closer spacing of conductors.

- ✓ **Useful life:** The useful life of underground system is much longer than that of an overhead system. An overhead system may have a useful life of 25 years, whereas an underground system may have a useful life of more than 50 years.

- ✓ **Maintenance cost:** The maintenance cost of underground system is very low as compared with that of overhead system because of fewer chances of faults and service interruptions from wind, ice, and lightning as well as from traffic hazards.

- ✓ **Interference with communication circuits**: An overhead system causes electromagnetic interference with the telephone lines. The power line currents are superimposed on speech currents, resulting in the potential of the communication channel being raised to an undesirable level. However, there is no such interference with the underground system.

3. Connection scheme of distribution system

All distribution of electrical energy is done by constant voltage system. In practice, the following distribution circuits are generally used:

1. Radial System.

In this system, separate feeders radiate from a single substation and feed the distributors at one end only as shown on Fig. 6.

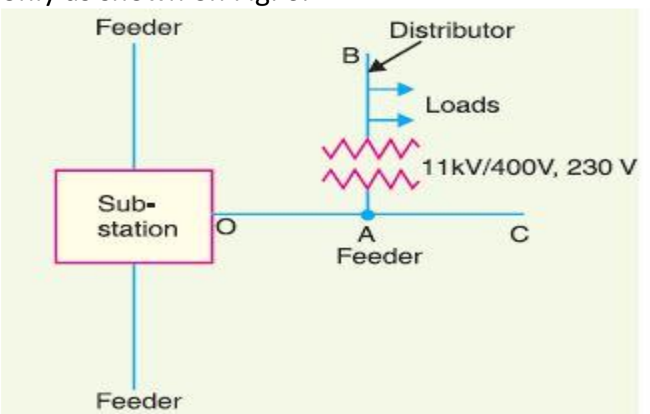


Fig. 11 Shows a single line diagram of radial system for a.c. distribution.

The radial system is employed only when power is generated at low voltage and the substation is located at the Centre of the load. This is the simplest distribution circuit and has the lowest initial cost. However, it suffers from the **following drawbacks:**
(a) The end of the distributor nearest to the feeding point will be heavily loaded.
(b) The consumers are dependent on a single feeder and single distributor. Therefore, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the substation.
(c) The consumers at the distant end of the distributor would be subjected to serious voltage fluctuations when the load on the distributor changes.
Due to these limitations, this system is used for short distances only.

2. Ring main system.

In this system, the primaries of distribution transformers form a loop.
The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation. Fig12. Shows the single line diagram of ring main system for a.c. distribution where substation supplies to the closed feeder LMNOPQRS.
The distributors are tapped from different points M, O and Q of the feeder through distribution transformers.

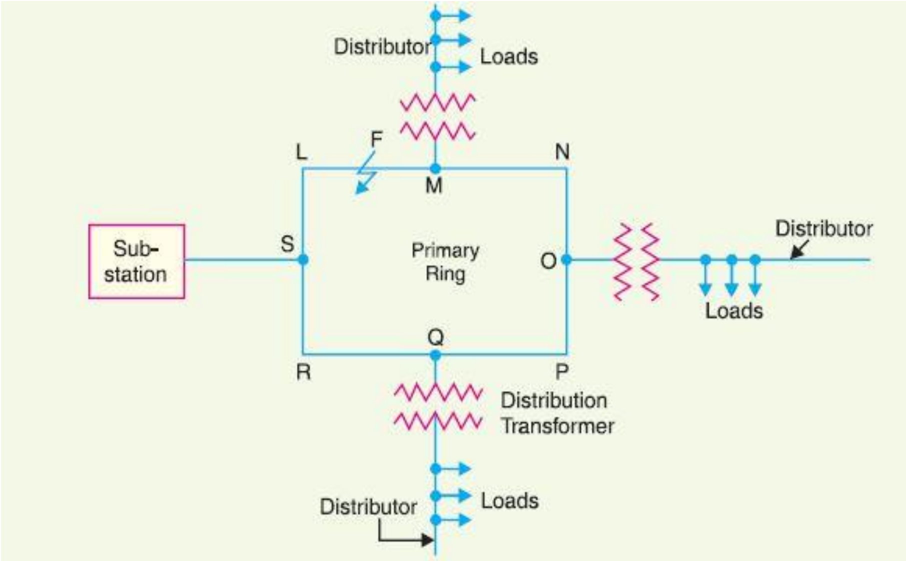


Fig.12.Single line diagram of ring main system for a.c. distribution

The ring main system has the following advantages:

a) There are less voltage fluctuations at consumer's terminals.
b) The system is very reliable as each distributor is fed via *two feeders.

In the event of fault on any section of the feeder, the continuity of supply is maintained. For example, suppose that fault occurs at any point F of section SLM of the feeder. Then section SLM of the feeder can be isolated for repairs and at the same time continuity of supply is maintained to all the consumers via the feeder SRQPONM.

3. Interconnected system.

When the feeder ring is energized by two or more than two generating stations or substations, it is called **inter-connected system**.

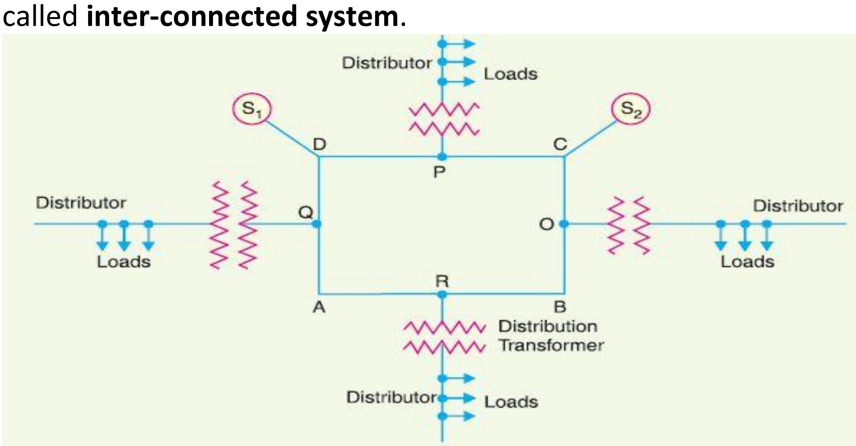


Fig.13 Single line diagram of interconnected

The interconnected system has the following advantages*:*

(a) It increases the service reliability.
(b) Any area fed from one generating station during peak load hours can be fed from the other generating station. This reduces reserve power capacity and increases efficiency of the system.

Content/Topic 2. Types of AC wiring systems

1. Single-phase A.C. system
(*i*) Single-phase two-wire.
(*ii*) Single-phase two-wire with mid-point earthed.
(*iii*) Single-phase three-wire.

2. Two-phase A.C. system
(*i*) Two-phase four-wire.
(*ii*) Two-phase three wire.

3. three-phase A.C. system
(*i*) Three-phase three-wire.
(*ii*) Three-phase four-wire.

1. Single-phase two-wire

Fig 14.shows a single phase 2-wire a.c. system with one conductor earthed. The maximum voltage between conductors is Vm so that r.m.s. value of voltage between them is Vm / 2.

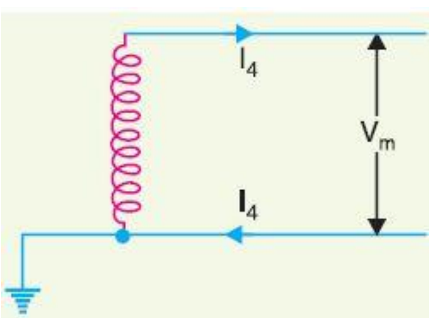


Fig. 14 Single-phase two-wire

2. Single phase 2-wire system with mid-point earthed

Fig. 15 shows a single phase a.c. system with mid-point earthed. The two wires possess equal and opposite voltages to earth (*i.e., Vm*).
Therefore, the maximum voltage between the two wires is 2*Vm*. The r.m.s. value of voltage between conductors is equal to

$$2V_m / \sqrt{2} = \sqrt{2}\, V_m .$$

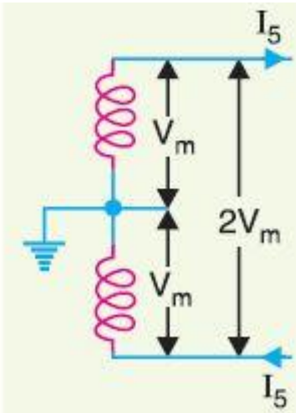


Fig.15 Single phase 2-wire system with mid-point earthed

3. Single phase, 3-wire system.

This system consists of two outers and neutral wire taken from the mid-point of the phase winding as shown in Fig16. If the load is balanced, the current through the neutral wire is zero.

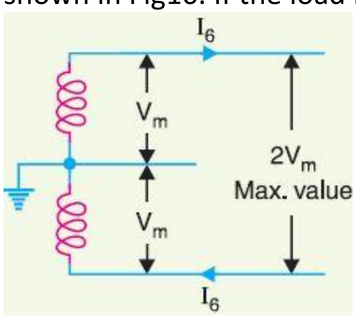


Fig.16 Single phase, 3-wire system

4. Two phase 4-wire a.c. system.

As shown in **Fig17**, the four wires are taken from the ends of the two-phase windings and the mid-points of the two windings are connected together. This system can be considered as two independent single phase systems, each transmitting one half of the total power.

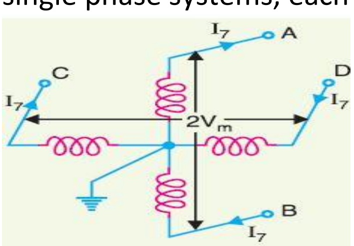


Fig.17 Two phase 4-wire a.c. system.

5. Two-phase, 3-wire system.

The third or neutral wire is taken from the junction of two-phase windings whose voltages are in quadrature with each other. Obviously, each phase transmits one half of the total power. The R.M.S. voltage between outgoing conductor and neutral equals

$$V_m/\sqrt{2}$$

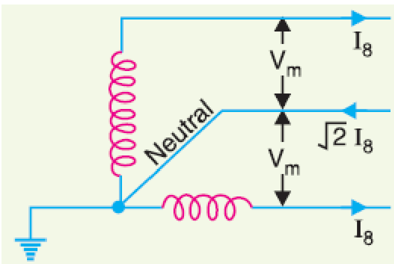


Fig.18. shows two-phase, 3-wire a.c. system.

6. 3-Phase, 3-wire system.

This system is almost universally adopted for transmission of electric power. The 3-phase, 3-wire system may be star connected or delta connected. Current in the neutral wire is the phasor sum of currents in the outer wires. Now, the currents in the outers are in quadrature (i.e., 90^0 apart) with each other.

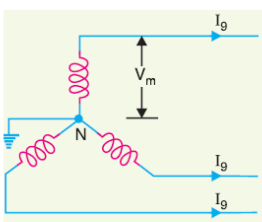


Fig.19 shows 3-phase, 3-wire star-connected system.

7. Three -phase, 4-wire system.

In this case, 4th or neutral wire is taken from the neutral point as shown in **Fig 20.** The area of X-section of the neutral wire is generally one-half that of the line conductor. If the loads are balanced, then current through the neutral wire is zero. This system is mostly used for the distribution of power to the consumers for utilization.

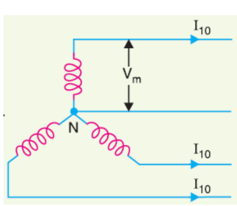


Fig.20.Three-phase, 4-wire system

Learning unit 2: Elaborate technical specifications

LO 2.1: Calculate electrical design requirements

Content/Topic 1. Calculation of load power requirements

1. Demand factor and diversity factor

- Demand factor is the ratio of the maximum demand of a system, or part of a system, to the total connected load on the system, or part of the system under consideration. Demand factor is always less than one.

Demand Factor = Maximum demand of a system / Total connected load on the system

Example: if a residence having 6000W equipment connected has a maximum demand of 300W, Then demand factor = 6000W / 300W = 20%.

The lower the demand factor, the less system capacity required to serve the connected load

- ***Diversity factor*** is the ratio of the sum of the individual maximum demands of the various subdivisions of a system, or part of a system, to the maximum demand of the whole system, or part of the system, under consideration. Diversity factor is usually more than one.

For example, these terms, when used in an electrical design, should be applied as follows: **The sum of the connected loads supplied by a feeder-circuit can be multiplied by the demand factor to determine *the load* used to size the components of the system**.
The sum of the maximum demand loads for two or more feeders is divided by the diversity factor for the feeders to derive the maximum demand load

Given: Consider four individual feeder-circuits with connected loads of 250 kVA, 200 kVA, 150 kVA and 400 kVA and demand factors of 90%, 80%, 75% and 85% respectively. Use a diversity factor of 1.5.
Solution: Calculating demand for feeder-circuits

- 250 kVA x 90% = 225 kVA
- 200 kVA x 80% = 160 kVA
- 150 kVA x 75% = 112.5 kVA
- 400 kVA x 85% = 340 kVA

The sum of the individual demands is equal to 837.5 kVA

If the main feeder-circuit were sized at unity diversity: kVA = 837.5 kVA ÷ 1.00 = 837.5 kVA the main feeder-circuit would have to be supplied by an 850 kVA transformer.
However, using the diversity factor of 1.5, the kVA = 837.5 kVA ÷ 1.5 = 558 kVA for the main feeder. For diversity factor of 1.5, a 600 kVA transformer could be used. Note that a 600 kVA transformer can be used instead of an 850 kVA when applying the 1.5 diversity factor.

Although feeder-circuit conductors should have an ampacity sufficient to carry the load, the ampacity of the feeder-circuit need not always be equal to the total of all loads on all branch-circuits connected to it. Remember*, **the demand factor*** permits a feeder-circuit ampacity to be less than 100% of the sum of all branch-circuit loads connected to the feeder.

"Demand factor" is a percentage by which the total connected load on a service or feeder is multiplied to determine the greatest probable load that the feeder will be called upon to carry. In hospitals, hotels, apartment complexes, and dwelling units, it is not likely that all of the lights and receptacles connected to every branch-circuit served by a service or feeder would be "on" at the same time. Therefore, instead of sizing the feeder to carry the entire load on all of the branches, a percentage can be applied to this total load, and the components sized accordingly.

Calculation:

- (1) A Residence Consumer has 10 No's Lamp of 400 W but at the same time It is possible that only 9 No's of Bulbs are used at the same time. Here Total Connected load is 10×40=400 W. Consumer maximum demand is 9×40=360 W. Demand Facto of this Load = 360/400 =0.9 or 90%.
- (2) One Consumer have 10 lights at 60 kW each in Kitchen, the load is 60 kW x 10 = 600 KW. This will be true only if All lights are Turns ON the same time (Demand factor=100% or 1)
- For this Consumer it is observed that only half of the lights being turned ON at a time so we can say that the demand factor is 0.5 (50%). The estimated load = 600 kW X 0.5 = 300 kW.

Use of demand factors:

- Feeder conductors should have sufficient Ampere Capacity to carry the load. The Ampere Capacity does not always be equal to the total of all loads on connected branch-circuits.
- This factor must be applied to each individual load, with particular attention to electric motors, which are very rarely operated at full load.
- As per National Electrical Code (NEC) demand factor may be applied to the total load. The demand factor permits a feeder ampacity to be less than 100 percent of all the branch-circuit loads connected to it.
- Demand factor can be applied to calculate the size of the sub-main which is feeding a Sub panel or a fixed load like a motor etc. If the panel have total load of 250 kVA, considering a Demand factor of 0.8, we can size the feeder cable for 250 x 0.8= 200 kVA.
- Demand factors for buildings typically range between 50 and 80 % of the connected load.
- In an industrial installation this factor may be estimated on an average at 0.75 for motors.
- For incandescent-lighting loads, the factor always equals 1.

Diversity Factor is ratio of the sum of the individual maximum demands of the various sub circuit of a system to the maximum demand of the whole system.

