A Simplified Analyzing Method for Operating Characteristics of Power Distribution System-II

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A Simplified Analyzing Method for Operating Characteristics of Power Distribution System-II

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The authors suggested, in the previous paper(1), that the complicated distribution system, such as loop, banking, network and the like, may be systematically analyzed by treating the whole system as a combination of simple four terminal network.

In this paper, Part-II, the analyzing method for the loop primary system is described and formulized by the above treatment.

1. Introduction

The authors presented, in the previous paper(1), a simplified analyzing method for operating characteristics of the tree-type distribution system, having a rectangular load area with uniform load distribution, by representing the load as an equivalent admittance and treating the system as a simple four terminal network.

According to this method, it can be expected that the complicated system may be systematically analyzed. In this paper, the systematized analyzing method for the loop system is described.

2. The Loop Primary Circuit

(fed by two loop primary feeders)

Consider the loop primary circuit which starts from a substation bus and, making a loop through the area to be served, returns to the same bus as shown in Fig. 1. The powers in its area are supplied through the three-phase, three-wire distribution lines and all balanced unless otherwise specified notes.

In this figure;

$\dot{E}_s$; phase voltage at the substation bus in volt,
$\dot{E}_0$, $\dot{E}_3$; phase voltages at the feeding point of main line A and B in volt,
$\dot{E}_1$, $\dot{E}_2$; phase voltages at the end of main line A and B in volt,
$\dot{I}_s$, $\dot{I}_{s'}$; line currents at the sending ends of the loop primary feeder A and B in ampere,
$\dot{D}_a$, $\dot{D}_b$; load-densities of the load area A and B in volt-ampere per square kilometer,
$\cos\theta_a$, $\cos\theta_b$; power factors of the load area A and B,
a_a, a_b ; lengths of main line A and B in kilometer,
c_a, c_b ; lengths of laterals A and B in kilometer,
$\dot{z}_{1a}$, $\dot{z}_{1b}$; series impedances of main line A and B in ohm per kilometer,

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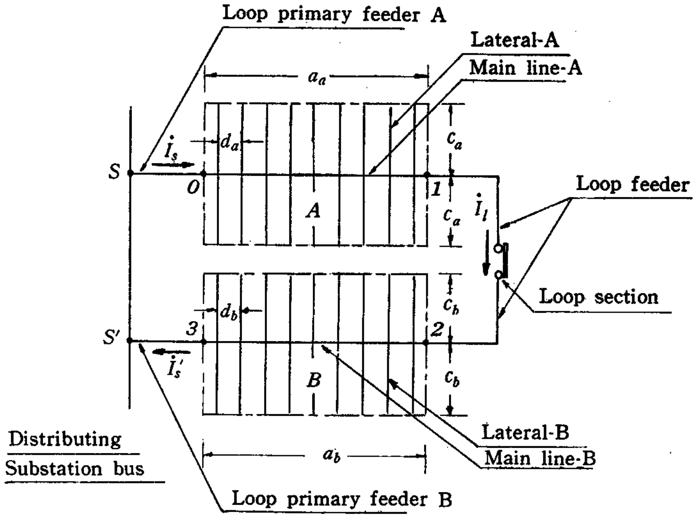

Fig. 1. The Loop primary circuit.

Note: The positive direction of current flow is indicated by the arrow.

$$\dot{z}_{1a}=r_{1a}+jX_{1a},\quad \dot{z}_{1b}=r_{1b}+jX_{1b},$$

Z_{1a}, Z_{1b} ; effective impedances of main line A and B per kilometer,

$$Z_{1a}=r_{1a}\cos\theta_a+X_{1a}\sin\theta_a,\quad Z_{1b}=r_{1b}\cos\theta_b+X_{1b}\sin\theta_b$$

$\dot{z}_{2a}$, $\dot{z}_{2b}$; series impedances of laterals A and B in ohm per kilometer,

$$\dot{z}_{2a}=r_{2a}+jX_{2a},\quad \dot{z}_{2b}=r_{2b}+jX_{2b}.$$

Z_{2a}, Z_{2b} ; effective impedances of laterals A and B per kilometer,

$$Z_{2a}=r_{2a}\cos\theta_a+X_{2a}\sin\theta_a,\quad Z_{2b}=r_{2b}\cos\theta_b+X_{2b}\sin\theta_b$$

