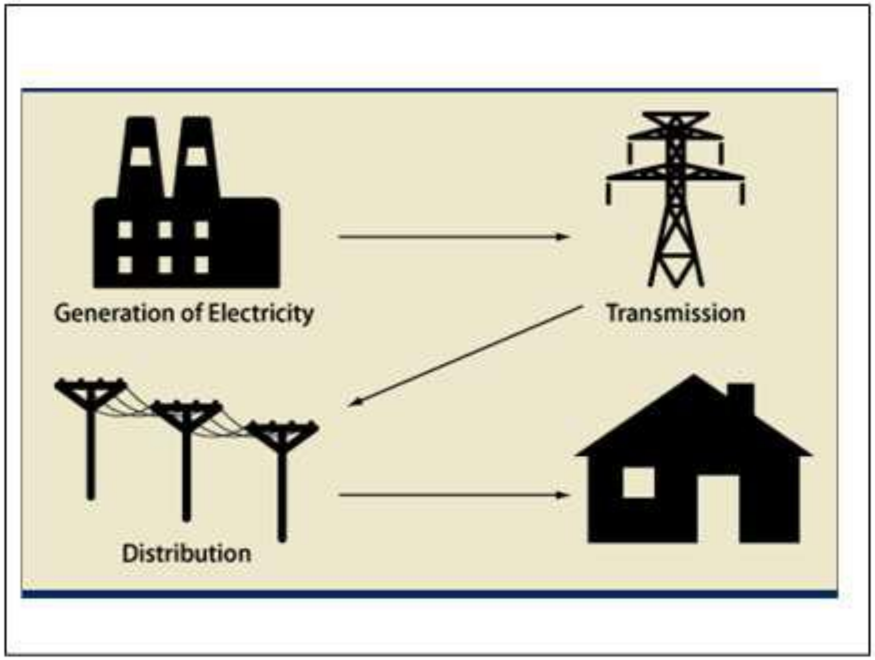
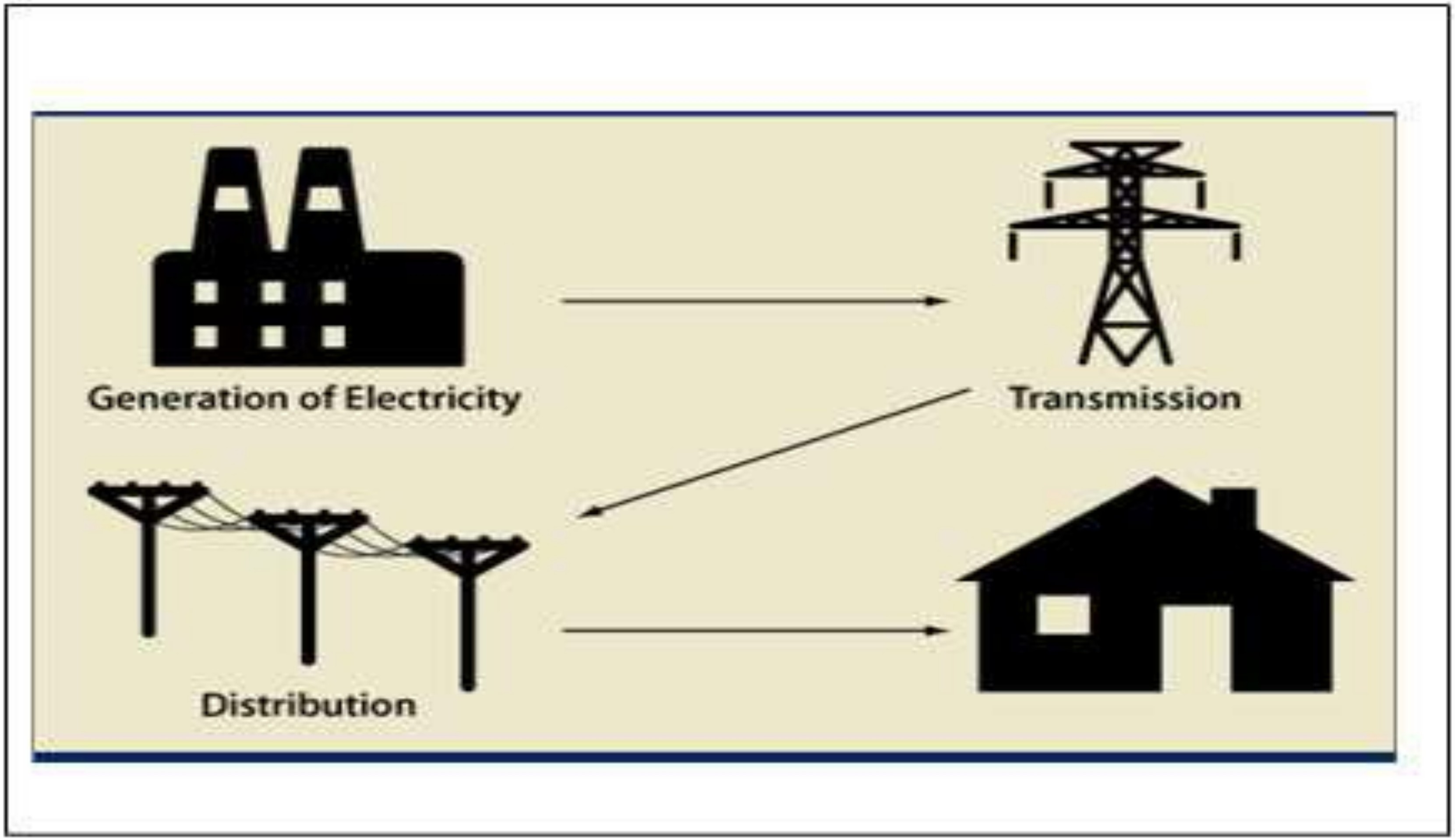
UNIT-I

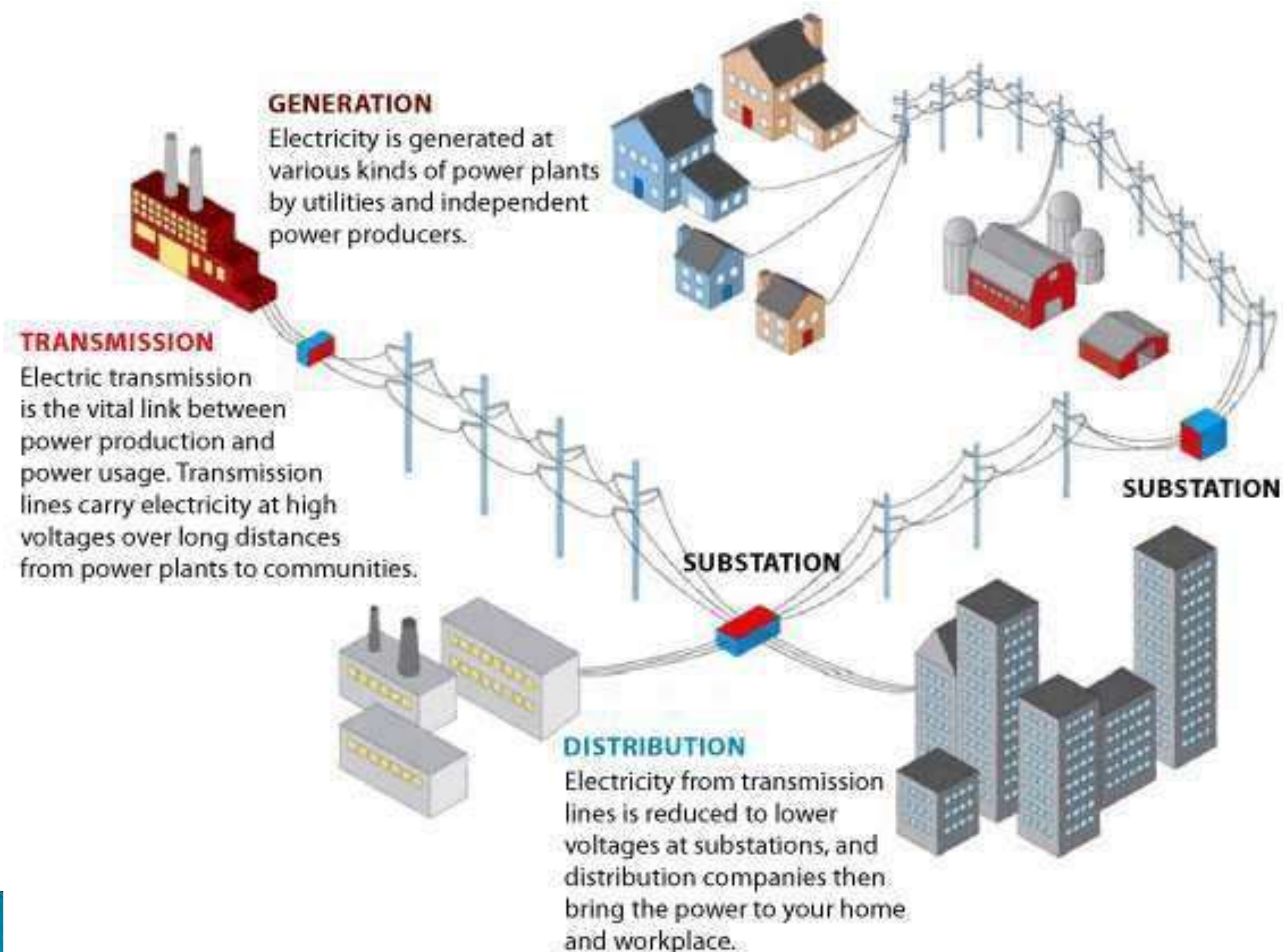
ELECTRICAL DISTRIBUTION SYSTEMS



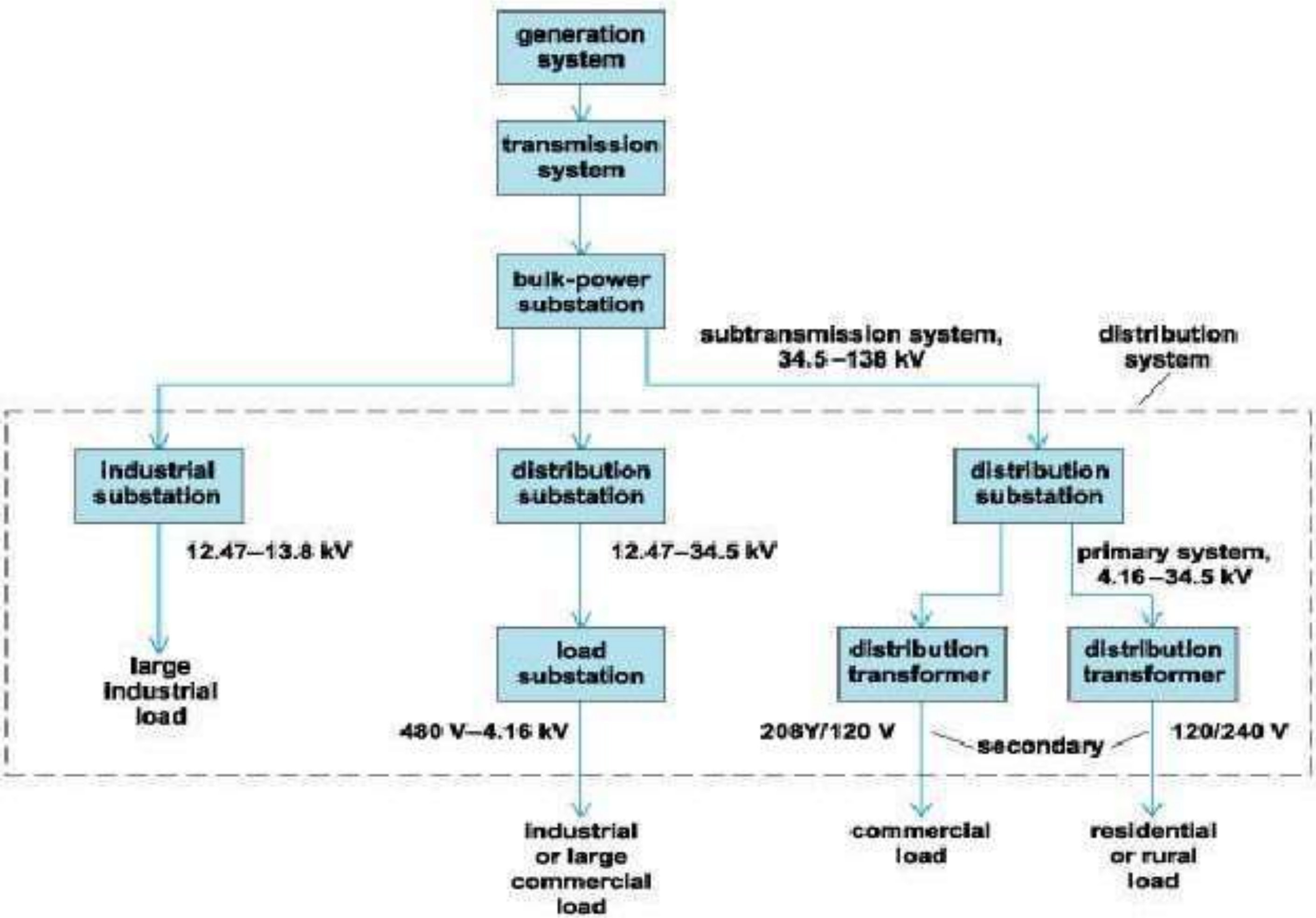
Departmen **Engineering**

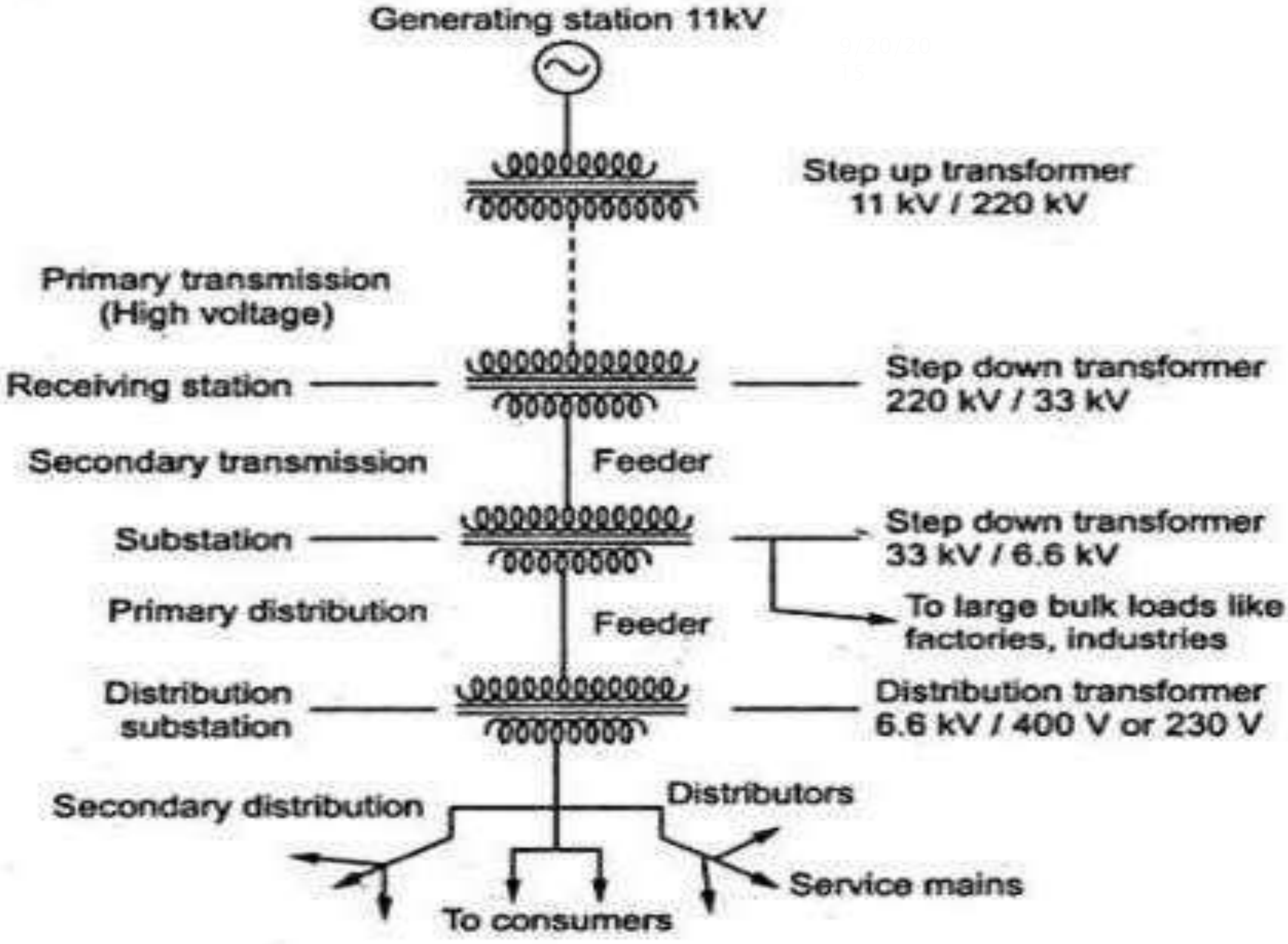
INTRODUCTION




GENERATION
Electricity is generated at various kinds of power plants by utilities and independent power producers.
TRANSMISSION
Electric transmission is the vital link between power production and power usage. Transmission lines carry electricity at high voltages over long distances from power plants to communities.
SUBSTATION
SUBSTATION
DISTRIBUTION
Electricity from transmission lines is reduced to lower voltages at substations, and distribution companies then bring the power to your home and workplace.

Distribution system layout




Generating station 11kV
Step up transformer
11 kV / 220 kV
Primary transmission
(High voltage)
Receiving station
Step down transformer
220 kV / 33 kV
Secondary transmission
Feeder
Substation
Step down transformer
33 kV / 6.6 kV
To large bulk loads like
factories, industries
Primary distribution
Feeder
Distribution
substation
Distribution transformer
6.6 kV / 400 V or 230 V
Secondary distribution
Distributors
Service mains
To consumers

DEFINITIONS

- **Demand:** The demand of a system is the load at receiving end over a specified time interval.
- **Maximum Demand:** The maximum demand of a system is the greater of all the demands within the time interval specified.
- **Diversified demand (or coincident demand):** It is the demand of the composite group, as a whole, of somewhat unrelated loads over a specified period of time.
- **Demand factor:** It is the "ratio of the maximum demand of a system to the total connected Load. It is dimension less.
- Demand factor is usually less than 1.0.
- Demand factor = Maximum demand/ Total connected demand
- **Non-coincident demand:** It is the sum of the demands of a group of loads with no restrictions on the interval to which each demand is applicable."
- **Connected load :** It is the sum of the continuous ratings of the load- consuming apparatus connected to the system
- **Utilization factor:** It is the ratio of the maximum demand of a system to the rated capacity of the system "

F_u = Maximum Demand/ rated system capacity

LOAD FACTOR:

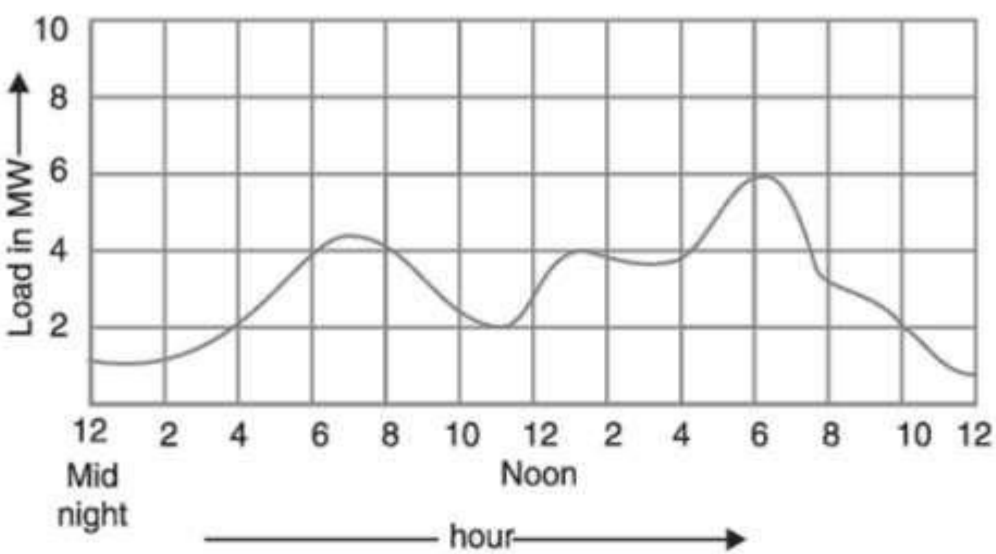
- **Load factor** is defined as the ratio of the average **load** over a given period to the maximum demand (peak **load**) occurring in that period.
- In other words, the **load factor** is the ratio of energy consumed in a given period of the times of hours to the peak **load** which has occurred during that particular period.
- It is the measure of utilization of electric energy during a given period to the maximum energy which would have been utilized during that period.
- **Load factor** plays a very **important** role in the cost of generation per unit (kWh).

DAILY LOAD CURVE

WHAT IS LOAD FACTOR?

ELECTRONICS HUB

Its Importance, Calculation and Improving



$$\text{Load Factor} = \frac{\textit{Average Load}}{\textit{Maximum Load}}$$

$$\text{Load Factor} = \frac{\textit{Energy Generated in the Given Period}}{\textit{Maximum Load X Hours of Operation}}$$

Diversity factor:

The diversity factor is the ratio of the sum of the maximum demands of the individual consumers and simultaneous maximum demand of the whole group during a particular time.

∴ Diversity factor

$$= \frac{\text{Sum of individual maximum demands}}{\text{Simultaneous maximum demand at a given time}}$$

Diversity factor is always greater than unity.

Plant Capacity factor:

It is defined as the ratio of actual energy produced in kilowatt hours (kWh) to the maximum possible energy that could have been produced during the same period.

$$\therefore \text{Plant capacity factor} = \frac{\text{Average load x 24}}{\text{Plant capacity x 24}} = \frac{\text{Average load}}{\text{Plant capacity}}$$

- Loss factor: Loss factor is the ratio of the average to the maximum power loss in a circuit variably loaded over a given period.

- **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"

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

- **Contribution f a c t o r :** 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 i_{th} load

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

$$F_{LD} = \frac{P_{av}}{P_{max}} = \frac{P_{av}}{P_2}. \quad D_g = c_1 \times D_1 + c_2 \times D_2 + c_3 \times D_3 + \cdots + c_n \times D_n.$$

Substituting Equation 2.18 into Equation 2.15,

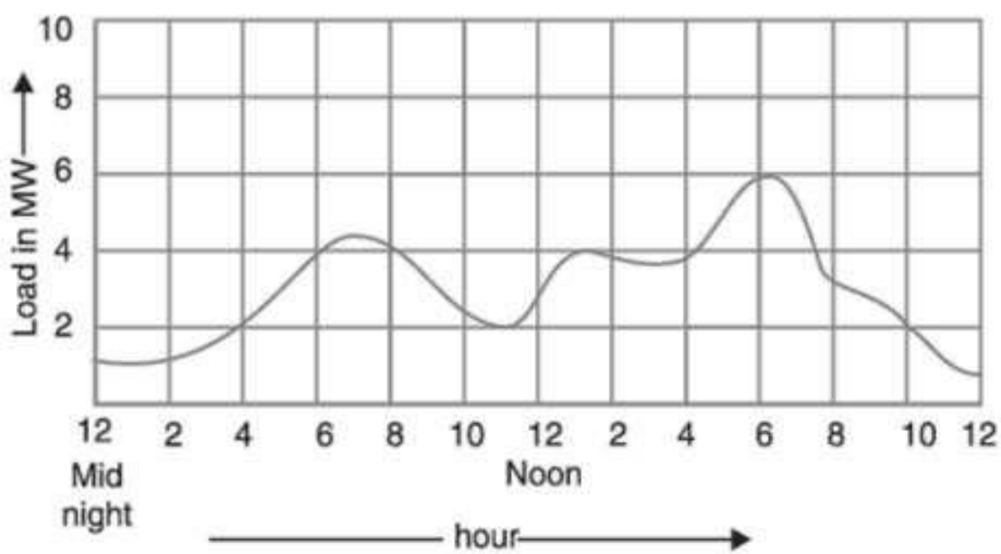
$$F_c = \frac{c_1 \times D_1 + c_2 \times D_2 + c_3 \times D_3 + \cdots + c_n \times D_n}{\sum_{i=1}^{n} D_i}$$

DAILY LOAD CURVE

WHAT IS LOAD FACTOR?

ELECTRONICS HUB

Its Importance, Calculation and Improving



$$\text{Load Factor} = \frac{\textit{Average Load}}{\textit{Maximum Load}}$$

$$\text{Load Factor} = \frac{\textit{Energy Generated in the Given Period}}{\textit{Maximum Load X Hours of Operation}}$$

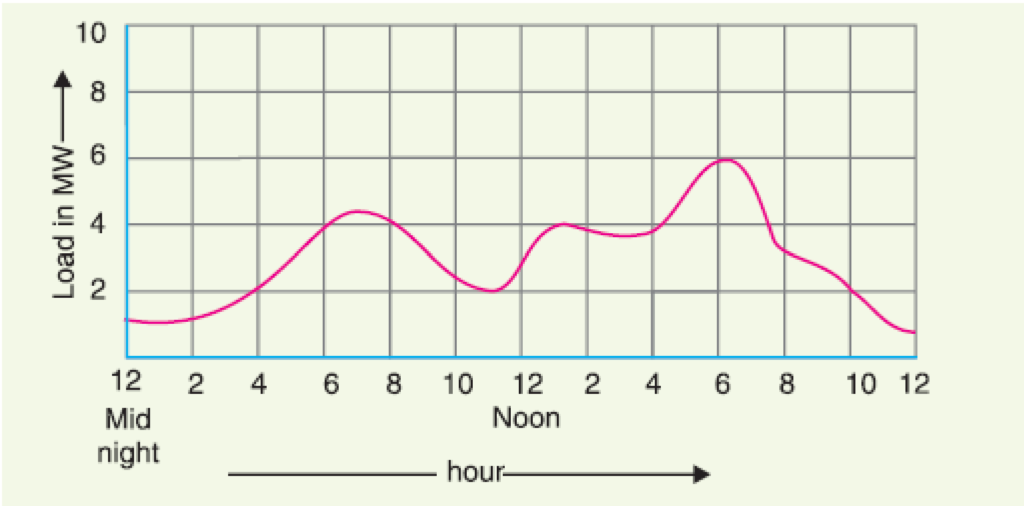
Importance of Load Curve:

- The Daily Load Curve gives the information of load on the power station during different running hours of the day.
- The number of unit's generation per day is found from the area under the daily Load Curve.
- Average load is found from the Load Curve.
- **Average load= [Area (KWh) under daily load curve/24 hours]**
- The maximum demand of the station on that day is found from the highest point of the daily Load Curve.
- The size and the number of generating units can be determined from the load curve.
- This Load Curve helps to determine the operation schedule of the station. In that case when all the units or the less units needs to running is found.

