Unit-I Introduction to Distributed Systems

Introduction

Distribution systems serve as the link from the distribution substation to the customer. This system provides the safe and reliable transfer of electric energy to various customers throughout the service territory. Typical distribution systems begin as the medium-voltage three-phase circuit, typically about 30–60 kV, and terminate at a lower secondary three- or single-phase voltage typically below 1 kV at the customer's premise, usually at the meter. Distribution feeder circuits usually consist of overhead and underground circuits in a mix of branching laterals from the station to the various customers. The circuit is designed around various requirements such as required peak load, voltage, distance to customers, and other local conditions such as terrain, visual regulations, or customer requirements. These various branching laterals can be operated in a radial configuration or as a looped configuration, where two or more parts of the feeder are connected together usually through a normally open distribution switch. High-density urban areas are often connected in a complex distribution underground network providing a highly redundant and reliable means connecting to customers. Most three-phase systems are for larger loads such as commercial or industrial customers.

The part of power system which distributes electric power for local use is known as ***distribution systems.***

In general, the distribution system is the electrical system between the sub-station fed by the transmission system and the consumers meters. It generally consists of *feeders, distributors* and the *service mains.* Fig. 12.1 shows the single line diagram of a typical low tension distribution system.

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

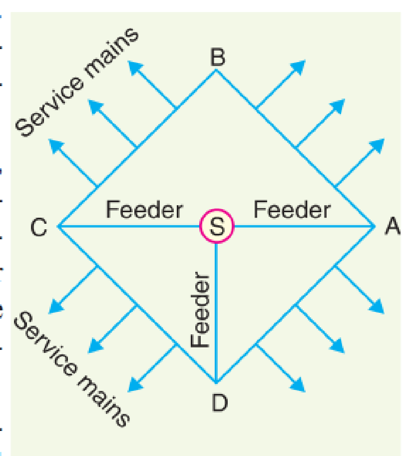
(*ii*) *Distributor.* A distributor is a conductor from which tappings are taken for supply to the consumers. In Fig. 12.1, *A B*, *BC*, *CD* and *DA* are the distributors. The current through a distributor is not constant because tappings are taken at various places along its length. While designing a distributor, voltage drop along its length is the main consideration since the statutory limit of voltage variations is ± 6% of rated value at the consumers' terminals.

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

Classification of distribution systems

A distribution system may be classified according to ;

(*i*) *Nature of current.* According to nature of current, distribution system may be classified as (*a*) d.c. distribution system (*b*) a.c. distribution system. Now-a-days, a.c. system is universally adopted for distribution of electric power as it is simpler and more economical than direct current method.



(*ii*) *Type of construction.* According to type of construction, distribution system may be classified as (*a*) overhead system (*b*) underground system. The overhead system is generally employed for distribution as it is 5 to 10 times cheaper than the equivalent underground system. In general, the underground system is used at places where overhead construction is impracticable or prohibited by the local laws.

(*iii*) *Scheme of connection.* According to scheme of connection, the distribution system may be classified as (*a*) radial system (*b*) ring main system (*c*) inter-connected system.

A.C. Distribution

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

There is no definite line between transmission and distribution according to voltage or bulk capacity. However, in general, the a.c. distribution system is the electrical system between the step-down substation fed by the transmission system and the consumers' meters. The a.c. distribution system is classified into **(*i*)** primary distribution system and **(*ii*)** secondary distribution system.

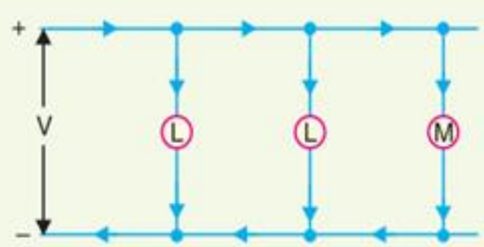
Primary distribution system. It is that part of a.c. distribution system which operates at voltages somewhat higher than general utilisation and handles large blocks of electrical energy than the average low-voltage consumer uses. The voltage used for primary distribution depends upon the amount of power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

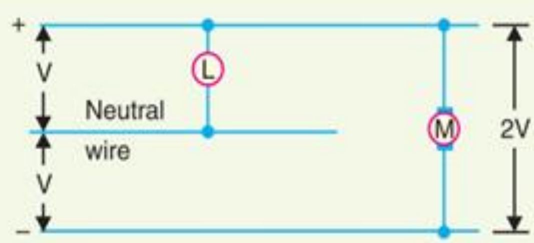
Secondary distribution system. It is that part of a.c. distribution system which includes the range of voltages at which the ultimate consumer utilises the electrical energy delivered to him. The secondary distribution employs 400/230 V, 3-phase, 4-wire system.

D.C. Distribution

It is a common knowledge that electric power is almost exclusively generated, transmitted and distributed as a.c. However, for certain applications, d.c. supply is absolutely necessary. For instance, d.c. supply is required for the operation of variable speed machinery (*i.e.*, d.c. motors), for electro-chemical work and for congested areas where storage battery reserves are necessary. For this purpose, a.c. power is converted into d.c. power at the substation by using converting machinery *e.g.*, mercury arc rectifiers, rotary converters and motor-generator sets. The d.c. supply from the substation may be obtained in the form of (*i*) 2-wire or (*ii*) 3-wire for distribution.

(*i*) *2-wire d.c. system.* As the name implies, this system of distribution consists of two wires. One is the outgoing or positive wire and the other is the return or negative wire. The loads such as lamps, motors etc. are connected in parallel between the two wires as shown in Fig. This system is never used for transmission purposes due to low efficiency but may be employed for distribution of d.c. power.



