VSM COLLEGE OF ENGINEERING

EEE DEPARTMENT

LECTURE NOTES

ON

ELECTRICAL DISTRIBUTION SYSTEMS (R16reg)

syllabus

UNIT – I: General Concepts

Introduction to distribution systems, Load modeling and characteristics – Coincidence factor – Contribution factor loss factor – Relationship between the load factor and loss factor – Classification of loads (Residential, commercial, Agricultural and Industrial) and their characteristics.

UNIT – II:

Substations

Location of substations**:** Rating of distribution substation – Service area within primary feeders – Benefits derived through optimal location of substations.

Distribution Feeders

Design Considerations of distribution feeders**:** Radial and loop types of primary feeders – Voltage levels – Feeder loading – Basic design practice of the secondary distribution system.

UNIT – III: System Analysis

Voltage drop and power–loss calculations**:** Derivation for voltage drop and power loss in lines – Manual methods of solution for radial networks – Three phase balanced primary lines.

UNIT – IV:

Protection

Objectives of distribution system protection – Types of common faults and procedure for fault calculations – Protective devices**:** Principle of operation of fuses – Circuit reclosures – Line sectionalizes and circuit breakers.

Coordination

Coordination of protective devices**:** General coordination procedure – Residual current circuit breaker RCCB (Wikipedia).

UNIT – V:

Compensation for Power Factor Improvement

Capacitive compensation for power–factor control – Different types of power capacitors – shunt and series capacitors – Effect of shunt capacitors (Fixed and switched) – Power factor correction – Capacitor allocation – Economic justification – Procedure to determine the best capacitor location.

UNIT – VI:

Voltage Control

Voltage Control**:** Equipment for voltage control – Effect of series capacitors
– Effect of AVB/AVR –Line drop compensation.

Text Book:

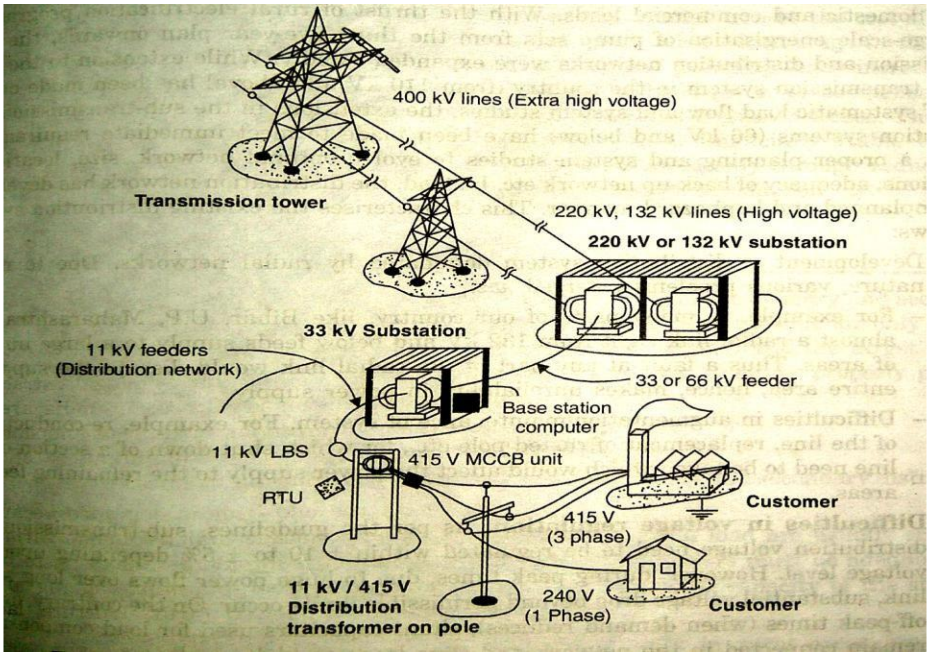
1. "Electric Power Distribution system, Engineering" – by TuranGonen, McGraw–hill Book Company.

Reference Books:

1. Electrical Distribution Systems by Dale R.Patrick and Stephen W.Fardo, CRC press
2. Electric Power Distribution – by A.S. Pabla, Tata McGraw–hill Publishing company, 4th edition, 1997.
3. Electrical Power Distribution Systems by V.Kamaraju, Right Publishers.

UNIT-I

Electric power is normally generated at 11-25 kV in a power station. To transmit over long distances, it is then stepped-up to 220-kVor 400kV as necessary. Power is carried through a transmission network of high voltage lines. Usually, these lines run into hundreds of kilometers and deliver the power in to a common power pool called the grid. The grid is connected to load centers (cities) through a sub-transmission network normally 132kV (or sometimes 66kV)lines. These lines terminate into a 132kV (or 66kV) substation, where the voltage is stepped-down to 33kV or11kV for power distribution network of lines at 11kV and lower.



T&D System Consists of Several Levels of Power Delivery Equipment

The power network, which generally concerns the common man, is the distribution network of 11kV lines or feeders downstream of the 33kV substations. Each 11kV feeder, which emanates from the 33kV substation branches further into several subsidiary 11kV feeders to carry power close to the load points (localities, industrial areas, villages, etc..). At these load points, a transformer further reduces the voltage from 11kV to 415kV to provide the last-mile connection through 415v feeder(also called as Low Tension(LT)feeders)to individual customers, either at 240v(as single-phase supply)or at 415v(as three-phase supply).A feeder could be either an overhead line or an underground cable. In urban areas, owing to the density of customers, the length of an 11kV feeder is generally up to 3km.On the other hand ,in rural areas, the feeder length is much larger(up to 20km).A415v feeder should normally be restricted to about 0.5-1.0 km unduly long feeders lead to low voltage at the consumer end.

CHARACTERISTICS OF PRESENT DISTRIBUTION SYSTEM

In the initial stages of power development in our country, power supply facilities and transmission and distribution system were built mainly catering to urban areas/towns to feed mostly domestic and commercial loads. With the thrust of rural electrification programmed and large-scale energisation of pump sets from the third five-year plan onwards, the sub transmission and distribution networks were expanded rapidly. While extension both the high voltage transmission system in the country (from 110kV and above)has been made on the basis of systematic load flow and system studies, the extensions in the sub- transmission and distribution systems(66kV and below)have been made to meet immediate requirements without a proper planning and system studies to evolve optimal network, size, location of substations, adequacy of back-up network etc. Instead, the distribution network has developed in an unplanned and haphazard manner. This characterizes the existing distribution system as follows:

- Development of distribution system dominated by radial networks. Due to radial nature, various problems emerged, viz..,
  - For example, in many parts of our country, like Bihar, U.P, Maharastra etc, almost a radial link right from 132kV and below feeds supply to a large number of areas. Thus a fault at any part of the radial link would disrupt the supply to entire area. hence, makes unreliability in power supply.
  - Difficulties in augmentation/maintenance of system. For example, re-conductoring of the line, replacement of rusted pole etc.., for which shut down of a section of the line need to be taken which would affect the power supply to the remaining feeding areas.
- **Difficulties in voltage regulation:** As per the guide lines, sub-transmission and distribution voltage need to be regulated within $\pm 10 \ to \ \pm 5$% depending upon the voltage level. However, during peak times, due to huge power flows over long radial link, substantial voltage drop beyond permissible limits occur. On the country, during off-peak times (when demand reduces),shunt capacitors used for load compensation remain connected in the network and thus leads to higher voltages.
- **Inadequacy in system:** Due to non-systematic planning for growth of the network without considering long-term requirement, many parts of the sub-transmission and distribution network are loaded heavily without adequate redundancies. This inadequacy causes frequent tripping as well as high technical losses.
- **Development of long LT lines:** Distribution network all over the country uncharacteristically have mesh of long low tension (LT) lines

with inadequate transformer capacity. This leads to substantial voltage drop, high technical losses, unreliability in supply etc..

- **Absence of proper energy accounting system/audit:** This makes actual estimation of losses and ratio of technical and commercial losses difficult, thus high loss areas, specific elements etc, remain unidentified.
- Poor quality of equipment and lack of proper maintenance, accounts for the high level of technical losses at the distribution stage. Further, improper load management and inadequate reactive compensation at load points also lead to high losses.

In addition to above, distribution system is also suffering from high level of commercial losses due to poor billing, revenue collection and theft of power by various users. These constitute a large component of overall losses. There are also losses on account of defective/slow energy meters, burnt meters, no metering etc. In fact that the energy loss in EHV transmission system only around 4-5% whereas, about 40-45% of the total energy loss takes place in sub- transmission and distribution system. This is the most crucial area as the cost of energy at the distribution stage is about Rs 2.75 per unit-the most value added stage in the entire power sector. Further, the rise in industrial and agricultural pumping loads increased the reactive power requirements. Adequate attention has not been given to compensate this reactive demand, which resulted in poor voltage conditions and increased losses. Therefore, attentions need to be p[aid to make the distribution system financially viable through improvement of distribution system efficiency. It can be achieved only through reduction in losses, improvement in revenue collections, improved customer satisfaction etc.

DISTRIBUTION SYTEM LOSSES

It has been established that 70% of the total losses are occurring in the primary and secondary distribution system, while transmission and sub-transmission lines account for only 30% of the total losses. Distribution losses are 15.5% of generation capacity and the target level is 7.5% .Therefore ,the primary and secondary distribution system must be properly planned to ensure losses within the acceptability limits.

Factors Effecting Distribution System Losses

Factors contributing to the increase in the line losses in the primary and secondary distribution system are:

(a) Inadequate size of conductor: As stated above, rural load are usually scattered and generally fed by radial feeders. The conductor size of the feeders must be adequate. The size of the conductor should be selected on the basis of km-kVA capacity of the stranded conductors.

(b) Feeder Length: In practice, 11kV and 415V lines in rural areas are widely extended radially over long distances to feed loads scattered over large areas. This results in high line resistance, low voltage and high current and therefore leads to high I2R losses in the line.

(c) Location of distribution transformers: Often the distribution transformers are not located centrally with respect to the customer. Consequently, the end customers obtain an extremely low voltage even though a reasonably good voltage level is maintained at the transformer secondary. This again leads to higher line losses.

Therefore in order to reduce the voltage drop in the line to the further consumers, the distribution transformer should be located at the load center to keep voltage drop within permissible limits.

(d) Use of over rated distributed transformers: Studies on 11kV feeders have revealed that often the rating of distribution transformers (DTs) is much higher than the maximum kVA demand on the low tension (LT) feeder. Over rated transformer produces an unnecessarily high iron loss.

From the above it is clear that the rating of distribution transformer (DT) should be judiciously selected to keep the losses with the permissible limits.

(e)Low Voltage: Whenever the voltage applied to an induction motor deviates from rated voltage, its performance is adversely affected. Reduced voltage in case of an induction motor results in higher currents drawn for the same output, which leads to higher losses. This can be overcome by adjusting the tap changer at power transformer and at distribution transformer, if available.

(f) Low power factor: In most of the LT distribution systems, it is found that the power factor varies from as worse as 0.65 to 0.75. A low power factor contributes towards high distribution losses. For a given load, if the power factor is low, the current drawn is high, consequently the losses proportional to square of the current, will be more.

Thus, line losses owing to the poor power factor can be reduced by improving the power factor. This can be done by application of shunt capacitor.

.Methods for the Reduction of Line Losses

As explained in the previous section as the losses in Indian power system are on the higher side, the Government of India has decided to reduce the line losses and set a target for reduction of T&D losses by 1% per annum in order to realize an overall reduction of 5% in the national average by the end of 8th five year plan.

The following methods are adopted for reduction of distribution system losses.

(i) HV distribution system
(ii) Feeder reconfiguration
(iii) Reinforcement of the feeder
(iv) Grading of conductor
(v) Construction of new substation
(vi) Reactive power compensation

(i) HV distribution system: The low voltage distribution system contributes about 1/3 of the total losses. The main contributing factors for the losses in this system are the wrong distribution system practice chosen by our country coupled with the non-adherence of prescribed norm for voltage drops. The LT distribution system, based on European practice where loads are concentrated in small areas with high load densities and that too with high power factor and load factor is most ill suited to cater the scattered highly inductive load with very low load densities, low power factor and load factor common in our country .The situation prevailing is that LV lines are extended irrespective of voltage drops up to full capacity of the distribution transformer, sometimes over and above the transformer capacity. Hence, no purpose will be served by prescribing low kVA-km loading limits for LV lines when the existing norms are not adhered to at all. The only practice and feasible solution is to eliminate or minimize LV lines by switching over to single –phase high voltage distribution. By adopting HV distribution, the losses in the LV distribution can be reduced by 85%.

Advantages of HV distribution system:

- It will eliminate losses on lengthy LT lines
- It will give better voltage regulation
- It will improve the power factor as starting and running capacitors are inherently provided to single-phase motors
- It will improve the supply reliability
- It virtually eliminates pilferage by direct tapping of energy from LT over head lines.
- Line losses will reduced by 85% of the line losses.

(ii) Feeder reconfiguration: Feeder reconfiguration is defined as the process of altering the topological structure of distribution feeders by changing the open/closed status of the sectionalizing and ties switches. Feeder reconfiguration allows the transfer of loads from heavily loaded feeders to less heavily loaded feeders. Such transfers are effective not only in terms of altering the levels of loads on the feeders being switched, but also in improving the voltage profile along the feeders and effecting reduction in the overall system power losses.

(iii) Reinforcement of the feeder: Studies on several distribution feeders have indicated that first few main sections(usually 3 to5) of the feeder contributes to 60% to 80% of the feeder total losses. This is mainly due to the fact that the conductor size used at the time of erection of feeders is no more optimal with reference to the increased total load. The total cost is the sum of fixed cost of investment of the line and variable cost of energy losses in the conductor due to the power flow.

Addition of a new load on existing feeder is limited by its current carrying capacity. So if the existing feeder gets overloaded, the alternative for catering the extra load is only reinforcement of the feeder. This method is considered to be good for short term planning measures.

Reinforcement of conductor is considered necessary as the smaller sized conductor's results in high loses due to non-standard planning. However, at the time of reinforcement much supply interruption will take place, which leads in loss of revenue.

(iv) Grading of conductor: In normal practice, the conductor is used for radial distribution feeder is of uniform cross-section. However, the load magnitude at the substation is high and it reduces as we proceed on to the tail end of the feeder .This indicates that the use of a higher size conductor, which is capable of supplying load from the source point, is not necessary at tail end point. Similarly use of different conductor cross-section for intermediate section will lead to a minimum both in respect of capital investment cost and line loss point of view.

The use of larger number of conductors of different cross-section will result in increased cost of inventory. A judicious choice can, however be made in the selection of number of size of cross-section for considering the optimal design.

If tie lines are existed already it is the most economical method to reduce losses but in practice in rural India tie-lines are uncommon. Constructing new tie lines for small excess loads leads to unnecessary increase in capital investment.

(v) Construction of new substation: If a new substation is to be constructed and connected to an existing network, several possible solutions are to be studied .These solutions may include various connection schemes of the substation and several feasible locations, while the principle connection scheme is defined by a limited number of possibilities. The number of possible sites of the newly constructed HT(33kV) line and thus its location determines the cost of their construction and operation. Due to large number of possible sites, an economical comparison may overlook the optimum technical solution. The final decision is usually influenced by additional factors such as topography; land ownership, environment considerations etc,. The optimum site for a substation is defined as that location which will result in minimum cost for construction and minimum losses. These include both the investments for the 11kV and 33kV voltage systems and the cost of operating the system.

So, by constructing a new substation at load center, the line losses will be reduced due to improvement in voltage profile and reduction in length of the lines. But for an excess small quantum of load, the decision for constructing of new substation cannot be made as the capital investment is high and the substation will run on under load condition for a long time resulting in poor return on the capital. In such situations, alternate arrangements can be attempted.

(vi) Reactive power compensation: It is universally acknowledged that the voltage reactive power control function has vital role to play in the distribution automation. The problem of reactive power compensation can be attempted by providing static capacitors.

The present practice to compensate reactive power component is to increase reactive power by increasing the terminal voltage of the generator (or) By increasing the field current of the synchronous machine in condenser mode at generating stations. This procedure is not effective because the power system losses will be further increased due to increase of reactive power in the transmission system. An alternate method for compensating the reactive power is the use of capacitor in distribution systems at customer points.

Shunt capacitors supply the amount of reactive power to the system at the point where they are connected .Mainly capacitors are used to develop reactive power near the point of consumption. By capacitor compensation at load ,the user gets the same advantage as the power utility for higher power factor on small scale. Also, if each load is compensated, the power factor remains relatively constant since in plants, loads are switched on and off and the dangers of over – compensation do not exist. If a power factor has been corrected only at the service entry, system power can make relatively wide swings, as heavy loads are switches on and off. Suitable capacitor banks at grid or main substation are desirable to feed reactive power of lines, transformers and domestic consumers, etc. Who have no capacitors at terminals?

There are two methods in capacitors compensation viz.,

1. Series compensation (capacitors are placed in series with line)

2. Shunt compensation (capacitors are placed in parallel with load)

The fundamental function of capacitors, whether they are series or shunt in a power system is to generate reactive power to improve power factor and voltage, thereby enhancing the system capacity and reducing lossless. In series capacitors the reactive power is proportional to the square of the load current, where as in shunt capacitors it is proportional to the square of the voltage.

DISTRIBUTION SYSTEM PLANNING

Planning of distribution system is necessary to ensure that the growing demand of electricity can be met by expansion, which should be both technically adequate and reasonably economical. Even though some work has been done in the past on the application of some types of approach to generation and transmission system planning, but distribution system planning has received little attention. In the future, electrical utilities need a fast and economic planning tool to determine the consequence of different proposed alternatives and their impact on the rest of the system to provide the necessary cheap, reliable and safe electrical power to customers.

The aim of planning should ensure the growing demand for electricity in terms of increasing growth rate and high load densities which has to be done in an optimum way by additional sub-systems (the secondary circuit from bulk power substation). Distribution system planners must determine the capacity of load and its geographic location. Then the distribution substations must be located and should be designed in such a way as to serve the load at optimum.

The distribution system in particularly important to an electrical utility for two reasons:

(i) Its close proximity to the customer

(ii) Its high cost of investment. Since the distribution system is the closest one to the consumer, its outages effect consumer service more directly.

However, outages on the transmission and generating systems, which usually may cause service interruptions also effects on the consumers

The demand, type, load factor, and other consumer load characteristics necessitate the type of distribution system required. once the consumer loads are found, they are grouped for service from secondary lines connected to distribution transformers that step down from primary voltage .The distribution transformer loads are then combined to determine the demands on the primary distribution system. These loads are then assigned to substations that step down from transmission voltage. The distribution system loads, in turn, determine the capacity and location of the sub stations as well as the routing and capacity of the associated transmission lines etc.

Thus, the planner of the distribution system has to divide the problem into a set of sub-problems. The planner, in the absence of accepted planning techniques, may restate the problem as an attempt to minimize the cost of sub-transmission, substations, feeders, laterals, etc…, and the cost of losses. In this process, however, the planner is usually restricted by permissible voltage dips, flickers, etc.., as well as service continuity and reliability.

LOAD MODELLING AND ITS CHARACTERISTICS

LOAD MODELLING

Many electric appliances and devices have an electrical load that varies as the supply voltage is changed and the loads are grouped into three categories depending on how their demand varies as a function of voltage, viz.., constant power (demand is constant regardless of voltage)or as a constant impedance (power is proportional to square of voltage).The load at a particular point might be a mixture of some proportion of all these.

It is quite important in both planning and engineering to model the voltage sensitivities of load correctly. For example, incandescent lighting, resistive water heaters cooking loads shunt compensation and many other loads are constant impedance loads .On a feeder with a 7.5 % voltage drop from substation to feeder end a constant impedance load will vary upto 14.5% depending upon where it is located on the feeder. The same set of incandescent light that creates 1kW of load at the feeder head would produce only 844 watts at the feeder end .Induction motors, controlled power supplies as well as tap changing transformers in the power systems are relatively constant power loads.

In general, these load static models can be written as:

$$P=P^0(V/V^0)^{k1} \quad \ldots(1.2)$$

$$Q=Q^0(V/V^0)^{k2} \quad \ldots(1.3)$$

Where P^0,Q^0=Nominal values of real and reactive power loads

V^0=Voltage at nominal load

K1 and k2 values for different type of loads as given in **table 1.2**

TABLE 1.2 Typical values of k1 and k2 for different static load models

S no	Type of load	K1	K2
1	Battery charge	2.59	4.06
2	Fluorescent lamps	2.07	3.21
3	Constant impedance	2	2
4	Air-conditioner	0.5	2.5
5	Constant current	1	1
6	Resistance space heater	2	0
7	Pumps, fans other motors	0.08	1.6
8	Incandescent lamps	1.54	0
9	Compact fluorescent lamps	1	0.35
10	Small industrial motors	0.1	0.6
11	Large industrial motors	0.05	0.5
12	Constant power	0	0
13	Fluorescent lighting	1	3

CHARACTERISTICS OF LOAD MODELS

The response of nearly all loads to voltage changes can be represented by some combination of constant impedance, constant current and constant power(or MVA).Actually, the constant current model is unnecessary as it is nearly equivalent to 50% constant impedance load combined with 50% constant power load. It has been found convenient to retain the constant current model as it is easily comprehended and is frequently used in the absence of more complete data. Figures show the relationships of load current and power with voltage for three simple load types from equations

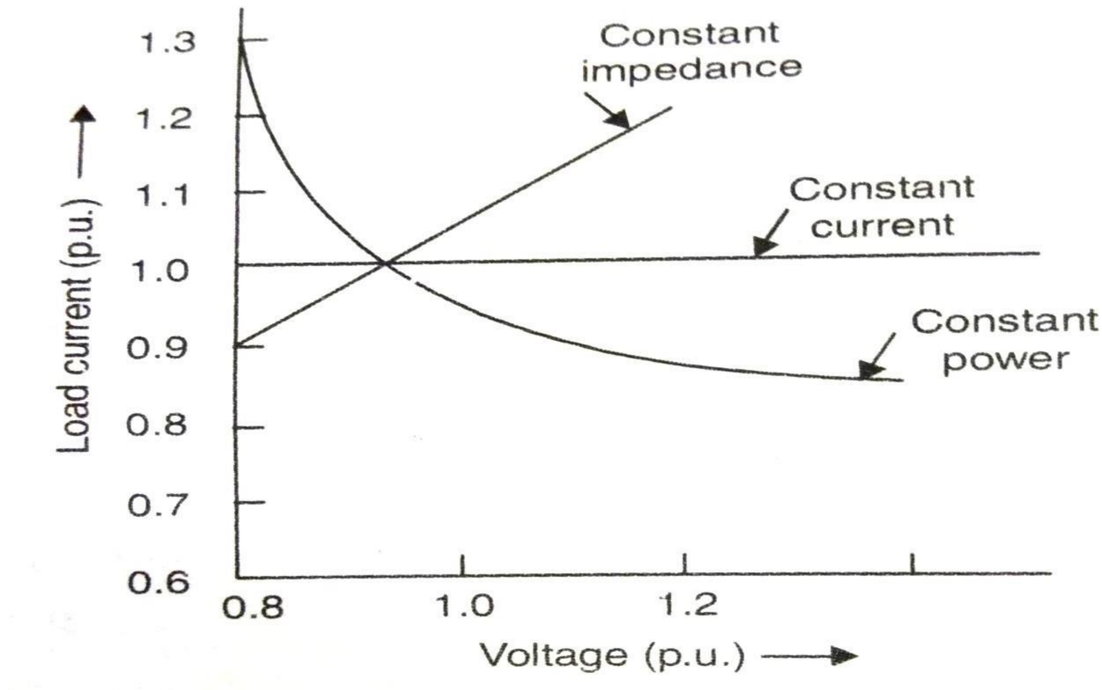


FIG RELATION BETWEEN LOAD CURRENT AND NODE VOLTAGE FOR SIMPLE LOAD TYPES

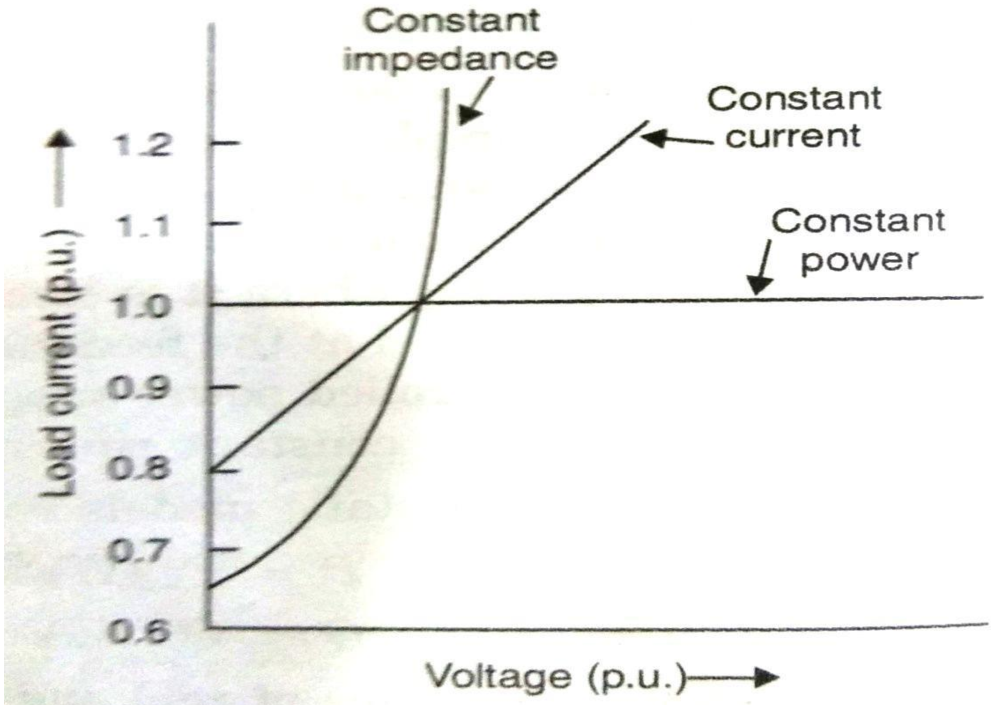


FIG 1. RELATIONSHIP BETWEEN LOAD MVA AND NODE VOLTAGE FOR SIMPLE LOAD TYPES

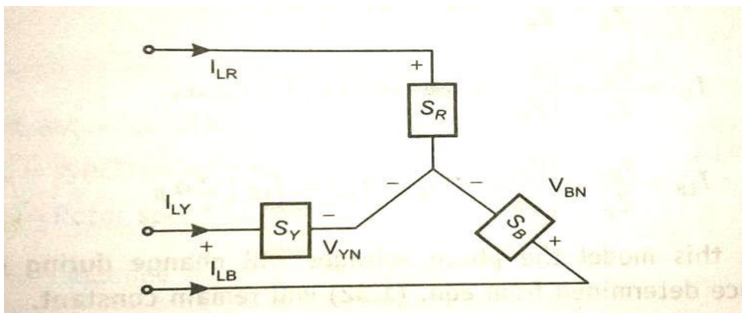
The constant power type load representation is the most severe representation from the system stability point of view because of the affect in amplifying voltage oscillations. For example, a drop in voltage will cause an increase in load current resulting further voltage drop.

Conversely, constant impedance load have a decided damping effect on voltage oscillations.

The three phase un-balanced load models developed are to be used in the iterative process of load flow technique where the load voltages are initially assumed. One of the results of the load flow analysis is to replace the assumed voltages with the actual operating load voltages. All models are initially defined by a complex power and as assumed line to neutral voltage (star load) or an assumed line-to-line voltage (delta load).

STAR CONNECTED LOADS:

The model of the star connected load is shown in the figure below.