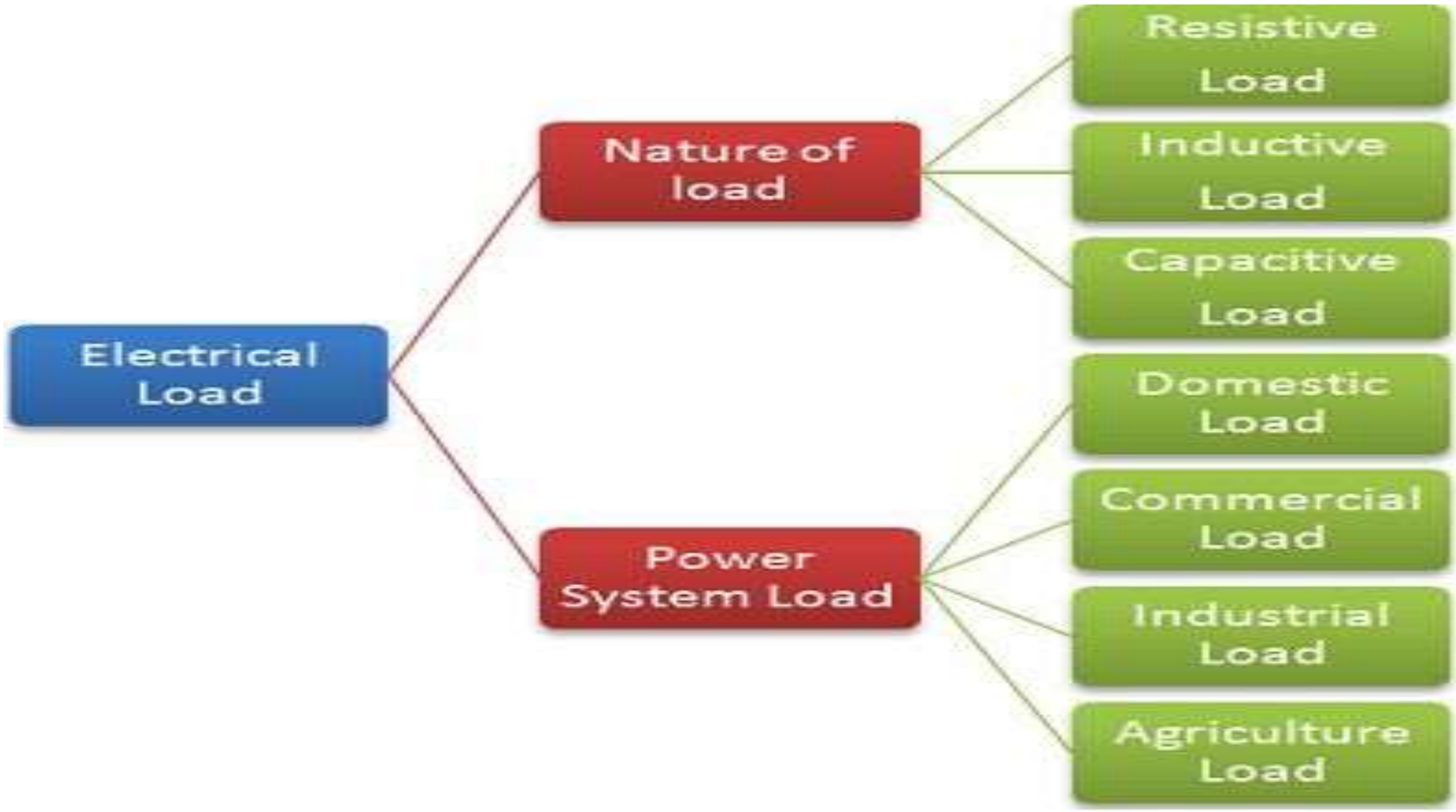
Load Curves

- *The curve showing the variation of load on the power station with respect to (w.r.t) time is known asa* ***load curve.***
- *DAILY LOAD CURVE*
- *MONTHLY LOAD CURVE*
- *YEARLYLOAD CURVE*

DAILY LOAD CURVE



TYPES OF LOADS



Municipal load.
Irrigation load.
Traction load.

Load Modeling and Characteristics

- Experimental results of load model parameter determination on a substation middle voltage level are shown in this paper. This substation supplies residential load.
- The obtained parameters are different from literature data, because they depend on many factors such as climatic, economic and social ones.
- The measurements are performed for different day intervals and week days during winter. It is pointed out that real and reactive power sensitivities on voltage vary with voltage value.
- Mean polynomial static characteristics are presented, too. The obtained static characteristics are approximated by an exponential model with constant coefficients in the examined voltage range

Load Characteristics

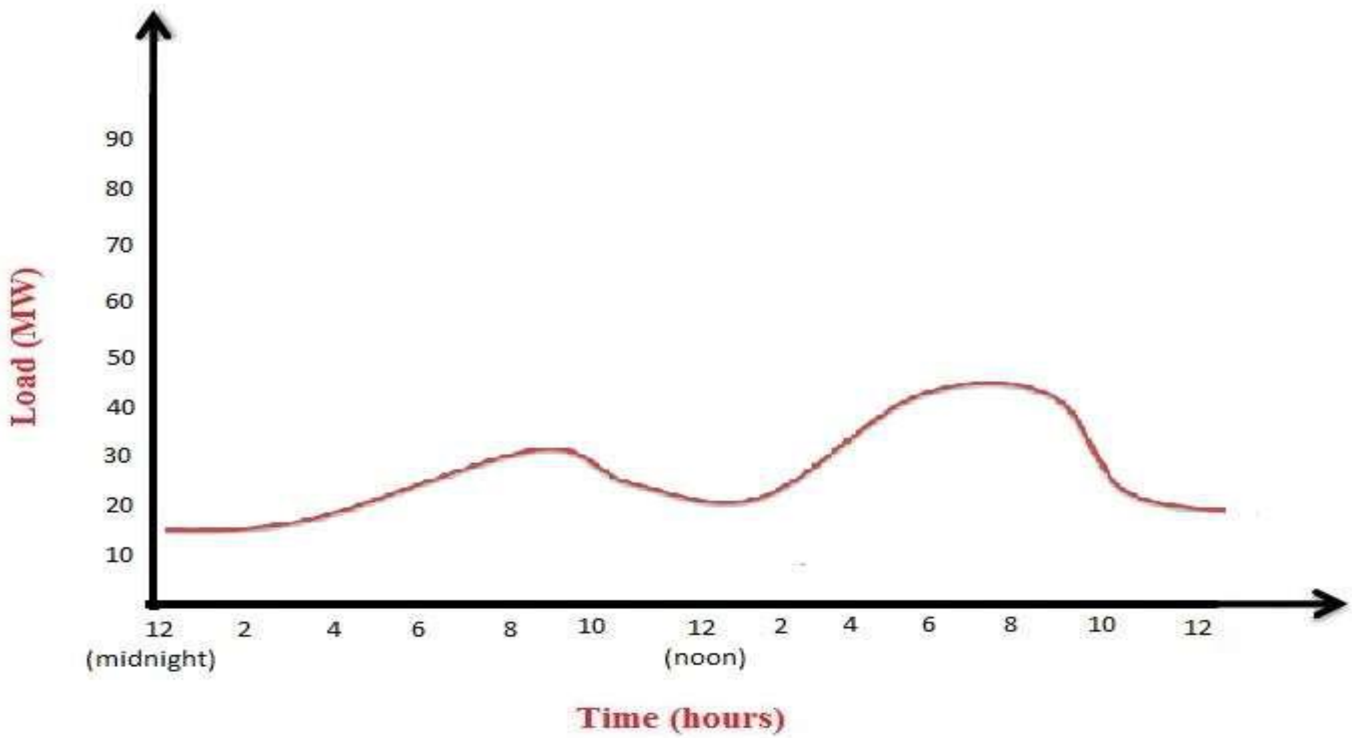


Figure: A typical daily load curve

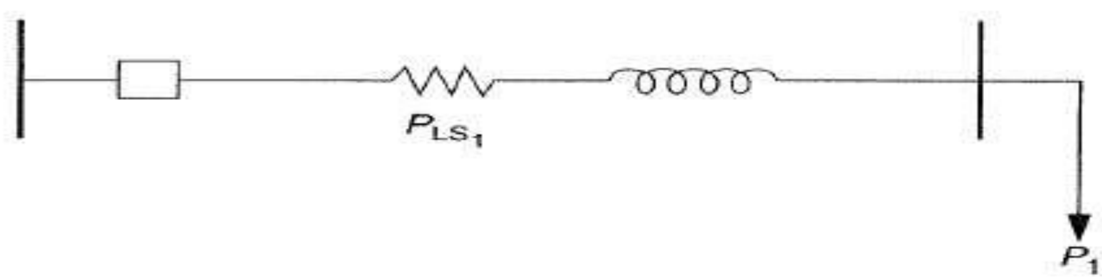
Relationship between the load and loss factors

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

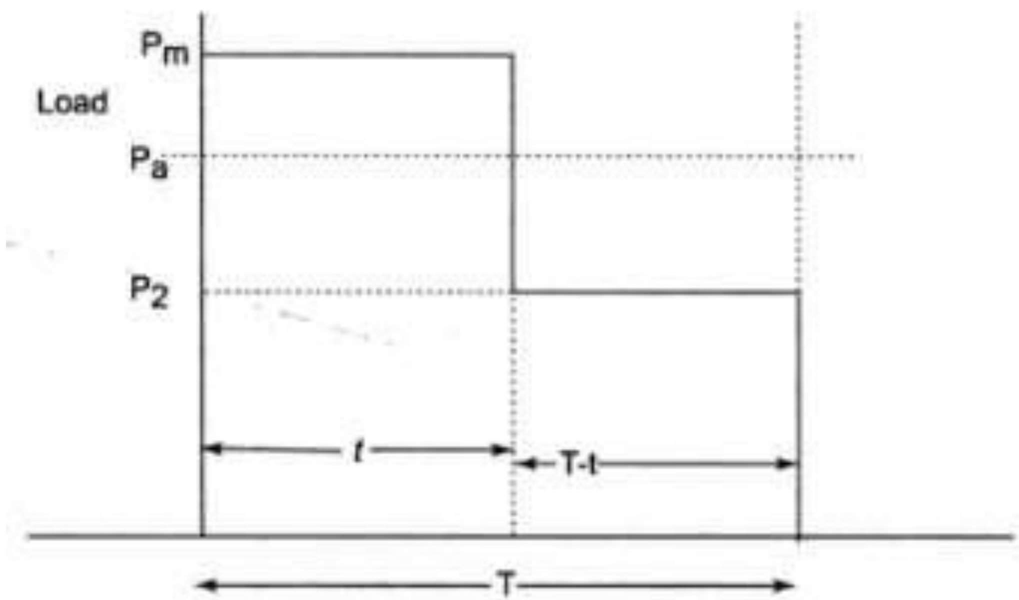
$$P_{av} = \frac{P_2 \times t + P_1 \times (T - t)}{T}.$$

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

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



Relationship between the load and loss factors



Example 3.2. *A generating station has a connected load of 43MW and a maximum demand of 20 MW; the units generated being* $61{\cdot}5 \times 10^6$ *per annum. Calculate (i) the demand factor and (ii) load factor.*

Solution.

(i)

$$\text{Demand factor} = \frac{\text{Max. demand}}{\text{Connected load}} = \frac{20}{43} = \mathbf{0{\cdot}465}$$

(ii)

$$\text{Average demand} = \frac{\text{Units generated / annum}}{\text{Hours in a year}} = \frac{61\cdot5\times10^6}{8760} = 7020 \text{ kW}$$

$$\therefore \quad \text{Load factor} = \frac{\text{Average demand}}{\text{Max. demand}} = \frac{7020}{20\times10^3} = \mathbf{0{\cdot}351} \text{ or } \mathbf{35{\cdot}1\%}$$

Example 3.3. *A 100 MW power station delivers 100 MW for 2 hours, 50 MW for 6 hours and is shut down for the rest of each day. It is also shut down for maintenance for 45 days each year. Calculate its annual load factor.*

Solution.

Energy supplied for each working day

$$= (100 \times 2) + (50 \times 6) = 500 \text{ MWh}$$

$$\text{Station operates for} = 365 - 45 = 320 \text{ days in a year}$$

$$\therefore \quad \text{Energy supplied/year} = 500 \times 320 = 160{,}000 \text{ MWh}$$

$$\text{Annual load factor} = \frac{\text{MWh supplied per annum}}{\text{Max. demand in MW} \times \text{Working hours}} \times 100$$

$$= \frac{160{,}000}{(100)\times(320\times24)} \times 100 = \mathbf{20{\cdot}8\%}$$

Example 3.4. *A generating station has a maximum demand of 25MW, a load factor of 60%, a plant capacity factor of 50% and a plant use factor of 72%. Find (i) the reserve capacity of the plant (ii) the daily energy produced and (iii) maximum energy that could be produced daily if the plant while running as per schedule, were fully loaded.*

Solution.

(*i*) $$\text{Load factor} = \frac{\text{Average demand}}{\text{Maximum demand}}$$

or $$0{\cdot}60 = \frac{\text{Average demand}}{25}$$

$$\therefore \quad \text{Average demand} = 25 \times 0{\cdot}60 = 15 \text{ MW}$$

$$\text{Plant capacity factor} = \frac{\text{Average demand}}{\text{Plant capacity}}$$

$$\therefore \quad \text{Plant capacity} = \frac{\text{Average demand}}{\text{Plant capacity factor}} = \frac{15}{0\cdot 5} = 30 \text{ MW}$$

$$\therefore \quad \text{Reserve capacity of plant} = \text{Plant capacity} - \text{maximum demand}$$

$$= 30 - 25 = \mathbf{5\ MW}$$

(*ii*) $$\text{Daily energy produced} = \text{Average demand} \times 24$$

$$= 15 \times 24 = \mathbf{360\ MWh}$$

(*iii*) Maximum energy that could be produced

$$= \frac{\text{Actual energy produced in a day}}{\text{Plant use factor}}$$

$$= \frac{360}{0\cdot 72} = \mathbf{500\ MWh/day}$$

Example 3.10. *A generating station has the following daily load cycle :*

Time (Hours)	*0—6*	*6—10*	*10—12*	*12—16*	*16—20*	*20—24*
Load (MW)	*40*	*50*	*60*	*50*	*70*	*40*

Draw the load curve and find (i) maximum demand (ii) units generated per day (iii) average load and (iv) load factor.

Solution. Daily curve is drawn by taking the load along Y-axis and time along X-axis. For the given load cycle, the load curve is shown in Fig. 3.6.

(*i*) It is clear from the load curve that maximum demand on the power station is 70 MW and occurs during the period 16—20 hours.

∴ Maximum demand = **70 MW**

Fig. 3.6

(*ii*) Units generated/day = Area (in kWh) under the load curve

$= 10^3\,[40 \times 6 + 50 \times 4 + 60 \times 2 + 50 \times 4 + 70 \times 4 + 40 \times 4]$

$= 10^3\,[240 + 200 + 120 + 200 + 280 + 160]$ kWh

$= \mathbf{12 \times 10^5}$ **kWh**

(*iii*) Average load $= \dfrac{\text{Units generated / day}}{\text{24 hours}} = \dfrac{12 \times 10^5}{24} =$ **50,000 kW**

(*iv*) Load factor $= \dfrac{\text{Average load}}{\text{Max. demand}} = \dfrac{50{,}000}{70 \times 10^3} = 0{\cdot}714 =$ **71·4%**

CLASSIFICATION OF DISTRIBUTION SYSTEMS

CONTENTS

- CLASSIFICATION OF DISTRIBUTION SYSTEMS
- COMPARISION OF AC AND DC SYSTEMS
- UNDER GROUND VS OVER HEAD SYSTEMS
- REQUIREMENTS AND DESIGN OF DISTRIBUTION SYSTEMS
- DESIGN CONSIDERATIONS OF DISTRIBUTION SYSTEMS
- RADIAL AND LOOP TYPE PRIMARY FEEDERS
- VOLTAGE LEVELS AND FEEDER LOADING
- VOLTAGE DROP CALCULATIONS

- **Feeder:** 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.
- **Distributor:** A distributor is a conductor from which tappings are taken for supply to the consumers.

  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.
- **Service mains:** A service mains is generally a small cable which connects the distributor to the consumers' terminals.

Classification of distribution systems

- AC & DC distribution system
- Over head and under ground systems
- Radial, ring main & inter connected systems

AC distribution systems:

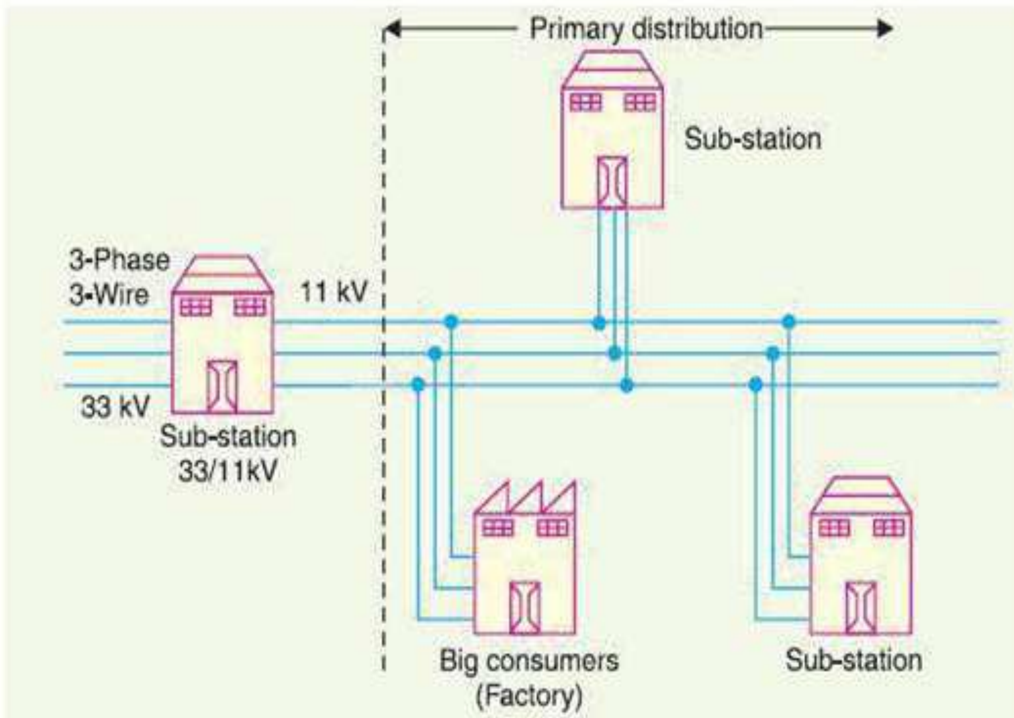
Now-a-days electrical energy is generated, transmitted and distributed in the form of alternating current.

- The a.c. distribution system is classified into

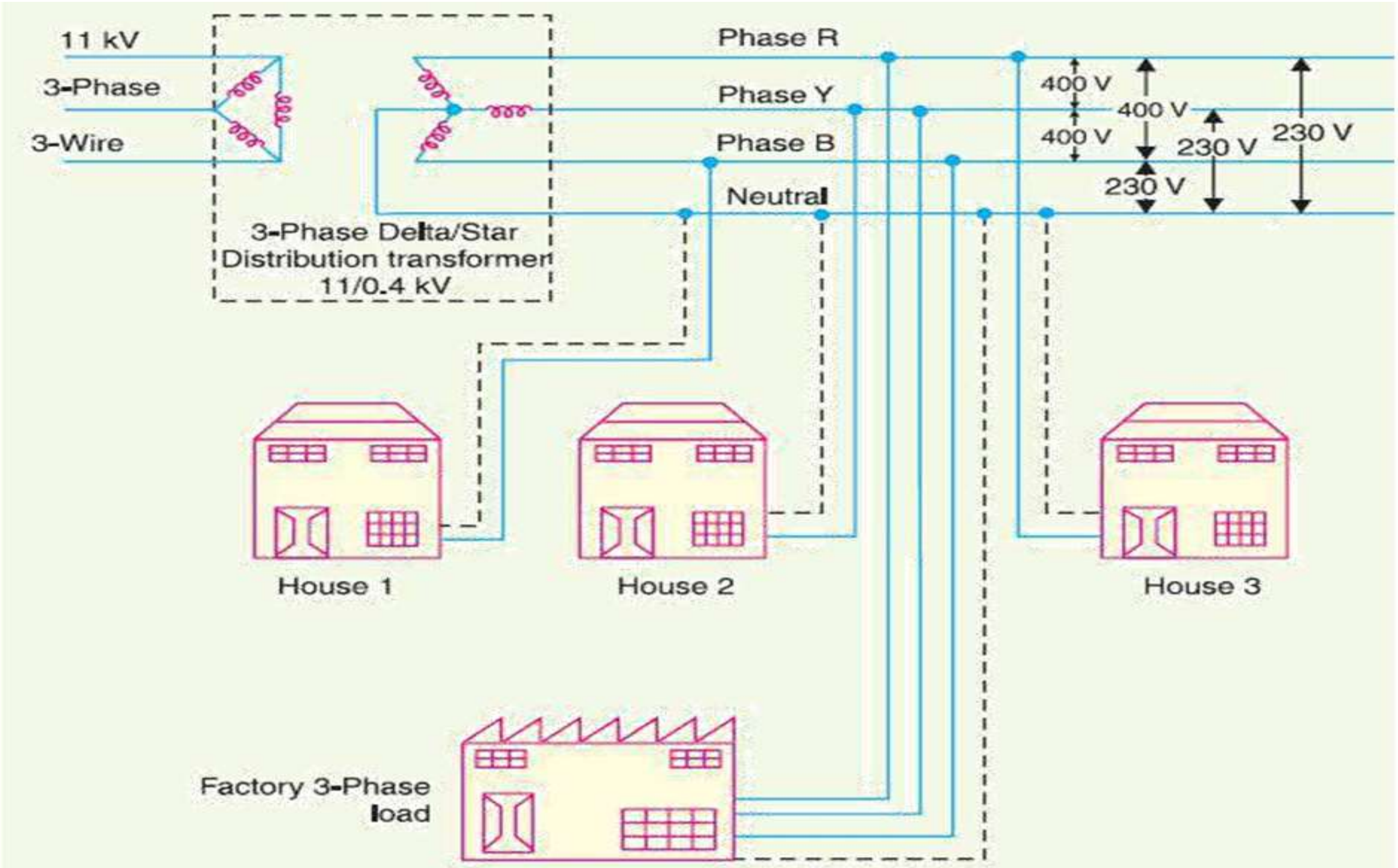
(i) primary distribution system

(*ii*) secondary distribution system.

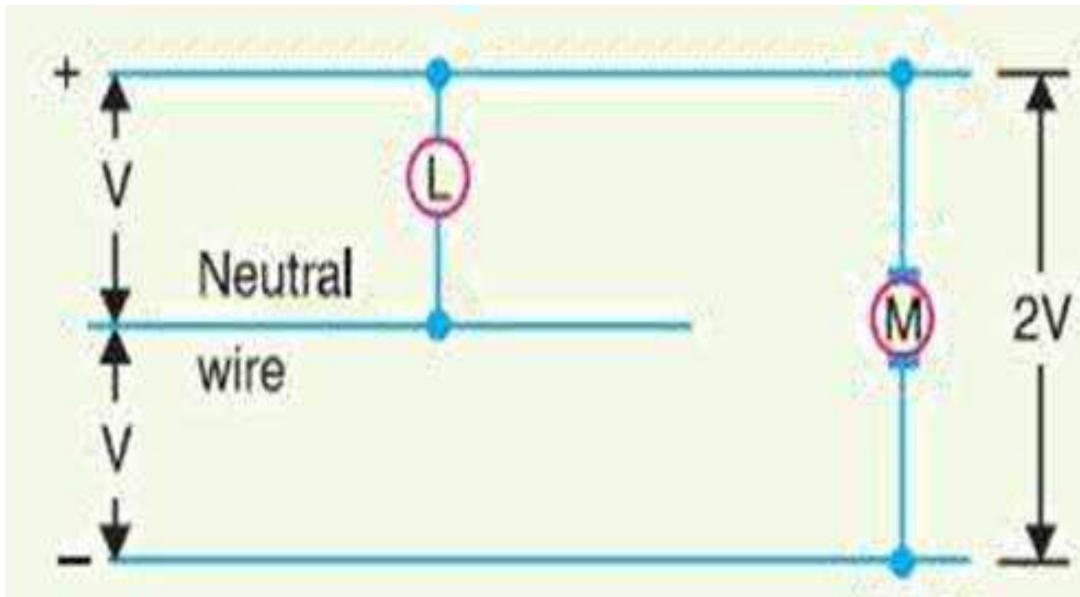
PRIMARY DISTRIBUTION SYSTEM



SECONDARY DISTRIBUTION SYSTEM



Dc distribution system



- **<u>D.C DISTRIBUTION:</u>**

ADVANTAGES:

- It requires only two conductors as compared to three for a.c. distribution.
- There is no inductance, capacitance, phase displacement and surge problems in d.c. distribution.
- Due to the absence of inductance, the voltage drop in a d.c. distribution line is less than the a.c. line for the same load and sending end voltage. For this reason, a d.c. distrib ution line has better voltage regulation.
- There is no skin effect in a d.c. system. Therefore, entire cross-section of the line conductor is utilized.
- For the same working voltage, the potential stress on the insulation is less in case of d.c. system than that in a.c. system. Therefore, a d.c. line requires less insulation.
- A d.c. line has less corona loss and reduced interference with communication circuits.
- The high voltage d.c. distrubution is free from the dielectric losses, particularly in the case of cables.
- In d.c. distrubution, there are no stability problems and synchronising difficulties.

DISADVANTAGES

- Electric power cannot be generated at high d.c. voltage due to commutation problems.
- The d.c. voltage cannot be stepped up for distrubution of power at high voltages.
- The d.c. switches and circuit breakers have their own limitations.

A.C. DISTRIBUTION:

ADVANTAGES:

- The power can be generated at high voltages.
- The maintenance of ac sub-stations is easy and cheaper.
- The ac voltage can be stepped up or stepped down by transformers with ease and efficiency. This permits to transmit power at high voltages and distribute it at safe potentials.

DISADVANTAGES:

- An a.c. line requires more copper than a dc line.
- The construction of ac distribution line is more complicated than a dc distribution line.
- Due to skin effect in the ac system, the effective resistance of the line is increased.
- An ac line has capacitance. Therefore, there is a continuous loss of power due to charging current even when the line is open.

OVERHEAD VERSUS UNDERGROUND SYSTEM

The choice between overhead andunderground system depends upon a number of widely differing factors.

