UNIT 3

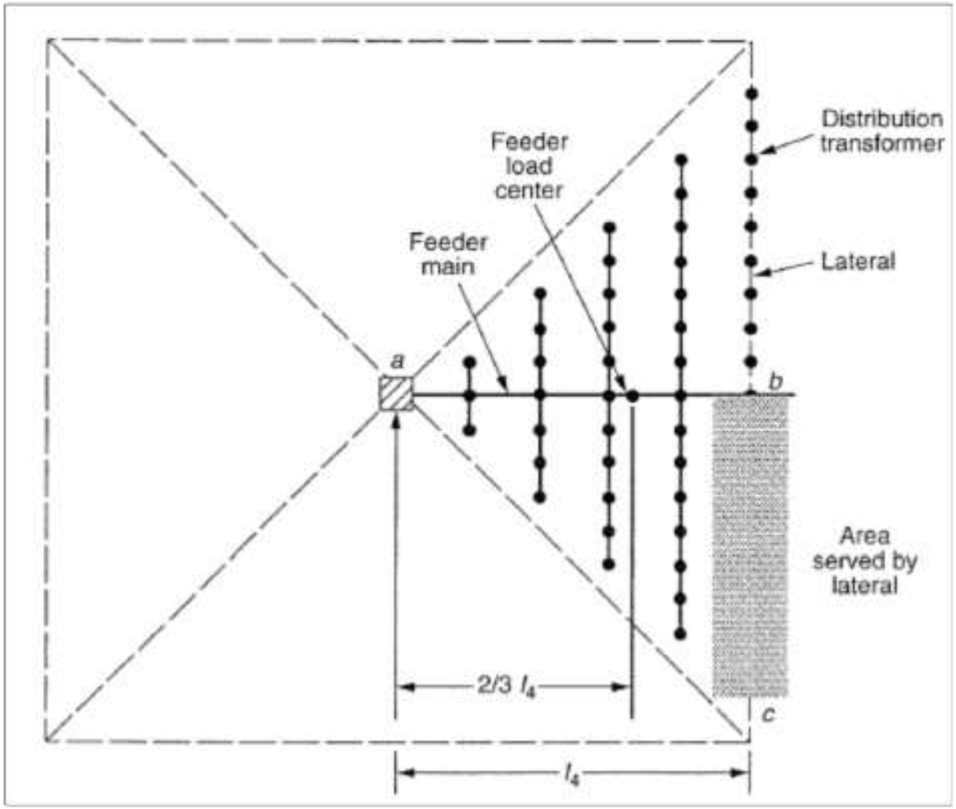
THE RATING OF A DISTRIBUTION SUBSTATION

Assumptions

(*i*) at constant load density for short-term distri- bution planning and

(*ii*) at increasing load density for long-term planning.

analyzed a square-shaped service area representing a part of, or the entire service area of, a distribution substation. It is assumed that the square area is served by four primary feeders from a central feed point, as shown in Figure 4.16. Each feeder and its laterals are of three-phase. Dots represent balanced three-phase loads lumped at that location and fed by distribution transformers.



the percent voltage drop from the feed point *a* to the end of the last lateral at *c* is

$$\%VD_{ac} = \%VD_{ab} + \%VD_{bc}.$$

Reps [5] simplified this voltage drop calculation by introducing a constant *K* which can be defined as *percent voltage drop per kilovoltampere-mile*. Figure 4.17 gives the *K* constant for various voltages and copper conductor sizes. Figure 4.17 is developed for three-phase overhead lines with an equivalent spacing of 37 inches between phase conductors. The following analysis is based on the work done by Denton and Reps [4] and Reps [5].

In Figure 4.16, each feeder serves a total load of

$$S_4 = A_4 \times D \text{ kVA} \qquad (4.1)$$

where S_4 is the kilovoltampere load served by one of four feeders emanating from a feed point, A_4 is the area served by one of the four feeders emanating from a feed point (mi^2), and D is the load density (kVA/mi^2).

