

Power Distribution Networks: A brief overview

Dr. Sanjib Ganguly

Associate Professor, Department of EEE,

IIT Guwahati (Email: sganguly@iitg.ac.in)

Contents

- Substation design
- Feeder topologies and power loss and voltage drop computations
- Substation and distribution transformers

Substation

- A primary distribution substation is the connection point of a distribution system to a transmission or a sub-transmission network.
- Outgoing feeders from a primary distribution substation are typically feeding distribution transformers and direct loads for the industrial consumers.
- A typical substation may include the following equipment: (1) power transformers, (2) circuit breakers, (3) isolators, (4) station buses and insulators, (5) current transformers, (6) potential transformers, (7) shunt capacitors, (10) grounding system, (11) lightning arresters and/or gaps, (12) protective relays, (13) station batteries, and (17) other apparatus.

Outdoor and Indoor Substations

- ▶ A typical primary distribution substation would include air-insulated outdoor-type high-voltage (HV) switchgear and an enclosed air-insulated indoor-type medium-voltage (MV) switchgear.
- ▶ A substation can also be built using Gas Insulated Switchgear (GIS) technology which requires lower space.
- ▶ In GIS substation, both the HV and MV switchgears are built as metal-enclosed indoor-type switchgear. This type of substation can be placed inside a building.

A typical outdoor rural primary distribution substation 110/20kV



- Needs comparatively larger space
- Comparatively cheap
- Most of the substations belong to this type
- Needs maintenance

A typical indoor Gas Insulated Substation



- Needs very less space
- Can be installed in cities with higher population density
- Expensive
- Needs little maintenance
- High reliability

Substation Location

- A substation is usually located close to the load center of its service area.
- A substation's location influences voltage regulation.
- A substation's location should be such that it provides proper access for incoming sub-transmission lines and outgoing primary feeders.
- A substation's location should provide enough space for the future expansion.
- The choice of substation location depends on land-use regulations, local ordinances, and neighbors.

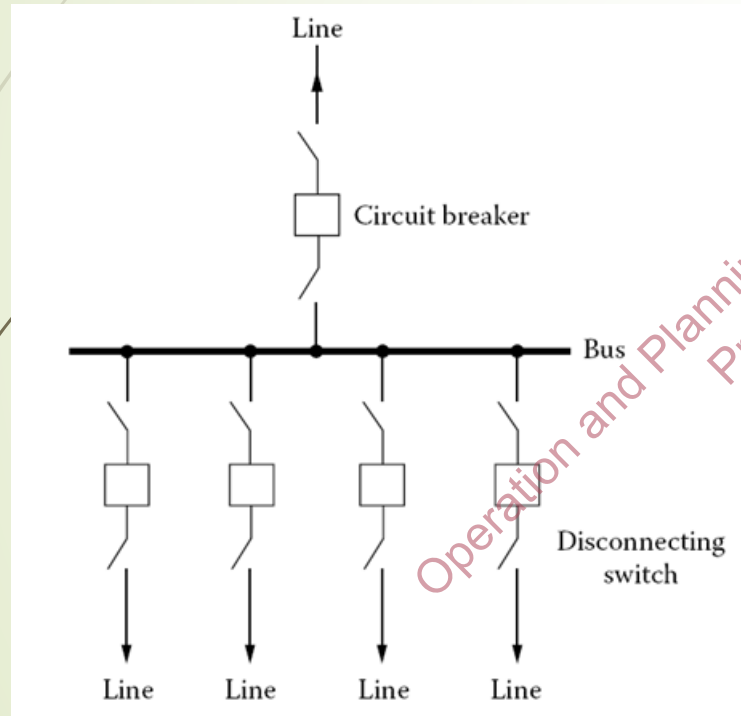
Rating of a Primary Distribution Substation

- Rating of the distribution substation depends on the rating of the service transformer used.
- The additional capacity requirements of a system with increasing load density can be met by either holding the service area of a given substation constant and increasing its capacity or developing new substations and thereby holding the rating of the given substation constant.

Different types of bus-bar arrangements

- Single bus scheme,
- Single bus with a sectionalizer scheme,
- Single bus with a sectionalizer and two power transformer scheme,
- Main-and-transfer bus scheme,
- Double busbar scheme,
- Ring bus scheme
- Breaker-and-a-half scheme.

Single-Busbar Arrangement with one Main Power Transformer



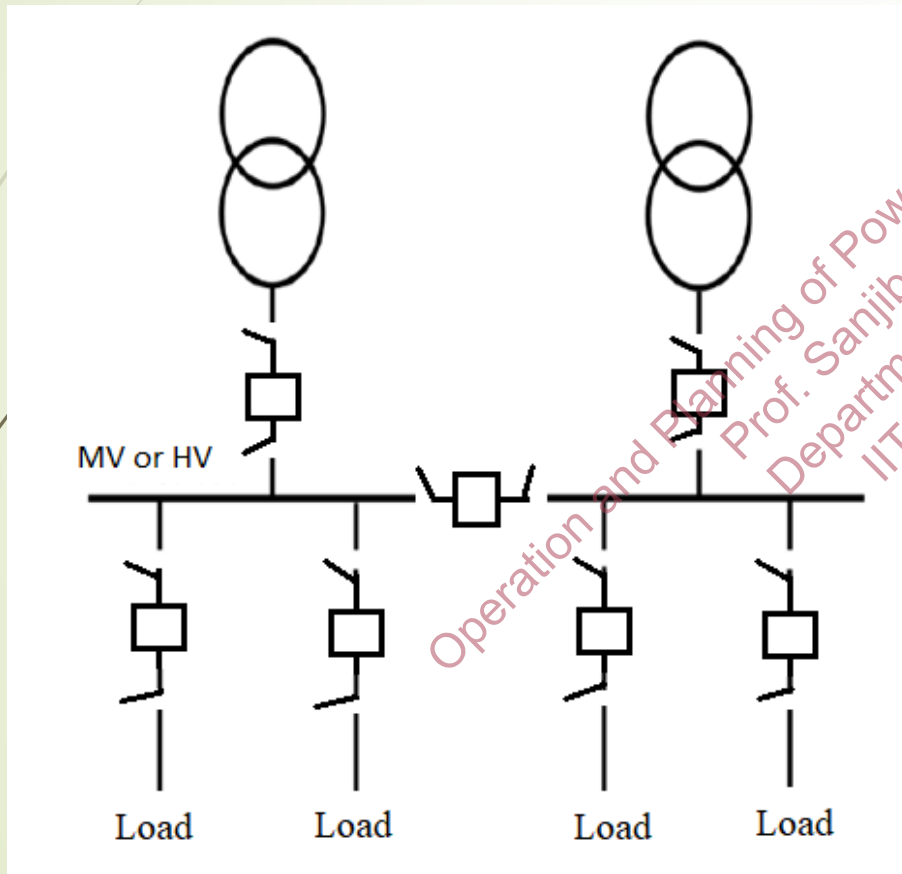
Advantages:

- Simple and low investment cost solution
- Control and protection functions straight forward

Drawbacks:

- No redundancy
- Whole substation out of service while power transformer or circuit breaker out of service
- Fault in the MV busbar would take the whole substation out of service

Single-Busbar Arrangement with Bus Sectionalizer and Two Power Transformers



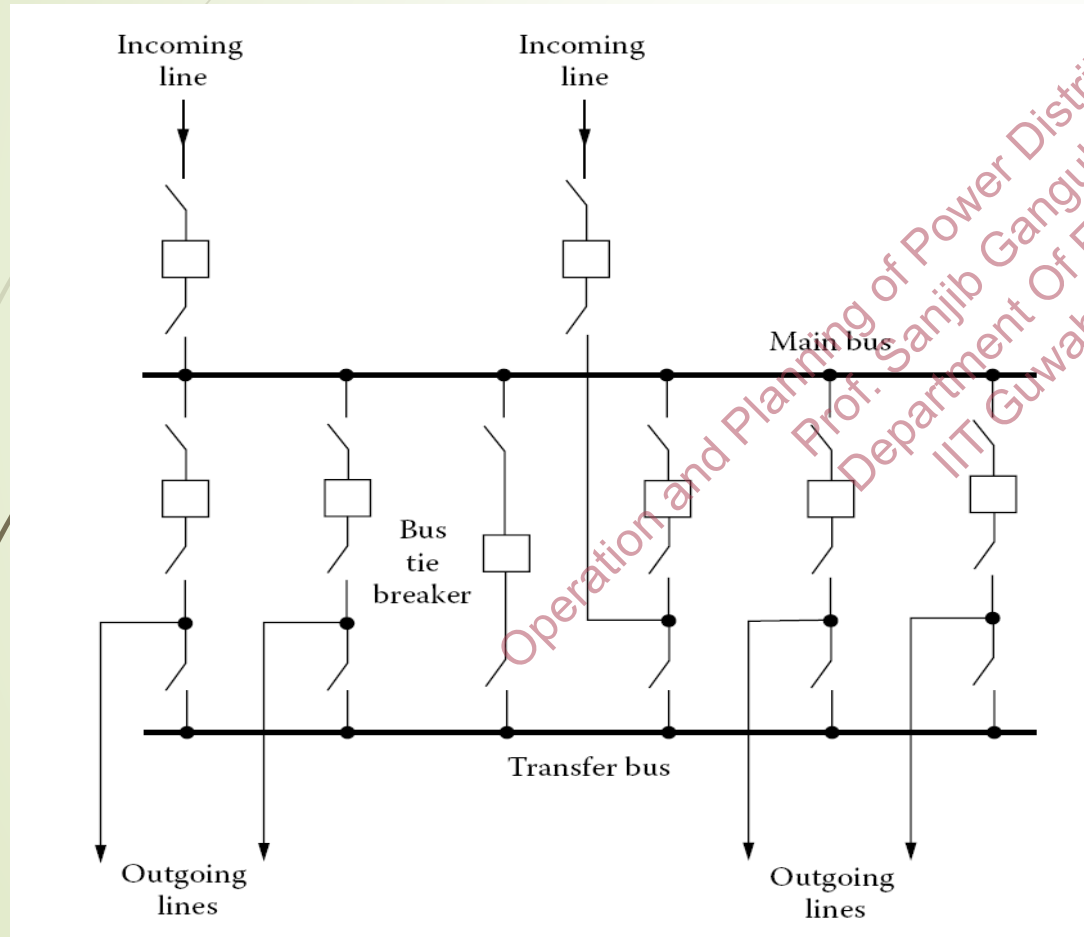
Advantages:

- Redundancy
- Increased operational flexibility
- Fault in the busbar would be limited to one section only.

Drawbacks:

- Higher investment cost
- Higher no-load losses as compared to solution with one power transformer with equal capacity
- Paralleling of the power transformers needs additional control logic.