Diversity Factor = Sum of Individual Maximum Demands / Maximum Demand of the System.

- The diversity factor is always >= 1.
- Diversity Factor is always >1 because sum of individual max. Demands >Max. Demand.

- In other terms, Diversity Factor (0 to 100%) is a fraction of Total Load that is particular item contributed to peak demand
- It is expressed as a percentage (%) or a ratio more than 1.
- **If we use diversity value in % than it should be multiply with Load and if we use in numerical value (>1) than it should be divided with Load.**
- Diversity occurs in an operating system because all loads connected to the System are not operating simultaneously or are not simultaneously operating at their maximum rating. The diversity factor shows that the whole electrical load does not equal the sum of its parts due to this time Interdependence (i.e. diverseness).
- In general terms we can say that diversity factor refers to the percent of time available that a machine. 70% diversity means that the device operates at its nominal or maximum load level 70% of the time that it is connected and turned ON.
- Consider two Feeders with the same maximum demand but that occur at different intervals of time. When supplied by the same feeder, the demand on such is less the sum of the two demands. In electrical design, this condition is known as diversity.
- Diversity factor is an extended version of demand factor. It deals with maximum demand of different units at a time/Maximum demand of the entire system.
- **Greater the diversity factor, lesser is the cost of generation of power.**
- Many designers prefer to use unity as the diversity factor in calculations for planning conservatism because of plant load growth uncertainties. Local experience can justify using a diversity factor larger than unity, and smaller service entrance conductors and transformer requirements chosen accordingly.
- The diversity factor for all other installations will be different, and would be based upon a local evaluation of the loads to be applied at different moments in time. Assuming it to be 1.0 may, on some occasions, result in a supply feeder and equipment rating that is rather larger than the local installation warrants, and an over-investment in cable and equipment to handle the rated load current. It is better to evaluate the pattern of usage of the loads and calculate an acceptable diversity factor for each particular case.

Calculation:

- One Main Feeder have two Sub feeder (Sub Feeder A and Sub Feeder B), Sub Feeder-A have demand at a time is 35 KW and Sub Feeder-B have demands at a time is 42 KW, but the maximum demand of Main Feeder is 70 KW.
- Total individual Maximum Demand =35+42=77 KW.
- Maximum Demand of whole System=70 KW
- So Diversity factor of The System= 77/70 =1.1
- Diversity factor can shoot up above 1.

Use of diversity factor:

- The Diversity Factor is applied to each group of loads (e.g. being supplied from a distribution or sub-distribution board).
- Diversity factor is commonly used for a complete coordination study for a system. This diversity factor is used to estimate the load of a particular node in the system.

- Diversity factor can be used to estimate the total load required for a facility or to size the Transformer
- Diversity factors have been developed for main feeders supplying a number of feeders, and typically 1.2 to 1.3 for Residence Consumer and 1.1 to 1.2 for Commercial Load. 1.50 to 2.00 for power and lighting loads

Diversity factor for distribution network

Elements of System	**Diversity Factors**			
	Residential	**Commercial**	**General Power**	**Large Industrial**
Between individual users	2.00	1.46	1.45	
Between transformers	1.30	1.30	1.35	1.05
Between feeders	1.15	1.15	1.15	1.05
Between substations	1.10	1.10	1.10	1.10
From users to transformers	2.00	1.46	1.44	
From users to feeder	2.60	1.90	1.95	1.15
From users to substation	3.00	2.18	2.24	1.32
From users to generating station	3.29	2.40	2.46	1.45

Content/Topic 2. Design considerations of feeders, distributors, service mains

Voltage drop in Cables

All conductors and cables (except Super conductor) have some amount of resistance, this resistance is directly proportional to the length and inversely proportional to the diameter of conductor $R \propto L/a$

- Laws of resistance $R = \rho\ (L/A)$
- Whenever current flows through a conductor, a voltage drop occurs in that conductor.
- Generally, voltage drop may be neglected for low length conductors but in a lower diameter and long length conductors, we cannot neglect that voltage drops.

Limit of Voltage drop

According to IEEE rule B-23, at any point between power supply terminal and installation, Voltage drop should not increase above 2.5% of provided (supply) voltage.

Example: if the Supply voltage is 220V, then the value of allowable voltage drop should be;

Allowable Voltage Drop = 220 x (2.5/100) = 5.5V

- In electrical wiring circuits, voltage drops also occur from the distribution board to the different sub circuit and final sub circuits, but for sub circuits and final sub circuits, the value of voltage drop should be half of that allowable voltage drops (i.e. 2.75V of 5.5V in the above case).

Tables & Charts for Suitable Cable & Wire Sizes

English unit and Metric unit

SI System or Metric (Decimal) system			English System (British)		
Current Carrying Capacity (in Amp)	Number of wires and Thickness of each wire	Area (in mm^2)	Current Carrying Capacity (in Amp)	Number of wires and Thickness of each wire	Area (in $Inch^2$)
11	1/1.13	1	11	1/.044	0.0015
13	1/1.38	1.5	13	3/.029	0.002
18	1/1.78	2.5	16	3/.036	0.003
24	7/0.85	4	21	7/.029	0.0045
31	7/1.04	6	28	7/.036	0.007
42	7/1.35	10	34	7/.044	0.01
56	7/1.70	16	43	7/.052	0.0145
73	7/2.14	25	56	7/.064	0.0225
90	19/1.53	35	66	19/.044	0.03
145	19/1.78	50	77	19/.052	0.04
185	19/2.14	70	105	19/.064	0.06
230	19/2.52	95	180	19/0.83	0.1

Table (1) current rating of Copper cables at 86°F or 30°C

SI System or Metric (Decimal) system			English System		
Current Carrying Capacity (in Amp)	Number of wires and Thickness of each wire	Area (in mm^2)	Current Carrying Capacity (in Amp)	Number of wires and Thickness of each wire	Area (in $Inch^2$)
3	16/0.20	0.5	3	14/0.0076	0.0006
6	24/0.20	0.75	6	23/0.0076	0.001
10	32/0.20	1	13	40/0.0076	0.00017
13	40/0.20	1.25	18	70/0.0076	0.003
15	48/0.20	1.5	24	110/0.0076	0.004
20	80/0.20	2.5	31	162/0.0076	0.007

Table (2) current rating of flexible cords Copper cables at 86°F or 30°C

- Temperature factors

Temp Factor	1.02	1	0.97	0.94	0.91	0.88	0.77	0.63
Temp F°	77	86	95	104	113	122	1131	140
Temp C°	25	30	35	40	45	50	55	60
Temp K°	298.15	303.15	308.15	313.15	318.15	323.15	328.15	333.15

Table (3) Temperature Factor

- English and Metric units.

Inside Trunking & Conduit				Conductor	
Single Phase One Cable AC & DC		Three Phase Three or four Core Cable		Number & Diameter of Wires (in Inch)	Cross Section Area (in Inch²)
Current Rating	Volt Drop / 100 feet	Current Rating	Volt Drop / 100 feet		
Amp	Volt	Amp	Volt		
11	14	9	9.8	1/.044	0.0015
13	12	11	9.1	3/.029	0.002
16	11	14	7.7	3/.036	0.003
21	8.4	18	6.4	7/.029	0.0045
28	7	23	5.3	7/.036	0.007
34	5.7	28	4.1	7/.044	0.01
43	5.5	36	4	7/.052	0.0145
56	4.8	48	3.5	7/.064	0.0225
66	4.3	56	3.2	19/.044	0.03
77	3.6	65	2.7	19/.052	0.04
105	3.4	88	2.5	19/.064	0.06

Table (4) Cable Size, Current Rating with voltage drop (English / British System)

Inside Trunking & Conduit				Conductor	
Single Phase One Cable AC & DC		Three Phase Three or four Core Cable		Number & Diameter of Wires (mm)	Cross Section Area (mm²)
Current Rating	Volt Drop / Amp-meter	Current Rating	Volt Drop / Amp-meter		
Amp	mVolt	Amp	mVolt		
11	41	9	35	1/1.13	1
13	28	12	24	1/1.38	1.5
18	17	16	15	1/1.78	2.5
24	11	22	9.1	7/0.85	4
31	7	27	6	7/1.04	6
40	4.1	37	3.6	7/1.35	10
53	2.6	47	2.2	7/1.70	16
60	1.7	53	1.5	7/2.14	25
74	1.2	65	1	19/1.53	35

Table (5) Cable Size, Current Rating with voltage drop (SI / Metric / Decimal System)

Determine the proper Cable Size for Given Load (with Examples)

- ***Determining the size of cable for a given load, take into account the following rules***:

1. For a given load except the known value of current, there should be 20% extra scope of current for additional, future or emergency needs.
2. From Energy meter to Distribution board, Voltage drop should be 1.25% and for final sub circuit, voltage drop should not exceed 2.5% of Supply voltage.
3. Consider the change in temperature, when needed, use temperature factor (Table 3)
4. When determining the cable size, consider the wiring system i.e. in open wiring system, temperature would be low but in conduit wiring, temperature increases due to the absence of air
5. Keep in mind Diversity Factor in Electrical Wring Installation while selecting the proper size of cable for electrical wiring installation

Solved Examples of Proper Wire & Cable Size

For Electrical wiring installation in a building, total load is 5.8 kW and total length of cable from energy meter to sub-circuit distribution board is 35 m. Supply voltages are 230V and temperature is 35°C (95°F). Find the most suitable size of cable from energy meter to sub circuit if wiring is installed in conduits.

Solution:

- Load = 5.8kW = 5800W
- Voltage = 230V
- Current = I = P/V = 5800 / 230 = 25.2A
- 20% additional load current = (20/100) x 5.2A = 5A
- **Total Load Current = 25.2A + 5A = 30.2A**

Now select the size of cable for load current of 30.2A (from Table 1) which is 7/1.04 (31 Amperes) it means we can use 7/0.036 cable according **table 1**.

Now check the selected (7/1.04) cable with temperature factor in Table 3, so the temperature factor is 0.97 (in table 3) at 35°C (95°F) and current carrying capacity of (7/1.04) is 31A, therefore, current carrying capacity of this cable at 35°C (104°F) would be;

- **Current rating for 35°C (95°F) = 31 x 0.97 = 30 Amp.**
- Since the calculated value (30 Amp) at 35°C (95°F) is less than that of current carrying capacity of (7/1.04) cable which is 31A, therefore this size of cable (7/1.04) is also suitable with respect to temperature.

Now find the voltage drop for per ampere meter for this (7/1.04) cable from (Table 5) which is 7mV, But in our case, the length of cable is 35 meter.

- Actual Voltage drop for 35meter = mV x I x L= (7/1000) x 31×35 = 7.6V
- And Allowable voltage drop = (2.5 x 230)/100 = 5.75V

Here the actual Voltage drop (7.6 V) is greater than that of maximum allowable voltage drop of 5.75V. Therefore, this is not suitable size of cable for that given load.

So we will select the next size of selected cable (7/1.04) which is 7/1.35 and find the voltage drop again. According to Table (5) the current rating of 7/1.35 is 40Amperes and the voltage drop in per ampere meter is 4.1 mV (See table (5)).

- Therefore, the actual voltage drop for 35 meter cable would be;
- Actual Voltage drop for 35meter ***= mV x I x L*** = (4.1/1000) x 40×35 = 7.35V = 5.74V

This drop is less than that of maximum allowable voltage drop. So this is the **most appropriate and suitable cable or wire size**.

<u>Exercise</u>

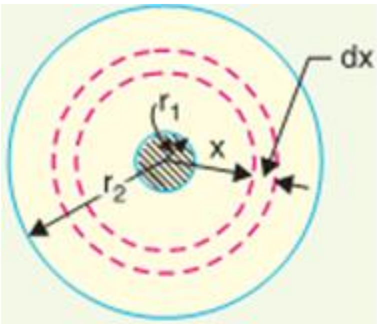
A 10H.P (7.46kW) three phase squirrel cage induction motor of continuous rating using Star-Delta starting is connected through 400V supply by three single core PVC cables run in conduit from 250feet (76.2m) away from multi-way distribution fuse board. Its full load current is 19A. Average summer temperature in Electrical installation wiring is 35°C (95°F). Calculate the size of the cable for motor?

3. Calculation of insulation resistance of under-ground cables

The cable conductor is provided with a suitable thickness of insulating material in order to prevent leakage current. The path for leakage current is radial through the insulation. The opposition offered by insulation to leakage current is known as insulation resistance of the cable. For satisfactory operation, the insulation resistance of the cable should be very high.

Consider a single-core cable of conductor radius r_1 and internal sheath radius r_2 as shown in Fig. 11.12. Let l be the length of the cable and ρ be the resistivity of the insulation.

Consider a very small layer of insulation of thickness dx at a radius x. The length through which leakage current tends to flow is dx and the area of X-section offered to this flow is $2\pi x\, l$.



$\therefore$ Insulation resistance of considered layer

$$= \rho \frac{dx}{2\pi x\, l}$$

Insulation resistance of the whole cable is

$$R = \int_{r_1}^{r_2} \rho \frac{dx}{2\pi x\, l} = \frac{\rho}{2\pi l}\int_{r_1}^{r_2} \frac{1}{x}\,dx$$

$$\therefore \quad R = \frac{\rho}{2\pi\, l}\log_e \frac{r_2}{r_1}$$

This shows that insulation resistance of a cable is inversely proportional to its length. In other words, if the cable length increases, its insulation resistance decreases and *vice-versa.*

A single-core cable has a conductor diameter of 1cm and insulation thickness of 0·4 cm. If the specific resistance of insulation is 5×10^{14} Ω-cm, calculate the insulation resistance for a 2 km length of the cable.

Solution

Conductor radius, $r_1 = 1/2 = 0{\cdot}5$ cm

Length of cable, $l = 2$ km $= 2000$ m

Resistivity of insulation, $\rho = 5 \times 10^{14}\ \Omega\text{-cm} = 5 \times 10^{12}\ \Omega\text{-m}$

Internal sheath radius, $r_2 = 0{\cdot}5 + 0{\cdot}4 = 0{\cdot}9$ cm

$\therefore$ Insulation resistance of cable is

$$R = \frac{\rho}{2\pi l}\log_e \frac{r_2}{r_1} = \frac{5\times 10^{12}}{2\pi \times 2000}\log_e \frac{0\cdot 9}{0\cdot 5}$$

$$= 0{\cdot}234 \times 10^9\ \Omega = \mathbf{234\ M\ \Omega}$$

LO 2.2: Calculate mechanical design requirements

Content/Topic1. Main components of over-head lines

An overhead line may be used to transmit or distribute electric power. The successful operation of an overhead line depends to a great extent upon the mechanical design of the line. While constructing an overhead line, it should be ensured that mechanical strength of the line is such so as to provide against the most probable weather conditions.

In general, the main components of an overhead line are:

(i) Conductors: which carry electric power from the sending end station to the receiving end station.

(ii) Supports: which may be poles or towers and keep the conductors at a suitable level above the ground?
(iii) Insulators: which are attached to supports and insulate the conductors from the ground.
(iv) Cross arms: which provide support to the insulators.
(v) Miscellaneous items such as phase plates, danger plates, lightning arrestors, anti-climbing wires etc.

1. Phase Plates Provided in order to distinguish the various phases.

2. Lightning Arrestors Discharge excessive voltages built upon the line to earth due to lightning.
3. Barbed Wire Installed over some portion of the pole at anti climbing device.

4. Guard Wires provided above or below power lines whole crossing telephone or telegraph lines.

The continuity of operation in the overhead line depends upon the judicious choice of above components. Therefore, it is profitable to have detailed discussion on them.

1. Conductor Materials

The conductor is one of the important items as most of the capital outlay is invested for it. Therefore, proper choice of material and size of the conductor is of considerable importance. The conductor material used for transmission and distribution of electric power should have the following properties:

(i) High electrical conductivity.
(ii) High tensile strength in order to withstand mechanical stresses.
(iii) Low specific gravity so that weight per unit volume is small.