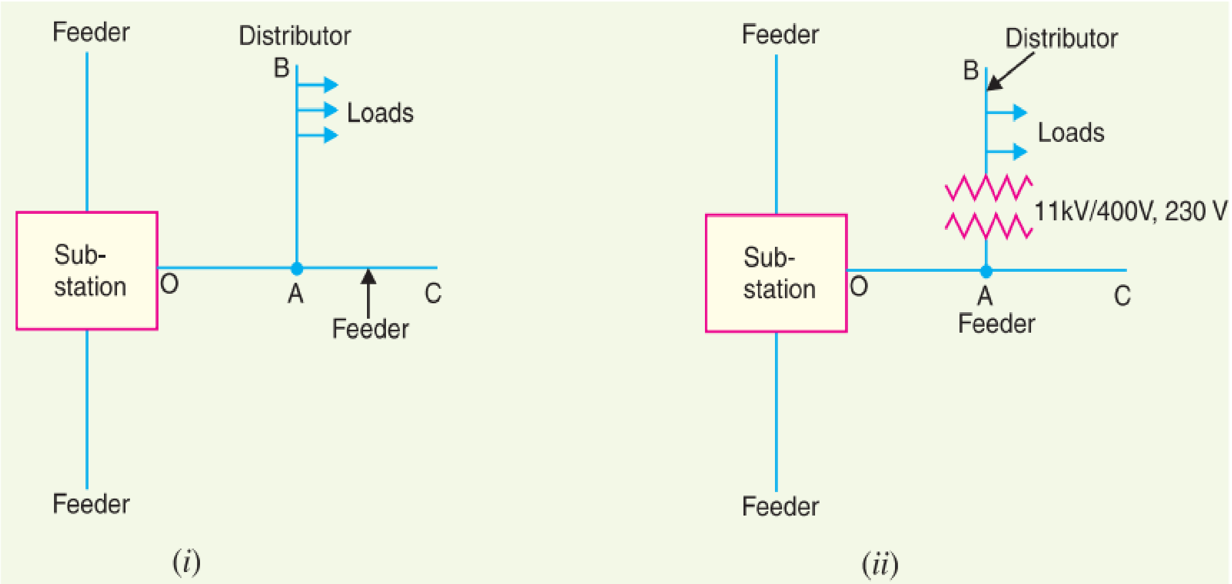


(*ii*) *3-wire d.c. system.* It consists of two outers and a middle or neutral wire which is earthed at the substation. The voltage between the outers is twice the voltage between either outer and neutral wire as shown in Fig. 12.5. The principal advantage of this system is that it makes available two voltages at the consumer terminals *viz.*, *V* between any outer and the neutral and 2V between the outers. Loads requiring high voltage (*e.g.*, motors) are connected across the outers, whereas lamps and heating circuits requiring less voltage are connected between either outer and the neutral. The methods of obtaining 3-wire system are discussed in the following article.

Connection schemes of distribution systems

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

(i) Radial System. In this system, separate feeders radiate from a single substation and feed the distributors at one end only. Fig. 12.8 (*i*) shows a single line diagram of a radial system for d.c. distribution where a feeder *OC* supplies a distributor *A B* at point *A*. Obviously, the distributor is fed at one end only *i.e.*, point *A* is this case. Fig. (*ii*) shows a single line diagram of radial system for a.c. distribution. The radial system is employed only when power is generated at low voltage and the substation is located at the centre of the load.



This is the simplest distribution circuit and has the lowest initial cost. However, it suffers from the following drawbacks :

(a) The end of the distributor nearest to the feeding point will be heavily loaded.

(b) The consumers are dependent on a single feeder and single distributor. Therefore, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the substation.

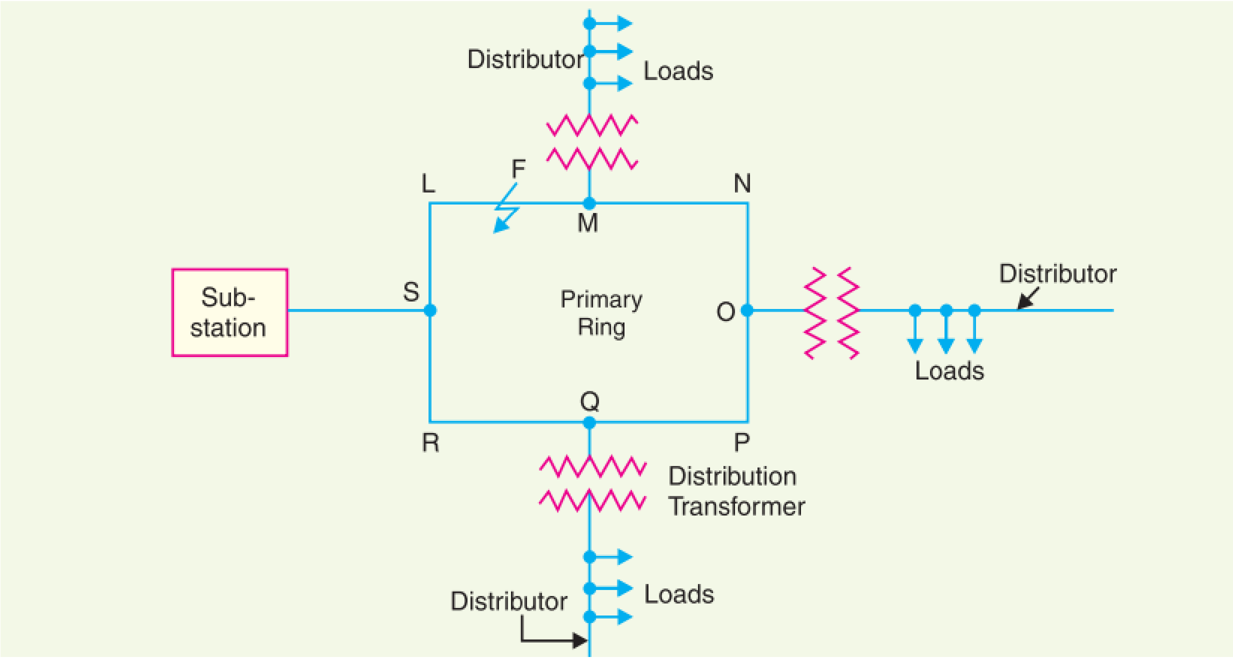
(c) The consumers at the distant end of the distributor would be subjected to serious voltage fluctuations when the load on the distributor changes.

Due to these limitations, this system is used for short distances only.