The complex power and voltages are represented as:

Phase R : $|S_R| \angle \theta_R = P_R + jQ_R$ and $|V_{RN}| \angle \delta_R$

Phase Y : $|S_Y| \angle \theta_Y = P_Y + jQ_Y$ and $|V_{YN}| \angle \delta_Y$

Phase B : $|S_B| \angle \theta_B = P_B + jQ_B$ and $|V_{BN}| \angle \delta_B$

CONSTANT POWER LOADS:

The line currents of load model is given by:

$$I_{LR} = \left(\frac{S_R}{V_{RN}} \right)^* = \frac{|S_R|}{|V_{RN}|} \angle (\delta_R - \theta_R) = |I_{LR}| \angle \alpha_R$$

$$I_{LY} = \left(\frac{S_Y}{V_{YN}} \right)^* = \frac{|S_Y|}{|V_{YN}|} \angle (\delta_Y - \theta_Y) = |I_{LY}| \angle \alpha_Y$$

$$I_{LB} = \left(\frac{S_B}{V_{BN}} \right)^* = \frac{|S_B|}{|V_{BN}|} \angle (\delta_B - \theta_B) = |I_{LB}| \angle \alpha_B$$

In this model, the line to neutral or phase voltages while change during each iteration until convergence is achieved.

CONSTANT CURRENT MODEL:

In this model the magnitudes of currents are computed using I_{LR} equation and are then held constant while the angle of voltage (δ) changes, resulting in a change angle on the current so that the power factor of the load remain constant.

$$I_{LR} = |I_{LR}|(\delta_R - \theta_R)$$
$$I_{LY} = |I_{LY}|(\delta_Y - \theta_Y)$$
$$I_{LB} = |I_{LB}|(\delta_B - \theta_B)$$

CONSTANT IMPEDANCE MODEL:

In this model first determine constant load impedance from the specified complex power and assumed phase voltages.

$$Z_R = \frac{|V_{RN}|^2}{S_R^*} = \frac{|V_{RN}|^2}{|S_R|} \angle\theta_R = Z_R \angle\theta_R$$

$$Z_Y = \frac{|V_{YN}|^2}{S_Y^*} = \frac{|V_{YN}|^2}{|S_Y|} \angle\theta_Y = Z_Y \angle\theta_Y$$

$$Z_B = \frac{|V_{BN}|^2}{S_B^*} = \frac{|V_{BN}|^2}{|S_B|} \angle\theta_B = Z_B \angle\theta_B$$

The load currents as a function of the constant load impedances are given by:

$$I_{LR} = \frac{V_{RN}}{Z_R} = \frac{V_{RN}}{Z_R} \angle(\delta_R - \theta_R) = |I_{LR}| \angle\alpha_R$$

$$I_{LY} = \frac{V_{YN}}{Z_Y} = \frac{|V_{YN}|}{|Z_Y|} \angle(\delta_Y - \theta_Y) = |I_{LY}| \angle\alpha_Y$$

$$I_{LB} = \frac{V_{BN}}{Z_B} = \frac{|V_{BN}|}{|Z_B|} \angle(\delta_B - \theta_B) = |I_{LB}| \angle\alpha_B$$

In this model the phase voltages will change during each iteration, but impedance determined from Z_R, Z_Y, Z_R will remain constant.

Similarly the load models are determined for the delta connected loads by considering line-to-line voltage instead of phase to neutral voltage.

Definition of terms

Several terms are used in connection with power suplly to an area, whether it be for the first time or subsequently. These terms are explained below:

(i) **Connected load :** a consumer, for example a domestic consumer, may have several appliances rated at different wattages. The sum of these ratings is called his connected load.
Connected load is defined as the sum of ratings (W,KW or MW)of the apparatus installed on a consumer premises.

(ii)**Maximum demand:** It is quite portable that the consumer does not use all the appliances at time, though he has the libert to do so. The maximum amoung the loads utilized by a consumer at a time is called maximum demand. Maximum demand is defined as the maximum load used by a consumer at any time.

(iii) **Demand Factor:** The ratio of maximum demand and connected load is called the demand factor.

(iv) **Load curve:** From out the load connected, a consumer uses different fractions of the total load at various times of the day as per his requirements. Since a power system is to supply load to all such consumers, the load to be supplied varies continuously with time and does not remain constant the load curve is a plot of the load demand on Y axis verses the time on the X axis in the chronological order.

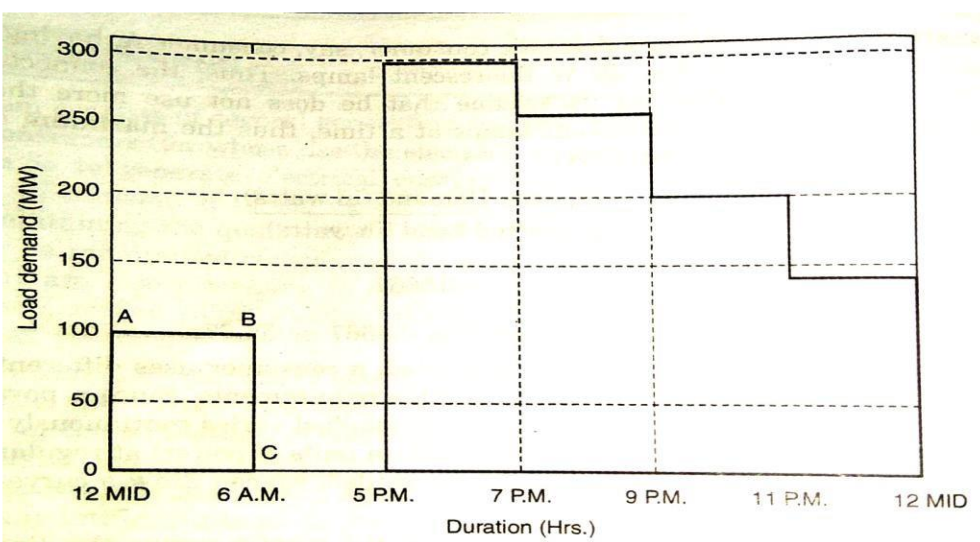


FIG Daily load curve of domestic consumer

If a time period of 24 hours only is considered, hence the resulting load curve is called daily load curve. However to predicate the annual requirements of energy ,the occurrence of load at different hours and days in a year and in the power supply economics, the annual load curves are used .A load curve is nothing but a plot of the load demand of the consumer against time in hours of the year (1 year=8760 hours)

(v) **Load Factor:** The power supply authorities realize the revenue by selling their product, viz.., units of the electrical energy to the consumers, who are granted with the right of using energy as per their requirements at any hour of the day. The ratio of average load of the maximum demand during a given period is known as load factor.

$$\text{Load factor}=\frac{average\ load}{\max imum\ demand}$$

If the plant is in operation for a period T,

$$\text{Load factor}=\frac{average\ load \times T}{\max imum\ demand \times T}$$

$$=\frac{units\ \ generated\ \ in\ T\ \ hours}{\max imum\ demand\ \times T}$$

The load factor may be daily load factor, monthly load factor or annual load factor. The load factor always less than 1 because average load is smaller than the maximum demand.

(vi) **Diversity Factor:** The ratio of the some individual maximum demands to the maximum demand on the power system is known as diversity factor.

$$\text{Diversity factor} =\frac{sum\ of\ individual\ maximum\ demand}{maximum\ demand\ on\ system}$$

A power system supplies load to various types of consumers whose maximum demands generally do not occur at the same time. Therefore the maximum demand on the power system is always less than the sum individual maximum demands of the consumers.

A high diversity factor implied that with a smaller maximum demand on the station, it is possible to cater to the needs of several consumers with varying maximum demands occurring at different hours of the day. A high diversity factor and a high load factor are the desirable characteristics of the load on power station

(vii) **Coincidence factor**: It is the ratio of the observed peak of the group of consumers to the sum of the individual peaks.

$$\text{Coincidence factor (C.F)}=\frac{Observed\ peak\ from\ group}{\Sigma(individual\ peaks)}$$

$$\text{C.F}=\frac{D_g}{\sum D_i} \quad \text{....(1.4)}$$

D_g=Maximum (D_i)

=Observed peak demand of group of ‘n’ loads

D_i=i^{th} individual peak load

The Coincidence Factor (C.F) can also be written as

$$\text{C.F.}=\frac{D_g}{\sum D_i} \quad \text{...(1.5)}$$

$$D_g=C_1 D_1+C_2D_2+\dots\dots\dots+C_nD_n=\sum_{i=1}^{n} C_i D_i$$

And C_i the contribution factor of the i^{th} load to the group maximum demand

$$\text{C.F.}=\frac{C_1D_1+C_2D_2+\dots\dots\dots\dots+C_nD_n}{\sum_{i=1}^{n} D_i}$$

$$\text{Or} \quad \frac{\sum_{i=1}^{n} C_i D_i}{\sum_{i=1}^{n} D_i} \quad \text{...(1.6)}$$

Peak load per consumer is generally a strictly decreasing value as a function of the number of consumers in a group. Therefore, the maximum value of C.F. is only about 0.25 to 0.3.

Distribution engineers use the factor inverse of C.F.., which is known as the diversity factor.

$$\text{Diversity factor}=\frac{1}{C.F}$$

Special cases

Case-I

I f maximum demands are equal i.e.., D_1=D_2=…….=D_n=D

The equation (1.6) becomes

$$\text{C.F.}=\frac{D\sum_{i=1}^{n}C_i}{nD}$$

Or

$$\text{C.F.}=\frac{\sum_{i=1}^{n}C_i}{n}$$

Therefore, coincides factor is equal to the average contribution factor.

Case-II

I f contribution factors are equal i.e.., $C_1=C_2=\ldots\ldots\ldots=C_n=C$

The equation (1.6) becomes

$$\text{C.F.}=\frac{C\sum_{i=1}^{n}D_i}{\sum_{i=1}^{n}D_i}=C$$

Therefore, coincidence factor is equal to the contribution factor.

(vii)Utilization Factor: The utilization factor is the ratio of maximum demand of a system to the rated capacity of the system.

$$\text{Utilization factor}=\frac{\text{Maximum demand of the system}}{\text{Rated capacity of the system}}$$

(ix) Loss factor: It is defined as the ratio of the average power losses over a specified period of time to the peak loss during the same period. While it is relatively easy to determine load factor, it is difficult to determine loss factor because average system losses cannot be easily determined. The reason for this is, in part ,due to the fact that system losses vary as the square of the current. The evaluation of energy losses is of prime important, for it represents the loss of a real saleable product.

i.e.., $$\text{Loss Factor} = \frac{\text{Average power loss}}{\text{Power loss at the peak load}}$$

One empirical approximation, Buller and Woodrow[2] formula is

$$\text{Loss factor}=(\text{load factor})^{1.732}$$

Another then rule is

$$\text{Loss factor}=C(\text{load factor})+(1-C)(\text{load factor})^2 \quad \ldots.(1.8)$$

Where C=0.3 for transmission system and 0.15 for distribution system

LOAD GROWTH:

The load growth of the geographical area served by a utility company is the most important factor influencing the expansion of the distribution system .Therefore, forecasting of load increase is essential to the planning process.

Fitting –trend after transformation of data is a common practice in technical forecasting. An arithmetic straight line that will not fit the original data, for example, the algorithms of the data as typified by the exponential trend.

$$Y=ab^x$$

This expression is sometimes called growth equation, since it is often used to explain the phenomenon of growth with time. For example, if the load growth is known ,the load at the end of the n^{th} year is given by

$$P_{Ln}= P_{Lo}(1+g)^n.$$

$$Q_{Ln}= Q_{Lo}(1+g)^n$$

Where P_{Ln} , Q_{Ln} =Real and reactive power load at the end of n^{th} year

P_{Lo} ,Q_{Lo}=Real and reactive power load at the base year

g=Annual growth rate, generally 7.5%

n=Number of years, in general for developing countries 7 to 10 years are considered for designing.

LOAD CHARACTERISTICS:

The following load characteristics are discussed in the following sections:

Nature of loads

It is necessary to know the general nature of load, which is characterized by the demand factor, load factor, diversity factor, utilization factor and power factor.

Types of loads

In general, the types of load can be divided into the following categories:

(i) Domestic loads: This type of loads mainly consists of domestic appliances such as lights ,fans, heaters, refrigerators, air conditioners, mixers, ovens, heating rangers and small motors for pumping, various other small house hold appliances, etc. The daily load curve (DLC) of week days of this type of load in terms of peak load is shown in fig, the various factors are: demand factor 70-100%,diversity factor 1.2-1.3 and load factor 10-15%.

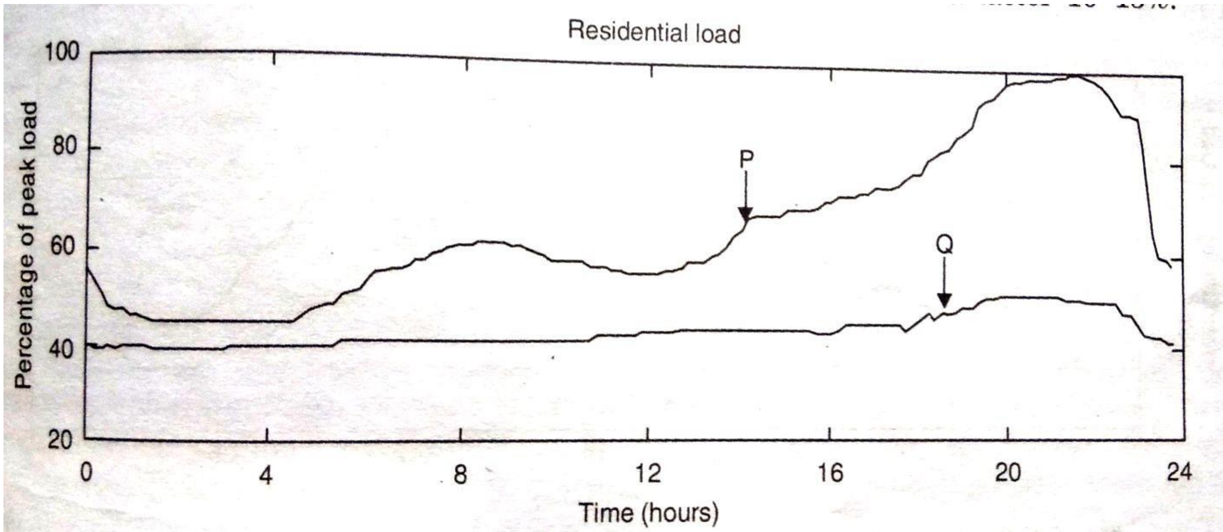


FIG Residential load curve in percentage of peak load

(ii) Commercial loads: Commercial loads consist of lighting for shops, fans, air-conditioning, heating and other electrical appliances used in commercial establishments, such as shops, restaurants, market places, etc. The daily load curve(DLC) of week days of this type of load in terms of peak load is shown in fig 1.7 .The demand factor is usually 90-100%,diversity factor is 1.1-1.2 and load factor is poor and it may be taken as 25-30%.

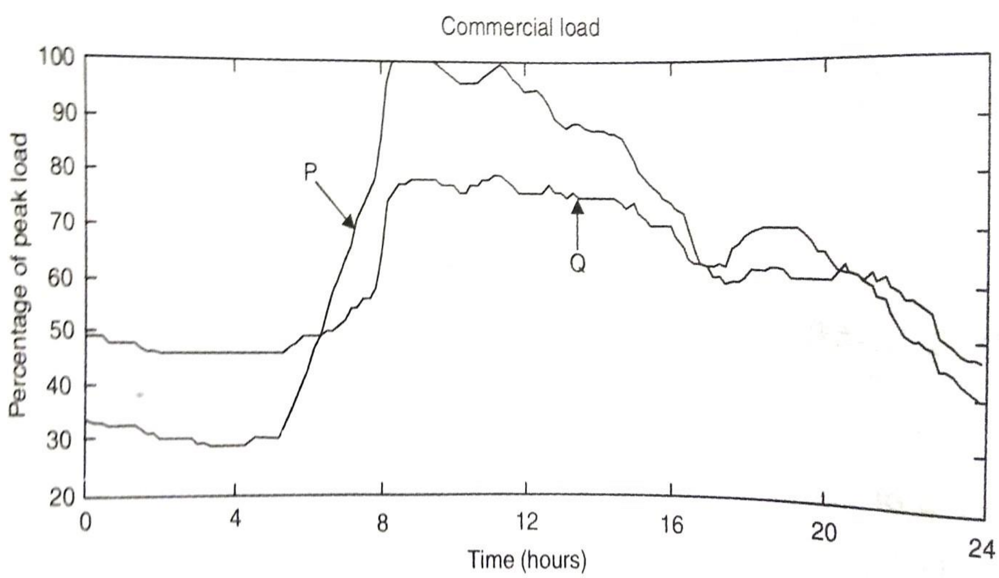


FIG Commercial load curve in percentage of peak load

(iii) Industrial loads: This type of loads may be sub divided into small, medium and heavy depending on the power range required. For example, small scale industries require load upto 25kW, medium scale industries between 25 to 100kW, and heavy industries require load more than 500kW.The chronological load curve for industrial load depends on the type of industry because of shift operation etc. These loads are considered base load that contain small weather dependent variation. The heavy industries the demand factor is 85 -90% with a load factor of 70-80%.The daily load curve (DLC) of week days of this type of load in terms of peak load is shown in fig .1.8.

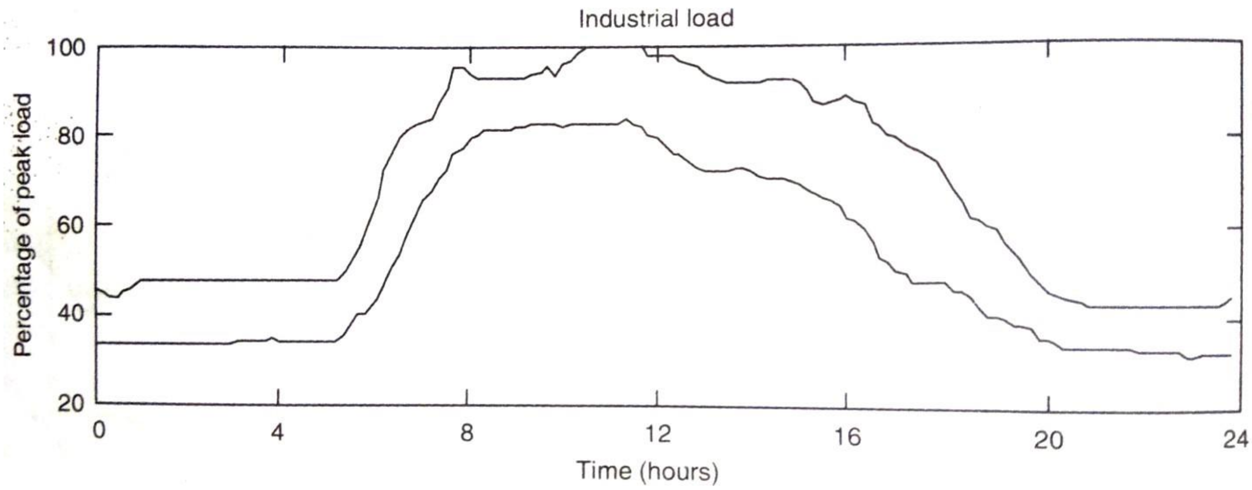


FIG Industrial load curve in percentage of peak load

(iv) Municipal loads: Municipal load consists of street lighting, power requirement for water supply and drainage purposes. This load is for street lighting and remains practically constant through out the night. For this the demand factor is 100% while diversity factor can be taken as 1.streetlights are required mainly at night but there may be the small load of traffic signals throughout the day also. The load factor for street light is usually taken as 25-30%.

(v) Agriculture load: For this type of load the electric power needed for pumps driven by motors to supply water to field. The load factor is generally taken as 20-25%,the diversity factor as 1.0-1.5 and the demand factor is 90-100%.

UNIT-II

INTRODUCTION

Distribution system is a part of power system, which is between distribution substations the consumer. According to design considerations, the primary distribution system is classified into three types i.e.., radial, loop and network systems.

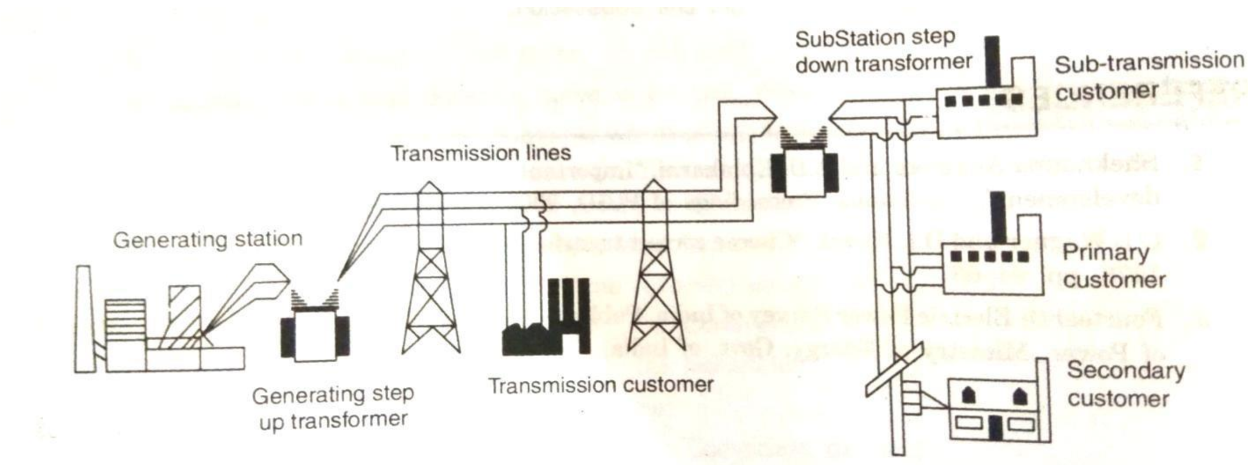


FIG 2.1 Schematic diagram of power system

DESIGN CONSIDERATIONS OF RADIAL TYPE DISTRIBUTION FEEDER

Most distribution systems are designed as radial distribution systems as shown in fig 2.2 .The radial system is characterized by having only on path between each customer and a substation. The electrical power flows exclusively away the substation and out to the customer along a single path, which, if interrupted results in complete loss of power to the customer. Radial design by far, is the most widely used form of distribution design, accounting for over ninety-nine percent of all distribution in India. Its predominance is due to two overwhelming advantages: its lower cost than the other two alternative and simple in planning, design and operation.

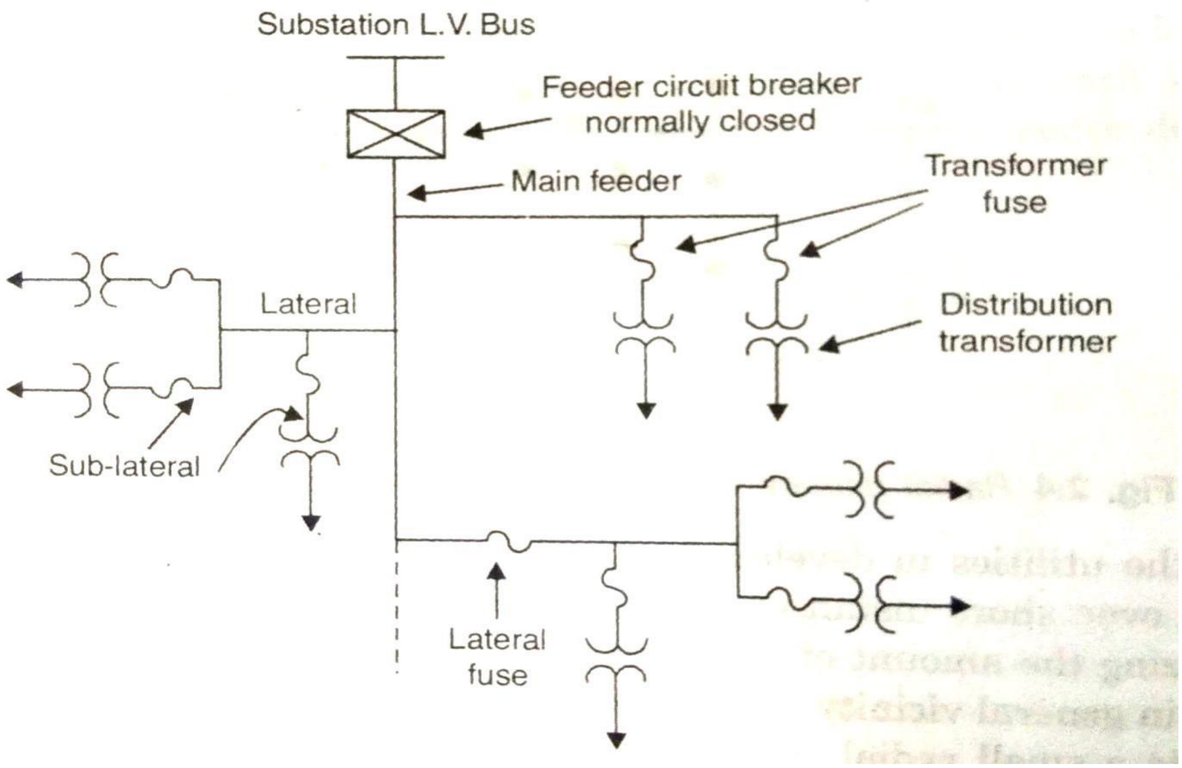


FIG 2.2 BASIC RADIAL PRIMARY FEEDER CONFIGURATION

Each radial feeder serves a definite service area. Most radial feeder systems are built as networks, but operated radially by opening switches at certain points throughout the physical network (shown in fig 2.3),so that the resulting configuration is electrically radial. The planner determines the layout of the network and the size of each feeder segment in that network and decides where the open points should be for proper operation as a set of radial feeders.

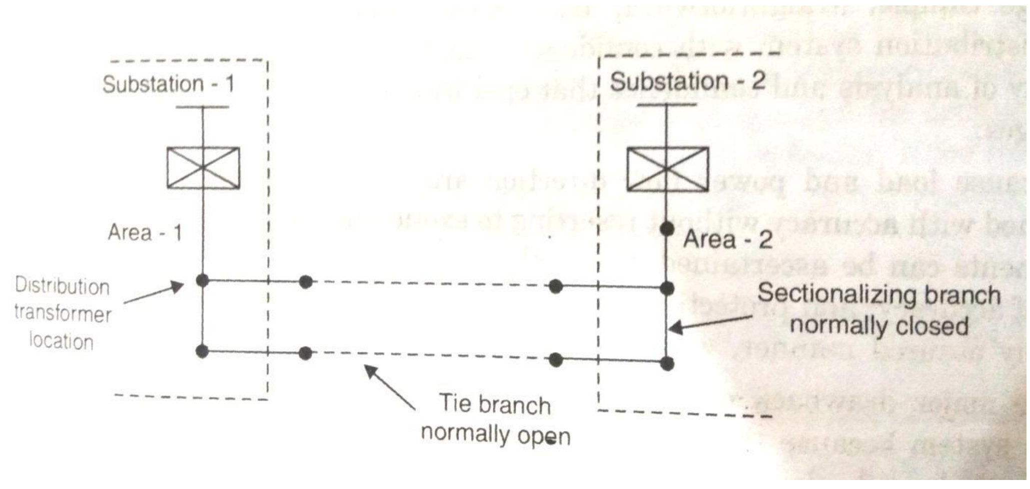


FIG 2.3 RADIAL PRIMARY FEEDER WITH TIE AND SECTIONALIZING SWITCHES

The other type of radial primary feeder with express feeder and back feed is as shown in fig 2.4.The section of the feeder between the substation LV bus and the load center of the service area is called express feeder. From which no sub feeders or laterals will be allowed to be tapped off. The portion from load center towards the substation is called back feed portion. However ,a sub feeder is allowed to provide a back-feed towards the substation from the load center.

