SOME FEATURES OF A MODERN OVERHEAD DISTRIBUTING SYSTEM

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SOME FEATURES of a MODERN DISTRIBUTING SYSTEM

An exhaustive study of the modern distributing system as it is now in use would entail a much more comprehensive study than is intended to be covered by this article and the problems that arise are so complex and are possible of so many variations and combinations that it is impossible to cover in any but a general way these problems in the scope of this paper, and in this connection it will be understood that any statements, except the fundamental laws, may fit a particular case and not be generally applicable.

With this in mind it will be sufficient to state that in this paper it is not intended to introduce any thing new into the theoretical considerations involved, but to make free use of existing literature for all theory and to devote the bulk of the matter to the consideration of some of the practical conditions which have come under the personal observation of the writer and to indicate their solution, which may not mean the only possible solution or even the best, but in any event a good and practical solution under the existing conditions. And it may be well to note that these local conditions may and do include national, state and municipal laws; the aesthetic taste of property owners expressed in their reluctance to have a line of poles injected into their outlook or to have some special pet tree cut down or disfigured; and many such things not encountered in the theoretical consideration of the problem. These conditions make the use of such expressions as "in some cases",

"possibly", et cet imperative.

The inspection of a distributing system offers none of the sensational features of the high voltage transmission line with its heavy construction and long distances, regulating features et cet, nor any of the bustle and activity of the main hydro-electric generating station with its water ways and large machines with their regulators, or the immense facilities of the steam plant ,and the observer who spends hours and days studying the operation of a device at the generating station which is intended to cut the cost of production a fraction of a cent per K.W.H. looses interest when shown the hole in the floor or wall where the low voltage cables leave for either the underground or overhead distributing systems. However the fact that this distributing system may represent from 30 to 70% of the total investment makes it a very important item and it is imperative that special attention should be given to the seemingly unimportant details of distribution where any inattentiveness will result in a loss per K.W.H. far greater than what can be saved by the installation of special machines at the power house.

To conform to good practice the distributing system must embody the following essentials;

1. Reliability
2. Efficient operation
3. Good regulation

It is not to be understood that this is the order of importance of these features for it is hard to say that any one is of more importance than the others. In addition these features are to be obtained with a minimum expend-

iture. This necessitates that the engineer who may be laying out a new system or planning extensions to an old system use a great deal of judgement as to which item shall be given the preference in view of the rather uncertain conditions which the future may bring up, and the entire design is a compromise between the relative importance of these details.

Reliability must include the factor of safe construction - both for the general public and for the employee who must work on the lines. In addition the system must be so laid out that the chance of interruption to service in case of trouble will be reduced to a minimum. Some methods of securing this condition will be taken up later.

The efficiency of the system is the ratio of the total energy registered by customers' meters (provided all energy sold is metered) plus that used in the street lighting system to the energy delivered to the bus bar. The losses are divided into several kinds - line loss, transformer loss, converter loss, error and unaccounted for. This latter may be stolen, due to leakage through tree grounds, et cet. These losses are divided into two parts - that part which is fixed, independent of the load,including core loss of transformers, copper loss in the constant current circuits, loss in the shunt coils of meters, friction and windage in converter apparatus, and a variable loss varying as a function of the current including copper loss in constant potential circuits, transformers and converter apparatus.

One of the largest factors in the cost of a distributing system is the cost of conductors and it is important to see that these are of the proper size compatible with an

allowance for growth and good regulation. According to Lord Kelvin the most economical size of conductor is that in which the interest on the investment is equal to the cost of the lost power.

In applying this rule the item of regulation must be borne in mind in selecting a size of conductor, for it is quite possible to comply with Kelvin's law and not have the regulation of the circuit within the limits of good practice. By regulation is meant the variation of voltage above or below a certain point and is usually expressed in per cent of this standard which is usually the nominal rated voltage or the average delivered voltage.

Ordinarily the regulation of a lighting system should be within 5% or 2 1/2% above or below the rated voltage, and is usually kept well within these limits. For power work the limit is usually 10% but may exceed this without giving serious trouble.