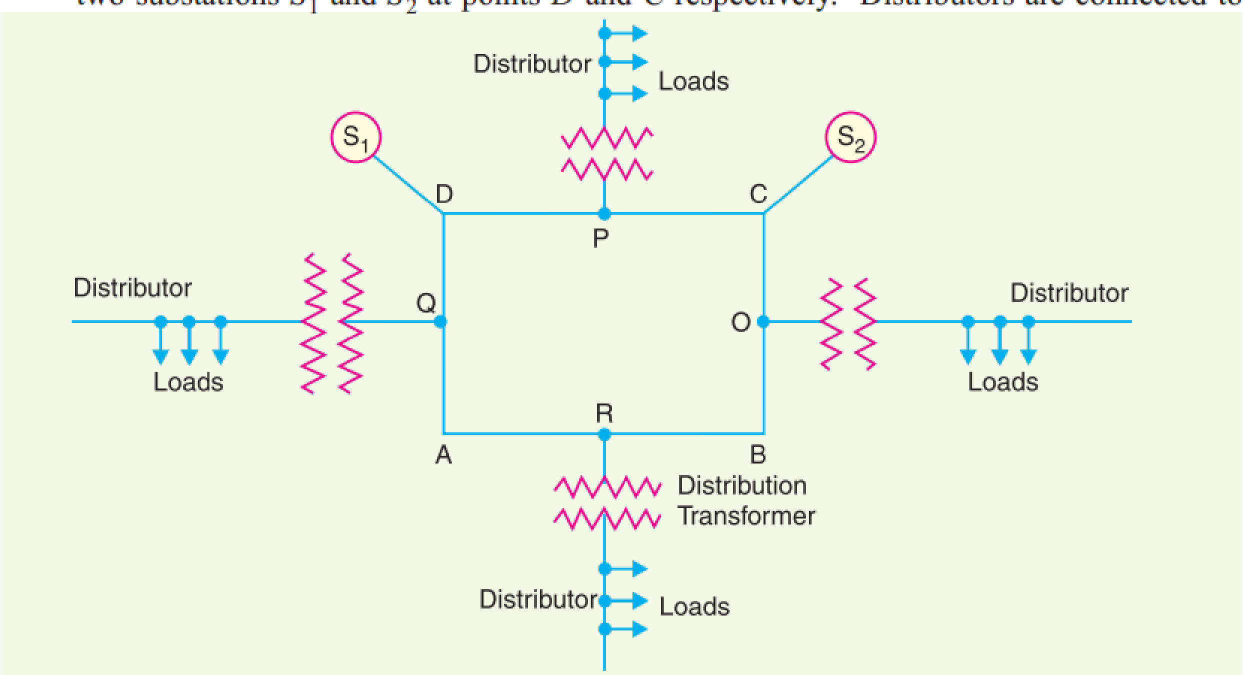
(ii) Ring main system. In this system, the primaries of distribution transformers form a loop. The loop circuit starts from the substation bus-bars, makes a loop through the area to be served, and returns to the substation. Figure shows the single line diagram of ring main system for a.c. distribution where substation supplies to the closed feeder LMNOPQRS. The distributors are tapped from different points *M*, *O* and *Q* of the feeder through distribution transformers. The ring main system has the following advantages :

(*a*) There are less voltage fluctuations at consumer's terminals.

(*b*) The system is very reliable as each distributor is fed *via* *two feeders. In the event of fault on any section of the feeder, the continuity of supply is maintained. For example, suppose that fault occurs at any point *F* of section SLM of the feeder. Then section SLM of the feeder can be isolated for repairs and at the same time continuity of supply is maintained to all the consumers *via* the feeder *SRQPONM*.



(*iii*) **Interconnected system.** When the feeder ring is energised by two or more than two generating stations or substations, it is called inter-connected system. Fig. shows the single line diagram of interconnected system where the closed feeder ring *ABCD* is supplied by two substations S_1 and S_2 at points *D* and *C* respectively. Distributors are connected to



points *O*, *P*, *Q* and *R* of the feeder ring through distribution transformers. The interconnected system has the following advantages :

(*a*) It increases the service reliability.

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

Requirements of a Distribution System

A considerable amount of effort is necessary to maintain an electric power supply within the requirements of various types of consumers. Some of the requirements of a good distribution system are : proper voltage, availability of power on demand and reliability.

(*i*) **Proper voltage.** One important requirement of a distribution system is that voltage variations at consumer's terminals should be as low as possible. The changes in voltage are generally caused due to the variation of load on the system. Low voltage causes loss of revenue, inefficient lighting and possible burning out of motors. High voltage causes lamps to burn out permanently and may cause failure of other appliances. Therefore, a good distribution system should ensure that the voltage variations at consumers terminals are within permissible limits. The statutory limit of voltage variations is ± 6% of the rated value at the consumer's terminals. Thus, if the declared voltage is 230 V, then the highest voltage of the consumer should not exceed 244 V while the lowest voltage of the consumer should not be less than 216 V.

(*ii*) **Availability of power on demand.** Power must be available to the consumers in any amount that they may require from time to time. For example, motors may be started or shut down, lights may be turned on or off, without advance warning to the electric supply company. As electrical energy cannot be stored, therefore, the distribution system must be capable of supplying load demands of the consumers. This necessitates that operating staff must continuously study load patterns to predict in advance those major load changes that follow the known schedules.

(*iii*) **Reliability.** Modern industry is almost dependent on electric power for its operation. Homes and office buildings are lighted, heated, cooled and ventilated by electric power. This calls for reliable service. Unfortunately, electric power, like everything else that is man-made, can never be absolutely reliable. However, the reliability can be improved to a considerable extent by (*a*) interconnected system (*b*) reliable automatic control system (*c*) providing additional reserve facilities.

Design Considerations in Distribution System

Good voltage regulation of a distribution network is probably the most important factor responsible for delivering good service to the consumers. For this purpose, design of feeders and distributors requires careful consideration.

(*i*) *Feeders.* A feeder is designed from the point of view of its current carrying capacity while the voltage drop consideration is relatively unimportant. It is because voltage drop in a feeder can be compensated by means of voltage regulating equipment at the substation.

(*ii*) *Distributors.* A distributor is designed from the point of view of the voltage drop in it. It is because a distributor supplies power to the consumers and there is a statutory limit of voltage variations at the consumer's terminals (± 6% of rated value). The size and length of the distributor should be such that voltage at the consumer's terminals is within the permissible limits.