Equation 4.1 can be rewritten as

$$S_4 = l_4^2 \times D \text{ kVA} \tag{4.2}$$

since

$$A_4 = l_4^2 \tag{4.3}$$

where l_4 is the linear dimension of the primary-feeder service area in miles. Assuming uniformly distributed load, that is, equally loaded and spaced distribution transformers, the voltage drop in the primary-feeder main is

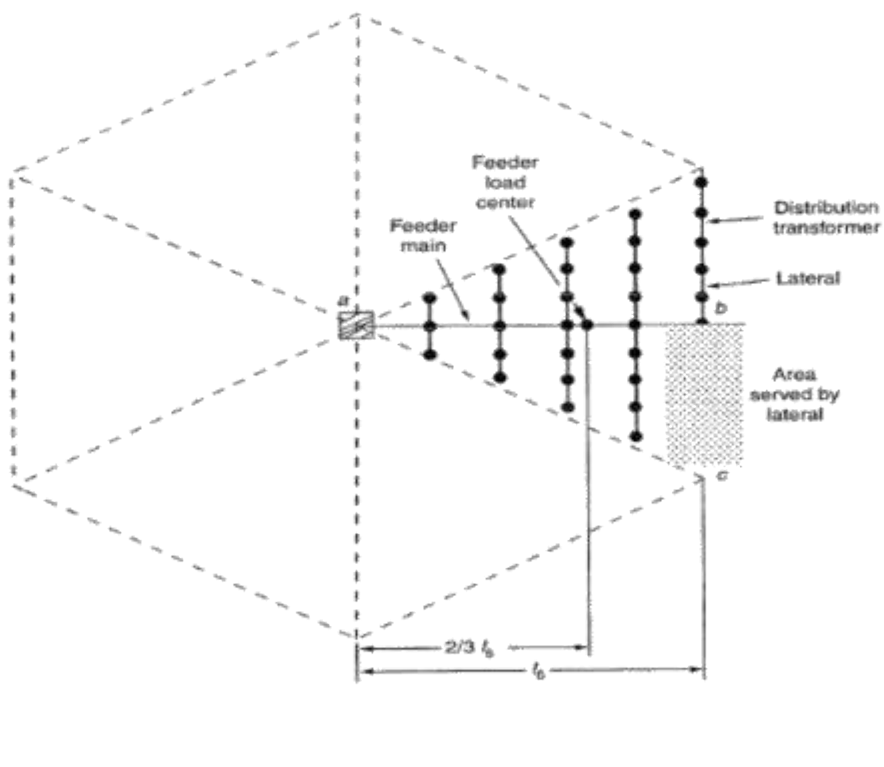
$$\%\text{VD}_{4,\text{main}} = \frac{2}{3} \times l_4 \times K \times S_4 \tag{4.4}$$

or substituting Equation 4.2 into Equation 4.4,

$$\%\text{VD}_{4,\text{main}} = 0.667 \times K \times D \times l_4^3. \tag{4.5}$$

In Equations 4.4 and 4.5, it is assumed that the total or lumped sum load is located at a point on the main feeder at a distance of $2/3 \times l_4$ from the feed point a.

Reps [5] extends the discussion to a hexagonally shaped service area supplied by six feeders from the feed point which is located at the center, as shown in Figure 4.18. Assume that each feeder service area is equal to one-sixth of the hexagonally shaped total area, or



$$A_6 = \frac{l_6}{\sqrt{3}} \times l_6$$
$$= 0.578 \times l_6^2 \tag{4.6}$$

where A_6 is the area served by one of the six feeders emanating from a feed point (mi^2) and l_6 is the linear dimension of a primary-feeder service area (mi).