- Public safety
- Initial cost
- Flexibility
- Faults
- Apperance
- Fault location repair

DESIGN CONSIDERATIONS IN DISTRIBUTION SYSTEM

(i) The total network area and load density

(ii) The number of primary feeders and its circuit distance

(iii) The number of outages, and time duration, per year

(iv) The number of planned or scheduled outages (for maintenance power cut etc.) and outage time per year

(v) The alternate or standby arrangement for the important loads in the area

(vi) The secondary and sub-system

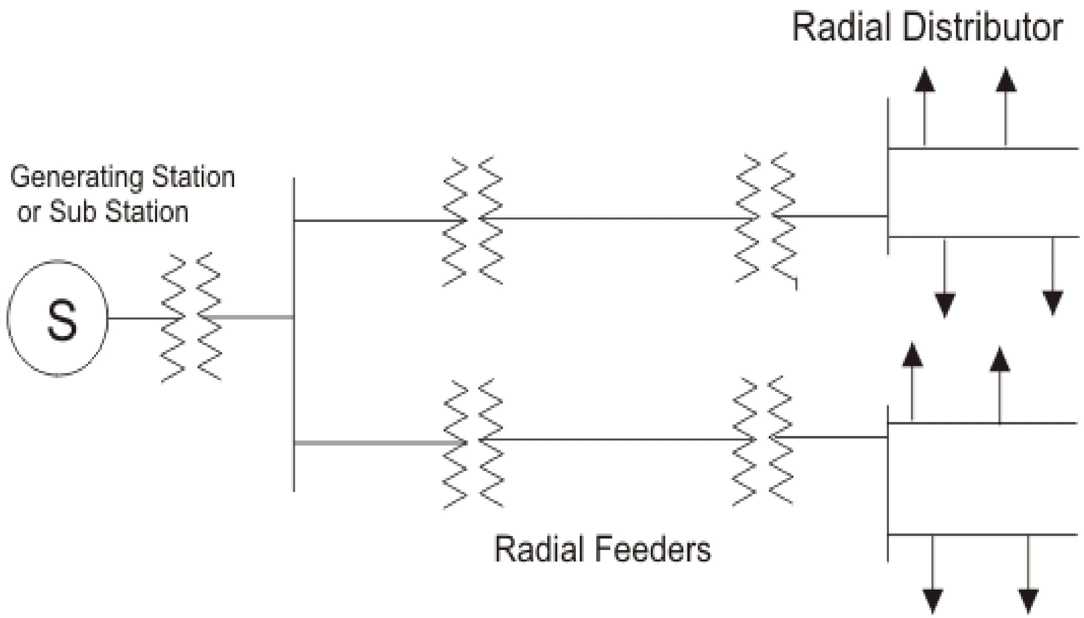
(vii) The number of main (primary) substations, the number of transformers to be installed

(viii) The secondary substations and LT system

REQUIREMENTS OF A DISTRIBUTION SYSTEM

- Proper voltage
- Availability of power on demand
- Reliability

RADIAL TYPE SYSTEMS



ADVANTAGES OF RADIAL TYPE FEEDER

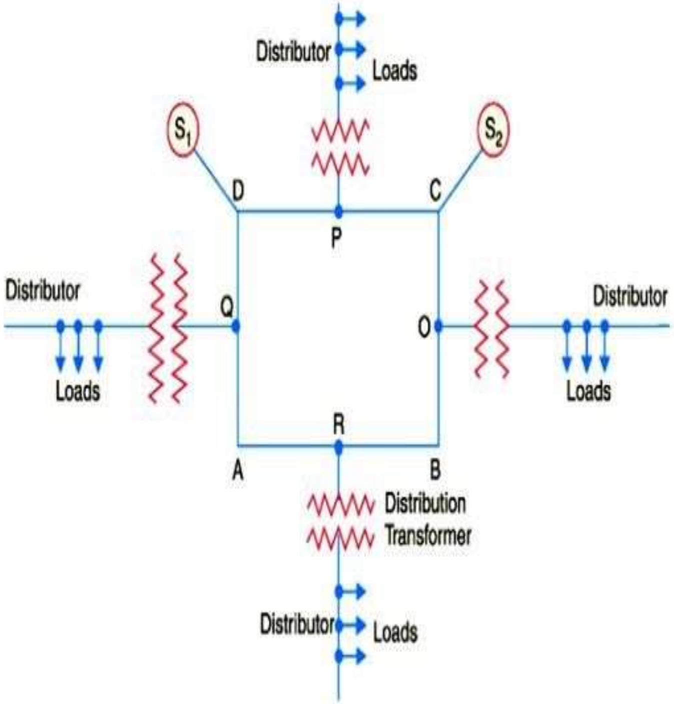
- Simplest as fed at only end.
- The initial cost is low.
- It is useful when the generating is at low voltage.
- Preferred when the station is located at the center of the load.
- More economical for some areas which have a low load requirement
- Require less amount of cables
- It has a low maintenance

DISADVANTAGES

- The end of distributor near to the substation gets heavily loaded.
- When load on the distributor changes, the clients at the distant end of the distributor face serious voltage fluctuations.
- As users are dependent on single feeder and distributor, a fault on any of these two causes interruption in supply to all the users connected to that distributor

3. Inter Connected System

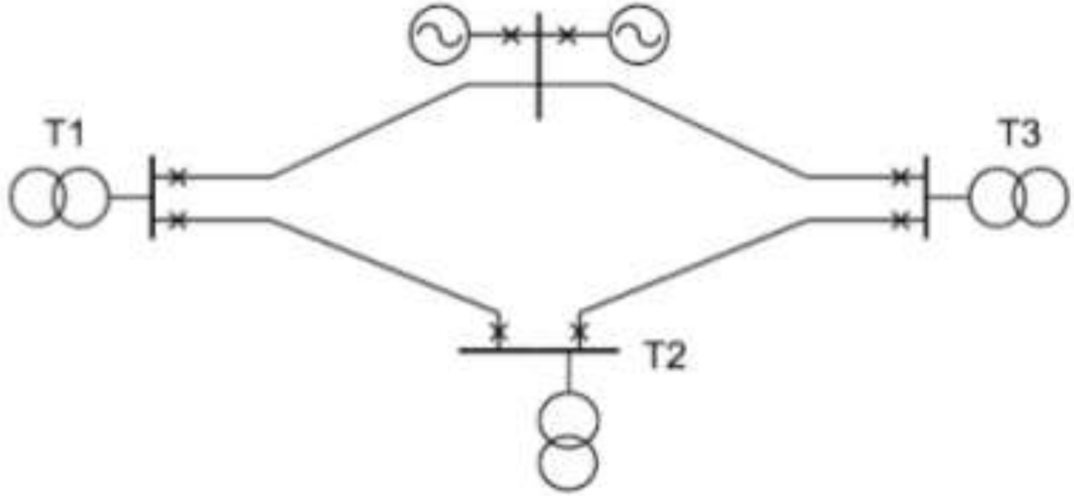
- When the feeder ring is energised by two or more than generating stations or substations, it is called inter-connected system. The single line diagram of interconnected system where the closed feeder ring ABCD is supplied by two substations S_1 and S_2 at points D and C respectively.
- Distributors are connected to points O, P, Q and R of the feeder ring through distribution transformers.



Advantages

- It increases the service reliability.
- 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.

Ring main distribution system



Advantage :
Essentially, meets the requirements of two alternative feeds to give 100% continuity of supply, whilst saving in cabling/copper compared to parallel feeders.

Disadvantage :
The fault currents in particular could vary depending on the exact location of the fault.

Typical distribution system

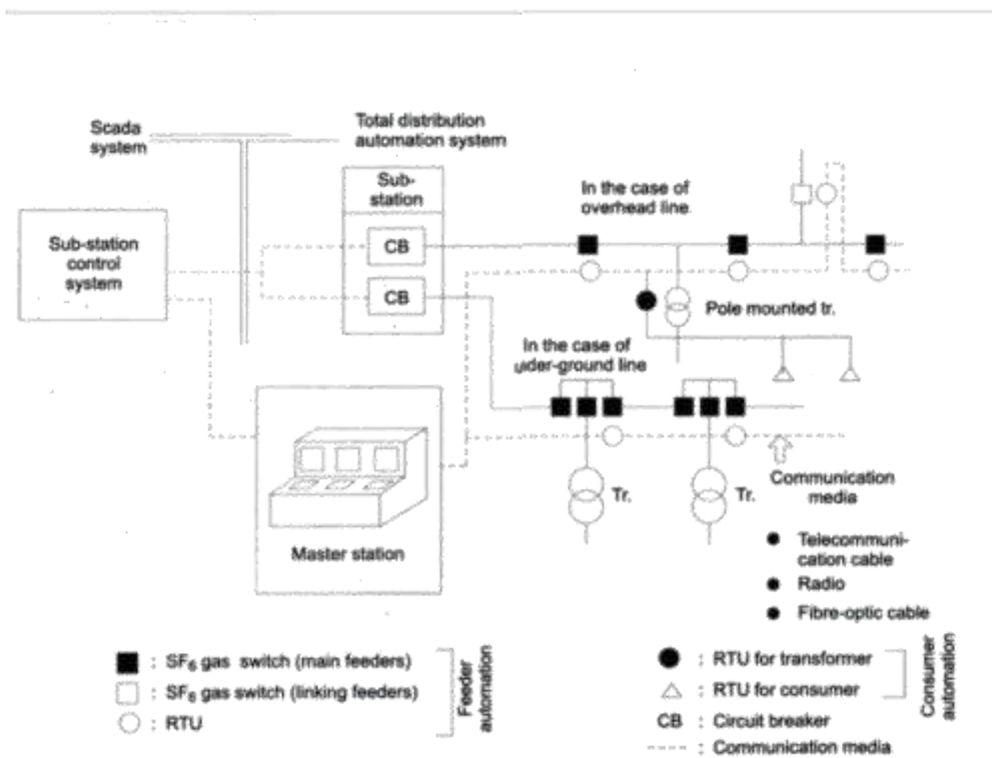


Fig. 5.14 *Typical distributionautomation system*

Unit-IV

OUTLINE

- Voltage Drop and Power-Loss Calculations?
- Methods of Solution for Radial Networks
- Methods of Improving P.F
- Most Economical P.F. for Constant KW Load
- Effect of Shunt Capacitors
- Power Factor Correction

VOLTAGE DROP AND POWER-LOSS CALCULATIONS

- SINGLE PHASE 2-WIRE LATERALS WITH GROUNDED NEUTRALS:
- Assume that an overloaded single-phase lateral is to be changed to an equivalent three-phase three-wire and balanced lateral, holding the load constant. As the power input lateral is

$$S_{1\phi} = S_{3\phi} \quad \text{---- 4.1}$$

$$\left(\sqrt{3} \times V_s\right) I_{1\phi} = 3V_s I_{3\phi}$$

$$I_{1\phi} = \sqrt{3} \times I_{3\phi} \quad \text{---- 4.2}$$

- The current in the single-phase lateral is 1.73 times greater than the one in the equivalent in three phase.

- The voltage drop in the three lateral can be expressed as

$$VD_{3\phi} = I_{3\phi}(R\cos\theta + X\sin\theta) \quad \text{---- 4.3}$$

$$VD_{1\phi} = I_{3\phi}(K_R R\cos\theta + K_X X\sin\theta) \quad \text{---- 4.4}$$

where K_R and K_X are conversion constants of R and X and are used to convert them from their three-phase values to the equivalent single-phase values.

K_R =2.0

K_X=2.0 | when underground cable is used

K_X=2.0 when overhead line is used, with approximately +10% accuracy.

$$VD_{1\phi} = I_{3\phi}(2R\cos\theta + 2X\sin\theta) \quad \text{---- 4.5}$$

$$VD_{1\phi} = \sqrt{3}\, I_{3\phi} \left(2R\cos\theta + 2X\sin\theta \right) \quad [\because I_{1\phi} = \sqrt{3}\, I_{3\phi}] \text{ From eq (1)}$$

$$VD_{1\phi} = 2\sqrt{3}\, I_{3\phi} \left(R\cos\theta + X\sin\theta \right) \quad \text{--- (4)}$$

$$\text{Eq} \frac{(4)}{(2)} \Rightarrow \frac{VD_{1\phi}}{VD_{3\phi}} = \frac{2\sqrt{3}\, I_{3\phi} \left(R\cos\theta + X\sin\theta \right)}{I_{3\phi} \left(R\cos\theta + X\sin\theta \right)}$$

$$\boxed{\frac{VD_{1\phi}}{VD_{3\phi}} = 2\sqrt{3}} \quad \text{--- (5)}$$

$$\boxed{VD_{1\phi} = 3.46\, VD_{3\phi}}$$

voltage drop in the 1ϕ ungrounded lateral is approximately 3.46 times larger than the 3ϕ lateral.

$$V_{B(1\phi)} = \sqrt{3} \times V_{S,L-N}$$

$$V_{B(3\phi)} = V_{S,L-N}$$

Substituting in eq (5) we get

$$\frac{VD_{pu,1\phi}}{VD_{pu,3\phi}} = \frac{2\sqrt{3} \times V_{s,L-N}}{V} \qquad \frac{V_{D1\phi}}{V_{D3\phi}} = 2\sqrt{3}$$

$$\boxed{\frac{VD_{pu,1\phi}}{VD_{pu,3\phi}} = 2.0}$$

The Power losses due to the load currents in the conductors of 1ϕ lateral and the equivalent 3ϕ lateral are

$$\boxed{P_{LS,1\phi} = 2 \times I_{1\phi}^2 R}$$

$$\boxed{P_{LS,3\phi} = 3 \times I_{3\phi}^2 R}$$

$$P_{LS,1\phi} = 2 \times (\sqrt{3}\, I_{3\phi})^2 R \quad [\text{From eq } ①]$$

$$P_{LS\,1\phi} = 2 \times 3\, I_{3\phi}^2 R$$

$$\frac{P_{LS,1\phi}}{P_{LS3\phi}} = \frac{2\times 3\, I_{3\phi}^2 R}{3\, I_{3\phi}^2 R}$$

$$\frac{P_{LS,1\phi}}{P_{LS,3\phi}} = 2.0$$

Power loss due to the load currents in the conductors of the 1-Ø lateral is two times larger than 3-Ø.

MANUAL METHODS OF SOLUTION FOR RADIAL NETWORKS

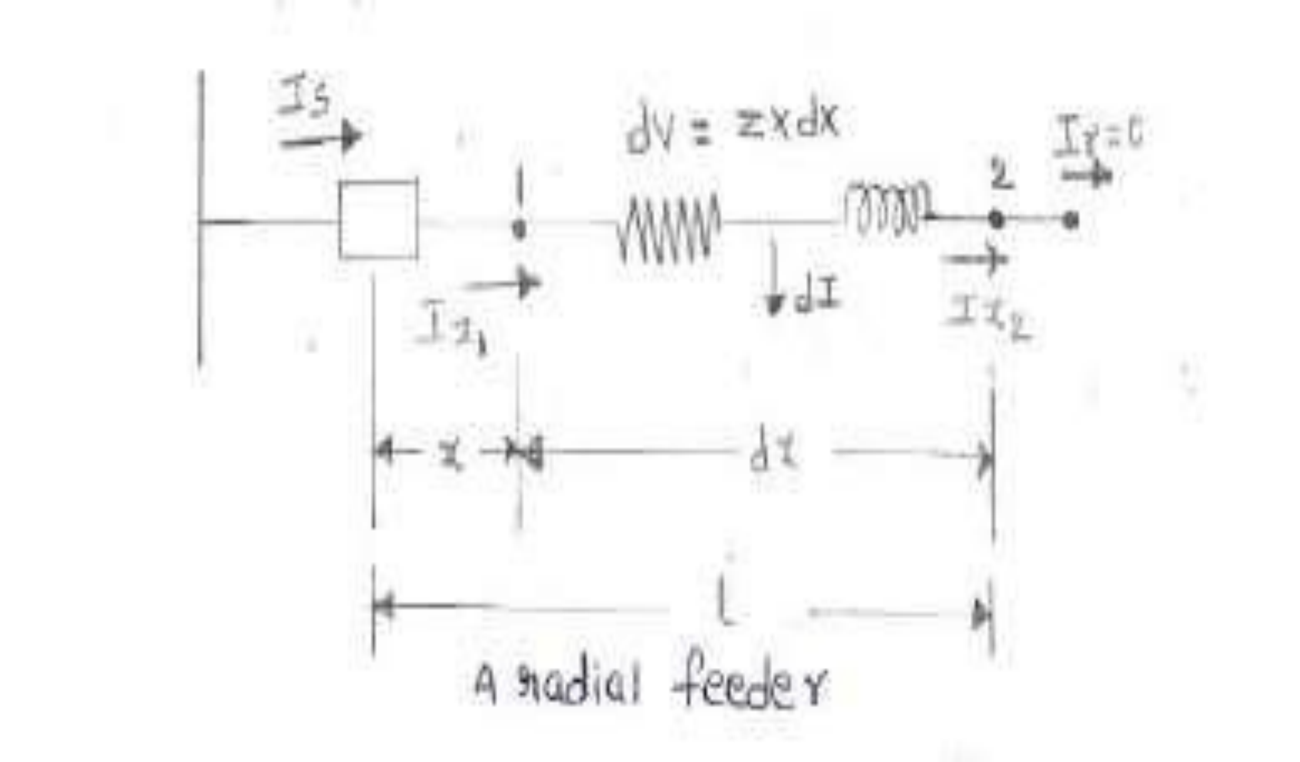


FIG: 4.1 RADIAL FEEDER

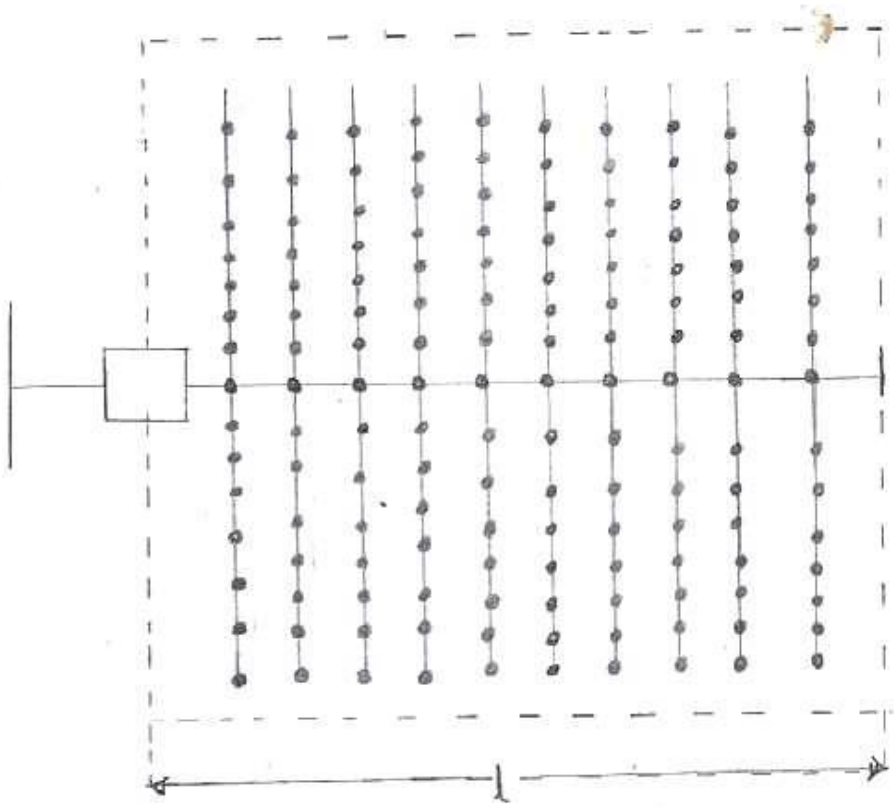


FIG: 4.2 UNIFORMLY DISTRIBUTED MAIN FEEDER

- The single line diagram illustrates a three-phase feeder main having the same construction that is in terms of cable size or open wire size and spacing, along its entire length ‘l’. Here line impedance z= r+jx per unit length. Since the load is uniformly distributed along the main, the load current in the main is a function of the distance here ‘l’ is the total length of the feeder.

- ‘x’ is the distance of the point ‘1’ on the feeder from the beginning end of the feeder.
- The distance of the point ‘2’ on the feeder from the beginning end of the feeder is x+dx. $I_s$is the sending end current I_r is the receiving end current Ix1 and Ix2 are currents at point 1 &2. As the load is uniformly distributed from 1 to 2 $\frac{di}{dx} = K$.
- I_x is the current in the main of some x of distance away from the circuit breaker can be found as function of sending end current I_s and distance x therefore for the dx distance.
-

$$I_{x_1} = I_{x_2} + dI$$

$$I_{x_2} = I_{x_1} - dI$$

$$I_{x_2} = I_{x_1} - \frac{dI}{dx} \cdot dx$$

$$I_{x_2} = I_{x_1} - K\,dx \quad \left[\text{From eq } ① \;\; K = \frac{dI}{dx}\right]$$

$$I_{x_1} = I_{x_2} + K\,dx$$

Therefore for the total feeder

$$\boxed{I_r = I_s - Kl} \quad \text{—— } ②$$

$$I_s = I_r + Kl$$

when $x = l$

From Eq ② $I_r = I_s - Kl = 0$ $[\because I_r = 0 \text{ at } x = l]$

$$I_s - Kl = 0$$

$$Kl = I_s$$

$$\boxed{K = \frac{I_s}{l}}$$

Substituting 'K' value in eq ②.

$$I_r = I_s - Kl \Rightarrow I_r = I_s - Kx \quad [\text{since } x = l]$$

$$I_r = I_s - \frac{I_s}{l} x$$

$$\boxed{I_r = I_s\left[1 - \frac{x}{l}\right]} \quad \text{—— ③}$$

For a given 'x' distance $I_x = I_r$

Eq ③ can be written as $\boxed{I_x = I_s\left[1 - \frac{x}{l}\right]}$ —— ④

which gives the current in the main at some 'x' distance away from the circuit breaker.

From eq ④ $I_s = \begin{cases} I_r = 0 & \text{at } x = l \\ I_r = I_s & \text{at } x = 0 \end{cases}$

The differential series voltage drop can be found as:

$$\boxed{dv = I_x \times z\,dx}$$

$$dv = I_s\left[1 - \frac{x}{l}\right] z\,dx \quad \left[\text{From eq ④ } I_x = I_s\left[1 - \frac{x}{l}\right]\right]$$

$$\boxed{dv = I_s \times z\left[1 - \frac{x}{l}\right] dx}$$

the series voltage drop VD_x because of 'I_x' current at any point 'x' on the feeder is

$$VD_x = \int_0^x dv$$

$$VD_x = \int_0^x I_s \times z \left[1 - \frac{x}{l}\right] dx$$

$$VD_x = I_s z \left[x - \frac{x^2}{2l}\right]$$

$$VD_x = I_s z x \left[1 - \frac{x}{2l}\right].$$

∴ The total series voltage drop ΣVD_x on the main feeder when $x = l$ is:

$$\Sigma VD_x = I_S z l \left[1 - \frac{l}{2l}\right]$$

$$\boxed{\Sigma VD_x = \frac{1}{2} I_S z l}.$$

Differential Power loss $\boxed{dP_{LS} = I_x^2 \times r dx}$

$$dP_{LS} = \left[I_S \left(1 - \frac{x}{l}\right)\right]^2 r dx \quad \left[\text{From eq (4)} \; I_x = I_S\left[1 - \frac{x}{l}\right]\right]$$

$$dP_{LS} = I_S^2 \left[1 - \frac{x}{l}\right]^2 r \, dx.$$

The total copper loss per phase in the main because of I^2R losses is

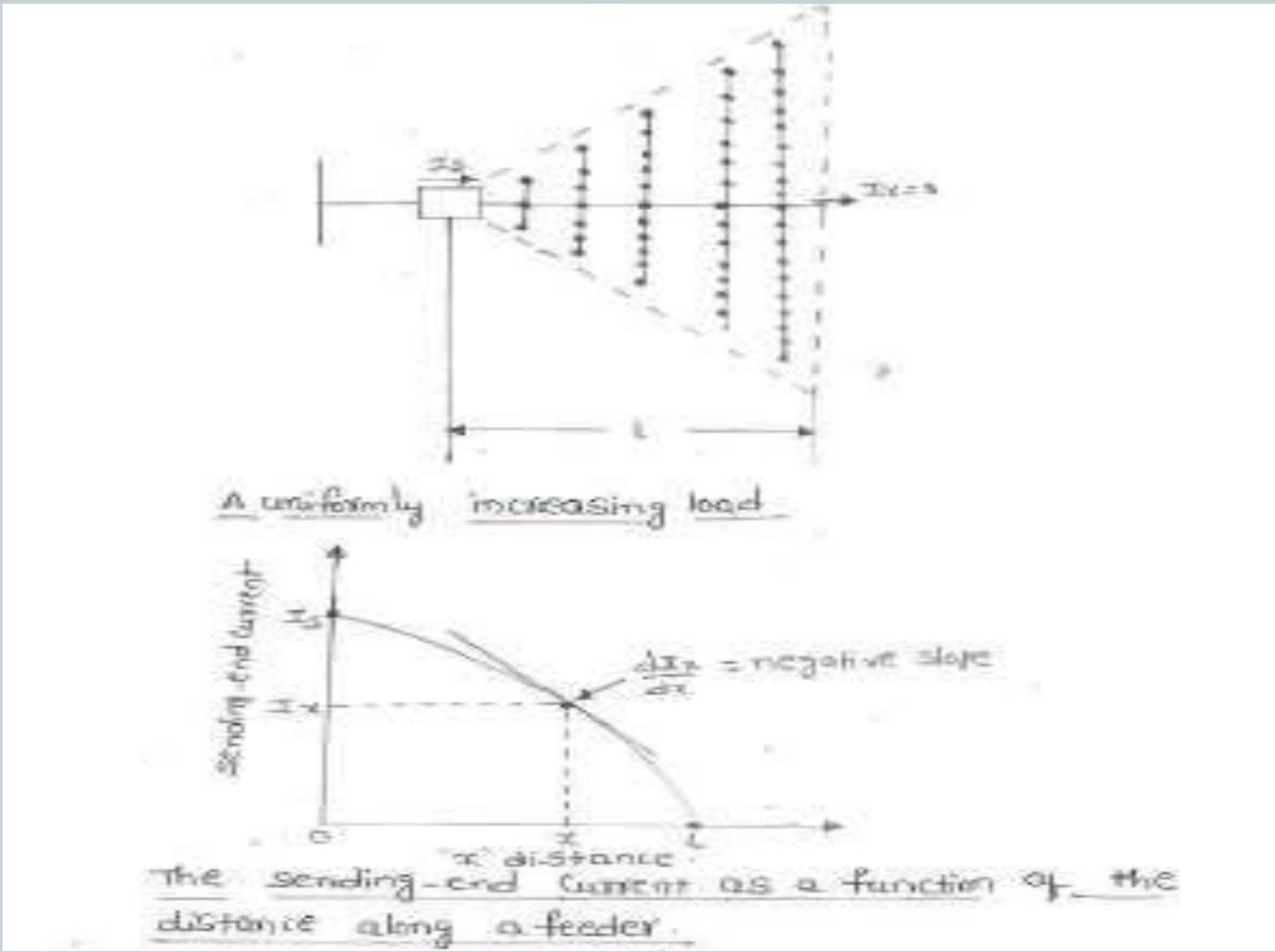
$$\Sigma P_{LS} = \int_0^l dP_{LS}$$

$$= \int_0^l I_S^2 r \left[1 - \frac{x}{l}\right]^2 dx$$

$$\boxed{\Sigma P_{LS} = \frac{1}{3} I_S^2 r l}.$$

RADIAL FEEDERS WITH NON UNIFORM DISTRIBUTED LOAD

FIG: 4.3 A UNIFORMLY INCREASING LOAD



A uniformly increasing load

The sending-end current as a function of the distance along a feeder.

- The single line diagram illustrates 3Ø feeder main which has the tapped-off load increasing linearly with distance ‘x’. Note that load is zero when x=0.

The negative slope can be written as

$$\frac{dI_x}{dx} = -K \times I_S \times x \quad \text{—— (1)}$$

'K' is constant can be found from

$$I_S = \int_{x=0}^{l} -dI_x$$

$$= \int_{x=0}^{l} K \times I_S \times x \, dx$$

$$I_S = K I_S \left[\frac{x^2}{2}\right]_0^l$$

$$I_S = K I_S \frac{l^2}{2}$$

$$K = \frac{2}{l^2}$$

Substituting 'K' value in eq (1)

$$\frac{dI_x}{dx} = -\frac{2}{l^2} I_S x$$

$$\frac{dI_x}{dx} = -2 I_S \frac{x}{l^2}$$

∴ The current in the main at some 'x' distance away from the circuit breaker can be found as

$$I_x = I_S \left[1 - \frac{x^2}{l^2}\right] \quad \text{—— (2)}$$

The differential series voltage drop

$$\overline{dV} = I_x \times z\,dx$$

$$\overline{dV} = I_s\left[1-\frac{x^2}{l^2}\right] z\,dx \quad \text{[From ②]}$$

$$\overline{dV} = I_s z\left[1-\frac{x^2}{l^2}\right] dx$$

The series voltage drop because of I_x current at any point 'x' on the feeder is $VD_x = \int_0^x \overline{dV}$

$$VD_x = \int_0^x I_S z \left[1 - \frac{x^2}{l^2}\right] dx$$

$$VD_x = I_S z x \left[1 - \frac{x^2}{3l^2}\right]$$

∴ The total series voltage drop on the main feeder when $x = l$ is

$$\Sigma VD_x = \frac{2}{3} z l I_S$$

The differential power loss $dP_{LS} = I_x^2 \times r\, dx$

$$dP_{LS} = I_S^2 r \left[1 - \frac{x^2}{l^2}\right]^2 dx.$$

The total copper loss per phase in the main as a result of I^2R losses is

$$\Sigma P_{LS} = \int_0^l dP_{LS}$$

$$= \int_0^l I_S^2 r \left[1 - \frac{x^2}{l^2}\right]^2 dx$$

$$\Sigma P_{LS} = \frac{8}{15} I_S^2 r l$$

ELECTRICAL DISTRIBUTION SYSTEM

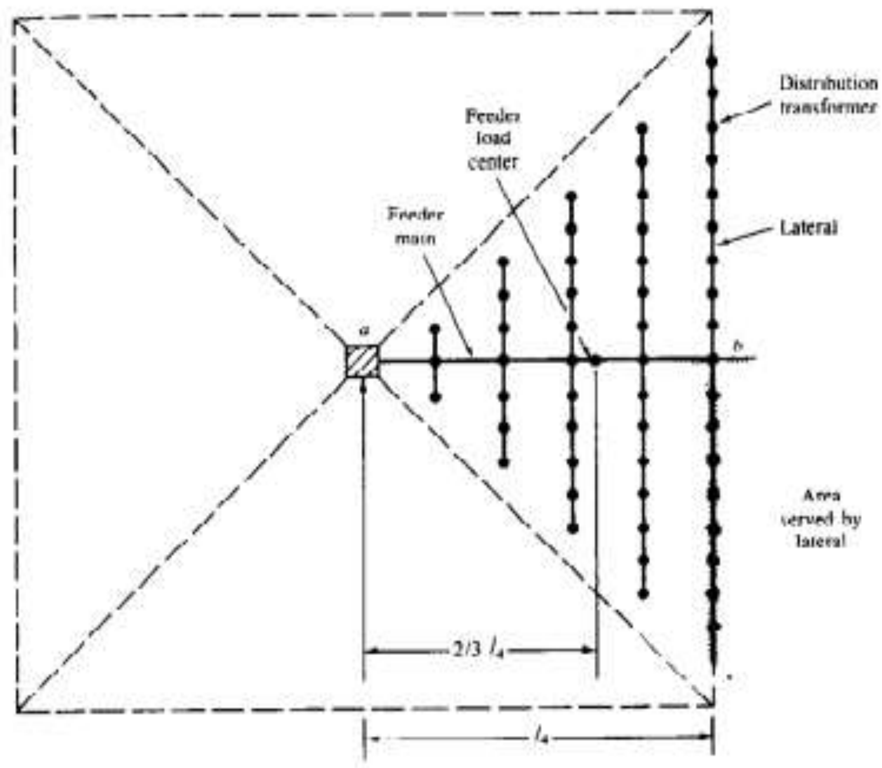
RATING OF DISTRIBUTION SUBSTATION

- The rating of distribution substation depends up on the load density and service area
- With increase in load density the additional load requirement can be met by

1. Either service area of given distribution substation maintaining constant and increasing its rating
2. By installing new distribution substation.