Important factors and Terms

Load-Electrical power needed in kW or kVA .

Demand-The power requirement (in kVA or kW) at the load averaged over a specified interval (15 min or 30 min). Sometimes it is given in amperes at a specified voltage level.

Demand Intervals-The time interval specified for demand (D_i), usually 15 min or 30 min. This is obtained from daily demand curves or load duration curves.

Maximum Demand-The maximum load (or the greatest if a unit or group of units) that occurred in a period of time as specified. This can be daily, weekly, seasonal or on annual basis (for billing purpose in India it is monthly and in kVA).

Connected Load-The sum total of the continuous rating of all the apparatus, equipment, etc., connected to the system.

Demand Factor-The ratio of maximum demand to the total load connected to the system

Utilization Factor-The ratio of maximum demand to the rated capacity of the system.

Load Factor-The ratio of average load in given interval of time to the peak during that interval.

Annual Load Factor-The ratio of total energy supplied in an year to annual peek load multiplied by 8760.

Diversity Factor (Df)-The ratio of sum of the individual maximum demands of various sub-divisions of the system to the maximum demand of the entire or complete system.

Coincident Maximum Demand (Dg)-Any demand that occurs simultaneously with any other demand and also the sum of any set of coincident demands.

Classification of loads

A load or power requirement (also kVA) of a consumer varies widely. But in general the consumers can be grouped into a few categories as their needs and demands are the same.

Broad classifications of loads are;

(i) Residential loads

(ii) Commercial loads

(iii) Industrial loads

(iv) Agricultural loads

(v) Municipal loads

Domestic and Residential Loads

The important part in the distribution system is domestic and residential loads as they are highly variable and erotic. These consist of lighting loads, domestic appliances such as water heaters, washing machines , grinders and mixes ,TV and electronic gadgets etc. The duration of these loads will be few minutes to few hours in a day. The power factor of these loads in less and may vary between 0.5 to 0.7. In residential flats and bigger buildings, the diversity between each residence will be less typically between 1.1 to 1.15 . The load factor for domestic loads will be usually 0.5 to 0.6.

Industrial Loads

Industrial loads are of greater importance in distribution systems with demand factor 0.7 to 0.8 and load factor 0.6 to 0.7. For heavy industries demand factor may be 0.9 and load factor 0.7 to 0.8

Typical power range for various loads

Cottage and small-scale industries : 3 to 20 kW.

Medium industries (like rice mills, oil mills, workshops, etc.) : 25 to 100 kW

Large industries connected to distribution feeders (33 kV and below) : 100 to 500 kW

Water supply and Agricultural Loads

Most of the panchayats , small and medium municipalities have protected water system which use pumping stations. They normally operate in off peak time and use water pumps ranging from 10 h.p to 50 h.p or more, depending on the population and area.

Agricultural and Irrigation Loads

Most of the rural irrigation in India depends on ground water pumping or lifting water from tanks or nearby canals. In most cases design and pump selection is very poor with efficiencies of the order of 25%. Single phase motors are used (up to 10 h.p.) for ground water level 15 m in depth or less with discharge of about 20 l/sec while multi stage submersible pumps with discharge of 800 to 1000 l/m may require motors of 15 to 20 h.p.

Sensitive and important Loads

With computer applications in every area, computer loads and computer controlled process loads are often non-linear and sensitive. They require close tolerance limits for voltage and frequency (voltage limit ± 5% and frequency ± 0.5 Hz with unbalance and wave form distortion less than 3%. This requires special attention while providing the distribution of electric power.

Load Characteristics

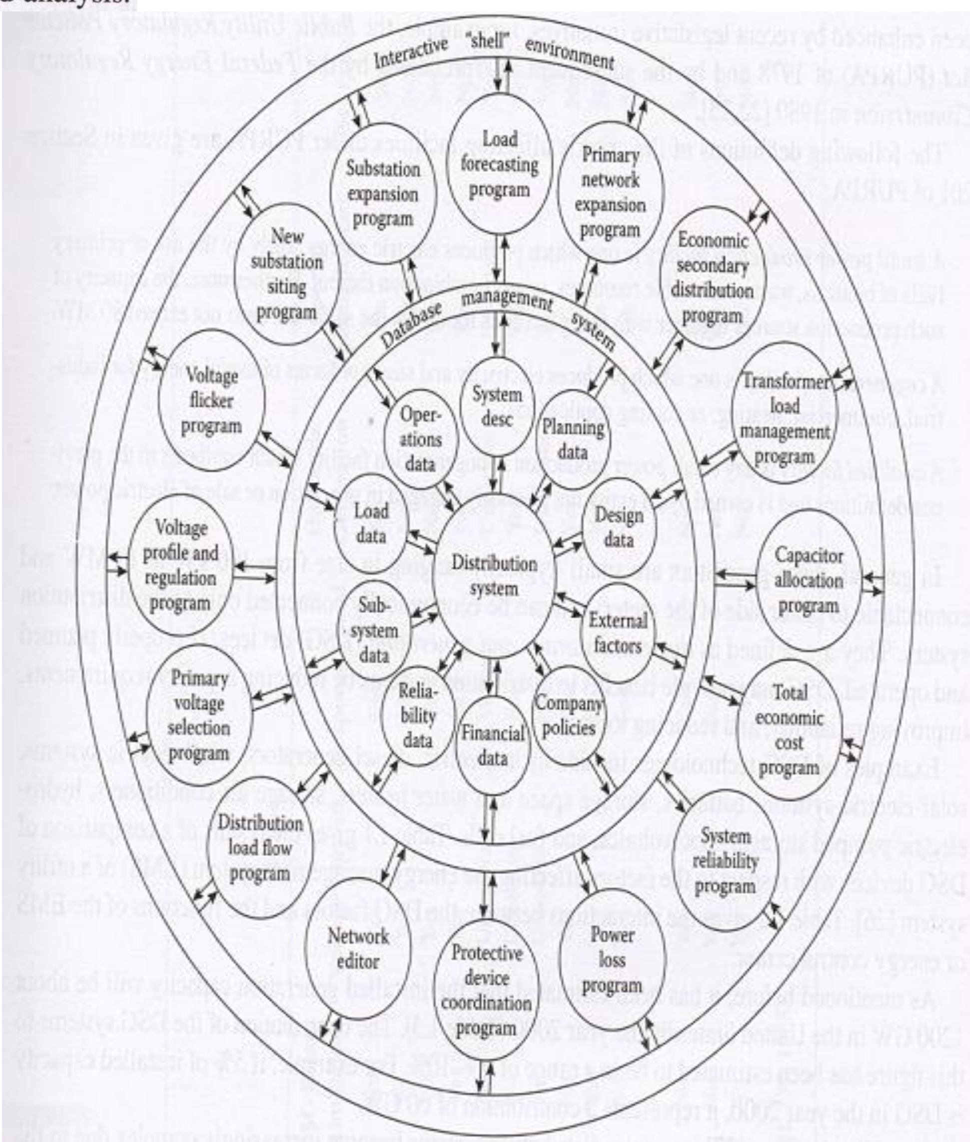
The consumption of electrical power or energy by any utility varies from time to time in a day as well as during a week, month, season or year. For example in summer fans, AC units, cooler etc are used but not during winter or cold season. Industries working during day time will consume only lighting load during night (10 pm to 6 am). Hence knowledge of variation of loads and their nature is essential for distribution planning. The load characteristics are usually presented as load curves and load duration curves