$\dot{y}_{1a}$, $\dot{y}_{1b}$; load admittances of main line A and B in mho per kilometer,

$$\dot{y}_{1a}=\frac{2c_a\dot{D}_a}{3E_{na}^2},\quad \dot{y}_{1b}=\frac{2c_b\dot{D}_b}{3E_{nb}^2},$$

$\dot{y}_{2a}$, $\dot{y}_{2b}$; load admittances of laterals A and B in mho per kilometer,

$$\dot{y}_{2a}=\frac{d_a\dot{D}_a}{3E_{na}'^2},\quad \dot{y}_{2b}=\frac{d_b\dot{D}_b}{3E_{nb}'^2},$$

$E_{na}(E'_{na})$, $E_{nb}(E'_{nb})$; represented phase voltages of main line (or laterals) A and B in volt,

d_a, d_b ; spacing of laterals A and B in kilometer,

$[\dot{A}_{mn}]$; an abridged notation of general circuit constants from m to n,

$$[\dot{A}_{mn}]=\begin{bmatrix}\dot{A}_{mn} & \dot{B}_{mn}\\ \dot{C}_{mn} & \dot{D}_{mn}\end{bmatrix}.$$

Here, concerning the represented phase voltage of each load area, the values derived from assuming that each load area is served by the respective tree-type distribution system may be adopted approximately. (See Appendix.)

Now, the equivalent sequence circuit of the loop primary circuit in Fig. 1 is given by a combination of four terminal network as shown in Fig. 2, in which the loop primary feeder, B, is disconnected from the substation bus at the point, S', but, in compensation for it, the phase voltatge $\dot{E}_s$ is impressed at this point.

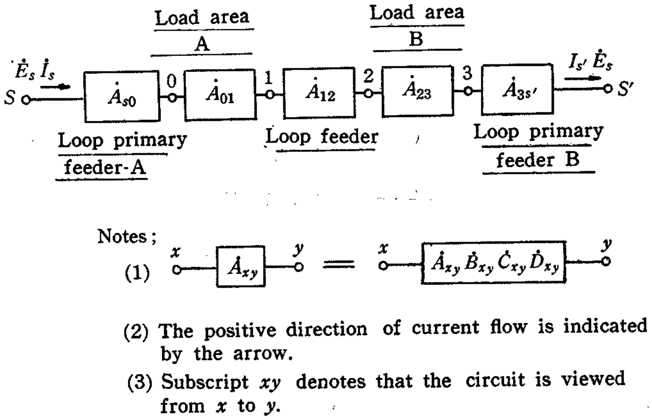

Fig. 2. The equivalent sequence circuit of Fig. 1.

The equivalent circuit is a kind of tree-type primary distribution circuit in which the same phase voltage $\dot{E}_s$ is impressed at both ends.

(1) Current and power at the sending end

The current and power at the sending end can be immediately calculated as follows[2]:

$$\begin{bmatrix}\dot{E}_s\\ \dot{I}_s\end{bmatrix}=\begin{bmatrix}\dot{A}_{ss'} & \dot{B}_{ss'}\\ \dot{C}_{ss'} & \dot{D}_{ss'}\end{bmatrix}\cdot\begin{bmatrix}\dot{E}_s\\ \dot{I}_{s'}\end{bmatrix}=[\dot{A}_{ss'}]\cdot\begin{bmatrix}\dot{E}_s\\ \dot{I}_{s'}\end{bmatrix}, \tag{1}$$

where, $[\dot{A}_{ss'}]=[\dot{A}_{s0}]\cdot[\dot{A}_{01}]\cdot[\dot{A}_{12}]\cdot[\dot{A}_{23}]\cdot[\dot{A}_{3s'}]$.