Commonly used conductor materials.

The most commonly used conductor materials for overhead lines are copper, aluminum, steel-cored aluminum, galvanized steel and cadmium copper. The choice of a particular material will depend upon the cost, the required electrical and mechanical properties and the local conditions.

2. Line Supports

The supporting structures for overhead line conductors are various types of poles and towers called line supports. In general, the line supports should have the following properties:
i) High mechanical strength to withstand the weight of conductors and wind loads etc.
ii) Light in weight without the loss of mechanical strength.
iii) Cheap in cost and economical to maintain.
iv) Longer life.
v) Easy accessibility of conductors for maintenance

The line supports used for transmission and distribution of electric power are of various types including wooden poles, steel poles, R.C.C. poles and lattice steel towers. The choice of supporting structure for a particular case depends upon the line span, X-sectional area, line voltage, cost and local conditions.

3. Insulators

The overhead line conductors should be supported on the poles or towers in such a way that currents from conductors do not flow to earth through supports i.e., line conductors must be properly insulated from supports. This is achieved by securing line conductors to supports with the help of insulators. The insulators provide necessary insulation between line conductors and supports and thus prevent any leakage current from conductors to earth.

Properties of insulators

High mechanical strength in order to withstand conductor load, wind load etc.
i) High electrical resistance of insulator material in order to avoid leakage currents to earth.
ii) High relative permittivity of insulator material in order that dielectric strength is high.
iii) The insulator material should be non-porous; free from impurities and cracks otherwise the permittivity will be lowered.
v) High ratio of puncture strength to flashover.

3.1 Types of Insulators

The successful operation of an overhead line depends to a considerable extent upon the proper selection of insulators. There are several types of insulators but the most commonly used are pin type, suspension type, strain insulator and shackle insulator.

1. Pin type insulators

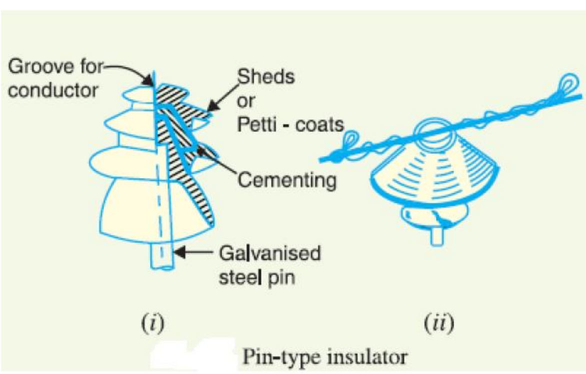


Fig. 21 Pin type insulators

As the name suggests, the pin type insulator is secured to the cross-arm on the pole. There is a groove on the upper end of the insulator for housing the conductor. Pin insulators are used for transmission and distribution of electrical power at voltages up to 33kV. Beyond operating voltage of 33kV, the pin type insulators become too bulky and hence uneconomical.

2. Suspension type insulators.

The cost of pin type insulator increases rapidly as the working voltage is increased. Therefore, this type of insulator is not economical beyond 33kV. For high voltage (> 33kV), it is a usual practice to use suspension type insulators.

Suspension insulator

Fig.22 Suspension type insulators.

They consist of a number of porcelain connected in series by metal links in the form of a string. The conductor is suspended at the bottom end of this string while the other end of the string is secured to the cross-arm of the tower. Each unity or disc is designed for low voltage, say 11kV. The number of discs in series would obviously depend upon the working voltage. For instance, if the working voltage is 66kV, then six discs in series will be provided on the string.

Advantages

i) Suspension type insulators are cheaper than pin type insulators for voltage beyond 33kV.
ii) Each unit or disc of suspension type insulator is designed for low voltage, usually 11kV. Depending upon the working voltage, the desired number of discs can be connected in series.
iii) If anyone disc is damaged, the whole string does not become useless because the damaged disc can be replaced by the sound one.
iv) The suspension arrangement provides greater flexibility to the line. The connection at the cross arm is such that insulator string is free to swing in any direction and can take up the position where mechanical stresses are minimum.
v) In case of increased demand on the transmission line, it is found more satisfactory to supply the greater demand by raising the line voltage than to provide another set of conductors. The additional insulation required for the raised voltage can be easily obtained in the suspension arrangement by adding the desired number of discs.
vi) The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross-arm of the tower, therefore, this arrangement provides partial protection from lightning.

3. Strain insulators

When there is a dead end of the line or there is corner or sharp curve, the line is subjected to greater tension. In order to relieve (lift up) the line of excessive tension, strain insulators are used. The disc of strain insulators are used in the vertical plane. When the tension in lines is exceedingly high, as at long river spans, two or more strings are used in parallel.

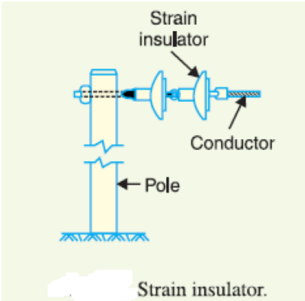


Fig.23 Strain insulators

4. Shackle insulators

In early days, the shackle insulators were used as strain insulators. But now-a-days, they are frequently used for low voltage distribution lines. Such insulators can be used either in a horizontal position or in a vertical position. They can be directly fixed to the pole with a bolt or to the cross arm. The conductor in the groove is fixed with a soft binding wire.

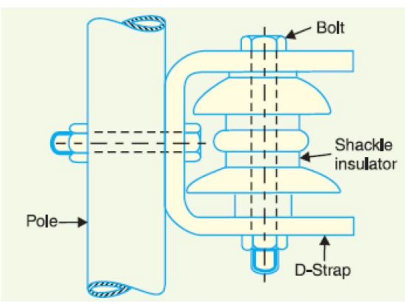


Fig. 24 Shackle insulators

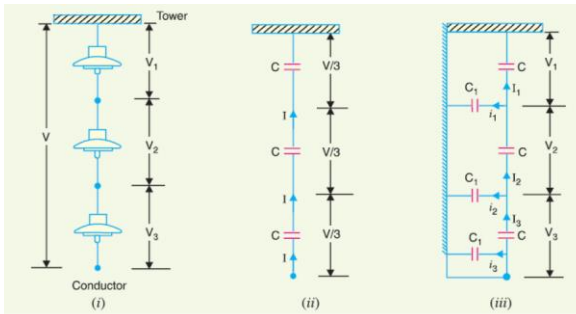
3.2 Potential distribution over suspension insulator string

A string of suspension insulators consists of a number of porcelain disc connected in series through metallic links. The porcelain portion of each disc is in between two metal links. Therefore, each disc forms a capacitor C. This is known as mutual capacitance or self-capacitance. If there were mutual capacitance alone, then charging current would have been the same through the entire disc and consequently voltage across each unit would have been the same i.e., V/3. However, in actual practice, capacitance also exists between metal fitting of each disc and tower or earth. This is known as shunt capacitance C1. Due to shunt capacitance, charging is not the same through all the discs of the string. Therefore, voltage across each disc will be different. Obviously, the disc nearest to the conductor will have the maximum voltage. Thus, referring to the figure (iii), V3 will be much more than V2 or V1

The following points may be noted regarding the potential distribution over a string of suspension insulators:

i. The voltage impressed on a string of suspension insulators does not distribute itself uniformly across the individual disc due to the presence of shunt capacitance.
ii. The disc nearest to the conductor has maximum voltage across it. As we move towards the cross-arm, the voltage across each disc goes on decreasing.

iii. The unit nearest to the conductor is under maximum electrical stress and is likely to be punctured.
iv. If the voltage impressed across the string were d.c., then voltage across each unit would be the same. It is because insulator capacitances are ineffective (useless) for d.c.



3.3 String efficiency

The disc nearest to the conductor has much higher potential than the other discs. This unequal potential distribution is undesirable and is usually expressed in terms of string efficiency.

The ratio of the voltage across the whole string to the product of number of disc and the voltage across the disc nearest to the conductor is known as string efficiency i.e.
String efficiency is an important consideration since it decides the potential distribution along the string. The greater the string efficiency, the more uniform is the voltage distribution.

$$\text{String efficiency} = \frac{\text{Voltage across the string}}{n \times \text{Voltage across disc nearest to conductor}}$$

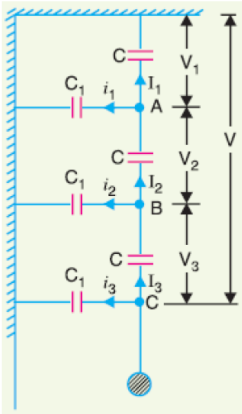
$$n = \text{number of discs in the string.}$$

String efficiency is an important consideration since it decides the potential distribution along the string. The greater the string efficiency, the more uniform is the voltage distribution.

3.4 Mathematical expression

The figure below shows the equivalent circuit for a 3 disc string. Let us suppose that self-capacitance of each disc is C. let us further assume that shunt capacitance C1 is some fraction K of self-capacitance i.e., C1 = KC.

$\therefore V$



Starting from the cross arm or tower, the voltage across each unit is V1, V2 and V3 respectively as shown.
Applying Kirchhoff's current law to node A we get,

$$
\begin{aligned}
& & I_2 &= I_1 + i_1 \\
&\text{or} & V_2 \omega C &= V_1 \omega C + V_1 \omega C_1 \\
&\text{or} & V_2 \omega C &= V_1 \omega C + V_1 \omega K C \\
&\therefore & V_2 &= V_1 (1 + K)
\end{aligned}
$$

Applying Kirchhoff's current law to node *B*, we get,

$$
\begin{aligned}
& & I_3 &= I_2 + i_2 \\
&\text{or} & V_3 \omega C &= V_2 \omega C + (V_1 + V_2)\, \omega C_1 \\
&\text{or} & V_3 \omega C &= V_2 \omega C + (V_1 + V_2)\, \omega K C \\
&\text{or} & V_3 &= V_2 + (V_1 + V_2) K \\
& & &= K V_1 + V_2 (1 + K) \\
& & &= K V_1 + V_1 (1 + K)^2 \\
& & &= V_1 [K + (1 + K)^2] \\
&\therefore & V_3 &= V_1 [1 + 3K + K^2]
\end{aligned}
$$

From the expressions above we get,

$$
\begin{aligned}
\text{Voltage across second unit from top, } V_2 &= V_1 (1 + K) \\
\text{Voltage across third unit from top, } V_3 &= V_1 (1 + 3K + K^2) \\
\text{\%age String efficiency} &= \frac{\text{Voltage across string}}{n \times \text{Voltage across disc nearest to conductor}} \times 100 \\
&= \frac{V}{3 \times V_3} \times 100
\end{aligned}
$$

Note that the current through the capacitor $= \dfrac{Voltage}{capacitive\ reactance}$

3.5 Important points

While solving problems relating to string efficiency, the following points must be kept in mind:

i) The maximum voltage appears across the disc nearest to the conductor (i.e., line conductor).
ii) The voltage across the string is equal to phase voltage i.e.

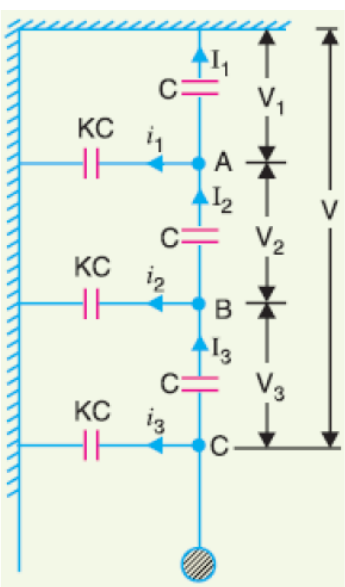
Voltage across string = Voltage between line and earth = Phase Voltage Line voltage = √3 x Voltage across string.

Example1

In a 33kV overhead line, there are three units in the string of insulators. If the capacitance between each insulator pin and earth is 11% of self-capacitance of each insulator, find:
i) The distribution of voltage over 3 insulators and
ii) String efficiency.

Solution

The figure below shows the equivalent circuit of string insulators. Let V1, V2 and V3 be the voltage across top, middle and bottom unit respectively. If C is the self-capacitance of each unity, the KC will be the shunt capacitance.



$$K = \frac{\text{Shunt Capacitance}}{\text{Self - capacitance}} = 0.11$$

Voltage across string, $V = 33/\sqrt{3} = 19{\cdot}05$ kV

At Junction A

$$I_2 = I_1 + i_1$$

or $$V_2 \omega C = V_1 \omega C + V_1 K \omega C$$

or $$V_2 = V_1(1 + K) = V_1(1 + 0{\cdot}11)$$

or $$V_2 = 1{\cdot}11\ V_1$$

At Junction B

$$I_3 = I_2 + i_2$$

or $$V_3 \omega C = V_2 \omega C + (V_1 + V_2) K \omega C$$

or $$V_3 = V_2 + (V_1 + V_2) K$$

$$= 1{\cdot}11 V_1 + (V_1 + 1{\cdot}11\ V_1)\ 0{\cdot}11$$

∴ $$V_3 = 1{\cdot}342\ V_1$$

(i) Voltage across the whole string is

$$V = V_1 + V_2 + V_3 = V_1 + 1{\cdot}11\ V_1 + 1{\cdot}342\ V_1 = 3{\cdot}452\ V_1$$

or $$19{\cdot}05 = 3{\cdot}452\ V_1$$

$\therefore$ Voltage across top unit, $V_1 = 19{\cdot}05/3{\cdot}452 = \mathbf{5{\cdot}52\ kV}$

Voltage across middle unit, $V_2 = 1{\cdot}11\ V_1 = 1{\cdot}11 \times 5{\cdot}52 = \mathbf{6.13\ kV}$

Voltage across bottom unit, $V_3 = 1{\cdot}342\ V_1 = 1{\cdot}342 \times 5{\cdot}52 = \mathbf{7.4\ kV}$

(ii) $$\text{String efficiency} = \frac{\text{Voltage across string}}{\text{No. of insulators} \times V_3} \times 100 = \frac{19 \cdot 05}{3 \times 7 \cdot 4} \times 100 = \mathbf{85.8\%}$$

Content/Topic 2: Corona effect

A. DEFINITION

When an alternating potential difference is applied across two conductors whose spacing is large as compared to their diameters, there is no apparent charge in the condition of atmospheric air surrounding the wires if the applied voltage is low. However, when the applied voltage exceeds a certain value, called critical distruptive voltage, the conductors are surrounded by a faint violet glow called corona.

The phenomenon of corona is accompanied by a hissing sound, production of ozone, power loss and radio interference. The higher the voltage is raised, the larger and higher the luminous envelope becomes, and greater are the sound, the power loss and the radio noise. If the applied voltage is increased to breakdown value, a flash over will occur between the conductors due to the breakdown of air insulation.

The phenomenon of violet glow hissing noise and production of ozone gas in an overhead transmission line is known as corona.

B. Factors affecting corona

The phenomena of corona is affected by the physical state of the atmosphere as well as by the conditions of the line. The following are the factors upon which corona depends:

1. Atmosphere: As corona is formed due to ionization of air surrounding the conductors, therefore, it is affected by the physical state of atmosphere.

2. Conductor size: The corona effect depends upon the shape and conditions of the conductors.

3. Spacing between conductors: If the spacing between the conductors is made very large as compared to their diameters, there may not be any corona effect.

4. Line voltage: The line voltage greatly affects corona. If it is low, there is no chance in the condition of air surrounding the conductors and hence no corona is formed.

C. Advantages and disadvantages of corona effect

Corona has many advantages and disadvantages. In the correct design of a high voltage overhead line, a balance should be struck between the advantages and disadvantages.

Advantages

(*i*) Due to corona formation, the air surrounding the conductor becomes conducting and hence virtual diameter of the conductor is increased. The increased diameter reduces the electrostatic stresses between the conductors.

(*ii*) Corona reduces the effects of transients produced by surges.

Disadvantages

(*i*) Corona is accompanied by a loss of energy. This affects the transmission efficiency of the line.