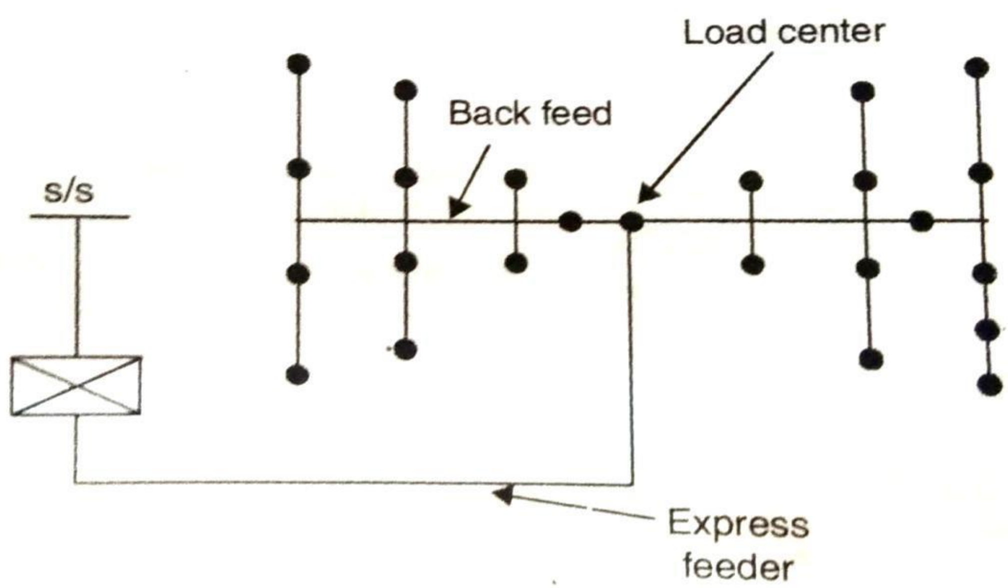


FIG 2.4 RADIAL PRI,ARY FEEDER WITH EXPRESS AND BACK FEED CONFIGURATION

Most of the utilities in developed countries are using single and two-phase laterals to deliver power over short distances by tapping off only one or two phases of the primary feeder minimizing the amount of wire that need be strong for the short segment required to get the power in general vicinity of few customers. Each service transformer in these systems feed power into a small radial system around it.

Regardless of whether it uses single-phase laterals or not, the advantages of the radial system, in addition to its lower cost, are the simplicity of analysis and predictability for performance. Because there is only one path between each customer and the substation, the direction of power flow is absolutely certain. Equally important is that the load on any branch of the system can be determined in the most straightforward manner by simply adding up all the customer loads “downstream” from that piece of equipment .Before the advent of economical and widely available computer analysis, this was only an over helming advantage. Simple, straight forward, ”back of the envelope” design procedures can be applied to the distribution system with confidence that the resulting system would work well. The simplicity of analysis and confidence that operating behavior is strictly predictable are major advantages.

Because load and power flow direction are easy to establish, voltage profiles can be determined with accuracy without resorting to exotic calculation methods; equipment capacity requirements can be ascertained at exactly fault levels, can be predicted with a reasonable degree of accuracy; and protective devices, breaker-relays and fuses can be coordinated in an absolutely assured manner, without resorting to network methods of analysis.

The major drawback of radial feeder is that it is less reliable than loop or network system because there is only one path between the substation and the customer. Thus, if any branch along this path fails a loss of power delivery results. Generally, when such failure occurs, a repair crew is dispatched to re-switch temporarily the radial pattern network, transferring the interrupted customers onto another feeder, until the damaged branch can be repaired. This minimizes the period of outages, but an outage still occurred because of the failure.

DESIGN CONSIDERATIONS OF LOOP TYPE DISTRIBUTION FEEDER

An alternative to purely radial feeder design is a loop system as shown in fig 2.5 consisting of a distribution design with two paths between the power sources(substations, service transformers) and every customer. Equipment is sized and each loop is designed so that service can be maintained regardless of where an open point might be on the loop. Because of this requirement, whether operated radially(with one open point in each loop) or with closed loops, the basic equipment capacity requirements of the loop feeder design do not change.

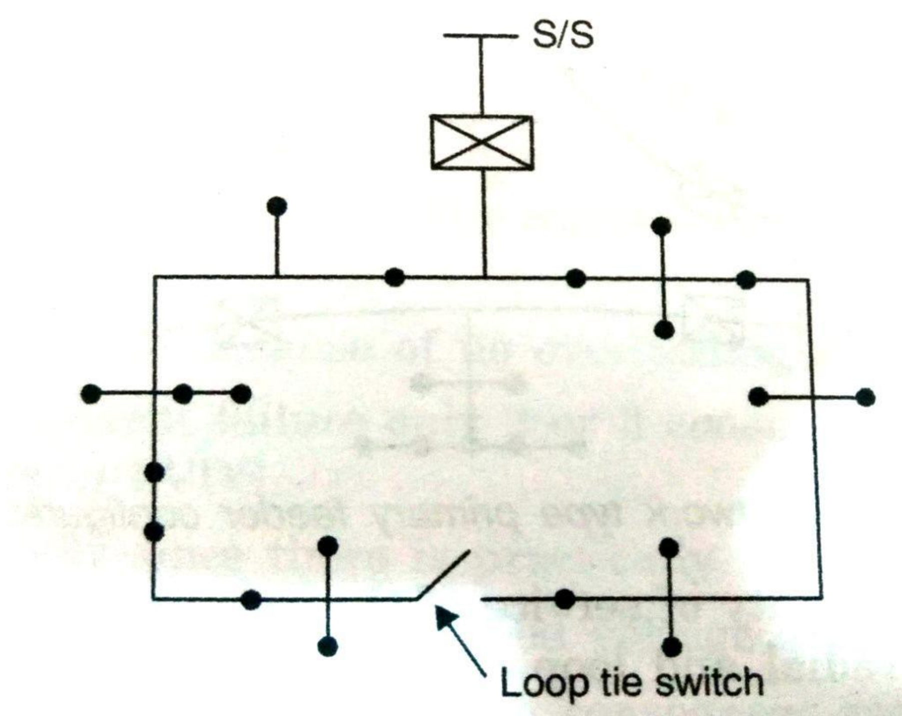


FIG 2.5 LOOP PRIMARY FEEDER CONFIGURATION

In terms of complexity, a loop type distribution system is only slightly more complicated than a radial system, power usually flows out from both sides toward the middle. Voltage drop, sizing and protection engineering are slightly more complicated than radial systems.

But if designed thus and if the protection (relay-breakers and sectionalizes) is also built to proper design standards the loop system is more reliable than radial systems. Service will not be interrupted to the majority of customers whenever a segment is out of service, because there is no “downstream” portion of any loop. The major disadvantage of loop systems is capacity and cost. A loop must be able to meet all power and voltage drop requirements when fed from only one end, not both. It needs extra capacity on each end and the conductor must be large enough to handle the power and voltage drop of the entire feeder, if fed from either end. This makes the loop system inherently more reliable than a radial system, but the larger conductor and extra capacity increase cost.

DESIGN CONSIDERATIONS OF NETWORK TYPE DISTRIBUTION FEEDER

Distribution network is the most complicated; the most reliable and even in very rare cases also it is the most economical method of distributing electric power. A network involves multiple paths between all points in the network as a shown in fig 2.6.Power flow between any two points is usually split among several paths and if a failure occurs it instantly and automatically re-routes itself.

Rarely in a distribution network primary voltage-level network design is involed, in which all or most of the switches between feeders are closed so that the feeder system is connected between substations. This is seldom done because it proves very expensive and often will not work well. Instead, a “distribution network” almost always involves “interlaced” radial feeders and a network secondary system grid of electricity strong conductor connecting all the customers together at utilization voltage. Most distribution networks are underground simply because they are employed only in high density areas, where overhead space is not available.

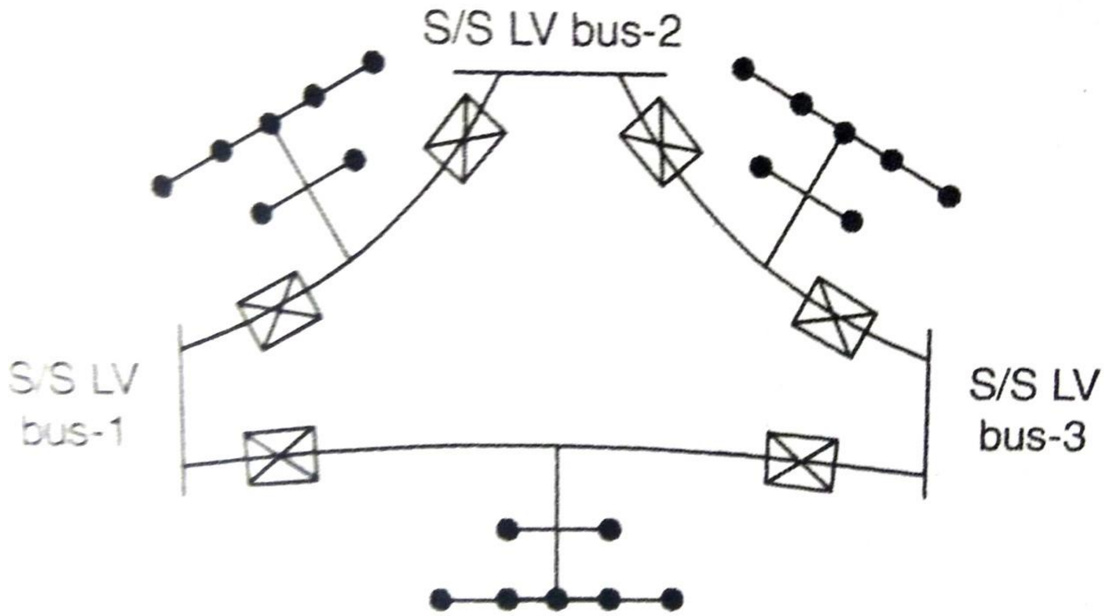


FIG 2.6 NETWORK TYPE PRIMARY FEEDER CONFIGURATION

The reliability and the quality of service of the network type distribution arrangement are much higher than the radial and loop arrangements. However, it is more difficult to design and operate than the radial or loop type systems.

DESIGN PRACTICE OF SECONDARY DISTRIBUTION SYSTEM

The Secondary distribution system receives power from secondary side of distribution transformer at low voltage and supplies power to various connected loads via, service lines. The secondary distribution system is the final sub system of the power system.

The secondary distribution systems are generally radial type expect for specific service areas such as hospitals, business centers, and military installations which require highly reliable service. In such areas, secondary distribution system may be a grid or mesh type network.

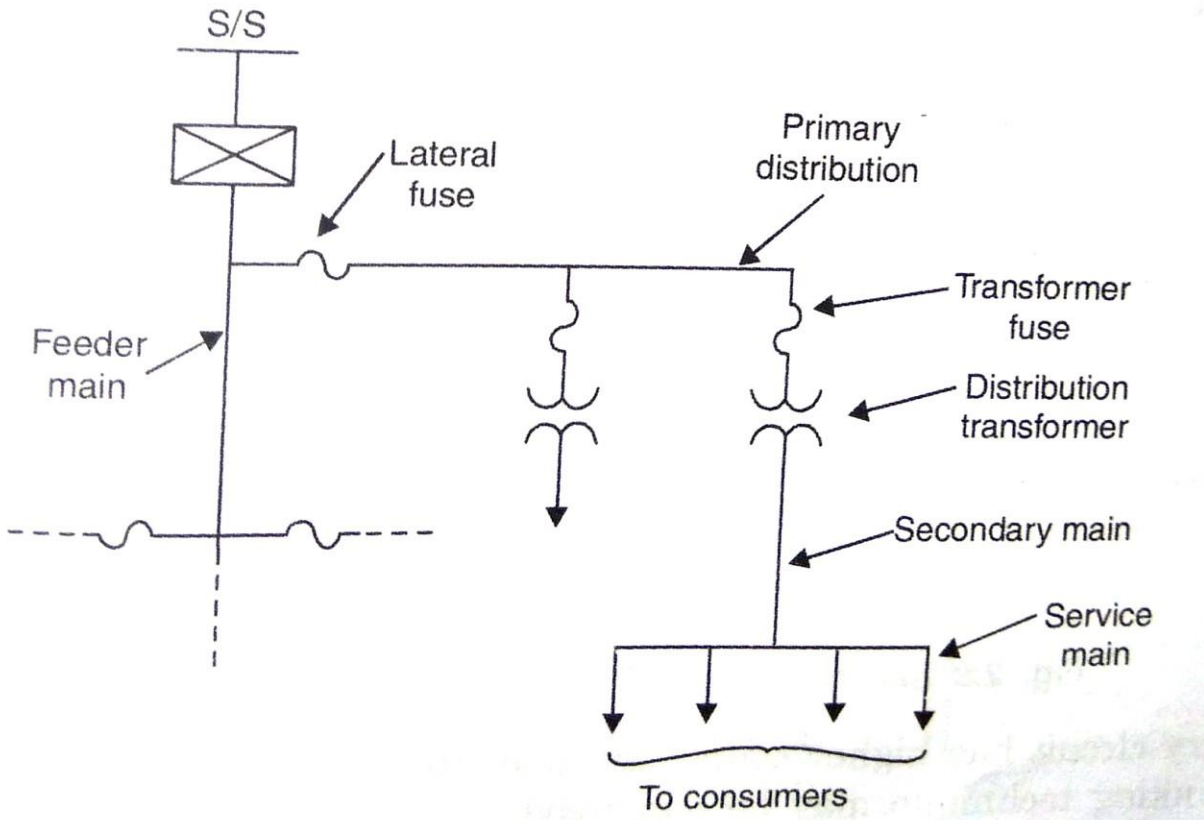


FIG 2.8 RADIAL SECONDARY DISTRIBUTION SYSTEM CONFIGURATION

Radial secondary circuit is shown in fig .2.8.The secondary transformers are located near load areas. The primary of distribution transformers receives power from primary laterals via, fuse cut-out or fuse switch, whereas the secondary side of distribution transformer (DT) supplies power through secondary mains, through service conductor to service meter and also includes:

- A separate service system for each customer with separate DT and secondary connection(example, single phase DT)
- The radial system with a common secondary main which is supplied by one DT and feeding a group of customers(example, Three phase DT)
- The parallel connection system with a common secondary main that is supplied by several DT's that are all fed like common primary feeders secondary banking of DT's.

SECONDARY BANKING OF DISTRIBUTION TRANSFORMERS

'Banking' denotes parallel connections. Banking of distribution transformers on secondary side refers to connection between secondary mains supplied by two or more distribution transformers connected to the common primary. Figure 2.9 shows radial circuits in which several transformer ordinaries are connected to primary laterals and secondaries are in parallel.

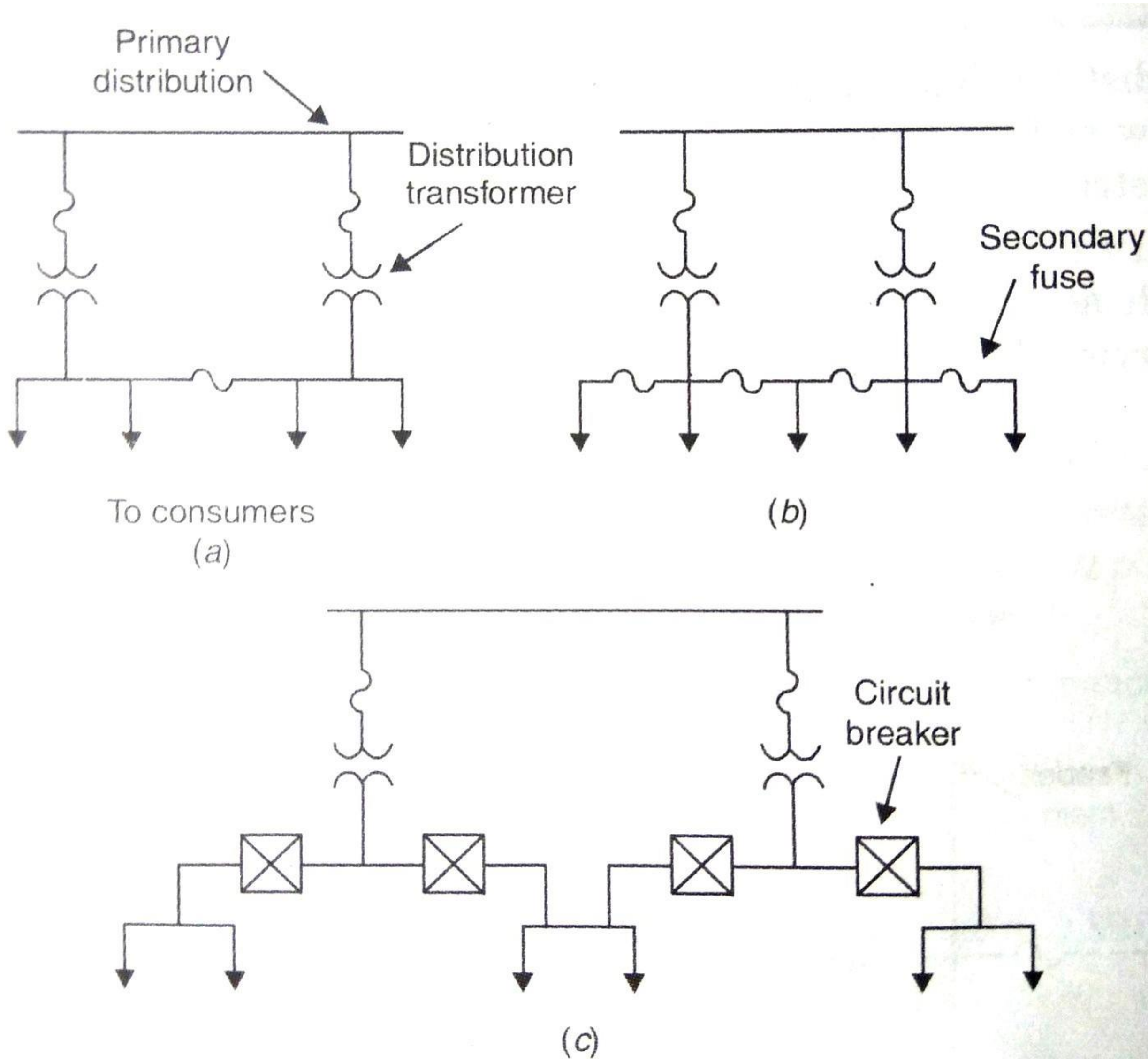


FIG 2.9 SECONDARY BANKING OF DISTRIBUTION TRANSFORMERS

If secondary circuit has higher connected load, than one distribution transformer KVA rating, then banking technique may be employed.

Merits of banking are:

- Better voltage regulation due to reduced equivalent impedance(X_e=X_t/2 for a bank of two transformers or X_t/3 for a bank of three transformers)
- Reduced voltage dip and lamp flicker
- Improved service continuity and reliability. At least one transformer continues to feed in the event of failure of other
- Easy to supply higher loads

SECONDARY NETWORK TYPES

For higher reliability of secondary distribution system, secondary network is preferred for high load density areas like hospitals, business localities etc. In secondary network system the secondaries of distribution transformer are connected to a common secondary network. Thus the secondary network has power supply from several distribution. The loads are connected to the secondary grid network.

Secondary network is two basic types:

(1)Grid network (2) Spot network

Grid network is used for suburban commercial loads spread over large area, where as spot network is used for concentrated essential loads such as commercial buildings ,hospitals, shopping centers etc.

GRID NETWORK

The essential components of the grid network are shown in FIG 2.10 .Secondary cables are installed along various streets in the commercial area and all conductors of each phase are connected together at each street intersection to form a secondary cable grid. Customer service connections are taken from these cables. The cables grid is energized by means of several distribution transformer network units. Each unit consists of a network transformer and a network protector. At least two to five primary feeders are used to supply the network unit.These feeders are usually in a voltage range of 11kV or 33kV .Each feeder supplies several network unit and adjacent network units are supplied from different primary feeders. The overall design of the grid network system provides voltage within prescribed limits to all customers, each with outage of any major system component i.e.., primary feeder network unit. Some utilities use a double contingency criteria for their networks such that service will be maintained to all customers with any two major components out of service.

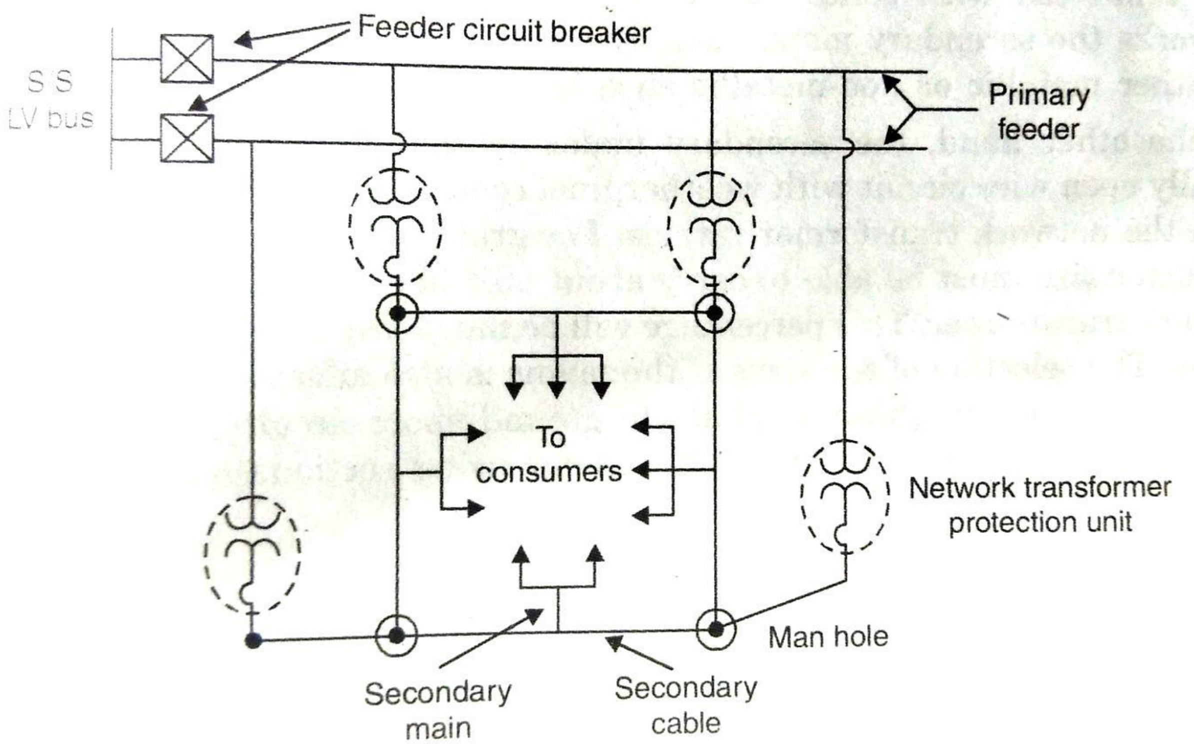


FIG 2.10 SECONDARY GRID NETWORK

All parts of secondary network are usually underground. This includes the network itself, service connections to customers, network units and primary cables. Both primary and secondary network cables are inducts under the street. Network units are in vault under the street or under a footpath or in a building vault. At street crossing, there are manholes large enough to hold the cable bus work necessary for the formation of the network and for the workers to pull and slice cables. At points where services to individual customers take off from the network, handholds provide access for doing necessary work from the street level.

SPOT NETWORK FOR SECONDARY DISTRIBUTION

It is usually not practical to serve new commercial buildings in the down town areas form the grid network due to the magnitude; many utilities use spot networks to serve these loads. Spot networks may also be used to supply loads outside the down town area that requires high service reliability.

The design concept and the equipments used in the spot network are essentially the same as in the grid network. The spot network has a common secondary bus fed by several distribution transformer secondary’s. The service connections are tapped from the common bus. The spot network gives better capacity utilization of distribution transformer and is used generally for low voltage secondary system.

SECONDARY MAINS

The objective of secondary main would be:

- Proper distribution of load among the transformer which serves as link between two feeders(which are often referred to as network transformer because alternate path can be provided by closing of switches to other feeders)
- All the secondary mains are routed along the streets and are three phase four-wire star connected with solidly grounded neutral conductor. In the under grounded networks the secondary mains usually consist of single conductor cables which may be either metallic or non-metallic sheated.
- On the other hand, the secondary mains in the overhead secondary usually open wire circuit with weather proof conductors. The size of conductor depends upon the network transformer ratings. For grid type secondary mains the minimum conductor size must be able to carry about 60% of the full load current to the largest network transformer. This percentage will be much less for the underground secondary mains .The selection of the sizes of the mains is also affected by the clearing of faults. In case of phase to phase to ground short- circuits the secondary network is to be designed to clear of itself without using sectionalizing fuses or other over load protective devices.

INTRODUCTION

The purpose of a substation is to take power at high voltage from the transmission or sub-transmission level, reduce its voltage, and route it onto a number of primary voltage feeders for distribution in the area surrounding it.In addition, it performs operational and contingency switching and protection duties at both the transmission and feeder level as well as provides a convenient local site for additional equipment such as communications, storage of tools,etc.

Substation are somewhat more important to system performance than their cost. From both cost and reliability stand point, their interaction with the transmission and distribution systems is often more important than they themselves, in the sense that their influence on transmission and distribution reliability and costs often out weights their own costs and reliability contributions. Thus,in many ways, good planning of the substation level is the key to good distribution system planning. Certainly, poor substation level planning forfeits any hope of achieving outstanding performance and economy at the distribution level.

In the substation, to perform any one or two or all the following operations:

- To switch on and off the power lines, known as switching operation

- To transform voltage from higher to lower or vice versa, known as voltage transformation operation
- To convert A.C to D.C or vice versa, known as power converting operations
- To improve the p.f by installing synchronous phase modifier at the end of the line known as p.f. correction operation

LOCATION OF SUBSTATION

The voltage levels, voltage regulation considerations, sub transmission cost, substation cost, the cost of the primary feeder mains and the distribution transformers dictate the location of substation. However, to select an ideal location for substation the following rules should be considered

(i) Location of the substation as much as feasible close to the load center of its service areas, so that the addition of load times the distances from the substation is minimum

(ii) Its selection must be provision for proper for proper voltage regulation can be obtainable without taking extensive measures

(iii) Its selection must be provision for proper access for incoming sub transmission lines and outgoing primary feeders.

(iv) It should provide enough space for the future substation expansion.

(v) It should help to minimize the number of customers affected by any service outage.

CLASSIFICATION OF SUB STATION

Substations are classified according to service mounting, function and type of apparatus used.

According to service

a) **Transformer substations:** In these sub stations which transform power from one voltage to another. These are:

(i) Transmission or primary substations: Which receive power from a local generating station (i.e., 11 kv or 33 kv) and step up its voltage (i.e.,220KV or 400 KV) for primary transmission so that huge blocks of power can be transmitted over a long distance to the load centers economically.

(ii) Sub-transmission or secondary substation: which receive power from primary substations through primary transmission at voltages above 132 KV and step down its voltage to 33 KV or 11 KV per secondary transmission

(iii) Step down or distribution substations: Which receive power from sub transmission substations or directly from power stations and step down its voltage i.e., 400 V for three phase or 230 V for single phase for secondary distribution.

b) **Industrial substations**: These supplies to the industrial consumers.

c) Switching substations: Which meant for switching operations of power lines without transformation of voltage.

d) **Synchronous substations:** At these substations, synchronous phase modifiers are installed for the purpose of system power factor improvement.

e) **Frequency change substations:** At times for industrial utilization high frequency supply is essential. Therefore, normal frequency is converted into other frequencies at these substations.

f) **Converting substations:** For special purposes such as electric traction, electric welding, battery charging DC supply is required. The substation converting AC to DC are called converting substations.

According to design

a) Indoor substations: When the atmosphere is contaminated with impurities such as metal corroding gases and fumes, conductive dust etc. It is usual to install the apparatus within a building such substations known as indoor substations are usually up to 33 KV or 11 KV only.

b) Outdoor substations: Outdoor substations are of two types namely.

i) Pole mounted substations: These are used for distribution purposes and are usually double or four pole structures with suitable platforms.

ii) Foundation mounted substations: These are used for higher capacity of transformers, because of rate of the transformer would be more than pole mounted.

MERITS AND DEMERITS OF INDOOR AND OUTDOOR SUBSTATIONS

Outdoor substations have the following merits over indoor substations are:

i) All the equipment is visible and hence fault identification is easier
ii) Extension of the installation is easier
iii) Required less erection time
iv) There is no building is necessary and require less building material.
v) The construction work required is comparatively smaller and hence the cost of the switch gear installation is low.

vi) Less in damages due to faults, as the operators can be spaced liberally.