Single-Busbar Arrangement with Transfer Bus



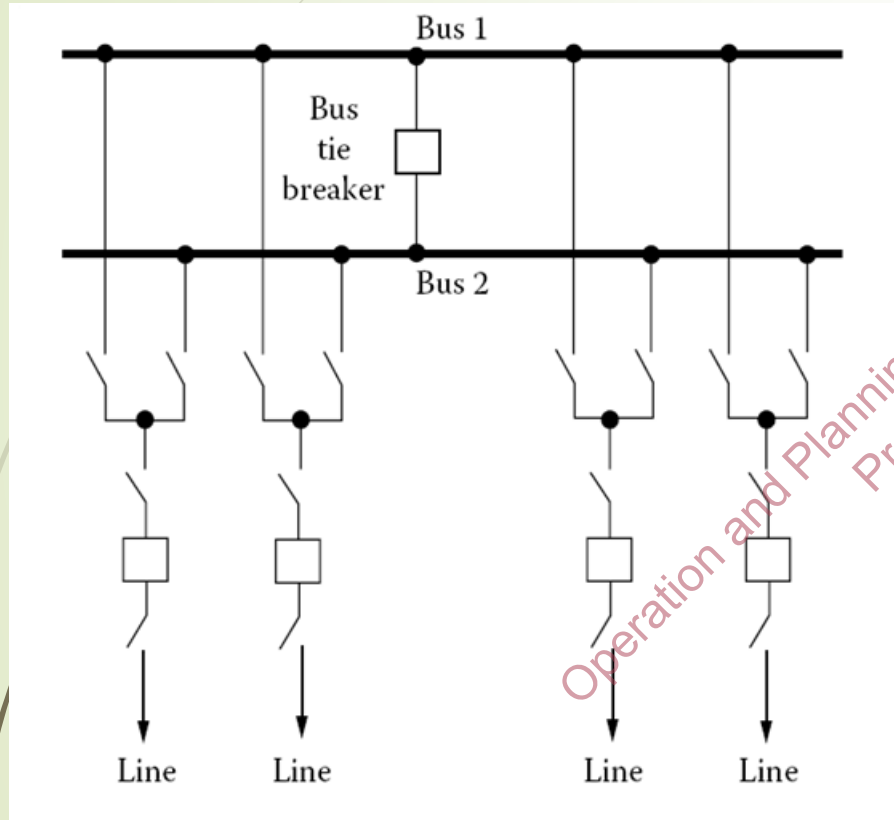
Advantages:

- Maintenance on one circuit breaker does not cause any interruptions for the load.

Drawbacks:

- Higher investment cost
- Whole substation out of service in a busbar fault case
- Protection and auto-reclosing circuits have to be switched over to the bus coupler bay during a transfer situation.

Double-Busbar Arrangement



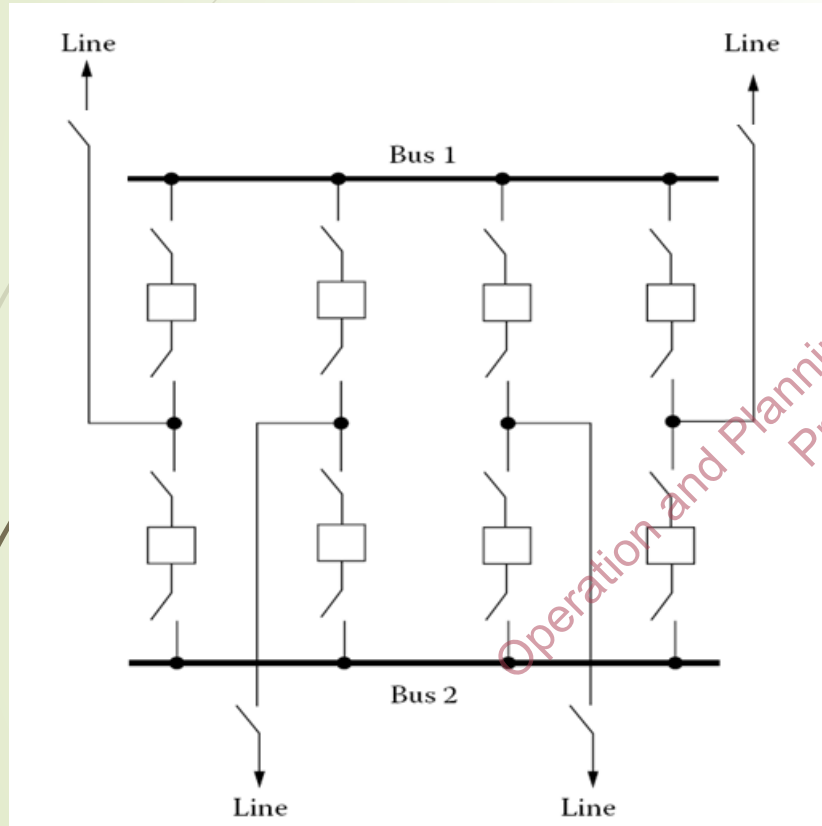
Advantages:

- Operational flexibility i.e. possibility to move loads between busses
- Effect of a busbar fault limited
- Substation extension possible under service

Drawbacks:

- Complicated interlocking
- Whole bay out of service when circuit breaker under maintenance

Double-Breaker Arrangement



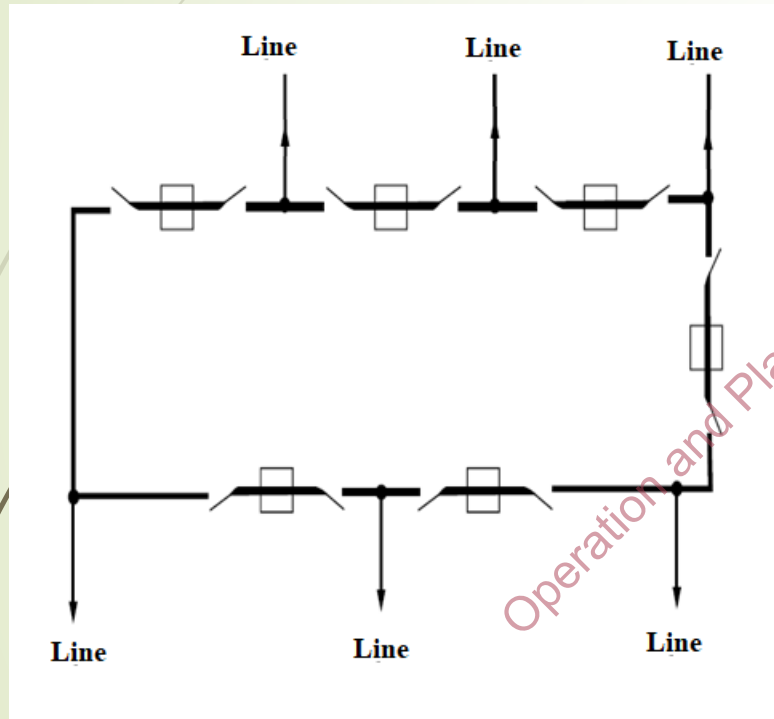
Advantages:

- Busbar fault does not disturb service.
- Circuit breaker maintenance can be carried out without load interruption
- Substation extension possible under service

Drawbacks:

- High investment cost
- Complicated protection and auto-reclosing circuits

Ring bus scheme



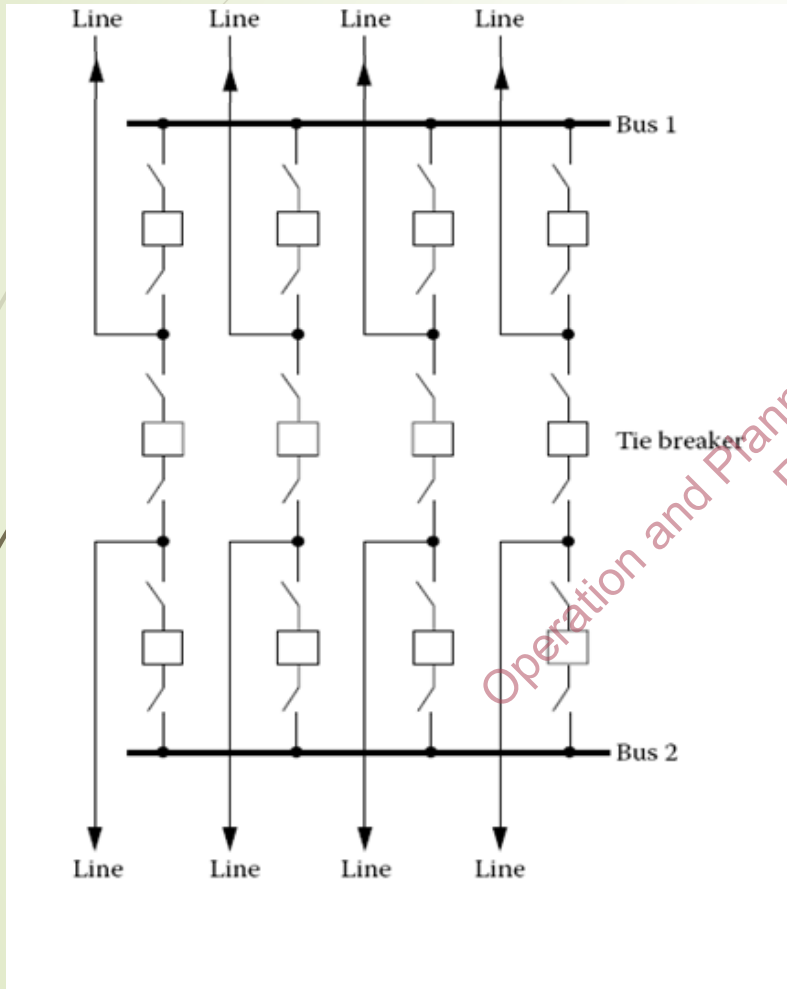
Advantages:

- Low initial and ultimate cost
- Flexible operation for breaker maintenance
- Any breaker can be removed for maintenance without interrupting load
- Requires only one breaker per circuit
- Each circuit can be fed by two breakers.

Drawbacks:

- If a fault occurs during a breaker maintenance period, the ring can be separated into two sections
- Automatic reclosing and protective relaying circuitry rather complex

A breaker-and-a-half scheme



Advantages:

- Flexible operation
- High reliability
- Breaker failure of bus side breakers removes only one circuit from service.
- Bus failure does not remove any feeder circuits from service

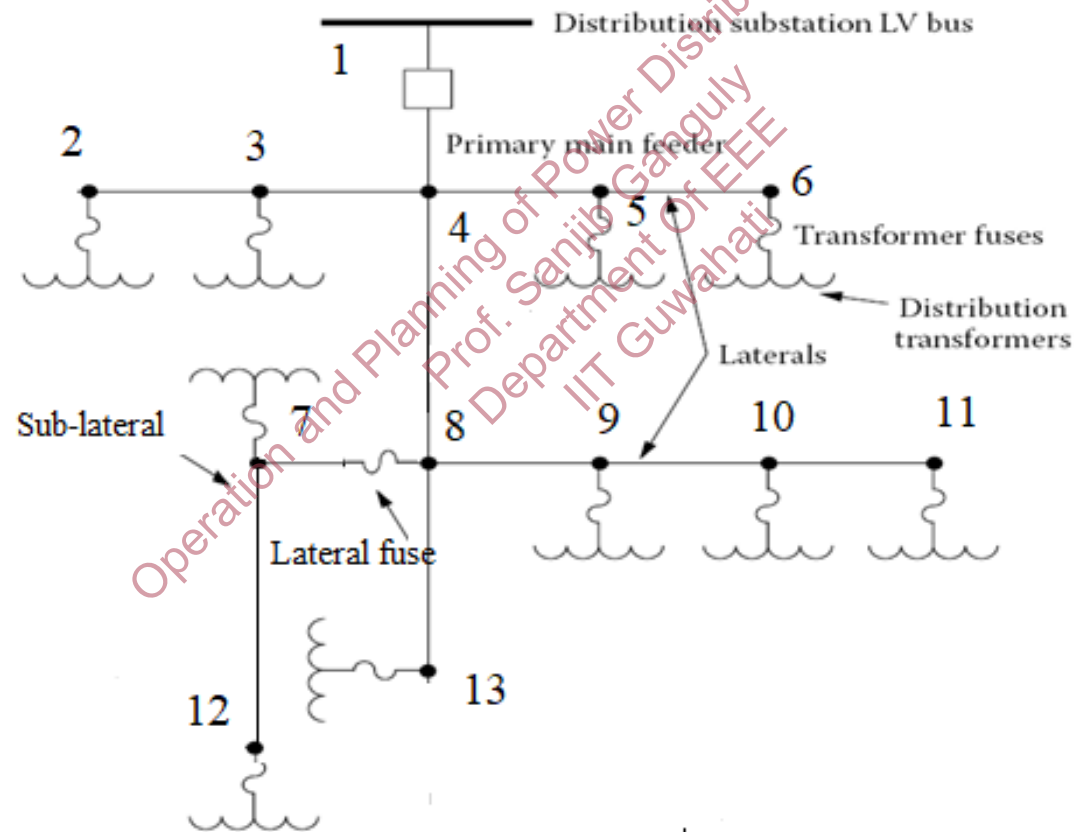
Drawbacks:

- $1\frac{1}{2}$ breakers per circuit
- Relaying and automatic reclosing are somewhat involved since the middle breaker must be responsive to either of its associated circuits

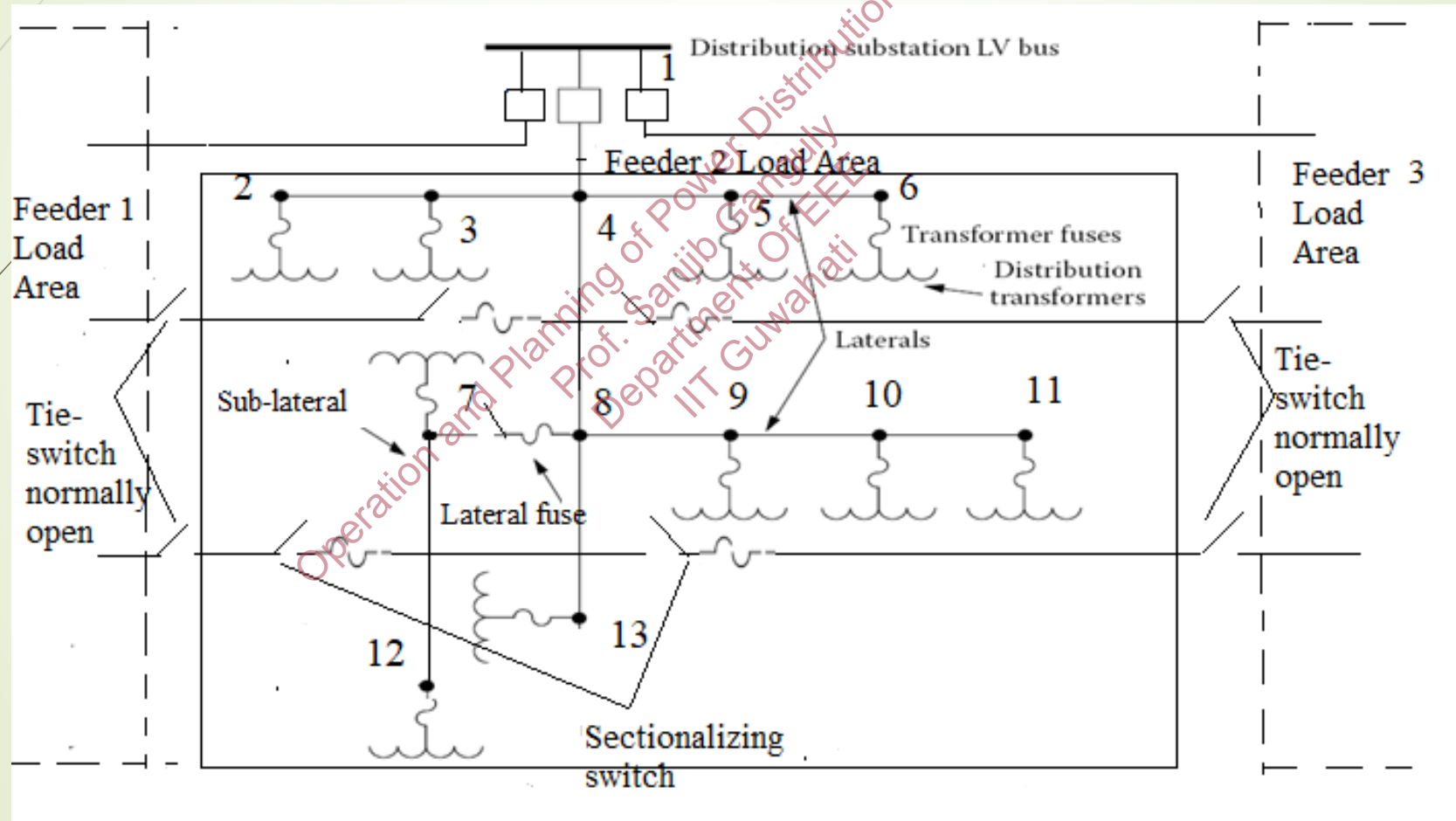
Primary distribution network topology

- The primary distribution networks are mostly of radial topology, which results in unidirectional power flow.
- The radial topology is preferred for its simplicity in construction, cost-effectiveness, and protection arrangement.
- The reliability of the radial topology is poor as compared to the loop topology, in which power flow is bi-directional.
- Loop topology is used in large cities and metros.
- In some cases, distribution networks operate as open-loop (this will be explained in next slides).

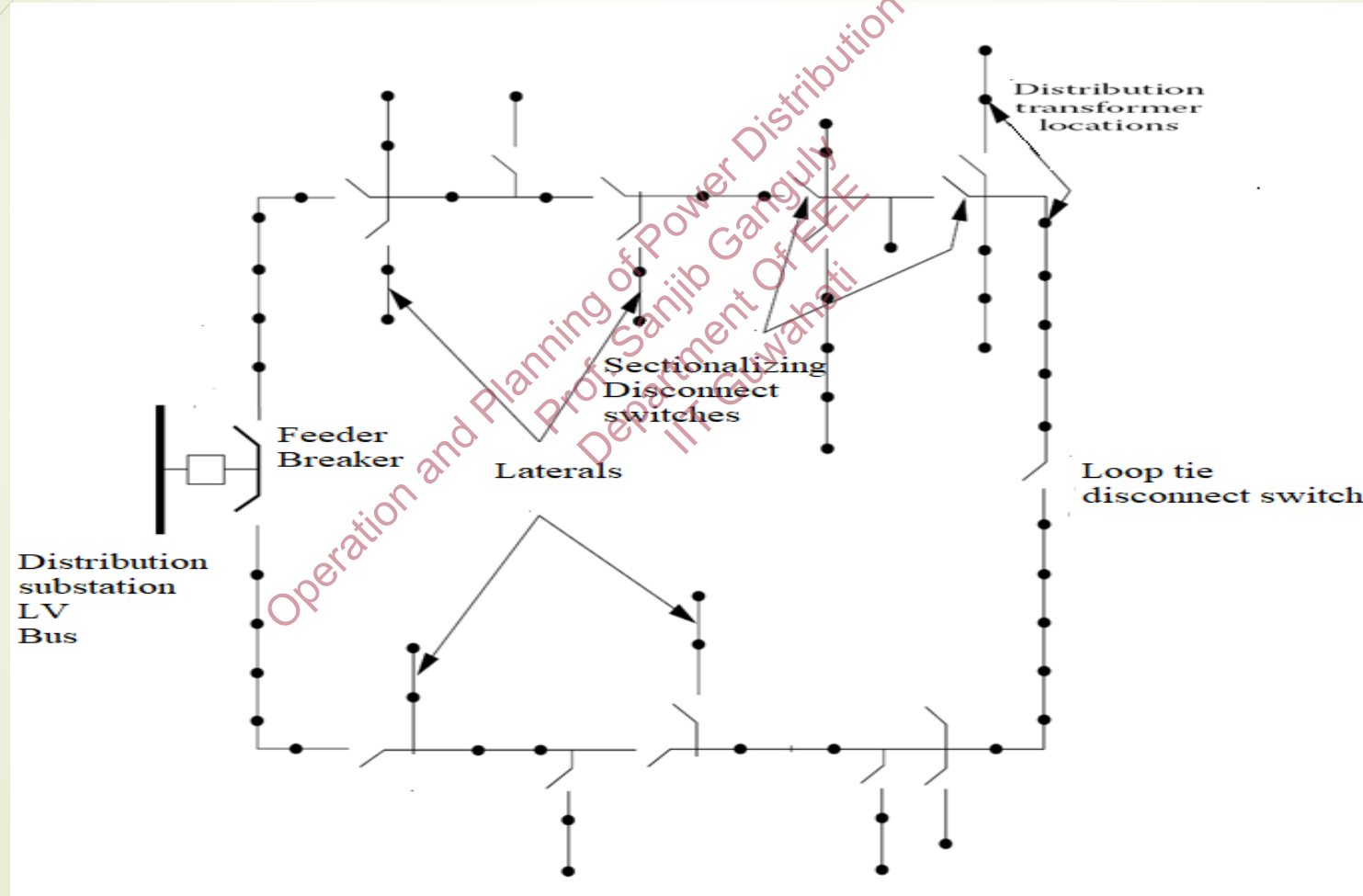
Distribution network with radial topology: Single feeder



Distribution network with radial topology: Multi-feeder with sectionalizing switch and tie-lines



Distribution network with loop topology



Primary distribution systems: Voltage Rating

- The primary feeders located in **low-load density areas** are restricted in length and loading **by permissible voltage drop** rather than by thermal restrictions.
- The primary feeders located in **high-load density areas**, for example, industrial and commercial areas, are restricted by **thermal limitations**.
- **Voltage-square rule:** Usually, if the feeder voltage is doubled, for the same percent voltage drop, it can supply the same power four times the distance.

Primary distribution systems: Voltage Rating

- The advantage obtained by the new and higher-voltage level through the voltage square factor, that is,

$$\text{Distance ratio} \times \text{Load ratio} = \text{Voltage-square factor} = \left(\frac{V_{L,new}}{V_{L,old}} \right)^2$$

where,

- Distance ratio is the ratio of new distance to old distance.
- Load ratio is the ratio of new feeder loading to the old feeder loading.

