1. Introduction

Industrial electrification is one of the oldest practice of utilization of electrical energy. Different industrial plants have different specific requirement, therefore a typical power distribution system is not adaptable in all plants. Proper analysis must be taken by an engineer to estimate specific requirements concentrating on present as well as future operating condition.
The electric power distribution and installation of an industrial plant depends upon its nature, size, layout, type and size of electric machine etc. Any installation must be drawn on paper and then the system wiring should be decided. There should be closed co-ordination between architect, building contractor and electrical engineer from the very beginning so that provision of Substation, switchgear room, cable duct, distribution board etc. can be planned.
The planning of installation should be done keeping in view not only the immediate load but also future expansion. Study of load cycle over 24 hour period should be carried out to estimate maximum demand.

1.1 Electric load estimate

It is always necessary to calculate the total maximum power demand of an industrial complex so that the capacity of transformer can be decided accordingly. In order to estimate the maximum power demand of an industrial complex, the following technical terms should be understood.

a) Total connected load. The sum of power rating of all electrical equipment, machineries, lighting fixtures etc. is called the total connected load of the building. For example,

SN	Description of Load	Quantity	Power rating (kVA)
1.	40W FTL pf 0.8	50	$\frac{40*50}{0.8*1000}$ =25
2.	1000W heater	20	$\frac{1000*20}{1000}$ = 20
3.	5kW induction motor with η=80% and pf 0.8	6	$\frac{5*6}{0.8}$ =37.5
4.	3kW water pump with η=80% and pf 0.75	2	$\frac{3*2}{0.75}$ =8
	Total		**67.5 kVA**

b) Maximum demand

Maximum demand is the maximum load which a consumer uses at any time of a day. The whole of the connected load will never be used at the same time. Therefore, the actual power required for the building will be less than *total connected load*. Maximum demand is the *greatest* of all "**Short time interval averaged**" (15 minute or half an hour or 1 hour) during given period (**a day or month or year**). It is the maximum demand which determines the size and cost of installation.

c) Demand Factor

The ratio of actual maximum demand on the system to the total rated load connected to the system is called ***Demand factor***. It is always less than ***unity***.

$$\text{Demand Factor} = \frac{\text{Maximum Demand}}{\text{Total Connected load}} \ (\textit{always} < 1)$$

d) Diversity Factor

In an industrial complex, we have various blocks and these block have various maximum demand. The maximum demand of various block will not occur at the same time. Therefore, the total capacity of a substation will be less than the sum of maximum demand of various blocks.
The diversity factor is the ratio of sum of individual maximum demand of various blocks to the maximum demand at substation.
Mathematically,

$$\text{Diversity Factor} = \frac{\text{Sum of indivisual maximum demand}}{\text{Maximum demand of power station}} \ (\textit{always} > 1)$$

e) Coincidence factor

The reciprocal of diversity factor is called coincidence factor.

$$\text{Coincidence factor} = \frac{1}{\text{Diversity factor}}$$

Q$_1$. In an industry, substation supplies power for four blocks. Block1 has 6 no. of machines with rating 70kW, 90kW, 20kW, 50kW, 10kW and 20kW respectively while maximum demand of block1 is 200kW. Block2 has 5 machines of 60kW, 40kW, 40kW, 70kW, 30kW and maximum demand of bloack2 is 160kW. Block3 and block4 has maximum demand of 150kW and 200kW respectively. Determine the demand factor of block1 and block2. If maximum demand of substation is 600kW, find the diversity factor of substation.

Solution:-

<u>Block1;-</u>

Total connected load = 70+90+20+50+10+20=260kW

Maximum demand = 200kW

$$\textbf{Demand factor} = \frac{\textbf{Maximum Demand}}{\textbf{Total Connected load}} = \frac{\textbf{200}}{\textbf{260}} = \textbf{0.76}$$

<u>Block2;-</u>

Total connected load = 60+40+40+70+30=240kW

Maximum demand = 160kW

$$\textbf{Demand factor} = \frac{\textbf{Maximum Demand}}{\textbf{Total Connected load}} = \frac{\textbf{160}}{\textbf{240}} = \textbf{0.66}$$