Voltage Drop at Substation Main Feeders

- The analysis of voltage drop at squire shaped service area represents the entire served area of a distribution substation
- Assume the squire shaped service area is fed by four primary feeders from central fed point as shown in Figure each feeder and laterals are of three phase.



voltage drop at squire shaped service area

- each feeder serves a total load of

$$S_4 = A_4 \times D \quad KVA$$

Where S_4= *KVA Load served by one of four feeders*

A_4= *Area served by one of four feeders*

D = *load density*

Here area served by one of four feeders is A_4= $(l4)^2$

- The voltage drop at main primary feeder is

$$\% VD_{4,main} = 2/3 \times l_4 \times K \times S_4$$

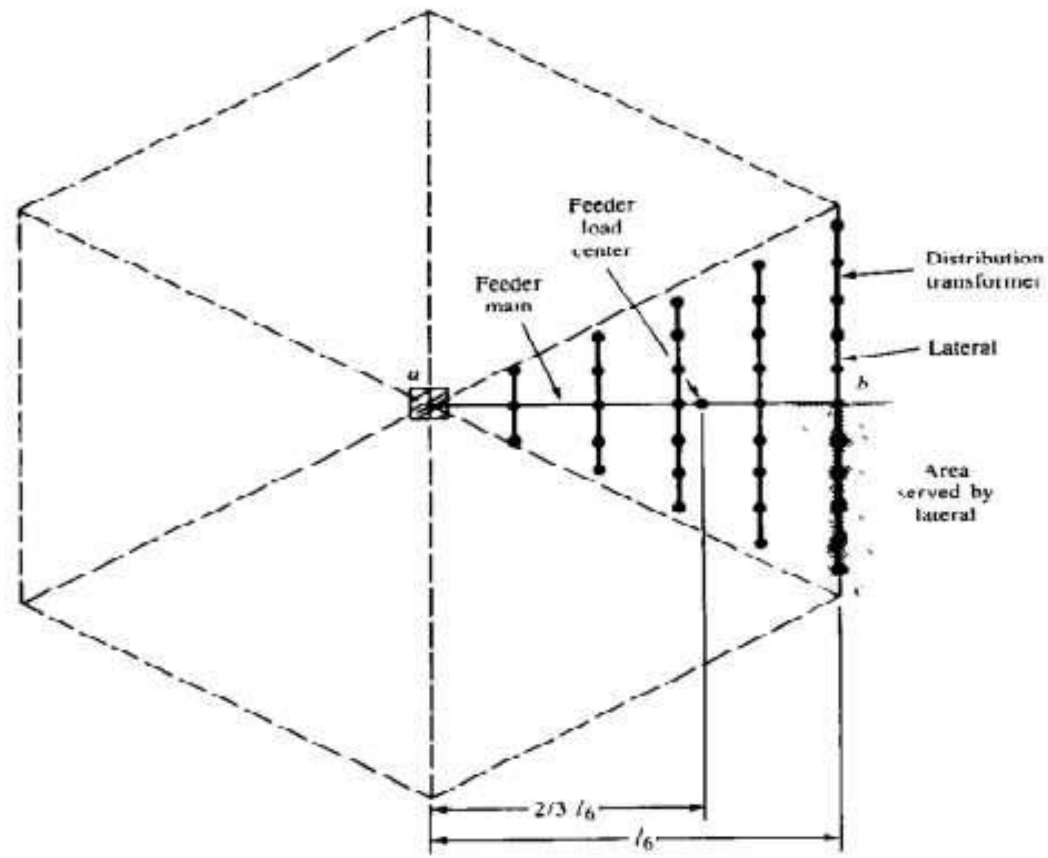
In this equation the total lumped load is assumed to be located at a distance of $2/3 l_4$ from central feed point.

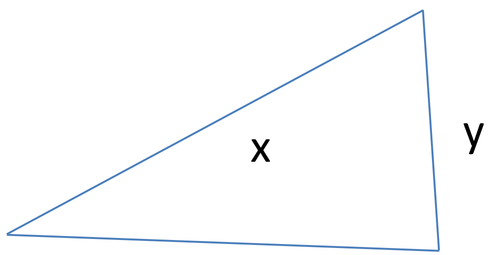
$$\% VD_{4,main} = 2/3 \times l_4 \times K \times A_4 \times D$$

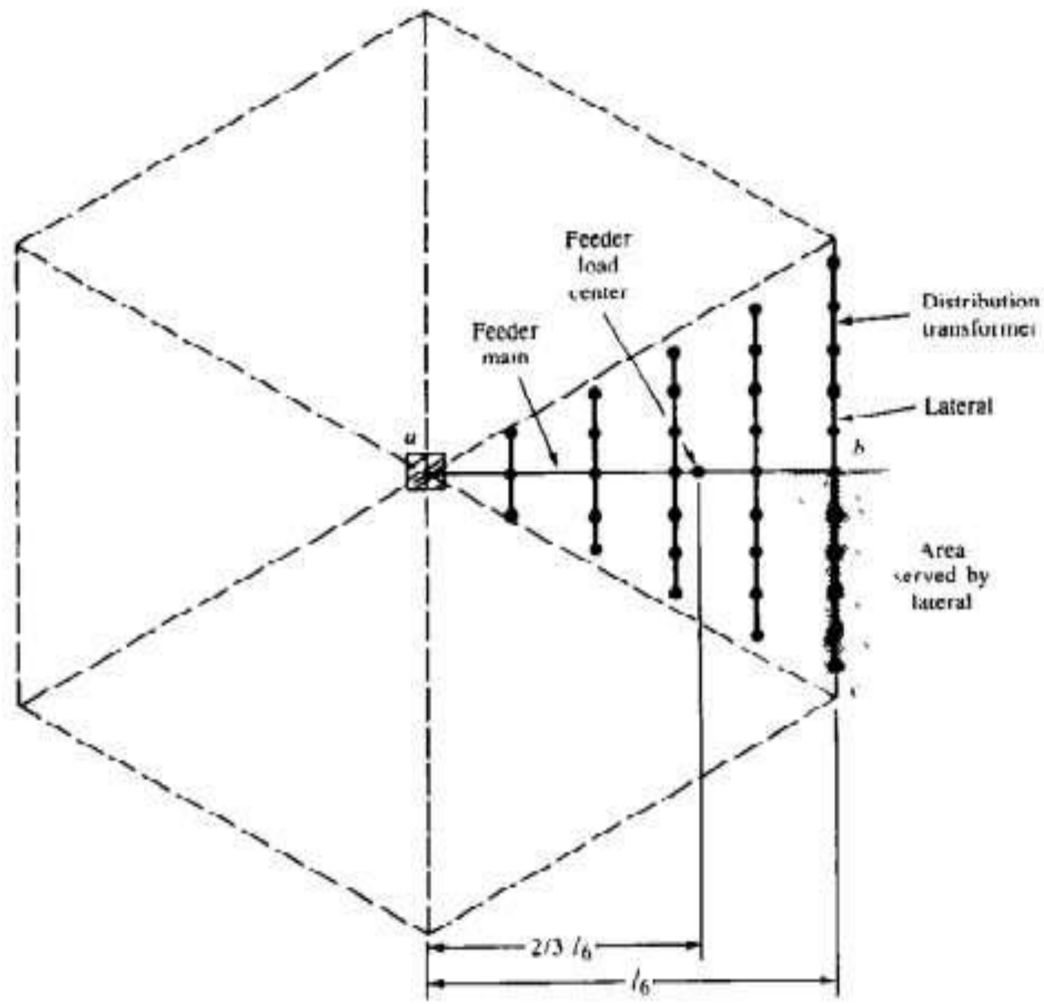
$$\% VD_{4,main} = 0.667 \times K \times D \times (l_4)3$$

voltage drop at hexagonally shaped service area

- If the served area is extend to hexagonally shaped served area supplied by six feeders from fed central point as shown in Figure . each feeder is feed area equal to 1/6 of the hexagonally.




x
y


Feeder
load
center
Feeder
main
Distribution
transformer
Lateral
a
b
Area
served by
lateral
2/3 l_6
l_6

voltage drop at hexagonally shaped service area

$$A_6 = 0.578 \times l_6$$

Where l_6 primary feeder dimension.

Each feeder serve a total load of

$$S_6 = A_6 \times D \;\; KVA$$

As before the total lumped load is located at distance of $2/3 l_6$ from the feed point.

therefore the percentage voltage drop is:

$$\% \, VD6,main = 2/3 \times l_6 \times K \times S_6$$

$$\% \, VD6,main = 0.385 \times K \times D \times (l_6)3$$

Comparison between square and hexagonally

- The total area served bt all four feeders
  $TA_4 = 4 A_4 = 4(l_4)^2$
- Total KVA served by all four feeders is
  $TS_4 = 4D \times (l_4)^2$
- Percentage voltage drop on the main feeder is
  $\% VD_{4,main} = 0.667 \times K \times D \times (l_4)^3$

The load current on the mian feeder at feed point a is

$$I_4 = \frac{S_4}{\sqrt{3} \times V_{L-L}} \Rightarrow I_4 = \frac{(l_4)^2 \times D}{\sqrt{3} \times V_{L-L}} \quad A$$

- The total area served bt all six feeders

$$TA_6 = \frac{6}{\sqrt{3}}(l_6)^2$$

- Total KVA served by all six feeders is

$$TS_6 = \frac{6}{\sqrt{3}} D \times (l_6)^2$$

- Percentage voltage drop on the main feeder is

$$\% VD_{6,main} = \frac{2}{3\sqrt{3}} K \times D \times (l_6)^3$$

- The load current on the mian feeder at feed point a is

$$I_6 = \frac{S_6}{\sqrt{3} \times V_{L-L}} \Rightarrow I_6 = \frac{D \times (l_6)^2}{\sqrt{3} \times V_{L-L}}$$

- The relation between the served areas of four and six feeders can be found under two assumption
  1- Feeder circuit are thermally limited(That mean I4= I6)

  2- Feeder circuit are voltage drop limited (*%VD4 = %VD6)*
- WHEN WE SUBSTITUTE I4= I6 WE GET

$$\left(\frac{l_6}{l_4}\right)^2 = \sqrt{3}$$

$$\frac{TA_6}{TA_4} = \frac{6/\sqrt{3}\,(l_6)^2}{4(l_4)^2} = \frac{\sqrt{3}}{2}\,\left(\frac{l_6}{l_4}\right)^2 \qquad \frac{TA_6}{TA_4} = \frac{3}{2}$$

- The six feeder area could carry **1.5** time as much as four feeder if they are thermally limited.

For Feeder circuit are voltage drop limited then we have

$$\%VD4 = \%VD6$$

$$l4 = 0.833 \times l6$$

The total area served by all six feeders :

$$TA_6 = \frac{6}{\sqrt{3}} (l_6)^2$$

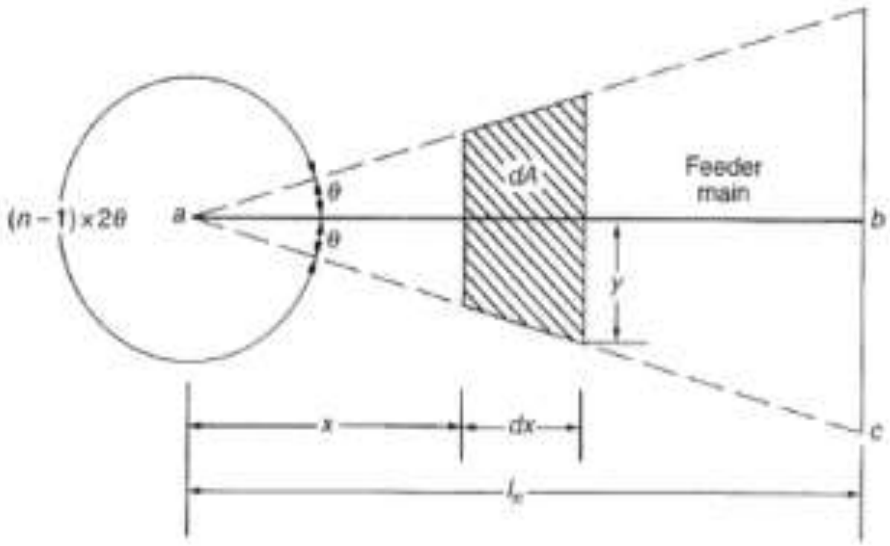
$$TA_4 = 2.78 \times (l_6)^2$$

$$\frac{TA_6}{TA_4} = \frac{5}{4}$$

Therefore, the six feeder area could carry **1.25** time as much as four feeder if they are voltage drop limited.

Substation service area with N primary feeders

- The service area of the distribution substation is supplied by N number of primary feeders from feed point 'a' is shown below
- Consider the load is uniformly distributed in the supplied area and each feeder supplies an area of triangle shape



Here dA=differential service area of the feeder

dS= differential load service by the feeder in the differential area of Da

D= Load density

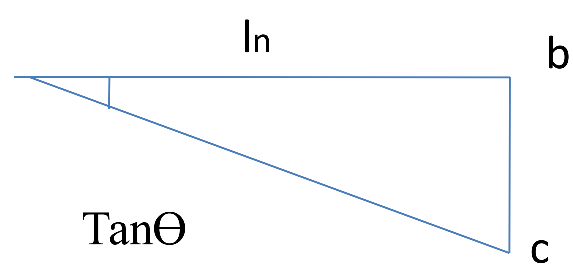
We know that dS=D*dA KVA

From the fig $\tan\theta = \frac{y}{x+dx}$

$$y = X \times \tan\Theta$$

Total service area can be calculated as ‘An

$$A_n = \int_{x=0}^{l_n} dA = l_n^2 \times \tan\theta.$$



- The total KVA load served by one of n feeders can be calculated as

$$S_n = \int_{s=0}^{l_n} dS = D \times l_n^2 \times \tan\theta.$$

- Wkt dS=D*dA

the total lumped load is located at distance of 2/3l_n from the feed point 'a'

therefore the percentage voltage drop is:

% VDn = 2/3× l_n × K × S_n

$$\%VD_n = \frac{2}{3} \times K \times D \times l_n^3 \times \tan\theta$$

Substation of S_n in above equation we have

$$n(2\theta) = 360$$

% VDn = 2/3× l_n × K ×D ×(*l_n*)*2* × TanΘ

$$\%\text{VD}_n = \frac{2}{3} \times K \times D \times l_n^3 \times \tan\theta$$

$$n(2\theta) = 360$$

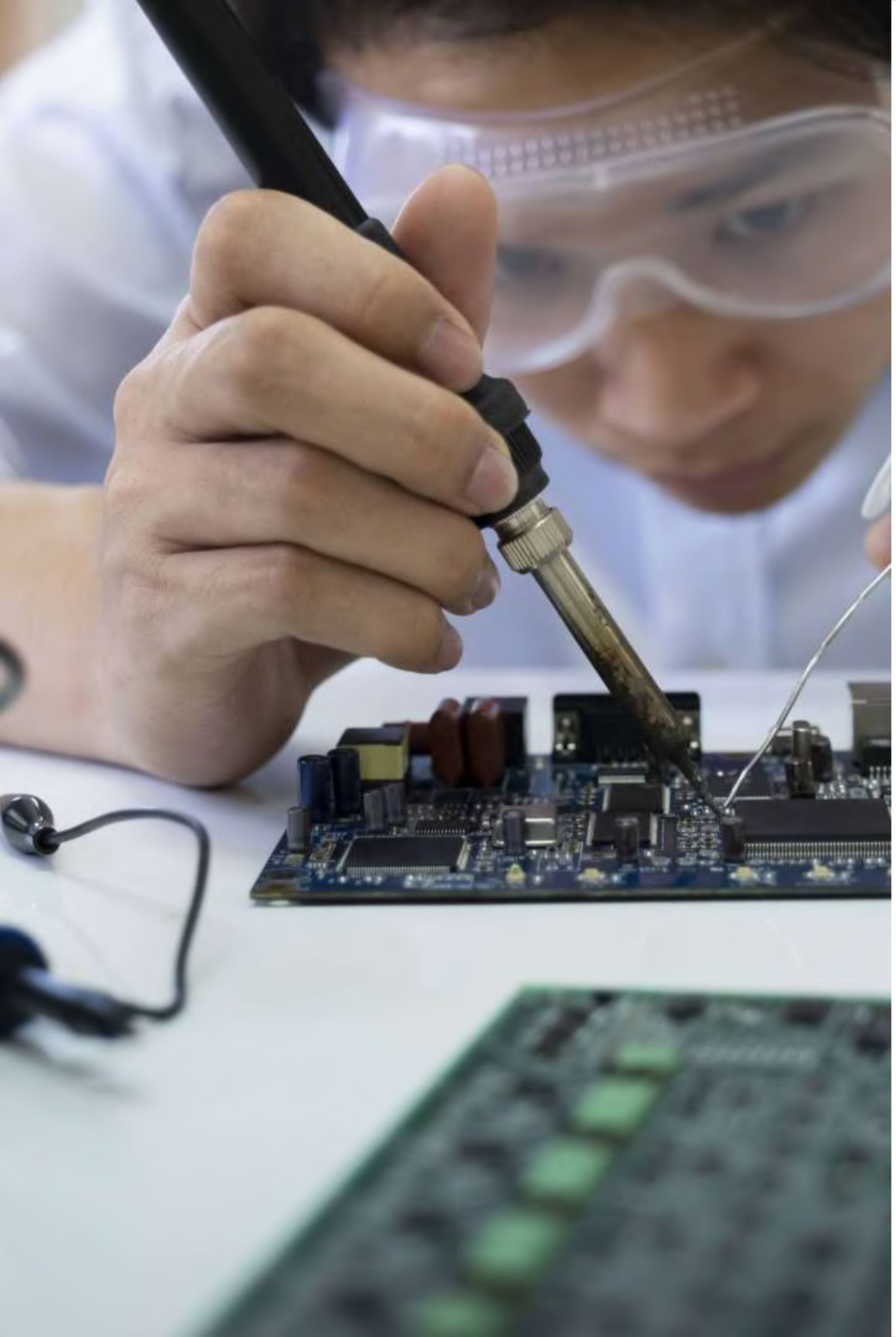
$$\%\text{VD}_n = \frac{2}{3} \times K \times D \times l_n^3 \times \tan\frac{360^\circ}{2n}.$$

For $n = 1$, the percent voltage drop in the feeder main is

$$\%\text{VD}_1 = \frac{1}{2} \times K \times D \times l_1^3$$

and for $n = 2$ it is

$$\%\text{VD}_2 = \frac{1}{2} \times K \times D \times l_2^3$$

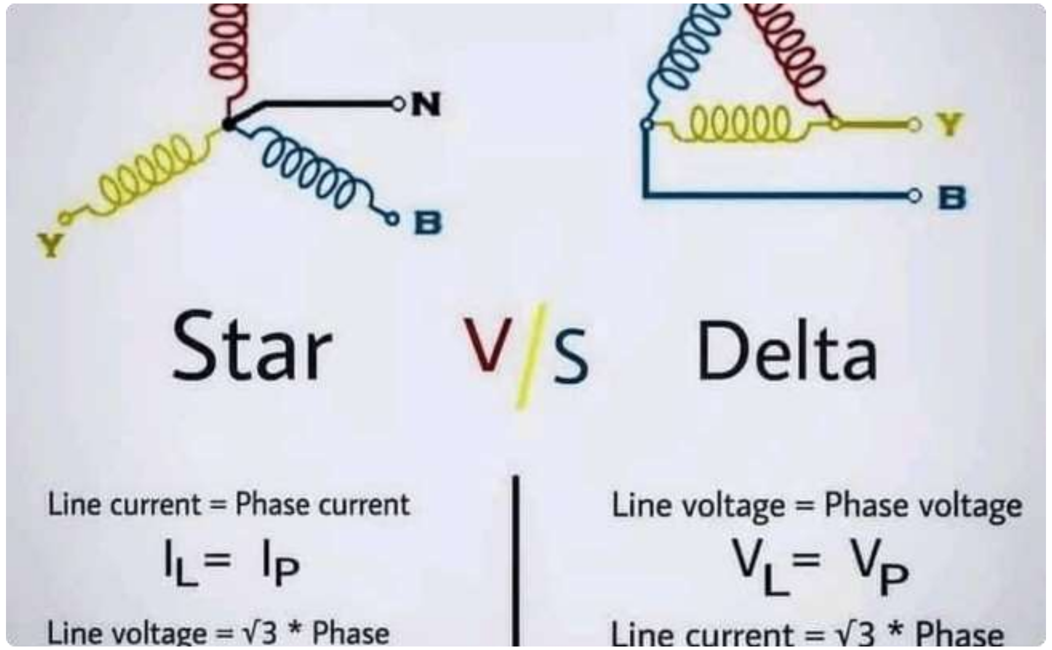


Mastering Electrical Engineering: Modelling of Star and Delta Connected Loads, Two Phase Single Phase Loads Shunt Capacitors

Electrical engineering is a challenging and rewarding field that involves designing, developing, and testing electrical equipment and systems. In this presentation, we will explore the modelling of various electrical loads and the use of shunt capacitors to improve power factor and energy efficiency.

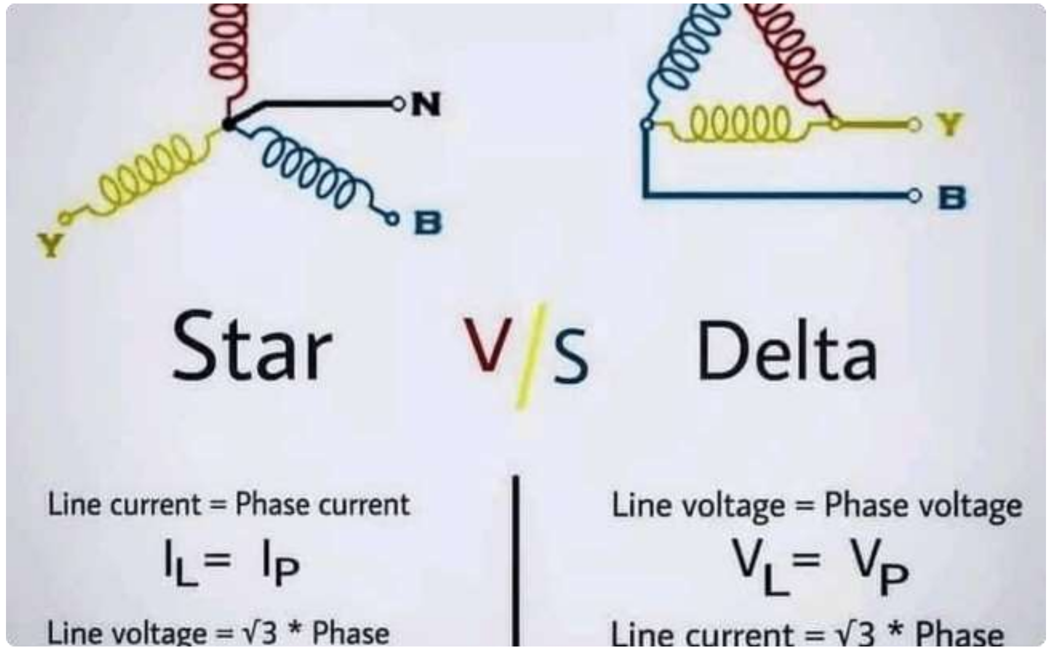
pr by prasanna reddy

Star and Delta Connected Loads



Star Connected Loads

Star connected loads are commonly found in three-phase electrical systems. These loads are connected between one phase and the neutral wire, making them suitable for low and medium power applications.



Delta Connected Loads

Delta connected loads are also commonly found in three-phase electrical systems. These loads are connected between two phases, making them suitable for high power applications. Delta loads are more efficient than star loads because they use all three phases.

Two Phase Load

What is a Two Phase Load?

A two-phase load is a type of electrical load that requires two phases of an AC power supply to operate properly. In practice, two-phase power systems are rare and have been largely replaced by three-phase power systems.

Example of Two Phase Load

A common example of a two-phase load is an electric stove. Depending on the stove's settings, it may require two phases or all three phases to operate.

Single Phase Load

Appliance	Power
Refrigerator	100-400 W
T.V	100-400 W
Fan	5-50 W
Computer	200-600 W

Single phase loads are everywhere in our daily life. Common examples of single-phase loads include televisions, refrigerators, fans, and computers. These loads are connected to a single phase of an AC power supply and consume power intermittently.

Shunt Capacitor

1

2

What is a Shunt Capacitor?

A shunt capacitor is a capacitor that is connected in parallel with a load to improve power factor and energy efficiency. It works by drawing current that leads the voltage, reducing the reactive power demand from the electrical system.

Where are Shunt Capacitors Used?

Shunt capacitors are commonly used in power factor correction systems to improve the energy efficiency of industrial loads such as motors and transformers. They are also used in residential and commercial buildings with fluorescent lighting and other inductive loads.

Advantages of Shunt Capacitor

Improved Power Factor

Shunt capacitors improve power factor by reducing the reactive power demand from the electrical system. This leads to reduced energy costs and improved voltage regulation.

Improved Energy Efficiency

Shunt capacitors reduce energy losses due to reactive power and help to extend the life of electrical equipment. This results in improved energy efficiency and lower operating costs for factories and other industrial facilities.

Cleaner Energy

Shunt capacitors reduce energy losses by reducing the reactive power demand from the electrical system. This results in cleaner power and lower greenhouse gas emissions.

Conclusion

1 Modelling of Electrical Loads

Understanding the modelling of electrical loads is essential for designing safe, efficient, and reliable electrical systems for both residential and commercial applications.

2 Importance of Shunt Capacitors

Shunt capacitors are a cost-effective way to improve the power factor and energy efficiency of electrical power systems, making them an essential component of modern electrical engineering.

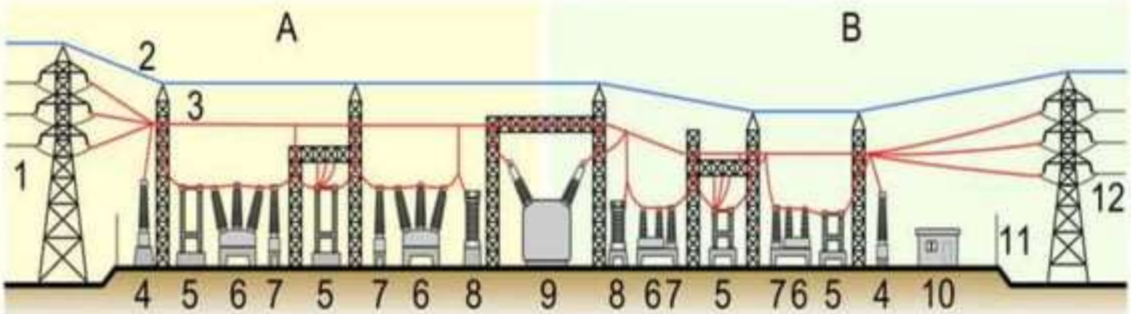
GAS INSULATED SUBSTATION

Contents:

- Substation
- Conventional substations (AIS)
- Limitations of AIS
- The need for GIS
- Introduction to GIS
- Properties of SF6
- GIS assembly
- Advantages of GIS
- Design features
- Drawbacks
- SF_6 – Environmental concerns
- SF_6 /N_2 mixtures
- Future trends in GIS
- Conclusion.

Substation:

- An assembly of apparatus installed to control transmission and distribution of electric power.