Load Curves: The load (power requirement) of any concern or unit is tabulated as the amount of power required or consumed during a certain period in a day, week or a given season.

Load-Duration Curves: This is a graph obtained from load curve showing the load in (kw) and duration over which it occurs in descending order of load magnitudes.

An overview of rate of computers in distributed system planning

As is well known, distribution system planners have used computers for many years to perform the tedious calculations necessary for system analysis. However, it has only been in the past few years that technology has provided the means for planners to truly take a system approach to the total design and analysis.



A schematic view of a distribution planning system

System Approach

A collection of computer programs to solve the analysis problems of a designer necessarily constitutes neither an efficient problem-solving system nor such a collection even when the output of one can be used as the input of another. The system approach to the design of a useful tool for the designer begins by examining the types of information required and its sources. The view taken is that this information generates decisions and additional information that pass from one stage of the design process to another. At certain points, it is noted that the human engineer must evaluate the information generated and add his or her input. Finally, the results must be displayed for use and stored for later reference.

With this conception of the planning process, the system approach seeks to automate as much of the process as possible, ensuring in the process that the various transformations of information are made as efficiently as possible. One representation of this information flow is shown in Figure, where the outer circle represents the interface between the engineer and the system. Analysis programs forming part of the system are supported by a database management system (DBMS) that stores, retrieves, and modifies various data on distribution systems

Database Concept

As suggested in Figure, the database plays a central role in the operation of such a system. It is in this area that technology has made some significant strides in the past 5 years so that not only is it possible to store vast quantities of data economically, but it is also possible to retrieve desired data with access times on the order of seconds.

The DBMS provides the interface between the process that requires access to the data and the data themselves. The particular organization that is likely to emerge as the dominant one in the near future is based on the idea of a relation. Operations on the database are performed by the *DBMS*.

New Automated Tools

In addition to the database management program and the network analysis programs, it is expected that some new tools will emerge to assist the designer in arriving at the optimal design. One such new tool that has appeared in the literature is known as a network editor. The network consists of a graph whose vertices are network components, such as transformers and loads, and edges that represent connections among the components.

The features of the network editor may include network objects, for example, feeder line sections, secondary line sections, distribution transformers, or variable or fixed capacitors, control mechanisms, and command functions. A primitive network object comprises a name, an object class description, and a connection list. The control mechanisms may provide the planner with natural tools for correct network construction and modification.

Load Modelling and Characteristics

Load modelling and characteristics

Depending upon the lemand variations the load are classified into 3 classes as a function of voltages. They are;

1. constant power ~~control~~ model
2. constant current ~~control~~ model
3. constant impedance model.

Constant power model: In constant power model, the load representation is most severe when the system stability is considered which is due to effect in amplifying voltage oscillations.

* A drop in voltage will cause increase in load current result in a further voltage drop.

Let S_R, S_Y, S_B be the apparent powers of R, Y, B phases respectively

$\theta_R, \theta_Y, \theta_B$ be the power factor angle of R, Y, B phases respectively

P_R, P_Y, P_B be the real powers of R, Y, B phases respectively

V_{RN}, V_{YN}, V_{BN} be the phase voltages of R, Y, B phases respectively

I_{LR}, I_{LY}, I_{LB} be the line currents of R, Y, B phases respectively

$\delta_R, \delta_Y, \delta_B$ be the load angles of R, Y, B phases respectively

Z_R, Z_Y, Z_B be the phase impedance of R, Y, B phases respectively.

Let us consider the load is star connected then the complex power is given by

At phase R : $|S_R| \angle \theta_R = P_R + jQ_R$

At phase Y : $|S_Y| \angle \theta_Y = P_Y + jQ_Y$

At phase B : $|S_B| \angle \theta_B = P_B + jQ_B$

similarly respective voltages is given by:

$$V_{RN} = |V_{RN}| \angle \delta_R$$

$$V_{YN} = |V_{YN}| \angle \delta_Y$$

$$V_{BN} = |V_{BN}| \angle \delta_B$$

The line currents of this load model is given by

$$S_R = P_R + jQ_R = V_{RN} * I_{LR}^*$$

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

$$\therefore \frac{|S_R| \angle \theta_R - \delta_R}{|V_{RN}|} \Rightarrow \frac{|S_R|^*}{|V_{RN}|} = \frac{|S_R|}{|V_{RN}|} \angle \delta_R - \theta_R$$

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

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

In this model, the line to neutral of phase voltages will change during each interaction until convergance is acheived.

Constant current model:

In this model, the magnitudes of currents are kept constant and voltage is changed which results in a change of current angle to keep power factor constant.