<u>Block3;-</u> Maximum demand=150kW

<u>Block4;-</u> Maximum demand=200kW

Sum of individual maximum demand=200+240+150+200=710kW

Maximum demand of substation=600kW

$$\textbf{Diversity Factor} = \frac{\textbf{Sum of indivisual maximum demand}}{\textbf{Maximum demand of power station}} = \frac{\textbf{710}}{\textbf{600}} = \textbf{1.18}$$

f) Load curve

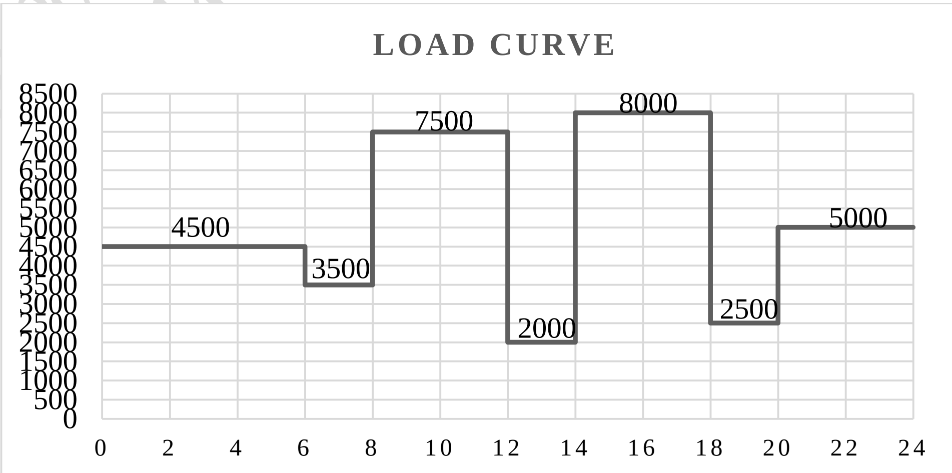
Load at any installation varies with time in day. If these variation in load demand is plotted chronologically, it is known as load curve.

Example,

Q1. An industry substation has the following daily loads

SN	Time in hour	Load in kW	SN	Time in hour	Load in kW
1.	0-6	4500	5.	14-18	8000
2.	6-8	3500	6.	18-20	2500
3.	8-12	7500	7.	20-24	5000
4.	12-14	2000			

Sketch the load curve. **Sol^n:-**



The load curves provides following information,

- The variation of the load during different hours of the day
- The area under the curve represents the total number of unit consumed in the given period
  From above example the total unit consumed during a day
  =4500*6+3500*2+7500*4+2000*2+8000*4+2500*2+5000*4 = 12500kWh
- The peak demand at substation during particular period of time.
  For the given example Maximum demand = 8000kW

g) Average load or Average Demand

Average load is the energy delivered in a given period divided by the number of hours in the period. Depending upon the duration of time period such as a day, a month, a year, we get daily, monthly, yearly average load.

$$\text{Daily average load} = \frac{\text{Energy consumed in a day (kWh)}}{24}$$

$$\text{Monthly average load} = \frac{\text{Energy consumed in a month (kWh)}}{24*30}$$

$$\text{Annual average load} = \frac{\text{Energy consumed in a year (kWh)}}{24*365}$$

For the given example,

$$\text{Daily average load} = \frac{\text{Energy consumed in a day (kWh)}}{24}$$

$$= \frac{12500}{24} = 5208.33\text{kW}$$

h) Load Factor

Load factor is the ratio of actual energy consumed in given period by a group of loads to maximum energy that would be consumed by the same group of loads during the same period.

Mathematically,

$$\text{Load factor} = \frac{\int_0^T \mathrm{p}\,\mathrm{dt}}{\int_0^T \mathrm{P_{max}}\,\mathrm{dt}} = \frac{\frac{1}{T}\int_0^T \mathrm{p}\,\mathrm{dt}}{\mathrm{P_{max}}}$$

$$= \frac{\mathrm{P_{av}}}{\mathrm{P_{max}}}$$

$$= \frac{\text{Average demand}}{\text{Maximum demand}}$$

Load factor can also be defined as the ratio of *average load* to the *maximum demand* during the *period under study* (a day or a month a year). It is always less than *unity*.