Decision on primary feeder routing

- ☐ Load Density
- ☐ Physical barriers
- ☐ Voltage drops
- ☐ Future load growth
- ☐ Number of Feeders
- ☐ Total cost

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Decision on number of feeders

- ☐ Load Density
- ☐ Feeder Length
- ☐ Feeder Limitations
- ☐ Primary Voltage Levels
- ☐ Substation Capacity
- ☐ Conductor Size
- ☐ Voltage Drops
- ☐ Future load growth

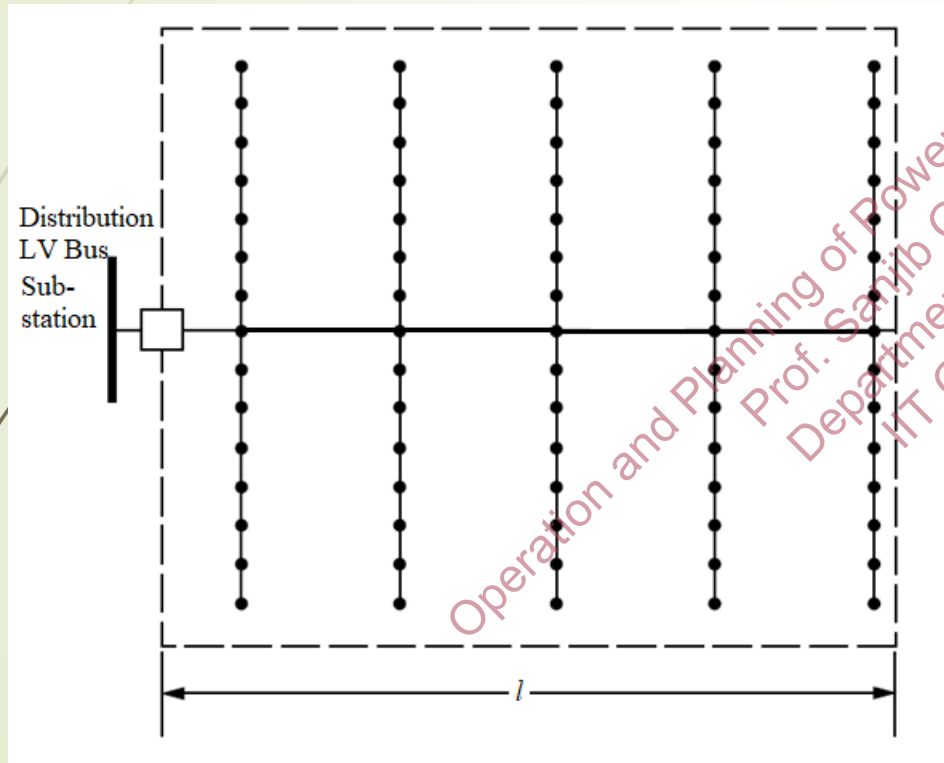
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Decision on conductor sizes

- ☐ Voltage drops
- ☐ Load forecast
- ☐ Load growth rate
- ☐ Power losses
- ☐ Total cost
- ☐ Transformer rating
- ☐ Conductor rating

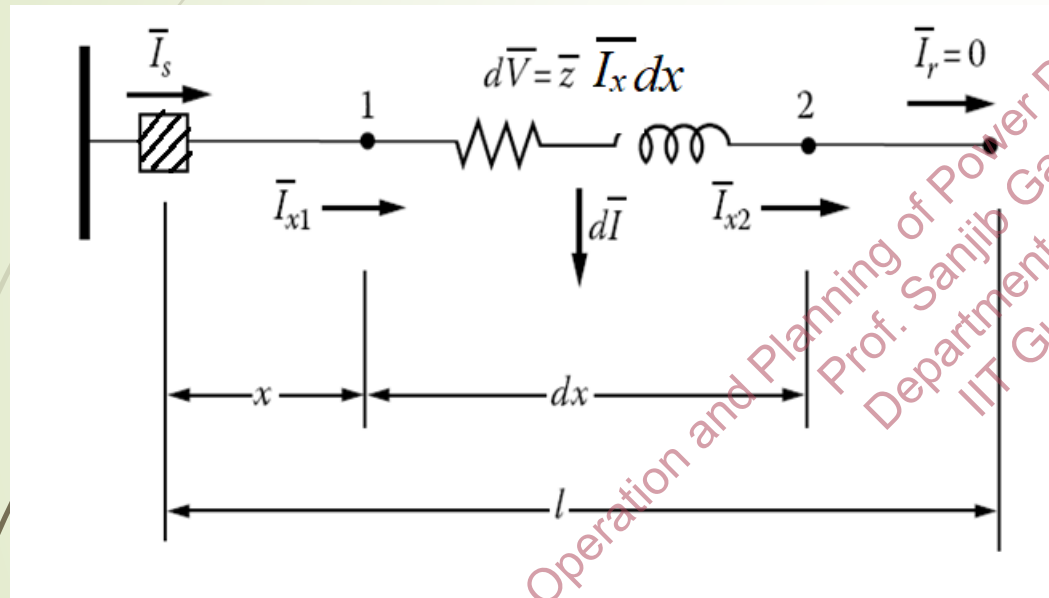
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Power loss and voltage drop computation of radial feeder with uniformly distributed load



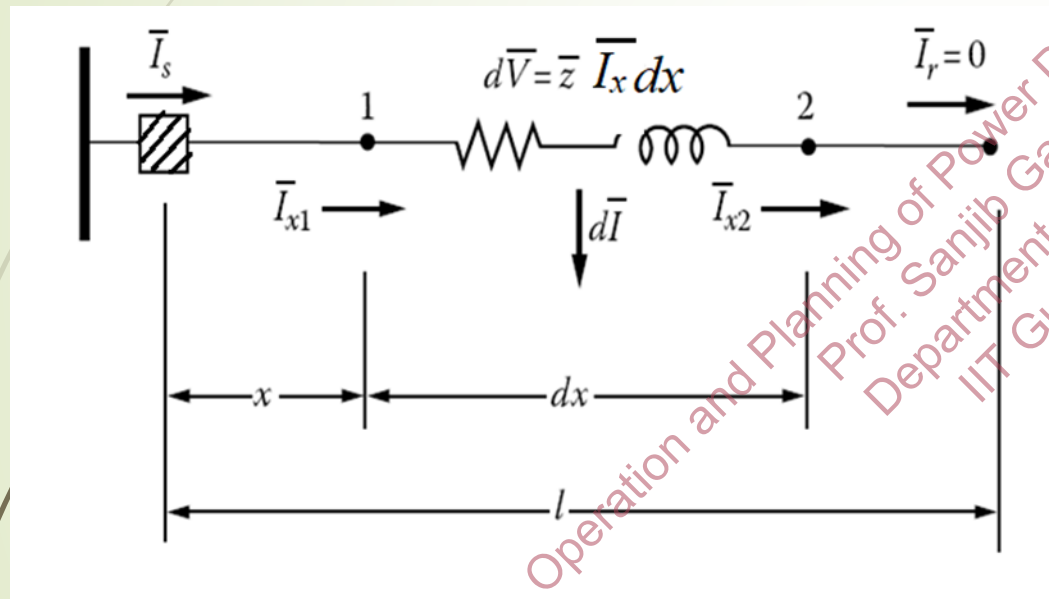
- Assume that there are many closely spaced loads and/or lateral lines connected to the main feeder as shown in the Figure.
- Since the load is uniformly distributed along the main feeder, the load current in the main is a function of the distance.
- The feeder length is assumed to be l .

Power loss and voltage drop computation of radial feeder with uniformly distributed load



- ✓ The radial network is represented with a single line diagram as shown in the figure.
- ✓ Let consider a small elementary segment dx at a distance x from the substation.
- ✓ Since the loads are assumed to be equally distributed/spaced, the differential tapped-off load current would be dI .

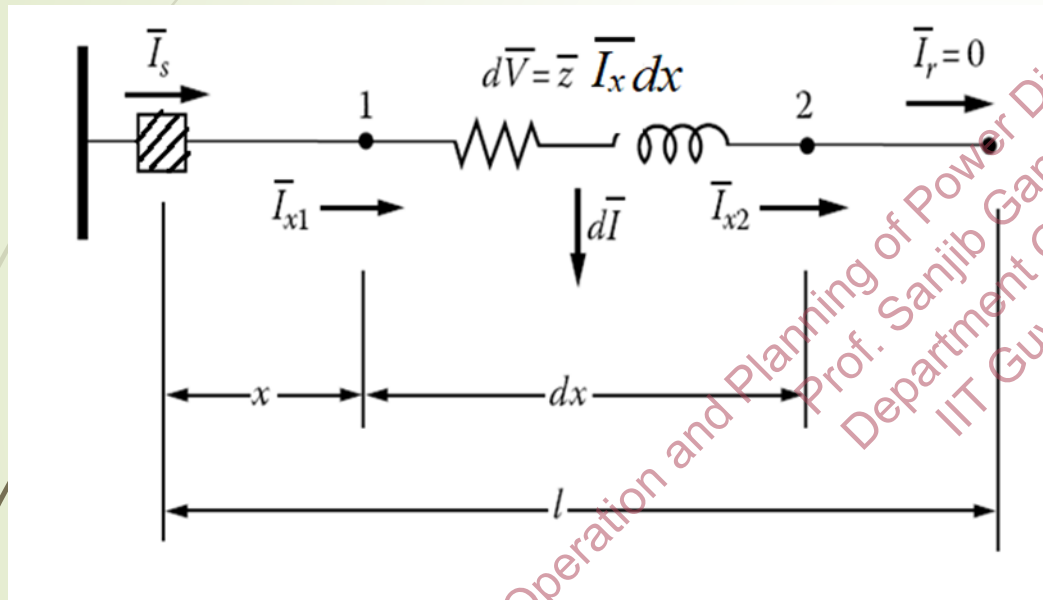
Power loss and voltage drop computation of radial feeder with uniformly distributed load



- $\bar{I}_s$ is the sending-end current at the feeder breaker, and $\bar{I}_r$ is the receiving-end current.
- $\bar{I}_{x1}$ and $\bar{I}_{x2}$ are the currents in points 1 and 2, respectively.
- Assume that all loads connected to the feeder have the same power factor.
- Since the total load is uniformly distributed from $x = 0$ to $x = l$, we can write,

$$\frac{dI}{dx} = k \text{ (some constant)}$$

Power loss and voltage drop computation of radial feeder with uniformly distributed load



- By applying KCL at node 1, we can write,

$$\bar{I}_{x1} = \bar{I}_{x2} + d\bar{I}$$

Or,

$$\bar{I}_{x2} = \bar{I}_{x1} - d\bar{I}$$

Or,

$$\bar{I}_{x2} = \bar{I}_{x1} - kdx$$

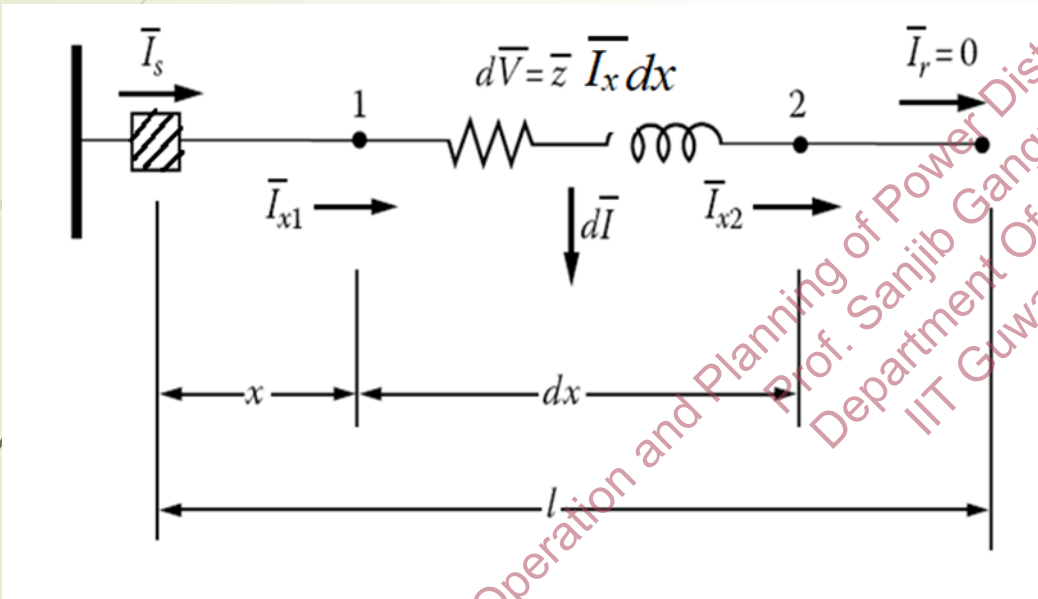
- If $x = l$, the equation becomes

$$I_r = I_s - kl = 0$$

- This yields $k = \frac{I_s}{l}$
- The current at a distance x is

$$I_x = I_s \left(1 - \frac{x}{l}\right)$$

Power loss and voltage drop computation of radial feeder with uniformly distributed load