Then, $\dot{E}_s=\dot{A}_{ss'}\dot{E}_s+\dot{B}_{ss'}\dot{I}_{s'}$, (2), $\dot{I}_s=\dot{C}_{ss'}\dot{E}_s+\dot{D}_{ss'}\dot{I}_{s'}$. (3)

From Eqs. (2) and (3),

$$\dot{I}_s=\frac{\dot{D}_{ss'}}{\dot{B}_{ss'}}\dot{E}_s-\frac{1}{\dot{B}_{ss'}}\dot{E}_s=\frac{\dot{D}_{ss'}-1}{\dot{B}_{ss'}}\cdot\dot{E}_s, \tag{4}$$

$$\dot{I}_{s'}=\frac{1}{\dot{B}_{ss'}}\dot{E}_s-\frac{\dot{A}_{ss'}}{\dot{B}_{ss'}}\dot{E}_s=\frac{1-\dot{A}_{ss'}}{\dot{B}_{ss'}}\cdot\dot{E}_s. \tag{5}$$

The current at the sending end, $\dot{I}_{ss'}$, is derived as follows:

$$\dot{I}_{ss'}=\dot{I}_s-\dot{I}_{s'}=\frac{\dot{A}_{ss'}+\dot{D}_{ss'}-2}{\dot{B}_{ss'}}\cdot\dot{E}_{ss}=\dot{Y}_{ss'}\dot{E}_s. \tag{6}$$

$\dot{Y}_{ss'}$ means the apparent load admittance viewed from the distributing substation.

The power, $\dot{W}_{ss'}$, to be served is, $\dot{W}_{ss'}=3\dot{E}_s\dot{I}_{ss'}=3\dot{Y}_{ss'}E_s^2$. (7)

(2) Voltage at any point on distributing main

Consider the voltage at any point on distributing main in Fig. 1. The circuit from the substation bus to any point, k, is shown in Fig. 3 and the sequence circuit is shown in Fig. 4.

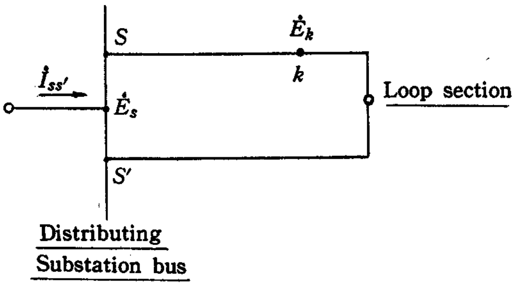

Fig. 3. The circuit from the distribution bus to the objective point, k.

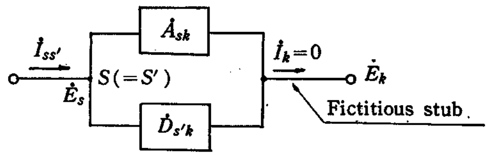

Fig. 4. The sequence circuit of fig. 3.

Here, draw out a fictitious stub connection with open terminal from the point, k. Then, the following relation is obtained:

$$\dot{E}_k=\frac{1}{\dot{A}_{sk}^{sk}}\cdot\dot{E}_s \tag{8}$$

where,

$$\dot{A}_{sk}^{sk}=\frac{\dot{A}_{sk}\dot{B}_{s'k}+\dot{A}_{s'k}\dot{B}_{sk}}{\dot{B}_{sk}+\dot{B}_{s'k}}, \tag{9}$$

which is the constant $\dot{A}$ for two four terminal networks in parallel between the substation and any point, k, on main.

Now, $$[\dot{A}_{ss'}]=[\dot{A}_{sk}]\cdot[\dot{A}_{ks'}]=[\dot{A}_{sk}]\cdot[\dot{D}_{s'k}]=\begin{bmatrix}\dot{A}_{sk} & \dot{B}_{sk}\\ \dot{C}_{sk} & \dot{D}_{sk}\end{bmatrix}\cdot\begin{bmatrix}\dot{D}_{s'k} & \dot{B}_{s'k}\\ \dot{C}_{s'k} & \dot{A}_{s'k}\end{bmatrix}$$
$$=\begin{bmatrix}\dot{A}_{sk}\dot{D}_{s'k}+\dot{B}_{sk}\dot{C}_{s'k} & \dot{A}_{sk}\dot{B}_{s'k}+\dot{B}_{sk}\dot{A}_{s'k}\\ \dot{C}_{sk}\dot{D}_{s'k}+\dot{D}_{sk}\dot{C}_{s'k} & \dot{C}_{sk}\dot{B}_{s'k}+\dot{D}_{sk}\dot{A}_{s'k}\end{bmatrix},$$