From above example,

$$\text{Load factor} = \frac{\text{Average demand}}{\text{Maximum demand}} = \frac{5208.33}{8000} = 0.651$$

Estimation of actual maximum kVA demand

All individual industrial loads are not necessarily operating at full rated nominal power or necessarily at the same time. Therefore, *factor of maximum utilization* (***k_u***) and *factor of simultaneity* (***k_s***) are used to determine the actual maximum power which is required for the installation.

Factor of maximum utilization (k_u)

In normal operating conditions the power consumption of a load is less than that indicated as its nominal power rating, fairly common occurrence that justifies the application of an utilization factor (***k_u***) in the estimation of realistic values.

This factor must be applied to each individual load, with particular attention to electric motors, which are very rarely operated at full 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***.

For socket-outlet circuits, the factors depend entirely on the type of appliances being supplied from the sockets.

Factor of simultaneity (k_s)

All the installed loads in a given installation never operate at the same time. Therefore, ***k_s*** is also very important in determination of total load.

Factor of simultaneity for an apartment building.

No. of consumer	Ks
2 to 4	1
5 to 9	0.78
10 to 14	0.63
15 to 19	0.53
20 to 24	0.49
25 to 29	0.46
30 to 34	0.44
35 to 39	0.42
40 to 49	0.41
50 and above	0.4

Factor of simultaneity for distribution board

Circuits	Ks
i) Lighting	1
ii) Heating and air conditioning	1
iii) Socket outlets	0.1 to 0.2
iv) Lifts and catering hoist	
a) Most powerful Motor	1
b) Second Powerful Motor	0.75
c) For all other motors	0.6

Q. A 5 storey building with 25 consumers and each having 6kVA of connected load. Find the total connected load f apartment, rating of protective switch and size of transformer. Also determine current entering third floor.

6
4
5
6
4

SOL^n: done in class

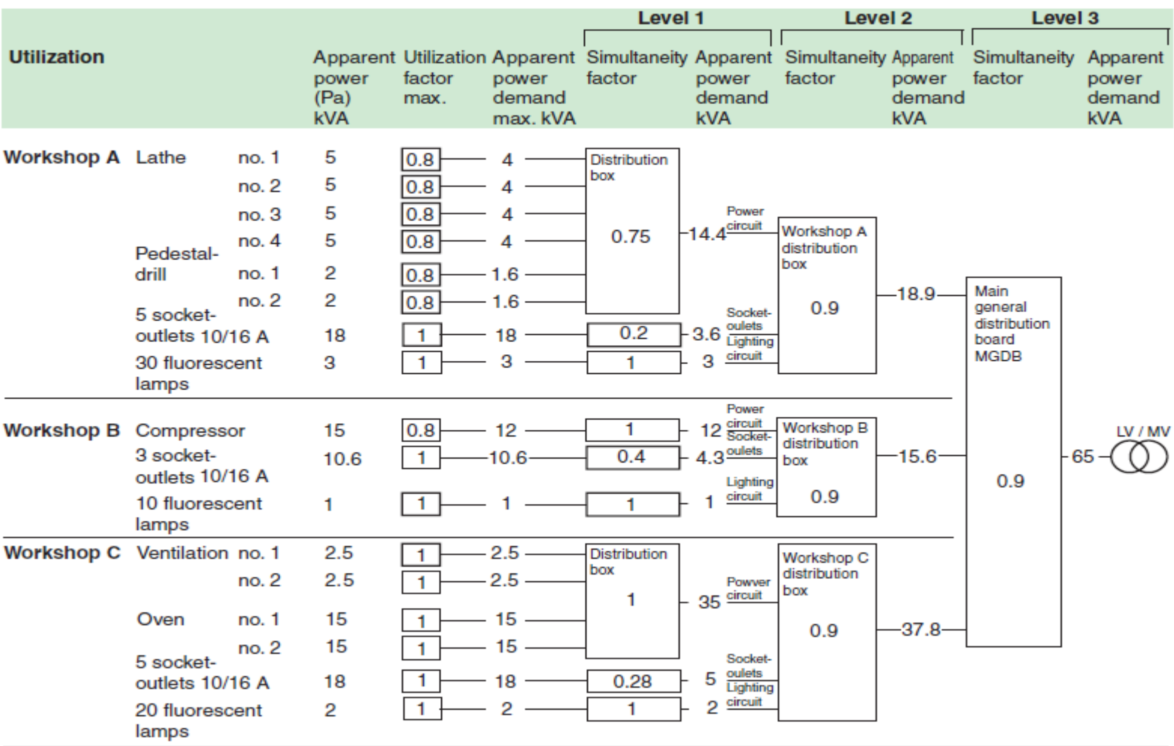


Fig A14 : An example in estimating the maximum predicted loading of an installation (the factor values used are for demonstration purposes only)