The demerits of outdoor substations over indoor substations are:

i) Switching operation, supervision and maintenance of apparatus is to be performed in the open air during all kinds of weather.
ii) Required more space for the substation
iii) They are exposed to sun, therefore to higher temperature and hence special design of the apparatus to withstand those temperatures is necessary.
iv) Dust and dirt deposits upon the outdoor substation equipments needs higher maintenance.
v) These are prone to lightening strokes.

The choice of particular arrangement depends upon the relative importance placed on such items as safety, reliability, simplicity of releasing, flexibility of operations, initial cost, ease of maintenance, availability of good area, location of connecting lines, provision for expansion and appearance.

RATING OF THE DISTRIBUTION SUBSTATION

The rating of the distribution substation depends upon the following factors:

- Nature of the load connected
- Load density of the area feeder
- Rate of load growth
- Type of design adopted and equipment for the substation
- Quality of service to be provided
- Number of feeder emerging from the substation
- Voltage levels of primary feeders.

With increase in the load density, the additional load requirement can be met by:

(i) Either the service area of the given distribution substation maintaining constant and increasing its rating or
(ii) Installing new distribution substations and there by maintaining the capacity of the given distribution substation constant

It is helpful to consider that the system changes:

(a) For short- term distribution planning the load density is constant
(b) For long-term planning the load density is increasing

It simplifies greatly to analyze a squared shape area representing a part of or the entire service area of a distribution substation. Consider the square area is served by four primary feeders from a central feed point as shown in fig in which each feeder and its sub –feeders are of 3-Φ circuit

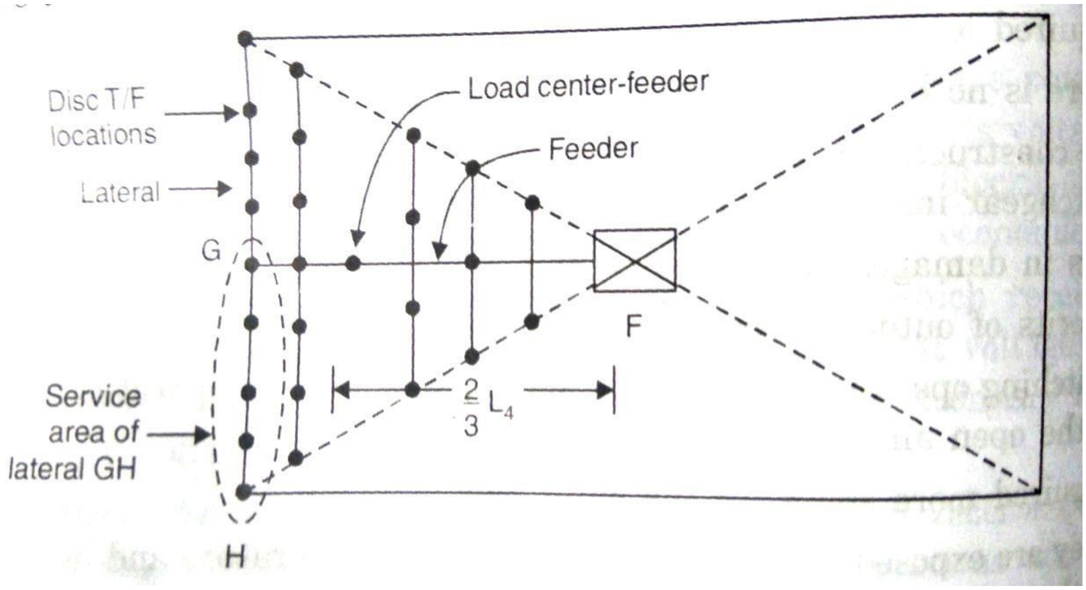


FIG SQUARE SHAPED SERVICE AREA OF DISTRIBUTION SUBSTATION

The % of voltage drop from the feed point ‘F’ to the end of the feed point ‘H’as

$$\%\, Vd_{FH} = \%Vd_{FG} + Vd_{GH}$$

From the fig 4.1 ,each feeder supplies a total load of

$$S_4 = A_4 D (Kva) \qquad (2.1)$$

Where A_4=Area supplied by one of four feeders emerging from load center ‘F’,km^2

D=Load density, kVA/km^2

For square shaped area, the equation 4.2 can be modified as

$$S_4 = L_4^2 D \quad (kVA) \qquad (A_4 = L_4^2) \qquad (2.2)$$

For uniformly distributed load, the % voltage drop in the main feeder at $2/3L_4$ is given by

$$\%Vd_4 = \left(\frac{2}{3} L_4\right) CS_4 \qquad (2.3)$$

Where C=% Vd/kVA-km ,various depends on source voltages and conductors sizes substituting equation 2.2 in equation 2.3

$$\%Vd_4 = \frac{2}{3} L_4^{\,3} CD \qquad (2.4)$$

From the equation 2.4, it can be concluded that the total is located at a point on the main feeder at a distance of 2/3 L_4 from the feed point 'F'

A analysis of square shaped service area of distribution substation can be extended for a hexagonal shaped service area of distribution substation served by 6 feeders feeds from center point 'F' of the substation location as shown in FIG

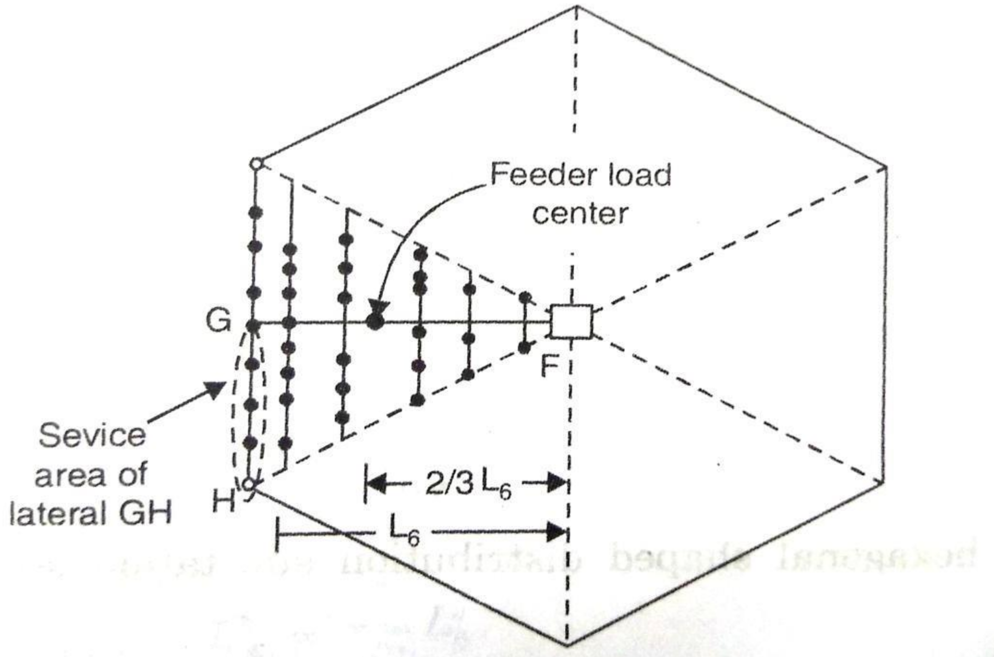


FIG HEXAGONAL SHAPED SERVICE AREA OF DISTRIBUTION SUBSTATION

Consider each feeder service area is equal to 1/6 pf the hexagonal shaped service area or

$$A_6 = \frac{L_6}{\sqrt{3}} \times L_6 = \frac{L_6^2}{\sqrt{3}} \quad (2.5)$$

The total load served from each feeder is given by

$$S_6 = A_6 D \ \text{kVA} \quad (2.6)$$

Substituting the equation(2.5) in equation (2.6)

$$S_6 = \frac{L_6^2}{\sqrt{3}} D \quad (2.7)$$

The load served by the feeder is assumed to be lumped, the % voltage drop in the main feeder at $2/3L_6$ distance from the feeding point 'F' and is given by

$$\% Vd_6 = \left(\frac{2}{3} L_6\right) CS_6 \tag{2.8}$$

Substituting equation 2.7 in equation 2.8

$$\% Vd_6 = \frac{2}{\sqrt{3}} L_6^3 CD \tag{2.9}$$

From the equation 2.9 it can be concluded that the total load is located at a point on the main feeder at a distance of $\frac{2}{3\sqrt{3}} L_6$ from the feed point ‘F’

COMPARISION BETWEEN FOUR FEEDER AND SIX FEEDER MODEL

Consider a square shaped service area of distribution substation served by four feeders from the center of substation i..e, n=4

The area served by each one of the feeder, $A_4 = L_4^2 m^2$

Total area served by all 4 feeders, $A_{T4} = 4A_4 = 4L_4^2$

Similarly ,total load served by all 4 feeders, $S_{T4} = 4L_4^2 D$ kVA

The % voltage drop in the main feeder, $\% Vd_4 = \frac{2}{3} L_4^3 CD$

The load current flowing in the feeder from the feeding point ‘F’ is given by

$$I_4 = \frac{S_4}{\sqrt{3} V_L} = \frac{L_4^2 D}{\sqrt{3} V_L} \text{Amps}$$

Similarly, for hexagonal shaped distribution substation service area served by six feeders.

Total area served by all 6 feeders, $A_{T6} = \frac{6}{\sqrt{3}} L_6^2$

Total load served by all 4 feeders, $S_{T6} = \frac{6}{\sqrt{3}} L_6^2 D \quad kVA$

The %voltage drop in the main feeder, $\% Vd_6 = \frac{2}{3\sqrt{3}} L_6^3 CD$

The load current flowing in the feeder from the feeding point "F" is given by

$$I_6 = \frac{S_6}{\sqrt{3}V_L} = \frac{L_6^2 D}{3V_L} \text{ Amps}$$

Compare the service area of 4 and 6 feeder model in the following two cases:

Case-I

Thermally limited feeder: for a given size of conductor and voltage drop is neglected

$$I_4 = I_6$$

$$\frac{L_4^2 D}{\sqrt{3}V_L} = \frac{L_6^2 D}{3V_L}$$

$$\left(\frac{L_6}{L_4}\right)^2 = \sqrt{3} \qquad (2.10)$$

$$\frac{A_{T6}}{A_{T4}} = \frac{\frac{6}{\sqrt{3}} L_6^2}{4L_4^2} = \frac{\sqrt{3}}{2}\left(\frac{L_6}{L_4}\right)^2 \qquad (2.11)$$

Substituting equation 2.10 in equation 2.11

$$\frac{A_{T6}}{A_{T4}} = \frac{\sqrt{3}}{2} \times \sqrt{3} = \frac{3}{2} = 1.5$$

OR $\quad A_{6T} = 1.5A_{4T}$

Hence ,six feeder circuits can carry 1.5 times as much load as of the four feeder circuit

Case-II

Voltage drop limited feeder: For a given size of conductor and consider voltage drop is equal

i.e.., $\quad \%Vd_4 = \%Vd_6$

From equation(4.5) and (4.10)

$$\frac{2}{3} L_4^3 CD = \frac{2}{3\sqrt{3}} L_6^3 CD$$

OR $\quad L_4^3 = \frac{1}{\sqrt{3}} L_6^3$

OR $L_4 = 0.832\, L_6$

From equation(4.12) $\frac{A_{T6}}{A_{T4}} = \frac{\sqrt{3}}{2}\left(\frac{L_6}{L_4}\right)^2$

From the above equation, L_4 is replaced with $0.832L_6$

$$\frac{A_{T6}}{A_{T4}} = \frac{\sqrt{3}}{2}\left(\frac{L_6}{0.832L_6}\right)^2$$

or $A_{6T} = 1.25A_{4T}$

hence, six feeder circuits can carry 1.25 times as much load as of the four feeder circuit

SUBSTATION SERVICE AREA WITH 'N' PRIMARY FEEDERS

The service area of the distribution substation is supplied by 'n' number of primary feeders emerging from feed point 'F' is shown in fig 4.3 .Consider the load is uniformly distribution in the supplied area and each feeder supplies an area of triangle shape.

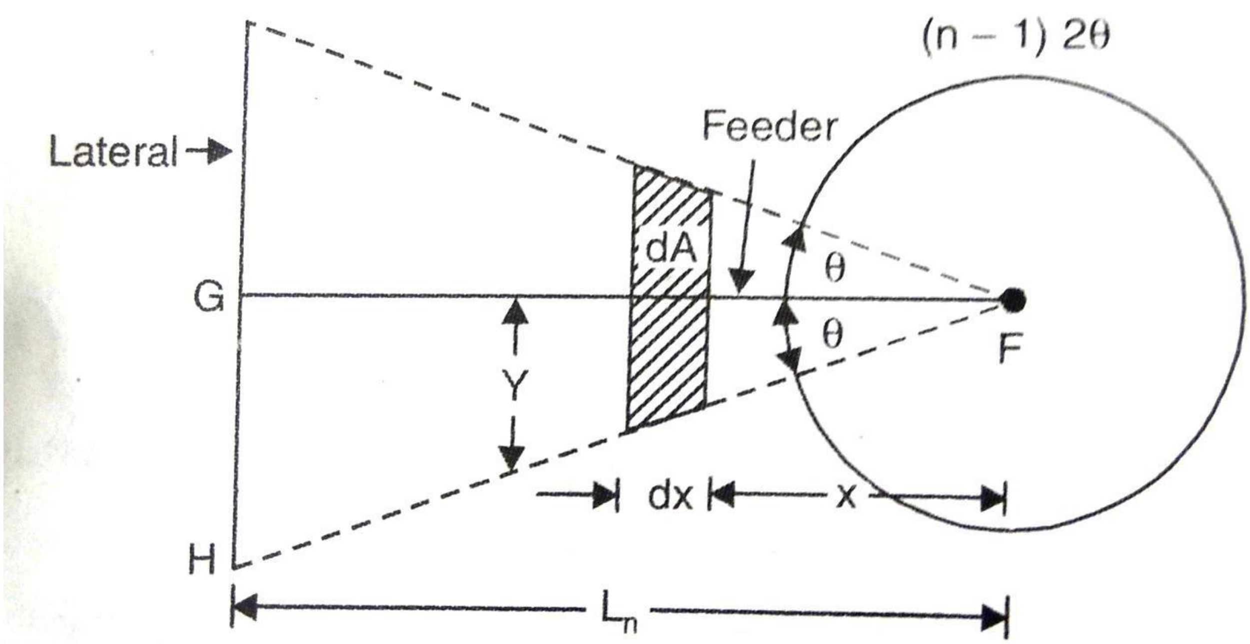


FIG SUBSTATION SERVICE AREA WITH 'n' PRIMARY FEEDERS

The differential load supplied by the feeder in a differential area of dA is

$$dS = DdA$$

where ,dA=differential area of the feeder,km^2

from fig, $\tan\theta = \frac{Y}{x+dx}$

$$Y=(x+dx)\tan\theta$$

$$=x\tan\theta$$

The total supplied area of the feeder circuit can be determined as

$$A_n = \int_{X=0}^{Ln} dA = L_n^{\ 2}\tan\theta$$

And total load supplied by one of the 'n' feeders can be determined as

$$S_n = \int_{x=0}^{Ln} dS = \int_{x=0}^{Ln} D\, dA = DL_n^2\ \tan\theta \qquad (2.15)$$

Consider this total load is located on the feeder circuit at $\frac{2}{3}L_n$ distances from the feed point 'F'

Addition of the % voltage drop contributions of all such areas is given by

$$\%Vd_n = \frac{2}{3}L_n CS_n \qquad (2.16)$$

Substituting Sn from equation 2.15 in equation 2.16

$$\%Vd_n = \frac{2}{3}L_n^{\ 3}\ DC\tan\theta \qquad (2.17)$$

From the fig n(2θ)=360

$$\theta = \frac{360}{2n}$$

The equation 2.17 can be modified as

$$\%Vd_n = \frac{2}{3}L_n^{\ 3}\ CD\ \tan\left(\frac{360}{2n}\right) \qquad (2.18)$$

The equation 2.18 is suitable, if the number of feeders 'n' ≥ 3

If number of feeders is one (i.e.., ,n=1)

$$\%Vd_1 = \frac{1}{2}CDL_1^{\ 3}$$

If n=2

$\%Vd_2 = \frac{1}{2} CDL_2^3$

OPTIMAL LOCATION OF SUBSTATION

Every consumer in a utility system should be supplied from the nearest substation .Supplying each consumer from the nearest substation assumes that the distribution delivery distance is as short as possible, which reduces feeder cost, electric power losses costs and service interruption exposure. Substations must be located as close possible to the consumer. There are a host of reasons why "all things are not equal" in most real world situations, but as concepts, "serve every consumer from the nearest substation", and "locate substation's so they are as close as possible to as many consumer as possible", are useful guidelines for optimizing site, size and service area good concepts for the layout of a power delivery system

The following benefits can be obtained for optimal location of substations:

- Design of substation become simple and cheap
- It is very near to the load center of its service area
- Low initial cost
- Voltage regulation is improved
- Product of kVA and the distance is minimum
- Access of incoming and outgoing lines are good,if future loads are increased
- Due to possible of alternate supply arrangement, the number of customers affected by any failure is minimum
- Cost of feeder material and power loss is minimum

PERPENDICULAR BISECTOR RULE

It is a simple, graphical method of applying the concept "Serve every consumer from the nearest substation" to a map in order to determine "optimum" substation service areas and their peak loads. Applied ion a somewhat tedious, iterative manner, it can also be used to determine where to locate a new substation to maximize its closeness to as many consumer loads as possible

Although simple in concept and at best approximate, the perpendicular bisector rule is a useful qualitative concept that every distribution planner should understand. Application of this rule to a service area map consists of several simple steps:

Step1:Draw a straight line between a proposed substation site and each of its neighbours

Step 2: Perpendicularly bisect each of those lines(i.e.., divide it in two with a line that intersects it at a ninety degree angle

Step 3:The set of all the perpendicular bisectors around a substation defines its service territory

Step4:The target load for this substation will be the sum of all loads in its service territory

This process is illustrated in fig step(2) of this process determines a set of lines that are equidistant between the substation and each of its neighbours.The set of all such lines around a proposed substation site encloses the area that is closer to it than any other substation. As a starting point in the planning process, this should be considered its preferred service area. The sum of all loads inside this set of lines defines the required peak demand to be served by the substation. The impact on the loading of the nearly substation can be determined in a similar manner, by using the perpendicular bisector method to identify how their service area boundaries change, what area they give up to the new substation, and how much their load is reduced by the new substation taking a part of their service area away from them.

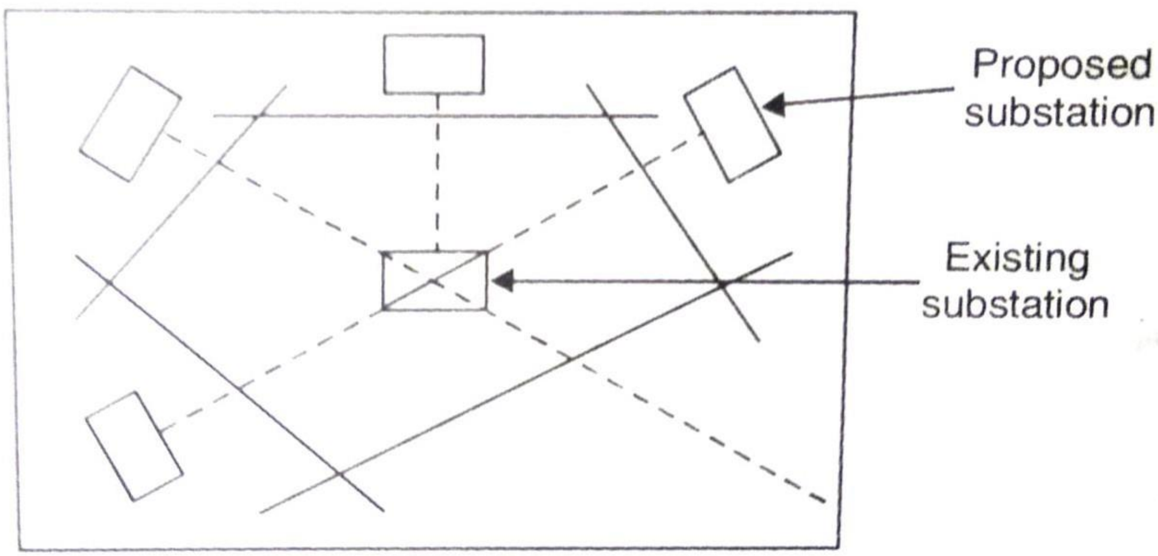


FIG OPTIMAL LOCATION OF SUBSTATION

X,Y CO-ORDINATE METHOD

Total KVA load fed through a particular node is $TKVA_{(i)}$ for i=1,2,3,………. number of nodes (nn).$TKVA_{(i)}$ is always available from the load flow computation. Optimum location of substation is computed through an interactive algorithm. It is worth mentioning here that substation is choosen as node or bus1(i.e, S=1).By minimizing real power loss,the optimal location of substation (X(s),Y(s)) for substation's', can be computed through the following interactive algorithm[1,2]:

$$X(s)=\frac{\sum_{i=2}^{m} W_{(i)} X_{(i)}}{\sum_{i=2}^{m} W_{(i)}}$$

$$Y(s)=\frac{\sum_{i=2}^{nn} W_{(i)} X_{(i)}}{\sum_{i=2}^{nn} W_{(i)}}$$

Where $X_{(i)}$ and $Y_{(i)}$=X and Y coordinates of the consumer load point for i=2,3,…..,NB

$W_{(i)}$=Real load at node i

UNIT-III

Introduction:

The performance of the distribution system and quality of the service provided are measured in terms of freedom from the interruption and maintenance of satisfactory voltage levels at the consumer premises i.e. within limits appropriate for this type of service.

Based on experience, too high steady state voltage causes reduced life of lamps and electronic devices, premature failure of some type of apparatus on the other hand too low steady state voltage causes the lowered illumination levels, slow hearing of heating devices, difficulties in motor starting

At the same time power losses in the distribution system should be minimum so as to make the system more efficient, without affecting its performance.

Thus the calculation of voltage drop and power losses in the distribution system is much significant. The size of the conductor for primary feeder is based on acceptable voltage drop and losses in the conductor mechanical requirement will be the decision factor.

CALCULATION OF VOLATGE DROP AND POWER LOSSES IN LINE HAVING UNIFORMLY DISTRIBUTED LOADING:

Single line diagram of 3phase feeder circuit is shown in figure.1. Consider the size and spacing along its entire length 'L' and power factor of all the loads connected to the system is same.

The line impedance $z = (r + jx_L)$ per unit length

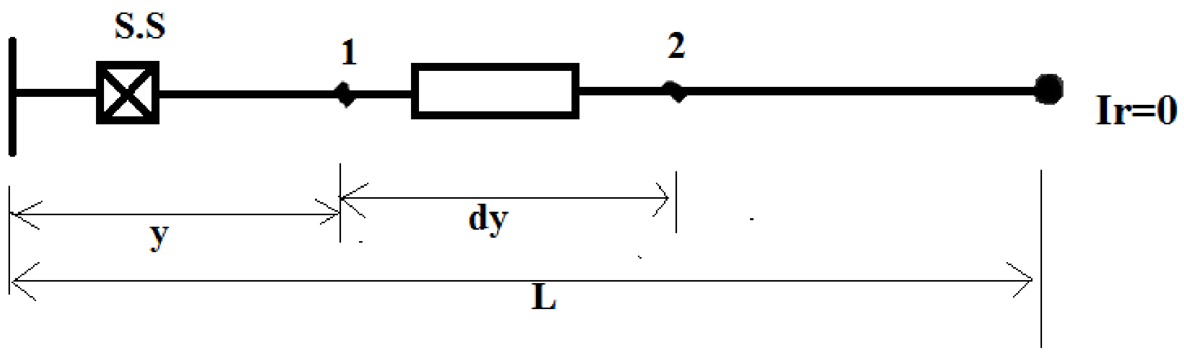


Fig:1 single line diagram of 3 phase circuit.

The feeder load is uniformly distributed as shown in fig:2 . The differential tapped off load current 'dI' which corresponds to differential distance 'dx', y and (y+dy) is the distance between the point 1& 2 from the feeding end of the circuit respectively.

I_s and I_r are the sending end and receiving end currents of circuit, I_1 and I_2 are the currents in the main feeder at points 1 and 2 respectively.

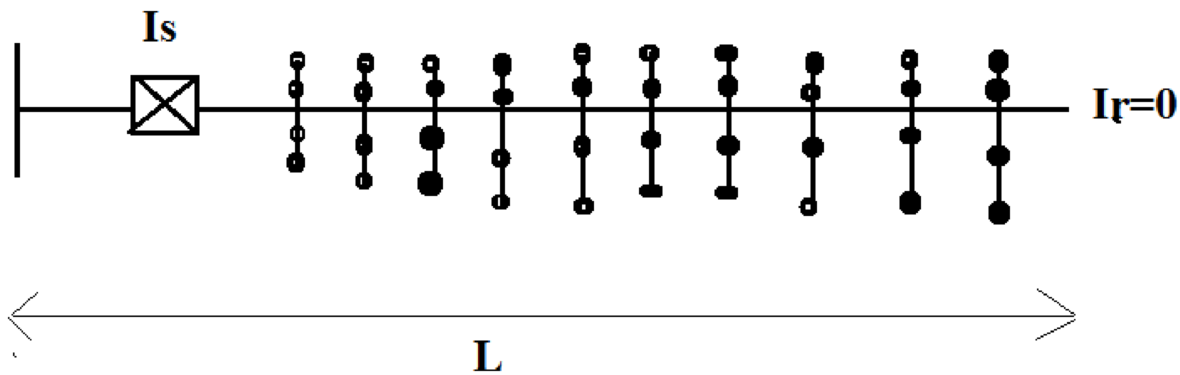


Fig 2 uniformly distributed load of the circuit

Consider total load is uniformly distributed from y=0 to y=L

FIG 1 the current at point 1 is

$I_1 = I_2 + dI \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$

Multiplying and dividing the equation 1 with 'dy' it can be modified as

$$I_2 = I_1 - \left(\frac{dI}{dy}\right) dy$$

$$I_2 = I_1 - Cdy \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where $C = \frac{dI}{dY}$ (i.e. current tapped per unit length)

For total circuit length 'L' the receiving end current is

$$I_r = I_s - CL \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

When y=L, the receiving end current is zero.

$$I_r = I_S - CL = 0$$

$$C = \frac{I_S}{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Substituting constant 'C' in equation (3)

$$I_r = (I_S - \frac{I_s}{L} y)$$

$$I_r = I_s\left(1 - \frac{y}{L}\right)$$

Let for a given distance y $I_s = I_y$

$$I_y = I_s\left(1 - \frac{y}{L}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

From equation 5: $I_y = 0$ when y=L, and $I_y = I_S$ when y=0

From the above expression it can be observed that I_y changes with distance

The series voltage drop due to I_y at any point 'y' from the source of the main circuit is

$$Vdy = \int_0^y z\, I_Y dy$$

Total voltage drop $V_d = \int_0^L z\, I_Y dy$

$$V_d = zI_s \int_0^L \left(1 - \frac{y}{L}\right) dy$$

$$= zI_s [y - \frac{y^2}{2L}]_0^L$$

$$V_d = \frac{I_s z L}{2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(6)}$$

Similarly the total power loss,

$$P_{LOSS} = \int_0^L I_y^2\, r\, dy = r\, I_s^2 \int_0^L \left(1 - \frac{y}{L}\right)^2 dy$$

$$= rI_s^2 \left[L + \frac{L^3}{3L^2} - \frac{2L^2}{2L}\right] = \frac{I_s^2 Lr}{3} \dots\dots\dots\dots\dots\dots .(7)$$

VOLTAGE DROP AND POWER LOSS CALCULARTIONS FO LINE WITH NON - UNIFORMLY DISTRIBUTED LOADS:

The single line diagram of 3 phase non uniformly distributed load of feeder circuit is shown in figure (1), in which tapped off load increases linearly with a distance 'dy'.

