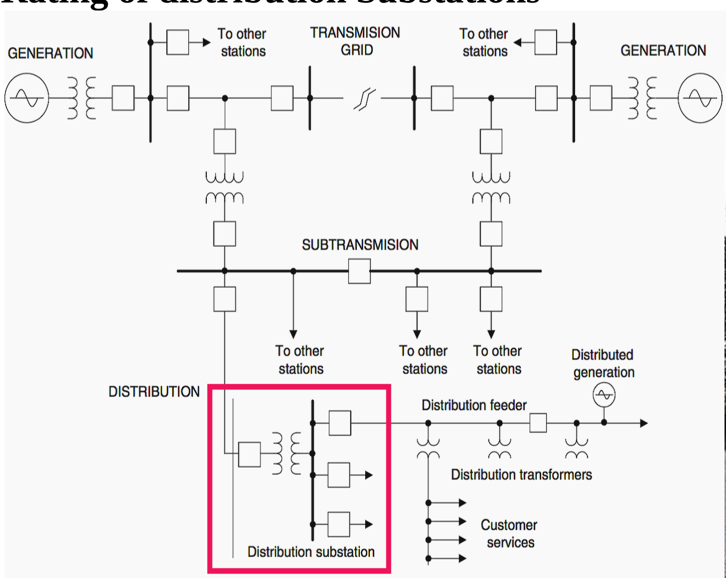
Unit-III Location of Substations

Location of substations

Selection of the location of a substation must consider many factors:

1. Sufficient land area
2. Necessary clearances for electrical safety
3. Access to maintain large apparatus such as transformers.
4. The site must have room for expansion due to load growth or planned transmission additions.
5. Environmental effects such as drainage, noise and road traffic effects.
6. Grounding must be taking into account to protect passers-by during a short circuit in the transmission system
7. The substation site must be reasonably central to the distribution area to be served

Rating of distribution Substations



The additional capacity requirements of a system with increasing load density can be met by:

1. Either holding the service area of a given substation constant and increasing its capacity
2. Or developing new substations and thereby holding the rating of the given substation constant

It is helpful to assume that the system changes (1) at constant load density for short-term distribution planning and (2) at increasing load density for long-term planning. Further, it is also customary and helpful to employ geometric figures to represent substation service areas, as suggested by Van Wormer [3], Denton and Reps [4], and Reps [5]. It simplifies greatly the comparison of alternative plans which may require different sizes of distribution substation, different numbers of primary feeders, and different primary-feeder voltages.

Reps [5] 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 Fig. 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.