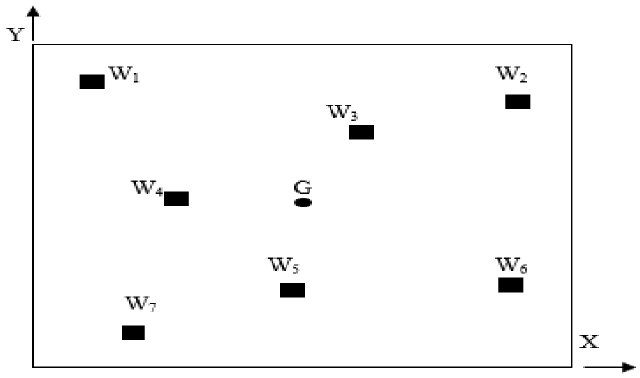
1.2 Load Center

Load center is the weighted center of the total connected load. It accounts where the maximum connected load is placed. It should not be kept or placed at the geometric load center, but should be placed at weighted average of the load. This is important for the reduction of cable loss.

An electric load center consist of

a) <u>Incoming section:</u> It provides the connection of one or more incoming high voltage circuits. Each of circuit may or may not be provided with power circuit breaker.
b) <u>Transformer:</u> This section may have one or more transformer
c) <u>Outgoing section:</u> It provides the connection of one or more outgoing feeder. They may or may not be provided with a low voltage circuit breaker.

Let us consider, an industrial complex as shown in figure below, consisting of seven blocks with corresponding connected loads (W_1,W_2,....W_7) kVA, at corresponding locations (x_1,y_1),(x_2,y_2)…..(x_7,y_7). The load center of the complex is calculated using following equation.



Electric load center

$$(\bar{X},\bar{Y})=\left(\frac{W_1*x_1+W_2*x_2+W_3*x_3+W_4*x_4+W_5*x_5+W_6*x_6+W_7*x_7}{W_1+W_2+W_3+W_4+W_5+W_6+W_7},\right.$$
$$\left.\frac{W_1*y_1+W_2*y_2+W_3*y_3+W_4*y_4+W_5*y_5+W_6*y_6+W_7*y_7}{W_1+W_2+W_3+W_4+W_5+W_6+W_7}\right)$$
$$=\left(\frac{\sum_{i=1}^{N} W_i*x_i}{\sum_{i=1}^{N} W_i},\frac{\sum_{i=1}^{N} W_i*y_i}{\sum_{i=1}^{N} W_i}\right)$$

In the given figure, point **G** is the geometric center of the complex. If the transformer is installed at the point G, the distribution system may not be economical. The size of cable laying to various blocks depends upon maximum demands of the blocks, and distance from the substation. Because more maximum demand cause more current and more distance causes more voltage drop in the cable. It is more economical to select the position of transformer near to block having greater maximum demand.

1.3 Supply system for industrial plant

A variety of basic circuit arrangements are available for industrial power distribution. Selection of best system or combination of system will depend on the needs of the manufacturing process.

In general, system cost increases with increase in reliability. Assuming that the component quality is equal, maximum reliability per unit investment can be obtained by using properly applied and well-designed components.

For the processes that are little affected by power interruption, a simple radial system is satisfactory. For other processes that may sustain long term damage by even a brief interruption, a more complex system with a alternate power source for critical load, may be justified.

For majority of application today, the radial and secondary selective arrangement are preferred.

With modern equipment properly installed and maintained, these two arrangements offer optimum, reliability, flexibility and expandability consistent with minimum cost.

The secondary network is used only in a small percentage of total.