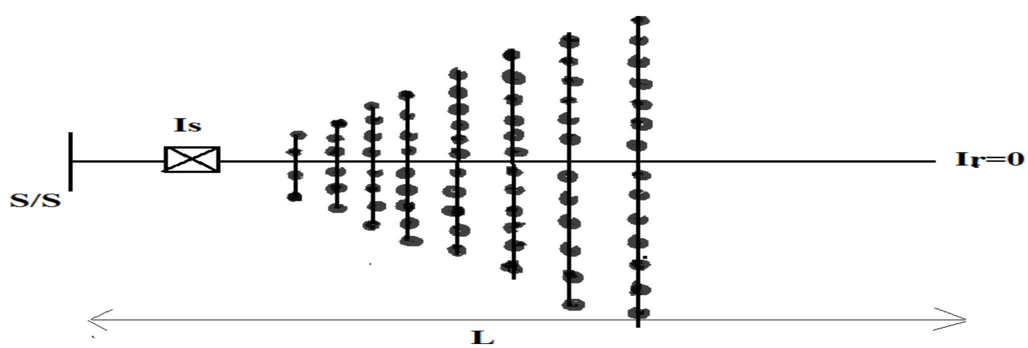


Fig. 1 non-uniformly distributed loads

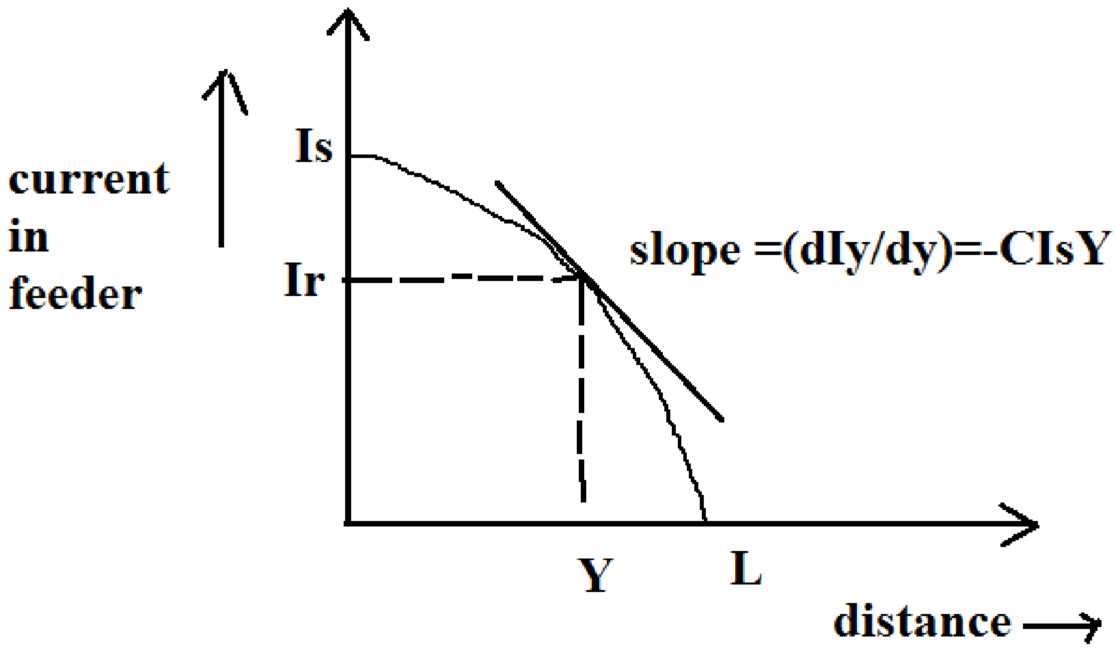


Fig 2 variation of current in feeder w.r.t distance

The negative slope of the fig2 is given by

$$\frac{dI_y}{dy} = -CI_sY \dots\dots\dots\dots(1)$$

Where C can be determined by

$$I_s = -\int_0^L CI_sY\,dY = -CI_S\left[\frac{Y^2}{2}\right]_0^L = -\frac{CI_SL^2}{2}$$

$$C = -\frac{2}{L^2}\dots\dots\dots\dots\dots\dots(2)$$

Substituting the value of ‘C’ in equation (1)

$$\frac{dI_Y}{dY} = -\frac{2I_SY}{L^2}\dots\dots\dots\dots\dots\dots\dots\dots(3)$$

The current in the feeder at a distance “Y” away from the feeder circuit breaker can be determined from the equation (3)

$$I_Y = \int_0^Y -\frac{2I_SY}{L^2}dY = \frac{2I_SY^2}{2L^2} + A\dots\dots\dots(4)$$

Where A is the integral constant

When Y=0, $I_Y = I_S$

$I_S = 0 + A$

A=I_S

substituting the value of ‘a’ in equation (4)

$$I_Y = \frac{2I_S Y^2}{2L^2} + I_S = I_S[1 - \frac{Y^2}{L^2}] \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The voltage drop due to current I_Y at any point 'Y' from the source of the circuit is

$$V\,dY = \int_0^Y z\, I_Y dY$$

Total voltage drop

$$V_d = \int_0^L z\, I_Y\, dY$$

$$= z \int_0^L I_S \left[1 - \frac{Y^2}{L^2}\right] dY$$

$$= zI_S[L - \frac{L}{3}]$$

$$V_d = \frac{2}{3} z\, L\, I_S$$

And similarly total power losses.

$$P_{loss} = \int_0^L I_Y^2 r\, dY = \int_0^L I_s^2 \left[1 - \frac{Y^2}{L^2}\right]^2 r\, dY$$

$$= I_s^2\, r \int_0^L \left[1 + \frac{Y^4}{L^4} - \frac{2Y^2}{L^2}\right] dY$$

$$= I_s^2\, r[L + \frac{L^5}{5L^4} - \frac{2L^3}{3L^2}]$$

$$= I_s^2\, r\, L \left[1 + \frac{1}{5} - \frac{2}{3}\right]$$

$$P_{loss} = \frac{8}{15} I_s^2\, r\, L$$

Non three phase systems:

In general there are many sub feeders or laterals on a primary system, which are not necessary in 3 phase , for example a 1 phase which causes the voltage drop and power loss due to load current not only in the phase wire but also in the return path.

The voltage drop and power loss are compared with the balanced 3 phase system.

Single phase, 2 wire system:

Consider a loaded 1 phase system, which is to be changed to an equivalent 3 phase, 3 wire balanced system maintaining the load constant.

Since the power input to the 3 phase system is same as that of the 1 phase system.

$$S_{1-\emptyset} = S_{3-\emptyset} \dots \dots \dots \dots \dots \dots \dots . (1)$$

Where V= line to neutral voltage

From the eq (1) we get $I_{1-\emptyset} = \sqrt[2]{3}\, I_{3-\emptyset}$

i.e. the current in the single phase system is equal to $\sqrt[2]{3}$ times the current of the system

Voltage drop in 3 phase system

$$V_{d\,3-\emptyset} = I_{3\emptyset}(R\cos\emptyset + X\sin\emptyset)$$

Voltage drop in 1 phase system

$$V_{d\,1-\emptyset} = 2I_{1\emptyset}(R\cos\emptyset + X\sin\emptyset)$$

$$\frac{V_{d\,1-\emptyset}}{V_{d\,3-\emptyset}} = \frac{2I_{1\emptyset}}{I_{3\emptyset}} = 2\frac{\sqrt{3}\,I_{3\emptyset}}{I_{3\emptyset}} = 2\sqrt{3}$$

i.e. voltage drop in single phase 2 wire system ungrounded system is equal to $2\sqrt{3}$ times voltage drop of 3 phase system

the power loss in the single phase system is

$$P_{LOSS\,1-\emptyset} = 2\,I_{1-\emptyset}^2 R$$

The power loss in the 3 phase system is

$$P_{LOSS\,3-\emptyset} = 3I_{3-\emptyset}^2 R$$

$$\frac{P_{LOSS\,1-\emptyset}}{P_{LOSS\,3-\emptyset}} = 2\frac{I_{1-\emptyset}^2 R}{3I_{3-\emptyset}^2 R} = \frac{2}{3}\frac{\left(\sqrt{3}\,I_{3\emptyset}\right)^2}{I_{3\emptyset}^2 R} = 2$$

i.e. the power loss due to the load current in the conductors of the single phase system is equal to 2 times the power loss in one of the conductors of 3phase system.

Single phase, 2 wire with unigrounded system:

A system having grounding at only one location is called unigrounded system. There is no earth current flowing through in this system, therefore presently it is not generally used. It can be compared with 3 phase 4 wire balanced system maintaining the load constant.

Since the power input to 3 phase system is same as that of the single phase unigrounded system.

$$S_{3-\emptyset} = S_{1-\emptyset}$$

$$3V_S I_{3\emptyset} = V_S I_{1\emptyset}$$

$$I_{1\emptyset} = 3I_{3\emptyset}$$

i.e. the current in the single phase unigrounded system is equal to the 3 times the current of 3 phase system.

Voltage drop in 3 phase system

$$V_{d\,3\emptyset} = I_{3\emptyset}(R\cos\emptyset + X\sin\emptyset)$$

Voltage drop in single phase

$$V_{d\,1\emptyset} = 2I_{1\emptyset}(R\cos\emptyset + X\sin\emptyset)$$

$$\frac{V_{d\,1\emptyset}}{V_{d\,3\emptyset}} = \frac{2I_{1\emptyset}}{I_{3\emptyset}} = 2 * 3 * \frac{I_{3\emptyset}}{I_{3\emptyset}} = 6$$

i.e. the voltage drop in single phase , 2 wire unigrounded system is equal to 6 times voltage drop of 3 phase 4 wire system.

Similarly the ratio of power loss due to the load current in the conductors of single phase unigrounded system with full capacity neutral and to the 3 phase 4 wire balanced system is given by

$$\frac{P_{LOSS\,1-\emptyset}}{P_{LOSS\,3-\emptyset}} = \frac{2I_{1\emptyset}^2}{3I_{3\emptyset}^2} = 6$$

i.e. the power loss due to the load current in the conductor of the single phase 2 wire unigrounded system is equal to 6 times the power loss in t conductor of 3 phase 4 wire system.

Single phase , 2 wire system with multigrounded common neutral:

Single pahse , 2 wire multi grounded common neutral system as shown in the figure. In this case the neutral is connected in parallel with ground at various places through ground electrodes in order to reduce the current in neutral conductor.

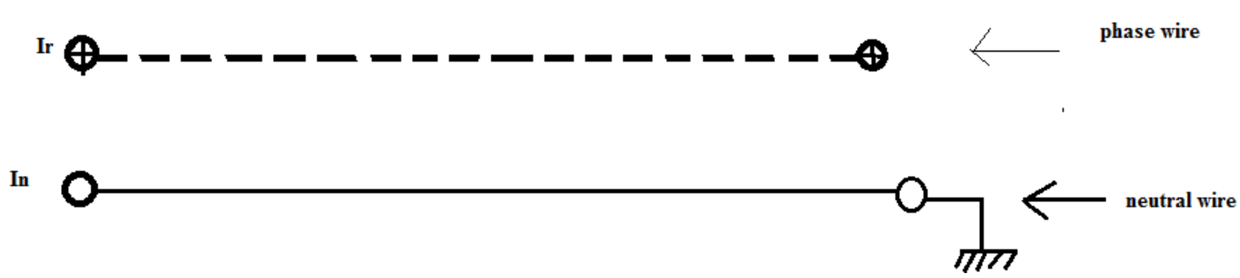


Fig . single phase 2 wire lateral with multiple grounded neutral

Let current in the phase conductor in I_r and return current in the neutral conductor is I_N .

The return current in neutral conductor $=K_1 I_r$

Where K_1 varies from 0.25 to 0.33 and it is almost independent of size of the neutral conductor.

The voltage drop and power loss in per unit are

$V_{d\,1\emptyset} = K_2\, V_{d\,3\emptyset}$, where K_2 varies from 3.8 to 4.2

(Or) $V_{d\,1\emptyset} = 4\,V_{d\,3\emptyset}$ (Approximately)

And $P_{LOSS\,1\emptyset} = K_3\,P_{LOSS\,3\emptyset}$ where K_3 varies from 3.5 to 3.75

$$P_{LOSS\,1\emptyset} = 3.625\,P_{LOSS\,3\emptyset}$$

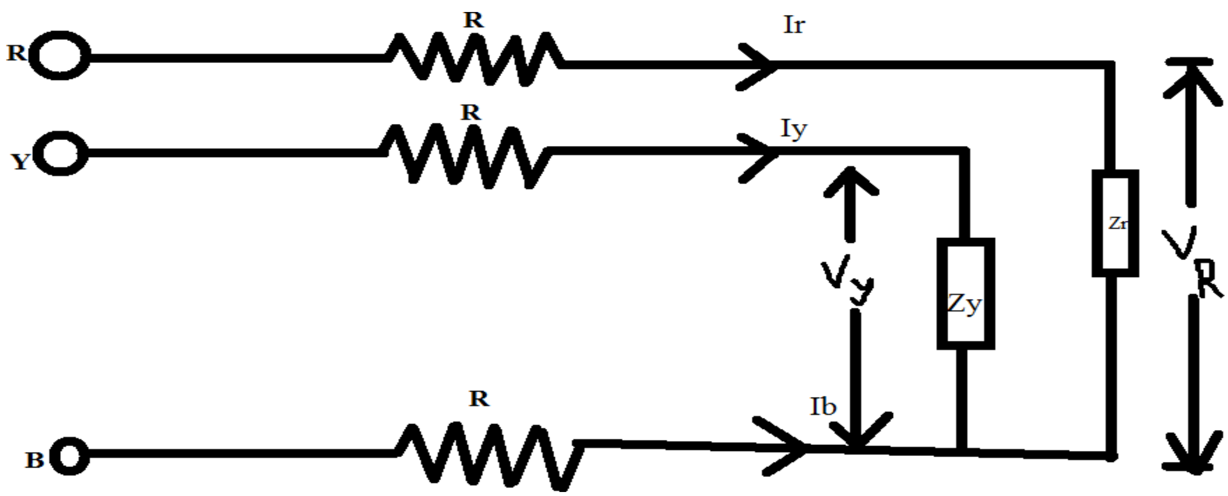
TWO PHASE PLUS NEUTRAL SYSTEM:

Two phase with neutral system in shown in figure. The neutral conductor can be unigrounded or multigrounded. if the neutral is unigrounded all neutral current is in neutral conductor itself.

Therefore it can be expressed as
$V = IZ$

From phase R and Y $V_R = I_R Z_R \; and \; V_y = I_y Z_y$

The above equation is for balanced loads



Let assume equal load division takes place among the phase.

Since the power input to the 3 phase system is same as two phase with neutral system.

$S_{3\emptyset} = S_{2\emptyset}$

$3V_S I_{3\emptyset} = 2V_S I_{2\emptyset}$

$I_{2\emptyset} = \frac{3}{2} I_{3\emptyset}$

i.e. the current in the 2 phase with neutral system is equal to 1.5 times the current of 3 phase system.

The voltage drop analysis can be performed depending upon whether the neutral is unigrounding or multigrounding.

If the neutral is unigrounded and neutral impedance is equal to zero.

$V_{d\,2\emptyset} = I_{2\emptyset}(Rcos\emptyset + Xsin\emptyset)$

$V_{d\,3\emptyset} = I_{3\emptyset}(Rcos\emptyset + Xsin\emptyset)$

$$\frac{V_{d\ 2\emptyset}}{V_{d\ 3\emptyset}} = \frac{3}{2}$$

If the neutral is multigrounded and neutral impedance is greater than zero.

$$V_{d\ 2\emptyset} = 2V_{d\ 3\emptyset}$$

The power loss analysis also depends upon whether the neutral is unigrounded or multigrounded

If the neutral is unigrounded

$$\frac{P_{loss\ 2\emptyset}}{P_{loss\ 3\emptyset}} = \frac{3I_{2\emptyset}^2 R}{3I_{3\emptyset}^2 R} = \frac{9}{4} = 2.25$$

On the other hand , if the neutral is multigrounded

$$\frac{P_{loss\ 2\emptyset}}{P_{loss\ 3\emptyset}} < 2.25$$

Unit – IV

PROTECTION AND CO-ORDINATION

INTRODUCTION

The capital investment involved in a power system for the generation, transmission and distribution of electrical power is so great precautions must be ensured that the equipment not only operates as nearly as possible to peak efficiencies, but also that it is protected the correct relay so as to disconnect only the faulty equipment from the system as quickly possible, thus minimizing the troubles and damage caused by faults when they do occur

The modern power system is complex and even through protection equipment from 4 to 5% of the total cost involved in the system, they play a very important role in the system design for good quality and reliability

OBJECTIVES OF DISTRIBUTION SYSTEM PROTECTION

The primary objectives of distribution system protection are mainly:

- Minimize the fault duration
- Minimize the number of consumers affected by the fault

The secondary objectives of distribution system protection are to:

- Eliminate safety hazards as fast as possible
- Minimize service failure to the smallest possible branch of the distribution system
- Protect the consumers apparatus
- Protect the distribution system from unnecessary service interruptions and disturbances
- Disconnect faulted branches, transformers or other components

TYPES OF FAULTS

Overhead systems are subjected to broadly two types of faults and these are temporary or transient and permanent faults

Depending on the nature of the system involved, most of the faults are transient in nature. These faults occur when phase conductors of the system electrically contact other phase conductors or to the ground, momentarily due to tress, birds or other animals, high winds, lightning flashovers etc.The duration of fault is to be minimized using instantaneous or high speed tripping. Automatic reclosing of a relay prevents unnecessary fuse breaking

Permanent faults are those which requires repair by a repair crew in term of:

- Replacing burden down conductors, blown fuses or any other damaged apparatus
- Removing tree limbs from the lines
- Manually reclosing a circuit breaker or recloser to restore service

The number of consumers affected by a fault is to be maintained by properly selecting and locating the protective apparatus on the line, at the tap point of each line section and at critical location on main feeder. By using the fuses the permanent faults on overhead systems are generally sectionalized. The number of faults occurring on an under grounded system is relatively much less than the overhead distribution system

Generally there are again subdivided to four possible fault types which occur in distribution systems:

1. Single line-to-ground fault(SLG)

2. Line-to-line fault (L-L)

3. Double line –to-ground fault (DLG)

4. Three –phase fault (3L OR3LG)

FAULT-CURRENT CALCULATIONS

The possible fault types that might occur in a distribution system are mentioned above four types.

The first, second and third type of faults on two phase or three phase feeders, and the fourth type of fault can take place only on three-phase feeder. However, even on these feeders usually only single line –to- ground fault will take place due to the multigrounded construction. The relative numbers of the occurrence of different type of faults depend upon various factors, feeder configuration, height of ground wires, voltage levels, grounding methods, relative insulation level of ground and between phases, speed of fault clearing atmospheric conditions etc.

The actual fault current is usually less than the bolted three-phase value. However the single line-to –ground fault often produces a greater fault current than that of the 3-f fault especially when the generator neutral is solidly grounded because $X_0 << X_1 (=X_2)$ in generator or low impedance neutral with star-grounded side of delta star grounded transformer. If the fault occurs on the line three phase fault is more severe than SLG fault because for lines $X_0 >> X_1 (=X_2)$ In general usually the SLG fault is the most severe with the 3-ϕ DLG and L-L following in that order

In general the maximum and minimum fault currents are both calculated for a given distribution system. The maximum fault current is determined based on the following assumptions:

- Maximum generators are connected
- The fault is a dead short-circuit one
- The load is maximum peak

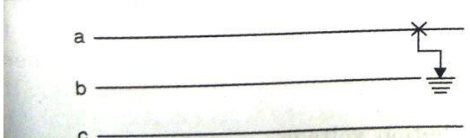
While minimum fault current is determined based on the following

- Minimum number of generators is connected
- The fault is not dead short-circuit one, but fault impedance is not zero
- The load is minimum peak

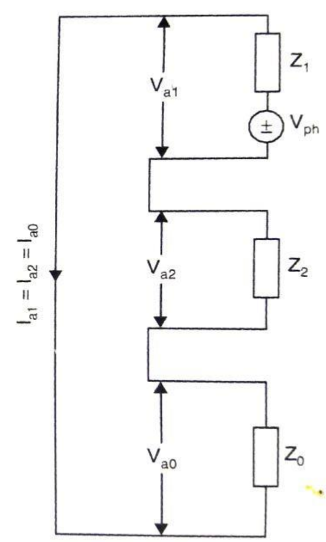
Usually these fault-currents are determined for each sectionalizing point, including the substation, and for the ends of the longest sections. The calculated maximum fault-current values are used in determining the required interrupting capacities of the fuses, circuit breakers or other fault-clearing apparatus

To determine the fault currents one has to determine the positive, negative and zero sequence impedances of the system at the high-voltage side of the distribution substation transformer. These impedances are usually readily available from transmission system fault studies. Therefore for any given fault on a radial distribution feeder, one can simply add to the appropriate impedances as the fault is moved away from the substation along the feeder.

SINGLE LINE TO GROUND FAULT (LGF)



(a) LGF on phase 'a'



(b) Equivalent circuit for LGF

FIG SINGLE LINE TO GROUND FAULT

Figure shows a single line to ground fault occurs at phase ‘a’ .the fault current flows through phase ‘a’ and the remaining currents are zero. The voltage and current relations are:

$$V_a=0$$

$$I_b=I_c=0$$

$$I_a=I_f$$

Consider Z_1,Z_2 and Z_0 are the positive, negative and zero sequence impedances of the system and V_{ph} is the line to neutral voltage distribution voltage

Fault current, $$I_a=I_f=\frac{V_{ph}}{Z_G}$$

$$Z_G=\text{impedance to ground}=\frac{Z_1+Z_2+Z_0}{3}$$

$$Z_G=\frac{2Z_1+Z_0}{3}$$

(Since $Z_1=Z_2$ for transformers and distribution lines)

In case of source, transformer and distribution circuit impedance are considered

Z_1=Total positive sequence impedance=$Z_{1s}+Z_{1tr}+Z_{1ckt}$

Z_{1s}=Dource impedance

Z_{1tr}=Transformer impedance

Z_{1ckt} –Distribution circuit impedance

$$I_f=\frac{1}{3}\left(\frac{V_{ph}}{2Z_1+Z_0}\right)=\left(\frac{3V_{ph}}{2Z_1+Z_0}\right)$$

However, if a fault occurs through some fault impedance Z_f

Fault current,

$$I_f=\left(\frac{3V_{ph}}{2Z_1+Z_0+Z_f}\right)$$

If the source connected in star grounded equation 6.1 and 6.2 are valid. In case of source connected in delts,zero sequence impedance Z_0 becomes infinite

,these equations are not valid. This is obvious because of there is no return path for the current flow.

If the primary distribution network in delta and the lines are connected by delta/star with solid grounded neutral point of substation transformer, the transformer primary side current can be determined by

$$I_{Fll} = \frac{V_{LL}}{\sqrt{3}V_{STLL}} I_f$$

Where V_{LL}=line to line distribution voltage

V_{STLL}=line to line sub-transmission voltage

I_f=line to ground fault current

From equation it is clear that the sequence networks i.e.., positive and negative and zero sequence networks must be connected in series. The interconnection of sequences network is shown in fig

Therefore,

$$I_f = I_a = 3I_{a1} = 3I_{a2} = 3I_{a0}$$

Or

$$I_{a1} = I_{a2} = I_{a0} = \frac{I_f}{3} = \frac{V_{ph}}{2Z_1 + Z_0 + Z_f}$$

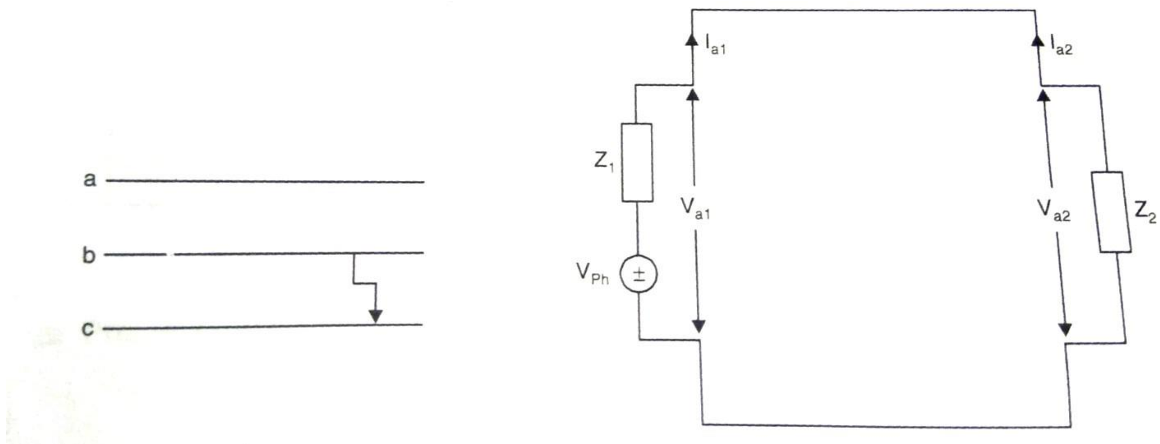
The voltages of other healthy phases are determined by

$$V_b = V_{ph}\left(\frac{(\alpha^2 - \alpha)Z_1 + (\alpha^2 - \alpha)Z_0}{2Z_1 + Z_0 + Z_f}\right)$$

$$V_c = V_{ph}\left(\frac{(\alpha^2 - \alpha)Z_1 + (\alpha - 1)Z_0}{2Z_1 + Z_0 + Z_f}\right)$$

Where α = operator $= 1.0\angle 120^0$

LINE TO LINE FAULT (LLF)



(A) LLF BETWEEN PHASES ‘b’ AND ‘c’ (B) EQUIVALENT CIRCUIT FOR LLP

FIG LINE TO LINE FAULT

Figure (a) shows a line to line fault or double line fault occurs in between phases ‘b’ and ‘c’ .the voltage and current relations are:

$I_a=0$

$I_b+I_c=0$ of $I_b=-I_c$

$V_b=V_c$

The fault current $I_f=I_b=-I_c=\dfrac{-j\sqrt{3}V_{ph}}{(Z_1+Z_2)}$

or $I_f=\dfrac{-j\sqrt{3}V_{ph}}{2Z_1}$

however ,if a fault occurs through some fault impedance Z_f

Fault current , $I_f=\dfrac{-j\sqrt{3}V_{ph}}{2Z_1+Z_f}=\dfrac{-j\sqrt{3}V_{ph}}{2(Z_{1s}+Z_{1tr}+Z_{1ckt})+Z_f}$

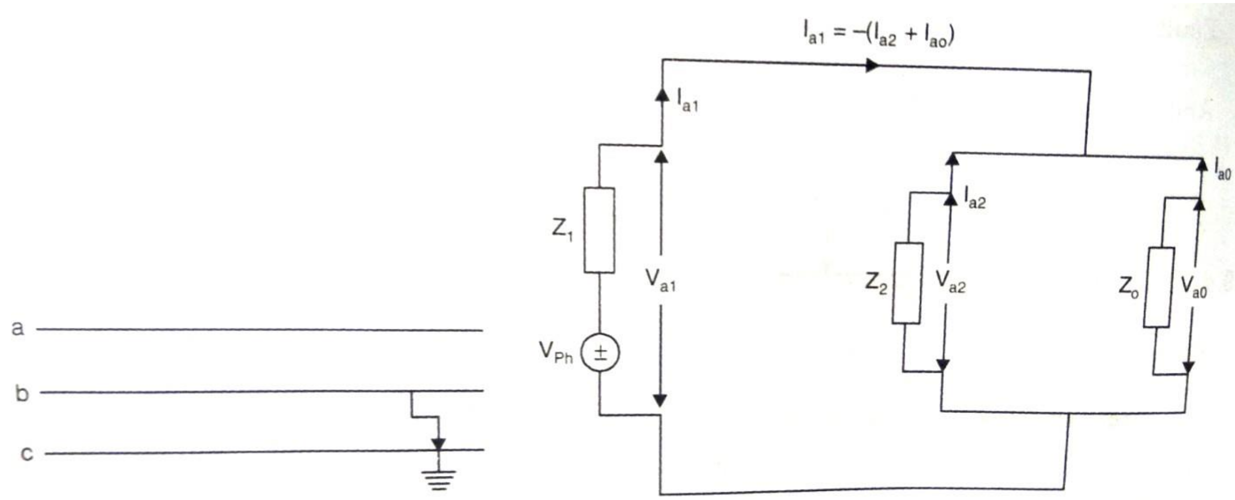
The sequence currents are determined by

Or $I_{a2}=-I_{a2}=\dfrac{V_{ph}}{2Z_1}$ (since I_{a0} is zero)

From equation it is clear that the sequence networks i.e.., positive and negative sequence networks must be connected in parallel and opposite. The interconnection of sequence networks is shown in fig 6.7(b)

Zero sequence current will be absent in this case. This is in consistence with the fact that no ground current can flow. The presence or absence of a grounded source neutral does not affect the fault current. If the source neutral is not grounded, Z_0 is infinite and V_{a0} is in terminate ,but line to line voltage may be found since they contain no zero sequence component.