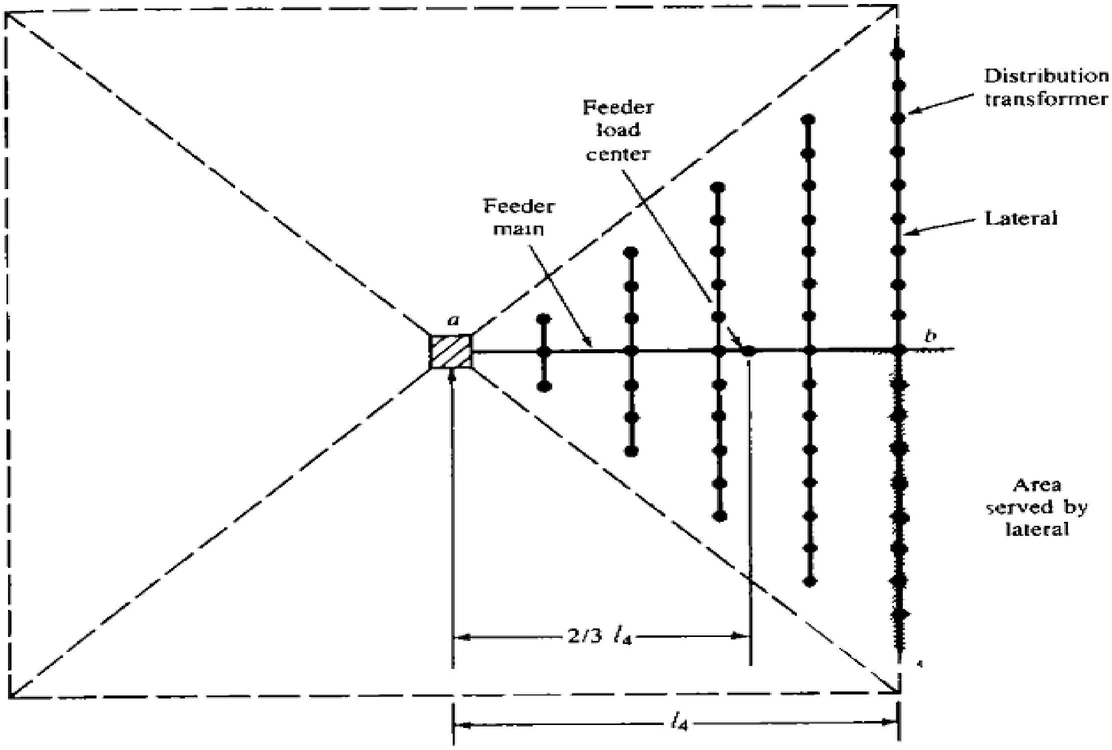


Figure 4-16 Square-shaped distribution substation service area. (*Based on* [5].)

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

$$\%\,\mathrm{VD}_{ac} = \%\,\mathrm{VD}_{ab} + \%\,\mathrm{VD}_{bc}$$

Reps [5] simplified the above 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 in between phase conductors. The following analysis is based on the work done by Denton and Reps [4] and Reps [5].

In Fig. 4-16, each feeder serves a total load of

$$S_4 = A_4 \times D \qquad \text{kVA} \tag{4-1}$$

where S_4 = kilovoltampere load served by one of four feeders emanating from a feed point

A_4 = area served by one of four feeders emanating from a feed point, mi^2

D = load density, kVA/mi^2

Equation (4-1) can be rewritten as

$$S_4 = l_4^2 \times D \qquad \text{kVA} \tag{4-2}$$

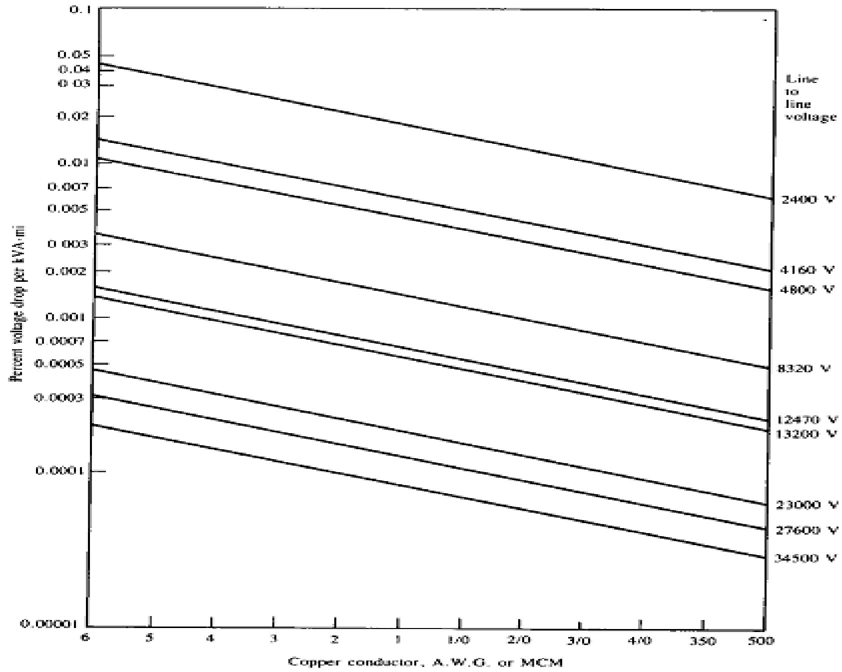


Figure 4-17 The K constant for copper conductors, assuming a lagging-load power factor of 0.9.

since

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, i.e., equally loaded and spaced distribution transformers, the voltage drop in the primary-feeder main is

$$\% \mathrm{VD}_{4,\,\mathrm{main}} = \tfrac{2}{3} \times l_4 \times K \times S_4 \tag{4-4}$$

or substituting Eq. (4-2) into Eq. (4-4),

$$\% \mathrm{VD}_{4,\,\mathrm{main}} = 0.667 \times K \times D \times l_4^3 \tag{4-5}$$