(*ii*) Ozone is produced by corona and may cause corrosion of the conductor due to chemical action.

(*iii*) The current drawn by the line due to corona is non-sinusoidal and hence non-sinusoidal voltage drop occurs in the line. This may cause inductive interference with neighbouring communication lines.

D. Methods of reducing corona effect

It has been seen that intense corona effects are observed at a working voltage of 33 kV or above. Therefore, careful design should be made to avoid corona on the sub-stations or bus-bars rated for 33 kV and higher voltage otherwise highly ionized air may cause flash over in the insulators or between the phases, causing considerable damage to the equipment. The corona effects can be reduced by the following methods:

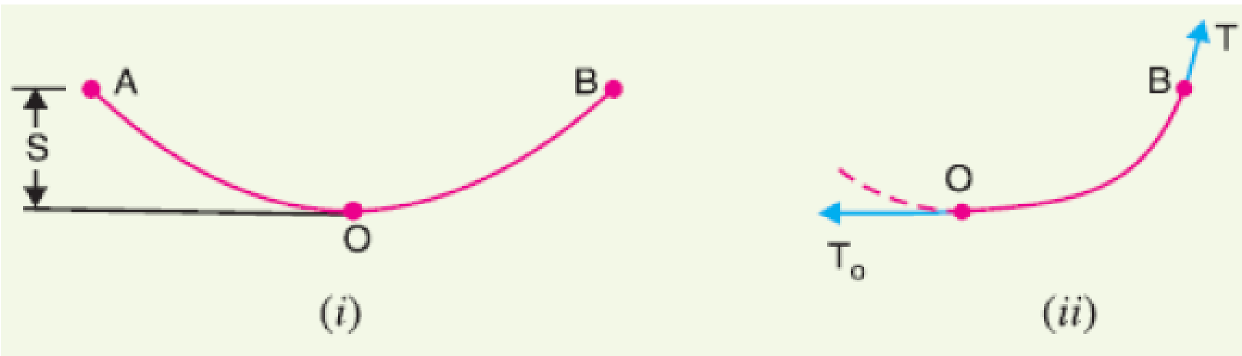
i) By increasing conductor size. By increasing conductor size, the voltage at which corona occurs is raised and hence corona effects are considerably reduced.

ii) By increasing conductor spacing. By increasing the spacing between conductors, the voltage at which corona occurs is raised and hence corona effects can be eliminated.

Content/Topic 3. Sag in over-head lines

While erecting an overhead line, it is very important that conductors are under safe tension. If the conductors are too much stretched between supports in a bid to save conductor material, the stress in the conductor may reach unsafe value and in certain cases the conductor may break due to excessive tension. In order to permit safe tension in the conductors, they are not fully stretched but are allowed to have a dip or sag.

The difference in level between points of supports and the lowest point on the conductor is called **sag.**



The figure (i) shows a conductor suspended between two equilevel supports A and B. the conductor is not fully stretched but is allowed to have a dip. The lowest point on the conductor is O and the sag is S. The following points may be noted:

i) When the conductor is suspended between two supports at the same level, it takes the shape of catenary. However, if the sag is very small compared with the span, then sag-span curve is like a parabola.

ii) The tension at any point on the conductor acts tangentially. Thus tension To at the lowest point O acts horizontally.

iii) The horizontal component of tension is constant throughout the length of the wire.

iv) The tension at supports is approximately equal to the horizontal tension acting at any point on the wire. Thus if T is the tension at the support B, then T = To.

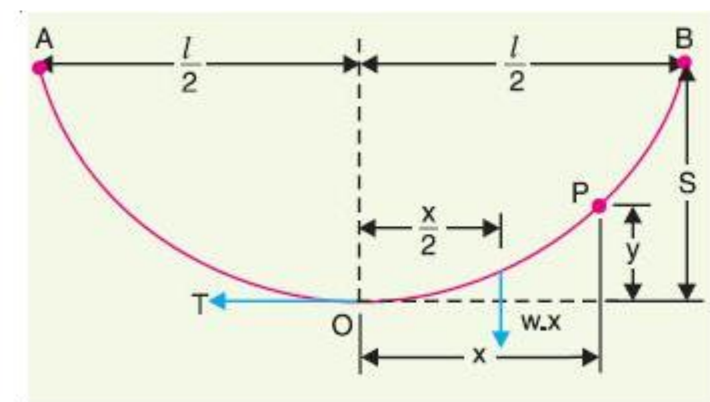
Conductor sag and tension. This is an important consideration in the mechanical design of overhead lines. The conductor sag should be kept to a minimum in order to reduce the conductor material required and to avoid extra pole height for sufficient clearance above ground level. It is also desirable that tension in the conductor should be low to avoid the mechanical failure of conductor and to permit the use of less strong supports. However, low conductor tension and minimum sag are not possible. It is because low sag means a tight wire and high tension, whereas a low tension means a loose wire and increased sag.

Calculation of Sag.

In an overhead line, the sag should be so adjusted that tension in the conductors is within safe limits. The tension is governed by conductor weight, effects of wind, ice loading and temperature variations. It is a standard practice to keep conductor tension less than 50% of its ultimate tensile strength *i.e.,* minimum factor of safety in respect of conductor tension should be 2. We shall now calculate sag and tension of a conductor when (*i*) supports are at equal levels and (*ii*) supports are at unequal levels.

i) When supports are at equal levels.

Consider a conductor between two equivalent level supports A and B with O as the lowest point as shown in the following figure.



Let l = Length of span

W = Weight per unit length of conductor

T = Tension in the conductor

Consider a point *P* on the conductor. Taking the lowest point *O* as the origin, let the co-ordinates of point *P* be *x* and *y*. Assuming that the curvature is so small that curved length is equal to its horizontal projection (*i.e.,* $OP = x$), the two forces acting on the portion *OP* of the conductor are :

(*a*) The weight *wx* of conductor acting at a distance *x*/2 from *O*.

(*b*) The tension *T* acting at *O*.

Equating the moments of above two forces about point *O*, we get,

$$Ty = wx \times \frac{x}{2}$$

or

$$y = \frac{wx^2}{2T}$$

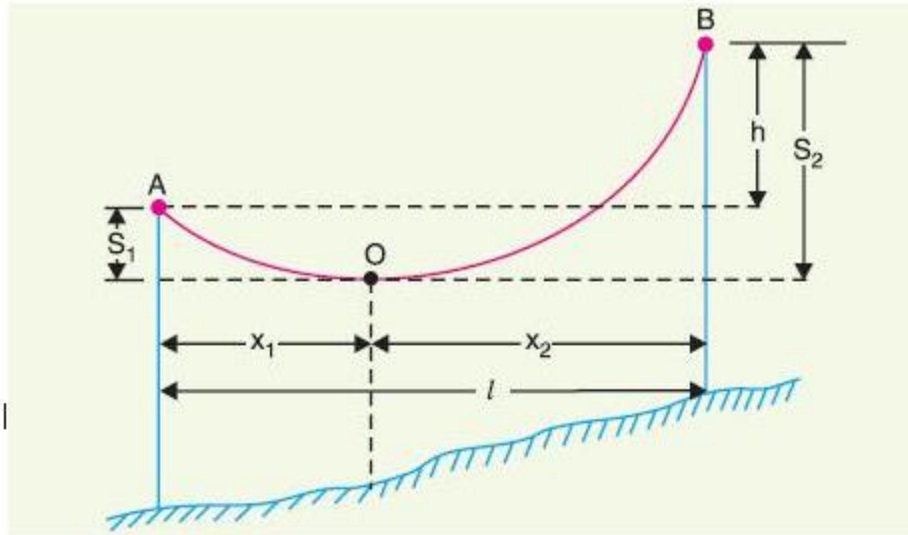
The maximum dip (sag) is represented by the value of *y* at either of the supports *A* and *B*.

At support *A*, $x = l/2$ and $y = S$

$$\therefore \quad \text{Sag,} \quad S = \frac{w(l/2)^2}{2T} = \frac{wl^2}{8T}$$

ii) When supports are at unequal levels.

In hilly areas, we generally come across conductors suspended between supports at unequal levels.



Let

l = Span length

h = Difference in levels between two supports

x_1 = Distance of support at lower level (*i.e.,* A) from O

x_2 = Distance of support at higher level (*i.e.* B) from O

T = Tension in the conductor

If w is the weight per unit length of the conductor, then,

$$\text{Sag } S_1 = \frac{w\,x_1^2}{2T}$$

and

$$\text{Sag } S_2 = \frac{w\,x_2^2}{2T}$$

Also

$$x_1 + x_2 = l \qquad \ldots(i)$$

Now

$$S_2 - S_1 = \frac{w}{2T}[x_2^2 - x_1^2] = \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$$

$\therefore$

$$S_2 - S_1 = \frac{w\,l}{2T}(x_2 - x_1) \qquad [\because x_1 + x_2 = l]$$

But

$$S_2 - S_1 = h$$

$\therefore$

$$h = \frac{w\,l}{2T}(x_2 - x_1)$$

or

$$x_2 - x_1 = \frac{2\,Th}{w\,l} \qquad \ldots(ii)$$

Solving exps. (*i*) and (*ii*), we get,

$$x_1 = \frac{l}{2} - \frac{T h}{w l}$$

$$x_2 = \frac{l}{2} + \frac{T h}{w l}$$

Having found x_1 and x_2, values of S_1 and S_2 can be easily calculated.

Content/Topic 3: Construction of under-ground cables

An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover.
Although several types of cables are available, the type of cable to be used will depend upon the working voltage and service requirements. In general, a cable must fulfill the following necessary requirements:

(i) The conductor used in cables should be tinned stranded copper or aluminum of high conductivity. Stranding is done so that conductor may become flexible and carry more current.

(ii) The conductor size should be such that the cable carries the desired load current without overheating and causes voltage drop within permissible limits.

(iii) The cable must have proper thickness of insulation in order to give high degree of safety and reliability at the voltage for which it is designed.

(iv) The cable must be provided with suitable mechanical protection so that it may withstand the rough use in laying it.

(v) The materials used in the manufacture of cables should be such that there is complete chemical and physical stability throughout.

ig. 11.1 shows the general construction of a 3-conductor cable. The various parts are :

(i) *Cores or Conductors.* A cable may have one or more than one core (conductor) depending upon the type of service for which it is intended. For instance, the 3-conductor cable shown in Fig. 11.1 is used for 3-phase service. The conductors are made of tinned copper or aluminium and are usually stranded in order to provide flexibility to the cable.

(ii) *Insulatian.* Each core or conductor is provided with a suitable thickness of insulation, the thickness of layer depending upon the voltage to be withstood by the cable. The commonly used materials for insulation are impregnated paper, varnished cambric or rubber mineral compound.

(iii) *Metallic sheath.* In order to protect the cable from moisture, gases or other damaging liquids (acids or alkalies) in the soil and atmosphere, a metallic sheath of lead or aluminium is provided over the insulation as shown in Fig. 11.1

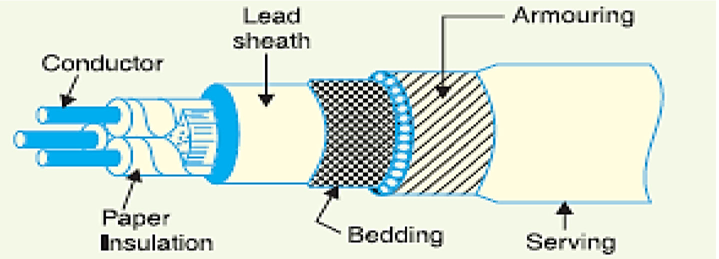


Fig. 11.1 Construction of a Cable

(iv) *Bedding.* Over the metallic sheath is applied a layer of bedding which consists of a fibrous material like jute or hessian tape. The purpose of bedding is to protect the metallic sheath against corrosion and from mechanical injury due to armouring.

(v) *Armouring.* Over the bedding, armouring is provided which consists of one or two layers of galvanised steel wire or steel tape. Its purpose is to protect the cable from mechanical injury while laying it and during the course of handling. Armouring may not be done in the case of some cables.

(vi) *Serving.* In order to protect armouring from atmospheric conditions, a layer of fibrous

material (like jute) similar to bedding is provided over the armouring. This is known as serving.

Content/Topic 4. Classification of under-ground cables

Cables for underground service may be classified in two ways according to (*i*) the type of insulating material used in their manufacture (*ii*) the voltage for which they are manufactured. However, the latter method of classification is generally preferred, according to which cables can be divided into the following groups :

(*i*) Low-tension (L.T.) cables — upto 1000 V
(*ii*) High-tension (H.T.) cables — upto 11,000 V
(*iii*) Super-tension (S.T.) cables — from 22 kV to 33 kV
(*iv*) Extra high-tension (E.H.T.) cables — from 33 kV to 66 kV
(*v*) Extra super voltage cables — beyond 132 kV

A cable may have one or more than one core depending upon the type of service for which it is intended. It may be

(i) Single-core
(ii) two-core
(iii) Three-core and four-core etc. For a 3-phase service, either 3-single-core cables or three-core cable can be used depending upon the operating voltage and load demand.

Content/Topic 5. Insulation of underground cable

Commonly used Cable Insulation Materials are: ***thermoplastic*** (eg. PVC) or ***thermosetting*** (e.g EPR, XLPE) type materials and Paper Based insulation.

Thermoplastic type material

Thermoplastic compounds are materials that go soft when heated and harden when cooled, It includes,

- **PVC (Polyvinyl Chloride)** is the most commonly used thermoplastic insulator for cables. It is cheap, durable and widely available. However, the chlorine in PVC (a halogen) causes the production of thick, toxic, black smoke when burnt and can be a health hazard in areas where low smoke and toxicity are required (e.g. confined areas such as tunnels).

- **PE (Polyethylene**) is part of a class of polymers called polyolefin. Polyethylene has lower dielectric losses than PVC and is sensitive to moisture under voltage stress (i.e. for high voltages only).

Thermosetting type

Thermosetting compounds are polymer resins that are irreversibly cured (e.g. by heat in the vulcanization process) to form a plastic or rubber. This type of insulation material includes:

- **XLPE (Cross-Linked Polyethylene)** has different polyethylene chains linked together ("cross-linking") which helps prevent the polymer from melting or separating at elevated temperatures. Therefore,
  - XLPE is useful for higher temperature applications.
  - XLPE has higher dielectric losses than PE, but has better ageing characteristics and resistance to water treeing.

- **EPR (Ethylene Propylene Rubber*)*** is a copolymer of ethylene and propylene, and commonly called an "elastomer". EPR is more flexible than PE and XLPE, but has higher dielectric losses than both.

Paper Based

Paper Based insulation is the oldest type of power cable insulation and is still used mainly for high voltage cables. The paper insulation must be impregnated with a dielectric fluid (e.g. oil resin or a synthetic fluid). A lead sheath is commonly applied over the insulation to prevent water or moisture ingress into the paper insulation, which is sensitive to moisture.

A comparison of common insulating materials is as follows:

Material	Advantages	Disadvantages
PVC	▪Cheap ▪Durable ▪Widely available	▪Highest dielectric losses ▪Melts at high temperatures ▪Contains halogens ▪Not suitable for MV / HV cables
PE	▪Lowest dielectric losses ▪High initial dielectric strength	▪Highly sensitive to water treeing ▪Material breaks down at high temperature
XLPE	▪Low dielectric losses ▪Improved material properties at high temperatures ▪Does not melt but thermal expansion occurs	▪Medium sensitivity to water treeing (although some XLPE polymers are water-tree resistant)
EPR	▪Increased flexibility ▪Reduced thermal expansion (relative to XLPE) ▪Low sensitivity to water treeing ▪Low-Medium dielectric losses	▪Medium-High dielectric losses ▪Requires inorganic filler additive ▪High weight ▪High cost
Paper / Oil	▪Not harmed by DC testing ▪Known history of reliability	▪Requires hydraulic pressure / pumps for insulating fluid ▪Difficult to repair ▪Degrades with moisture

LO 2.3: Specify switching and protection equipment

Content/Topic1. Types of switching and protection equipment

There are several instances when the elements of a power system (e.g. generators transmission lines, insulators etc.) are subjected to over-voltages i.e voltage greater than the normal value. These over-voltages on the power system may be caused due to many reasons such as lightning, the opening of a circuit breaker, the grounding of a conductor etc. Most of the over-voltages are not of large magnitude but may still be important because of their effect on the performance of circuit interrupting equipment and protective devices.