DOUBLE LINE TO GROUND FAULT (DLGF)



(A) DLGF IN BETWEEN PHASE ‘b’ AND ‘c’ (B) EQUIVALENT CIRCUIT FOR DLGF

FIG DOUBLE LINE TO LINE FAULT

Figures 6.8(a) shows a double line to ground fault in between phases ‘b’ and ‘c’ the voltage and current relations are:

$$I_a=0$$

$$I_b+I_c=I_f$$

$$V_b+V_c=0$$

The symmetrical components of voltage are:

$$V_{a1}=V_{a2}=V_{a0}=\frac{V_a}{3}$$

And fault current $I_f=I_b+I_c=3I_{a0}$

From the above realtions,the equivalent circuit for double line to ground fault is shown in fig (B) the negative and zero sequence networks are connected in parallel and this combination is connected in series with the positive sequence network

The sequence currents can be calculated by

$$I_{a1} = \frac{V_{ph}}{Z_1 + \frac{Z_0 Z_2}{Z_0 + Z_2}}$$

$$I_{a2} = V_{ph}\left(\frac{Z_0}{Z_1 Z_2 + Z_2 Z_0 + Z_0 Z_1}\right)$$

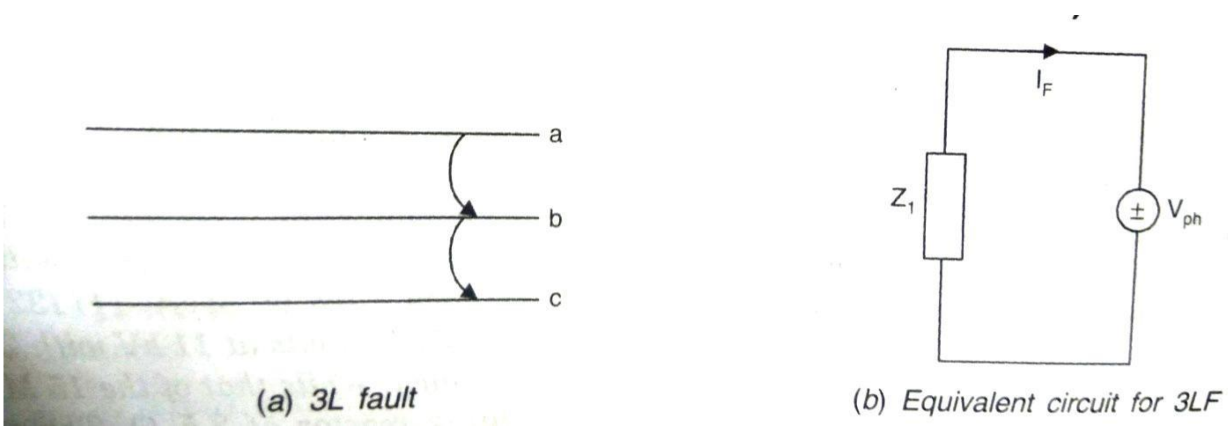
$$I_{a0} = V_{ph}\left(\frac{Z_2}{Z_1 Z_2 + Z_2 Z_0 + Z_0 Z_1}\right)$$

Fault current, $I_f = I_b + I_c = 3V_{ph}\left(\frac{Z_2}{Z_1 Z_2 + Z_2 Z_0 + Z_0 Z_1}\right)$

And voltage of phase 'a' is

$$V_a = V_{ph}\left(\frac{3Z_2 Z_0}{Z_1 Z_2 + Z_2 Z_0 + Z_0 Z_1}\right)$$

THREE PHASE GROUNDED/UNGROUNDED FAULT (3LF OR 3LGF)



(A) 3L FAULT (B) THREE PHASE FAULT

FIG THREE PHASE FAULT

Figure 6.8 (A) shows a three phase or three phase to ground fault. In this case all the phases are short-circuited .the voltage and current relations are:

$V_a = V_b = V_c = 0$

$I_a + I_b + I_c = 0$

Fault current, $I_f = I_a = I_b = I_c = \frac{V_{ph}}{Z_1}$

However,if there is a fault through some fault impedance ,Z_f

Fault current $I_f = \frac{V_{ph}}{Z_1 + Z_f}$

Equivalent for this type of fault is shown in fig 6.8(a)

OVER CURRENT PROTECTIVE DEVICES

The over current protective devices applied to distribution systems include relay controlled circuit breakers, automatic circuit reclosers, fuses and automatic line sectionalizes etc.

FUSE

It is an over current device with a circuit opening ability when directly heated and gets destroyed by the flowing over current through it in the event of an overload or short-circuit conditions. Therefore, the purpose of fuse is to isolate the failure line or segment from the system

The fuse element is generally made of material having low melting point, high conductivity and least deterioration due to oxidation e.g.., silver, copper etc. I t is inserted in series with the circuit to be protected. Under normal operating conditions, the fuse element is at a temperature below its melting point. Therefore, it carries the normal current without overheating. However, when a short-circuit or overload occurs, the current flowing through the fuse will increase beyond its rated value. This raises the temperature and fuse element melts, disconnecting the circuit protected by it. The time required to blow out the fuse depends upon the magnitude of excessive current. The greater the current, the smaller is the time taken by the fuse to blow out.

ADVANTAGES

The advantages of the fuse are:

(i) Cheapest form of protection available
(ii)Requires no maintenance
(iii) Break heavy short-circuit current without noise or smoke
(iv) The minimum time of operation can be made much shorter than that of the circuit breaker

DISADVANTAGES

The disadvantages of the fuse are:

(i) Considerable time is required in removing or replacing a fuse after operation The current time characteristics of a fuse cannot always be correlated with that of the protected apparatus.

AUTOMATIC CIRCUIT RECLOSER

It is an over current protective device that automatically trips and reclosed a number of times to clear temporary faults or isolate permanent faults. About 90% of faults on overhead distribution lines are of temporary nature and caused by lightning or by-passing of objects near or through lines(birds, vines, tree branches etc) or touching of conductors. These conditions result in arcing faults and the arc in the air faults can be extinguished by de-energizing the system by simultaneous opening of circuit breakers on both ends of the feeder or one end of the feeder. After a short time called dead time, the circuit breakers can be reclosed as soon as the arc in fault has been extinguished and the path has regained its dielectric strength. Reclosing of feeders stores the supply.

In distribution systems, multishot auto-reclosing feature is generally provided. The auto-reclosers controlling primary feeder performs two. three or four reclosing cycles(shot) if necessary

If the temporary fault has vanished during the dead time, the auto-recloser remains closed. I f fault persists after first/second recloser one more enclosing is attempted. If fault persists after third/final recloser, the auto-recloser is opened and locked. With auto-reclosing breakers in primary feeders the circuit continuity during temporary faults is improved. Auto –reclosing is generally not adopted for underground cables. The faults on cables are generally not temporary

ADVANTAGES

(i) It can be perform the tasks that can be fulfilled by the combination of circuit breaker, over current relay and reclosing relay

(ii) It is light in weight and maintenance free

(iii) When a permanent fault occurs near the end of the lengthy feeder, then this feeder can be sectionalized using auto-recloser so as to reduce the outages

DISADVANTAGES

(i) it cannot clear the permanent faults completely

(ii) it is costlier than the circuit breaker

(iv) It is not suitable for cables as the breakdown of insulation in cables causes a permanent outage.

AUTOMATIC LINE SECTIONALIZER

It is the over current protective devices installed only with backup circuit breakers or auto-reclosing circuit breaker. It is a no-load switching device which is provided with over current relays, earth fault relays and counters. The counter counts the number of operations of the back-up circuit breaker/auto-recloser. A fter a predetermined number of back up circuit breaker/auto-recloser, if the circuit breaker/auto-recloser open has not cleared the line f ault,the circuit breaker/auto-recloser opens and thereafter the automatic sectionalizer opens under no current condition

The operating modes of automatic sectionalizers are as follows:

1. If the fault on distribution line is temporary and is cleared while the auto-recloser is open, the connector of sectionalizer is reset automatically to its normal position after auto-recloser is closed, the fault current counter in the sectionalizer will prepare for counting of next opening of the auto-recloser
2. If the auto-recloser is set to lockout on the fourth opening operation, the automation sectionalizer will be set to trip during the open circuit time following the third tripping operation of the auto-recloser

Application aspects of automation sectionalizer

Several aspects must be considered to finalize the scheme:

(i) It must be used in series with auto-reclosers
(ii) It must not be located between two auto-reclosers
(iii) With two or three sectionalizers after one auto-recloser,the sequence must be co-ordinate
(iv) The minimum fault current has to be more than minimum fault current at the end of line section controlled by the sectionalizer
(v) Under no circumstances the short time circuit current and momentary peak current at the location of sectionalizer should be less than respective ratings of the sectionalizer

ADVANTAGES

(i) Automation sectionalizer are cheaper and required less maintenance than auto-reclosers

(ii) They may be employed for interrupting or switching loads within their rating

The main drawback is that the failure rate is in general greater than that of fuse

CIRCUIT BREAKER

Circuit breaker is a switch that opens and cuts-off flow of current when the current exceeds a certain level. Circuit breakers are placed at critical points in circuits to protect against damage that could result from excessive current flow, which is typically caused by component failure

High voltage circuit breakers are intended for making high voltage circuits and for breaking load currents and short-circuit currents. The circuit breakers must have adequate MVA breaking capacity ,the shortest possible total break time and be highly reliable in service and operation. high voltage circuit breakers must be explosion proof and fire proof, and weight as their duty will permit.

In brief, the function of C.B is to isolate the faulty part of the power systems network from that of healthy part under abnormal conditions. These abnormal conditions will be sensed a trip signal to the C.B after receiving a trip signal from the relay, the fault part will be isolated from the power system.

A circuit breaker can be operated by manually by a remote control or automatically .The automatic operating phenomena can be observed only under fault conditions.

HOW A CIRCUIT BREAKER WORKS? BASIC PRINCIPLE OF OPERATION

A circuit breaker consists of fixed and moving contacts which are touching each other user normal conditions i.e.., when circuit breaker is closed. The end of the moving contact attached to a handle which can be manually operated or it can be operated automatically with the help of a mechanism which has a trip coil energized by the secondary of the current transformer. The power supply is brought to the terminals of the circuit breaker. Under normal conditions the e.m.f induced in the secondary winding of the circuit transformer is not sufficient to energize the trip coil fully for operation. But under fault condition the abnormality in the value of the current in the primary circuit of the current transformer induces a sufficient e.m.f in the secondary circuit to energize the trip coil. When the trip coil get energized the moving contacts are pulled by some mechanism and there by the circuit is broken

The basic construction of a circuit breaker requires the separation of contacts in an insulating fluid which serves two functions

They are (i) extinguishing the arc between the contacts on the opening of circuit breaker.(ii) providing insulation or fluids between the contacts and from each contact to earth

The medium or fluids commonly used for the purpose of arc extinction in circuit breaker are:

(i)Air at atmospheric pressure

(ii)Compressed air

(i) Oil producing hydrogen for arc extinction
(ii)Ultra high vacuum
(iii) Sulphur hexa fluoride(SF_6)

The fluids that can be used in a circuit breaker should have the following properties:

(i) High dielectric strength

(ii) Non inflammability

(iii)High thermal stability

(iv)Chemical stability

(v)Arc extinguishing ability

(vi) Commercial availability at moderate constant

AUTOMATIC CIRCUIT BREAKER

It is an automatic interrupting device, which is capable of breaking and enclosing a circuit under all conditions, i.e., faulted, or normal operating conditions

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 faulted. Of course, the contacts can be opened manually or by remote control whenever desired, when a fault occurs on any part of the distribution system, the trip coils of the circuit breakers get energized 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 of the system or to the circuit breaker itself. Therefore, the primary task of a circuit breaker is to extinguish the arc that develops due to separation of its contacts in an arc-extinguishing medium, for example, in air as is the case for sir circuit breakers, in oil, as is the case for oil circuit breakers, in SF_6 or in vacuum.

NECESSITY OF CO-ORDINATION

Time-current characteristics of over current protective devices in distribution system are selected and set such that the protective devices operate in desired pre-set time sequence the event of fault. This is called protection co-ordination. When two protective apparatus installed in series have same/different characteristics, which provide a pre-set initially to isolate the fault is defined as the protective device. It is usually the apparatus, which will be nearer to the fault. The apparatus, which furnishes back up protection but operates only when the protecting device fails to operate to clear the fault, is defined as the protected device. It is usually the apparatus, which will be faraway to the fault.

OBJECTIVES OF CO-ORDINATION

The main objectives of properly co-ordinate protective devices are:

- Minimize the extent of faults in order to reduce the number of customers affected
- Minimize the service interruptions due to temporary faults
- Minimize the duration of service outages to identify the location of the fault

PROCEDURE OF CO-ORDINATION

Salient points of co-ordination procedure

(i) Draw the diagram of the distribution system indicating location of over current relays, fuses, auto-reclosers etc.

(ii) Determine the following
  - Steady state short-circuit current
  - Asymmetrical peak short-circuit current
  - Normal load current
  - Minimum short-circuit current at above locations

(iii) Co-ordinate protective devices starting from substation outward or from the end of the distribution feeder back to the substation

(iv) Draw time current characteristics for the co-ordination

The above information is not readily available and therefore, it can be gathered from the different sources. Generally, time current characteristics(TCC) curves of the protective devices are platted by collecting the data from the manufacturer. The values of load current and fault current are obtained from power flow study and fault flow study

General co-ordination procedure:

The over current protective devices i.e.., fuse, CB, recloser and line sectionalizer must be co-ordinate for identifying and isolating the faults. According to a specific operating sequence, the two over current devices are said to be co-ordinate or selected. For all types of co-ordination the co-ordination procedure is same and as follows:

1. Necessary and required data for co-ordination of protective devices should be collected

2. For a given distribution network, select the initial location of protective device

3. Calculate the minimum and maximum value of fault current for various types of faults at ever selected location and at the end of main feeder or lateral or sub-laterals

4. Choose the necessary protective devices located at the distribution substation in order to protect the substation transformer properly from any type of faults occurs in the distribution system

5. The over current protective devices should be co-ordinate either from substation onwards or end of the distribution system back to the substation

6. If necessary, reconsider and change the initial location of the protective device

7. Reconsider the selected protective device for current carrying capacity, interrupting capacity and minimum pickup time

8. Draw the TCC curves showing the co-ordination of all protective devices used with common base voltage

9. Finally ,draw the distribution network diagram which shows the minimum and maximum value of fault current and also the rating of the various protection devices used.

TYPES OF CO-ORDINATION

The different types of co-ordination methods are:

1. Fuse to fuse co-ordination
2. Auto –recloser to fuse co-ordination
3. Circuit breaker to fuse co-ordination
4. Circuit breaker to auto-recloser co-ordination

FUSE TO FUSE CO-ORDINATION

Fuse 'A' is called the protective fuse and fuse 'B' is called the protecting fuse are drawn single graph as shown in fig for perfect co-ordination, fuse 'B' must melt and clear the fault before fuse 'A' is damaged .To ensure this, three things are required

(i) the maximum characteristics of the fuse B is platted

(ii)The minimum characteristics of the fuse A is plotted

(iii)75% of the minimum melting curve of A is plotted to make sure that the fuse is not damaged and to account for any degradation in the fuse characteristics

If the damage curve of fuse A and the time clearance curve of fuse B never cross, then it is said to be perfect protection. If they cross, at some value of current, then it is called the limit of co-ordination. For example, suppose the curves cross at 200A .This means that co-ordination more than 200A is unlikely.However,if the maximum available short circuit current of the system at that location is only 150A the fuse would be considered to be fault co-ordinate.

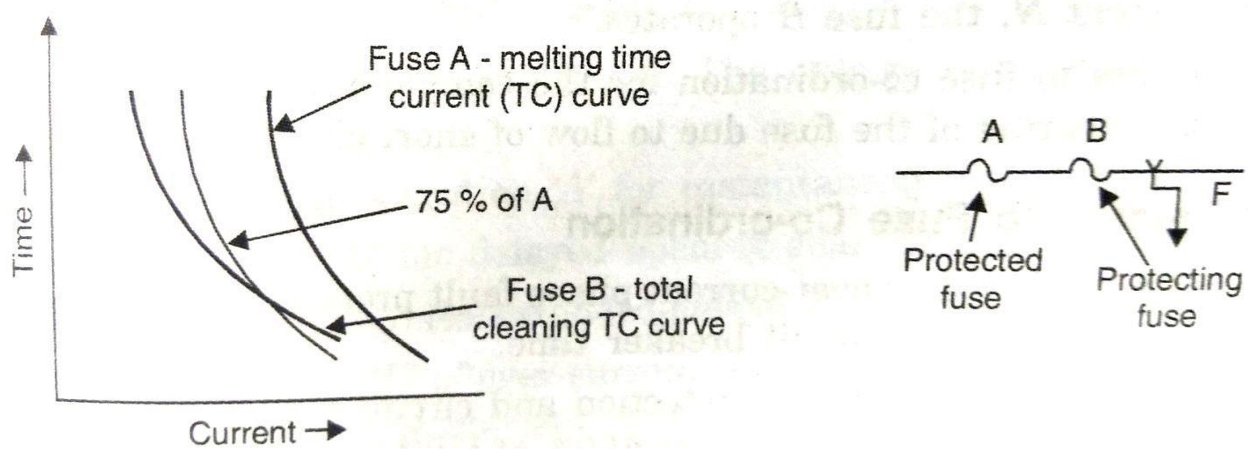


Fig CO-ORDINATION BETWEEN TWO FUSES IN SERIES

AUTO-RECLOSER TO FUSE CO-ORDINATION

The time-current characteristics of auto-recloser (AR) in the main feeder circuit and fuse B in the lateral is as shown in fig

If the fault 'F' beyond the fuse B is temporary, the auto-recloser 'AR' should clear it without blowing of fuse b

The time-current characteristics of the fuse B are in two parts:

1. Minimum melting time versus fuse B current

2. First operating time versus fuse B current

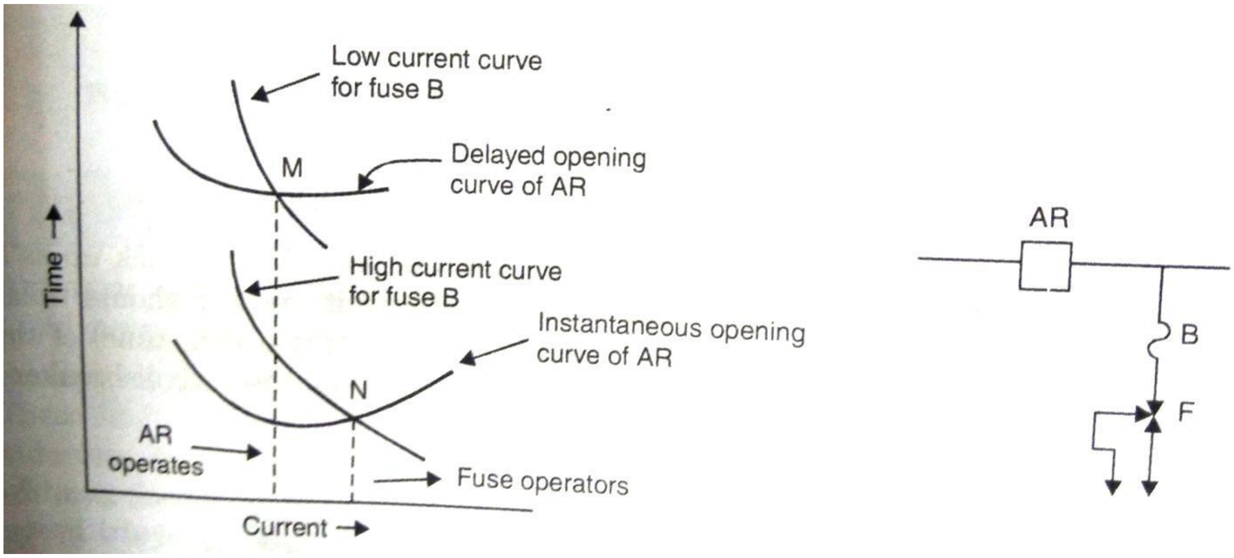


FIG AUTO-RECLOSER AND FUSE CO-ORDINATION

The above two curves of fuse B is co-ordinate with below two curves of tripping characteristics of ‘AR’

1. Delayed auto-recloser opening characteristics

2. Instantaneous auto-recloser opening characteristics

- If fault current is less than ‘M’ the closer operates with delayed opening time
- If fault current is less than ‘N’ the auto –recloser operates with instantaneous operating time.
- Beyond current N, the fuse B operates
- Auto-recloser to fuse co-ordination for the complete auto-reclosing cycle takes into account the heating of the fuse due to flow of short-circuit current time in the cycle

CIRCUIT BREAKER TO FUSE CO-ORDINATION

The circuit breaker is tripped by over-current phase fault protection. Total fault clearing time is equal to the relay time plus circuit breaker time.’

When fuse ‘A’ is used as a main protection and circuit breaker as a backup is shown in fig , the operating time is selected as 150% of total operating time of the fuse of over current relays for phase to phase fault. Therefore the fuse A operates first and the circuit breaker operates next only if fise fails to operate.

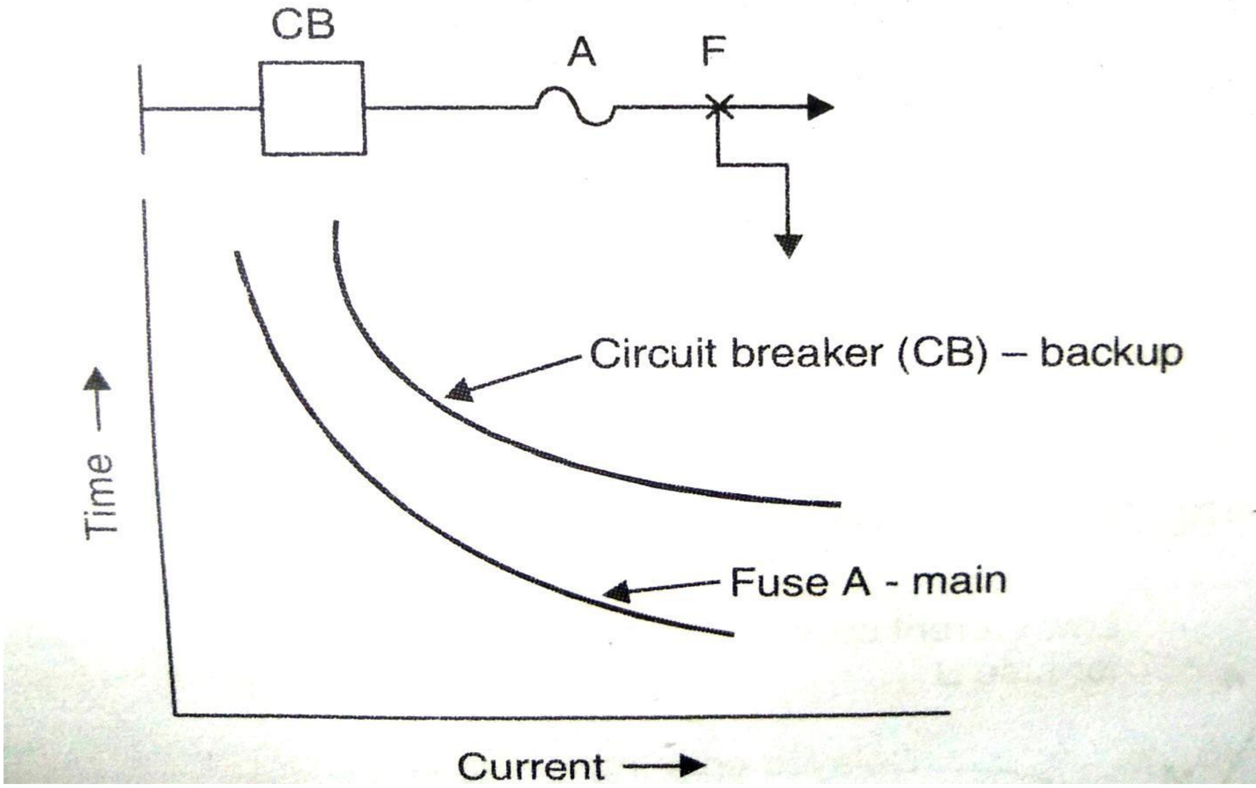


FIG FUSE GIVES MAIN PROTECTION AND CIRCUIT BREAKER GIVEN BACK UP

If circuit breaker provides the main protection and the fuse 'A' as a back up as shown in fig the relays should operate instantaneously and circuit breaker should isolate the fault before blowing up the fuse. The minimum melting time of the fuse should be about 135% more than fault 'clearing time' of the circuit – breaker relay combination for phase to phase faults.