In this, the load Y star connected, then the line currents are given by;

$$I_{LR} = |I_{LR}| \angle \delta_R - \theta_R$$

$$I_{LY} = |I_{LY}| \angle \delta_Y - \theta_Y$$

$$I_{LB} = |I_{LB}| \angle \delta_B - \theta_B$$

Constant Impedance model:

In this model, first determine constant load, impedance from the specified complex power & assume phase voltages

$$Z = \frac{V}{I} = \frac{V}{\left(\frac{S}{V}\right)^*} = \frac{V}{\frac{S^*}{V^*}} = \frac{V \times V^*}{S^*}$$

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

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

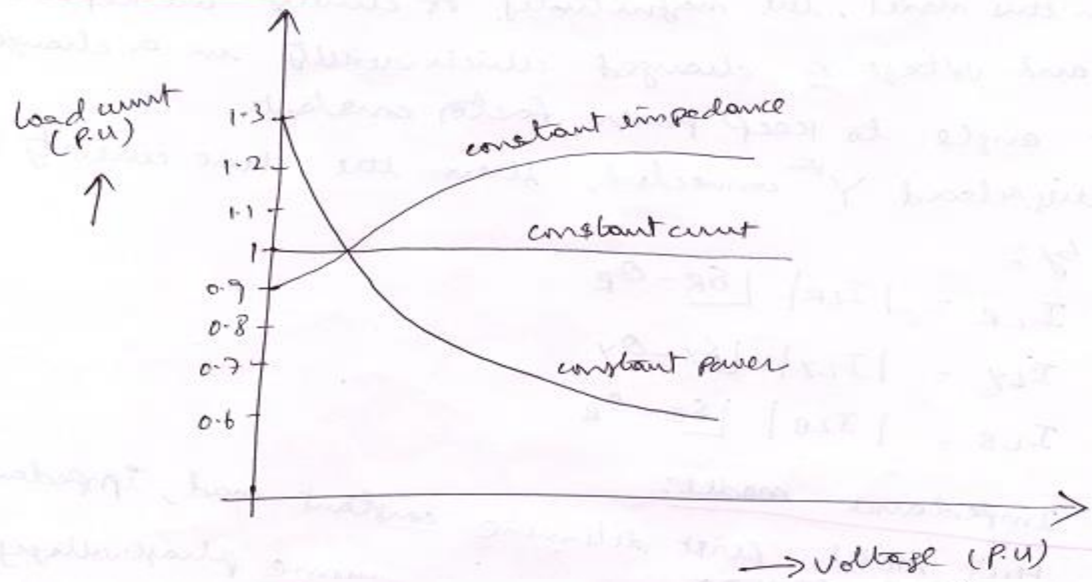
$$I_{LR} = \frac{V_{RN}}{Z_R} = \frac{|V_{RN}|}{|Z_R|} \angle \delta_R - \theta_R$$

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

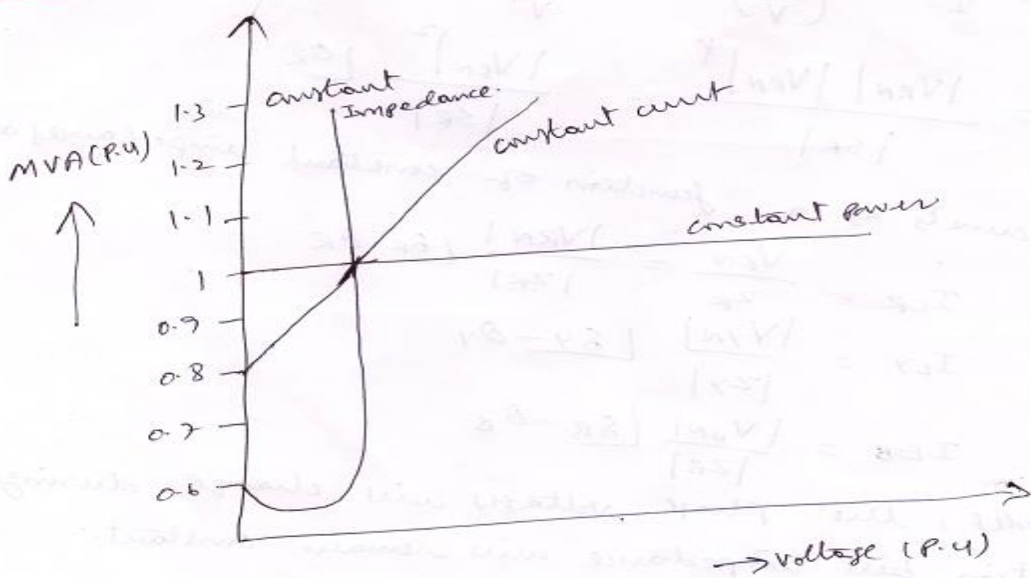
$$I_{LB} = \frac{|V_{BN}|}{|Z_B|} \angle \delta_B - \theta_B$$

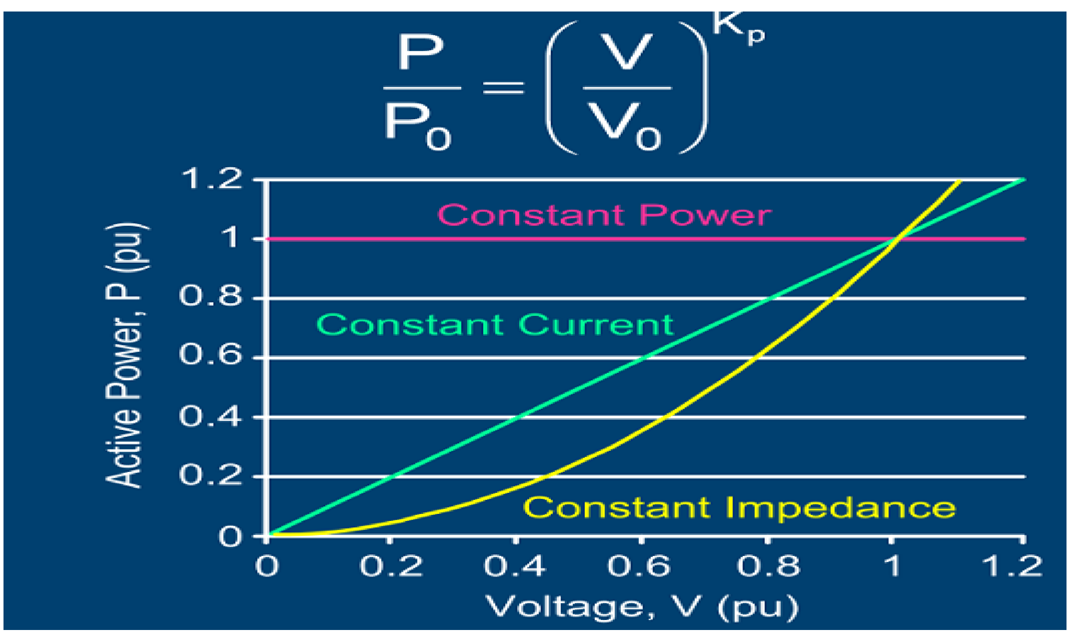
In this model, the phase voltages will change during each iteration but impedance will remain constant.