Here, each feeder serves a total load of

$$S_6 = A_6 \times D \text{ kVA} \tag{4.7}$$

or substituting Equation 4.6 into Equation 4.7,

$$S_6 = 0.578 \times D \times l_6^2 \tag{4.8}$$

As before, it is assumed that the total or lump sum is located at a point on the main feeder at a distance of $\frac{2}{3} \times l_6$ from the feed point. Hence, the percent voltage drop in the main feeder is

$$\%\text{VD}_{6,\text{main}} = \frac{2}{3} \times l_6 \times K \times S_6 \tag{4.9}$$

or substituting Equation 4.8 into Equation 4.9,

$$\%\text{VD}_{6,\text{main}} = 0.385 \times K \times D \times l_6^3. \tag{4.10}$$

GENERAL CASE: SUBSTATION SERVICE AREA WITH *N* PRIMARY FEEDERS

Denton and Reps [4] and Reps [5] extended the discussion to the general case in which the distribution substation service area is served by n primary feeders emanating from the point, as shown in Figure 4.19. 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

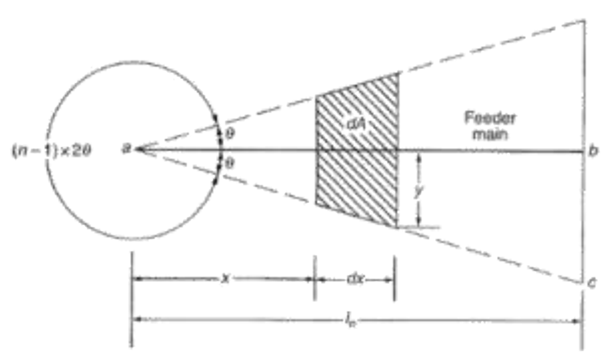


FIGURE 4.19 Distribution substation service area served by n primary feeders.

$$dS = D\,dA \text{ kVA} \tag{4.11}$$

where dS is the differential load served by the feeder in the differential area of dA(kVA), D is the load density (kVA/mil), and, dA is the differential service area of the feeder (mi^2).

In Figure 4.19, the following relationship exists:

$$\tan\theta = \frac{y}{x + dx} \tag{4.12}$$

or

$$\begin{aligned} y &= (x + dx)\tan\theta \\ &\cong x \times \tan\theta. \end{aligned} \tag{4.13}$$

The total service area of the feeder can be calculated as

$$\begin{aligned} A_n &= \int_{x=0}^{l_n} dA \\ &= l_n^2 \times \tan\theta. \end{aligned} \tag{4.14}$$

The total kilovoltampere load served by one of the n feeders can be calculated as

$$\begin{aligned} S_n &= \int_{x=0}^{l_n} dS \\ &= D \times l_n^2 \times \tan\theta. \end{aligned} \tag{4.15}$$

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 contributions of all such areas is

$$\%\text{VD}_n = \frac{2}{3} \times l_n \times K \times S_n \tag{4.16}$$

or, substituting Equation 4.15 into Equation 4.16,

$$\%\text{VD}_n = \frac{2}{3} \times K \times D \times l_n^3 \times \tan\theta \tag{4.17}$$

or, since

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

(4.18)

Equation 4.17 can also be expressed as

$$\%\text{VD}_n = \frac{2}{3} \times K \times D \times l_n^3 \times \tan\frac{360^\circ}{2n}. \tag{4.19}$$

Equations 4.18 and 4.19 are only applicable when $n \geq 3$. Table 4.2 gives the results of the application of Equation 4.17 to square and hexagonal areas.

TABLE 4.2
Application Results of Equation 4.17

n	θ	$\tan\theta$	$\%VD_n$
4	45°	1.0	$\frac{2}{3}\times K\times D\times l_4^3$
6	30°	$\frac{1}{\sqrt{3}}$	$\frac{2}{3}\times K\times D\times l_6^3$

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

$$\%VD_1 = \frac{1}{2}\times K\times D\times l_1^3 \tag{4.20}$$

and for $n = 2$ it is

$$\%VD_2 = \frac{1}{2}\times K\times D\times l_2^3 \tag{4.21}$$

To compute the percent voltage drop in uniformly loaded lateral, lump and locate its total load at a point halfway along its length, and multiply the kilovoltampere-mile product for that line length and loading by the appropriate K constant [5].

Bus Schemes

The substation design or scheme selected determines the electrical and physical arrangement of the switching equipment. Different bus schemes can be selected as emphasis is shifted between the factors of safety, reliability, economy, and simplicity dictated by the function and importance of the substation.