hence, as $\dot{B}_{ss'}=\dot{A}_{sk}\dot{B}_{s'k}+\dot{A}_{s'k}\dot{B}_{sk}$ substituting this relation into Eq. (9),

$$\dot{A}_{sk}^{sk}=\frac{\dot{B}_{ss'}}{\dot{B}_{sk}+\dot{B}_{s'k}}, \tag{10}$$

Thus, the voltage at any point, k, on distributing main is given by Eqs. (8) and (10) as

$$\dot{E}_k=\frac{\dot{B}_{sk}+\dot{B}_{s'k}}{\dot{B}_{ss'}}\dot{E}_s. \tag{11}$$

(3) Maximum voltage drop

Consider the point of maximum voltage drop on the main line of loop primary circuit and calculate the voltage drop at the last end of the lateral tapped off at the above point, that is, the maximum voltage drop of loop primary circuit.

Now, the following question is preliminarily considered.

That is "where is the point of maximum voltage drop on the main line fed from its both sides ?"

In such a case, it must be found the point on main where is no current, because, at this point, the maximum voltage drop arises.

Then, assuming that there is no current at the point where is at x on main from the feeding point, 0, in Fig. 5, the following equations are obtained:

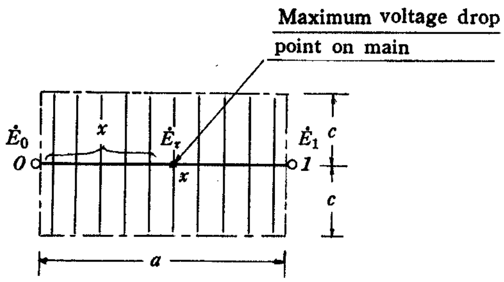

Fig. 5. Load distribution area fed from both ends on its main.

$$\dot{E}_x=\frac{1}{\dot{A}_x}\dot{E}_0, \qquad \dot{E}_x=\frac{1}{\dot{D}_{a-x}}\dot{E}_1. \tag{12}$$

From Eq. (12), $$\frac{\dot{E}_1}{\dot{E}_0}=\frac{\dot{D}_{a-x}}{\dot{A}_x}=\frac{\cosh\dot{\gamma}(a-x)}{\cosh\dot{\gamma}x}, \tag{13}$$

$$\frac{E_1}{E_0}=\left|\frac{\dot{E}_1}{\dot{E}_0}\right|=\left|\frac{\cosh\dot{\gamma}(a-x)}{\cosh\dot{\gamma}x}\right|\simeq\frac{1+\frac{1}{2}yZ(a-x)^2}{1+\frac{1}{2}yZx^2}\simeq 1-\frac{1}{2}yZa(2x-a), \tag{14}$$

therefore, $$x\simeq\frac{1}{2}a+\frac{1}{yZa}\left(\frac{E_0-E_1}{E_0}\right). \tag{15}$$

Rewriting this equation, $$x\simeq\frac{1}{2}a\left(1+\frac{1}{\frac{1}{2}yZa^2}\cdot\frac{\%E_1}{100}\right). \tag{16}$$

Moreover, putting, $$K=\frac{\%E_1/100}{(1/2)\,yZa^2}, \tag{17}$$

the maximum voltage drop point is given by the equation,

$$x=\frac{1}{2}a(1+K). \tag{18}$$

The existence of the maximum voltage drop or its position on main line is determined by the value of K which is the rate of voltage difference between both ends to the voltage drop at the last end of the main line in the case of regarding the system as a tree-type distribution system fed from one end, 0.

The discriminant for the above question is shown in Table-1.

Table 1. The discriminant for the position of maximum voltage drop.