1. Circuit breakers

A circuit breaker is defined as a protective device used for protecting the electrical system or electrical equipment under normal operation and abnormal operation.

A circuit breaker is a piece of equipment which can

(*i*) make or break a circuit either manually or by remote control under normal conditions

(*ii*) break a circuit *automatically* under fault conditions

(*iii*) make a circuit either manually or by remote control under fault conditions

Thus a circuit breaker incorporates manual (or remote control) as well as automatic control for switching functions. The latter control employs relays and operates only under fault conditions.

1.1 Operating principle

A circuit breaker essentially consists of fixed and moving contacts, called electrodes. Under normal operating conditions, these contacts remain closed and will not open automatically until and unless the system becomes faulty. Of course, the contacts can be opened manually or by remote control whenever desired. When a fault occurs on any part of the system, the trip coils of the circuit breaker get energised and the moving contacts are pulled apart by some mechanism, thus opening the circuit.

When the contacts of a circuit breaker are separated under fault conditions, an arc is struck between them. The current is thus able to continue until the discharge ceases. The production of arc not only delays the current interruption process but it also generates enormous heat which may cause damage to the system or to the circuit breaker itself. Therefore, the main problem in a circuit breaker is to extinguish the arc within the shortest possible time so that heat generated by it may not reach a dangerous value.

1.2 Classification of circuit breakers

There are several ways of classifying the circuit breakers. However, the most general way of classification is on the basis of medium used for arc extinction. The medium used for arc extinction is usually oil, air, sulphur hexafluoride (SF_6) or vacuum. Accordingly, circuit breakers may be classified into :

(*i*) *Oil circuit breakers* which employ some insulating oil (*e.g.*, transformer oil) for arc extinction.

(*ii*) *Air-blast circuit breakers* in which high pressure air-blast is used for extinguishing the arc.

(*iii*) *Sulphur hexafluroide circuit breakers* in which sulphur hexafluoride (SF_6) gas is used for arc extinction.

(*iv*) *Vacuum circuit breakers* in which vacuum is used for arc extinction.

Each type of circuit breaker has its own advantages and disadvantages. In the following sections, we shall discuss the construction and working of these circuit breakers with special emphasis on the way the arc extinction is facilitated.

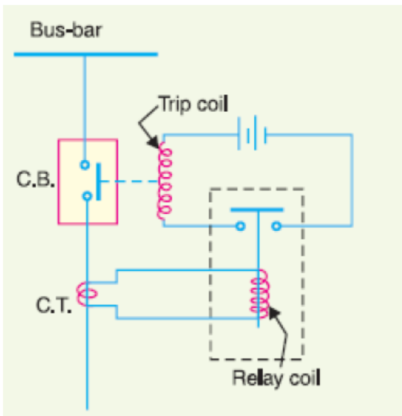
2. Protective relays

A relay is a device which detects the fault and supplies information to the breaker for circuit interruption. Fig. _ (*ii*) shows a typical relay circuit. It can be divided into three parts *viz.*

(*i*) The primary winding of a current transformer (C.T.) which is connected in series with the circuit to be protected. The primary winding often consists of the main conductor itself.

(*ii*) The second circuit is the secondary winding of C.T. connected to the relay operating coil.

(*iii*) The third circuit is the tripping circuit which consists of a source of supply, trip coil of circuit breaker and the relay stationary contacts.



(*ii*)

Under normal load conditions, the e.m.f. of the secondary winding of C.T. is small and the current flowing in the relay operating coil is insufficient to close the relay contacts. This keeps the trip coil of the circuit breaker unenergised. Consequently, the contacts of the circuit breaker remain closed and it carries the normal load current. When a fault occurs, a large current flows through the primary of C.T. This increases the secondary e.m.f. and hence the current through the relay operating coil. The relay contacts are closed and the trip coil of the circuit breaker is energised to open the contacts of the circuit breaker.

3. Fuses

A fuse is a short piece of wire or thin strip which melts when excessive current flows through it for sufficient time. It is inserted in series with the circuit to be protected. Under normal operating conditions, the fuse element it at a temperature below its melting point. Therefore, it carries the normal load current without overheating. However, when a short circuit or overload occurs, the current through the fuse element increases beyond its rated capacity. This raises the temperature and the fuse element melts (or blows out), disconnecting the circuit protected by it. In this way, a fuse protects the machines and equipment from damage due to excessive currents. It is worthwhile to note that a fuse performs both detection and interruption functions.

4. Disconnectors

It is essentially a knife switch and is designed to open a circuit under *no load*. Its main purpose is to isolate one portion of the circuit from the other and is not intended to be opened while current is flowing in the line. Such switches are generally used on both sides of circuit breakers in order that repairs and replacement of circuit breakers can be made without any danger. They should never be opened until the circuit breaker in the same circuit has been opened and should always be closed before the circuit breaker is closed.

Content/Topic 2. Sizing of switching and protection equipment

- ✓ **Circuit breaker**

Circuit breakers are designed to carry 100% of their rated current while the NEC dictates an 80% application.

CB Design

A CB is designed and evaluated to carry 100% of its rated current for an indefinite period of time under standard test conditions. These conditions, per UL 489, Underwriters Laboratories Standard for Safety for Molded-Case Circuit Breakers and Circuit Breaker Enclosures, include mounting the CB in free air (i.e.: with no enclosure) where the ambient temperature is held at 40 [degrees] C (approximately 104 [degrees] F). Under these conditions, molded-case CBs are required not to trip at rated current.

However, a CB most frequently is applied in equipment at 80% of its rated current under NEC Sec. 384-16(c). If you understand why this requirement is in place, you'll be able to apply CBs correctly.

CB Characteristic Trip Curves

CB characteristic trip curves document how long it takes for specific CBs to trip depending upon the level of current. Fig. 1 shows a typical curve for a thermal-magnetic CB. The curved portion at the top represents the time it takes for the CB to trip on overload. An overload condition will cause heat buildup around the current path, within the CB as well as along the power conductors. This heat, which is generated by the current flow, is actually what causes the CB to trip in this region not simply the magnitude of the current flow. This portion of the curve is said to have an inverse time characteristic, which means that the CB will trip in less time at higher levels of current flow.

Since the current path (including both the CB and the conductor) reacts to heat, the overall operating temperature of the equipment becomes a factor in sizing a CB in an enclosure. Other factors that may affect this equipment operating temperature include:

- Size and location of the enclosure;
- More than one current carrying device housed in the same enclosure;
- Level of current each device is carrying; and
- Environmental conditions in the area of the equipment.

Consequently, simply designing a CB to hold 100% of its rated current only addresses a portion of the concern. The equipment must be able to safely sustain the heat generated by all sources without exceeding the temperature limits in the product test standard. Both of these factors are accounted for by the sizing rules imposed by the NEC.

CB Sizing Examples

The following are examples of sizing rules.

Example 1: 50A continuous load and 125A noncontinuous load.

> OCPD = 100% noncontinuous load + 125% continuous load = (1.00 x 125A) + (1.25 x 50A) = 187.5A
> Therefore, a 200A OCPD is needed. If a 100%-rated CB is chosen, a 175A rating (125A + 50A) is acceptable.

- ✓ **Fuse**

For those of you who want to get right down to business, let's not waste any more time, here's how you'd go about calculating fuse size correctly in 3 simple steps:

- Determine the wire gage you already have by locating it on the package or simply by measuring it.
- Use the following table to determine the maximum current for whatever wire gage is being used.

AWG Gauge	Maximum Current (A)
0	300
1	238
2	188
3	150
4	120
5	94
6	74
7	60
8	48
9	38
10	30
11	24
12	18.6
13	14.8
14	11.8
15	9.4
16	7.4
17	5.8
18	4.6
19	3.6
20	3
21	2.4
22	1.84
23	1.458
24	1.154
25	0.914

- ❖ Take the maximum current value obtained from the table and find the largest fuse you can find that still falls within the limitations. DO NOT EXCEED THE VALUES ON THIS TABLE! Common automotive blade-style fuses exist at 5A-20A in 5A Increments. Ex: 5A,10A,15A,20A.

- ✓ **Protection relays**

Relay Ratings and Limits

Relays often have two ratings: AC and DC. These rating indicate how much power can be switched through the relays. This does not necessarily tell you what the limits of the relay are. For instance, a 5 Amp relay rated at 125VAC can also switch 2.5 Amps at 250VAC. Similarly, a 5 Amp relay rated at 24VDC can switch 2.5 Amps at 48VDC, or even 10 Amps at 12VDC.

Volts x Amps = Watts - Never Exceed Watts!

An easy way to determine the limit of a relay is to multiply the rated Volts times the rated Amps. This will give you the total watts a relay can switch. Every relay will have two ratings: AC and DC. You should determine the AC watts and the DC watts, and never exceed these ratings.

Example Calculations

AC Volts x AC Amps = AC Watts	DC Volts x DC Amps = DC Watts
Example: A 5 Amp Relay is Rated at 250 Volts AC. 5 x 250 = 1,250 AC Watts	Example: A 5 Amp Relay is Rated at 24 Volts DC. 5 x 24 = 120 DC Watts
If you are switching AC Devices, Make Sure the AC Watts of the Device you are Switching DOES NOT Exceed 1,250 when using a 5A Relay.	If you are switching DC Devices, Make Sure the DC Watts of the Device you are Switching DOES NOT Exceed 120 when using a 5A Relay.

- ✓ **Disconnectors**

The National Electric Code specifies that large, permanently-wired appliances such as air conditioners or whole house attic exhaust fans have a disconnecting means within sight of the appliance. The disconnecting means must be a listed device and must be rated to disconnect the same horsepower as the appliance it is installed for. A 3-horsepower motor requires a switch rated at 3-horsepower or more. Most disconnect switches are fused so any disconnect installed must accept the correct fuse size for the appliance.

Step 1

Examine the appliance manufacturer nameplate on the appliance. Determine the horsepower rating of the appliance. If no horsepower rating is given, look for volt-amps, watts or kilowatts.

Step 2

Convert from volt-amps, watts or kilowatts to horsepower. Divide watts or volt-amps by 745.7 to obtain horsepower. Divide kilowatts by 0.7457 to convert to horsepower.

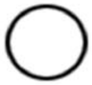
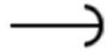
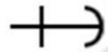
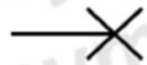
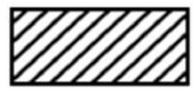
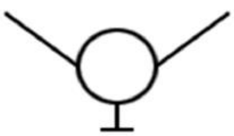
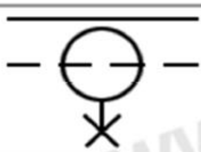
Step 3

Select a disconnect switch with the same or greater horsepower rating as the appliance. The disconnect switch must also have the correct fuse size. An appliance requiring a 30-amp double circuit breaker will need a disconnect rated to its horsepower and will accept two 30-amp fuses.

LO 2.4: Elaborate technical drawings

<u>Content/Topic1: Symbols used in electrical power distribution systems</u>

Symbols	Description	Symbols	Description
	Electrical distribution line Cable / Wire		Line inside a conduit Line inside a tube duct...
	Line through an access chamber		Underground line
	Underwater line		Underground line
	Line block with oil or gas		Bypass Line of the gas or oil
	Line detection valved gas or oil		Online probing
	Line under plastering		Power line AC
	Protection anode		Power line DC
	End of line not connected		End of line not connected and isolated
	Overhead line		Vertical retention

	Overhead line support		Inclined retention
	Wooden stand for overhead line		Antiskid the cable
	Metal holder for overhead line		Luminary
	Overhead line on wood stand		Electric tower support
	Overhead line on metal support		Distribution panel
	Overhead line on wood stand and inclined retention		Board embedded
	Overhead line carrier and vertical retention		Cabin for outdoor installation generic symbol
	Underground line with bracket and luminaire		Cabin for outdoor installation Ex: Cabin amplification
	Overhead line with wooden stand and luminaire		

Content/Topic2. Electrical power distribution line diagrams

1. **Single line diagram** is a simplified notation for representing a three-phase power system, Instead of representing each of three phases with a separate line or terminal, only one conductor is represented. It is a form of block diagram graphically depicting the paths for power flow between entities of the system. Simply it shows symbols to denote components.

2. **Architectural diagram**: An architecture diagram is a graphical representation of a set of concepts, which are part of architecture, including their principles, elements and components.

3. **Bloc diagram** this type of drawing illustrates the main parts and shows way the parts connect, A block diagram is a diagram of a system in which the principal parts or functions are represented by blocks connected by lines that show the relationships of the blocks. They are heavily used in engineering in hardware design, electronic design, software design, and process flow diagrams.

4. **Wiring diagram** is a simplified conventional pictorial representation of an **electrical circuit**. It shows the components of the **circuit** as simplified shapes, and the power and signal connections between the devices.

Learning Unit 3. Estimate cost

LO 3.1 Determine quantity of materials

Content/Topic1: Identification of purpose of preparation of bill of quantity

0. Introduction to Cost Estimation

There are always two questions asked by a client considering an investment in construction: "**How much**?" and **"How long?**" Estimating responds to the first question. Very few projects can go forward before the cost of the construction has-been determined.

Estimating is a distinct function in the construction management field, and unlike some other jobs in construction, the estimator's role is pretty specific. The estimator's primary focus is costs. They have the awesome responsibility of accurately determining the price of the project while maintaining a competitive edge in the market place. Projects are won or lost by the efforts of the estimator.

Whatever the estimator estimate depend on what is in the Bill of Quantity. In the Bill of Quantity, the main focus is on Description of item, unit and Quantity as measured.

All these terms are going to be explained in the next chapters.

1. Determine quantity of materials

For better determination of Quantity of materials, the primary task is to prepare the **takeoff** by using the drawings then the site condition may be taken into consideration.

Takeoffs, or take offs, are the estimated quantities of items that the electrical contractors need for a project. Using the plans or drawings, estimators determine the specific items and number of items that they would need to order for the job. Depending on the tools and experience of the estimator, they have many ways to calculate the takeoffs. Some estimators will do manual takeoffs from designs and drawings. Other estimators use estimating software to determine appropriate takeoffs for a given project. Takeoffs have to be as accurate as possible.

The Quantity obtained in the takeoff is the one inserted and described in the Bills of Quantity. You may wonder why to prepare the Bills of quantity, **Yes,** so let see the purpose of preparing it.

1.1 Purpose of preparation of bill of quantity

BOQ is the core element for any project whether its Civil, Electrical, Mechanical or any other filed. If all the quantities worked out properly no further variation comes during the execution phase.

In simple language you can consider BOQ as a list of items with their description and quantities provided to contractors and asked to bid their rates against each item and respective amount.

The main purposes of a BoQ are:

- To provide the same information to all tendering Contractors or Principal Contractors, that enables them all to prepare their tenders efficiently and accurately based on the same information
- Provide a basis for the valuation of completed work for the purpose of making interim payments to the Contractor or Principal Contractor
- Provide a basis for the valuation of variation work
- It provides a very strong basis for budgetary control and accurate cost reporting of the contract (i.e. post contract cost control)
- The first few words in a written description should indicate clearly the nature of work required to be completed

- BoQ helps to monitor and control the project as well as it will help to identify new items in the project
- Through BOQ, progress billing is done based on the work done for each portion as a percentage completed with the rates agreed to get the figure.

The major Parts of BoQ

Parts of BOQ can be varied according to the project size as well the practices. Generally it has measured works, Preliminaries & Provisional sums. The contract sum would be addition of these three items.