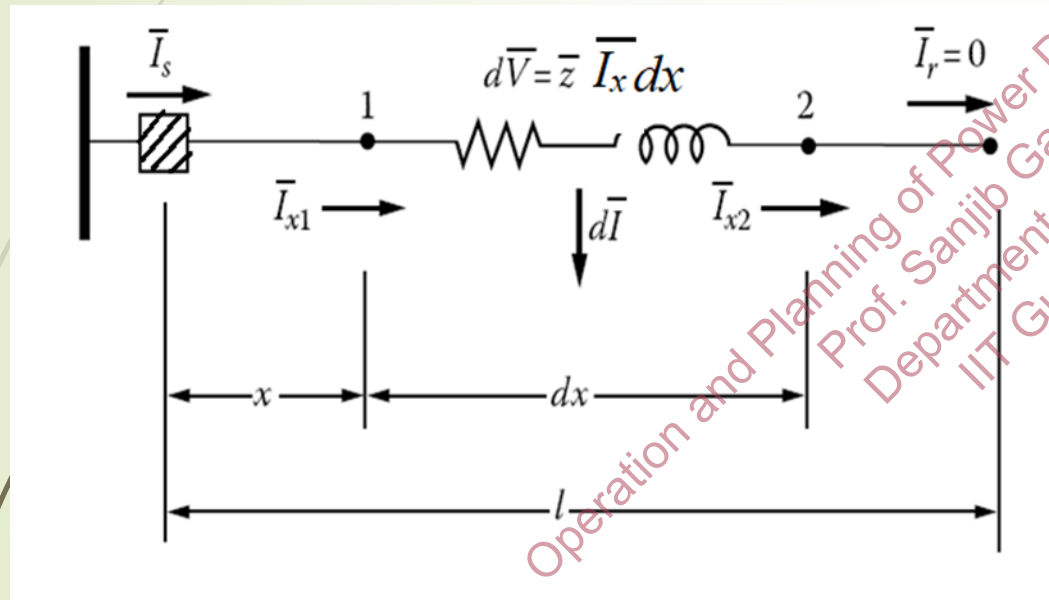


- The differential series voltage drop dV and the differential power loss dP_L due to ohmic losses can also be found as a function of the sending-end current I_s and the distance x in a similar manner.

$$dV = I_x * z dx = I_s \left(1 - \frac{x}{l}\right) * z dx$$

$$dP_L = I_x^2 * r dx = \left\{ I_s \left(1 - \frac{x}{l}\right) \right\}^2 * r dx$$

Power loss and voltage drop computation of radial feeder with uniformly distributed load

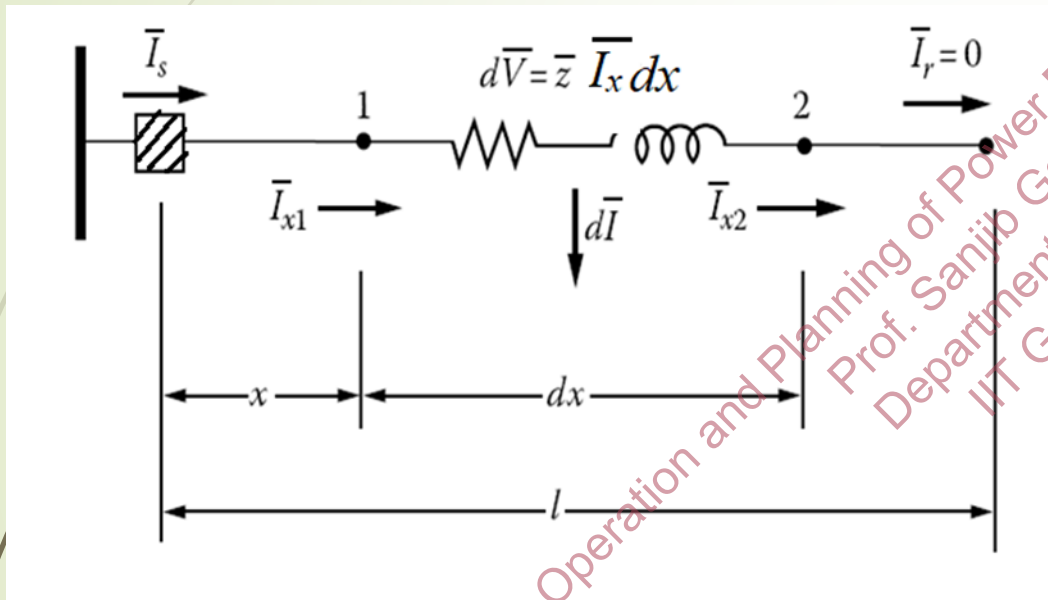


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Power loss and voltage drop computation of radial feeder with uniformly distributed load



- The series voltage drop VD_x due to I_x current at any point x on the feeder is:

$$VD_x = \int_0^x dV = I_s \left(1 - \frac{x}{2l}\right) * zx$$

- Hence, the total series voltage drop along the full length is:

$$VD = I_s \left(1 - \frac{l}{2l}\right) * zl = \frac{1}{2} I_s zl$$

- Similarly, the total power loss would be:

$$TP_L = \int_0^l dP_L = \frac{1}{3} I_s^2 rl$$

Power loss and voltage drop computation of radial feeder with uniformly distributed load

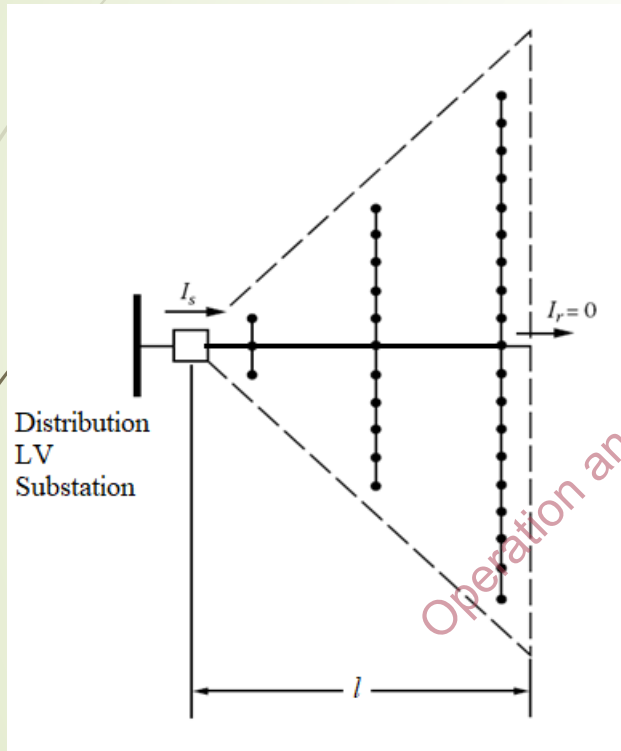
- Therefore, for a uniformly distributed feeder, the voltage drop will be similar to a lump load connected at the mid-point of the feeder.

$$\text{i.e., } x = \frac{l}{2}$$

- For a uniformly distributed feeder, the power loss will be similar to a lump load connected at the one-third length of the feeder.

$$\text{i.e., } x = \frac{l}{3}$$

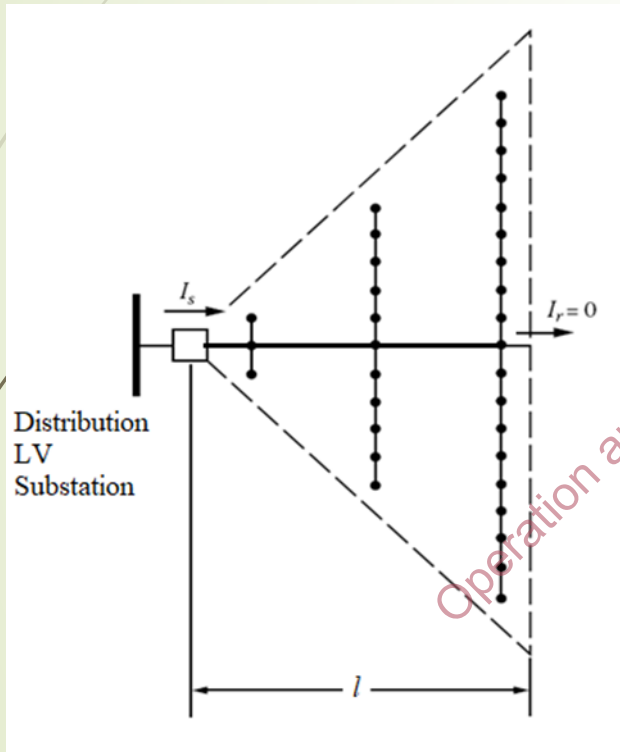
Power loss and voltage drop computation of radial feeder with non-uniformly distributed load



- Let's have a three-phase feeder main, which has the tapped-off load increasing linearly with the distance x . Note that the load is zero when $x = 0$.
- The plot of the current given below.

$$\frac{dI_x}{dx} = -kI_s x$$

Power loss and voltage drop computation of radial feeder with non-uniformly distributed load



- The constant k can be obtained as:

$$I_s = \int_0^l dI_x = \int_0^l k * I_s * x dx = k * I_s * \frac{l^2}{2}$$

- Hence, $k = \frac{2}{l^2}$

- Substituting k , we get

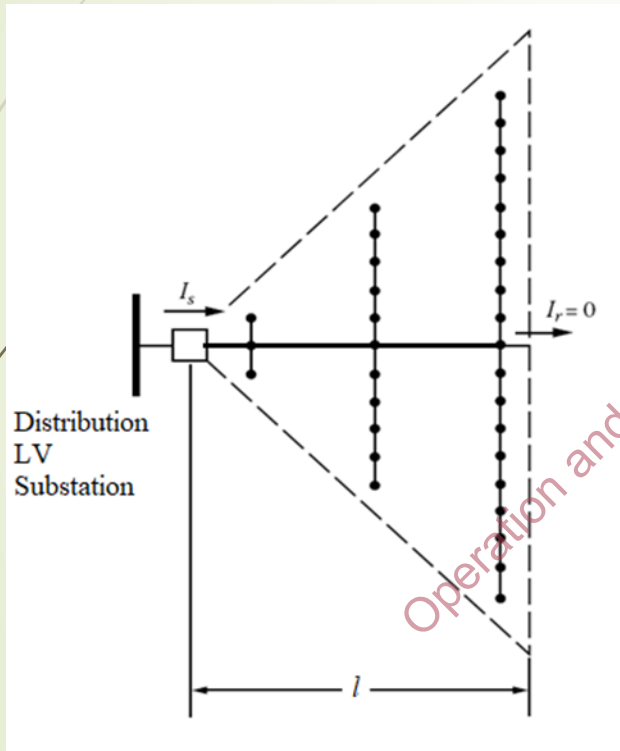
$$\frac{dI_x}{dx} = -2I_s \frac{x}{l^2}$$

- Integrating this, we get the current at x

$$\int_{I_s}^{I_x} dI_x = -\frac{2I_s}{l^2} \int_0^x x dx$$

$$I_x = I_s \left(1 - \frac{x^2}{l^2}\right)$$

Power loss and voltage drop computation of radial feeder with non-uniformly distributed load



- The expressions for the voltage drop and power loss can be computed as:

$$dV = I_x * zdx = I_s \left(1 - \frac{x^2}{l^2}\right) * zdx$$

$$dP_L = I_x^2 * rdx = \left\{I_s \left(1 - \frac{x^2}{l^2}\right)\right\}^2 * rdx$$