In Eq. (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 $\frac{2}{3} \times l_4$ 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 Fig. 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 = area served by one of six feeders emanating from a feed point, mi^2
l_6 = linear dimension of a primary-feeder service area, mi

Here, each feeder serves a total load of

$$S_6 = A_6 \times D \qquad \mathrm{kVA} \tag{4-7}$$

or substituting Eq. (4-6) into Eq. (4-7),

$$S_6 = 0.578 \times D \times l_6^2 \tag{4-8}$$

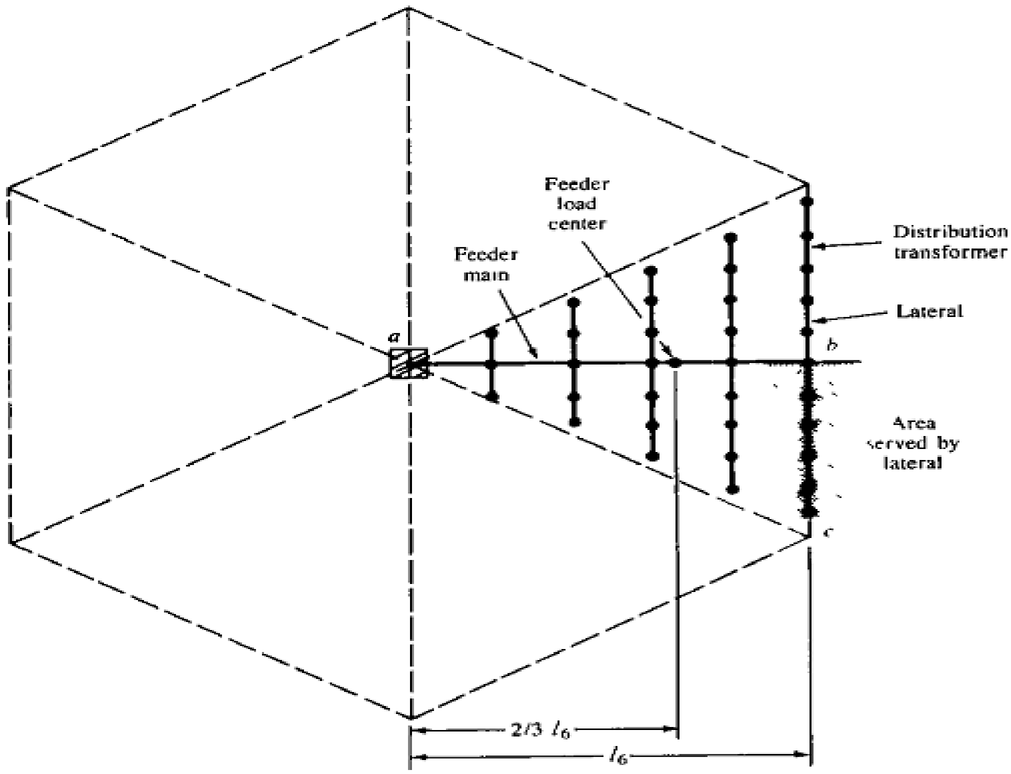


Figure 4-18 Hexagonally shaped distribution substation area. (*Based on* [5].)

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. Therefore, the percent voltage drop in the main feeder is

$$\% \, VD_{6,\,main} = \tfrac{2}{3} \times l_6 \times K \times S_6 \tag{4-9}$$

or substituting Eq. (4-8) into Eq. (4-9),

$$\% \, VD_{6,\,main} = 0.385 \times K \times D \times l_6^3 \tag{4-10}$$

Service area with 'n' primary feeders

Denton and Reps [4] and Reps [5] extend 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 Fig. 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

$$dS = D\,dA \qquad \text{kVA} \tag{4-11}$$

where dS = differential load served by the feeder in the differential area of dA, kVA
D = load density, kVA/mi^2
dA = differential service area of the feeder, mi^2