Preliminary considerations

1. Selection of voltages
2. Selection of routes
3. Selection of type
    - D.C. or A.C. - frequency
    - Division of circuits for light and power
    - Feeder and main or tree system
4. Design of system
    - Calculations
    - Graphic solution

1. The voltage of the secondary lines is determined by the type of appliances that are to be served and the distributing apparatus (transformers et cet) which are manufactured for this use, e.g;

100 to 120 volts for lamps and small power uses
200 " 240 " " power - medium
400 " 480 " " " - large
500 " 600 " " street railway power and some commercial

Most of the standard voltages on the primary side are derived from the lamp voltages of 50 or 100 volts in the ratio of multiples of 10: 1 increased by 5, 10 or 20 % for various reasons, principally to compensate for line loss. In addition there are voltages on the primary side which arise from the use of a star - delta connection of transformers in a three phase system and are related to the above voltages by the $\sqrt{3}$ used either as a divisor or as a multiplier. The early type of transformers were made in ratios of 1000-2000 / 100-200 volts or 1040-2080 / 52-104-208

but in as much as motors on these circuits did not operate well on account of voltage drop in transformers and secondary leads " power transformers " were introduced with a ratio of 9:1 or 1040-2080 / 115-230 ,but this brought trouble by having transformers of two ratios where lighting and power were taken off of the same secondaries so that the manufacturers soon discontinued the making of two types and standardized on the 10:1 ratio because it allows the higher voltage on the primary side and agrees with the general principles according to which the voltages are standardized.

In direct current work the standard voltages are as given above and owing to their low value the distance from the power house over which the D.C. net work extends is not very great and is usually confined to the crowded business districts of a city except in the case of the 500 volt D.C. for the railway system which is supplemented by feeders,and in the case of interurban or large city system, by transmission as A.C. with suitably located transforming stations.

The most common voltages for primary distribution are;
2000 to 2400 volts for lighting and power
4000 " 5000 } " " large power in rural districts,and
6000 " 7200 } for intermediate distribution
10000 " 15000 " " " " "

2. In the newer cities, where it is probable that the contents of this paper would apply, the streets are laid out along a well defined system in which the blocks are uniform in shape and size and usually rectangular and under these conditions the pole lines should have the following characteristics:

The pole line should be on the same side of the street throughout its entire length and on corresponding sides of parallel streets.

The spacing of poles should be an exact divisor of the length of a block to secure uniformity.

Where a line crosses a street on which there is or may be an intersecting line there should be a pole set on the proper corner to form a junction.

The system should be laid out to ultimately cover every building site with a view also to possible growth and the building of extensions with a minimum of changes in existing lines.

Where the location of the power house is fixed by the price of land or by ordinance or by natural or railroad facilities the trunk lines must be laid out from this point, and if this be a central location there should be a trunk line in each of the four principal directions and they should follow the back streets or alleys where the heavy construction and guying will be most inconspicuous, and so that interruptions due to fire in adjacent buildings will be infrequent and on streets where there are few trees and as few jogs as possible which necessitate guying and a weakening of the line and on streets which lead directly to the center of distribution of the district which they are to serve. Even under the best of conditions due to a good selection of power house site these conditions will have to be compromised to a large extent.

The pole line performs two functions - that of carrying feeders from the power house to the centers of distribution and of carrying the mains fed by these feeders to the

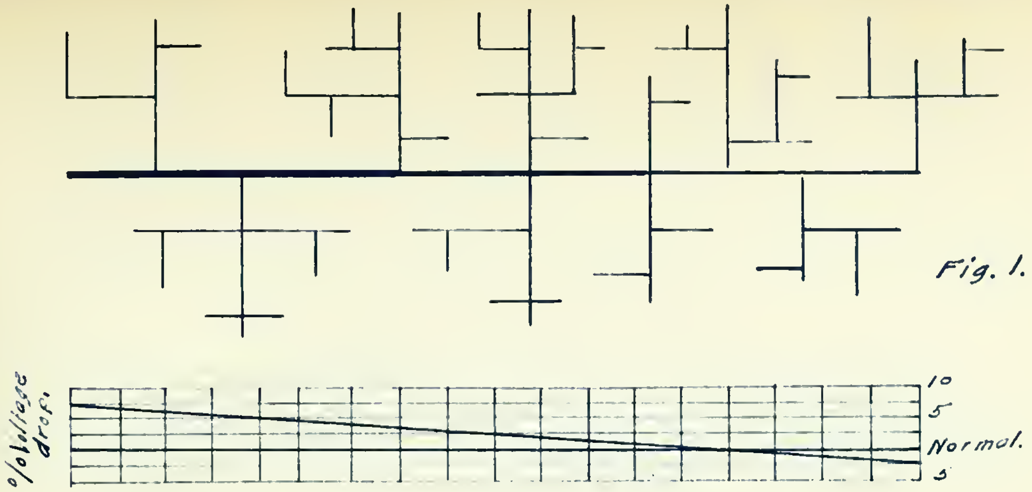


Fig. 1.