Relation between load current and load voltage:



Relation between load MVA and load voltage:





K_p Coefficient

$$K_p \approx \frac{\frac{\Delta P}{P_0}}{\frac{\Delta V}{V_0}}$$

Kp is also approximately the ratio of the power change in per unit (pu) to the voltage change in pu. This approximation provides a better idea of the value of Kp.

The equation shown in the above figure is used to represent the sensitivity of the real power requirements of a load for small voltage changes. In this equation, P is the new real power and P_0 is the previous real power (the difference between P and $P_0$is the change in real power). V is the new voltage, and V_0 is the previous voltage (the difference between V and V_0 is the change in voltage). The exponent, Kp, provides a measure of sensitivity of the load to voltage changes. It answers the question, for a given change in voltage, how do we expect the real power to change? The equation for reactive power, Q, is similar. These models are valid for voltage changes of plus or minus 10 percent. Assuming a constant frequency, the real power equation simplifies to that shown on the slide. If Kp is 0, then the load is constant real power (e.g., induction motors). If Kp is 1, then the load is constant current (e.g., fluorescent lighting). If Kp is 2, then the load is constant impedance (e.g., an electric range or stovetop).

Important Factors

Coincidence factor It is "the ratio of the maximum coincident total demand of a group of consumers to the sum of the maximum power demands of individual consumers comprising the group both taken at the same point of supply for the same time" [1]. Therefore, the coincidence factor (F_c) is

$$F_c \triangleq \frac{\text{coincident maximum demand}}{\text{sum of individual maximum demands}}$$

$$F_c = \frac{D_g}{\sum_{i=1}^{n} D_i}$$

Thus, the coincidence factor is the reciprocal of diversity factor; that is,

$$F_c = \frac{1}{F_D}$$

These ideas on the diversity and coincidence are the basis for the theory and practice of north-to-south and east-to-west interconnections among the power pools in this country. For example, during wintertime, energy comes from south to north, and during summer, just the opposite occurs. Also, east-to-west interconnections help to improve the energy dispatch by means of sunset or sunrise adjustments, i.e., the setting of clocks 1 h late or early.

Contribution factor Manning defines c_i as "the contribution factor of the ith load to the group maximum demand." It is given in per unit of the individual maximum demand of the ith load. Therefore,

$$D_g \triangleq c_1 \times D_1 + c_2 \times D_2 + c_3 \times D_3 + \cdots + c_n \times D_n \text{.........(1)}$$

Substituting Eq.(1) into Eq. $F_c = \frac{D_g}{\sum_{i=1}^{n} D_i}$,

$$F_c = \frac{c_1 \times D_1 + c_2 \times D_2 + c_3 \times D_3 + \cdots + c_n \times D_n}{\sum_{i=1}^{n} D_i}$$

or

$$F_c = \frac{\sum_{i=1}^{n} c_i \times D_i}{\sum_{i=1}^{n} D_i}$$

Special cases

Case 1: $D_1 = D_2 = D_3 = \cdots = D_n = D$. From above equation

$$F_c = \frac{D \times \sum_{i=1}^{n} c_i}{n \times D}$$

or

$$F_c = \frac{\sum_{i=1}^{n} c_i}{n}$$

That is, the coincident factor is equal to the average contribution factor.

Case 2: $c_1 = c_2 = c_3 = \cdots = c_n = c$. Hence, from above equation

$$F_c = \frac{c \times \sum_{i=1}^{n} D_i}{\sum_{i=1}^{n} D_i}$$

or

$$F_c = c$$

That is, the coincident factor is equal to the contribution factor.

Loss factor It is "the ratio of the average power loss to the peak-load power loss during a specified period of time" [1]. Therefore, the loss factor (F_{LS}) is

$$F_{LS} \triangleq \frac{\text{average power loss}}{\text{power loss at peak load}} \quad \text{........... (1)}$$

Equation (1) is applicable for the copper losses of the system but not for the iron losses.

Load diversity It is "the difference between the sum of the peaks of two or more individual loads and the peak of the combined load". Therefore, the load diversity (LD) is

$$\text{LD} \triangleq \left(\sum_{i=1}^{n} D_i \right) - D_g$$

Diversity factor It is "the ratio of the sum of the individual maximum demands of the various subdivisions of a system to the maximum demand of the whole system". Therefore, the diversity factor (F_D) is

$$F_D \triangleq \frac{\text{sum of individual maximum demands}}{\text{coincident maximum demand}}$$

or

$$F_D = \frac{D_1 + D_2 + D_3 + \cdots + D_n}{D_g}$$

or

$$F_D = \frac{\sum_{i=1}^{n} D_i}{D_g} \quad \text{......(1)}$$

where

D_i = maximum demand of load i, disregarding time of occurrence

$D_g = D_{1+2+3+\cdots+n}$

= coincident maximum demand of group of n loads

The diversity factor can be equal to or greater than 1.0.