K	position of maximum voltage drop (on main)	note
$\lvert K\rvert >1$	non-existence	Non-existence within the load distribution area concerned.
$K=1$	$x=a$	It is equivalent to the tree-type circuit fed from 0. $E_0>E_1,\ E_1/E_0=1-\frac{1}{2}yZa^2$.
$0<K<1$	$\frac{a}{2}<x<a$	$E_0>E_1$.
$K=0$	$x=\frac{1}{2}a$	It is equivalent to the uniform load loop circuit the length of which is a. $E_1=E_0$.
$-1<K<0$	$0<x<\frac{a}{2}$	$E_1>E_0$.
$K=-1$	$x=0$	It is equivalent to the tree-type circuit fed from 1. $E_0<E_1,\ E_1/E_0=1+\frac{1}{2}yZa^2$.

Then, the maximum voltage drop of loop primary circuit in Fig. 1, can be obtained by the following steps:

(a) Calculate the voltages at the points (0,1,2 and 3), where are at the ends on main line of each load area.

(b) Select the area having maximum voltage drop on main between two load distribution areas, on reference to the above voltages and the discriminant shown in Table-1.

(c) If the load area A is selected in Step (b), the distance x from the feeding point, 0, on main line A to the point where shows maximum voltage drop is calculated by Eq. (18).

(d) The maximum voltage drop of loop primary circuit can be obtained by the equation,

$$\begin{aligned}\%E_{sc}&=\frac{|\dot{E}_s|-|\dot{E}_{oc}|}{|\dot{E}_s|}\times 100\\&=\frac{|\dot{E}_s|-|\dot{E}_0|\left(1-\frac{y_{1a}Z_{1a}}{2}\cdot x^2-\frac{y_{2a}Z_{2a}}{2}c_a^2\right)}{|\dot{E}_s|}\times 100\\&=\left[\frac{|\dot{E}_s|-|\dot{E}_0|}{|\dot{E}_s|}+\frac{|\dot{E}_0|}{|\dot{E}_s|}\cdot\left(\frac{y_{1a}Z_{1a}}{2}x^2+\frac{y_{2a}Z_{2a}}{2}c_a^2\right)\right]\times 100\\&=\%E_{so}+\left|\frac{\dot{E}_0}{\dot{E}_s}\right|\cdot\left(\frac{y_{1a}Z_{1a}}{2}x^2+\frac{y_{2a}Z_{2a}}{2}c_a^2\right)\times 100\end{aligned}\tag{19}$$

where, $\%E_{so}=\dfrac{|\dot{E}_s|-|\dot{E}_0|}{|\dot{E}_s|}\times 100$

which is the voltage drop from S to 0, (refer to Eq. (26) in Part-1)

$$|\dot{E}_{0c}| \simeq |\dot{E}_0|\left(1-\frac{y_{1a}Z_{1a}}{2}x^2-\frac{y_{2a}Z_{2a}}{2}c_a^2\right),$$

which is the voltage drop from 0 to the last end of the lateral tapped off at x.

Giving the load density D_a in $kVA/k\text{m}^2$ and the voltages in kV,

$$\%E_{sc}=\%E_{s0}+\left(\frac{c_aD_aZ_{1a}}{10V_{na}^2}x^2+\frac{d_aD_aZ_{2a}}{20V_{na}'^2}c_a^2\right)\left(1-\frac{\%E_{s0}}{100}\right). \tag{20}$$

In the case of loop primary circuit having the load distribution areas of various load densities more than two, the following method is adopted.

That is, first, the equivalent circuit as shown in Fig. 6 is made up, and the load distribution area concerned is selected on reference to Eq. (11) and Table-1, and next, the maximum voltage drop of this circuit is calculated on reference to Eq. (19) or (20).

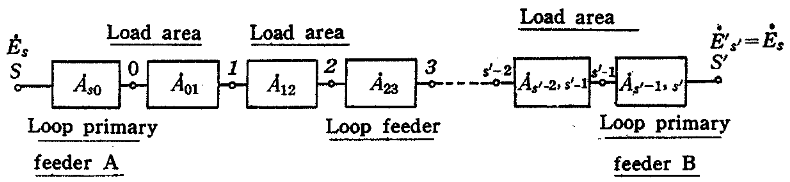

Fig. 6. The equivalent sequence circuit.