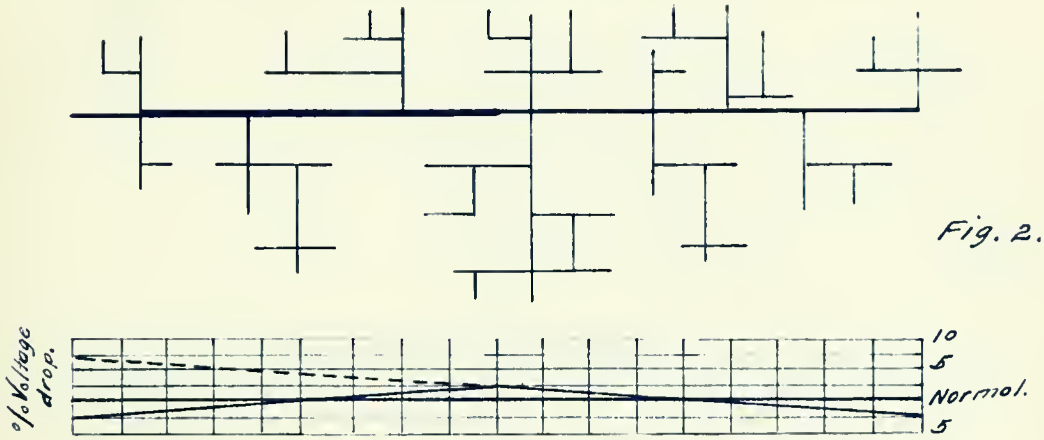


Fig. 2.

Diagram of Feeder and Tree Systems
Showing Voltage Drop.

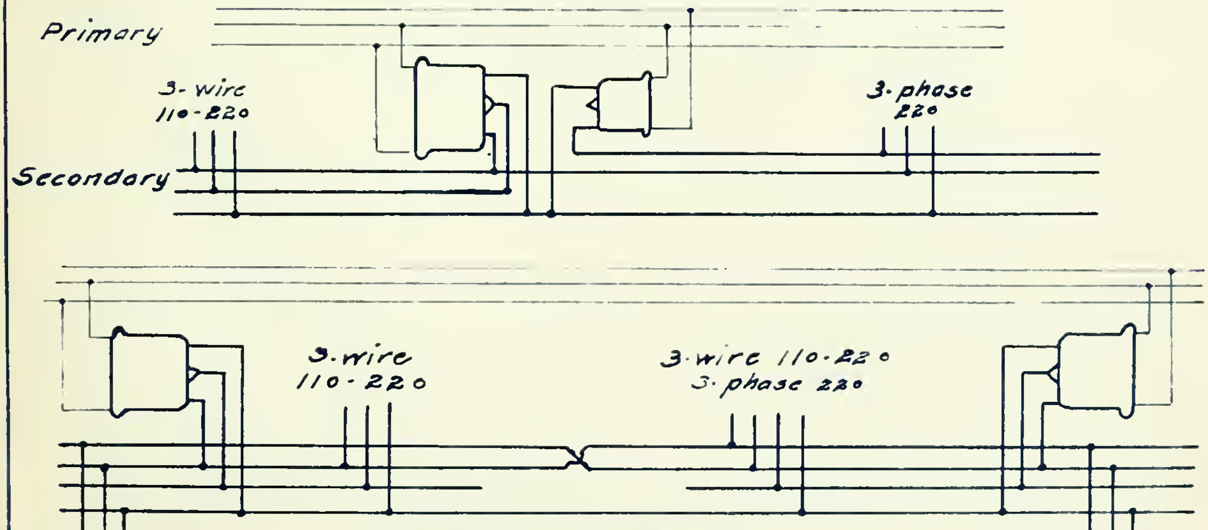


Diagram showing
various transformer connections
giving Edison 3-wire and 3-phase open Δ

Fig. 3.

points adjacent to where the power is to be used, thence by service wires to the building or power site.

The feeders may be arranged in what is known as the "tree system" or in the "feeder and main" system. In the former (Fig. 1) a tapered conductor may be used and run through the district to be served, taps being taken off where necessary. In the latter (Fig. 2) a feeder is run to the to the center of distribution of the district to be served and from this point mains are branched out to reach the customer.