From Eq. (2-1), the demand factor is

$$\text{DF} = \frac{\text{maximum demand}}{\text{total connected demand}}$$

or

$$\text{Maximum demand} = \text{total connected demand} \times \text{DF} \quad \text{........(2)}$$

Substituting Eq. (2) into Eq. (1), the diversity factor can also be

$$F_D = \frac{\sum_{i=1}^{n} \text{TCD}_i \times \text{DF}_i}{D_g}$$

where TCD_i = total connected demand of group, or class, i load

DF_i = demand factor of group, or class, i load

Loss factor: It is " the ratio o f the average power l o s s to the peak-load power loss during a specified period o f time"

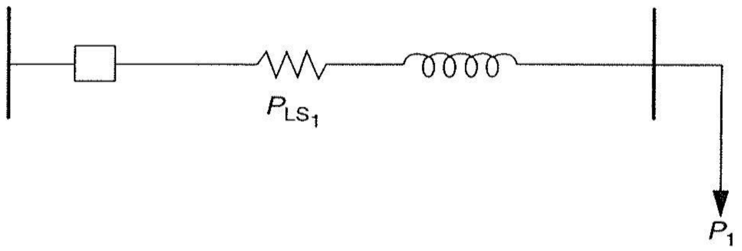
Relationship between Load & loss factors:

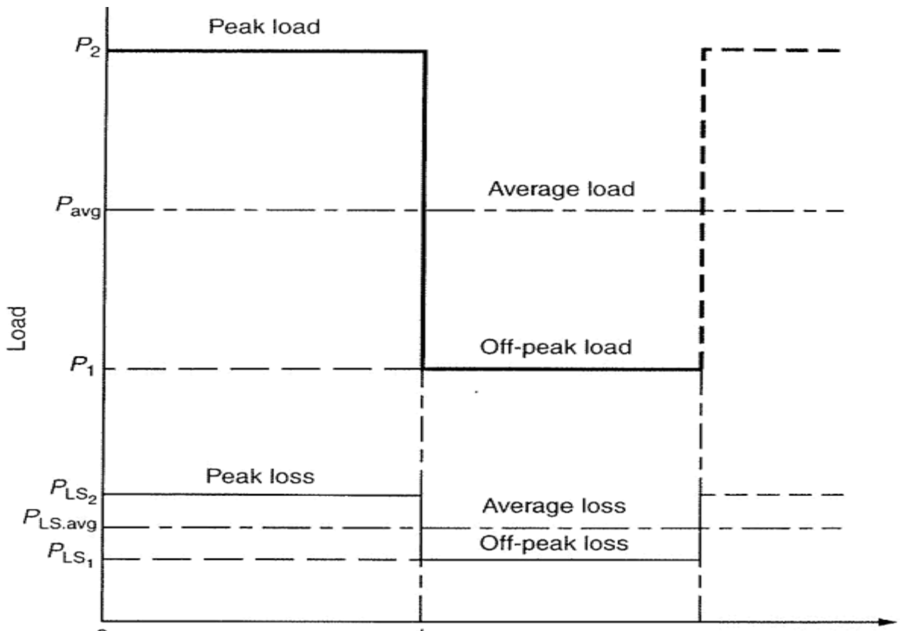
$$F_{LD} = \frac{P_{av}}{P_{max}} = \frac{P_{av}}{P_2}.$$

$$P_{av} = \frac{P_2 \times t + P_1 \times (T - t)}{T}.$$

$$F_{LD} = \frac{P_2 \times t + P_1 \times (T - t)}{P_2 \times T}$$

$$F_{LD} = \frac{t}{T} + \frac{P_1}{P_2} \times \frac{T - t}{T}$$





$$F_{LS} = \frac{P_{LS,av}}{P_{LS,max}} = \frac{P_{LS,av}}{P_{LS,2}},$$

Where $P_{Ls,avg}$ the average power loss, $P_{LS,max}$ is the maximum power loss, and $P_{LS,2}$ is the peak loss at peak load.

$$P_{LS,av} = \frac{P_{LS,2} \times t + P_{LS,1} \times (T-t)}{T}.$$

Substituting

Where $P_{Ls,avg}$ the average power loss, $P_{LS,max}$ is the maximum power loss, and $P_{LS,2}$ is the peak loss at peak load.

$$F_{LS} = \frac{P_{LS,2} \times t + P_{LS,1} \times (T-t)}{P_{LS,2} \times T},$$

Where $P_{LS,1}$ is the off-peak loss at off-peak load, *t* is the peak load duration, and *T - t i s* the off-peak load duration.

The copper losses are the function of the associated loads. Therefore, the off-peak and peak loads can be expressed, respectively, as

$$P_{LS,1} = k \times P_1^2$$

$$P_{LS,2} = k \times P_2^2$$

Where *k* is a constant. Thus, substituting Equations 2.32 and 2.33 into Equation 2.31, the loss factor can be expressed as

$$F_{LS} = \frac{(k \times P_2^2) \times t + (k \times P_1^2) \times (T-t)}{(k \times P_2^2) \times T}$$

$$F_{LS} = \frac{t}{T} + \left(\frac{P_1}{P_2}\right)^2 \times \frac{T-t}{T}.$$

Load factor can be related to loss factor for three different cases

Case 1: Off-peak load is zero. Here, $P_{LS,1} = 0$

Since P, = 0. Therefore $F_{LD} = F_{LS} = \frac{t}{T}.$

Since P, = 0. Therefore

That is, the load factor is equal to the loss factor and they are equal to the *t/T* constant

Case 2: Very short lasting peak. Here, $t \longrightarrow 0$

$$\frac{T-t}{T} \longrightarrow 1.0;$$

$$F_{LS} \longrightarrow (F_{LD})^2$$

That is, the value of the loss factor approaches the value of the load factor squared

Case 3: Load is steady. Here, $t \longrightarrow T.$

That is, the difference between the peak load and the off-peak load is negligible. For example, if the customer's load is a petrochemical plant, this would be the case

$$F_{LS} \longrightarrow F_{LD.}$$

That is, the value of the loss factor approaches the value of the load factor. Therefore, in general, the value of the loss factor is

$$F_{LD}^2 < F_{LS} < F_{LD}.$$

Therefore, the loss factor cannot be determined directly from the load factor. The reason is that the loss factor is determined from losses as a function of time, which, in turn, is proportional to the time function of the square load

However, Buller and Woodrow developed an approximate formula to relate the loss factor to the load factor as

$$F_{LS} = 0.3\,F_{LD} + 0.7\,F_{LD}^2$$

Where FLS is the loss factor (pu) and FLD is the load factor (pu).