In Fig. 4-19, the following relationship exists:

$$\tan \theta = \frac{y}{x + dx} \tag{4-12}$$

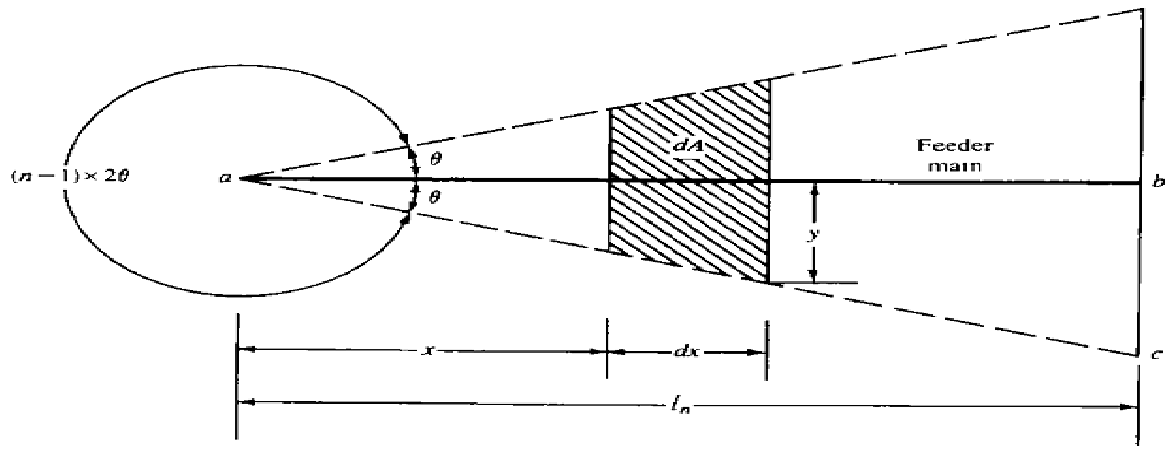


Figure 4-19 Distribution substation service area served by n primary feeders.

or

$$y = (x + dx)\tan\theta$$
$$\cong x \cdot \tan\theta \qquad (4\text{-}13)$$

Therefore the total service area of the feeder can be calculated as

$$A_n = \int_{x=0}^{l_n} dA$$
$$= l_n^2 \times \tan\theta \qquad (4\text{-}14)$$

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

$$S_n = \int_{x=0}^{l_n} dS$$
$$= D \times l_n^2 \times \tan\theta \qquad (4\text{-}15)$$

This total load is located, as a lump-sum load, at a point on the main feeder at a distance of $\frac{2}{3} \times l_4$ from the feed point a. Therefore, the summation of the percent voltage contributions of all such areas is

$$\%\,\mathrm{VD}_n = \tfrac{2}{3} \times l_n \times K \times S_n \qquad (4\text{-}16)$$

or, substituting Eq. (4-15) into Eq. (4-16),

$$\%\,\mathrm{VD}_n = \tfrac{2}{3} \times K \times D \times l_n^3 \times \tan\theta \qquad (4\text{-}17)$$

or, since

$$n(2\theta) = 360^\circ \qquad (4\text{-}18)$$

Eq. (4-17) can also be expressed as

$$\%\,\mathrm{VD}_n = \tfrac{2}{3} \times K \times D \times l_n^3 \times \tan\frac{360^\circ}{2n} \qquad (4\text{-}19)$$

Equations (4-18) and (4-19) are only applicable when $n \geq 3$. Table 4-2 gives the results of the application of Eq. (4-17) to square and hexagonal areas.

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

$$\%\,\mathrm{VD}_1 = \tfrac{1}{2} \times K \times D \times l_1^3 \qquad (4\text{-}20)$$

Table 4-2 Application results of Eq. (4-17)

n	θ	$\tan\theta$	$\%\,\mathrm{VD}_n$
4	45°	1.0	$\frac{2}{3}K \times D \times l_4^3$
6	30°	$\frac{1}{\sqrt{3}}$	$\frac{1}{\sqrt{3}}\,(\frac{2}{3}K \times D \times l_6^3)$

and for $n = 2$ it is

$$\% \mathrm{VD}_2 = \frac{1}{2} \times K \times D \times l_2^3 \tag{4-21}$$

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 kilo-voltampere-mile product for that line length and loading by the appropriate K constant [5].

Benefits of optimal location of substations

1. Reduce line losses – A close coordination between the substation equipment, distribution feeders and associated equipment is necessary to increase system reliability
2. Deferred capital expenses - Capital expenses will decreases
3. Energy cost reduction
4. Economic benefits
5. Coordination – Number of substations connected. If one substations fails, another substations provides supply
6. Over load reduction
7. Reliability increases because of continuity of supply
8. Effectiveness
9. Efficiency – Losses will decreases so efficiency will increases