3. For certain purposes, mainly those using the electric current for heating purposes such as cooking, heating, lighting of carbon and tungsten lamps, either A.C. or D.C. current may be used. For other purposes such as charging storage batteries and electro-plating D.C. current is essential - for operating arc lamps and tantalum lamps it is preferrable and for some other classes of work such as Nernst lamps the A.C. current is better. For motive power in certain classes of work, notably where variable speed is necessary, D.C. current is advisable and where constant speed motors are the rule A.C. is desirable. These fields overlap to such an extent that it is usual in the larger cities to find both and it is usual to find all the power originally generated as A.C. and the part necessary as D.C. is converted to this form at a point near its application.

For the usual type of load consisting of both lighting and motors in a medium or sparsely settled district it is customary to use A.C. and services may be taken from the same set of secondaries which are supplied from a single primary main because the motor load is apt to come at a

time when it will not interfere with the lighting load. Under conditions where the loads over-lap it may be advisable to supply power and light from separate secondary mains and where the conditions are severe to separate them on the primary side as well. See sketch of transformer connections Fig. 3

As mentioned before the D.C. is confined to the close in sections on account of the low voltages involved, and hence it is usually carried underground because of the congestion of poles in a business district should it be overhead. It lends itself well to this type of construction since it can be carried in single conductor cables of a size that can be conveniently pulled into the ducts.

The most expensive part of the A.C. underground system is the getting the current from the mains to the customers' premises which includes the secondary mains, transformers, services and man holes. This leads to a type of construction known as the composite type where the primary feeders are run under ground through the streets and taken up a pole in the rear of buildings and from here the consumers in this particular block are served. A main is taken up in each block under this system and the secondaries extend only a span or two in each block. The objection to this is the fact that in nearly every case where poles are set on private property in the rear of buildings they are not permanent but are subject to the changing plans of owners of the property and in thickly built up blocks there is a mass of over head wires and services that constitute a fire menace and the construction is mostly used as the inter-

mediate step between underground and over head distribution.

The various systems of distribution are as follows:

D.C. The simplest form is the two wire system, in which all devices are connected in multiple across the leads and is used for light and power from isolated plants, and for 500 volt power, commercial and railway.

The Edison 3-wire system (Fig. 4) consists of two two wire systems combining one wire of each system to form the neutral, and is used extensively, with the lighting load connected from neutral to either outside wire, and power connected between the two outside wires. With a balanced load the saving of copper is 62 1/2 % over the use of a two wire system to carry the same load with the same regulation. This is the usual type of under-ground system used, and consists of an inter-connected 3-wire network fed by two wire feeders from the power house and the neutrals all tied together outside the power house. Where there is a great difference in the length of feeders they are sometimes fed from two sets of busses known as the "high bus" and the "low bus" (from the corresponding voltages) which are operated in parallel when the load is light and separated for the heavy load.

A.C. The simplest form of this is the single phase system which is used just as the D.C. system given above. It is usually used in connection with a polyphase system to take care of the lighting and small power, either as a part of the poly-phase system or as a separate system (outside of the power house,- though of course the two systems come from the same generator.) Where the lighting is taken from the poly-phase system it is usually attempted to bal-

ance it over all phases to avoid generator troubles, and where a separate circuit is run from the power house for lighting, the districts are usually divided among the various phases for the same reason.

The two- phase system consists of two single-phase systems set at 180 electrical degrees apart and,distributed on either the 3-wire, 4-wire or 5-wire systems, of which the 4-wire is most extensively used.

The most widely used is the 3-phase system which is a composition of three single-phase currents set 120 electrical degrees apart and may be distributed on a three, four, or six-wire system, of which the 3-wire is the most used.

The six-phase systemis only in use in the power house or sub-station and is never used for distribution.

Only the systems which are standard should be considered and the choice is governed by local conditions. In the case of a new system the problem is bsaed on existing conditions and the probable growth along any particular line.

The frequency should be chosen the same as that of other operating companies in the same neighborhood, to provide for an interchange of power should the occasion require. It is also dependent on the proportion of the total power that is to be used for motors. There are only two frequencies considered standard at present e.g. 25 and 60 cycles; 25 cycles being used for power purposes and 60 cycles for lighting and a system may include both if the load warrants it, either generated separately or generated as 25 cycles and changed by means of frequency changers to 60 cycles for the lighting load, though by far the most general use is of one or the other and not a combination.