- ✓ **Preliminaries**

In construction industry, preliminaries is known as the indirect cost for execution of project but these are the costs which is very much vital for the construction activities. The reason for these cost mentioned separately is it is very difficult to distribute these cost amongst with measured works.

The examples for preliminaries listed below.

1. Charges for performance bond, advance payment guarantee & Workmen compensation
2. Maintenance of the site clean
3. Requirement of site office, site stores & staff accommodation.
4. Cost towards the project management staff (QS, Project Manager, Engineering professionals)
5. Charges for drawings & safety

From the above mentioned examples, it can be understood these costs cannot be distributed to work item but without these expenses there will be no project.

Content/Topic 2. Identification of different methods used for elaboration of bill of quantity

1. Measured works

It is the actual or estimated work will be carried out to complete the project. The works have been measured in different units. They are liner meter, square meter, cubic meter, number, item & etc. Value of measured works will be calculated by multiplication of quantities and rate.

2. Provisional sums

It is the sum which is allocated for the undersigned works at the tender time. It will be adjusted after the execution of the project. In summary BOQ is very much important for the commercial management purposes. It should be understood by every construction professional to deliver a quality and expected product to client. In other words to provide value for money.

Content/Topic 3. Content of bill of quantity

- Material names
- Description of materials to be used in installation
- Evaluation of the unit cost of each material
- Evaluation of total cost

Material names: this can be named "item number "which just identify one item to another one.

Description of materials to be used in installation: Description column provides a brief explanation of what to be done, the materials to be used and a brief specification of materials to carry out a certain task.

Evaluation of the unit cost of each material: this is the cost of one unit of work of material as described. The unit cost/rate includes the price of material, the labor rate, the cost of tools and equipment, and overhead per each unit of work.

Evaluation of total cost: This is the evaluation of the unit cost of each unit of work multiplied by the quantity obtained in the takeoff.

The BoQ is prepared in the following steps:

1. Taking-Off Quantities: Working from the construction documents, a quantity surveyor will measure the tasks and items of work in a project. This requires scaling dimensions from drawings. One will record these in standard units such as linear meter, pieces, or set. For example, you can quantify Cabling in linear meters and Sockets or lights supports in pieces.

2. Squaring: Next, the quantity surveyor multiplies the dimensions of the component into square area and multiplies this by the number of times this work item occurs in the construction, thus getting the total dimensions, length, volume, pieces and area if applicable.

3. Abstracting: Abstracting is the collecting and ordering of the squared dimensions. Similar tasks and components are grouped together. Once you have taken off and squared all items and have obtained total dimensions, they must be merged. You make deductions for any voids or openings in the building, such as stairs.

4. Billing: This last step simply involves presenting item descriptions and quantities in a structured format, the bill of quantities. You usually present these in a hierarchy for group, subgroup, and work section. (Examples include cabling, lighting and power fittings, Lightening protection...)

Content/Topic 4. Determination the way of laying out the table of bill of quantity

Generally BOQ is in tabular form which contains Item number, description, unit, quantity, rate and amount in different columns as showed below:

PROPOSED XYZ CONSTRUCTION

Item No	Description	Qty	Unît	Rates	Amount
1.	**Electrical Works** Brief description of each unit of work to be done with specification of material to be used (Ex: Cabling, Lights, sockets, Power supply, Lightening protection, etc)	Quantity of described work as measured in takeoff	Pcs/ Set/ Lm/ Cm/ Sm/	Unit cost (Material price+ labour+ Overhead +Profit+ Tool& equipment)	Here the Rate is multiplied with the Quantity

Where Pcs is Pieces, LM is linear meter, CM is cubic meter, and SM is square meter.

For making the total,

- You can make a total at the end of each page and carry it to the next page
- You can make a total of related work and sum it up at the end
- You can make the total at the end of each page and make the grand total at the last page.

With the above format, let's take an example of Bill of Quantity for better understanding.

PROPOSED XYZ CONSTRUCTION

Item No	Brief Description	Qty	unit	Rates	Amount
	ELECTRICAL WORKS **1.0: LIGHTING AND SOCKETS INSTALLATION** Supply, install, test, commission and handover in working condition the following:				
001	Lighting points only excluding switches wired in $1.5mm^2$ pvc/sc copper cables drawn in 20mm dia. heavy gauge pvc conduits as shown on the layout drawings	20	No		
	The following switches mounted at minimum 1450mm from finished floor level and as described in the Schedule of symbols (ALL LEGRAND):				
002	5A 1 Gang, 1 Way	13	No		
003	5A 1 Gang, 2 Way	3	No		
	The following luminaries complete with rated gear and lamps (screw type). -				
004	Recessed down lighter fitting with floating glass ring with 2x28W with P-	20	No		

	LG24D2 LED bulb : 180mm diameter.					
005	600x600x4 by 18w fluorescent fitting with louvres complete with LED two feet tube: " Nation wide"	20	No			
	<u>Sockets and switches</u>					
006	Twin socket outlets points only for NORMAL and UPS mains excluding the outlet wired using 2.5mm^{2}pvc/sc copper cables and 2.5mm^{2}pvc/sce.c.c drawn in 25mm diameter pvc heavy gauge conduits or trunking.	48	No			
007	40A Double pole switch point only completely wired using 2.5mm2 pvc/sc copper cables plus 2.5mm2 earth continuity conductor for the Air Conditioning Units	6	No			
008	Supply and install only of 12-Way TPNMCB Distribution Board,PVC or sheet metal made complete with Integral Isolators, Bus bars and door for raw or UPS power distribution like LEGRAND or any other approved equivalent.	2	No			
	<u>Supply and install of the following MCBs:Legrand</u>					

009	80A TPNMCB main incomer	2	No		
010	40A TPNMCB Shunt for surge arrestor	1	No		
011	16A DP MCB for UPS power sockets	10	No		
012	TPN Surge Protector 15KA	1	No		
013	105 x 50mm,double Compartment, PVC trunking, AS LEGRAND set into double lane: complete with accessories: covers, end caps, bends etc	50	PCS		
	TOTAL CARRIED TO SUMMARY				

LO 3.2: Calculate materials cost

Content/Topic 1. Different methods of collecting information on the cost of materials

1. How to calculate materials cost

Developing an accurate cost estimate is the first step in a successful electrical job. A contractor who estimates poorly will ultimately fail, no matter how well his technical skills.

If he underestimates his costs, he will find himself either using his own funds to complete a job, returning to his client to ask for more money or leaving the job incomplete or completed poorly. Overestimating will put him at a competitive disadvantage and cause him to lose work to better estimators.

Material costs: Usually include the prices of materials or parts incorporated into a project. The price of materials is based on its purchase price with allowances for delivery, off- loading, storage and placing in position. In addition, an allowance must be made to cover wastage which may arise as follows:-

a) **Handling/breakages**: brittle materials such as bricks, clay tiles and precast concrete paving slabs, etc have high breakage rate even for the advances in mechanized handling of material which is wrapped and delivered to site on pallets.

b) **Site losses**: an allowance has to be made for loose material such as sand and aggregate which, when delivered and tipped on site will, to some extent, be trampled into the ground, washed away by rain, etc.

c) **Cutting losses**: sheet materials are manufactured in standard sizes, therefore plaster-board, plywood, glass, carpet; etc must be cut of it. Where the material is patterned has to be cut to a difficult shape, losses can be considerable.

Materials can be in any one of the categories below:-

(a) Permanent materials included in the final constructed product or structure.

(b) Expendable materials and supplies those are necessary for the work to be accomplished, but will not be incorporated into the final structure, or will otherwise be used up during the work, such as lubricants and concrete forms.

Estimating is not difficult but it does require practice and attention to detail. Calculating the material cost before starting the addition requires simple math and minimal construction knowledge but saves you time, money and headaches later.

For Simple Estimating material costs, the drawings should give you a clear idea of what you will need in terms of wire, receptacles, junction boxes, fuses and so forth. Call your supplier and get the current prices on all materials you will need. Add 10 percent to cover waste. Put into consideration the transportation expenses from the supplier to the site.

Since the cost of materials is prone to fluctuation based on market conditions and such factors as seasonal variations, cost estimators may look at historical cost data and the various phases of the buying cycle when calculating expected material cost.

2. Methods of collecting information on the cost of materials:

- Referring to the sellers
- Referring to the technicians
- Referring to the internet

Content/Topic 2. Compiling collected information on drafted bill of quantity

The question of whether BQ is still needed, useful or relevant in our construction industry should be considered holistically from various angles. It is an issue very much associated with project cost management which is an important part of Project Management Processes. Project cost management processes include cost estimating, cost planning, cost monitoring, cost control and cost information system. Since construction project development involves the client or the owner, the designers, the managers and contractors, it is fair to consider the issue of the use and relevance of BQ from the perspectives of these different groups.

i. From Contractor's Perspective

For contractors, any construction project will involves the process of tendering or bidding, resources planning (money, materials, labour, plant), work planning and execution, procuring of sub-contractors, supervision, monitoring and controlling.

The availability of BQ, prepared either by the owner's quantity surveyor or by they themselves, provide the contractors with the necessary information to carry out the various project management processes more effectively and efficiently. The descriptions and quantities of the works presented in the BQ provide the contractor with useful information to arrive at an accurate tender price. This information are also essential for preparing project budget and cash flow, to compute the quantities of material required for the project, to prepare labour requirements and schedules, to claims for payments and to procure sub-contractors.

The list of the work items and their quantities contain in the BQ is in fact a detail Work Breakdown Structure (WBS) of the project concerned. They are useful information for the contractor's project planner to prepare the work plan or programme for the project which include organising of activities into logical sequence and estimating activity duration. At the same time, the quantities, unit rate and the cost of the many work items are useful for the monitoring and controlling of the project finance.

These information can be readily processed or translate into cost of the various work section or cost of various trade contractor’s work and projected monthly income and expenditure.

ii. From Client’s Perspective

For the building owners, their main concern is to see that their projects are completed on time, within the estimated cost and within specified quality. But in today’s environment more owners want to be better informed of their projects and be provided with accurate and reliable information pertaining to the progress and financial aspects of the projects. Although it has been said that it is no more useful after the tendering process, the cost or financial information presented in the priced BQ can be translated into other cost information such as cash flows, periodic project account and cost variation. This information can then be communicated to the owners to continuously keep them informed of the progress and the financial status of the project.

iii. From Consultant’s Perspective

As the representative of the owner, the consultants are expected to manage the project properly and effectively to ensure that the owner get value for money for their projects. They must ensure that the project is of high quality, completed on time and more importantly within the estimated cost or budget. The owner also should be provided with accurate and reliable cost information at the early stage of the project and always kept informed of the project’s financial situation in term of monthly expenditure, any deviation from the estimated budget and how their fund are being used in the project.

A priced BQ, either prepared by the contractor or by the consultant QS, contains invaluable descriptive, quantitative and financial information for use by the consultants in the project cost management during pre-construction and construction phases. First of all, the priced s submitted by contractor provides useful information on the total cost of the project and the market condition. The qualitative and quantitative (including financial) information presented in the priced BQ are very useful for tender evaluation and selection of contractor for the project.

The quantities, unit rates and costs of the various items of work presented in a priced BQ are also useful for the valuation of interim payment and valuation of variation orders. The information, which as mentioned earlier, is a form of Work Breakdown Structure (WBS) of the project but complete with quantities and costs. They can be computed or translated into realistic work programme, cost plan, projected cash flow or budget and periodic financial reports that can be used for more effective project supervision and cost monitoring and controlling.

BQ can also be considered as a complete ‘shopping list’ of the various item of works necessary for the construction and completion of a project as such it can also be used for the preparation of project final account.

Content/Topic 3. Identification of number of manpower needed to accomplish the task

By quantifying manpower productivity, business owners and managers see how employees' efforts translate to income and profits. Evaluating the factors that affect productivity can help business organizations make any necessary changes to boost the bottom line.

Manpower Calculation by Industry

Productivity can be defined as the amount of output that is generated with a given amount of input. Depending on the industry, the output may be goods, services or sales; the manpower productivity formula is essentially the same. To calculate manpower or labor productivity, you divide the value of goods and services produced by the total hours worked by employees over a specified period. You can also calculate labor productivity by dividing the total sales by the total amount of hours worked. Here are the step-by-step instructions for running a manpower calculation:

a. Figure Hours Worked

Determine the total hours that employees worked. For employees who work a specified number of hours each day, subtract the hours or fractions of hours allocated to lunch and break times. You may need to ask employees to keep a log of tasks and times over a given period.

Time management software calculates work hours automatically for employees who punch a time clock. In some small companies with few employees, employees maintain time cards with manual entries. Calculate hours worked by subtracting the start time from the end time. Make manual calculations easier by using a 24-hour clock. For example, noon is designated 12:00. One o'clock is 13:00, two o'clock is 14:00, etc..

b. Quantify the Work Product

Determine the unit of measurement for your employees' work product. For example, if you employ salespeople, use either the number of sales or the dollar value of sales. If you employ factory workers, look at the number of units of an item produced. Evaluate customer service employees on the number of phone calls answered or the number of people served. Employees who work one-on-one with clients can be evaluated according to their billable hours.

c. Total the Units of Work Product

For a given period, add the work units produced by each employee. Add the individual numbers to arrive at the total number of work products produced by all members of the organization.

d. Determine Work Units per Hour

For the same period, total the total number of hours worked by all employees. If time management software calculates the hours, you may want to round the number to the nearest hour.

Divide the number of hours by the number of units produced to get the number of work units produced by the organization in one hour.

e. Determine Work Units per Employee

Divide the number of work units produced in an hour by the total number of employees. The resulting figure tells you how many employees it takes to produce the number of work units in an hour.

Content/Topic 4. Determination of an appropriate labor rate per man-hour

Estimating for labor rates involves the analysis of both the **basic wage and the labor burden.** It is common knowledge that the labor rates do not involve the wages only as the labor burden can form a big proportion of the labor costs. The labor burden includes items such as taxes, insurance, etc. which employers are required by law to pay. Basic wage is determined based on labor **productivity.**

The term **productivity** broadly refers to the measure of the quantity of output of goods and services that can be produced by a given input of factor of production. In construction, labor productivity refers to the output per person in a given period of time.