A:Primary power lines' side B:Secondary power lines' side
1.Primary power lines 2.Ground wire 3.Overhead lines 4.Transformer for measurement of electric voltage 5.Disconnect switch 6.Circuit breaker 7.Current transformer 8.Lightning arrester 9.Main transformer 10.Control building 11.Security fence 12.Secondary power lines

Air Insulated Substation(AIS):

- Air used as a dielectric.
- Normally used for outdoor substations.
- In very few cases used for indoor substations.
- Easy to expand (in case that space is not an issue)
- Excellent overview, simple handling and easy access.

Limitations of AIS:

- Large dimensions due to statutory clearances and poor dielectric strength of air.
- Insulation deterioration with ambient conditions and susceptibility to pollutants.
- Wastage of space.
- Life of steel structures degrades.
- Seismic instability.
- Large planning & execution time.
- Regular maintenance of the substation required.

The need for G.I.S:

- Non availability of sufficient space.
- Difficult climatic and seismic conditions at site.
- Urban site (high rise building).
- High altitudes.
- Limitations of AIS.

Gas Insulated Substation:

Introduction:

- Compact, multi-component assembly.
- Enclosed in a ground metallic housing.
- Sulphur Hexaflouride (SF6) gas – the primary insulating medium.
- (SF6) gas- superior dielectric properties used at moderate pressure for phase to phase and phase to ground insulation
- Preferred for voltage ratings of 72.5 kV, 145 kV, 300 kV and 420 kV and above.
- Various equipments like Circuit Breakers, Bus-Bars, Isolators, Load Break Switches, Current Transformers, Voltage Transformers, Earthing Switches, etc. housed in metal enclosed modules filled with SF6 gas.

Properties of SF_6:

- Non-toxic, very stable chemically.
- Man-made.
- Lifetime – Very long (800 to 3200 years!).
- Insulating properties 3-times that of air.
- Colorless & heavier than air.
- Almost water insoluble.
- Non inflammable.

Gas insulated substation

GIS Assembly:

ESSENTIAL PARTS OF GIS:

1. Bus bar
2. Circuit Breaker
3. Disconnector (line or bus)
4. Earthing switch (line or bus)
5. Current transformer (feeder / bus)
6. Voltage transformer (feeder/ bus)
7. Feeder Disconnector
8. Feeder Earthing switch
9. Lightning / Surge Arrester
10. Cable termination
11. Control Panel.

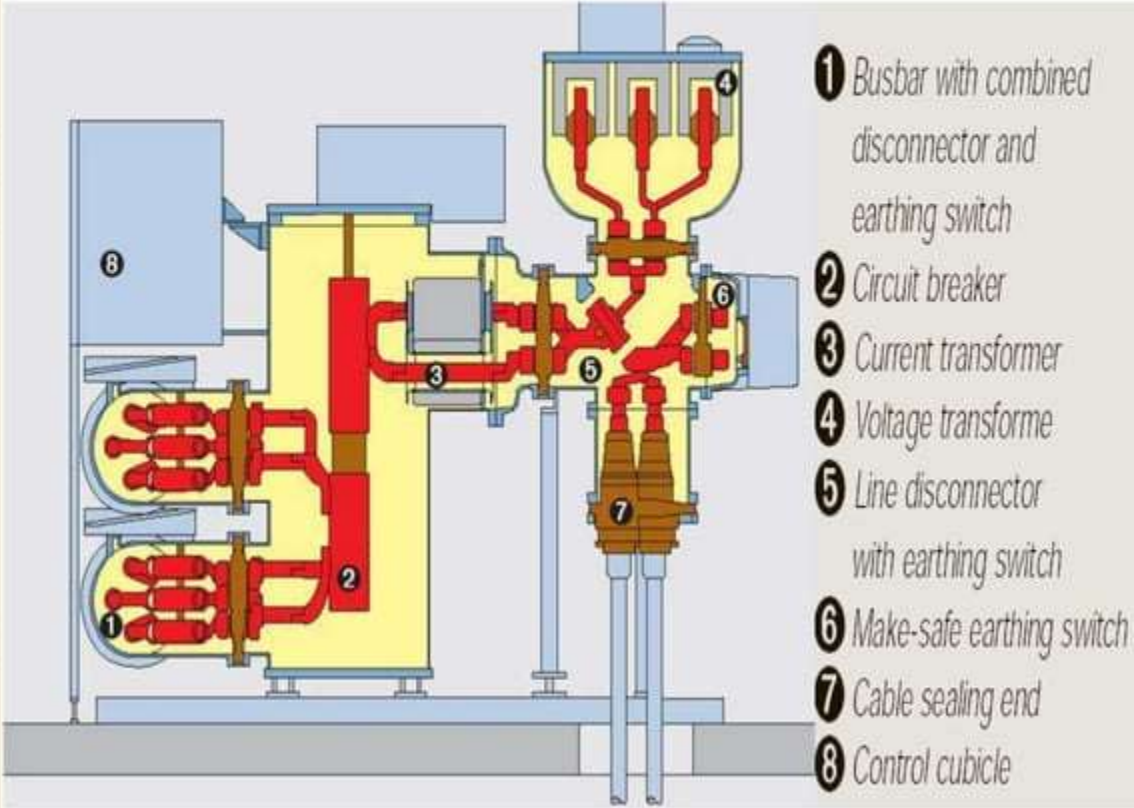


Fig: essential parts of Gas insulated substation

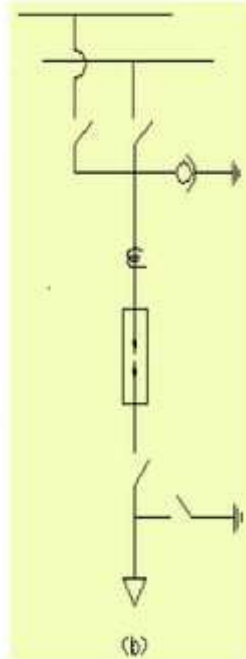


Fig:36 KV Gas insulated substation with 3-phase double bus

Fig: Gas insulated substation with double bus arrangement

Advantages :

- Occupies very less space (1/10th) compared to ordinary substations.
- Hence, most preferred where area for substation is small (eg: Cities)
- Most reliable compared to Air Insulated Substations.
- Number of outages due to the fault is less
- Maintenance Free.
- Can be assembled at workshop and modules can be commissioned in the plant easily.


GIS vs AIS
Life cycle assessment

Design Challenges:

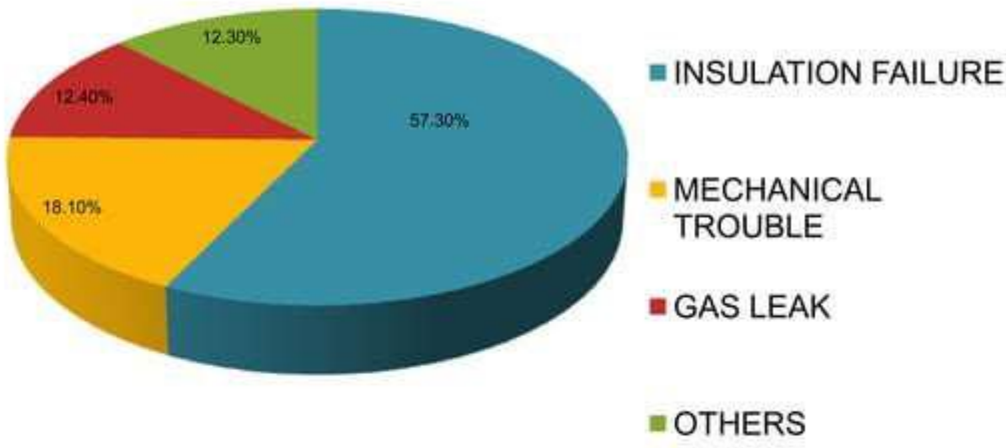
1. Safety:

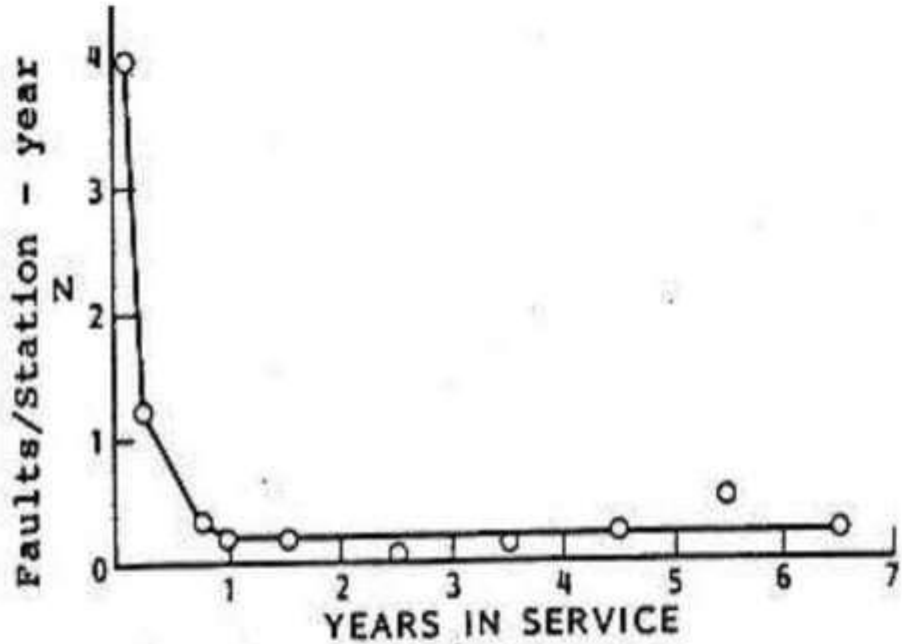
- Optimizing operating electrical stresses to safe levels by better inter electrode spacing .
- Increasing the gas volume and the thermal inertia of the system to enhance cooling and retain insulation strength.

2. High reliability:

- Superior contact systems for Circuit Breakers and
  Disconnectors.
- Multi-contact and friction free surfaces incorporated for long operating cycles.
- Rugged, time proven operating drives used.

GIS Failure Statistics:





In-service fault rate (faults/station-year)

vs.

years in service for 25 North American GIS

Main Drawbacks:

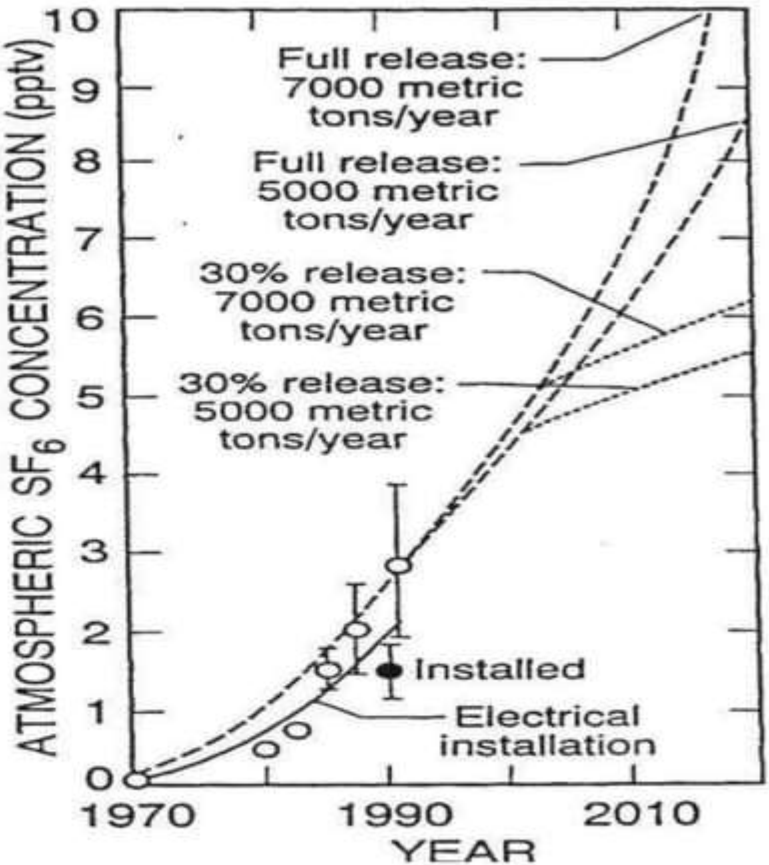
- High cost compared to conventional substation(AIS).
- Excessive damage in case of internal fault.
- Diagnosis of internal fault and rectifying takes very long time (high outage time).
- SF6 gas pressure must be monitored in each compartment.
- Reduction in the pressure of the SF6 gas in any module results in flash over and faults.
- SF6 causes ozone depletion and global warming.

SF6 – Environmental Concerns:

- Currently, 80% used by Electrical Power industry.
- Other Uses – micro-electronics; Al & Mg production.
- 7000 metric tons/yr in 1993.
- Reached 10,000 metric tons/yr by 2010.
- Two areas of Health and Environmental impact:

I. Through its normal use in a work place – Arcing byproducts.

II. Global Environmental impact - Ozone depletion and Global warming.



ATMOSPHERIC SF_6 CONCENTRATION (pptv)
10
9
8
7
6
5
4
3
2
1
0
1970
1990
2010
YEAR
Full release: 7000 metric tons/year
Full release: 5000 metric tons/year
30% release: 7000 metric tons/year
30% release: 5000 metric tons/year
Installed
Electrical installation

SF6/N2 Mixtures for GIS?

- SF6 gas – specifically mentioned in Kyoto protocol.
- Small quantities of SF6 in N2 can improve dielectric strength drastically.
- All of the dielectric strength of SF6, nearly, can be achieved by adding less than 20% SF6 into N2.
- SF6/N2 mixtures less susceptible to effects of field non uniformity than pure SF6.
- Thus mitigating the effects of particles and surface protrusions.

Future trends:

- Compact design of switch gear by using three phase modules.
- Use of vacuum circuit breaker cells in the medium high voltage GIS.
- Optimization of GIS design to allow easier maintenance.
- Development of DC GIS for incorporating into expanding national/international HVDC systems.
- Search for replacement gases for SF_6.
- The most promising - an 80%/20% N_2/SF_6 mixture.
- Replacement of existing AIS by GIS will accelerate especially near urban centers.

CONCLUSION:

- GIS – necessary for Extra HV & Ultra HV
- Some important areas to be studied include:
- More conservative design.
- Improved gas handling.
- Decomposition product management techniques.
- Achieving & maintaining high levels of availability require – more integrated approach to quality control by both users and manufactures.

Load Flow Analysis

Course Outline

1. The Load Flow Problem
2. Backward/Forward Sweep Load Flow

The Load Flow Problem

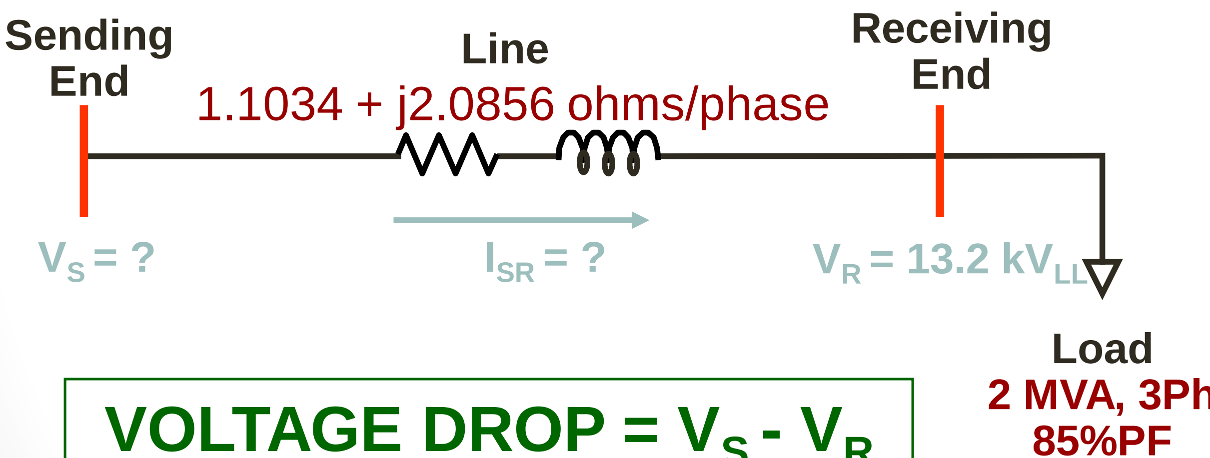
Load Flow Analysis simulates (i.e., mathematically determine) the performance of an electric power system under a given set of conditions.

Load Flow (also called Power Flow) is a snapshot picture of the power system at a given point.

The Load Flow Problem

Basic Electrical Engineering Solution

How do you determine the voltage, current, power, and power factor at various points in a power system?

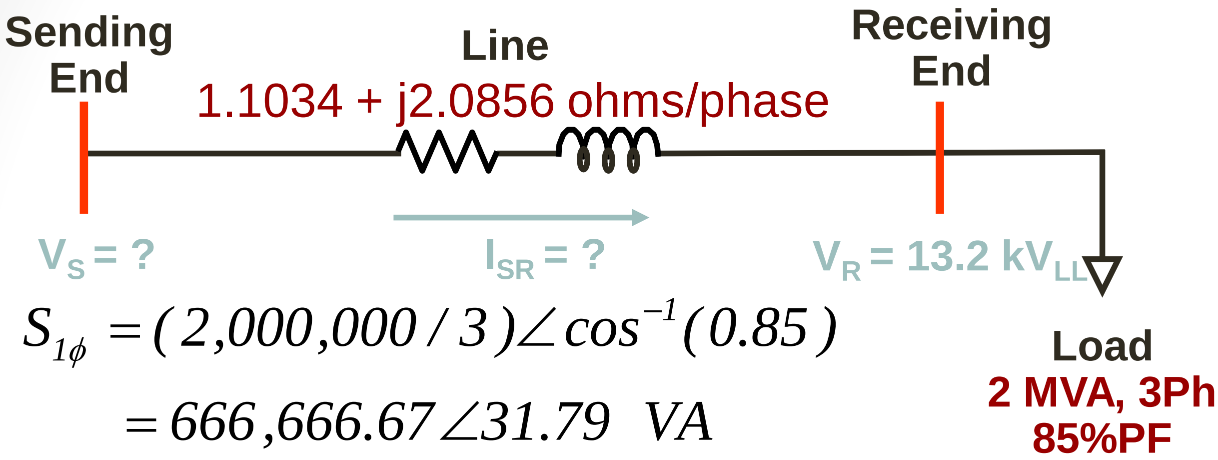


VOLTAGE DROP = V_S - V_R

Solve for:

1) $I_{SR} = (S_R/V_R)^*$
2) $VD = I_{SR}Z_L$
3) $V_S = V_R + VD$
4) $S_S = V_S x (I_{SR})^*$

The Load Flow Problem



Solve for:

1) $I_{SR} = (S_R/V_R)^*$
2) $VD = I_{SR}Z_L$
3) $V_S = V_R + VD$
4) $S_S = V_S x (I_{SR})^*$

$$S_{1\phi} = (2{,}000{,}000/3)\angle\cos^{-1}(0.85)$$

$$= 666{,}666.67\angle 31.79 \;\; VA$$

$$V_R = (13{,}200/\sqrt{3})\angle 0 = 7621.02\angle 0 \;\; V$$

$$I_{SR} = \left(\frac{666{,}666.67\angle 31.79}{7621.02\angle 0}\right)^* = 87.48\angle -31.79 \;\; A$$

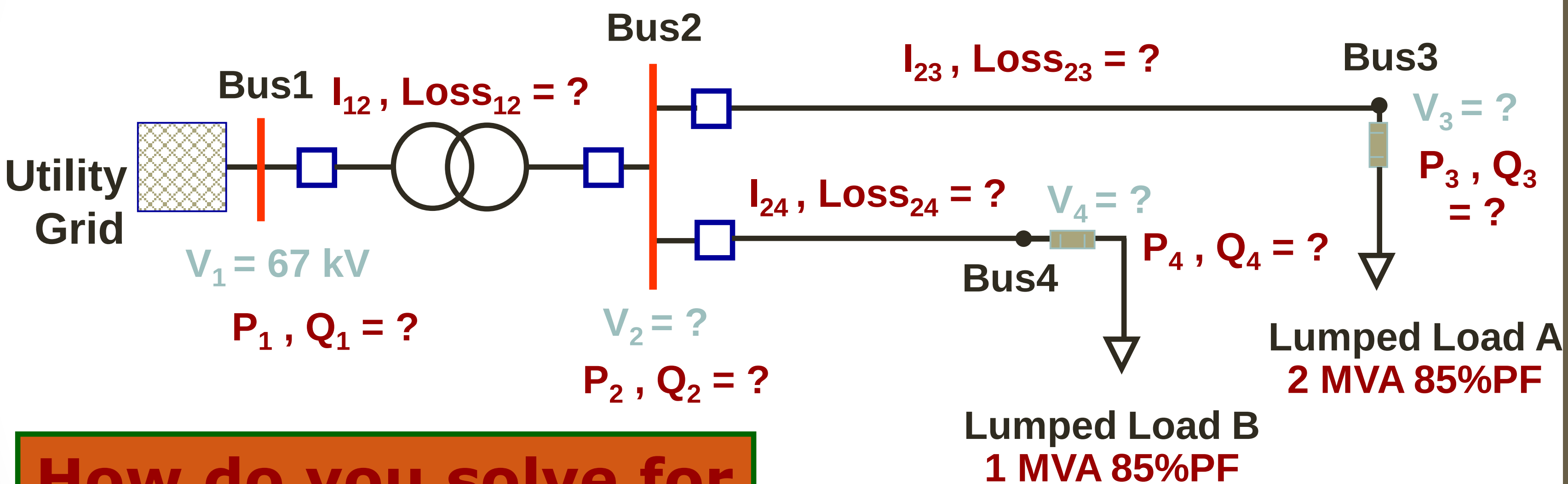
$$VD = (87.48\angle -31.79)(1.1034 + j2.0856) = 178.15 + j104.23 \;\; V$$

$$V_S = (7621.02 + j0) + (178.15 + j104.23) = 7{,}799.87\angle 0.77 \;\; V$$

$$V_S = 7{,}799.87\angle 0.77 / 1000 * \sqrt{3} = 13.51 \;\; kV$$

The Load Flow Problem

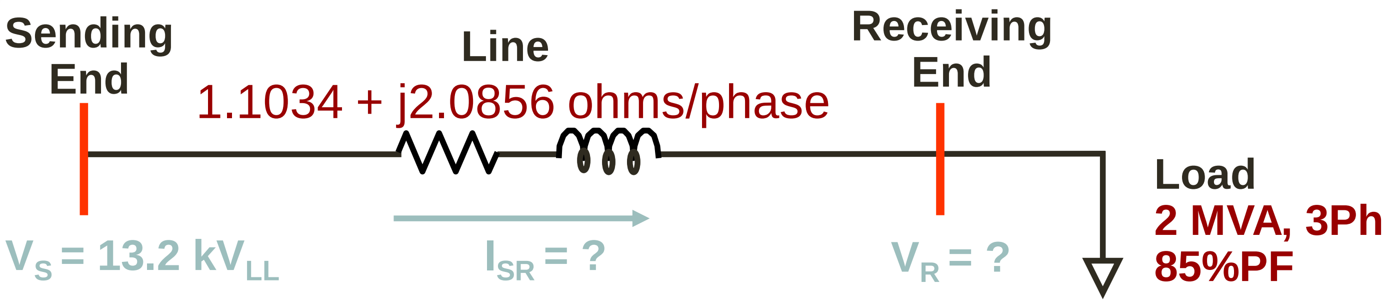
Load Flow of Distribution System



How do you solve for the Voltages, Currents, Power and Losses?

The Load Flow Problem

Load Flow of a Single Line



Injected Power at Receiving End

$$S_R = V_R \times (I_{SR})^*$$

Solving for the Current

$$I_{SR} = (S_R / V_R)^*$$

Voltage at Sending End

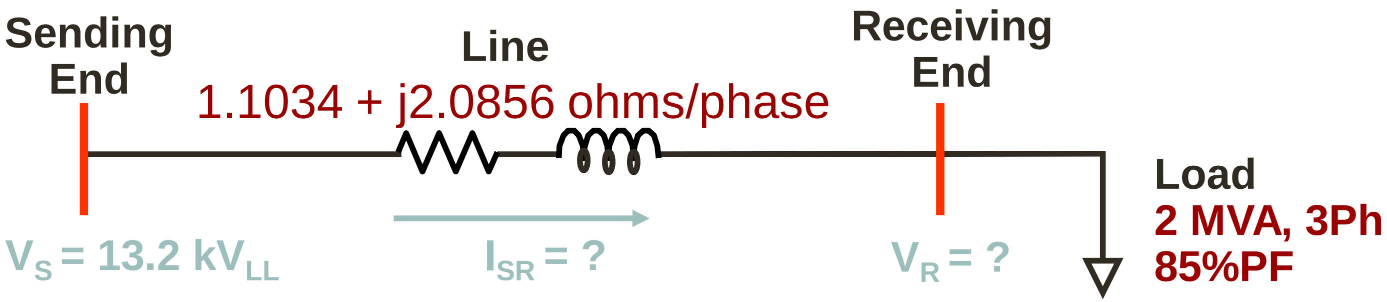
$$V_S = V_R + Z \times I_{SR}$$

Voltage at Receiving End

$$V_R = V_S - Z \times S_R^*/V_R^*$$

The Load Flow Problem

Load Flow of a Single Line



Converting Quantities in Per Unit

Base Power = 1 MVA

Base Voltage = 13.2 kV

Base Impedance = $[13.2]^2/1$

= 174.24 ohms

$V_{S(pu)} = 13.2 / 13.2 = 1\angle 0$

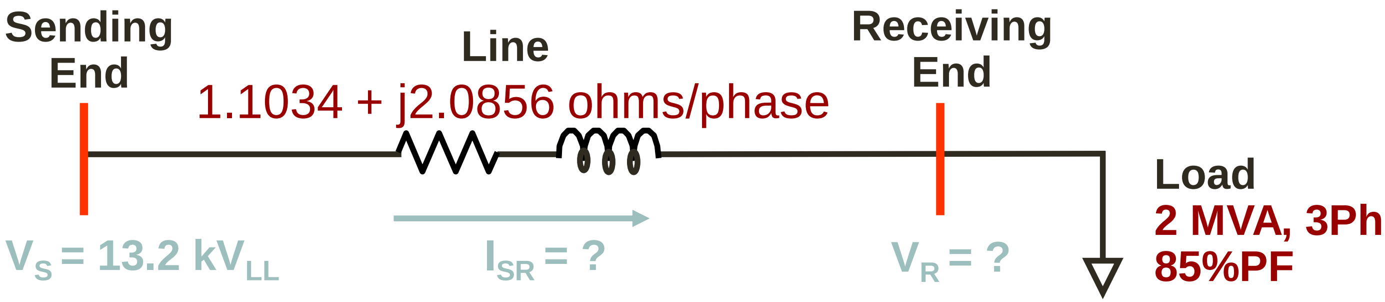
$S_{R(pu)} = 2\angle\cos^{-1}(0.85) / 1$