4. Calculations of the various items entering into the distributing circuit will be taken up very briefly here - reference being made to "Electric Central Station Distributing Systems"by Gear & Williams: "Electrical Conductors" by Perrine: articles in the Proceedings A.I.E.E. by Rhodes, Stillwell and others over a period of the past five or six years in case more detailed information is required.

If the % power loss = Q

$$Q = 100\,\frac{\text{total power lost in line}}{\text{total power delivered at load end}} \qquad (1)$$

and % voltage drop = D

$$D = 100\,\frac{(\text{voltage at generator end})-(\text{voltage at load end})}{\text{voltage at load end}} \qquad (2)$$

The problem may be either;-

1. With a line of known constants to calculate power loss and voltage drop for a given load or;

2. With a given distance to transmit a given amount of power with a given loss and voltage drop.

In a 2-wire line with load concentrated at the far end in a D.C. circuit:-

Let E = volts between wires at load end

$P = \frac{EI}{1000}$ load in K.W.

$I = \frac{1000\,P}{E}$ load in amperes

l = length of each wire in feet

r = ohms per 1000 ft. of conductor (see wire tables)

$R = \frac{rl}{500}$ resistance of line

Then

$$\text{Loss in K.W.} = p = \frac{RI^2}{1000} = \frac{rlI^2}{500\ 000} = \frac{2rlP^2}{E^2} \qquad (3)$$

$$\text{Loss in volts} = v = RI = \frac{rlI}{500} = \frac{2rlP}{E} \qquad (4)$$

$$\%\ \text{power loss} = Q = \frac{100\ p}{P} = \frac{rlI^2}{5000\ P} = \frac{200\ rlP}{E^2} \qquad (5)$$

$$\%\ \text{voltage loss} = D = \frac{100v}{E} = \frac{rlI}{5E} = \frac{200\ rlP}{E^2} \qquad (6)$$

resistance per 1000 ft. of conductor

$$r = \frac{500v}{lI} = \frac{QE^2}{200\ lP} = \frac{DE^2}{200\ lP} \qquad (7)$$

From any of the relations in (7) the resistance may be obtained and by reference to wire tables the corresponding guage noted. Usually take the next larger wire, though in practice it is not usual to find any thing under #6 B & S used in over head work and not all gauges larger than this are kept in stock, usually only the even numbers 6 - 4 - 2 - 0 - 00 - 0000.

To obtain the weight of wire W in pounds:

Let w = weight of wire per 1000 ft. from wire tables

$$W = \frac{wl}{500} \qquad (8)$$

or

$$W = \frac{KP}{Q}\left(\frac{l}{E}\right)^2 \qquad (9)$$

where values of K are given in the following table:

Material	K	
	E in volts l in feet P in K.W.	E in kilo-volts l in miles P in K.W.
Copper 98% conductivity	13.5	380
Aluminum 61% "	6.5	185

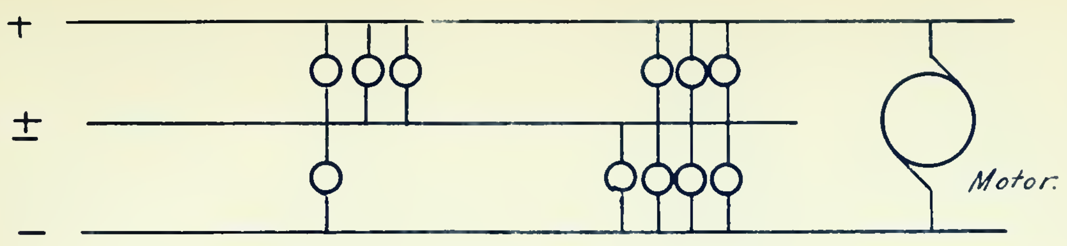


Fig. 4. The Edison three wire system.