In this case, the general circuit constants $\dot{A}$, $\dot{B}$, $\dot{C}$ and $\dot{D}$ are given as follows:

$$[\dot{A}_{ss'}]=\overbrace{[\dot{A}_{s0}]\cdot[\dot{A}_{01}]\cdot[\dot{A}_{12}]\cdots[\dot{A}_{k-1,k}]}^{[\dot{A}_{sk}]}\cdot\overbrace{[\dot{A}_{k,k+1}]\cdots[\dot{A}_{s'-2,s'-1}]\cdot[\dot{A}_{s'-1,s'}]}^{[\dot{A}_{ks'}]=[\dot{D}_{s'k}]}.$$

Here, as the supplement, consider the voltage at any point of tree-type primary circuit having the load distribution areas of various load densities.

It can be derived as follows, assuming that the circuit in Fig. 6 is a tree-type primary circuit fed from S only.

Putting the current at the last end S' is zero,

$$\dot{E}_s=\dot{A}_{ss'}\dot{E}_{s'} \tag{i}$$

and, the voltage at any point k, $\dot{E}_k$, is,

$$\dot{E}_s=\dot{A}_{sk}\dot{E}_k+\dot{B}_{sk}\dot{I}_k, \quad \text{(ii)}, \qquad \dot{I}_k=\frac{\dot{D}_{ks'}}{\dot{B}_{ks'}}\dot{E}_k-\frac{1}{\dot{B}_{ks'}}\dot{E}_{s'}, \quad \text{(iii)}$$

from Eqs. (ii) and (iii), $\dot{E}_s=\dot{A}_{sk}\dot{E}_k+\dfrac{\dot{B}_{sk}\dot{D}_{ks'}}{\dot{B}_{ks'}}\dot{E}_k-\dfrac{\dot{B}_{sk}}{\dot{B}_{ks'}}\dot{E}_{s'}$,

hence, $\dfrac{\dot{A}_{sk}\dot{B}_{ks'}+\dot{B}_{sk}\dot{D}_{ks'}}{\dot{B}_{ks'}}\dot{E}_k=\dfrac{1}{\dot{B}_{ks'}}(\dot{B}_{ks'}\dot{E}_s+\dot{B}_{sk}\dot{E}_{s'})$,

but, $\dot{A}_{sk}\dot{B}_{ks'}+\dot{B}_{sk}\dot{D}_{ks'}=\dot{B}_{ss'}$, therefore, $\dot{E}_k=\dfrac{\dot{B}_{ks'}\dot{E}_s+\dot{B}_{sk}\dot{E}_{s'}}{\dot{B}_{ss'}}$, (iv)

substituting (i) into the Eq. (iv),

$$\dot{E}_k=\left(\dot{B}_{ks'}+\frac{\dot{B}_{sk}}{\dot{A}_{ss'}}\right)\frac{\dot{E}_s}{\dot{B}_{ss'}}. \quad \text{(v)}$$

The above mentioned procedure is profitable in case that it is desirable to make the load density of load area some more subdivide.

(4) Current at the point of loop section (interchanging current)

Consider the current at the point of loop section, that is, the interchanging current as shown in Fig. 1.

The sequence circuit is shown in Fig. 7.

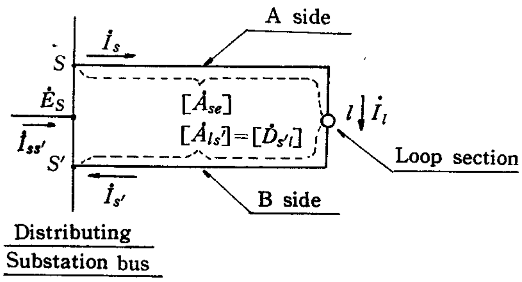

Fig. 7. The circuit for calculation of the interchanging current.

In Fig. 7, now it is assumed that the interchanging current, $\dot{I}_l$, flows from the A side to the B side.