$Z_{pu} = (1.1034 + j2.0856)/174.24$

$= 0.00633 + j0.01197$

The Load Flow Problem

Load Flow of a Single Line



$$V_R^{(k)} = V_S - Z \times [S_R]^* / [V_R^{(k-1)}]^*$$

Let $V_R^{(0)} = 1\underline{/0}$

For k = 1

$V_R^{(1)} =$ ________________

$\Delta V^{(1)} =$ ________________

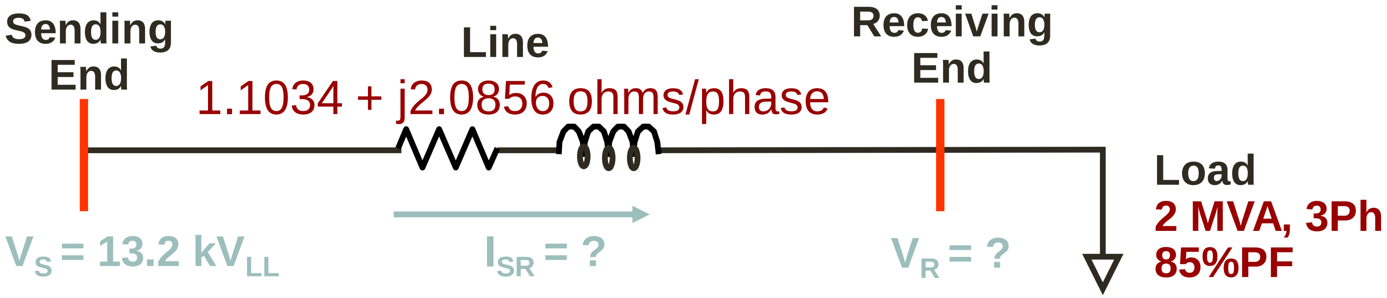
For k = 2

$V_R^{(2)} =$ ________________

$\Delta V^{(2)} =$ ________________

The Load Flow Problem

Load Flow of a Single Line



$$V_R^{(k)} = V_S - Z \times [S_R]^* / [V_R^{(k-1)}]^*$$

$V_R^{(2)}$ = ________________

For k = 3

$V_R^{(3)}$ = ________________

$\Delta V^{(3)}$ = ________________

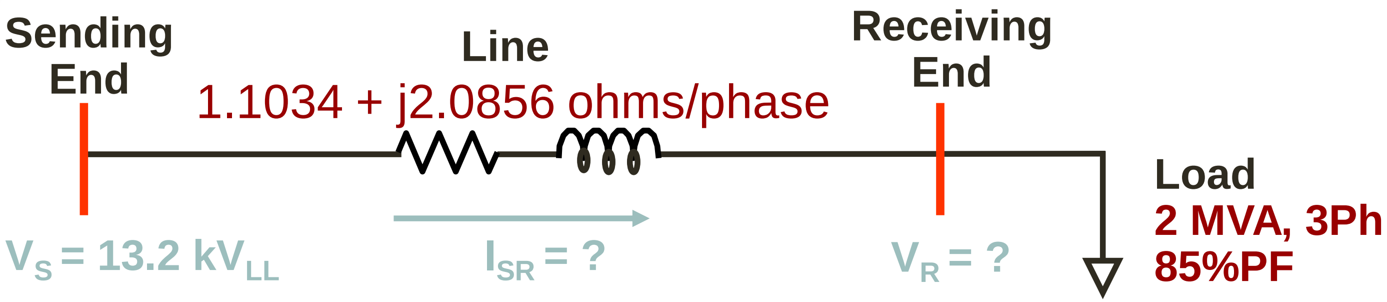
For k = 4

$V_R^{(4)}$ = ________________

$\Delta V^{(4)}$ = ________________

The Load Flow Problem

Load Flow of a Single Line



$$V_R^{(k)} = V_S - Z \times [S_R]^* / [V_R^{(k-1)}]^*$$

$V_R^{(4)}$ = ____________________

For k = 5

$V_R^{(5)}$ = ____________________

$\Delta V^{(5)}$ = ____________________

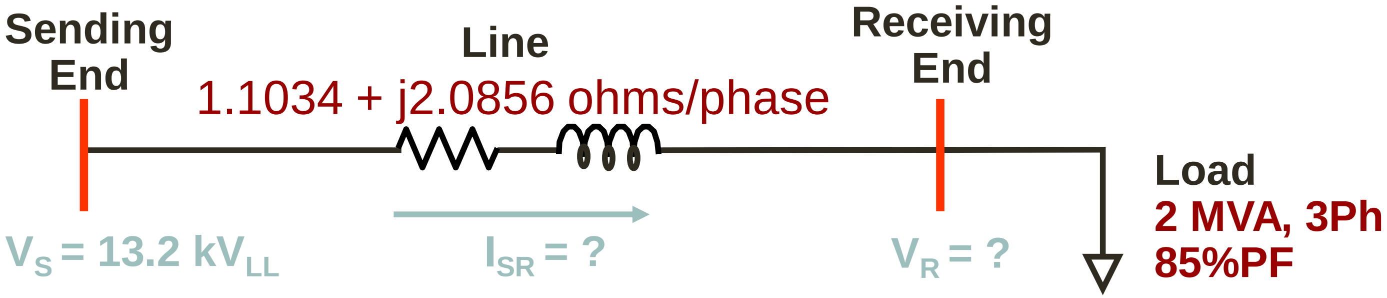
For k = 6

$V_R^{(6)}$ = ____________________

$\Delta V^{(6)}$ = ____________________

The Load Flow Problem

Load Flow of a Single Line



V_S = ________________

V_R = ________________

$VD = V_S - V_R$

VD = ________________

I_{SR} = ________________

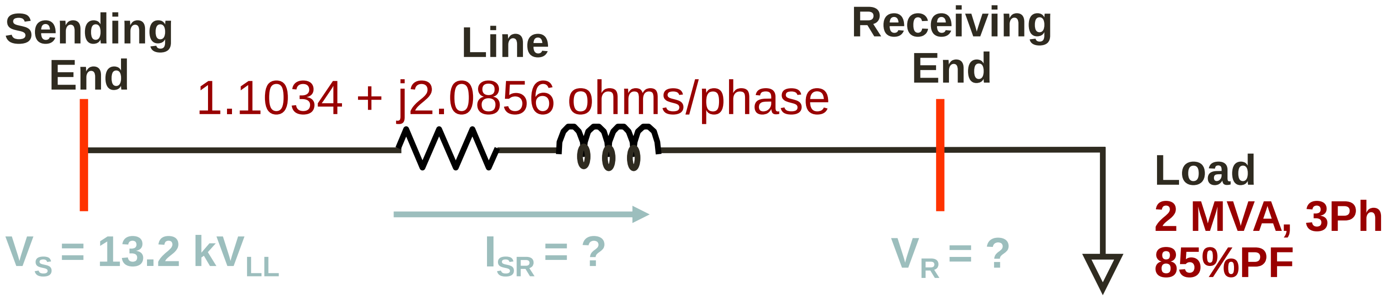
S_R = ________________

$S_S = V_S \times [I_{SR}]^*$

S_S = ________________

The Load Flow Problem

Load Flow of a Single Line



$PF_R = P_R / S_R$

$PF_R =$ ____________

$PF_S = P_S / S_S$

$PF_S =$ ____________

$S_{Loss} = P_{Loss} + Q_{Loss}$

$S_{Loss} = S_S - S_R$

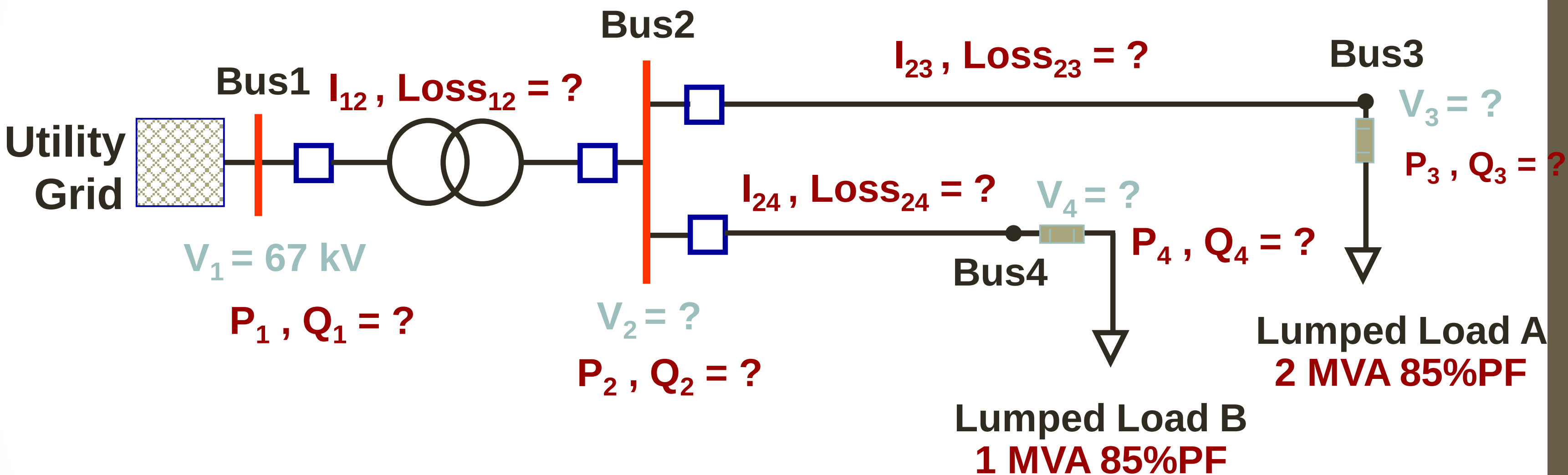
$P_{Loss} =$ ____________

$Q_{Loss} =$ ____________

Backward/Forward Sweep Load Flow

- Load Flow for Radial Distribution System
- Procedure: Iterative Solution
- Initialization
- Solving for Injected Currents
- Backward Sweep
- Forward Sweep
- Solving for Injected Power
- Solving for Voltage Mismatch

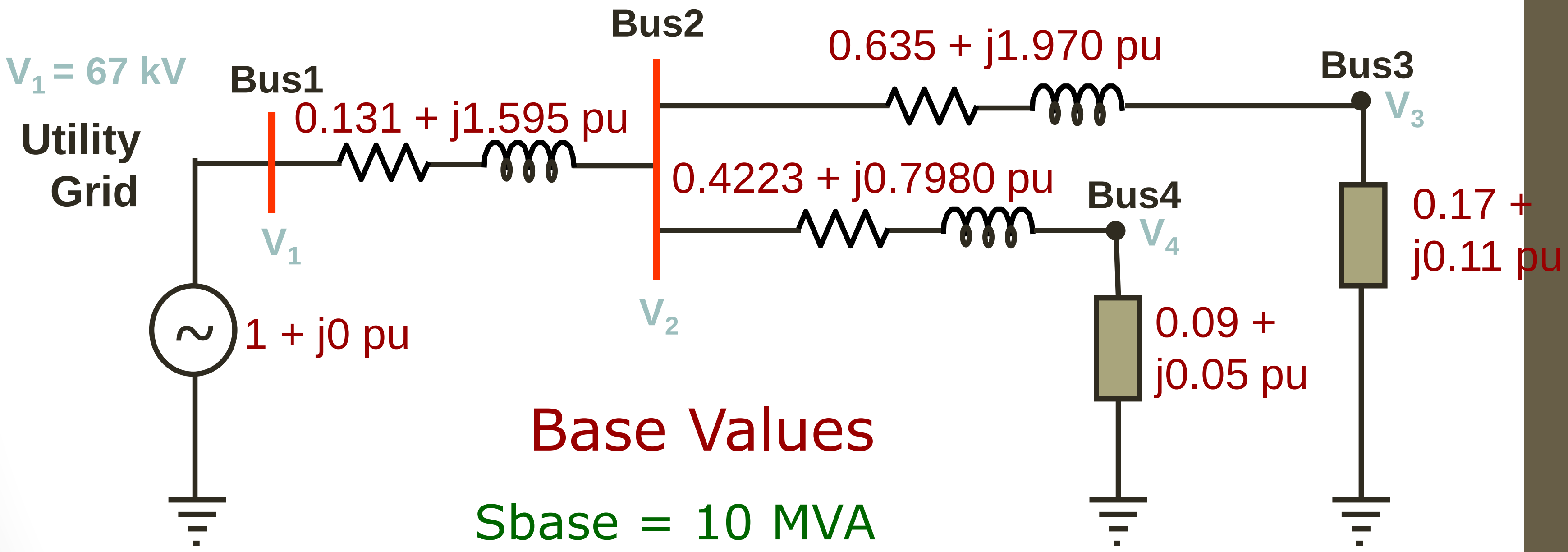
Backward/Forward Sweep Load Flow



Load Flow for Radial Distribution System

Backward/Forward Sweep Load Flow

Equivalent Circuit



Base Values

Sbase = 10 MVA

Vbase1 = 67 kV

Vbase2 = 13.2 kV

Backward/Forward Sweep Load Flow

Iterative Solution

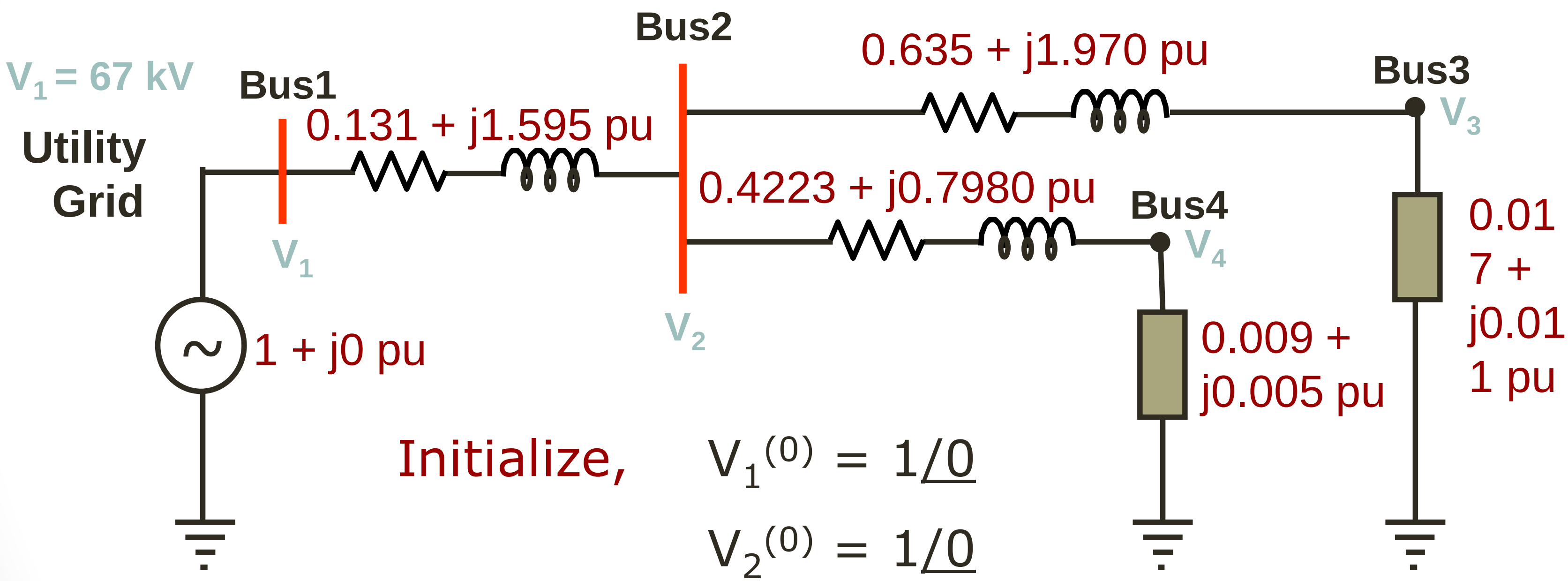
1. **Solve Injected Currents by Loads**
2. **Solve Line Currents *(Backward Sweep)***
3. **Update Voltages *(Forward Sweep)***
4. **Solve for Injected Power**
5. **Solve for Power Mismatch**

Continue iteration by *Backward-Forward Sweep* until convergence is achieved

After convergence, solve I_{inj}, P_{inj}, Q_{inj}, PF, P_{Loss}, Q_{Loss}

Backward/Forward Sweep Load Flow

Initialization



Initialize,

$$V_1^{(0)} = 1\angle 0$$

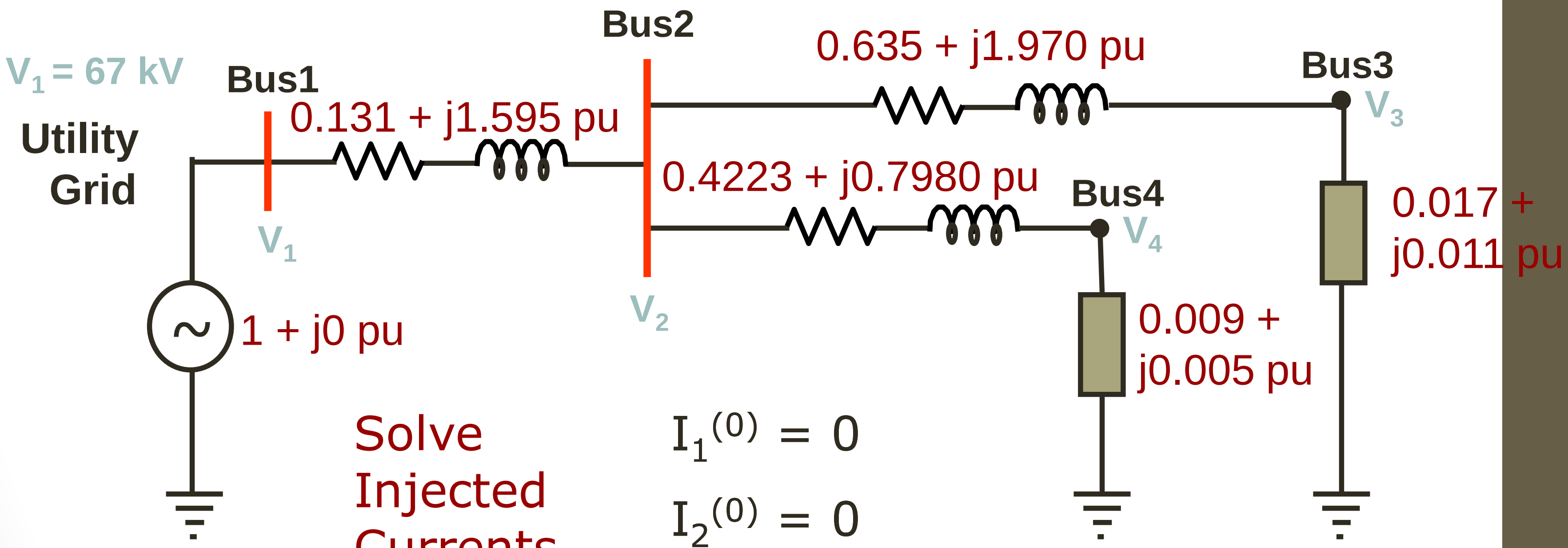
$$V_2^{(0)} = 1\angle 0$$

$$V_3^{(0)} = 1\angle 0$$

$$V_4^{(0)} = 1\angle 0$$

Backward/Forward Sweep Load Flow

Solving for Injected Currents



Solve Injected Currents by Loads

$I_1^{(0)} = 0$

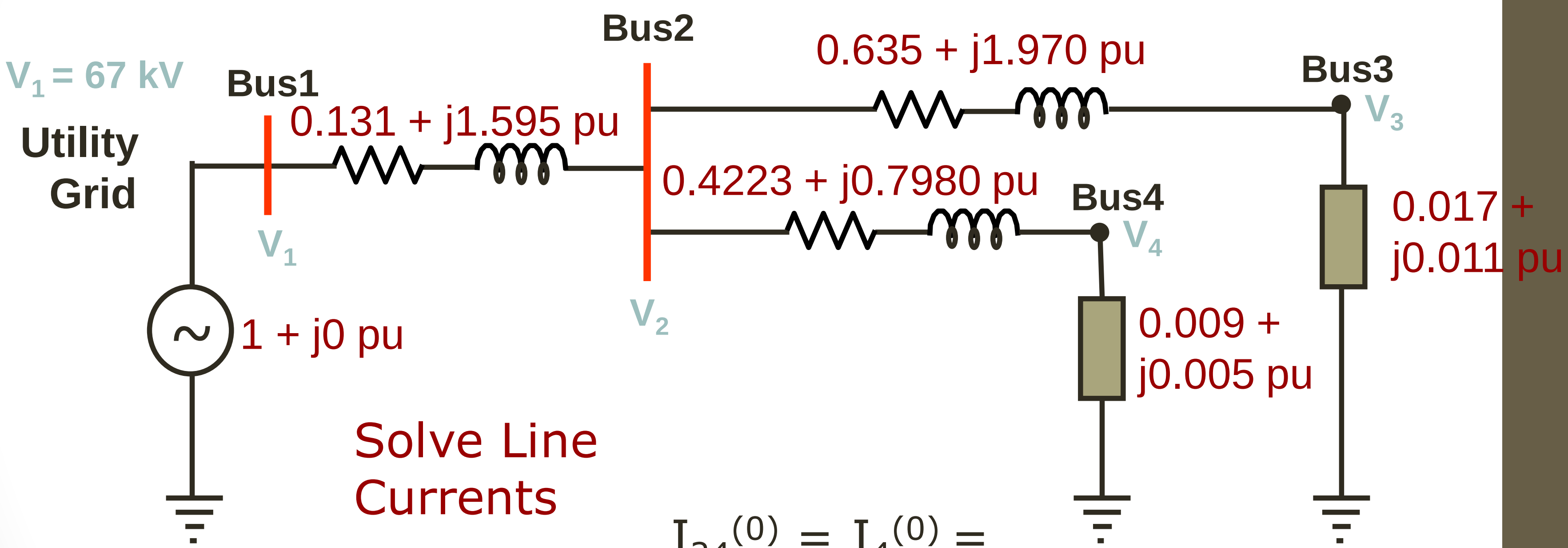
$I_2^{(0)} = 0$

$I_3^{(0)} = S_3^* / [V_3^{(0)}]^* =$ ____________

$I_4^{(0)} = S_4^* / [V_4^{(0)}]^* =$ ____________

Backward/Forward Sweep Load Flow

Backward Sweep



Solve Line Currents

(Backward Sweep)

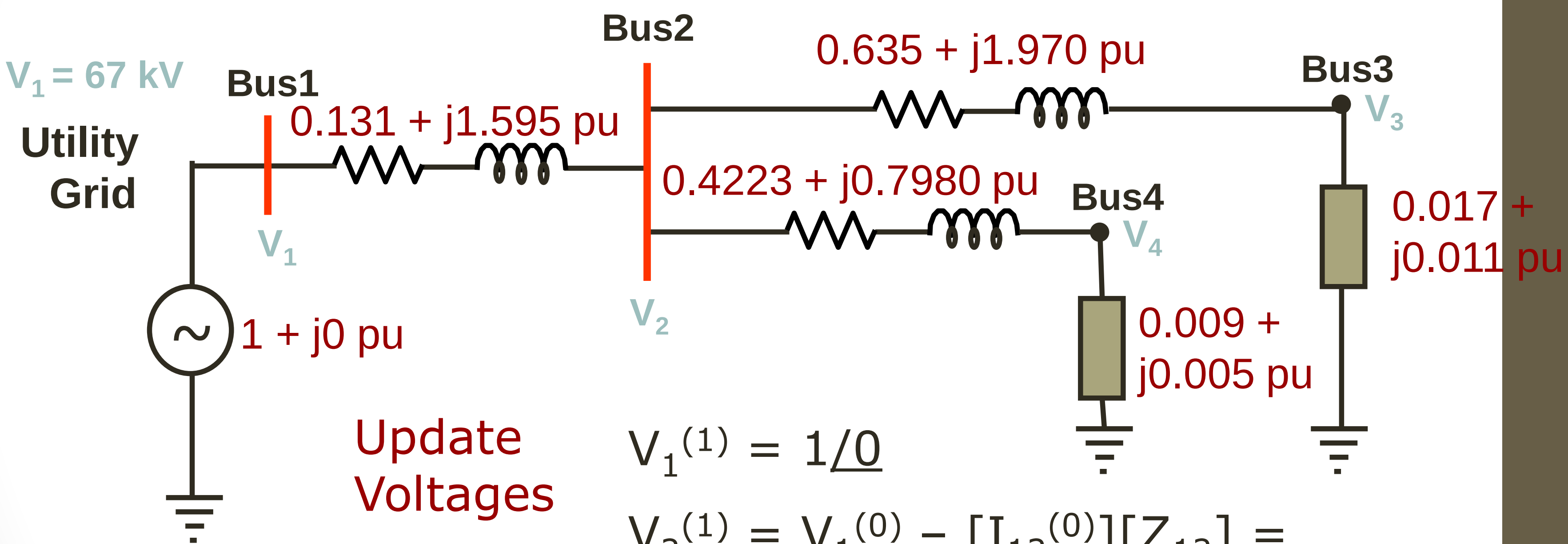
$I_{24}^{(0)} = I_4^{(0)} =$ _________

$I_{23}^{(0)} = I_3^{(0)} =$ _________

$I_{12}^{(0)} = 0 + I_{23}^{(0)} + I_{24}^{(0)} =$ _________

Backward/Forward Sweep Load Flow

Forward Sweep



Update Voltages

(Forward Sweep)

$V_1^{(1)} = 1\underline{/0}$

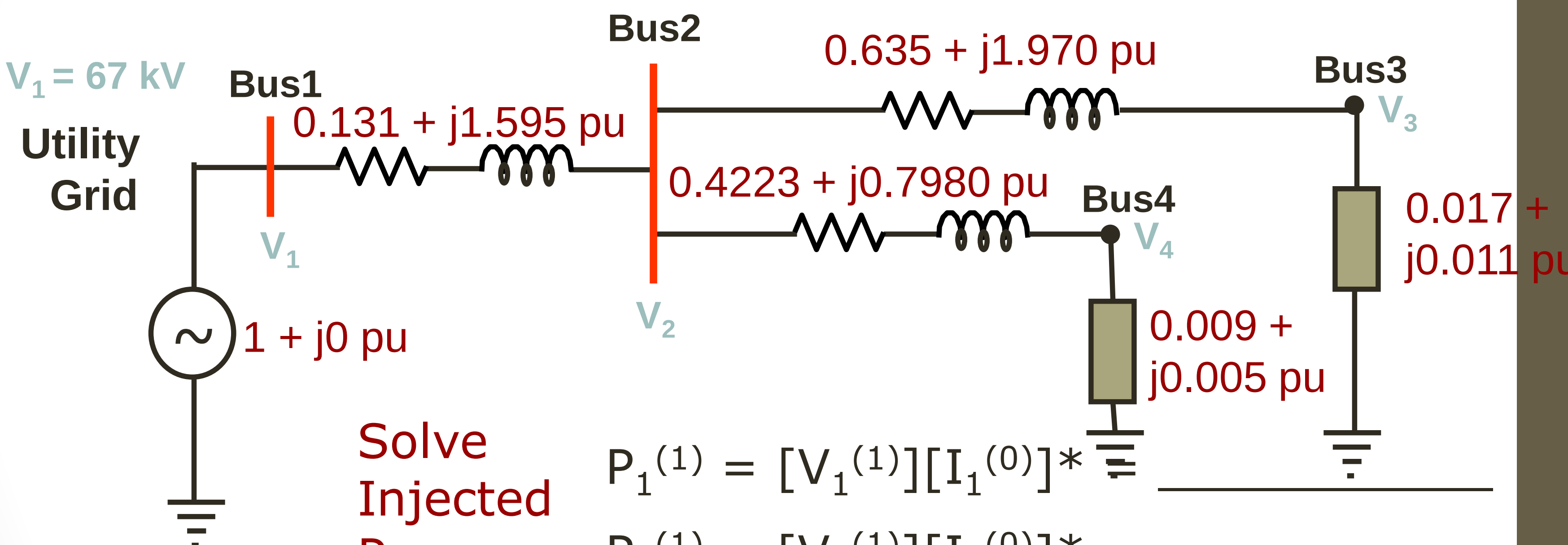
$V_2^{(1)} = V_1^{(0)} - [I_{12}^{(0)}][Z_{12}] =$ __________