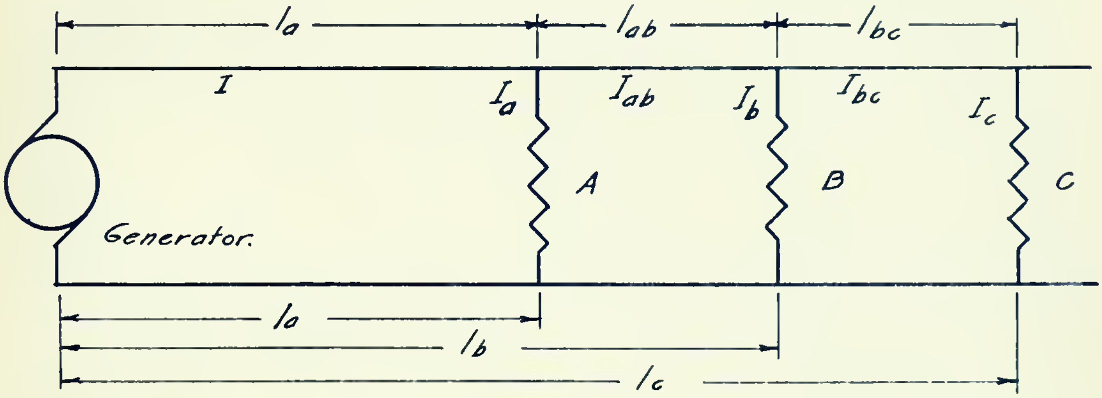


Fig. 5. Diagram of distributed D.C. load.

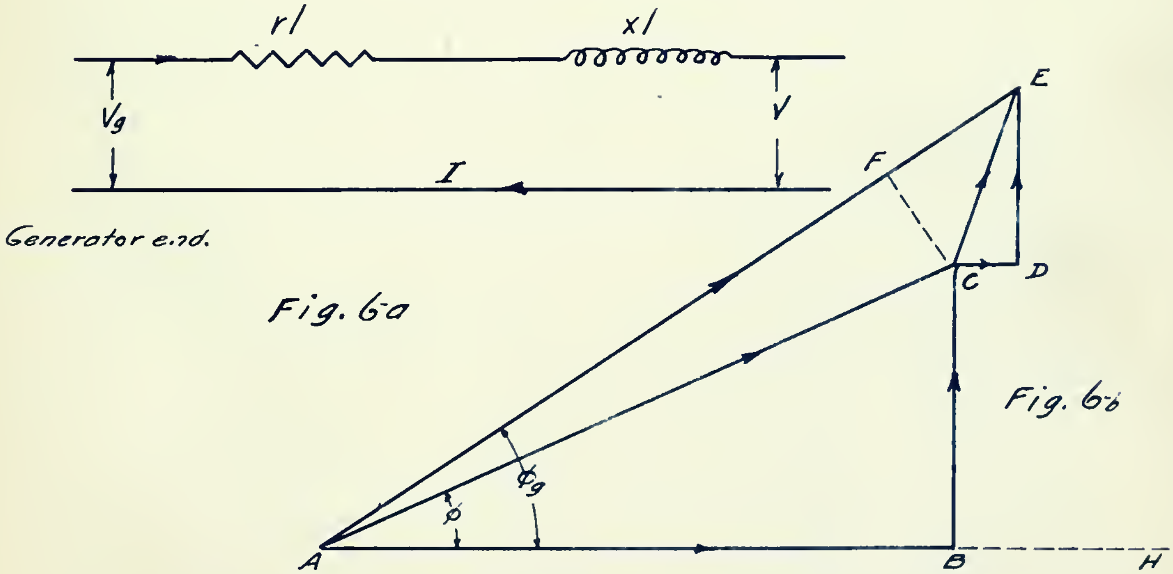


Fig. 6-a

Fig. 6-b

Diagram of circuit containing resistance and inductance with vector relations of current and voltage.

Note: These values are about 5% higher than theoretical to allow for practical working conditions.

These weights apply only to bare wire but corrections can be made from the wire tables for insulated wire, -that insulation for over head work being single, double, and triple braid; referring to the number of layers of braid covering the wire. Above 10 000 volts bare wire is used though at the lower voltages its use is to alleviate rather than prevent arcs due to accidental whipping together of wires. For under-ground work the insulation is usually rubber, paper or cambric with a lead sheath and where necessary to protect against mechanical injury this is covered with a jute wrapping and a steel armor laid over all.

All the above values may be obtained in terms of the generated voltage by noting that if E_g = generator voltage

then $$E = \frac{E_g}{2}\left[1 + \sqrt{1 - \frac{4000\ RP}{E_g^2}}\right] \qquad (10)$$

and applying the value of E so calculated in equations (3) to (9).