The several methods of the most commonly used distribution system for modern industrial plant are as follows,**.**

a) Radial System

The feeder radiates from the substation and branches to laterals which extends to all parts of the area served. In this system, a given secondary feeder is fed from only one transformer and one primary cable. Each substation operates independently and there is no duplication of equipment. No tie cables, circuit breaker, or transformer with large reserve capacity are needed. System investment is usually the lowest of all circuit arrangements. It is the simplest and most commonly used system, accounting for 55 to 65% of industrial installation.

Drawbacks

1) Poor reliability;
   When fault occurs at any point on the feeder, supply to all load groups beyond the fault point towards the tail end gets interrupted, until the repair can be made.
   This is often the reason for design engineer to select one of the other circuit arrangements, which can minimize production shut down.
2) In case of increase in load demand, the length of feeder has to be extended causing voltage drop.

A typical radial feeder system is as shown in following figure.

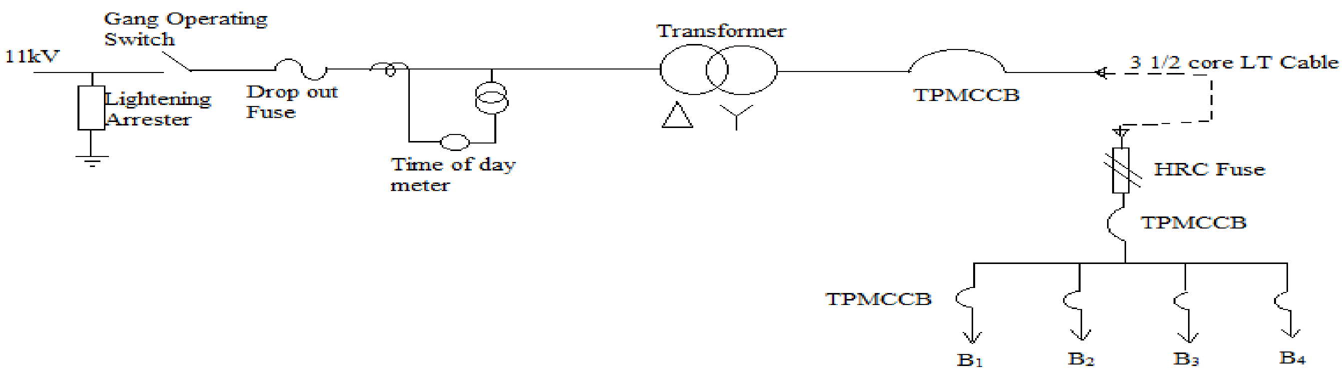


Fig Radial Feeder

b) Secondary selective system

The secondary selective system is highly used because it increases reliability by reducing the line that a load without power due to a fault in a unit station transformer or its primary feeder. It provides flexibility in operation particularly when equipment is being maintained or served. The circuit arrangement for the secondary selective system is as shown in figure below.