$V_3^{(1)} = V_2^{(0)} - [I_{23}^{(0)}][Z_{23}] =$ __________

$V_4^{(1)} = V_2^{(0)} - [I_{24}^{(0)}][Z_{24}] =$

Backward/Forward Sweep Load Flow

Solving for Injected Power



Solve Injected Power

$P_1^{(1)} = [V_1^{(1)}][I_1^{(0)}]^* =$ ____________

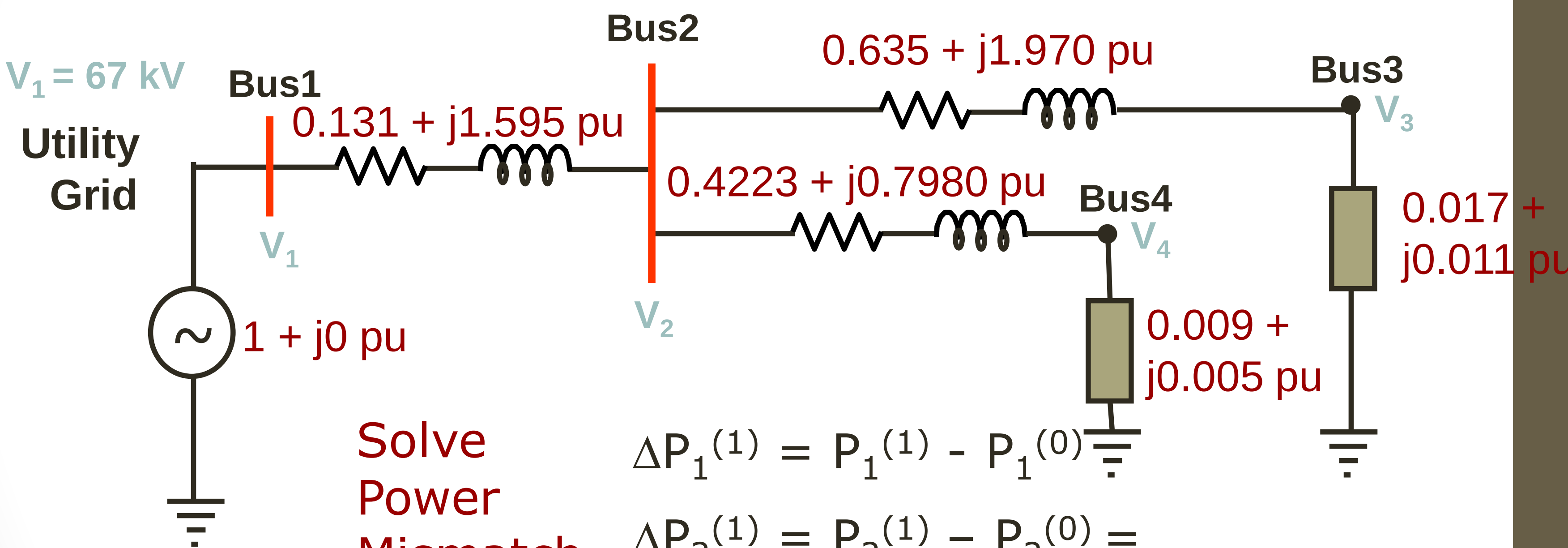
$P_2^{(1)} = [V_2^{(1)}][I_2^{(0)}]^* =$ ____________

$P_3^{(1)} = [V_3^{(1)}][I_3^{(0)}]^* =$ ____________

$P_4^{(1)} = [V_4^{(1)}][I_4^{(0)}]^* =$ ____________

Backward/Forward Sweep Load Flow

Solving for Power Mismatch



Solve Power Mismatch

$\Delta P_1^{(1)} = P_1^{(1)} - P_1^{(0)}$

$\Delta P_2^{(1)} = P_2^{(1)} - P_2^{(0)} =$ ____________________

$\Delta P_3^{(1)} = P_3^{(1)} - P_3^{(0)} =$ ____________________

$\Delta P_4^{(1)} = P_4^{(1)} - P_4^{(0)} =$ ____________________

Backward/Forward Sweep Load Flow

Iterative Solution

Iteration 2:

Solve Injected Currents by Loads

$I_1^{(1)} = 0$

$I_2^{(1)} = 0$

$I_3^{(1)} = S_3^* / [V_3^{(1)}]^* =$ ___________

$I_4^{(1)} = S_4^* / [V_4^{(1)}]^* =$ ___________

Solve Line Currents

(Backward Sweep)

$I_{24}^{(1)} = I_4^{(1)} =$ ________

$I_{23}^{(1)} = I_3^{(1)} =$ ________

$I_{12}^{(1)} = 0 + I_{23}^{(1)} + I_{24}^{(1)} =$ ________

Backward/Forward Sweep Load Flow

Iterative Solution

Update Voltages

(Forward Sweep)

$V_1^{(2)} = 1\underline{/0}$

$V_2^{(2)} = V_1^{(1)} - [I_{12}^{(1)}][Z_{12}] =$ __________

$V_3^{(2)} = V_2^{(1)} - [I_{23}^{(1)}][Z_{23}] =$ __________

$V_4^{(2)} = V_2^{(1)} - [I_{24}^{(1)}][Z_{24}] =$ ____________

Solve Injected Power

$P_1^{(2)} = [V_1^{(2)}][I_1^{(1)}]^* =$ ______________

$P_2^{(2)} = [V_2^{(2)}][I_2^{(1)}]^* =$ ______________

$P_3^{(2)} = [V_3^{(2)}][I_3^{(1)}]^* =$ ______________

$P_4^{(2)} = [V_4^{(2)}][I_4^{(1)}]^* =$ ______________

Backward/Forward Sweep Load Flow

Iterative Solution

Solve Power Mismatch

$$\Delta P_1^{(2)} = P_1^{(2)} - P_1^{(1)}$$

$$\Delta P_2^{(2)} = P_2^{(2)} - P_2^{(1)} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$\Delta P_3^{(2)} = P_3^{(2)} - P_3^{(1)} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$\Delta P_4^{(2)} = P_4^{(2)} - P_4^{(1)} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

If Mismatch is higher than set convergence index, repeat the procedure *(Backward-Forward Sweep) [Iteration 3]*

Backward/Forward Sweep Load Flow

Iterative Solution

Iteration 3:

Solve Injected Currents by Loads

$I_1^{(2)} = 0$

$I_2^{(2)} = 0$

$I_3^{(2)} = S_3^* / [V_3^{(2)}]^* =$ ____________

$I_4^{(2)} = S_4^* / [V_4^{(2)}]^* =$ ____________

Solve Line Currents

(Backward Sweep)

$I_{24}^{(2)} = I_4^{(2)} =$ ________

$I_{23}^{(2)} = I_3^{(2)} =$ ________

$I_{12}^{(2)} = 0 + I_{23}^{(2)} + I_{24}^{(2)} =$ ________

Backward/Forward Sweep Load Flow

Iterative Solution

Update Voltages

(Forward Sweep)

$V_1^{(3)} = 1\underline{/0}$

$V_2^{(3)} = V_1^{(2)} - [I_{12}^{(2)}][Z_{12}] =$ ________

$V_3^{(3)} = V_2^{(2)} - [I_{23}^{(2)}][Z_{23}] =$ ________

$V_4^{(3)} = V_2^{(2)} - [I_{24}^{(2)}][Z_{24}] =$ ________

Solve Injected Power

$P_1^{(3)} = [V_1^{(3)}][I_1^{(2)}]^* =$ ____________

$P_2^{(3)} = [V_2^{(3)}][I_2^{(2)}]^* =$ ____________

$P_3^{(3)} = [V_3^{(3)}][I_3^{(2)}]^* =$ ____________

$P_4^{(3)} = [V_4^{(3)}][I_4^{(2)}]^* =$ ____________

Backward/Forward Sweep Load Flow

Iterative Solution

Solve Power Mismatch

$$\Delta P_1^{(3)} = P_1^{(3)} - P_1^{(2)}$$

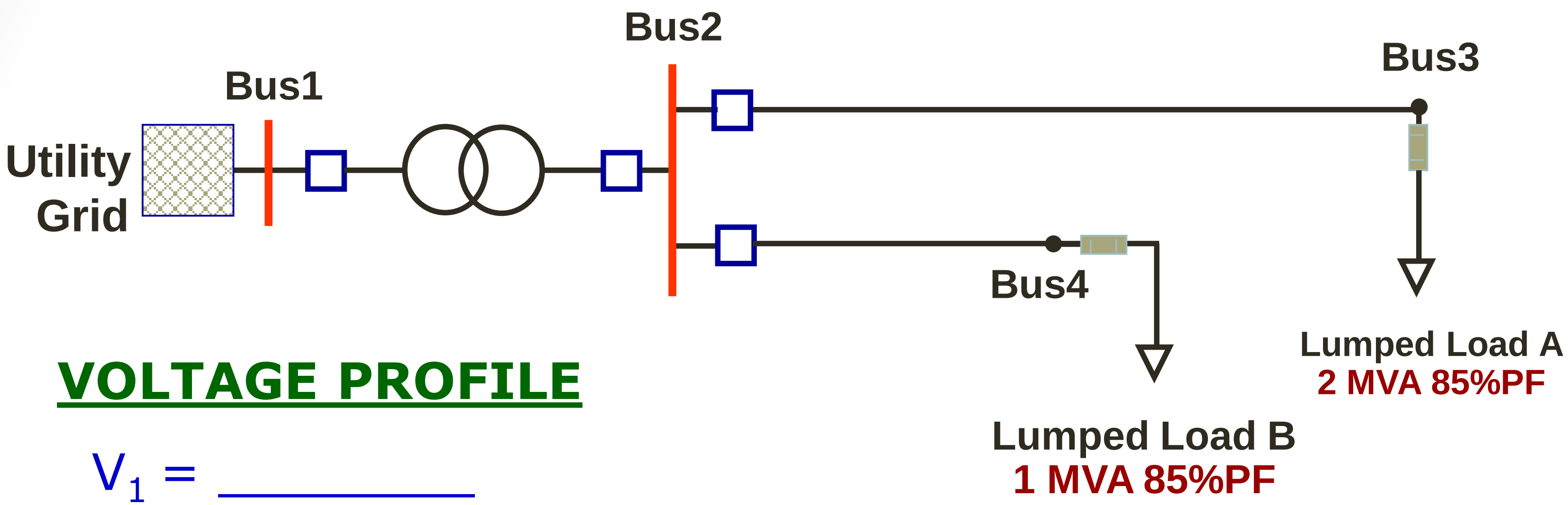
$$\Delta P_2^{(3)} = P_2^{(3)} - P_2^{(2)} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$\Delta P_3^{(3)} = P_3^{(3)} - P_3^{(2)} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

$$\Delta P_4^{(3)} = P_4^{(3)} - P_4^{(2)} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

If Mismatch is lower than set convergence index, compute power flows

Backward/Forward Sweep Load Flow



VOLTAGE PROFILE

V_1 = __________

V_2 = __________

V_3 = __________

V_4 = __________

INJECTED POWER

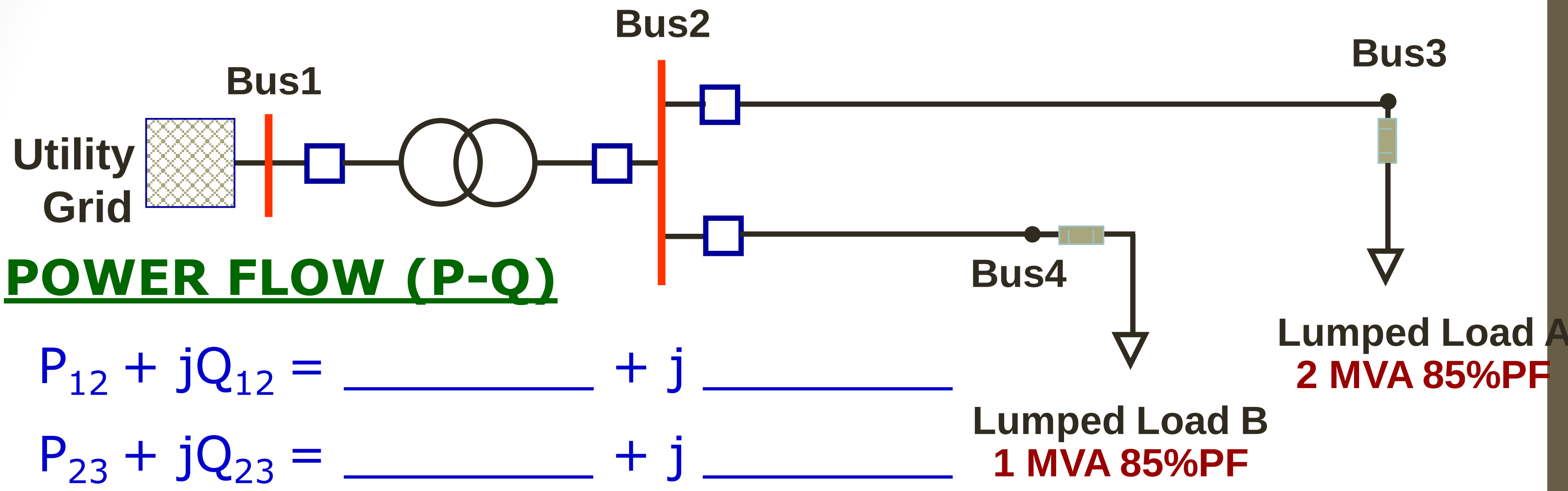
$P_1 + jQ_1$ = __________ + j __________

$P_2 + jQ_2$ = __________ + j __________

$P_3 + jQ_3$ = __________ + j __________

$P_4 + jQ_4$ = __________ + j __________

Backward/Forward Sweep Load Flow



POWER FLOW (P-Q)

$P_{12} + jQ_{12} =$ __________ + j __________

$P_{23} + jQ_{23} =$ __________ + j __________

$P_{24} + jQ_{24} =$ __________ + j __________

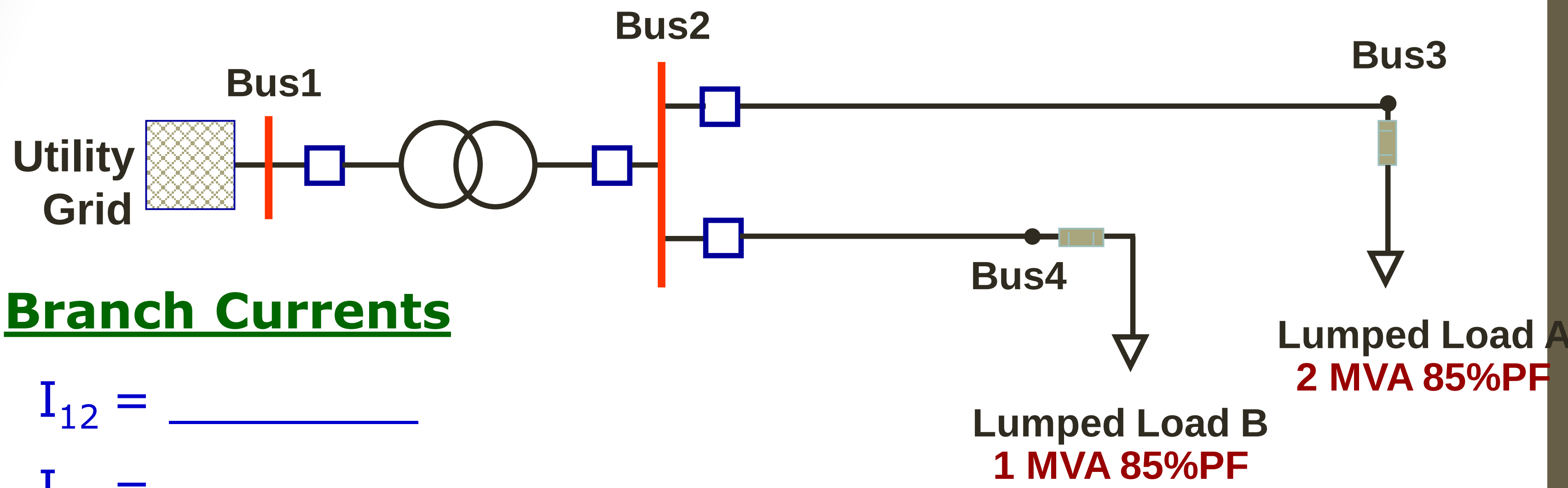
POWER FLOW (Q-P)

$P_{21} + jQ_{21} =$ __________ + j __________

$P_{32} + jQ_{32} =$ __________ + j __________

$P_{42} + jQ_{42} =$ __________ + j __________

Backward/Forward Sweep Load Flow



Branch Currents

I_{12} = __________

I_{23} = __________

I_{24} = __________

POWER LOSSES

$I^2R_{12} + jI^2X_{12}$ = __________ + j __________

$I^2R_{23} + jI^2X_{24}$ = __________ + j __________

$I^2R_{24} + jI^2X_{24}$ = __________ + j __________

Uses of Load Flow Study

- Sensitivity Analysis with Load Flow Study
- Analysis of Existing Conditions
- Analysis for Correcting PQ Problems
- Expansion Planning
- Contingency Analysis
- System Loss Analysis

Uses of Load Flow Studies

Sensitivity Analysis with Load Flow Study

1) Take any line, transformer or generator out of service.
2) Add, reduce or remove load to any or all buses.
3) Add, remove or shift generation to any bus.
4) Add new transmission or distribution lines.
5) Increase conductor size on T&D lines.
6) Change bus voltages.
7) Change transformer taps.
8) Increase or decrease transformer size.
9) Add or remove rotating or static var supply to buses.

ECONOMIC JUSTIFICATION FOR CAPACITORS

Overview

- Benefits due to Released Generation Capacity
- Benefits due to Released Transmission Capacity
- Benefits due to Released Distribution Substation Capacity
- Benefits due to Reduced Energy Losses
- Benefits due to Reduced Voltage Drops
- Benefits due to Released Feeder Capacity
- Financial Benefits due to Voltage Improvement
- Total Financial Benefits due to Capacitor Installations

Economic Justification of capacitors- Intro

- Loads on electric utility systems include two components
  - active power - generated at power plants
  - reactive power - provided by either power plants or capacitors
- shunt power capacitors - the most economical source to meet the reactive power requirements of inductive loads and transmission lines operating at a lagging power factor
- When reactive power is provided only by power plants, size of the system component increases

Cont...

- Capacitors reduces
  - reactive power demand
  - Line currents
  - losses and loadings are reduced in distribution lines, substation transformers, and transmission lines
- Depending upon the uncorrected power factor of the system, the installation of capacitors can
  - **increase generator** and **substation capability** for additional load at least 30%
  - increase individual circuit capability,
  - the voltage regulation also increases , approximately 30%–100%.

Cont...

- the economic benefits force capacitor banks to be **installed on the primary distribution system** rather than on the secondary.
- the economic benefits derived from **capacitor installation** can be summarized as
  - Released generation capacity
  - Released transmission capacity
  - Released distribution substation capacity
  - Additional advantages in distribution system
    - a. Reduced energy (copper) losses
    - b. Reduced voltage drop and consequently improved voltage regulation
    - c. Released capacity of feeder and associated apparatus
    - d. Elimination of capital expenditure due to system improvements and/or expansions
    - e. Revenue increase due to voltage improvements

Benefits due to Released Generation Capacity

- The released generation capacity due to the installation of capacitors can be calculated approximately from.

$$\Delta S_G = \begin{cases} \left[\left(1 - \frac{Q_c^2 \times \cos^2\theta}{S_G^2}\right)^{1/2} + \frac{Q_c \times \sin\theta}{S_G} - 1\right] S_G & \text{when } Q_c > 0.10 S_G \\ Q_c \times \sin\theta & \text{when } Q_c \le 0.10 S_G \end{cases}$$

- ΔS_G is the released generation capacity beyond maximum generation capacity at original power factor, kVA
- S_G is the generation capacity, kVA
- Qc is the reactive power due to corrective capacitors applied, kvar
- $\cos\theta$ is the original (or uncorrected or old) power factor before application of capacitors

Cont…

- Therefore, the annual benefits due to the released generation capacity can be expressed as

$$\Delta \$_G = \Delta S_G \times C_G \times i_G$$

- $\Delta \$_G$ is the annual benefits due to released generation capacity, \$/year
- ΔS_G is the released generation capacity beyond maximum generation capacity at original power factor, kVA
- C_G is the cost of (peaking) generation, \$/kW
- i_G is the annual fixed charge rate applicable to generation

Benefits due to Released Transmission Capacity

- The released transmission capacity due to the installation of capacitors can be calculated approximately as

$$\Delta S_T = \begin{cases} \left[\left(1 - \frac{Q_c^2 \times \cos^2\theta}{S_T^2} \right)^{1/2} + \frac{Q_c \times \sin\theta}{S_T} - 1 \right] S_T & \text{when } Q_c > 0.10 S_T \\ Q_c \times \sin\theta & \text{when } Q_c \le 0.10 S_T \end{cases}$$

- ΔS_T is the released transmission capacity beyond maximum transmission capacity at original power factor, kVA
- S_T is the transmission capacity, kVA

The annual benefits due to the released transmission capacity can be found as

$$\Delta \$_T = \Delta S_T \times C_T \times i_T$$

$\Delta \$_T$ is the annual benefits due to released transmission capacity, \$/year
ΔS_T is the released transmission capacity beyond maximum transmission capacity at original power factor, kVA
C_T is the cost of transmission line and associated apparatus, \$/kVA
i_T is the annual fixed charge rate applicable to transmission

Benefits due to Released Distribution Substation Capacity

- The released distribution substation capacity due to the installation of capacitors can be found approximately from

$$\Delta S_S = \begin{cases} \left[\left(1 - \dfrac{Q_c^2 \times \cos^2\theta}{S_S^2} \right)^{1/2} + \dfrac{Q_c \times \sin\theta}{S_S} - 1 \right] S_S & \text{when } Q_c > 0.10 S_S \\ Q_c \times \sin\theta & \text{when } Q_c \le 0.10 S_S \end{cases}$$

ΔS_S is the released distribution substation capacity beyond maximum substation capacity at original power factor, kVA

S_S is the distribution substation capacity, kVA

The annual benefits due to the released substation capacity can be calculated as

$$\Delta \$_S = \Delta S_S \times C_S \times i_s$$

$\Delta \$_S$ is the annual benefits due to the released substation capacity, $/year

ΔS_S is the released substation capacity, kVA

C_S is the cost of substation and associated apparatus, $/kVA

i_S is the annual fixed charge rate applicable to substation

Benefits due to Reduced Energy Losses

- The annual energy losses are reduced as a result of decreasing copper losses due to the installation of capacitors. The conserved energy can be expressed as

$$\Delta ACE = \frac{Q_{c,3\phi} R (2 S_{L,3\phi} \sin\theta - Q_{c,3\phi}) 8760}{1000 \times V_{L-L}^2}$$

ΔACE is the annual conserved energy, kWh/year
$Q_{c,3\phi}$ is the three-phase reactive power due to corrective capacitors applied, kvar
R is the total line resistance to load center, Ω
$Q_{L,3\phi}$ is the original, that is, uncorrected, three-phase load, kVA
sin θ is the sine of original (uncorrected) power factor angle
V_{L-L} is the line-to-line voltage, kV
The annual benefits due to the conserved energy can be calculated as

ΔACE is the annual benefits due to conserved energy, \$/year $\Delta \$_{ACE} = \Delta ACE \times EC$
EC is the cost of energy, \$/kWh

Benefits due to Reduced Voltage Drops

The following advantages can be obtained by the installation of capacitors into a circuit

1. The effective line current is reduced, and consequently, both IR and IX_L voltage drops are decreased, which results in improved voltage regulation.
2. The power factor improvement further decreases the effect of reactive line voltage drop.

The percent voltage drop that occurs in a circuit can be expressed as

$$\%VD = \frac{S_{L,3\phi}(r\cos\theta + x\sin\theta)l}{10 \times V_{L-L}^2}$$

%VD is the percent voltage drop
$S_{L,3\phi}$ is the three-phase load, kVA
r is the line resistance, 0hms/m
x is the line reactance, 0hms/ m
l is the length of conductors, m
V_{L-L} is the line-to-line voltage, kV

Cont...

- After the application of the capacitors, the system voltage rise due to the improved power factor and the reduced effective line current
- the voltage drops due to IR and IXL are minimized.
- The approximate value of the percent voltage rise along the line can be calculated as

$$\%VR = \frac{Q_{c,3\phi} \times x \times l}{10 \times V_{L-L}^2}$$

Voltage-rise phenomenon through every transformer from the generating source to the capacitors occurs due to the application of capacitors

It is independent of load and power factor of the line and can be expressed as

$$\%VR_T = \left(\frac{Q_{c,3\phi}}{S_{T,3\phi}}\right) x_T$$

$\%VR_T$ is the percent voltage rise through the transformer

$S_{T,3\phi}$ is the total three-phase transformer rating, kVA

x_T is the percent transformer reactance

Benefits due to Released Feeder Capacity

- The feeder capacity is restricted by allowable voltage drop rather than by thermal limitations.
- The installation of capacitors decreases the voltage drop and consequently increases the feeder capacity
- The feeder capacity can be calculated as $\Delta S_F = \frac{(Q_{C,3\phi})x}{x\sin\theta + r\cos\theta}$ kVA

The annual benefits due to the released feeder capacity can be calculated as

$$\Delta \$_F = \Delta S_F \times C_F \times i_F$$

$\Delta \$_F$ is the annual benefits due to released feeder capacity, \$/year

ΔS_F is the released feeder capacity, kVA

C_F is the cost of installed feeder, \$/kVA

i_F is the annual fixed charge rate applicable to the feeder

Financial Benefits due to Voltage Improvement

- The revenues to the utility are increased as a result of increased kilowatthour energy consumption due to the voltage rise produced on a system by the addition of the corrective capacitor banks
- The increase in revenues due to the increased kilowatthour energy consumption can be calculated as

$$\Delta\$_{BEC} = \Delta BEC \times BEC \times EC$$

Δ$BEC is the additional annual revenue due to increased kWh energy consumption, $/year

ΔBEC is the additional kWh energy consumption increase

BEC is the original (or base) annual kWh energy consumption, kWh/year

Total Financial Benefits due to Capacitor Installations

- The total benefits due to the installation of capacitor banks can be summarized as

$$\sum \Delta\$ = (\text{Demand reduction}) + (\text{Energy reduction}) + (\text{Revenue increase})$$
$$= (\Delta\$_G + \Delta\$_T + \Delta\$_S + \Delta\$_F) + \Delta\$_{\text{ACE}} + \Delta\$_{\text{BEC}}$$

The total cost of the installed capacitor banks can be found from

$$\Delta \text{EIC}_c = \Delta Q_c \times \text{IC}_c \times i_c$$

ΔEIC_c is the annual equivalent of the total cost of installed capacitor banks, \$/year
ΔQ_c is the required amount of capacitor-bank additions, kvar
IC_c is the cost of installed capacitor banks, \$/kvar
i_c is the annual fixed charge rate applicable to capacitors

References

- Turan Gonen, “Electric Power Distribution System Engineering” , CRC Press, 3rd Edition 2014.

Thank You

MULTI – GROUNDING IN THE DISTRIBUTION SYSTEM

WHAT IS GROUNDING?

As its name suggests, grounding is a connection of the electrical system, electrical devices, and metal enclosures to the ground. It is also known as earthing, i.e., connection to the earth.

Even though non-grounded electrical systems do exist — either because they are excepted from grounding by codes or by operational reasons — most arrays are grounded in one way or another.

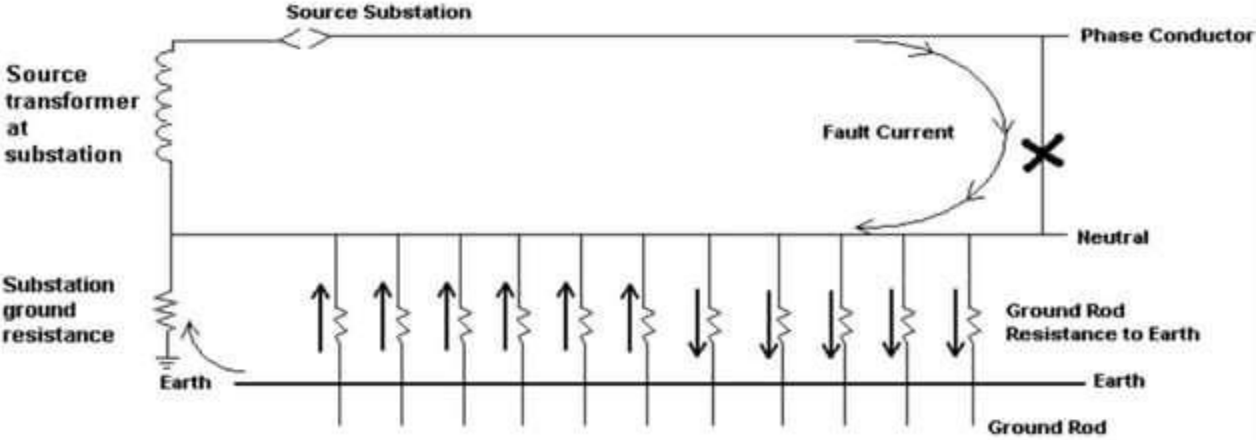
DISTRIBUTION SYSTEM GROUNDING

- A discussion on grounding is critical when discussing utility distribution systems because:
  - Utility distribution systems are subject to a variety of stressors which result in electrical "faults."
  - "Better" grounding enables "better" fault detection.
  - Good fault detection enables successful fault clearing, which limits outages.
  - Better grounding can lead to voltage swells on unfaulted phases during phase-to-ground faults.
- Primary fault clearing, when the fault is phase to earth, is unlikely to de-energize the phase in an ungrounded system.
- At various points (usually many) on utility systems using multi-point grounding, the neutral and various pieces of equipment (switches, guy wires, etc.) are tied to earth through ground rods.
- Utility neutral and grounds are the same.
- By installing grounds, the ground system becomes the destination for all electric currents. Safety impacts include risk to people if they contact both ground and energized facilities.