Calculation of a D.C. 2-wire line with a distributed load:

When the line supplies a number of power consuming devices at various distances from the generator the voltage loss is the same as that of a line of a length equal to that of the given line from the generator to the center of distribution, assuming both lines of equal cross sectional area for the full distance. The center of distribution is found as follows;

Let A, B, C, et cet be connected loads

and I_a, I_b, I_c, et cet be current respectively

at distances l_a, l_b, l_c, from the generator end and R_a, R_b, R_c, be total line resistances from the generator to the respective loads;

then $I = I_a + I_b + I_c + I_{..} ----$ (11)

and resistance from center of distribution to generator (both wires) is

$$R_g = \frac{R_a I_a + R_b I_b + R_c I_c + ---}{I} \qquad (12)$$

and the distance l_g to the center of distribution from the generator is

$$l_g = \frac{l_a I_a + l_b I_b + l_c I_c + ---}{I} \qquad (13)$$

The voltage loss to the end of the line is then

from (4) $$v = R_g I = \frac{r l_g I}{500} \qquad (14)$$

and loss in K.W. in the line is

$$p = \frac{1}{1000}\left[R_a I_a^2 + R_b I_{ab}^2 + R_c I_{bc}^2 \; --- \right] \qquad (15)$$

where I_a current to load A

and I_{ab} " between load A and B $= I_a + I_b + ----$

or $$p = \frac{r}{500\,000}\left[l_a I_a^2 + l_{ab} I_{ab}^2 + ---- \right] \qquad (15a)$$

where l_a, l_{ab}, l_{ac}, are in feet and r is resistance of line conductor per 1000 ft.

from (7) $$r = \frac{500\ v}{l_g I} \qquad (16)$$

from which the gauge of wire can be found from wire tables.

Under some conditions - notably when the bulk of the load is near the station, it may be advisable to use a tapered conductor then for a given voltage loss in the en-

tire line the minimum weight of conductor is obtained when the volts lost per unit length of coductor in each section of the line is proportional to the square root of the current in this section. Then in the case of the conductor between A and B (Fig. 5)

$$r_{ab} = \frac{1}{\sqrt{I_{ab}}} \times \frac{500\ v}{l_a \sqrt{I} + l_{ab}\sqrt{I_{ab}} + l_{bc}\sqrt{I_{bc}} + ---} \qquad (17)$$

and similarly for each section whence the weight per section from wire tables. The line proportioned from (17) will not have a minimum power loss for the weight of conductor used. For a given total weight of conductor the power loss will be a minimum when the power loss per unit length of conductor in each section is proportional to the current in this section or when the weight per 1000 ft. of line in section A - B is

$$W_{ab} = I_{ab} \times \frac{500\ W}{l_a I_a + l_{ab} I_{ab} + l_{bc} I_{bc} + ---} \qquad (18)$$

and similarly for the other sections

where W = total weight of conductor.

Where the values for sizes of wire differ greatly between (17) and (18) the engineer must compromise, being guided by which of the two considerations is of the most importance - to keep down voltage loss or to keep down power loss.

In calculating size and weight of copper for the 3-wire D.C. line it is assumed that the load is balanced because every effort is made in practice to keep it so by the use of various balancing devices and the formulas given above apply directly where E is the voltage between the outside wires and W becomes the weight of the two outside

wires. The neutral - or middle wire - is usually made the same size as the outside wires to allow for the extreme case of unbalanced load in which case the total weight of copper is 1.5 W. The exact calculation of voltage and power loss in the case of an unbalanced load can be effected by an application of Kirchoff's Law, but is seldom necessary.

A.C. calculations.

Size and weight of conductors.

The preliminary considerations to be noted are:

1. A power loss of 10 % is usually allowed.
2. A line voltage of approximately 1000 volts per mile is good practice, with 2200 volts as the standard for city work - that being low enough for comparative safety and high enough for economical distribution.

At unity power factor, with the above assumptions and copper at 15 cents per lb., the conductors for a three phase line will cost $4.00 and a single phase or 4-wire two phase line will cost $5.33 per K.W. delivered per mile of line.

In as much as this article is not a theoretical consideration of the problems involved, no attempt is made at a great refinement of formulas because the assumptions made in regard to the practical application - load factor, power factor, diversity factor et cet - are subject to such variation that they outweigh the fine corrections made in the formulas. Hence these formulas are based on the assumption that the charging current is negligible in comparison with the load current, which is true except in long transmission lines.

Let E = voltage between wires at load end.