The substation bus schemes used most often are:

Single bus

Main and transfer bus

Double bus, single breaker

Double bus, double breaker

Ring bus

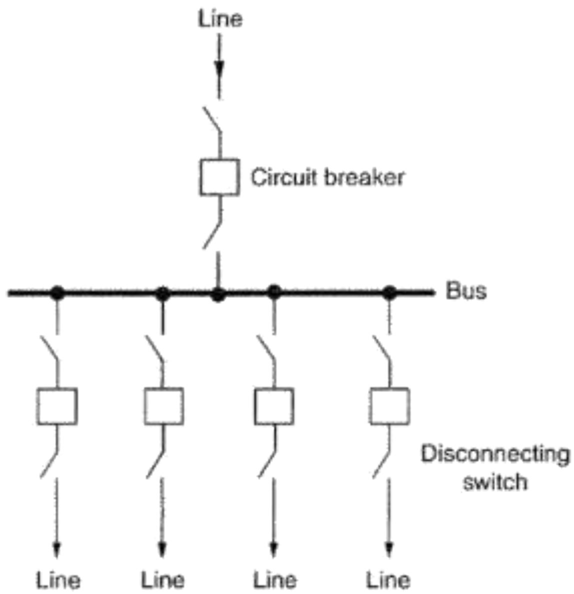
Breaker and a half

Some of these schemes may be modified by the addition of bus-tie breakers, bus sectionalizing devices, breaker bypass facilities, and extra transfer buses.

(*i*) single bus scheme;

Single bus bar scheme name it self indicates that it consists of only one bus bar

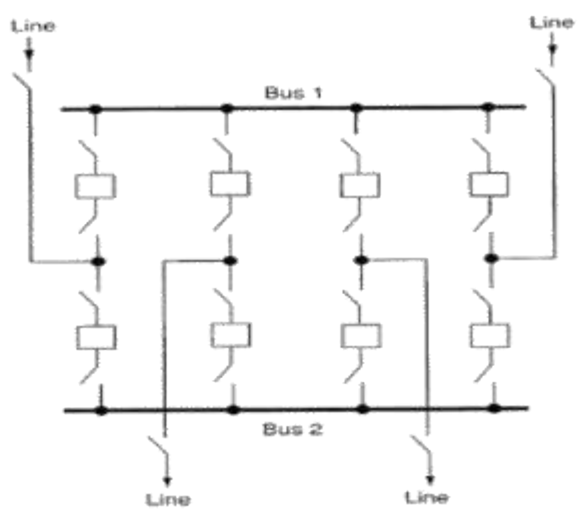
Each scheme has some advantages and disadvantages



A typical single-bus scheme.

Switching Scheme	Advantages	Disadvantages
. Single bus	1. Lowest cost.	1. Failure of bus or any circuit breaker results in shutdown of entire substation. 2. Difficult to do any maintenance. 3. Bus cannot be extended without completely de-energizing the substation. 4. Can be used only where loads can be interrupted or have other supply arrangements.

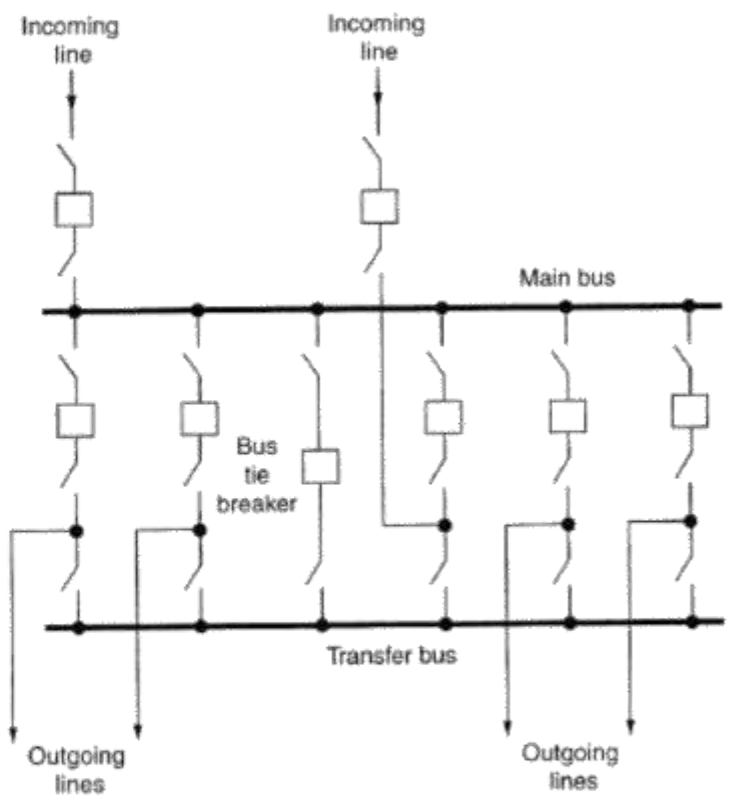
(*ii*) double bus-double breaker (or double main) scheme