The following equations are derived:

$$\dot{I}_l=\dot{A}_{sl}\dot{I}_s-\dot{C}_{sl}\dot{E}_s, \quad (21)$$

from Eq. (4), $\dot{I}_s=\dfrac{\dot{D}_{ss'}-1}{\dot{B}_{ss'}}\dot{E}_s$, (21)

where, $[\dot{A}_{sl}]$; general circuit constants from S to l,
$[\dot{A}_{ls'}]$; general circuit constants from l to S',
$[\dot{A}_{ss'}]$; general circuit constants from S to S',

$$[\dot{A}_{ss'}]=[\dot{A}_{sl}]\cdot[\dot{A}_{ls'}]=[\dot{A}_{sl}]\cdot[\dot{D}_{s'l}].$$

hence, $\dot{I}_l=\left(\dot{A}_{sl}\cdot\dfrac{\dot{D}_{ss'}-1}{\dot{B}_{ss'}}-\dot{C}_{sl}\right)\dot{E}_s=\dfrac{(\dot{A}_{sl}\dot{D}_{ss'}-\dot{C}_{sl}\dot{B}_{ss'})-\dot{A}_{sl}}{\dot{B}_{ss'}}\dot{E}_s$, (22)

but, $\dot{B}_{ss'}=\dot{A}_{sl}\dot{B}_{ls'}+\dot{B}_{sl}\dot{D}_{ls'}$, $\quad \dot{D}_{ss'}=\dot{C}_{sl}\dot{B}_{ls'}+\dot{D}_{sl}\dot{D}_{ls'}$,

so that, $\dot{A}_{sl}\dot{D}_{ss'}-\dot{C}_{sl}\dot{B}_{ss'}=\dot{A}_{sl}\dot{C}_{sl}\dot{B}_{ls'}+\dot{A}_{sl}\dot{D}_{sl}\dot{D}_{ls'}-\dot{C}_{sl}\dot{A}_{sl}\dot{B}_{ls'}-\dot{C}_{sl}\dot{B}_{sl}\dot{D}_{ls'}$
$=\dot{D}_{ls'}(\dot{A}_{sl}\dot{D}_{sl}-\dot{B}_{sl}\dot{C}_{sl})=\dot{D}_{ls'}=\dot{A}_{s'l}.$

therefore, the interchanging current is given by the equation,

$$\left.\begin{aligned} \dot{I}_l &= \frac{\dot{A}_{s'l}-\dot{A}_{sl}}{\dot{B}_{ss'}}\cdot\dot{E}_s = \frac{\dot{A}_{s'l}-\dot{A}_{sl}}{\dot{A}_{sl}\dot{B}_{s'l}+\dot{B}_{sl}\dot{A}_{s'l}}\cdot\dot{E}_s \\ &= \frac{\dfrac{1}{\dot{A}_{sl}}-\dfrac{1}{\dot{A}_{s'l}}}{\dfrac{\dot{B}_{sl}}{\dot{A}_{sl}}+\dfrac{\dot{B}_{s'l}}{\dot{A}_{s'l}}}\cdot\dot{E}_s \end{aligned}\right\} \tag{23}$$

As for the numerater of the right-hand side of this equation, the first term, $\left(\frac{1}{\dot{A}_{sl}}\dot{E}_s\right)$, shows the voltage at the point, l, regarded a tree-type distribution circuit ($S-l$) as been fed from S only and the second term, $\left(\frac{1}{\dot{A}_{s'l}}\dot{E}_s\right)$, shows the voltage at the point, l, regarded a tree-type distribution circuit ($S'-l$) as been fed from S' only, so that, the difference of each voltage shows the voltage which appears at the point when the loop section is open.

The each term of the denominator shows the driving point impedance of the each circuit viewed from the loop section, respectively.

3. The Loop Primary Circuit

(fed by one loop primary feeder)

Consider the loop primary circuit fed by one loop primary feeder as shown in Fig. 8.