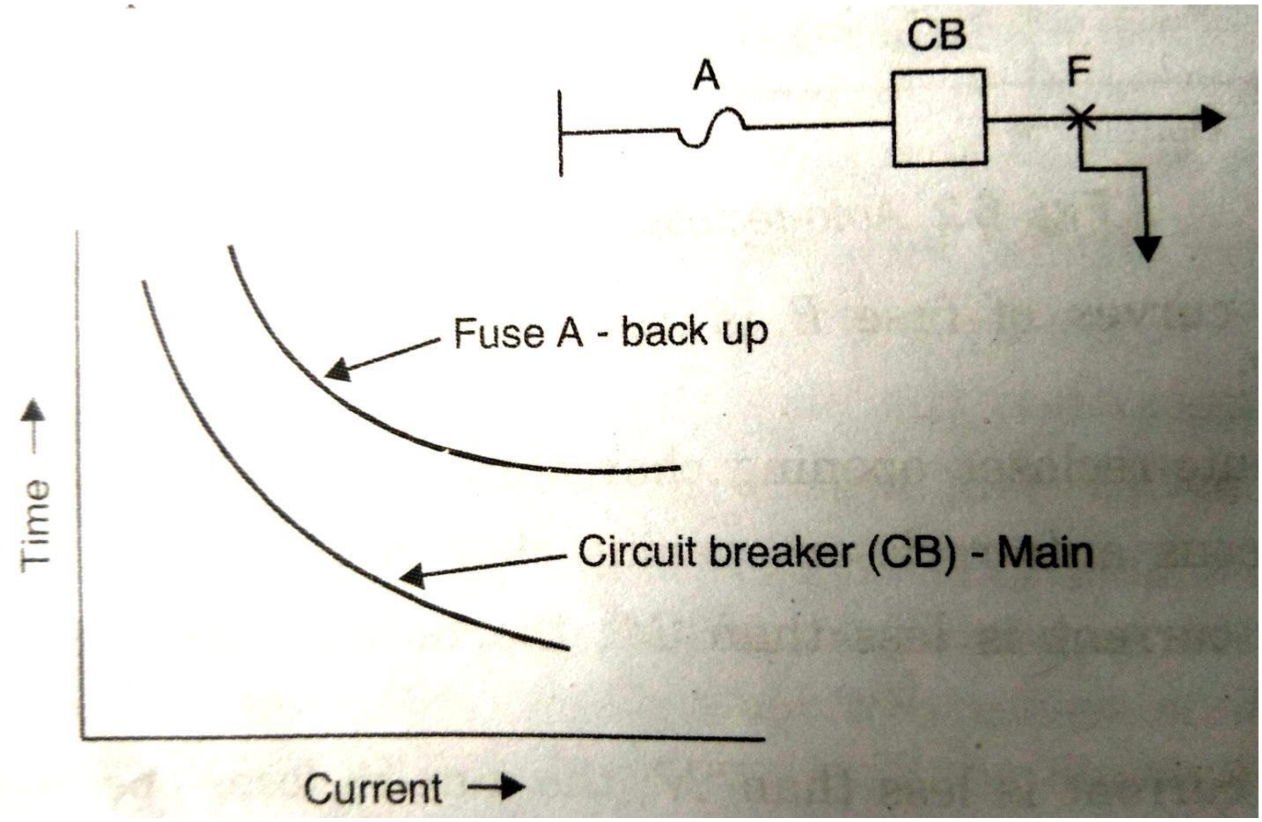


FIG CIRCUIT BREAKER GIVES MAIN PROTECTION AND FUSE GIVEN BACK UP

CIRCUIT BREAKER TO AUTO-RECLOSER CO-ORDINATION

The circuit breaker provides a back up protection. The auto-recloser has three principal opening characteristics

1. First and second opening operation 'A' for instantaneous opening characteristics

2. Third opening operation 'B' for delayed opening characteristics

3. Fourth opening operation 'C' for extended –delayed opening characteristics

The inverse time characteristics 'D' of over current relay and circuit breaker combination should be above that of the three characteristics of auto-rrecloser as shown in fig

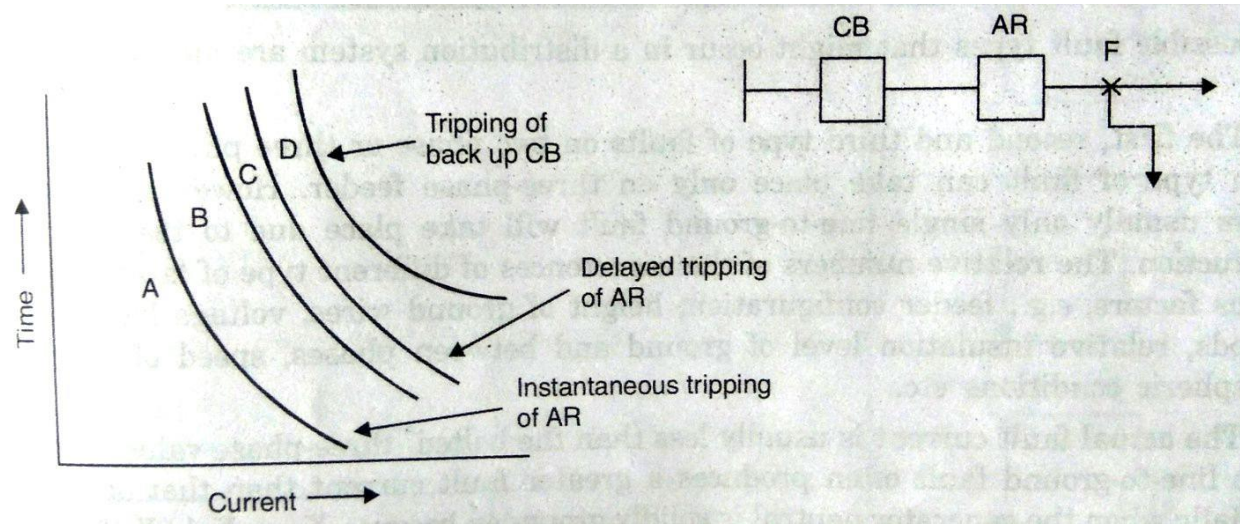


FIG CHARACTERISTICS OF CIRCUIT BREAKER TO AUTO-RECLOSER CO-ORDINATION

Unit – V

Compensation for Power Factor Improvement

5. CAPACITORS

In uncompensated distribution system the reactive power demand is usally met by the source, thus burden the system and results in poor voltage profile and increase in losses. if the reactive power demand can be met locally then the transmitting of reactive power from the source to the reactive elements can be reduced. Localized meeting of reactive power demand can be achieved by installing either switchable capacitors or fixed capacitors.

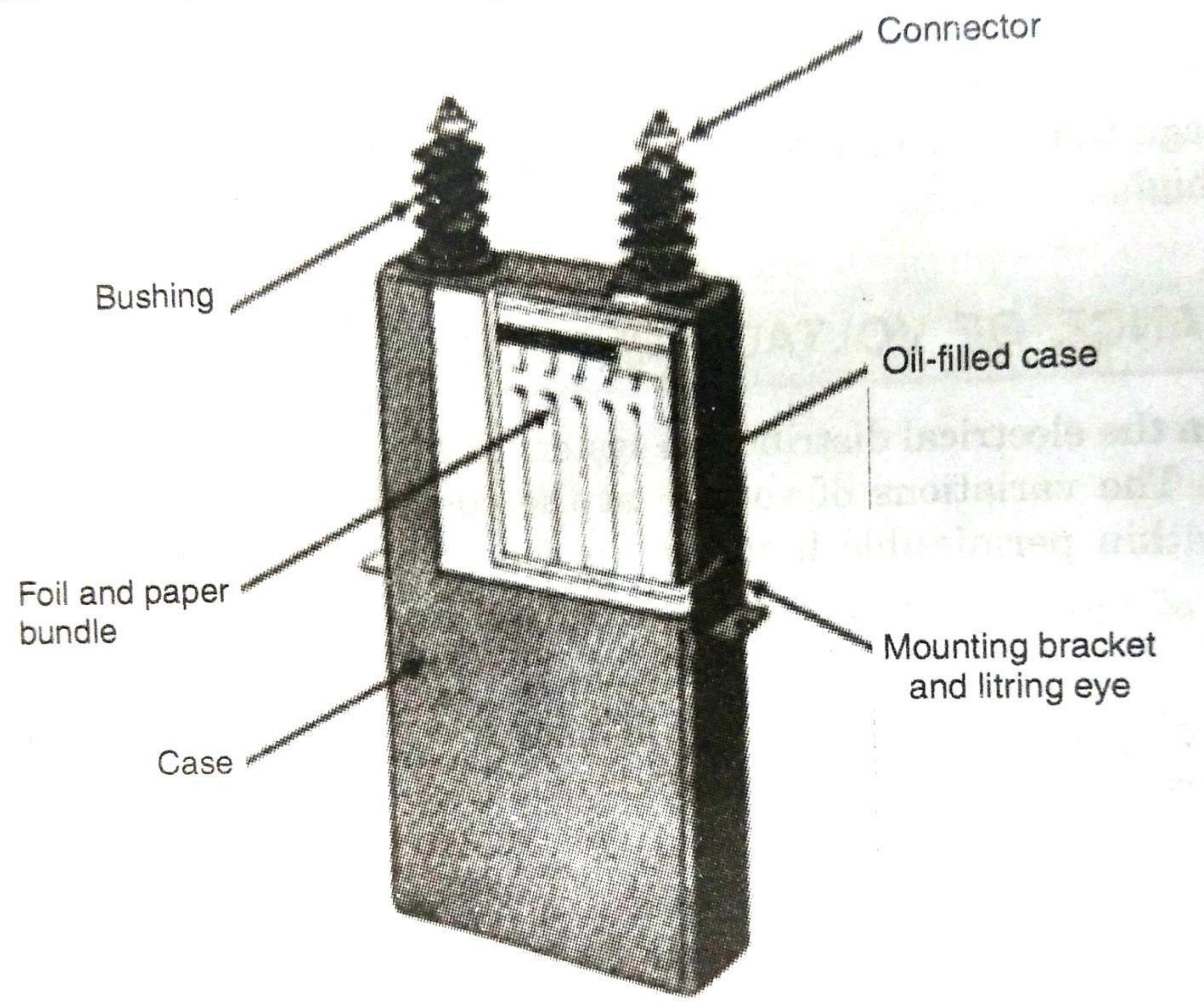


FIG 5.1 PRIMARY CAPACITOR

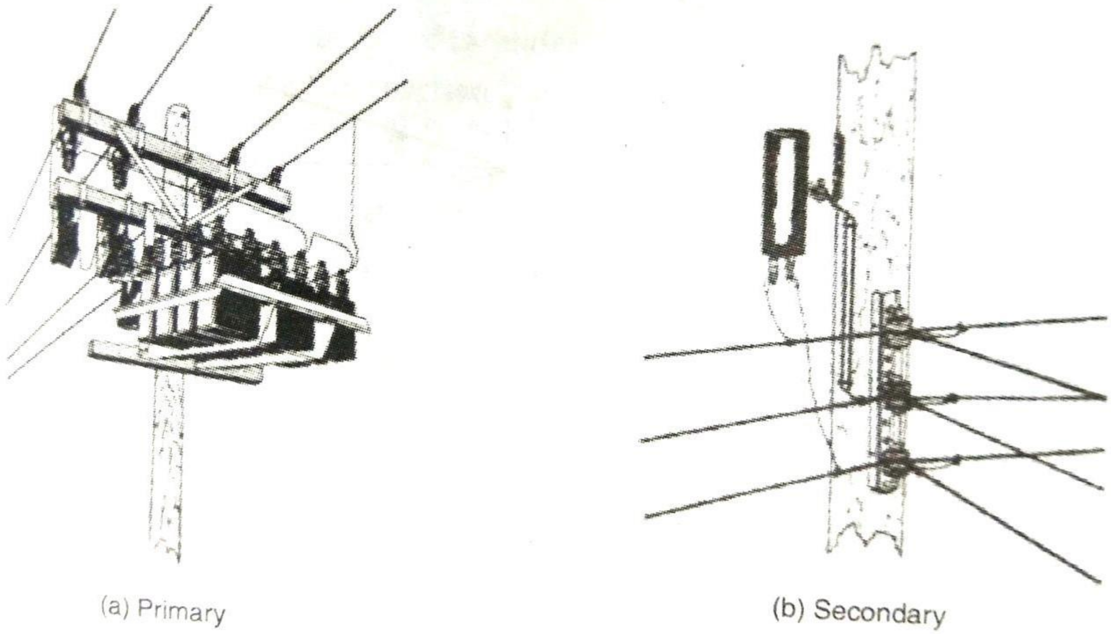


FIG 5.2 POLE MOUNTED CAPACITOR

5..1 EFFECT OF SHUNT CAPACITOR

The load incident on the distribution system is mostly inductive, requiring large reactive power. The best method is to compensate the reactive power at the load end itself but it is difficult to implement in pactice.Hence, providing compensation on the distribution system is essential. The equivalent circuit of basic configuration is shown in fig5.3(A).The circuit with shunt compensation is shown in fig 5.3(b).It is extensively used in distribution systems. Shunt capacitors are connected across an inductive load so as to supply the reactive power of current to reduce the out of phase component of current required by an inductive load i.e.., it modifies the characteristics of an inductive load by drawing a leading current which counter acts or opposes some or all of the lagging component of the inductive load current at the point of installation so that the reactive VA rs transmitted over the line are reduced, there by the voltage across the load is maintained within certain desirable limits. It has the same effect of synchronous condenser or phase modifier. The disadvantage of the use of this capacitor is that with fall of voltage at a particular node the corrected VArs will also be reduced.

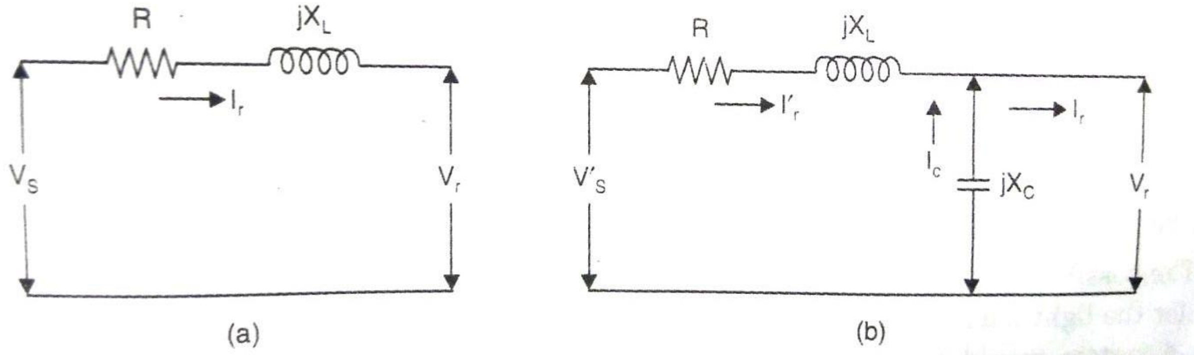


FIG 5.3 SINGLE LINE DIAGRAM WITHOUT AND WITH SHUNT COMPENSATION

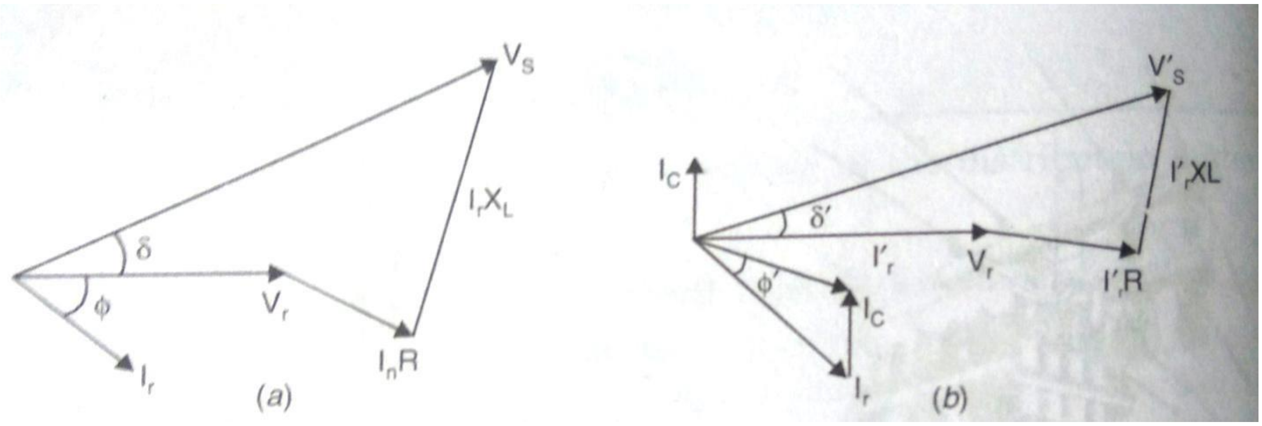


FIG5.4 PHASOR DIAGRAM OF FIG 5.3 (a) AND(b) RESPECTIVELY

By the application of the shunt capacitor to a feeder the magnitude of source current can be reduced, the p.f can be improved and consequently the voltage drop between the sending and receiving ends is also be reduced as shown in fig 5.4 .However it is important to note that, it does not effect current or p.f beyond their point of installation

Voltage drop of the line without and with shunt capacitors are given as:

$$Vd=I_rR\ COS\phi + I_rX_L\ \sin\phi$$

With shunt capacitor, $Vd=I_rR\ COS\phi + (I_r-I_C)X_L\ \sin\phi$

Wher I_C =Reactive component of current leading the voltage by 90^0

The voltage rise due to the location of the capacitor is the difference between the voltage drops determined by using equations 5.1 and 5.2 and is given by

Voltage rise=I_CX_L

And improved p.f.=$\frac{p}{\sqrt{p^2+(Q_1-Q_c)^2}}$

5..2 FIXED AND SWITCHED CAPACITORS

The distribution system load depends on the time of the day. during evening period ,the system has maximum load. During the day the load is moderate while it is generally low during late night

If the capacitor is connected at the end of the line, which is not feeding any load,it will cause the receiving end voltage to be more than the sending end voltage thus creating over voltage problem.Therefore,the rating of the capacitor should be such that it does not result in leading p.f. under light load condition

The optimum solution is to have a capacitor bank which can adjust the VA rs supplied match the VARs demand load exactly. Though it is possible to have such a system it would be very expensive and complex

The possible feasible solution is to have fixed and switched capacitors, the fixed capacitors bank for the light load conditions and switched capacitor bank for maximum load conditions. Such a system would cause leading p.f under light load condition but this is generally acceptable.

SWITCHED CAPACITOR BANKS

Switched capacitor banks provide benefits under the following situations:

- More loss reductions: As the reactive loading on the circuit changes, we reduce losses by switching banks on and off to track these changes
- Voltage limits: If optimally applied banks under the average loading scenario cause excessive voltage under light load ,then use switched banks

In addition, automated capacitors-those with communication-have the flexibility to also use distribution VA rs for transmission support. Fixed banks are relatively easy to site and size optimally witched banks are more difficult. Optimally sizing capacitors, placing them, and deciding when to switch them are difficult tasks. Several software packages are available that can optimize this solution.

To place switched capacitors using the ½ kVAr method, again place the banks at the location where the line kVAr equals half the capacitor bank rating. But instead of using the average reactive load profile (the rule for fixed banks),use the average reactive flow during the time the capacitor is on. With time switched banks and information on load profiles (or typical load profiles),we can pick the on time and the off time and determine the proper capacitor sizing based on the average reactive flow between the on and off times.Or,we can place a bank and pick the on and off times such that the average reactive line flow while the bank is switched on equals half of the bank rating. In these cases, we have specified the size and either the placement or switching time. To more generally optimize- including sizing, placement, number of banks, and switching time, we must use a computer, which iterates to find a solution.

Combinations of fixed and switched banks are more difficult. The following approach is not optimal but gives reasonable results. Apply fixed banks to the circuit with the ½ kVAr rule based on the light-load case. Check voltages. If there are under voltages, increase the size of capacitor, use more capacitor banks, or add regulators. Now, look for locations suitable for switched banks. Again,use the average reactive line flows for the time when the capacitor is on(with the already-placed fixed capacitors in the circuit model).When applying switched capacitors, check the light load case for possible over voltages, and check the peak-load case for under voltages.

EFFECT OF SERIES CAPACITOR

The maintenance of voltage at consumer premises within statutory limits at all loads is the responsibility of utility. Capacitors can also be installed in series with primary feeders to reduce voltage drop, but they are rarely employed in this fashion. Where shunt capacitors, connected in parallel with the load, correct the component of the current due to the inductive reactance of the circuit, series capacitors compensate for the reactance voltage drop in the feeder. A capacitor in series with a primary feeder serving a lagging p.f. load will cause a rise in voltage as the load increase. The p.f of the load through the series capacitor and feeder must be lagging if the voltage drop is to decrease appreciably. The voltage on the load side of the series capacitor is raised above the source side, acting to improve the voltage regulation of the feeder. Since the voltage rise or drop occurs instantaneously with the variations in the load, the series capacitor response as a voltage regulator is faster and smoother than the regulators.

Main drawback of this capacitor is the high voltage produced across the capacitor terminals under short-circuit conditions. The drop across the capacitor is I_f X_c, where I_f is the fault current which of many of times the full load current under certain conditions. It is essential, therefore, that the capacitor is to be taken out of service as quickly as possible. A spark gap with a high-speed contractor can be used to protect the capacitor under these conditions.

Because of the potential hazards, series capacitors as voltage regulators are usually restricted to transmission systems rather than in distribution systems

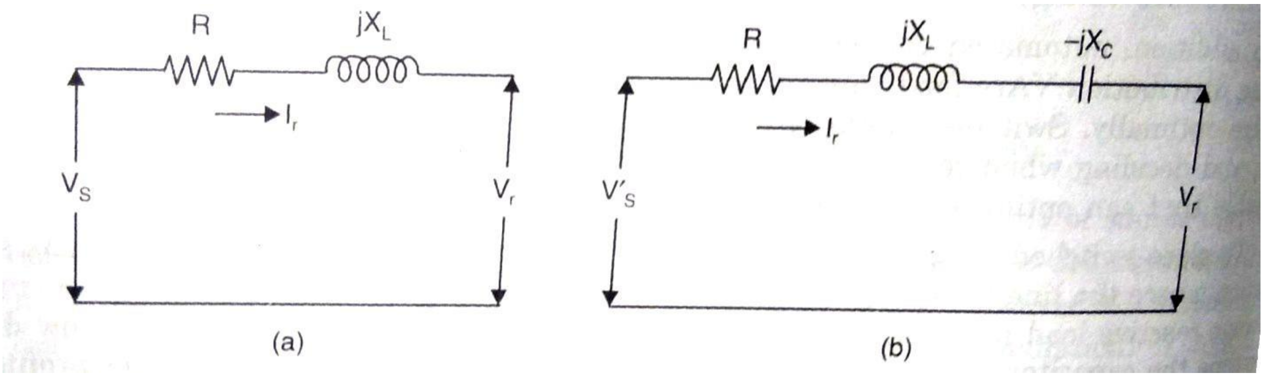


FIG 5.5 CIRCUIT DIAGRAM WITH OUT AND WITH SEREIS COMPENSTION

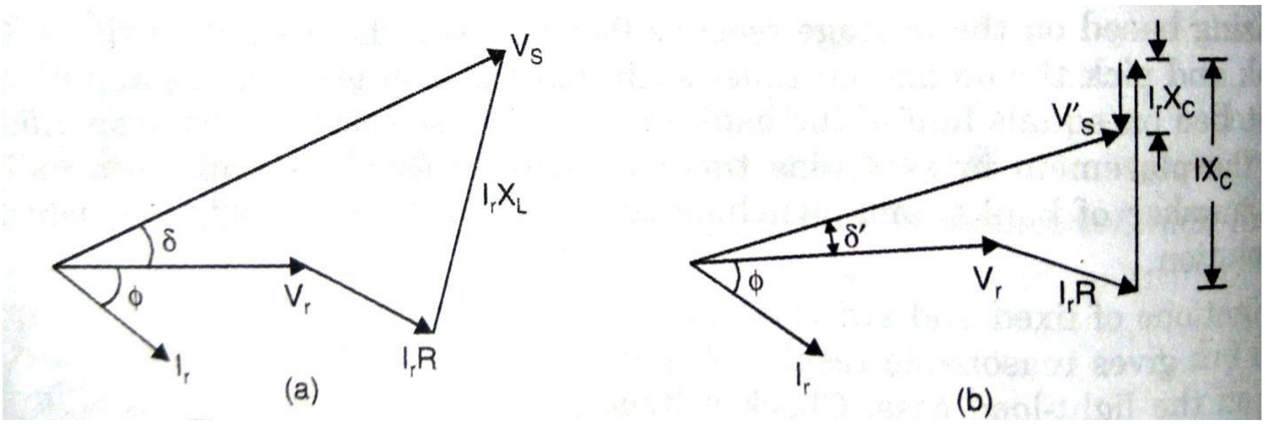


FIG 5.6 PHASOR DIAGRAM OF FIG 5.5(a) AND (B) RESPECTIVELY

Figures 5.5 and 5.6 show the line ans its voltage phasor diagram without and with series compensation. The approximate voltage drop of the line without series capacitor is given by equation (5.1)

And with series capacitor, $V_d = I_r R \, COS\phi + I_r(X_L - X_C) \sin\phi$

Where X_c= capacitive reactance of the series capacitor

DIFFRENCES BETWEEN SHUNT AND SERIES CAPACITORS

shunt capacitor	Series capacitor
1.supply fixed amount of reactive power to the system at the point where they are installed. Its effect if felt in the circuit from the location towards source only	1.quantum if compensation is independent on load current and instantaneous changes occur. Its effect is from its location towards load end
2.causes reduction in reactive power flowing in the line and causes:(a) improvement of p.f. of system (b)voltage profile improvement (c)decrease kVA loading on source i.e.., generators, transformers and line upto location and thus provide additional capacity	2.it is effective:(a) on radial feeders improve regulation automatically (b)on tie lines, power transfer are greater (c)specifically suitable when flickers due to repetitive load functions occur
3.the location has to be as near the load point as possible. in practice due to high compensation required, it is found economical to provide group compensation on lines and at substations	3.As a thumb rule. best location is 1/3rd of electrical impedance from the source bus
4.As fixed kVAr is supplied this may sometimes result in over compensation during light load period. switched banks, comparatively costlier become necessary	4.As fill load current is to pass through,the capacity should be more than the load current
5.As the p.f approaches unity, larger compensation is required for incremental improvement of p.f	5.As series capacitor feed faults also special protection is required
6.Where lines are heavily loaded compensation required will be more	6.causes sudden rise in voltage at the location
7.cost of compensation is lesser than seires capacitor	7.cost of series capacitor is higher than shunt capacitor

ECONOMIC JUSTIFICATION OF CAPACITORS

By placing the capacitor, the following benefits can be obtained

1. Released generation, transmission and distribution substation system capacity

2. Additional advantages in distribution system are:
   (i) Reduction the requirement of the feeder capacity
   (ii) Improve the voltage profile at loads
   (iii) Reduction in kVA demand for consumers
   (iv) Reduction in system power or energy loss
   (v) Reduction in system investment per kW of load supplied
   (vi) Improvement in voltage regulation
   (vii) Improve the p.f. of the source generators
   (viii) Revenue increases with improvement of voltages

Because of the above advantages, shunt capacitor a are widely used in present day most of the consumers in distribution system

BENEFITS DUE TO REALEASED FEEDER CAPACITY

Benefits due to released feeder capacity ,KF= $\Delta KF \times CKF \times IKF$

ΔKF =Released feeder capcity

CKF=cost of the feeder/kVA

IKF=A nnual rate of cost of feeder

BENEFITS DUE TO SAVING IN ENERGY

Benefits due to savings in energy KE= $\Delta KE \times r$

Where Δ KE=savings in energy

=(annual energy losses before installing the capacitor)-(annual energy losses after installing capacitor)

r= rate of energy in Rs./kWh

BENEFITS DUE TO REDUCED DEMAND

Benefits due to reduced demand KP= $\Delta KP \times CKP \times IKP$

Δ KP=Reduced demand (kW)

CKP=cost of generation /Kw

IKP=A annual rate for generation cost

5.4.6 CALCULATION OF POWER FACTOR CORRECTION

The p.f. correction can be determined from power triangle. from the fig 5.7 the triangle OAB is for the original p.f.($\cos\phi_1$) whereas triangle OAC is for the improved p.f. .($\cos \phi_2$) it may be observed that the active power (OA) does not change with p.f. improvement .However the lagging kVAr of the load is reduced by the p.f correction equipment, thus improving the p.f to $\cos\phi_2$

Leading kVAr(Q_C) supplied by p.f correction equipment as

$$BC=AB-AC$$

`

$$=Q_1-Q_2$$

$$=OA(\tan \phi_1 -\tan\phi_2)$$

$$=P(\tan \phi_1 -\tan\phi_2)$$

Knowing the leading kVAr (Q_C) supplied by the p.f correction equipment the desired results can be obtained

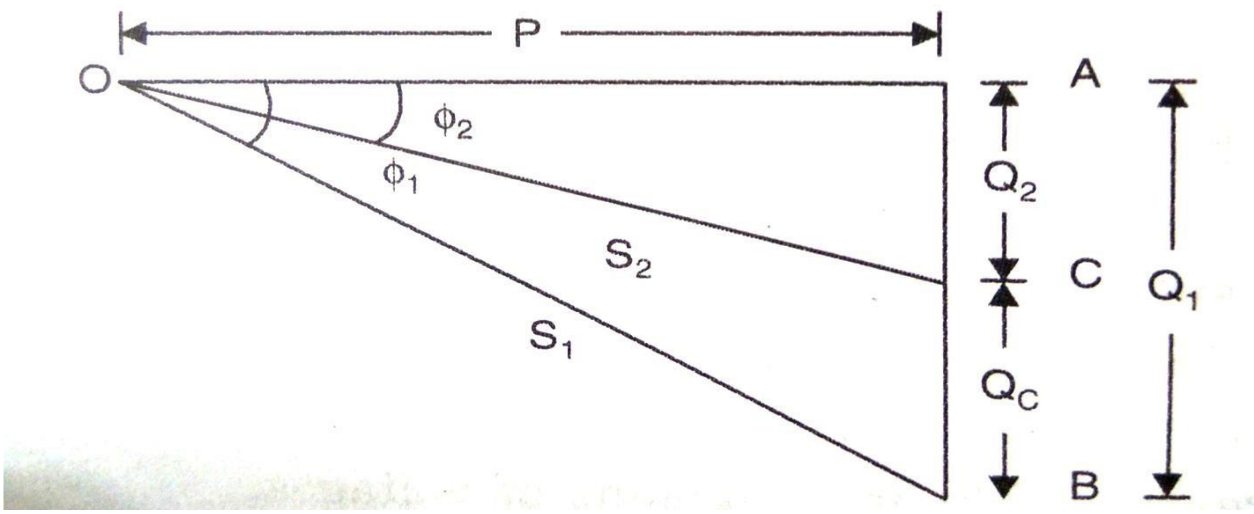


FIG 5.7 POWER TRIANGLE

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5.7 PROCEDURE TO DETERMINE THE BEST CAPACITOR LOCATION

Capacitors are placed in distribution system for the improvement of voltage profile and reduction of energy losses by improving power factor of distribution system. when capacitors are placed in distribution system and are controlled properly then they increase the economic benefit of the system .It is possible to generate all the reactive power needed in a system at the place of demand itself, an ideal situation will be that no reactive power will flow through the transformer and feeders. This requires shunt capacitors that are to be placed at every node. The cost of capacitors including their maintenance etc. may far exceed the cost of the benefits obtained by their installation. This fact suggests that capacitors to be installed at some selected nodes of the network only. Moreover the amount of reactive power generated (or size of capacitor installed) at these nodes is to be determined in order that the benefit obtained by capacitor installation is maximixed. Hence the capacitor placement problem thus becomes an optimization problem where the capacitor locations and sizes are to be determined in such a way that an objective function representing the difference between the costs of the benefit obtained by the capacitor placement and cost of the capacitor is maximized

The general iteration process requires the following steps:

1.read the data of the line, load and desired p.f. of the distribution system

2.Calculate the load inkW and p.f. of the system

3.calculate the correction factor of load (i.e.. kVAr per kW) necessary to correct the system p.f. from the original to the desired p.f. to calculate the rating of capacitor required, multiply this correction factor by a total kW of the system

4. calculate the individual kVA’s and p.f.’s of each load or group of loads

5.to calculate the kVAr of the feeder, multiply individual load or group of loads by their respective reactive factors

6.develop a nomograph to determine the feeder losses per km due to inductive loads tabulated in steps 4&5.Multiply these feeder losses by their respective feeder lengths in km.Repeat this process for all loads and feeder sections and add them to get total inductive feeder losses

7.In the case of having presently existing capacitor banks on the system, perform the same calculations as in step6,but this time subtract the capacitive feeder losses from the total inductive feeder losses. Use the capacitor kVAr’s calculated in step 3 and the nomograph developed for step 6 and finds the feeder losses in each branch due to capacitors

8.to determine the distance to capacitor location, divide total inductive feeder losses by capacitive feeder losses per km.if this co-efficient is greater than the feeder branch length

(i) divide the remaining inductive feeder losses by capacitive feeder losses next feeder branch to find the location

(ii) if this co-efficient is greater than the feeder branch length repeat step 8(i)

9. print the results and check the voltage limits

Unit – VI

VOLTAGE CONTROL

INTRODUCTION

The distribution system is said to be well designed if it gives a good quality of reliable supply. Good quality means that the voltage profiles are within the reasonable limits. In practice, all the equipment on the distribution system are designed to operate satisfactorily only when the voltage profile on the system corresponds to their voltages or at the most the variations are within permissible limits at the consumers terminals i.e.., ± 5%.To keep distribution system voltages within the permissible limits means that it must be provided to control the voltage that is to increase the circuit voltage when it is too low and to reduce it when it is too high.