A typical double bus-double breaker scheme.

Switching Scheme	Advantages	Disadvantages
Double bus-double breaker	1. Each circuit has two dedicated breakers. 2. Has flexibility in permitting feeder circuits to be connected to either bus. 3. Any breaker can be taken out of service for maintenance. 4. High reliability.	1. Most expensive. 2. Would lose half the circuits for breaker failure if circuits are not connected to both buses.

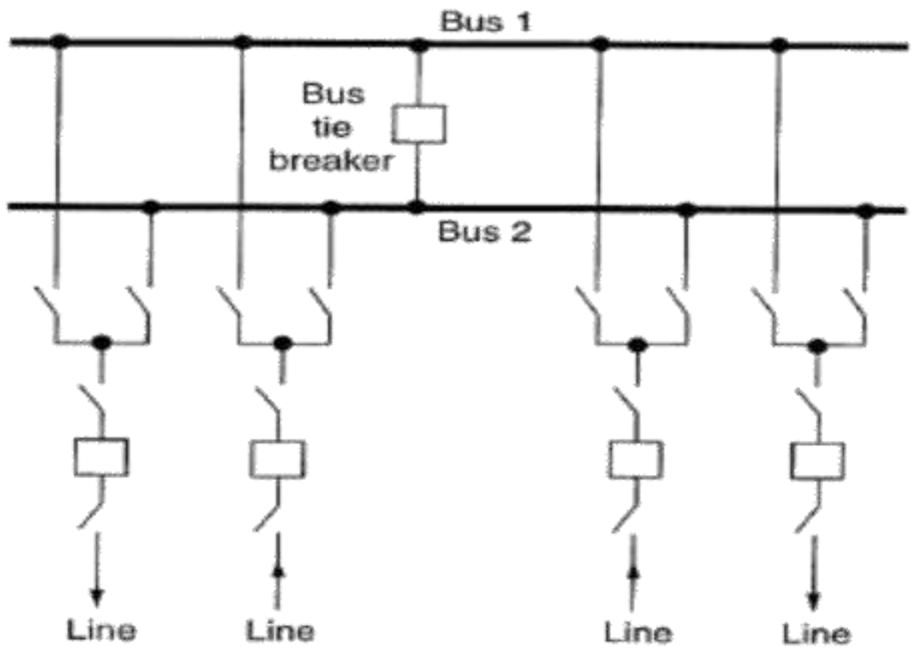
(*iii*) main-and-transfer bus scheme;



A typical main-and-transfer bus scheme.

Switching Scheme	Advantages	Disadvantages
Main-and-transfer	1. Low initial and ultimate cost. 2. Any breaker can be taken out of service for maintenance. 3. Potential devices may be used on the main bus for relaying.	1. Requires one extra breaker for the bus tie. 2. Switching is somewhat complicated when maintaining a breaker. 3. Failure of bus or any circuit breaker results in shutdown of entire substation.