In this case, the sequence circuit is as shown in Fig. 9, and the following equations are derived:

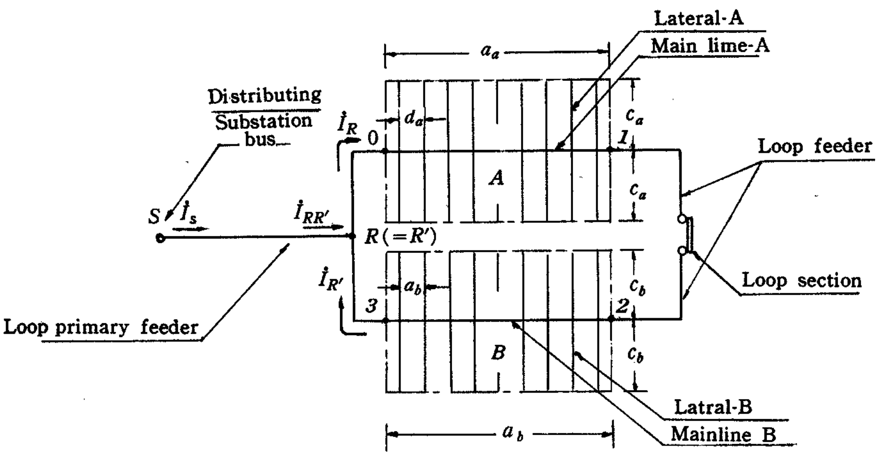

Fig. 8. The Loop primary circuit.

Note: The positive direction of current flow is indicated by the arrow.

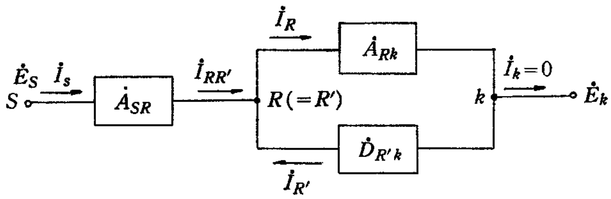

Fig. 9. The sequence circuit of Fig. 8.

$$\dot{E}_s=\dot{A}_{SR}\dot{E}_R+\dot{B}_{SR}\dot{I}_{RR'}=(\dot{A}_{SR}+\dot{B}_{SR}Y_{RR'})\dot{E}_R, \qquad (24)$$

$$\dot{I}_s=\dot{C}_{SR}\dot{E}_R+\dot{D}_{SR}\dot{I}_{RR'}=(\dot{C}_{SR}+\dot{D}_{SR}Y_{RR'})\dot{E}_R, \qquad (25)$$

where, $$Y_{RR'}=\frac{\dot{A}_{RR'}+\dot{D}_{RR'}-2}{\dot{B}_{RR'}}. \qquad \text{[refer to Eq. (6)]}$$

Now, represent the voltage drop in percent of loop primary feeder between S and R, for convenience, as

$$\%E_{SR}\simeq\frac{|\dot{E}_S|-|\dot{E}_R|}{|\dot{E}_R|}\times 100, \qquad (26)$$

then, this value is obtained by using Eq. (24).
Further, the voltage drop in percent on the circuit viewed to the right from the point R can be calculated by reference to Eq. (19) or (20).

In the result, the voltage drop in percent at any point, k, on main line is given by the equation,

$$\%E_{sk}=(\%E_{sR}+\%E_{Rk})\frac{E_R}{E_S}. \qquad (27)$$

4. Conclusion

By representing a load distribution area with the uniformly distributed load as a simple four terminal network, the loop system can be systematically analyzed and the electric characteristics of the loop system can be fairly precisely derived by reference to Part-I. About the problems, such as banking or network and the like, the authors wish to described in the next opportunity.

Appendix

The represented phase voltage

The represented phase voltage used for determination of load admittance in the tree-type circuit having a rectangular area with uniform load distribution is given generally as follows:[3]

For main; $$E_n=\left[1-\frac{(1-m)}{300}\cdot\varepsilon\right]E \quad \text{(v)},$$

For lateral; $E_n' = \left[1 - \frac{(2-m)}{300} \cdot \varepsilon\right] E$ (v),

where, ε =total voltage drop to the last end of distribution line in percent. (This value needs to be estimated.)

E=phase voltage at the feeding point in volt. (for convenience $E \simeq E_s$)

$$m = \frac{\text{voltage drop of lateral in present}}{\text{total voltage drop in percent}} \simeq \frac{Z_2 dc}{2Z_1 a^2 + Z_2 dc}$$

[refer to Eq. (35) in Part-I]

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