Productivity can be measured by using the value added on site. Value added is the difference between the price of construction contract and the cost of materials, prefabricated components and other inputs except labor. **Value added** is equal to **net output** (gross output - Inputs)

Productivity of Net Output per head = <u>Net Output</u>

Labor units

Output per head, per week = <u>Net Output</u>

Labor units X Time period

[P = NO/LXT]

Where P = Productivity

NO = Net output

L = Labour units

T = Time periods

In construction, from the available statistics, it is possible to estimate the value of construction output per man-hour, man-day, man-week or man-month over the industry as a whole. It is also possible to measure productivity in terms of real cost per unit of output. However, comparison of productivity on different projects and between operatives is much more difficult. Variations in output are experienced because the day-to-day performance of operatives is influenced by:

- Motivation, skills and health of the operatives
- Difficulty and complexity of work. Difficult and more complex works slows down output rate of the operatives
- Location of work (indoor, outdoor, higher up or below ground0
- Familiarity with the work: there is always a learning curve associated with unfamiliar tasks
- Degree of effectiveness of plant. This depends on the quality of the plant selected for production.
- Degree of quality of the finished work
- Weather conditions

In order to calculate the all-in hourly rate, that is the hourly rate charged by a contractor for a construction operative, the estimator must first decide on the following:

- The number of hours worked per week.
- Overtime rate – assumed to be time and a half.
- Annual holidays.
- Public holidays.
- Sick pay

- Social security

Calculation for 'All-in' Hourly Labour Rate of Skilled-Worker Earning RWF 5,000 per day and Un-skilled Worker Earning RWF 3,000 per day.				**September-2012**	
Description	**Entry Clmn**		**Calc Clumn**		
PERIOD	Number of weeks	52			
	Weekly hours	45			
	Total hours		**2,340**		
	Days annual holidays(Leave)	21	(168)		
	Days public holidays	18	(144)		
	Total hours for holidays		(312)		
	Sickness	8	(64)		
	TOTAL HOURS FOR PAYMENT		**1,964**		
	2% Allowance for bad weather		(39)		
	TOTAL PRODUCTIVE HOURS		**1,925**		
		Skilled	**Un-skilled**	**Skilled**	**Un-skilled**
ANNUAL EARNINGS	Basic wage	30,000	24,000		
	Attraction bonus 9%	2,700	2,160		
	Total weekly rate	**32,700**	**26,160**		
	Hourly rate of pay (45hrs)	**727**	**581**		
	Annual earnings (Total productive			1,427,828	1,141,084
	Public Holidays with Pay		144hours	104,688	83,664
ADDITIONALCOSTS	**NON PRODUCTIVE OVERTIME**				
	Hours per week		4.5		
	Hours per year(4.5 hrs x 49 weeks)		220.5 hours		
	Cost of non-productive overtime			240,455	192,166

	SICKPAY(64hrs x Hourly rate)		64 hours	46,528	37,184
	ANNUAL LEAVE WITH PAY		168 hours	122,136	97,608
			Sub-total	**1,941,635**	**1,551,706**
OVERHEADS	**1.SOCIAL SECURITY FUND**		10.0%	194,164	155,171
	2.WORKMANS COMPENSATION		4%	77,665	62,068
	3. TRAINING LEVY		1%	19,416	15,517
			Sub-total	**2,232,880**	**1,784,462**
SEVERANCE PAY&SUNDRIES			1.5%	33,493	26,767
ANNUAL COST OF OPERATIVE				**2,266,373**	**1,811,229**
Divide by Total Productive Hours			1,925		
	TOTAL HOURLY RATE			**1,180**	**940**

Content/Topic 5. Determination of execution delay

Construction delays are considered as time lag in completion of activities from its specified time as per contract or can be defined as late completion or late start of activities to the baseline schedule, directly affecting specified cost. As a result, there will be extensions of time required which will further result in fine, increased cost due to inflation, termination of contract, court cases etc. or combinations of above stated factors, resulting in delay damages.
Delay in construction project has a negative effect on clients, contractors, and consultants in terms of growth in adversarial relationships, mistrust, litigation, arbitration, and cash-flow problems.

In determining whether there is an execution delay, however, it is important to understand the types or categories which a delay falls into before analyzing construction delays. The delays are classified or categorized into four basic ways:

A) Critical or non-critical delays

B) Excusable or non-excusable delays

C) Concurrent delays

D) Compensable or non-compensable delays

The types of delays further described in brief as below;

A) Critical or non-critical Delays:

A delay that is responsible for extending project duration is a **critical delay**. The delay is going to extend your project's completion date and will require you to update your project plan. Critical delays need to be resolved immediately. Few results are mentioned below:

- Extended Field Overhead
- Unabsorbed home office Overhead
- Liquidated Damage
- Idle Labor & equipment cost
- Labor & Material Cost Escalation and many more.

A delay that is not the cause of extended project duration is a **non-critical delay**; however, it will have an effect in terms of activities getting completed late than scheduled completion. These activities will also affect project cost estimates as reiterated below;

a) Idle labor & equipment cost

b) Labor & Material Cost Escalation and many more.

B) Excusable & non-excusable Delay

A delay where the contractor is entitled for extension of time or compensation or both, under the terms & conditions of contract is **excusable delay**. In this case, contractor does not have any control on the activity getting delayed.

The causes may be ;

1. Force Measure Clause
2. Natural Calamities
3. Political / Social Unrest
4. Terrorist Attacks
5. Delay from Client (Approvals, Decisions), etc.

A delay where the contractor is fully responsible for the activities getting delayed and resulted in extending project duration (responsible for critical delays) are **non-excusable delays**. In this case, the contractor has to bear the risk of cost consequences including the liability to pay damages for itself but possibly for the other parties as well.

The causes may be:

- Delayed Mobilisation
- Delayed Procurement
- Delayed submission of important documents
- Planning &Scheduling
- Critical events that were not highlighted to client on right time, etc.

C) Concurrent Delays in Construction Projects

A situation where more than one delay event occurs at the same time affecting multiple activities simultaneously/independently affecting the completion is **concurrent delay**. However, not all those events enable the contractor to be entitled for extension of time & cost claim. Importantly, it is the causes of delay rather the delay themselves, that must overlap.

D) Compensable or non-compensable Delays in in Construction Projects

Scenario where contractor is liable for Time Extension & Cost compensation is **compensable delays**. All compensable delays fall under excusable delays-Whereas, if the contractor is solely at fault for a delay event, it is termed as **non-compensable delay**. However, non-compensable may fall under critical, non-critical, excusable or non-excusable; depending upon the situation it has created and conditions of contract.

Content/topic 6. Clarification of Job average labor rate

The job average method is one way of determining the labor rate for a job. This method requires you to anticipate the job crew, their skills, and their wage for the duration of the job. To determine this rate, calculate the number of persons on the job and their average rate. Naturally, this requires you to know the difficulty level of the job and how you expect to man the job.

If you incorrectly estimate how the job will be manned, you could end up with an overqualified crew and increased labor costs. At the other end of the spectrum, an incorrect estimate could leave you with a less-skilled staff, and this can result in a significant increase of labor hours and a likely increase in labor costs. So, the attention has to be taken in allocating labours of different levels as needed to the available works on a project.

Content/Topic 7. Clarification of labor Burden

In calculating the labor cost, you also must not forget to include in the estimate other related labor costs such as payroll taxes, insurance, vacation pay, holiday pay, sick pay, and pension. Typically, labor burden represents 38% of your total labor cost.

The labor burden includes items such as taxes, insurance, etc. which employers are required by law to pay as well as fringe benefits negotiated between employers and employees either individually or collectively through a trade union. So what are some of the possible components of "fringes" or "burden" labor costs.

i. Social Security: A statutory program designed to bring eventual retirement, medical, survivor, and other benefits to employees or their beneficiaries. It is funded equally and jointly on a per pay period basis by employees and employers. The premium rates are set by law, are subject to annual adjustment, and are set by a combination of a percentage multiplier and an income ceiling. Employers and employees each pay a percentage of the employee's income to social security as determined by the law. The estimator is concerned only with that part of social security cost borne by the employer since that portion paid by the employee is deducted from base salary.

ii. Unemployment Insurance: It is a program designed to provide protection to workers during times of unemployment. It is employer paid.

iii. Worker's Compensation Insurance:

Designed to provide protection to employees who are killed, injured, or suffer health problems due to job related accidents or conditions. It is a statutory requirement for all contractors. Cost is borne by employers. Contractors, manufacturers etc are required to maintain a worker's compensation insurance by law. The amount insured under is equivalent to say 5 year annual earnings or60 months earnings. In the event of death the employee's dependents should be able to receive the 60 month earnings. Injuries arising from the job site are treated separately where by the employee receives a percentage of the total amount insured. The percentage is determined by the medical reports and the degree of incapacity. The premiums payable are normally negotiable and range from 1½%- 3%.

iv. Vacations: For salaried employees, the cost is included in the annual salary amount. For hourly wage employees, it is considered to be an added cost since it is assumed that they will be physically on the job at all times.

v. Medical Insurance: The cost is borne either in whole or in part by the employer.

vi. Other Insurance: May include either group life or accident insurance. These are handled in a manner similar to medical insurance.

vii. Other benefits: May include pension plans, on-duty training, or off-duty education assistance.

Content/Topic 8. Preparation of final document on bill of quantity include materials cost and labor cost

To ensure you are properly preparing a final document on BoQ, take these steps and tips into consideration:

- **Estimating Overhead Costs**

First, knowing your overhead costs is key to establishing a base figure for an estimate. What it costs to run your business, like rent and utilities for your shop, administrative personnel, insurance, and taxes, is essential information to know, so you can ensure those costs are considered when compiling an estimate.

- **Estimation Labor Costs**

An important factor in your estimate is your labor costs. Calculate your labor costs and take into consideration any costs for contractors you may use. Make sure you get accurate estimates for work from contractors if you use them. Also, consider the need for overtime pay if the job is one that requires the extra labor.

- **Estimating Construction Materials**

Materials are also a primary consideration in any estimate. Have an accurate estimate on the items you will need to complete the job. Here you will want to take into consideration the need for any special tools or equipment that may be needed to complete the job. To help account for changes or waste, add ten percent.

Summing Up Electrical Estimating Costs

Once you have your labor, materials, and overhead figured out, determine an amount that pays you for your time and expertise. Total all of these costs, and add a ten percent cushion to the total to get your estimate.

Content/Topic 9. Format of cost report

Cost reporting is a process used to inform a client (or other party) about the magnitude of a construction projects predicted, or actual Cost. This can be expressed either in absolute terms or as a variance compared to the project budget.

Cost reports are typically prepared by a cost consultant (such as a quantity surveyor) and updated regularly (perhaps monthly), to keep the client informed and to help them and the project team control costs.

The first step when cost reporting is to ascertain what the production/series cost to date is.

Cost to date can be defined as follows: **Cost to date = costs invoiced/paid to date + costs incurred but not yet invoiced/paid to date (accruals)**

Costs invoiced/paid to date

The costs invoiced or paid to date are a statement of fact and can be determined by referring to the expenditure codes on the trial balance at the cost report date. For completeness, all received invoices and petty cash should be on the system and both bank and petty cash reconciliations performed up to the cost report date.

Costs incurred but not yet paid/invoiced (accruals)

These are the costs for goods and services that have been used or consumed at the cost report date but no invoice has been received or cash paid out yet.

Where a cost report is being sent to an external party it is helpful to send a written commentary on the cost report as part of the package. The extent of commentary is often down to personal style but as a general rule, it is best to keep the commentary relatively brief. It is important that key information or assumptions are brought to the attention of the person receiving the cost report. This can be achieved by starting the commentary with a progress report in which important information can be highlighted, but where a piece of information is fundamentally important to understanding the cost report it may be necessary to send a covering letter (or e-mail) with the cost report drawing attention to the matter of importance.

LO 3.3: Calculate labour cost

1. How to calculate labor cost

Estimating the labor cost for a job is just as important, and it can be the difference between making money and losing it. To determine the estimated labor cost for a job, **multiply the total adjusted labor man-hours by the labor rate per man-hour.** This is not as easy as it appears.

First, you must determine the anticipated labor required to complete the project (total adjusted labor man-hours). Use the time-tested labor units based on the material needs of the project, adjusting those labor units to accommodate the expected working conditions of the job, and then add any additional labor not included in the original take-off

Second, determine an appropriate labor rate per man-hour. Again, this is not as easy as you might think. The labor cost per man-hour is significantly different in different areas of the country. For example, in Karongi, a qualified licensed electrician might have a base pay rate of less than 1400Rwf per hour. In Kigali, the base pay rate might be over 1700 Rwf per hour. To determine the labor rate per man hour, you have to know the location of your project.

Content/Topic 1. Techniques of controlling labour cost

Techniques of controlling labour cost can be effectively used by coordinating the activities of various departments concerned with the labour, namely:

(A) Personnel department

(B) Engineering and work study department

(C) Time keeping department

(D) Pay roll department, and

(E) Cost accounting department.

The functions of these departments regarding labour cost ascertainment and control are discussed in detail below:

(A) Personnel Department:

The Board of Directors lays down the policies relating to the recruitment, training, placement, transfer and promotion of employees. The personnel officer who heads the personnel department has to implement these policies. The main function of this department is recruiting workers, training them and their placement in suitable jobs. The personnel department recruits workers on receipt of employee placement requisition from various departments.

(i) Employee Placement Requisition:

This is a document initiated by a department which is in need of employees. On receipt of the requisition, the personnel department initiates action to appoint workers by receipt of applications, scrutiny of applications, interviewing of applicants and finally selection of suitable candidates

The proforma of employee placement requisition is given below:

XYZ Co.

Employee Placement Requisition

Department .... Date ....

No. ....

Please provide workers as per the following details, with effect from ....

S. No.	*Categories*	*No. of Employees required*	*Job Specification*	*Description*
Prepared by			*Authorised by*	

All the workers are appointed as per labour budget. The budget specifies number of workers to be appointed and skills required. It is the task of the personnel department to adhere to the budget and appoint additional workers only if sanctioned by competent authority. On appointment, each worker is allotted a number, which is to be quoted on all correspondence concerned with the workers. This facilitates easy identification of workers and systematic maintenance of information concerned with the workers in EDP.

(ii) Employee History Card:

The personnel department maintains full details of workers employed. The particulars of each employee are maintained on employee's history card. The card contains all the relevant information like- (a) Name and address, (b) Number, (c) Department, (d) Date of employment, (e) Category, (f) Educational qualifications (g) Experience (h) Name of former employer and reason for leaving him (i) Scale of pay (j) Skills (k) Promotions (l) Reason for leaving. These details will help the management to assess the employees and particularly the last column will help the management to prevent labour turn over.

Specimen form of employee history card is as follows:

XYZ Co.

Employee's History Card

Name _________ Category _______

Number ________ Grade ___ _______

Department ______ Scale of Pay _____

Address

Date of Birth ________

Material Status ______

Date of Appointment _______

Educational Qualification ______

Previous Employer _________

Reason for leaving previous employer _____

Reason for leaving:

Particulars of service regarding changes in pay

Date	*Grade*	*Pay*	*Reason for change – Promotion, Increment, etc.*	*Remarks*

Leave Record				
Date	*Details of Eligible Leave*	*Leave applied*	*Reasons for leave*	*Balance of Leave*

In order to have optimum number of suitable workers, control over recruitment of workers is essential.

The following measures will help to control labour recruitment:

(1) Recruitment is to be routed through the personnel department.

(2) Recruitment is made as per labour budget.

(3) Recruitment is to be made only on receipt of employment placement requisition.

(4) Additional labour over and above the budgeted labour has to be recruited only if the sanction is made by appropriate authority.

(5) Recruitment of casual workers is to be properly sanctioned.

(6) Mechanization is to be introduced wherever possible.

(7) Labour utilization reports are to be insisted from all departments concerned to enable the management to take decisions regarding the surplus workers, employment of casual labour, utilization of surplus labour, reduction of labour, reduction of labour turnover, etc.

(B) Engineering and Work Study Department:

This department is concerned with improving working conditions by undertaking the following activities:

(1) Conducting work studies such as methods study, motion study and time study for each operation.

(2) Maintaining required safety standards.

(3) Conducting job analysis and job evaluation.

(4) Preparing specifications and time schedules for each job.

(5) Devising suitable wage system, and

(6) Conducting research and experimental work.

The engineering department is basically concerned with work content, standard time, work performance, etc. They are achieved by conducting detailed work study which includes method study, motion study and time study.

Work Study:

Work study is study of technical aspects of production. It involves a detailed study of processes, operations, evaluation and analysis of jobs and work measurement. Therefore, work study involves methods study, motion study and time study.

(i) Methods Study:

It is a procedure to analyze the work to remove unnecessary operations or practices, systematic arrangement of remaining work and standardization of work methods. It is only after deciding the best method of doing the work those motion study follows-

(ii) Motion Study:

This is a vital part of work study which divides the work into several important elements. Each of these elements is analyzed in detail separately and in relation to each other. When these elements are timed. 'Least waste is the result' because motion study eliminates unwanted and inefficient motions.

Main purpose of motion study is to standardize the method of working by economizing efforts, reducing fatigue and improving efficiency. Motion study takes into account human element in the job, plant and machinery, tools and materials to be used. When motion study is completed, 'Time Study' has to be undertaken.

(iii) Time Study:

Fixing of standard time for each operation is called 'Time Study'. It is also called **work measurement**. A standard hour is fixed for each operation which is a hypothetical hour which measures the amount of work to be done in one hour. This helps the management in assessing labour requirements, fixation of wage rates and introduction of incentive schemes. Systematic methods study along with motion study and time study helps in standardizing jobs, equipment and methods. It is also helpful in cost control and output and wages control.