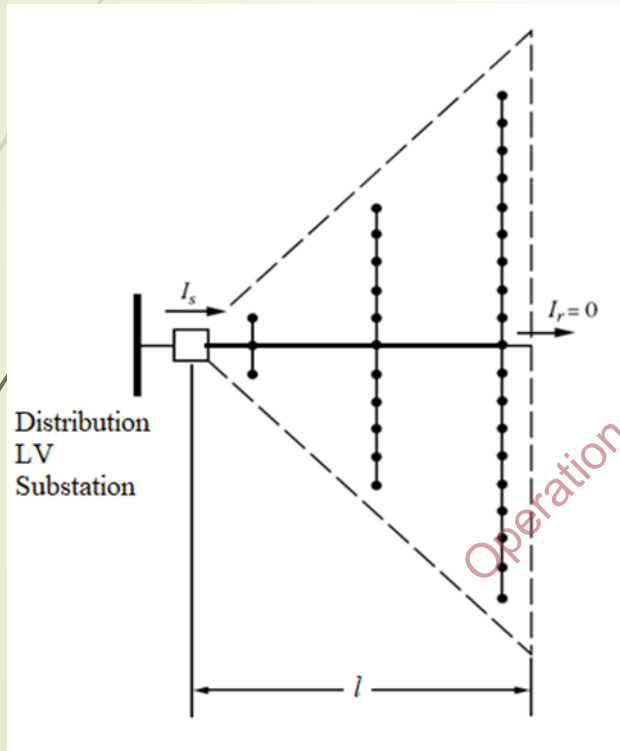
- The series **voltage drop** at the point x can be computed as:

$$VD_x = \int_0^x dV = I_s \left(1 - \frac{x^2}{3l^2}\right) * zx$$

- Hence, **the total series voltage drop** along the full length is:

$$VD = I_s \left(1 - \frac{l^2}{3l^2}\right) * zl = \frac{2}{3} I_s zl$$

Power loss and voltage drop computation of radial feeder with non-uniformly distributed load



- Similarly, the total power loss would be:

$$TP_L = \int_0^l dP_L = \frac{8}{15} I_s^2 r l$$

- Therefore, to determine the voltage drop, the total load current is assumed to be concentrated at:

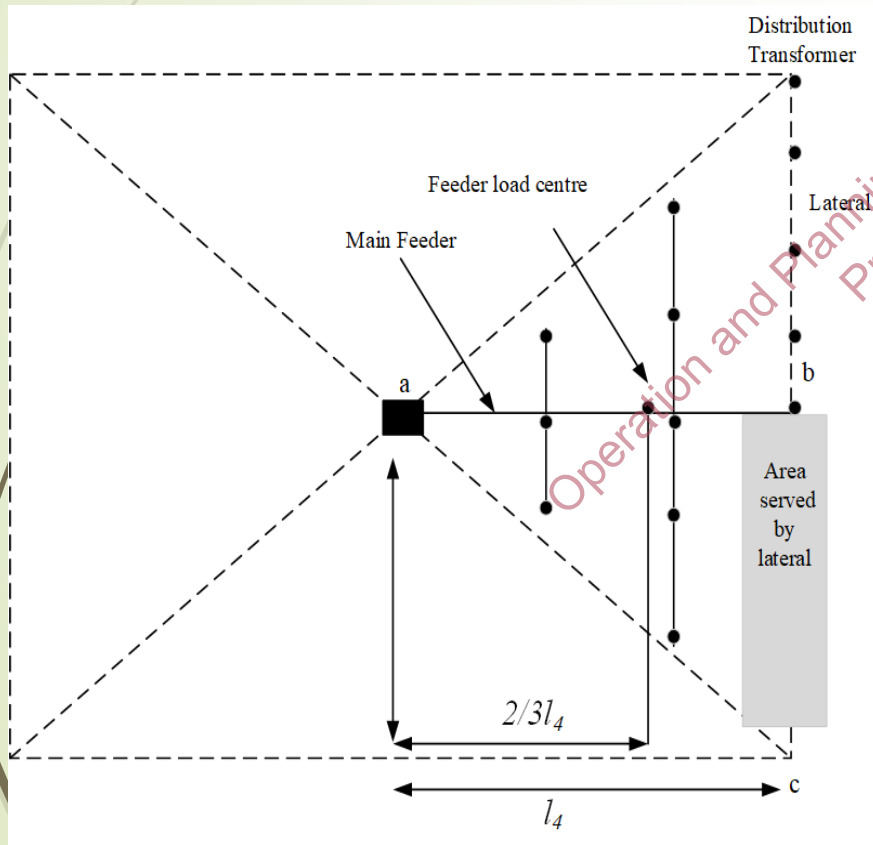
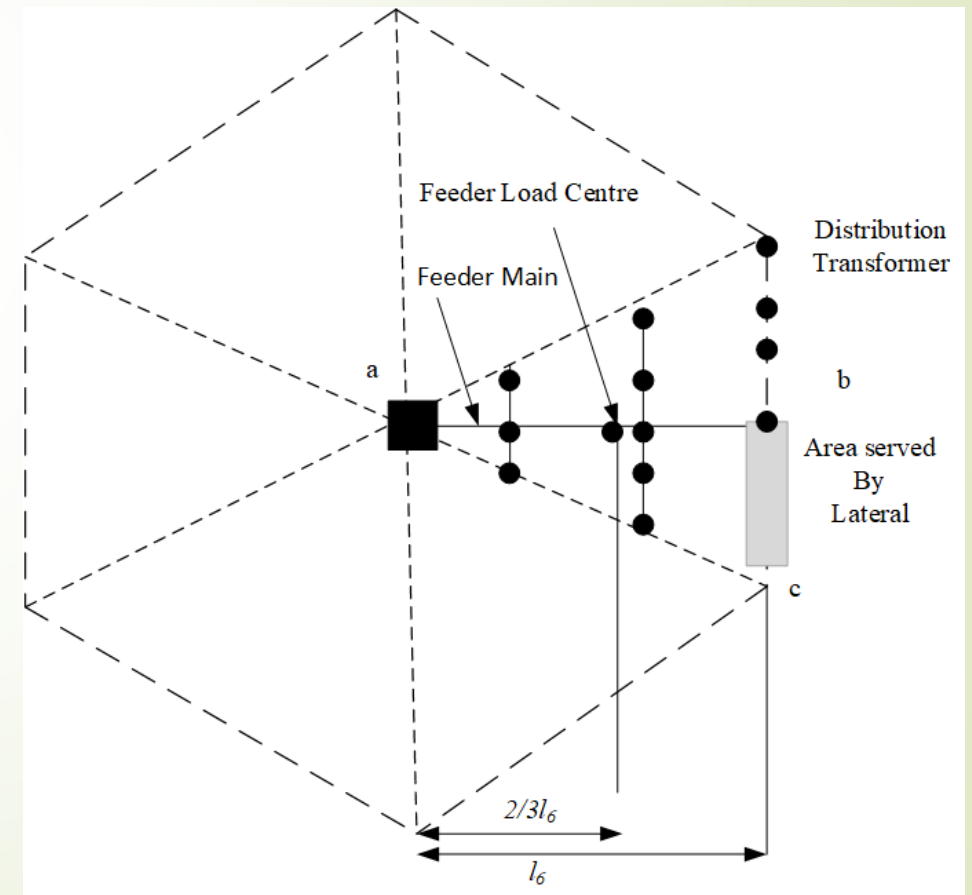
$$x = \frac{2l}{3}$$

- To determine the power loss, the total load current is assumed to be concentrated at

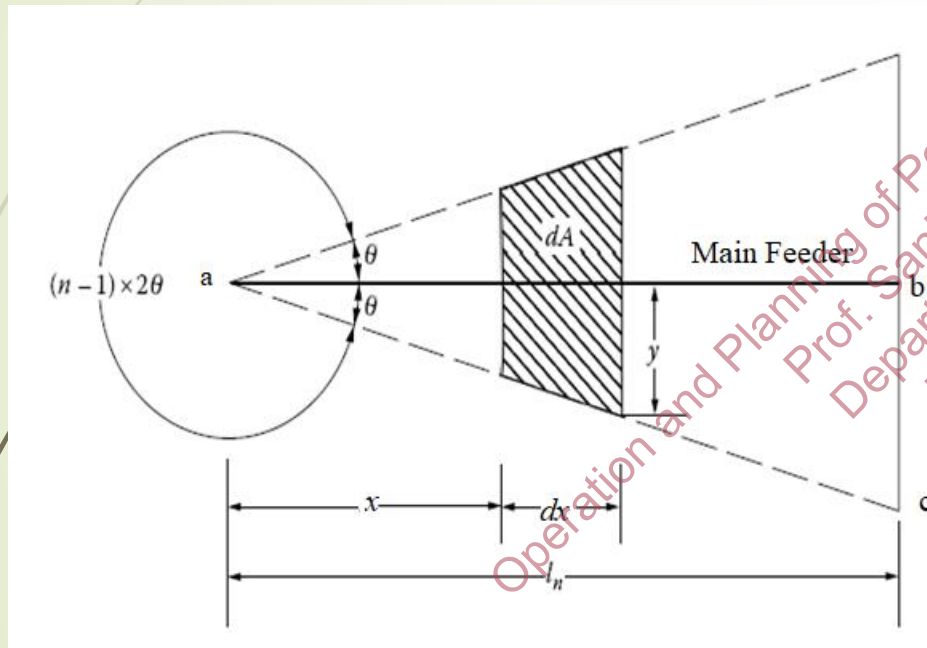
$$x = \frac{8l}{15}$$

Distribution Substation Service Area

- The distribution substation service area can be of different shapes, for example, square, circular, hexagonal etc.

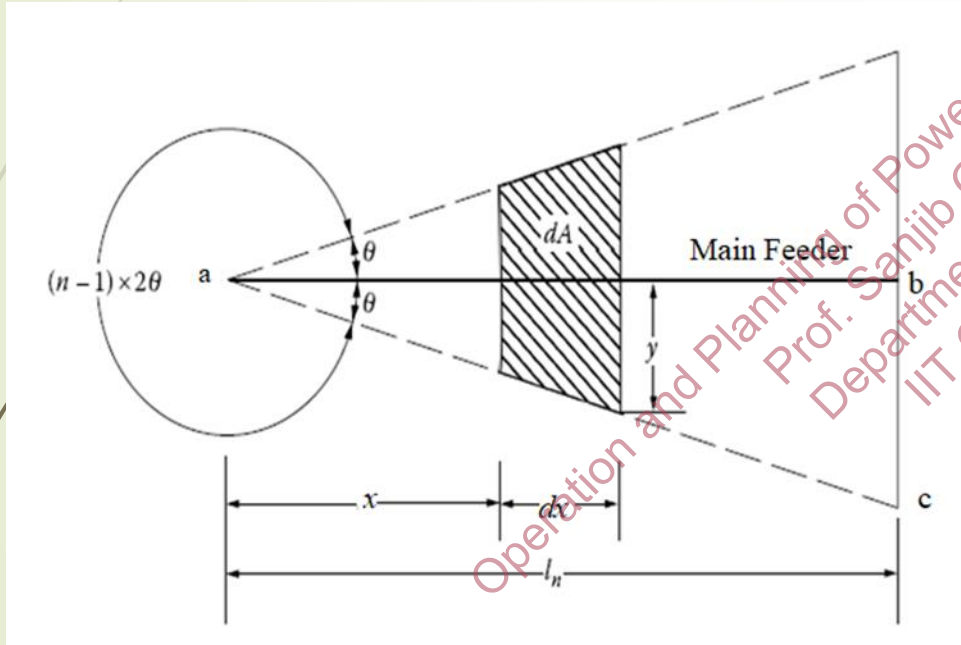


Substation Service area with n Primary Feeders



- Suppose that the distribution substation service area is served by n primary feeders .
- Substation is at point a.
- Assume that the load in the service area is uniformly distributed and each feeder serves an area of triangular shape.
- The differential load served by the feeder in a differential area of dA is $dS = DdA$ kVA
- where, dS is the differential load served by the feeder in the differential area of dA in kVA
- D is the load density

Substation Service area with n Primary Feeders



- From the figure, we get,

$$\tan \theta = \frac{y}{x+dx'}$$

$$\text{i.e., } y = (x + dx) \tan \theta \cong x \tan \theta$$

- Hence, we can write

$$dA = 2ydx = 2x \tan \theta$$

- The total service area of the feeder can be calculated as,

$$A_n = \int_0^{l_n} dA = l_n^2 \tan \theta$$

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

$$S_n = D l_n^2 \tan \theta$$

Substation Service area with n Primary Feeders

- This total load is located, as a lump-sum load, at a point on the main feeder at a distance of $(2/3) \times l_4$ from the feed point a . Hence, the summation of the percent voltage drop of all such areas is

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

- **where, K is a constant that can be defined as percent voltage drop per kilovolt-ampere-km.**
- Since from the figure it is found that $n(2\theta) = 360^\circ$, we can write

$$VD_n = \frac{2}{3} l_n K S_n = \frac{2}{3} K D l_n^3 \tan \frac{360^\circ}{2n}$$

Note that, this equation is applicable when $n \geq 3$ and primary feeders are linear.