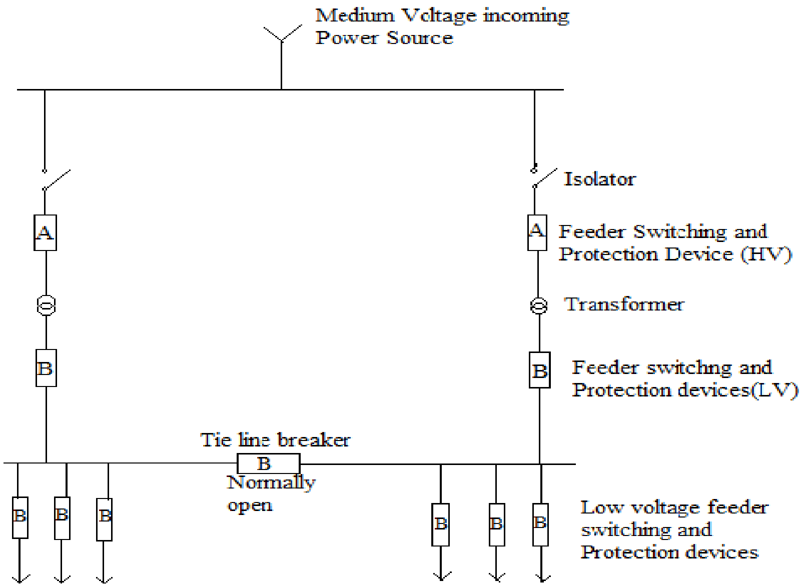


Fig. Secondary Selective System

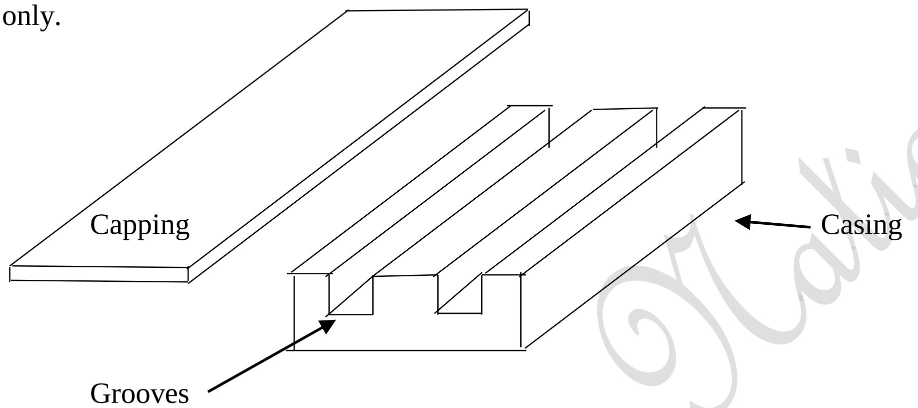
Under normal condition, the system is operated with the tie line breaker opened and each transformer supplies its own load. If fault occur in a transformer or its primary feeder, the transformer secondary switching device or breaker is opened and the tie line breaker is closed. The load connected to both buses is supplied by the energized transformer.

1.4 Classification of Electrical installation(Wiring)

The electrical installation/wiring can be classified as follows

a) **Cleated wiring:-** The cleated wiring system is almost absolute(no more uses) nowadays

b) **Wood casing and capping system:-**
In this system of wiring PVC insulated wire are run in grooves of varnished casing manufactured from seasoned teak or other hard wood.
The casing is covered with varnished casing fixed with iron nails. They should be laid on dry walls and plastered ceiling only.

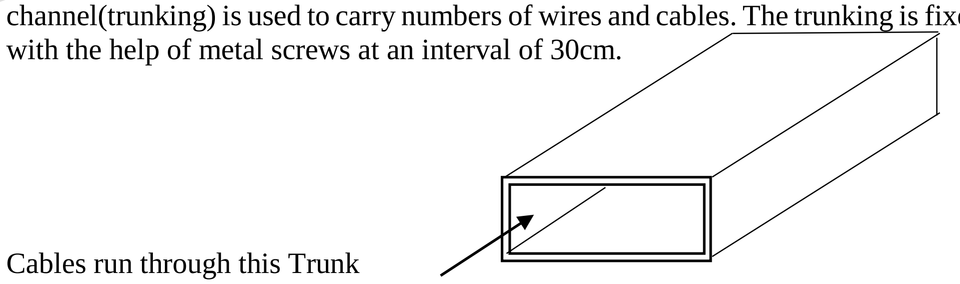


c) **Wood Batten wiring:-** This method is widely used for indoor installation. Here, PVC insulated wires are run on well varnished wooden batten strips, the width of which is such as to suit total width of cables laid on the batten. Tinned brass link clips are used to fasten the wires on batten.
Batten should be fixed on walls or ceiling by flat wood screws to wood plugs or other plugs at an interval not exceeding 75cm. The link clips should be spaced at an interval of 10cm in case of horizontal run and 15cm in case of vertical runs.

d) **Conduit wiring:-** This consists of PVC wires taken through rigid steel conduit pipes or PVC conduit pipes and run over the surface of walls and ceiling. The conduit should be laid completely before cables are drawn in. Surface wiring is mainly used for factory lighting and motor wiring. It is expensive system of wiring and requires more time for installation. It provides protection against mechanical damage and against fire due to short circuits. This system is water proof and replacement of defective wiring is easy.
Two types of conduits are used for this type of wiring
i. Non-metallic conduit
ii. Metallic conduit made of mild steel with anti-corrosive paint. The conduit must be earthed.