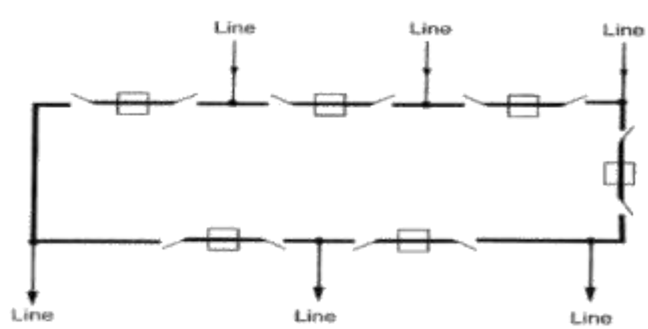
(*iv*) double bus- single breaker scheme;



A typical double bus-single breaker scheme.

Switching Scheme	Advantages	Disadvantages
. Double bus-single breaker	1. Permits some flexibility with two operating buses. 2. Either main bus may be isolated for maintenance. 3. Circuit can be transferred readily from one bus to the other by use of bus-tie breaker and bus selector disconnect switches.	1. One extra breaker is required for the bus tie. 2. Four switches are required per circuit. 3. Bus protection scheme may cause loss of substation when it operates if all circuits are connected to that bus. 4. High exposure to bus faults. 5. Line breaker failure takes all circuits connected to that bus out of service. 6. Bus-tie breaker failure takes entire substation out of service.

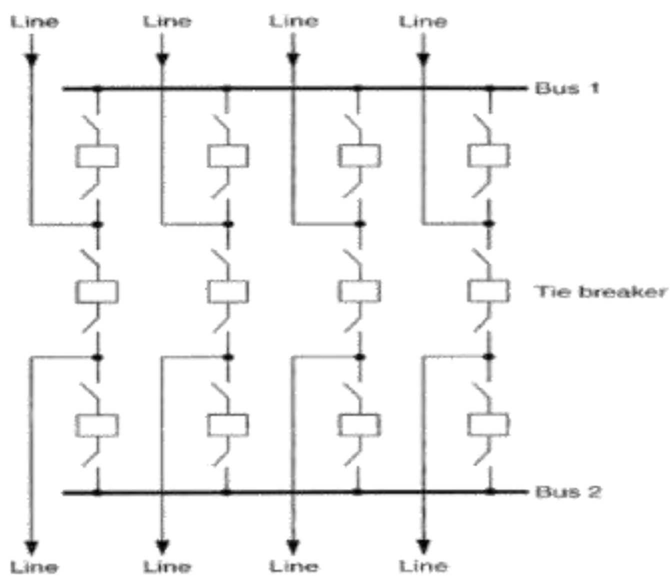
(*v*) ring bus scheme;



A typical ring bus scheme.

Switching Scheme	Advantages	Disadvantages
Ring bus	1. Low initial and ultimate cost. 2. Flexible operation for breaker maintenance. 3. Any breaker can be removed for maintenance without interrupting load. 4. Requires only one breaker per circuit. 5. Does not use main bus. 6. Each circuit is fed by two breakers. 7. All switching is done with breakers.	1. If a fault occurs during a breaker maintenance period, the ring can be separated into two sections. 2. Automatic reclosing and protective relaying circuitry rather complex. 3. If a single set of relays is used, the circuit must be taken out of service to maintain the relays (common on all schemes). 4. Requires potential devices on all circuits since there is no definite potential reference point. These devices may be required in all cases for synchronizing, live line, or voltage indication. 5. Breaker failure during a fault on one of the circuits causes loss of one additional circuit owing to operation of breaker-failure relaying.

(*vi*) breaker-and-a-half scheme.



A typical breaker-and-a-half scheme.

Switching Scheme	Advantages	Disadvantages
Breaker-and-a-half	1. Most flexible operation. 2. High reliability. 3. Breaker failure of bus side breakers removes only one circuit from service. 4. All switching is done by breakers. 5. Simple operation; no disconnect switching required for normal operation. 6. Either main bus can be taken out of service at any time for maintenance. 7. Bus failure does not remove any	1. 1½ breakers per circuit. 2. Relaying and automatic reclosing are somewhat involved since the middle breaker must be responsive to either of its associated circuits.