Substation Service area with *single and double* Primary Feeders

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

$$VD_1 = \frac{1}{2} K D l_1^3$$

- For $n = 2$, the percent voltage drop in the feeder main is:

$$VD_2 = \frac{1}{2} K D l_2^3$$

Comparison of the Four- and six-Feeder networks

- For a square-shaped distribution substation area served by four primary feeders, that is, $n = 4$, the area served by one of the four feeders is:

$$A_4 = l_4^2$$

- The total area served by all four feeders is:

$$TA_4 = 4A_4 = 4l_4^2$$

- The kilovolt-ampere load served by one of the feeders is: $S_4 = Dl_4^2$
- The total kilovolt-ampere load served by all four feeders is: $TS_4 = 4Dl_4^2$

Comparison of the Four- and six-Feeder networks

- ▶ The percent voltage drop in the main feeder is

$$VD = \frac{2}{3} K D l_4^3$$

- ▶ The load current in the main feeder at the feed point a is

$$I_4 = \frac{S_4}{\sqrt{3}V_{L-L}} = \frac{D l_4^2}{\sqrt{3}V_{L-L}}$$

- ▶ Note that, The ampacity, that is, the current-carrying capacity, of a conductor selected for the main feeder should be larger than this value.

Comparison of the Four- and six-Feeder networks

- For a hexagonally shaped distribution substation area served by six primary feeders, i.e., $n = 6$, the area served by one of the six feeders is: $A_6 = \frac{1}{\sqrt{3}} l_6^2$
- The total area served by all six feeders is: $TA_6 = \frac{6}{\sqrt{3}} l_6^2$
- The kilovolt-ampere load served by one of the feeders is: $S_6 = \frac{1}{\sqrt{3}} D l_6^2$
- The total kilovolt-ampere load served by all six feeders is: $TS_6 = \frac{6}{\sqrt{3}} D l_6^2$

Comparison of the Four- and six-Feeder networks

- ▶ The percent voltage drop in the main feeder is:

$$VD = \frac{2}{3\sqrt{3}} KD l_6^3$$

- ▶ The load current in the main feeder at the feed point a is

$$I_6 = \frac{S_6}{\sqrt{3}V_{L-L}} = \frac{Dl_6^2}{3V_{L-L}}$$

Thermally limited (TL) feeder

- For TL feeder, the thermal loading in each feeder remains same, i.e., $I_4 = I_6$, i.e., $\frac{Dl_4^2}{\sqrt{3}V_{L-L}} = \frac{Dl_6^2}{3V_{L-L}}$

$$\text{i.e., } \left(\frac{l_6}{l_4}\right)^2 = \sqrt{3}$$

- Hence, $\frac{TA_6}{TA_4} = \frac{\frac{6}{\sqrt{3}}l_6^2}{4l_4^2} = \frac{3}{2}$

- Therefore, the six feeders can carry 1.50 times as much load as the four feeders, if each feeder thermal loading is equal.

Voltage drop limited (VDL) feeder

- For VDL-feeder, the voltage drop remains equal for both four and six feeder networks, i.e.,

$$VD_4 = VD_6$$

- This results in: $l_4 = 0.833l_6$ and hence, $TA_6 = 1.25TA_4$

- Therefore, the six feeders can carry only 1.25 times as much load as the four feeders if they are VDL.

Derivation of the K constant

- Consider the primary-feeder main shown in Figure, Here, the effective impedance Z of the three-phase main depends upon the nature of the load.

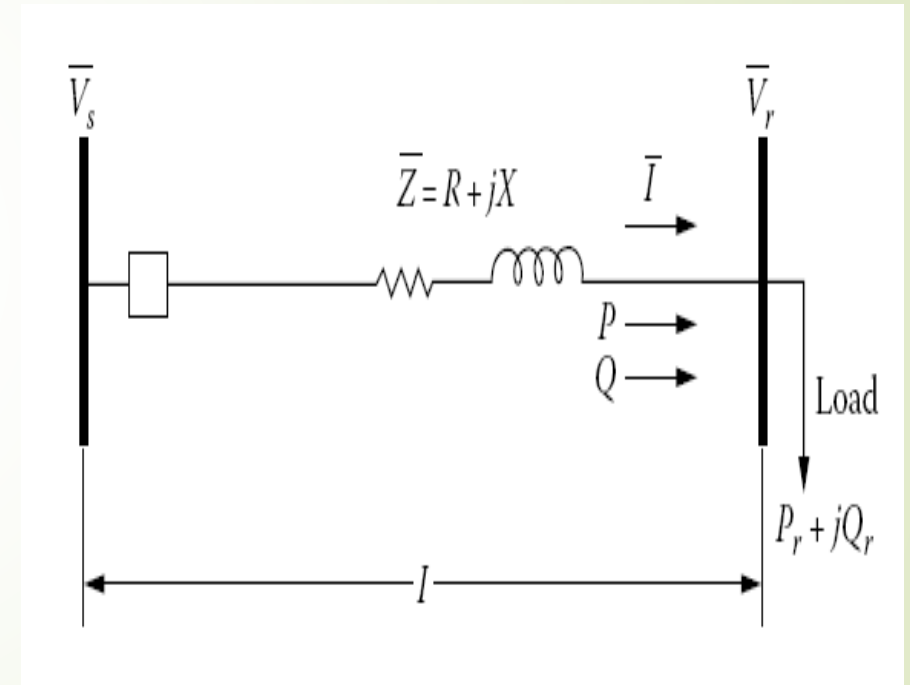
- when a lumped-sum load is connected:

$$Z = zl$$

- When the load is uniformly distributed:

$$Z = \frac{1}{2}zl$$

- When the load has an increasing load density: $Z = \frac{2}{3}zl$



Derivation of the K constant

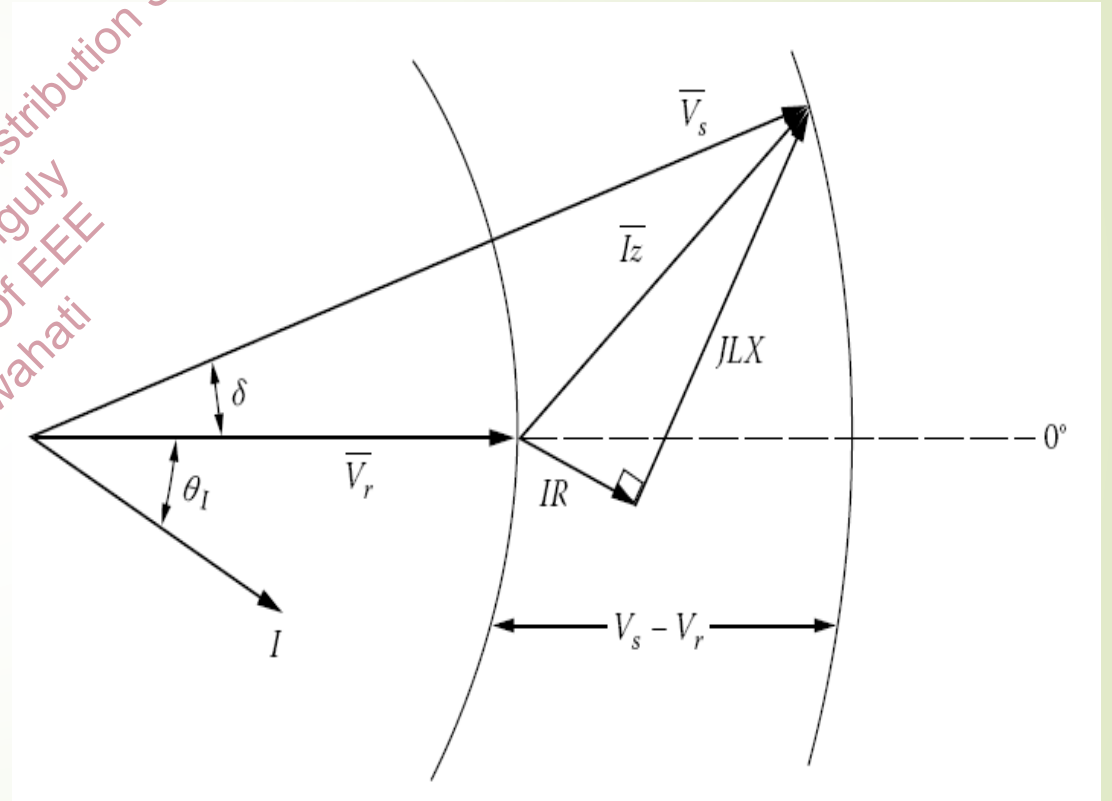
- Taking receiving end phasor as the reference,

$$\bar{V}_r = V_r \angle 0$$

- The sending end voltage and the current can be written as,

$$\bar{V}_s = V_s \angle \delta$$

$$\bar{I} = I \angle -\theta$$



Derivation of the K constant

- The percentage voltage regulation for this line is:

$$= \frac{V_s - V_r}{V_r} 100$$

- Applying KVL, the sending end voltage and the current can be written as,

$$\bar{V}_s = \bar{V}_r + \bar{I}z$$

$$V_s \cos \delta + jV_s \sin \delta = V_r + I(\cos \theta - j \sin \theta)(R + jX)$$

For lagging load.