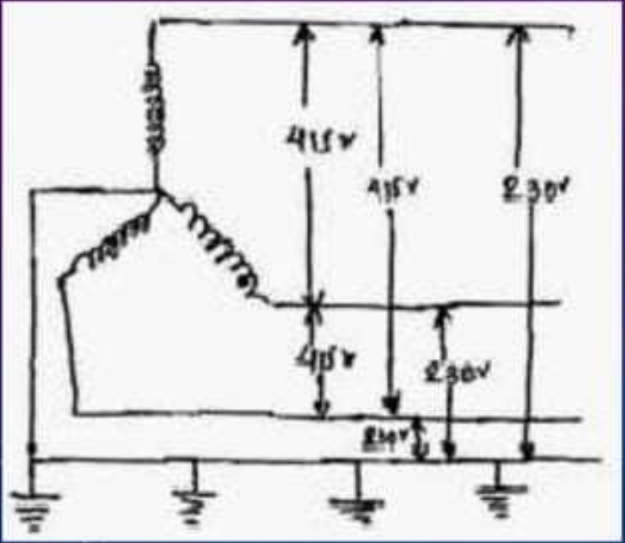
DISTRIBUTION SYSTEM GROUNDING

- Low ground rod resistance to earth is a good thing.

- Ground Rod Resistance Affected by:
  - Soil resistivity
  - Ground rod diameter (not too much)
  - Ground rod length (depth)
  - Parallel rods


Source Substation
Phase Conductor
Source transformer at substation
Fault Current
Neutral
Substation ground resistance
Ground Rod Resistance to Earth
Earth
Earth
Ground Rod

MULTI GROUNDED NEUTRAL SYSTEM



The neutral is used by some utilities to reduce the available ground fault current while at the same time still maintaining an effectively grounded system.

The multiple earthed neutral (MEN) system of earthing is one in which the low voltage neutral conductor is used as the low resistance return path for fault currents and where its potential rise is kept low by having it connected to earth at a number of locations along its length. The neutral conductor is connected to earth at the distribution transformer, at each consumer's installation and at specified poles or underground pillars. The resistance between the neutral conductor of the distribution system and the earth must not exceed 10 ohms at any location.

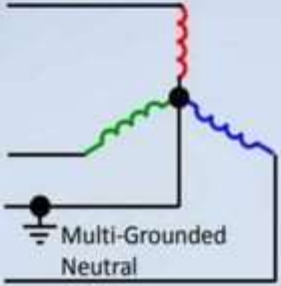
NEC Article 250 Part X Grounding of Systems and Circuits 1 kV and Over (High Voltage)

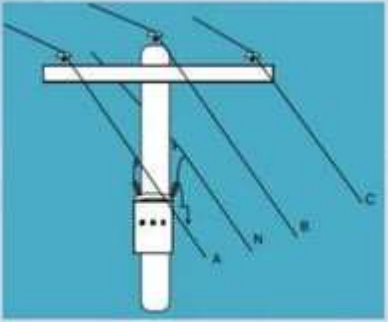
1) Multiple Grounding: The neutral of a solidly grounded neutral system shall be permitted to be grounded at more than one point.
2) Multi-grounded Neutral Conductor: Ground each transformer, Ground at 400m intervals or less, Ground shielded cables where exposed to personnel contact.

3-Phase Power Systems

Distribution Lines: Wye Configuration

Multi-grounded Neutral: At least four times per mile per the National Electric Safety Code



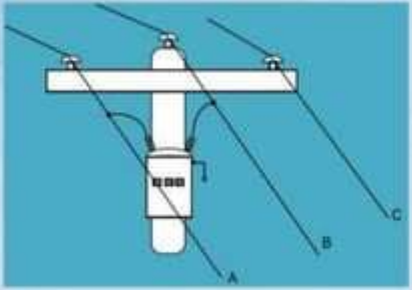


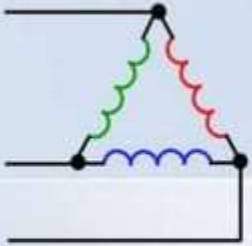
Grounded neutral

3-Phase Power Systems

Distribution Lines: Delta Configuration

Delta three-phase distribution lines use three wires, no neutral. Transformer tanks and lightning arresters are connected to ground rods at each pole.

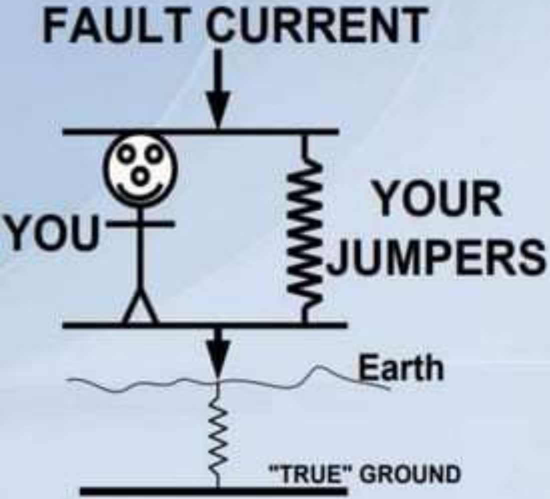




No grounded neutral!

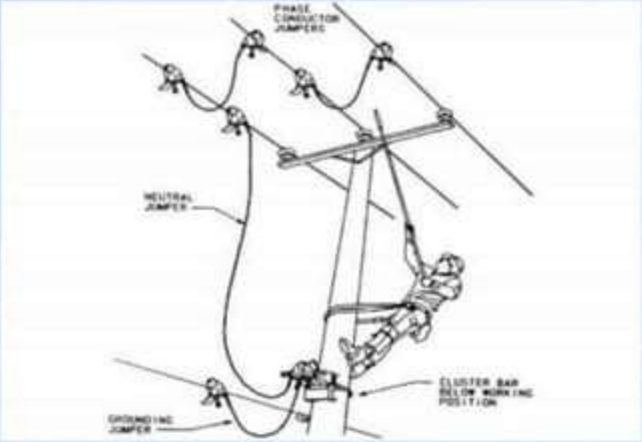
Electrical Grounding Safety

Conduction - Jumper Voltage Drop Protection

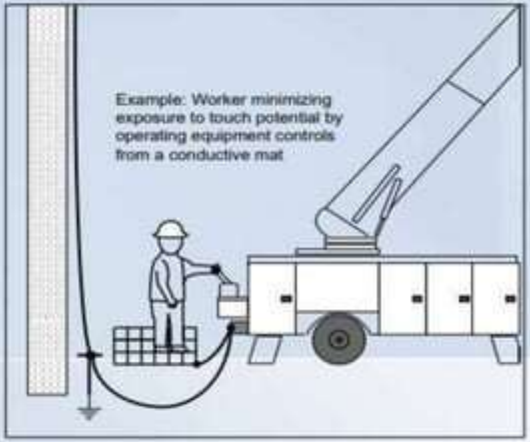


Electrical Grounding Safety

Conduction - Distribution Structure Safety



Single Point Grounding



Vehicle Arrangement

WHAT IS A FAULT?

- A "fault," in utility terms, is a problem with any energized conductor that either falls, fails in service, or is touched by a foreign entity. It is not necessarily a "short circuit," but can be.
  - Flashover – high heat generation from arc in a gas (air) plasma
  - Animal/tree contact
- Faults are either transient or permanent.
- Whether a fault exists is independent of whether high fault current flows.

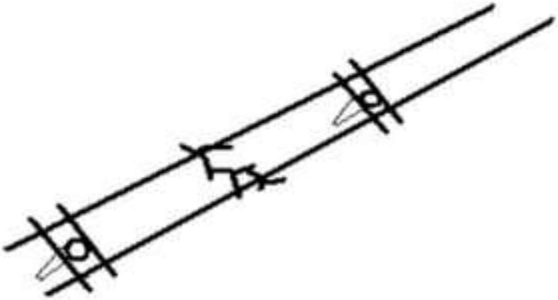
FAULTS

- Available fault current levels are rarely reached.
- Actual fault current values are dependent upon the impedance of the fault.
- It is BEST to characterize fault impedances as either "high" or "low."
- The tap wire length to transformers (and other distribution equipment) should be as short as possible. Long lead lengths have higher impedance values and, when fault current flows through them (say, to a lightning arrester), the voltage built up by the impedance severely limits fault current flow. This could inhibit the effectiveness of fault clearing.

TYPICAL PRIMARY SYSTEM FAULTS

- Result in phase to ground or phase to phase faults; sometimes, result in simple loss of a phase with no fault current.
- Wires burn down due to flashover and tree contacts, as well as mechanical damage.
- Electrically, bare conductors burn down less often than covered conductors since a bare conductor will allow a traveling arc to proceed down the line until it elongates and extinguishes. If such an arc encounters insulated wire covering, it stops but still burns and may burn through the conductor. So, conductor thickness plays a role in burn down events also.
- Connector failure

- Flashover
  - Flashover is a temporary conduction from any phase to another, or to ground.
  - Usually induced by another fault: Something contacts phase to phase or phase to ground, or lightning.
- Equipment failure



Tree Limb on Phases:

- Electric current through limb dries it out and, therefore, the amount of current through the limb goes down, i.e., the limb's conductivity is reduced.

- As the limb carbonizes, its conductivity rises and carbon tracking occurs.

- This is usually not fault current....the limb burns clear (self-trims)....or,

- The heat of the current flow at the wire-limb contact resistance may cause the wire to burn down.

PRIMARY SYSTEM FAULTS: FLASHOVER

- Flashover is a conduction through air between phases or from phase to ground. They can be cleared, or self clear, or become "better" or "worse."
- Some things that affect flashover probability:
  - Feeder geometry: Greater distances between phases is a good thing. Close proximity of phases or phases to neutral/ground raises the probability of flashover in any given event.
  - Pole arrester location and rating

TRANSFORMER FAILURES

- Most utility transformers are oil filled.
- Internal intermittent arcs on coils can point-boil oil, evolving gases in the tank. Gases include hydrogen and acetylene. Failure can be violent.
- Environmental (oil, oil additives, burning by-products)

PRIMARY FAULT CLEARING

Distribution protective devices have, as their main purpose, the isolation of system damage for purposes of protecting utility equipment. Their main function is not personal safety of either utility workers or the general public, though clearing of the fault if successful lends to overall safety

PRIMARY FAULT CLEARING: FUSES

- Fuses are the most wide-spread and the most consistently reliable form of line protection in use today. They are cost-effective, and can remain in service for many years without operating, yet still function when needed.

- Fuses are either expulsion fuses or current limiting fuses. (Current limiting fuses are used on the output of 277/480Y network protectors.)

PRIMARY FAULT CLEARING: FUSES

- Fuses must be coordinated to each other if in series, as well as being coordinated to the recloser and the substation circuit breaker.

- Greater fault current clears the fault faster but makes fuse coordination somewhat more difficult.
  - The 100T and 65T "cross" at 4000 amps…..At 4000 amps, the 65T will not necessarily clear the fault before the 100T

PRIMARY FAULT CLEARING: SUBSTATION CIRCUIT BREAKERS

"Quickly" clearing faults on the main line prevents outages and wire burn downs. Quickly clearing faults on fused taps not only saves the fuse, where possible, preventing a field repair, but prevents branch line outages. The substation circuit breaker serves a critical role in this fault clearing process.

PRIMARY FAULT CLEARING: SUBSTATION CIRCUIT BREAKERS

- 600A rating at 13kv
- "Typical fault current ~1800A
  - Fault current could range from ~8kA near the substation to <1kA further out on the feeder
  - Power dissipation in millions of watts
- Older, electromechanical relays in the breakers coordinate so the breaker at first is faster than an intervening fuse, then slower. Attempts to save the fuse.
- Digital relays are both faster, more controllable (down to cycles), more consistent, and programmable. If fault current is very high, the breaker can allow a fuse to blow, saving the momentary interruption. At lower fault current levels, can attempt to save the fuse.

“Reclosing, either automatic or manual through supervisory control, is critical to proper and prudent electric utility operations.”

Thank You!!!

INTRODUCTION

- Over a period of time the demand for electric power in India has changed drastically, both quantity and quality wise.
- Due to rapid developmental activities the dependence on electric power has increased the need for steady power supply.
- The main concern has been the reduction in the power interruption and fault restoration.
- Thus to overcome these issues automation of power distribution system needs to be adopted.
- Where in all the switches and circuit breakers involved in the grids need to be equipped with facilities for remote operations.
- As we know power system grid is complex network, the latest computer, communication and distribution technologies needs to be adopted with updated software.

DISTRIBUTION AUTOMATION

- DA is an integrated system concept for digital automation of distribution sub-station, feeder and user functions.
- It mainly includes control, monitoring and protection of the distribution system, load management and remote metering of consumer loads.
- The main components of Distribution Automation are:
- Computer Hardware
- Computer Software
- Remote Terminal Units (RTU)
- Communication Systems
- Consumer Metering Devices

Benefits of using DA are

- Improved quality of supply
- Improved continuity of supply
- Voltage level stability
- Reduced system losses
- Reduced Investment

Objectives of DA are:

- Providing automatic reclosing of relays, automatic feeder switching and provides remote monitoring and controlling of distribution equipment's (Transformer, capacitors, breakers)
- To minimize the outage time of power cuts and to improve consumer service there by reducing the power delivery cost.

CONTROL FUNCTIONS

DA has different control functions :

- Electrical grid analysis
- Work Management
- Trouble call analysis
- Consumer load monitoring
- Intelligent remote metering
- Automated capacitor control
- Sub-station automation
- Intelligent electric devices
- Advanced RTU
- Power Quality monitoring
- Energy Management

COMMUNICATION SYSTEM

- There are many communication methods which are available.
- Proper selection of different communication methods are required to communicate between Distribution control centre (DCC) and with any point on distribution network.
- The selection needs to be done during the planning stages only.
- The fundamental requirement for communication infrastructure are:

1. Determining the average message generated
2. If the system can handle the required amount of data and multitasking
3. Data sending and response time of the system should meet the requirements of different system.
4. Should allow network expansion and addition of new applications.

CONSUMOR INFORMATION SERVICE

- In India consumer service is mainly done in the manner of "fire fighting" that is it is complaint based.
- Consumers want fast, accurate and cost-effective service.
- Consumer information service provides the following function for better service to the consumer:

1. Consumer information
2. Account management
3. Service orders
4. Field service
5. New business
6. Meter reading
7. Service rates
8. Billing
9. Website Management

GEOGRAPHICAL INFORMATION SYSTEM

- GIS stores distribution system records for the entire network or an area, which also gives the Details of the age and position of sub-station, lines and cables.
- The main system operators will be aware of there equipment's and behaviors of their assets.
- Different topologies maps can be used for grid control, load analysis, cable lying, attending consumer complaints.
- Integrating GIS into business support system provides further benefits for an organization.
- For example, emergency repair can be carried out more efficiently if the control room operators could send the maps showing the location of faults or equipment with fault to the maintenance staff.

SCADA SYSTEM

- SCADA stands for Supervisory Control and Data Acquisition. SCADA refers to a system that collects data from various sensors at a factory, plant or in other remote locations and then sends this data to a central computer which then manages and controls the data.
- The feedback control is initiated through remote terminal unit(RTU) or Programmable logic controller (PLC), while the SCADA system monitors the overall performance.
- **For example:** A PLC may control the flow of cooling water through part of an industrial process, but the SCADA system may allow operators to change the set value for the flow, and enable alarm conditions, such as loss of flow and high temperature, to be displayed and recorded.
- Most essentially the SCADA system consists of three fundamental components (i.e. Master station (MS) or Central Monitoring System (CMS), Communication link and RTU or PLC).
- SCADA is not a specific technology or protocol but refers to any application where data is collected and stored from a system in order to control that system.

SCADA SYSTEM

- Example of SCADA System

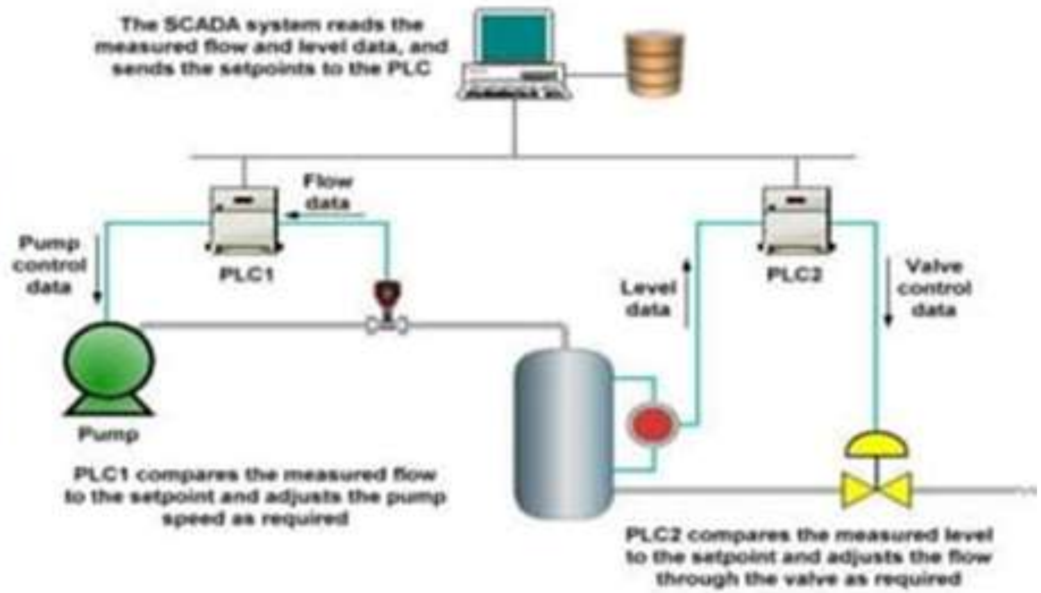


Fig. 1 Example of SCADA System

- Block Diagram

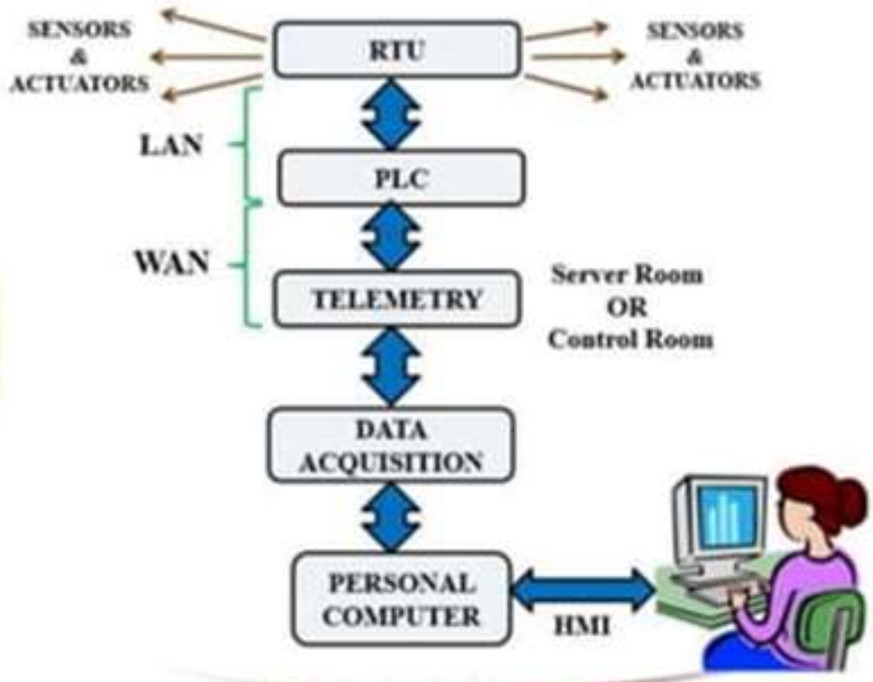


Fig. 2 Block of SCADA System

HOW SCADA SYSTEM LOOKS

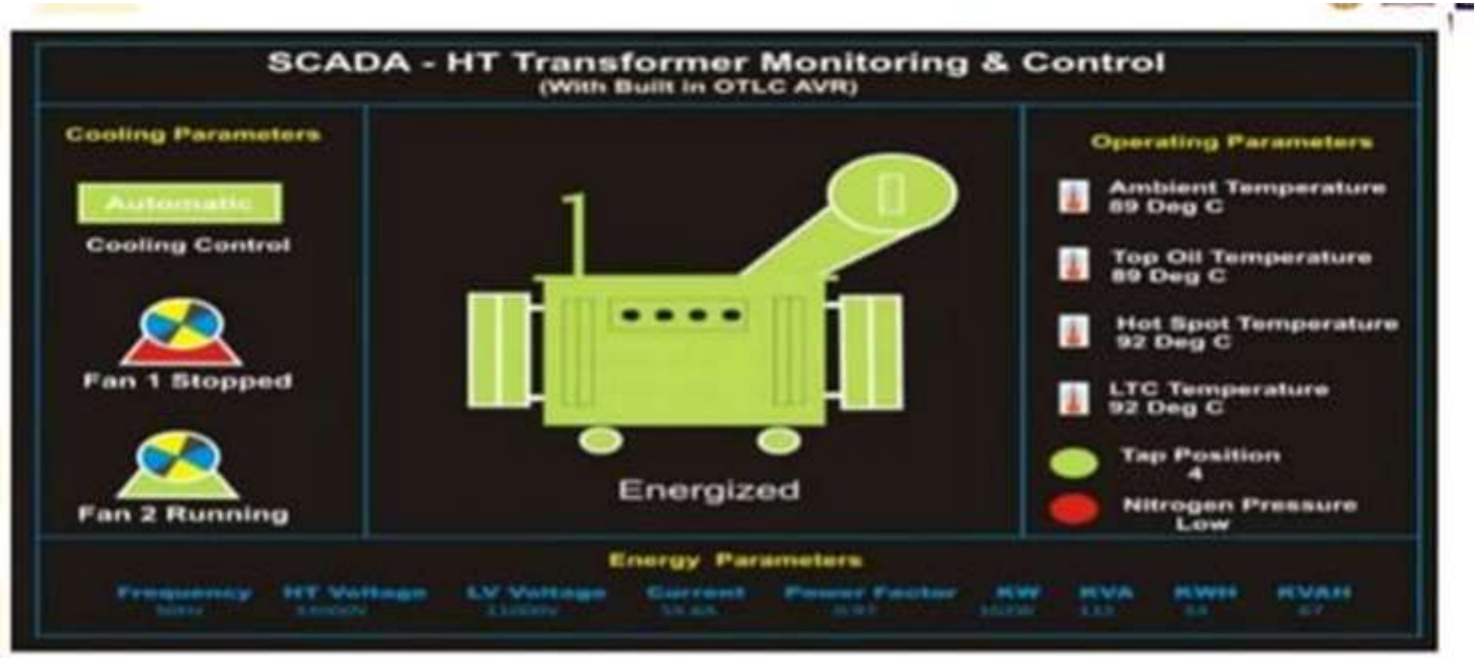


Fig. 3 Representation of SCADA in real time

PLC SCADA

- PLC - Programmable logic controller. Its a hardware, directly in contact with field instruments. It controls output according to the logic stored in PLC Memory.

- SCADA- Supervisory control and data acquisition. Its a software, shows the output and feedback in Visual manner, that PLC can't do. It monitors or supervises the devices and parameters of the system

ADVANTAGES AND APPLICATIONS

ADAVANTAGES

- Data acquisition
- Permits fewer employees to be more productive
- Simple monitoring, maintenance and operation
- Remotely accessible
- Increases the efficiency of process

APPLICATIONS

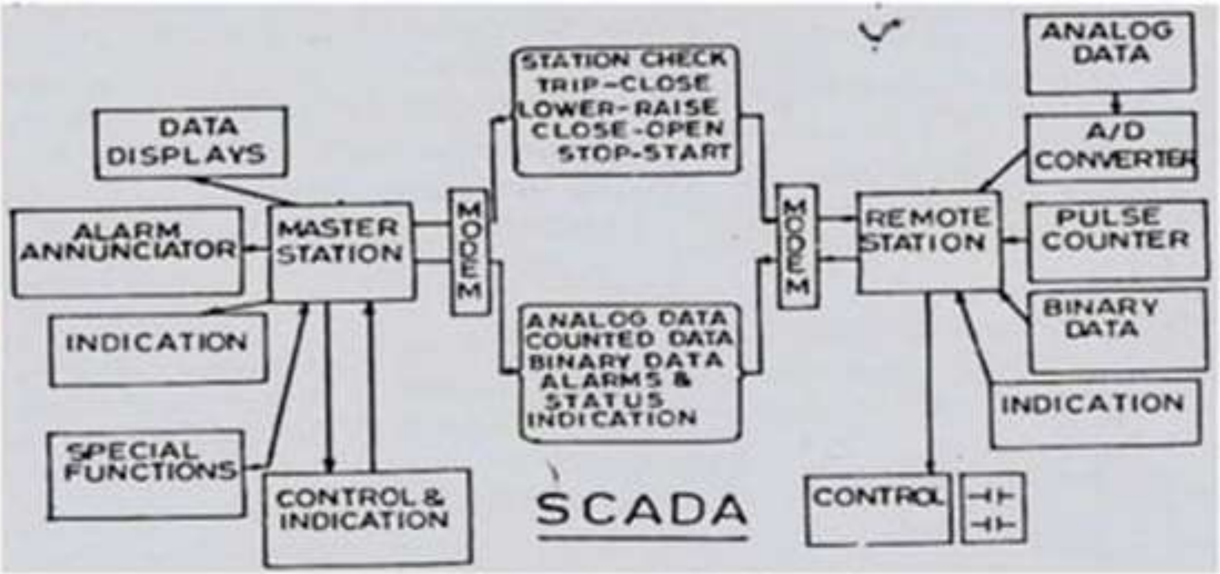
- Power grids
- Industries
- Automation
- Billing
- Research
- Hospitals

TECHNICAL FUNCTIONS OF SCADA

- The CMS houses the Control Server and the communications routers via a peer-to-peer network. The CMS collects and logs information gathered by the remote stations and generates necessary actions for events detected.
- A remote station consists of either a Remote Terminal Unit (RTU) or a Programmable Logic Controller (PLC) which controls actuators and monitors sensors.
- The SCADA system provides the following functions:
- **Data acquisition:** The basic information of the power system collected is called the Data Acquisition. The data is collected by means of CTs, PTs and transducers. It provides the telemetry measurement and status indication to the operator.
- **Supervisory control:** It enables the operator to remotely control the devices. For example open and close of the circuit breaker.
- **Tagging:** It prevents the device from unauthorized operation. Means it authorizes the device to perform the specific operation.
- **Alarms:** It informs the operator about the unnecessary events and undesired conditions.
- **Logging (Recording):** It logs all the operating entry, all alarms and other information. In other words it keeps the record of all the events.

TECHNICAL FUNCTIONS OF SCADA

- **Load shading:** It provides both the automatic and manual control tripping of load during the emergency.
- **Trending:** It plots the measurement on the selected time scale.



ESSENTIAL FEATURES OF SCADA

- The SCADA system enables the operator to attain the complete knowledge of the system in a single room by means of display.
- Almost all the SCADA systems are computer based (Digital computer). This computer is located in the master unit. The master unit is the heart of the SCADA system, it comprises many of the i/p and o/p equipment's to receive and send the control message from and to the RTU.
- All the data of operations of RTU are transmitted to the master control nd after collecting the information the data are feed back to the RTU.
- Also master unit consists of several modems which are used to convert the digital into analog or analog into digital message depending upon the requirement. The received information of the master unit is displayed on VDU and then is printed for permanent record.
- In addition the SCADA system also comprises some more peripheral equipment such as control console, VDU, Alarms, Printers, D/A converter and Recording instruments.

TECHNICAL FUNCTIONS OF SCADA

- Visual Display Unit (VDU) replaces mimic board to represent one line diagram, tabular display, bar charts, curves and event lists and used for entering commands to system.
- Modern system includes the color display which is used to distinguish b/w the different voltage levels. Also different colors differentiate the operator to understand the open and close of CB, also the flashing indication can be made which determines the change of the state of any device.
- The audible alarms can be used to alert the operator from the fault or condition. The printers are used to have the permanent records of the events.
- The D/A converter are used to convert the digital information into the analog information, and then the information is supplied to the indicating or the recording instruments. The recording instruments are used to store the data of each remote station unit. unit a

THANK YOU