e) **Concealed wiring:-** In this method of wiring, the PVC conduits are laid prior to the RCC casting and every part of conduits are concealed inside the slab and wall. After concealing the conduit, wires are drawn into the conduits with the help of pull wire.
Advantages
i. Better mechanical protection as compared to surface wiring
ii. Cheaper than surface wiring
iii. Better outlook of building
iv. Longer life than surface wiring
Disadvantages
i. Complete planning and design is necessary prior to civil construction
ii. No flexibility for future alteration and expansion.
Concealed wiring is nowadays widely used in modern building to improve appearance.

f) **PVC or Metal trunking System:-** It is a type of surface wiring where PVC or metal box channel(trunking) is used to carry numbers of wires and cables. The trunking is fixed on wall and ceiling with the help of metal screws at an interval of 30cm.



g) **Cable tray system:-** A unit or assembly of units or sections and associated fitting made of metals or other non-combustible materials forming a continuous rigid structures, is used to support cables. They are popular in commercial and industrial electrical systems because of low installed cost, flexibility, accessibility for repair, or addition of cables and space saving.


h) **Vertical rising main system:-** It is not the complete wiring system but the part of the system replacing the cable from main panel to DB's of various floors. In normal system DB's at various floor are supplied from main control panel with individual sets of cable. The single vertical rising main system supply the power to all DB's from the main control panel.

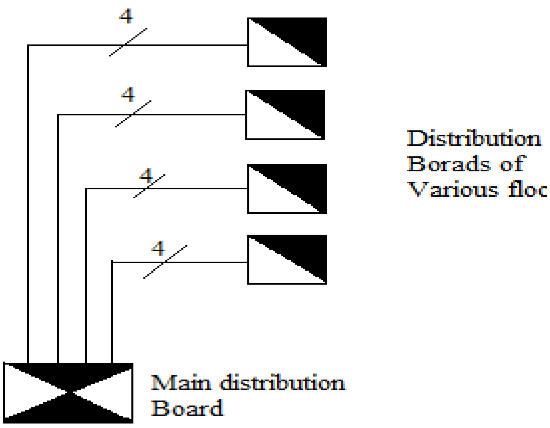


fig. Normal System

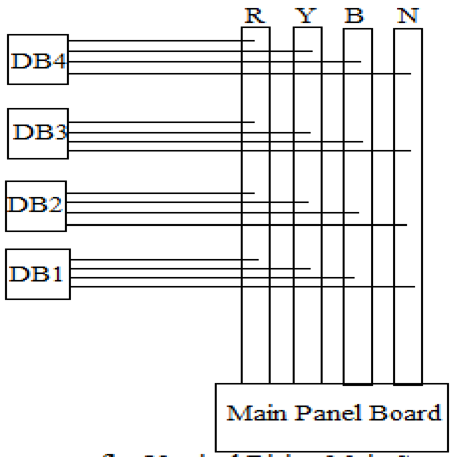


fig. Vertical Rising Main System

The vertical rising main system consist of copper or aluminium bars laid vertically in a metal enclosure or electrical duct. The bus bars insulated from metal enclosure and enclosure is earthed.
Power is tapped at each floor through smaller bus bars or insulated cables. A suitable switch fuse unit is provided at each tap off point. This system is most suitable for multi-storey building.

<u>Advantages;</u>

a) Easy installation
b) Long life
c) Reliable operation
d) Easy maintainance

Note: Current Density
Cu:1.9A/sq.mm(Ventilated)
Cu:1.5A/sq.mm(Non Ventilated)
Al: 1.2A/sq.mm

1.5 Reading and Interpretation of Building Drawing;-

1.6 Electrical Rules related to Electrical Installation & Testing;- *Study from"A course in Electrical Installation, Estimating & Costing, JB Gupta, page 143/144. For "Testing" look into Chapter 5*

<u>Voltage Levels in Nepal</u>

*In Nepal, we have **400/230V**, for **3-phase/1-phase** supply system. It is usual practice of supply authority that a building demanding **60A** load, will be supplied by **230V, 1-phase system**; i.e. maximum demand of **13.2kVA**.*
*If building is bigger and needs more power, the supply authority gives supply of **3-phase system up to 60A/phase**; i.e. maximum demand of **40kVA**.*
*If building is very big and needs more power, the supply authority gives supply through **11kV** line, through **a step down transformer** dependent of maximum demand.*