Derivation of the K constant

- In typical distribution systems, $R \cong X$, i.e., and the voltage angle δ is closer to zero or typically closed to zero. Hence,

$$V_s \cong V_r \cos \delta \quad \text{and} \quad V_s \cong V_r + IR \cos \theta + IX \sin \theta$$

- Therefore, the per unit voltage drop, for a lagging power factor, is

$$VD_{p.u.} = \frac{IR \cos \theta + IX \sin \theta}{V_{Base}}$$

Derivation of the K constant

- The complex power at the receiving end is

$$P_r + jQ_r = \bar{V}_r \bar{I}^*$$

- Hence, $\bar{I} = \frac{P_r - jQ_r}{\bar{V}_r}$

- The sending-end voltage can be written as:

$$\bar{V}_s = V_r + \frac{RP_r + XQ_r}{V_r} - j \frac{RQ_r - XP_r}{V_r}$$

Derivation of the K constant

- Since the angle $\delta \simeq 0$, the sending end voltage can be approximated as:

$$V_s \cong V_r + \frac{RP_r + XQ_r}{V_r}$$

- Hence, the voltage drop expression can be re-written as,

$$VD_{p.u.} \cong \frac{RP_r + XQ_r}{V_r V_{Base}}$$

- Since $P_r = S_r \cos \theta$ and $Q_r = S_r \sin \theta$, we can write

$$VD_{p.u.} = \frac{RS_r \cos \theta + XS_r \sin \theta}{V_r V_{Base}}$$

Derivation of the K constant

- The voltage drop can also be written as:

$$VD_{p.u.} = \frac{(r \cos \theta + x \sin \theta) l_e \left(\frac{1}{3} S_3 \phi * 1000 \right)}{V_r V_{Base}}$$

- where, r and x are resistance and reactance per length
- l_e is the effective length of the feeder main that depends upon the nature of the load

Derivation of the K constant

- Since we know that,

$$VD_{p.u.} = Kl_e S_{3\phi},$$

- We get the expression for K as:

$$K = \frac{(r \cos \theta + x \sin \theta) \left(\frac{1}{3} * 1000 \right)}{V_r V_{Base}}$$

Basically,

$$K = f(\text{conductor size, spacing, power factor})$$

Interpretation of Percent Voltage drop Formula

- The percentage voltage drop can be computed as:

$$VD = Kl_e S_{3\phi} = \frac{K \left(\frac{2}{3} l_n \right) (n D A_n)}{n}$$

$$= K \left(\frac{2}{3} l_n \right) \left(\frac{T S_n}{n} \right)$$

$$= K \left(\frac{2}{3} l_n \right) S_n$$

Use and Interpretation of Voltage drop formula

Case	length of feeder	K	Base, kV	No. of feeders	Load Density	Area served by one feeder	Total kVA	% voltage drop
Geographic Extensions	$\times 2 \uparrow$	-	-	-	-	$\times 4 \uparrow$	$\times 4 \uparrow$	$\times 8 \uparrow$
Load Growth	-	-	-	-	$\times 2 \uparrow$	-	$\times 2 \uparrow$	$\times 2 \uparrow$
Add new feeders	-	-	-	$\times 2 \uparrow$	-	$\times 1/2 \downarrow$	-	$\times 1/2 \downarrow$
Feeder re-conductoring	-	$\times 1/2 \downarrow$	-	-	-	-	-	$\times 1/2 \downarrow$

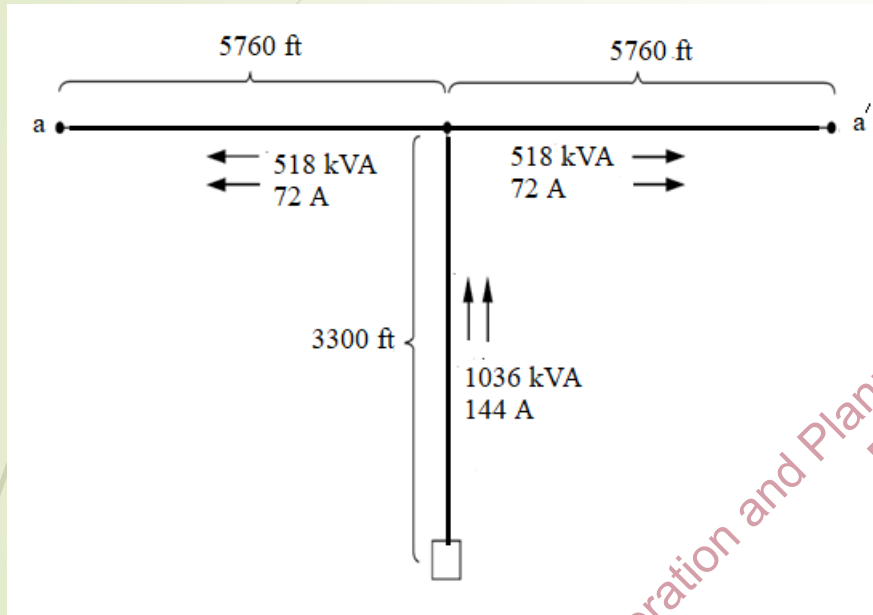
Interpretation of Percent Voltage drop Formula

- **Case #1:** If the length of the primary feeder is doubled, with other parameters constant, the service area of the feeder would increase four times, which results in an increase of voltage drop eight times. Therefore, the increase of the feeder length should be avoided.
- **Case #2:** If the load density is doubled, the feeder load would be doubled, which would result in the voltage drop of the feeder to be doubled. Therefore, increasing load density negatively effects on the voltage drop.

Interpretation of Percent Voltage drop Formula

- **Case # 3:** If the number of the feeders is doubled, it creates load under a feeder to be reduced by half, which results in voltage drop to become half. Therefore, new feeder addition is helpful.
- **Case # 4:** If the conductor size is doubled, it reduces the K constant by half, which makes the voltage drop by half.

Example...



➤ The Figure shows a primary distribution feeder, consisting of the 3300 ft main and the most remote laterals a and a' . There are three phase and one neutral conductors in that portion of the single-line diagram.

➤ Determine the following:

The percent voltage drops at the ends of the laterals and the main feeder.

The K constants for the laterals and the main feeder can be found as 0.025 and 0.01 %VD/kVA-mile, respectively. For lateral feeder, the load is uniformly distributed. For main, it is lumped at the end.

Solution...

- Since the load is assumed to be uniformly distributed along the lateral,

$$VD_{lat} = \frac{l}{2} KS = \frac{1}{2} \times \frac{5760}{5280} \times 0.025 \times 518 = 7.06\%$$

1 mile=5280 ft

- Since the main is considered to have a lumped-sum load of 1036 kVA at the end of its length, $VD_{main} = \frac{3300}{5280} \times 0.01 \times 1036 = 6.475\%$

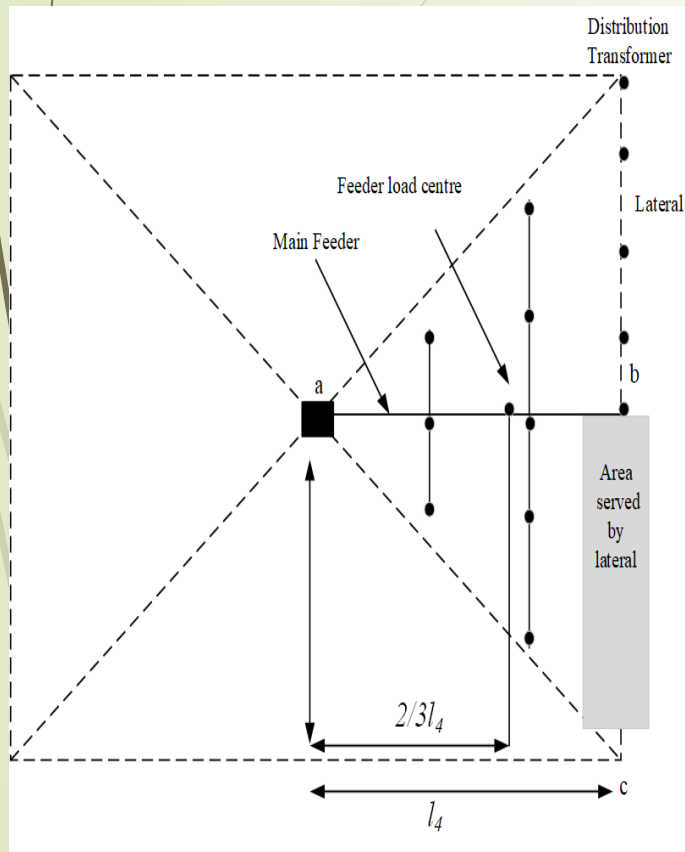
Solution...

- Therefore, the total percent primary voltage drop is

$$VD = VD_{main} + VD_{lat} = 6.475 + 7.06 = 13.535\%$$

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Prof. Saikat Ganguly
Department Of EEE
IIT Guwahati

Example...



A square-shaped distribution substation service area is shown. Assume that the substation is served by **four three-phase four-wire 4.16 kV grounded-wye primary feeders. Assume a lagging load power factor of 0.8 and a 1000 kVA/km² uniformly distributed load density.** Calculate the following:

a. Consider thermally loaded feeder mains and find the following:

- i. Maximum load per feeder
- ii. Substation size
- iii. Total percent voltage drop from the feed point to the end of the main

b. Consider VDL feeders that have 3% voltage drop and find the following:

- i. Maximum load per feeder
- ii. Substation size
- iii. Ampere loading of the main

The conductor ampacity can be taken as 230 A and K is 0.005 %VD/kVA-km.

Solution...

- ❑ Maximum load per feeder is $S_n = \sqrt{3} \times 4.16 \times 230 = 1657.2 \text{ kVA}$
- ❑ Since there are 4 feeders, the substation size is, $TS_n = 4 \times 1657.2 = 6628.8 \text{ kVA}$
- ❑ The length of the feeder is $l_4 = \sqrt{\frac{S_n}{D}} = \sqrt{\frac{1657.2}{1000}} = 1.287 \text{ km}$
- ❑ Total voltage drop of the main feeder will be,
$$= \frac{2}{3} l_4 K D l_4^2 = \frac{2}{3} \times 1.287 \times 0.005 \times 1000 \times 1.287^2 = 7.1\%$$

Solution...

❖ For VDL feeder, $VD = \frac{2}{3} l_4 K D l_4^2 = 3$, this gives the length of the

feeder, $l_4^3 = \frac{3 \times 3}{2KD} = \frac{9}{2 \times 0.005 \times 1000}$, i.e., $l_4 = 0.965$ km

❖ Maximum load per feeder is $S_n = D l_4^2 = 1000 \times 0.965^2 = 931.2$ kVA

❖ Substation size $TS_n = 4S_n = 4 \times 931.2 = 3724.9$ kVA

❖ Ampere loading in the main feeder $= \frac{S_n}{\sqrt{3}V} = \frac{931.2}{\sqrt{3} \times 4.16} = 129.24$ A

Distribution Transformer

- Distribution transformers are used to reduce primary system voltages (2.4–34.5 kV) to utilization voltages (120–600 V).
- They act as liaison between the primary distribution networks and the secondary distribution networks.
- Small distribution transformers are usually of pole mounting in overhead distribution.
- Transformers 100 kVA and below are attached directly to the pole, and transformers larger than 100 up to 500 kVA are hung on crossbeams or support lugs.
- If three or more transformers larger than 100 kVA are used, they are installed on a platform supported by two poles.
- In underground distribution, transformers are installed in street vaults, in manholes direct buried, on pads at ground level, or within buildings.

Types of Distribution transformers

- Heat is a limiting factor in transformer capacity.
- The distribution transformers can be classified as (1) dry type and (2) liquid-filled type.
- The dry-type distribution transformers are air-cooled and air-insulated.
- The liquid-filled-type distribution transformers are usually oil filled.

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Prof. Sanjib Ganguly
Department Of EEE
IIT Guwahati

Reference

- T. Gonen. *Electric Power Distribution System Engineering*; CRC Press, 3rd Edition, 2014.

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Prof. Sanjib Garuly
Department Of EEE
IIT Guwahati

Thank You...

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Prof. Sanjit Ganguly
Department Of EEE
IIT Guwahati