IMPORTANCE OF VOLTAGE CONTROL

When the load on the electrical distribution system changes voltage at the customer's terminals is also changes. The variations of voltage at the customer's terminals are undesirable and must be kept within permissible limit for the following reasons:

- In case of lighting loads, the lamp characteristics are very sensitive to change of voltage
- In case of power loads consisting of induction motors, the voltage variations may cause erratic operations. If the supply voltage is more than normal, the motor may operate with a saturated magnetic circuit and consequently large magnetizing current will be drawn .On the other hand,if the voltage is too below, it will reduce the starting torque
- Too wide variations of voltage causes excessive heating of distribution transformers. this may reduce the rating of transformers

METHODS OF VOLTAGE CONTROL

The following methods are used to improve the voltage in the distribution system:

- Generator voltage regulators
- Installing voltage regulating equipment and capacitors in the distribution substation.
- Load balancing on the primary feeders
- Adequate size of feeder conductor

- Conversion of 1-Φ feeder sections to multi-phase feeder sections
- Shifting the loads to new feeders or new substations
- Construct the new substation and primary feeders
- Increasing the voltage levels on primary feeders
- Location of shunt and series capacitors on primary feeders

EFFECT OF SERIES CAPACITOR

The maintenance of voltage at consumer premises within statutory limits at all loads is the responsibility of utility. Capacitors can also be installed in series with primary feeders to reduce voltage drop, but they are rarely employed in this fashion. Where shunt capacitors, connected in parallel with the load, correct the component of the current due to the inductive reactance of the circuit, series capacitors compensate for the reactance voltage drop in the feeder. A capacitor in series with a primary feeder serving a lagging p.f. load will cause a rise in voltage as the load increase. The p.f of the load through the series capacitor and feeder must be lagging if the voltage drop is to decrease appreciably. The voltage on the load side of the series capacitor is raised above the source side, acting to improve the voltage regulation of the feeder. Since the voltage rise or drop occurs instantaneously with the variations in the load, the series capacitor response as a voltage regulator is faster and smoother than the regulators.

Main drawback of this capacitor is the high voltage produced across the capacitor terminals under short-circuit conditions. The drop across the capacitor is $I_f X_c$, where I_f is the fault current which of many of times the full load current under certain conditions. It is essential, therefore, that the capacitor is to be taken out of service as quickly as possible. A spark gap with a high-speed contractor can be used to protect the capacitor under these conditions.

Because of the potential hazards, series capacitors as voltage regulators are usually restricted to transmission systems rather than in distribution systems

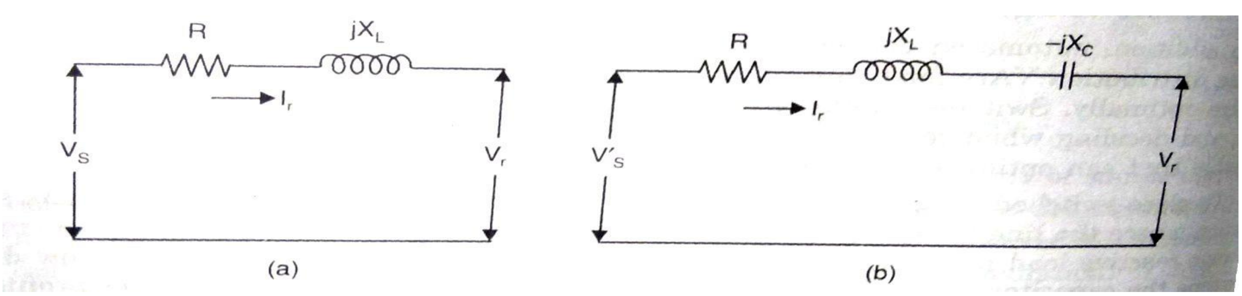

FIG 6.1 CIRCUIT DIAGRAM WITH OUT AND WITH SEREIS COMPENSTION

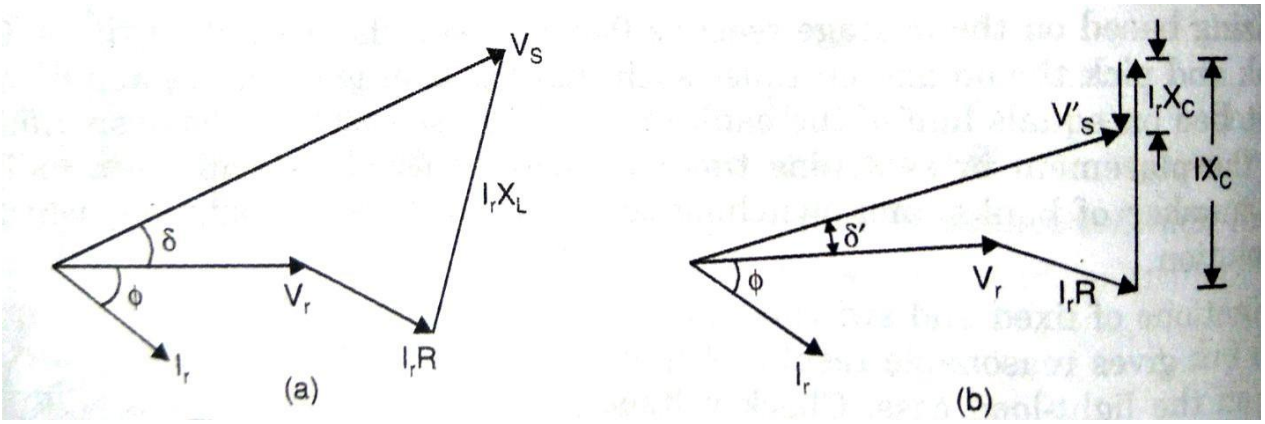

FIG 6.2 PHASOR DIAGRAM OF FIG 6.1(a) AND (B) RESPECTIVELY

Figures 6.1 and 6.2 show the line ans its voltage phasor diagram without and with series compensation. The approximate voltage drop of the line without series capacitor is given by equation

And with series capacitor, $V_d=I_rR\ COS\phi + I_r(X_L-X_C)\ sin\phi$

Where X_c= capacitive reactance of the series capacitor.

AUTOMATIC VOLTAGE REGULATORS (AVR)

It is also called automatic voltage booster(AVB).Voltage regulators are used to hold the voltage of a feeder at a predetermined value within a limit which the control equipment is capable of maintain and within acceptable tolerance values for distribution purpose. Regulators may be installed at substation or on distribution feeders on poles or platforms

These are essentially autotransformers, with the secondary (or series) portion of the coil arranged so that all or apart of its induced voltage can be added to or subtracted from the line or incoming primary voltage. The voltage variations are accomplished by changing the ratio of transformation automatically without de-enerzing the unit

Voltage regulators are classified in two types and they are:

(i) Induction type and
(ii) Step type or tap changing under load(TCUL) type regulators

VOLTAGE REGULATORS ARE EITHER OR MOTOR OPERATED AS SHOWN IN FIG 5.8

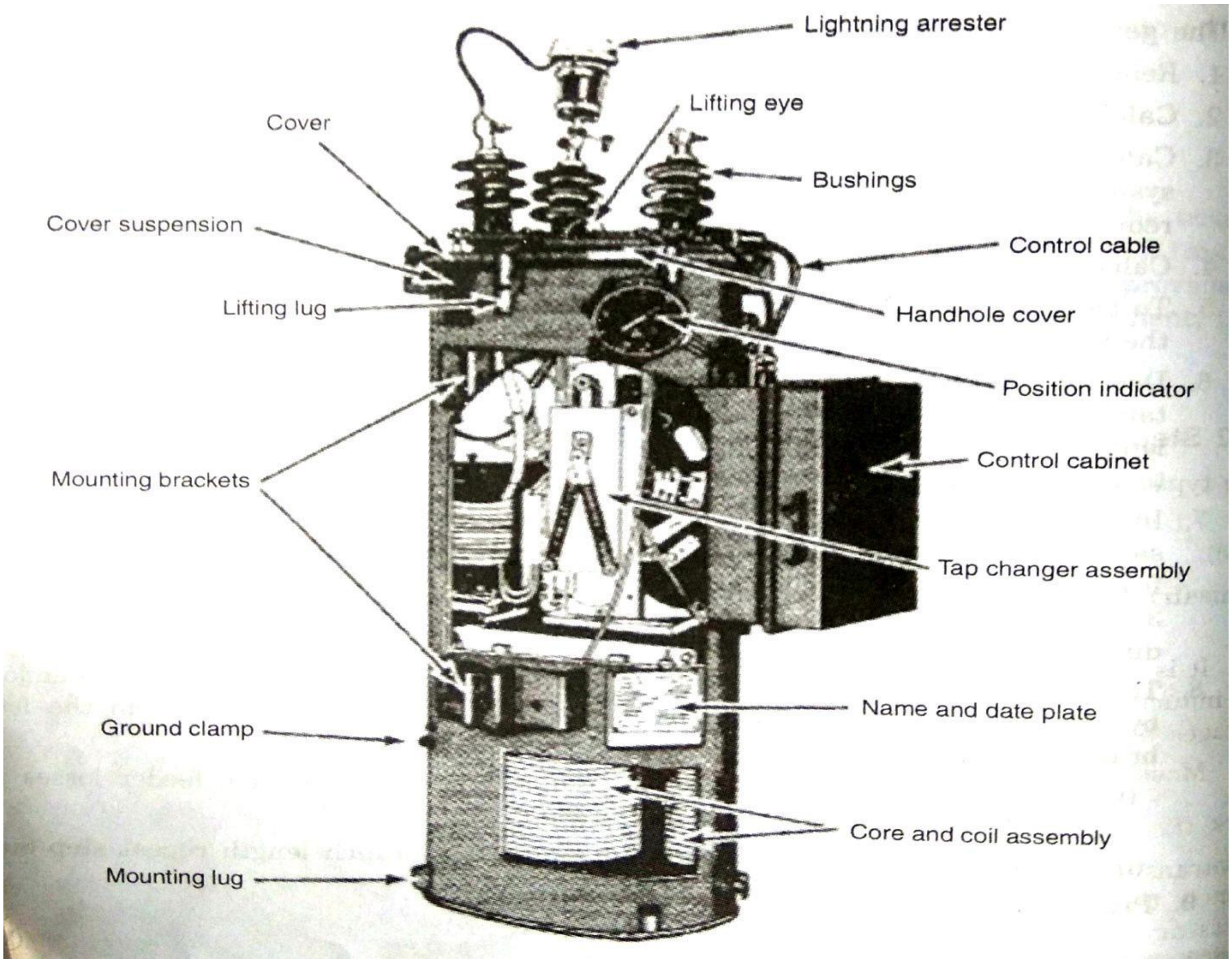

Fig 6.3 Voltage Regulator

INDUCTION TYPE REGULATOR

In this type of voltage regulator, the primary(HV) winding and secondary (or series) winding are so arranged that they rotate with respect to one another as shown in fig .The primary coil is usually the stator and the secondary coil the rotor, the direction of rotation generally depending on whether the incoming voltage is to be raised or lowered. The voltage induced in the secondary or in series winding will depend on the position in relation to the primary winding. Depending on the position, the induced voltage can add to or subtract the input voltage to obtain the output voltage

During the rotation of the primary coil, the moving magnetic field can cause a large reactance voltage drop in the secondary. To cancel this effect, a third coil is mounted at right angle to the primary coil on the movable core and short-circuited on itself. The moving primary coil will induce a voltage in the third coil which will, in turn set-up moving magnet field of its own, which will tend to oppose that set-up by the motion of the primary coil. The reactance of the regulator unit is thus kept essentially constant.

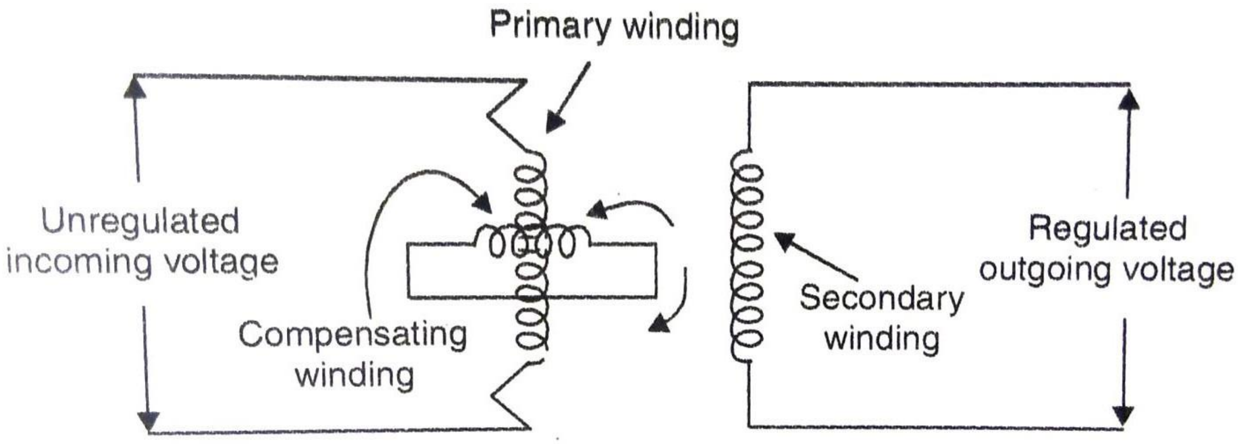

FIG 6.4 INDUCTION TYPE OF VOLTAGE REGULATOR

STEP TYPE REGULATORS

Step type or TCUL regulators are further classified as either:

(i) Station type ,which are 1- ϕ or 3-ϕ and it can be used in substation for bus voltage regulation or individual feeder voltage regulation

(ii) Distribution type, which can be only 1-ϕ and used for pole mounted on over head primary feeder

It is essentially an autotransformer, and is connected in the feeder as same manner as the induction regulator. This type does not employ rotation of one of the coils, but changes voltages by means of taps in the primary coils as shown in fig

Most of the regulators are designed to correct the line voltage from 10% boost to 10% buck (i.e.., $\pm 10\%$) in 32 steps ,with a 5/8% voltages change per step. In addition to its autotransformer components, a step type voltage regulator also has two major components namely the tap changing and control mechanisms. Each voltage regulator is consisting of necessary controls and accessories and so that the taps are changed automatically under loads by a tap changer which response to a voltage sensing control to maintain a predetermined output voltage. By receiving its inputs from PT's and CT'S the control mechanism provides control of voltage level and bandwidth. Further ,it provides the ability to adjust line drop compensation by selecting resistance and reactance settings

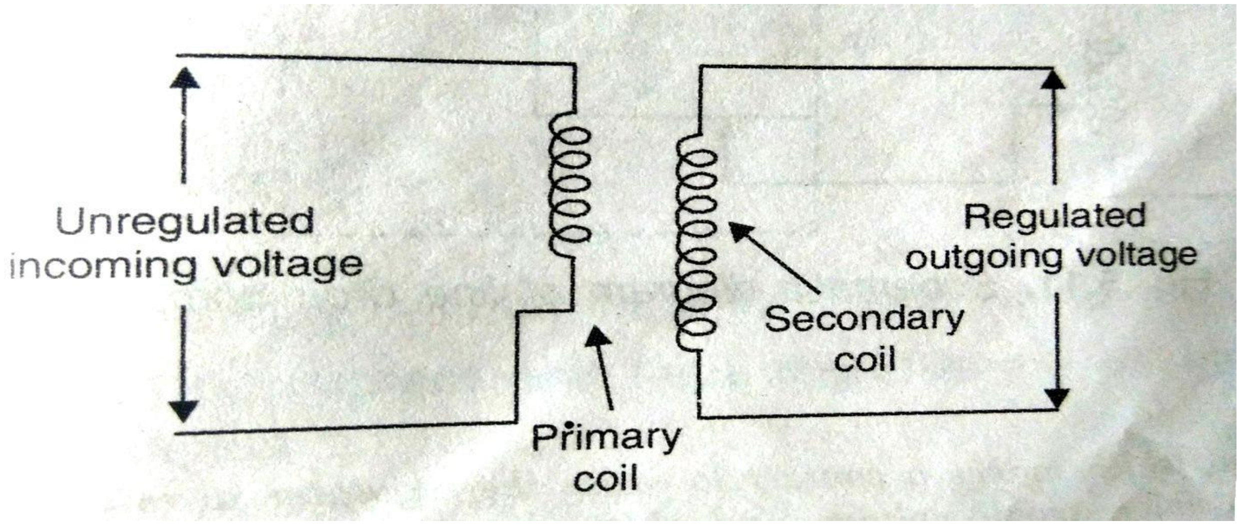

FIG 6.5 STEP TYPE VOLTAGE REGULATOR

CONTROL AND RATING OF VOLTAGE REGULATORS

The rotation of the primary coil in the induction regulator and the tap changing in the step type regulator are controlled by a voltage-regulating relay(known as a contact making voltmeter) connected to the output side of the regulator. Associated with it is a line drop compensator, which is essentially a miniature reproduction of the electric feeder to be regulated and determine the voltages, applied to the voltage –regulating relay.

Rating of these regulators is based on their nominal voltage classification and their change of percentage of voltage regulation. Their kVArating,as a percentage of the volt-amperes transformed is the same as the percentage voltage transformed using the incoming primary voltages as a base. This is the same rating used for autotransformers. For example if the regulator boosts or backs the voltage $\pm 10\%$,it transformers only 10% of the load in kVA

LINE DROP COMPENSATION

Voltage regulators located in a substation or on a feeder are used to keep the voltage constant at a regulating point without changing magnitude and p.f. of load. Where it is desired to regulate or maintain the voltage limit at some distance from the source of the distribution feeders(i.e.., at the first customer or at some point farther out on the feeder)a line drop compensator is used with the contact making voltmeter .This is an electrical miniature of the feeder to the point where the regulator is designed as shown in fig 5.11.Resistance and reactance values of the feeder are calculated and a resistance and reactance proportional to these values are set on the compensator, producing a voltage drop proportional to the current .This drop is subtracted from the feeder voltage representing the voltage at the point of compensation as shown in fig 5.12

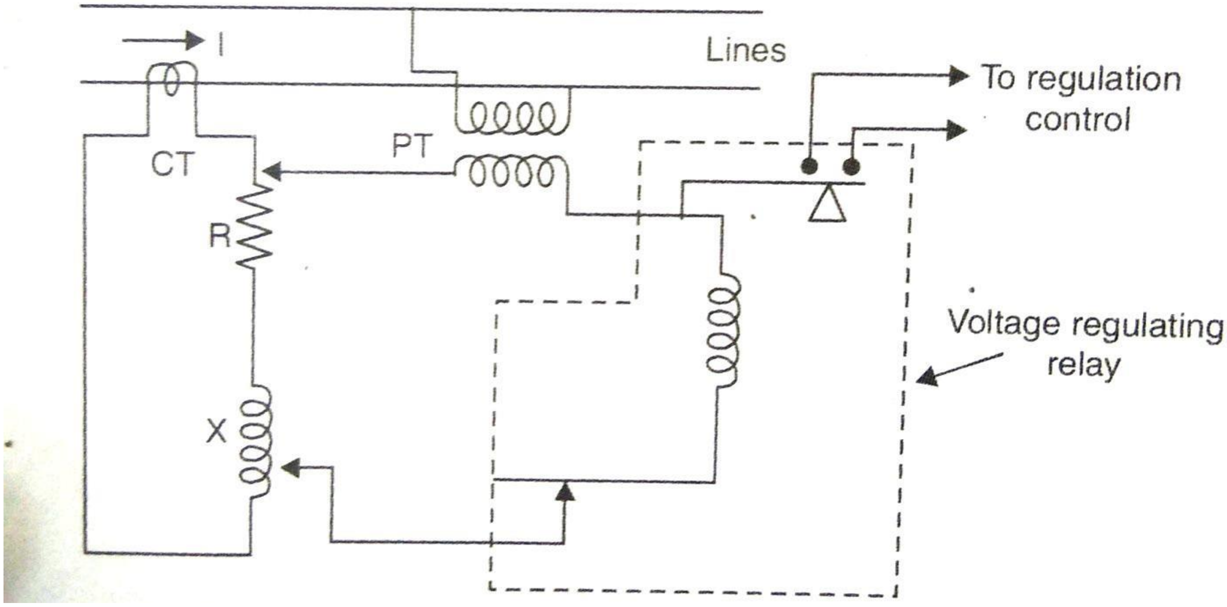

FIG 6.6 SCHEMATIC DIAGRAM OF LINE DROP COMPENSATOR

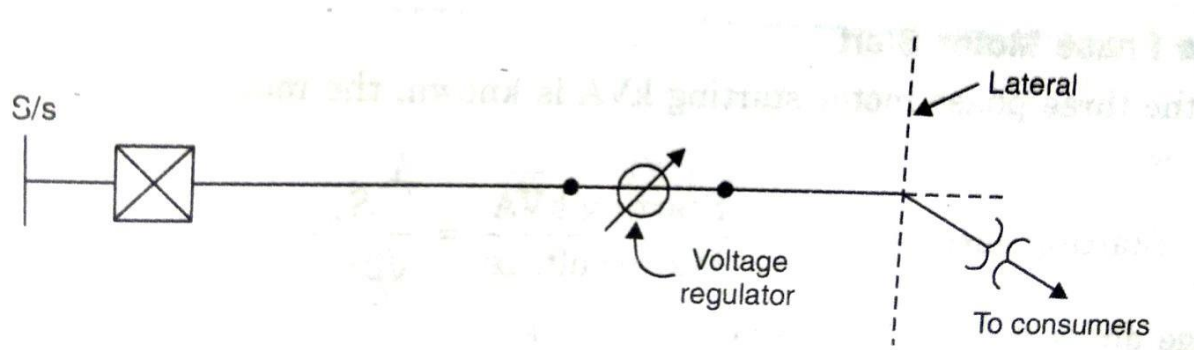

FIG 6.7 LOCATION OF FEEDER VOLTAGE REGULATOR

The point of compensation should be selected so that the customers farthest from the regulator will have the least lowest permissible voltage under the heaviest load while the customer nearest the regulator will have the highest permissible voltage under light load conditions

PREVIOUS QUESTION PAPERS

Code No: **RT41029** **R13** **Set No. 1**

IV B.Tech I Semester Supplementary Examinations, February - 2019

ELECTRICAL DISTRIBUTION SYSTEMS

(Electrical and Electronics Engineering)

Time: 3 hours **Max. Marks: 70**

Question paper consists of Part-A and Part-B
Answer ALL sub questions from Part-A
Answer any THREE questions from Part-B
*****

PART–A *(22 Marks)*

1. a) Define the terms w.r.t Load characteristics:
   (i) Load Diversity (ii) Contribution factor [4]
   b) Explain the design considerations that are taken for distribution feeders. [3]
   c) How do you fix the rating of a Distribution system? [4]
   d) Explain in brief the type of common faults that occur in Distribution System. [4]
   e) Explain the need of Switched capacitor in Distribution system. [4]
   f) Explain the use of tap changing transformers. [3]

PART–B *(3x16 = 48 Marks)*

2. a) Explain the different methods for reduction of Distribution system losses. [8]
   b) How do you classify the Loads and give its characteristics? [8]

3. a) List the factors that need to be considered for selecting an ideal location of Substation. [8]
   b) Explain the factors affecting the feeder voltage level. [8]

4. Derive the power Loss equation for Radial feeders with Uniformly distributed Load. [16]

5. a) Discuss in detail about the coordination among the Protective devices used in Distribution system. [8]
   b) A three phase, 11 KV, 30 MVA generator with X_3 = 0.06 PU, X_1 = 0.3 PU and X_2 = 0.3 PU is grounded through a reactance of 0.28 ohms. Calculate the total fault current for a Single line to Ground fault. [8]

6. a) Discuss in detail the procedure for best location of capacitor placement in a Distribution system. [8]
   b) A three phase 400 HP, 50 Hz, 11 KV star connected Induction motor has a full load efficiency of 88% at lagging power factor of 0.78 and is connected to a feeder. If it is desired to correct the power factor of 0.92 lagging load, determine i)the size of the capacitor bank in KVAR ii) the capacitance of each unit if the capacitors are connected in delta as well as in star. [8]

7. Write short notes on the following:
   a) Effect of Series capacitors on voltage control
   b) Effect of AVB [16]