Job Analysis

Job analysis is a process of determining the list of qualifications to be possessed by workers to perform the work effectively.

United states Department of Labour defines Job analysis as- "The process of determining, by observation and study and reporting pertinent information relating to the nature of Job. It is the determination of the tasks which comprise the Job and the skills, knowledge, abilities and responsibilities required of the worker for successful performance and which differentiates the Job from all others".

Thus Job analysis is the study of the job and identifying the duties and responsibilities involved in the performance of the job, conditions for performance, nature of the job, qualifications to be possessed, opportunities and privileges.

Elements of Job Analysis:

Information relating to a job can be analyzed under two sub-heads:

1. **Analysis of Information Relating to the Job**:

Under this analysis the requirements of the Job are analyzed. The requirements are known as Job descriptions.

2**. Analysis Relating to the Jobholder:**

Under this analysis qualities to be possessed by the employee are analyzed. The qualities to be possessed by the job holder are called job specifications.

Advantages of Job Analysis:

1. Fixation of Suitable Rates of Pay:

Since rates are fixed according to the nature of work of each job, the rates fixed will be suitable and equitable.

2. Elimination of Personal Prejudices:

Since the rates are fixed on the basis of job content rather than individual workers worth, disputes relating to pay disparities are avoided.

3. Effective Recruitment:

Job analysis ensures the policy of right man for the right job or “no square pegs in round holes” as the job description and job specifications are the main elements of job analysis.

4. Effective Training:

Job analysis procedure leads to identifying the qualifications and skills required for each job. Thus workers can be given training in the skills needed for a specific job.

Job Evaluation:

(1) Meaning and Purpose:

Job evaluation is the process of studying and assessing the relative values of jobs within an industry, to ascertain their comparative worth.

In addition to indicating relative wage value, job evaluation serves the following varied purposes:

(a) It helps to know whether workers are placed in jobs best suited to them and to the advantage of employers.

(b) It assists the personnel department in recruitment of workers by indicating the responsibilities, requirements and conditions of work and qualities required for each job.

(c) Job evaluation forms the basis for training schemes.

Advantages of Job Evaluation

(I) To the Employer:

(a) As the qualities required for a job are specified, the recruited employees will be suitable for jobs. Therefore there are 'no square pegs in round holes'.

(b) As the labour worth is ascertained by job evaluation, the wage fund is fairly distributed.

(c) Jobs evaluation helps in minimizing the labour turnover.

(II) To the Employee:

(a) The jobs are best suited to the employees as they are appointed to jobs based on the requisite qualities, skills and experience.

(b) Job evaluation reveals comparative worth of a job and any prospects it has for the employee.

(c) It makes workers happier as the total wages are distributed among the workforce fairly.

(3) Job Evaluation Procedure:

(a) Detailed study of the jobs

(b) Description of Jobs

(c) Job analysis

(d) Arrangement of Jobs in Progression, and

(e) Determining the wage value of Jobs.

(4) Methods of Job Evaluation:

There are four methods of job evaluation as explained below:

(a) Ranking Method:

Under this method the jobs are graded from the highest to lowest according to their relative responsibilities and complexities and not in terms of wage rates. The wage rates are assigned to the jobs on the basis of prevailing rates in the locality. This method is simple and suitable in case of small factories. It is limited in effectiveness as accurate measurement of work is not done.

(b) Grading or Classification Method:

Under this method, the basis of evaluation is defined and the jobs are classified into different grades. For example, grades may be classified as Skilled, Unskilled, Supervisory, Executive and Administrative. Once grades are established the jobs are reviewed and then placed in suitable grades. The jobs in each grade are ranked as a further refinement.

(c) Factor Point Scoring:

Job evaluation under this method is done by comparing and analyzing jobs into common factors. Points are allotted to each factor according to its relative importance.

Following are the common factors generally recognized:

(a) Education

(b) Experience and Skill

(c) Complexities of duties

(d) Responsibilities

(e) Effort, and

(f) Working conditions.

Once the jobs are analyzed and points are allotted on the basis of common i factors, the available wages are distributed among the jobs in the ratio of total points of respective jobs.

The main advantages of this method are that it is simple to operate and the results are accurate.

The main disadvantages are:

(1) The points are not clearly defined.

(2) The points to each factor are not scientifically allocated.

(3) Jobs requiring unusual expectations cannot be analyzed by fixed factors.

(d) Factor Comparison Method:

This is similar to factor point scoring method. Jobs are analyzed, compared and ranked under the following five factors:

(a) Mental requirements
(b) Skill requirements
(c) Physical requirements
(d) Responsibility, and
(e) Working conditions.

The factors are valued by apportioning existing rate of pay among each of them. The jobs are compared factor by factor with the scales of ‘Key Jobs’. The total of values of all the factors is the cash rate for each job.

(e) Merit Rating:

Merit rating aims at evaluating the performance of workers. Main objective of merit rating is to reward the employee on the basis of efficiency and merit. Merit rating brings out the comparative worth of workers. The traits generally considered for determining merit and worth of workers are as under:

(1) Educational Qualification and knowledge
(2) Skill and experience
(3) Attitude to the work
(4) Quality of work done
(5) Efficiency
(6) Regularity
(7) Integrity
(8) Reliability
(9) Qualities like leadership, initiative, self-confidence and sense of judgement
(10) Discipline, and
(11) Cooperation.

The above traits are allotted with points and total points scored on all traits determine the worth of workers. The employees may be rated individually as per the points they score and they may be put in groups based on their common scores of points.

Importance of Merit Rating: Merit rating is a valuable tool considered to be important for human resource measurement.

Merit rating has the following advantages:

(1) It helps to know the individual worker's worth and traits; this helps the supervisor to assign the tasks in which the worker is proficient.
(2) It points out traits in which the workers are not proficient. The workers will have an opportunity to improve by suitable training.
(3) It helps in increasing wages and promotion opportunities.
(4) It helps to stimulate the self-confidence of workers as it recognizes the merit and worth of workers.

Limitations of Merit Rating:

(1) The worker may be rated high based on a single trait. The rater may ignore the other traits in which the worker may not be good.
(2) The difference of opinion between the members of merit rating committee may lead to unsatisfactory evaluation.
(3) The men doing the rating may be influenced by their personal ill feelings towards particular workers which may lead to unsatisfactory ratings.

(C) Time-Keeping Department:

This department is concerned with maintenance of attendance time and job time of workers. Attendance time is recorded for wage calculation and job time or time booking is considered for computing time spent for each Department, Job, Operation and Process for calculating labour cost department wise, job wise and of each process and operation.

Objectives of Time-Keeping:

(1) Ensures regularity of employees

(2) Enforces discipline among work force;

(3) Satisfies safety requirements

(4) Useful for preparation of payroll, and

(5) Keeps track of normal! Time, late attendance and early leaving of workers.

(6) Used for Overheads absorption on the basis of labour hours.

Depending on the size of the organization, a separate time office may be maintained at the gate of the factory. If the firm is small personnel of the gate office may take care of time recording. Since payments of wages are on the basis of time spent by the-workers, accurate time recording is essential.

Essentials of a Good Time-Keeping System:

(1) Good time keeping system prevents 'proxy' for one another among workers.

(2) Time-keeping has to be done for even piece workers to maintain uniformity, regularity and continuous flow of production.

(3) Both the arrival and exit of workers is to be recorded so that total time spent by workers is available for wage calculations.

(4) Mechanized methods of time keeping are to be used to avoid disputes.

(5) Late arrival time and early departure time are to be recorded to maintain discipline.

(6) The time recording should be simple, quick and smooth.

(7) Time recording is to be supervised by a responsible officer to eliminate irregularities.

Methods of Time Keeping:

There are two methods of time keeping:

(1) Manual methods.

(2) Mechanical methods.

(1) Manual methods of time keeping are as follows:

(a) Attendance register method.

(b) Metal Disc method.

(a) Attendance Register Method:

This is one of the traditional methods of time keeping. An attendance register is kept at the time office adjacent to the factory gate or in each department for the workers of that department. The register contains details regarding name of the worker, worker’s number, department in which he is employed, arrival time, departure time, normal time, over time, etc. The arrival and departure times may be recorded by the time keeper.

This method is inexpensive and simple. It is suitable in small organizations. Dishonest practices are possible in this method on account of collusion between workers and time keeper.

(b) Metal Disc Method:

Under this method the workers are allotted a disc or token with a hole bearing the identification number of the workers. The discs or tokens are hung in board with pegs. Board may be maintained separately for each department. The workers remove their tokens as they enter the factory and put them in a specified box.

Once the scheduled time lapses the box is removed. The workers who come late have to remove their token and handover to time keeper who will record exact time of arrival. If any tokens remain they indicate the absentee workers. Later on the time keeper records the attendance in a register known as ‘Daily Muster roll’ which is used by the payroll department to prepare wage bill and wage slips.

This method is simple and easy to follow. It can be followed even if there are illiterate employees. They can easily identify their tokens. It is usable by companies which are large in size with more number of workers.

But it has certain disadvantages-

(a) An employee may remove his companion’s token to have the attendance marked even when his companion is absent.

(b) Disputes may arise regarding the arrival time of the workers as the time keeper may commit mistakes.

(c) There is possibility of time keeper including dummy or ghost workers in the muster roll.

(D) Pay Roll Department

This department prepares the pay bill of the entire organization. The objectives of the pay roll department are mentioned below:

(1) Maintaining a record of Job, department and wage rate of each worker and to arrive at each worker's total earnings, deductions and net earnings.
(2) Ascertaining wages of different cost centres.
(3) Summarizing the total deductions to post them to the accounts concerned.
(4) Ascertaining the total hours of each cost centre to calculate labour cost and rate per hour for control purpose.
(5) Ascertaining overtime and idle time wages.
(6) Providing internal check system in payment of wages.

Preparation of Pay Roll:
On the basis of time cards the departmental payroll or wage sheets are prepared. A full-fledged pay roll shows the gross wages, various deductions and net wages payable. The pay roll is the basis for ascertaining wages and posting entries to various control accounts. The details of pay roll depend on requirements of the organization.

The following is the specimen of pay roll:

ABC Co. Ltd.

Pay roll

Dept/Cost Centre Week ending ......

Name	No. of worker	Rate	Total hours	OT hours	Wages	D.A	Other Allowances	Gross wages	Deductions					
									ESI	P.T	IT	Others	Total deductions	Net wages
Total														

Prepared by .... Checked by ....

Preparation of pay roll has two aspects; one is to arrive at gross wages payable in the form of wages including over time premium and allowances. The second aspect of pay roll is to compute deductions in the form of ESI, PF, Income Tax, recovery relating to loans and advances, etc. Most of the firms prepare this nowadays through computers.

(E) Cost Accounting Department:

The department is responsible for ascertaining correct cost of production.

Cost ascertainment involves classification, collection and computation of labour cost of output. In most of the organizations a representative of cost department is posted in the production department to accumulate and classify the cost. The cost accountant supervises the work of the representatives and uses the information contained in time cards and pay roll to find the labour cost of production by production departments, operations, production orders, etc.

The cost accounting department also analyses the labour cost in the form of idle time and overtime. Labour cost reports are also submitted to the management to intimate the effectiveness of labour utilization.

LO 3.4: Elaborate cost report

0. Introduction

This guidance note sets out the principles of cost reporting from the perspective of the quantity surveyor to the client during construction. This guidance note explains the purpose of cost reporting, the factors affecting outturn cost and explores the different formats and types of cost report.

Content/Topic 1. The purpose of cost reporting

The purpose of cost reporting is to inform the client in a construction project of the likely outturn cost of the construction project. The forecast of outturn costs may be expressed as a variance against a budget amount, or expressed in absolute terms.

A cost report will record:

• All costs incurred at the date of the report, where they are known and can be accurately valued in accordance with the particular contract conditions

• All costs incurred at the date of the report, where they are known and can be estimated in accordance with the particular contract conditions

• The forecast of costs to be incurred as can reasonably be foreseen at the date of the report and estimated in accordance with the particular contract conditions; and

• The risk allowances necessary as can reasonably be foreseen at the date of the report.

A cost report prepared on a regular and frequent basis will afford the client and the project team the ability to control the outturn construction cost. Outturn cost is controlled by the recognition of cost changes incurred and planned implementation of future cost changes.

2. Cost reporting models

Costs can be reported at three basic levels in a construction project: A construction cost report captures historic and forecast costs incurred under a construction contract.

Examples of typical cost report headings for common contract arrangements include:

1. Lump sum contracts

- Contract sum
- Adjustment of variable costs
- Adjustment of variations
- Adjustment of fluctuations
- Claims for loss and/or expense; and
- Adjustment of risk allowances.

2. Remeasurable contracts

- Contract sum
- Adjustment of remeasurable work
- Adjustment of variable costs
- Adjustment of variations
- Adjustment of fluctuations
- Claims for loss and/or expense; and
- Adjustment of risk allowances.

3. Reimbursable contracts

- Contract sum/target cost
- Adjustment of reimbursable costs incurred
- forecast of reimbursable costs to be incurred; and
- Adjustment of risk allowances.

4. Management contracts

- Contract sum/target cost
- Adjustment of management fee
- Adjustment of reimbursable costs incurred
- forecast of reimbursable costs to be incurred; and
- Adjustment of risk allowance.

5. Construction management contracts

- Construction management fee
- Adjustments to the construction management fee
- Adjustments to the trade contracts
- Adjustment to project risk allowances.

A project cost report captures historic and forecast costs across a construction project. Typical cost report headings are given below:

- Construction costs
- Professional fees
- Statutory fees and charges
- Third-party costs
- Direct works costs
- Land costs
- Agency costs
- finance cost; and
- Legal fees.

The quantity surveyor may be asked to produce a project cost report and draw specific cost advice from other individual budget holders or advisers. The quantity surveyor should include a note in the cost report to draw attention to the costs provided by others and exclude liability for the accuracy of these costs.

A programme cost report captures historic and forecast costs across a programme of construction works. Typical cost report headings are given below:

- programme management office costs; and
- Project costs.

Detailed cost reports can be prepared to give a greater level of detail within a construction project.

Some examples are given below:

- **Elemental cost reports:** report costs at an elemental level. This type of cost reporting can assist in value management and value engineering when budgets have been established for each project element.
- **Building cost reports:** cost reports for individual buildings across a project comprising several buildings.
- **Budget holder reports**: cost reports prepared for the elements of the construction works under the control of individual budget holders. A budget holder may be a specific designer of the project i.e. architect, building services engineer, structural engineer.
- **Stakeholder reports:** cost reports prepared for individual stakeholders in projects with multiple stakeholders.

3. Report formats

There is no single type of cost report format recommended. Most professional practices have a preferred or standard format which is used in the absence of specific client requirements.

Some construction industry clients have specific cost report formats that they require quantity surveyors to adopt for the cost reporting of their projects. Some construction industry clients have specific cost reporting systems that they require quantity surveyors to input cost data into or operate remotely.

Example of report

A simple cost report should include the following headings:

Authorized expenditure	
Contract sum	10,000,000
Additional authorized expenditure	400,000
Total authorized expenditure	10,400,000
Forecast cost	
Contract sum	10,000,000
Less risk allowances	(300,000)

	9,700,000
Adjustment of provisional sums	20,000
Adjustment of prime cost sums	(120,000)
Adjustment of provisional quantities	20,000
Contract instructions	250,000
Anticipated instructions	100,000
Fluctuations	10,000
Loss and/or expense	120,000
Risk allowance for remainder of contract	150,000
Direct works	0
Total forecast cost	**10,250,000**
Remaining authorized expenditure	150,000
	10, 400,000

The format of the cost report should be discussed and agreed with the client at the outset.

Comment: According to the curriculum of this module; the content of L.O 3.2, L.O 3.3 and L.O 3.4 are the same.

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