P = total power delivered

$\cos\phi$ = power factor of load expressed in a decimal

l = length of line length of each conductor

Q = power loss in per cent of delivered power

Then the weight of all conductors is:

$$W = \frac{KP}{Q}\left[\frac{l}{E\cos\phi}\right]^2 \text{ in pounds} \qquad (19)$$

where K depends on the number of phases, material of the conductors and the units in which various quantities are expressed and is given below:

Material and units	K single phase or balanced 4-wire two phase	 balanced 3-wire 3-phase
Copper 98% conductivity		
E in volts, l in feet, P in K.W.	13.5	10
E in K.V., l in miles, P in K.W.	380	285
Aluminum 61% conductivity		
E in volts, l in feet, P in K.W.	6.5	4.9
E in K.V., l in miles, P in K.W.	185	140

(These values are about 5 % higher than theoretical to allow for working conditions.)

The value of W in (19) does not take into account commercial sizes of wire so that it is necessary to calculate the resistance per unit of length of conductor (r) and from wire tables obtain the commercial size and weight per unit length (w)

$$\text{where} \qquad r = \frac{K_1 Q\left[E\cos\phi\right]^2}{lP} \text{ in ohms} \qquad (20)$$

where K_1 is of value given below and depends on the same factors as K.

then $W = K_2 w l$ in pounds (21)

where K is given below:

		Single phase	Balanced 4-wire 2-phase	Balanced 3-wire 3-phase
in volts, l in feet, P in K.w. in ohms per 1000 ft, " lbs " " "		$K_1 = .005$	$K_1 = .01$	$K_1 = .01$
		$K_2 = .002$	$K_2 = .004$	$K_2 = .003$
in K.V., l in miles, P in K.w. in ohms per mile, " lbs " "		$K_1 = 5$	$K_1 = 10$	$K_1 = 10$
		$K_2 = 2$	$K_2 = 4$	$K_2 = 3$

The current per conductor may be calculated from the following-

$$\text{Single phase} \qquad I = \frac{P}{E \cos\phi}$$

$$\text{2-phase 4-wire} \qquad I = \frac{P}{2E \cos\phi} \qquad (22)$$

$$\text{3-phase 3-wire} \qquad I = \frac{P}{\sqrt{3}\, E \cos\phi}$$

where E is in kilo-volts (K.V.), P is in K.W. (total) and $\cos\phi$ is a fraction.

Calculation of conductors for a given voltage loss.

The voltage loss depends not only on the resistance of the circuit but also on the reactance, and in the case of long lines, upon the capacity; this latter will not be considered.

The most practical method of making these calculations is to assume that the % power loss is equal to the given % voltage loss and obtain the size of conductors from (20), then using this size of wire in formulas given below to calculate the voltage loss and if, after solving it is found that there is a discrepancy, take the next higher - or lower- size of wire, as the case may be, and again solve for voltage loss

The line constants entering into these calculations are:

r = resistance per unit length of conductor
L = inductance " " " " "
C = capacity " " " " "

From the inductance and capacity per unit length (see wire tables) the reactance $x = 2\pi fL$ and the capacity susceptance $b = 2\pi fC$ per unit length of conductor at a frequency f.

The skin effect is negligible for copper conductors up to 1 000 000 c.m. at 25 cycles and up to 450 000 c.m. at 60 c cycles. The corresponding values for aluminum are about 30 % higher. Also the leakage current is negligible in the scope of this article.

The various methods of calculating A.C. lines in the order of their simplicity are;

1. The simple impedance method
2. The single end condenser method
3. The middle condenser or T method
4. The split condenser or π method

In short distributing lines the first method is accurate for all practical purposes and this will be the only method discussed, the others applying to higher voltages and longer lines such as are found in transmission work.

The calculations are based on the assumption of a sine wave in currents and voltages and a balanced load. The voltage value used is that between wires and the neutral, instead of that between conductors, in order that the formulas may have a wider application, applying directly to single phase, 2-phase 4-wire, and to 3-phase 3-wire systems.

Simple impedance method.

In this the capacity of the line is neglected

and the impedance of the line is simply a resistance equal to the total resistance of the line conductor, and a reactance equal to the total inductive reactance of the line conductor.

Fig.(6a) is a diagram of such a line and Fig.(6·b) is the vector diagram of the relations between current and voltage.

$AH = I$ $\qquad BC \quad V \sin\phi$ $\qquad CE = zlI$

$AC = V$ $\qquad CD = rlI$ $\qquad AE = V_g$

$AB = V \cos\phi$ $\qquad DE = xlI$ $\qquad FE = V_g - V$

Let

V = volts to neutral at no load

= " between wires 2 for single phase line

= " " " 3 " three " "

V_g = " to neutral at generator end of line

I = amperes per wire from (22)

l = length of each conductor in miles

$Z = \dfrac{V}{lI}$ equivalent impedance of the load per mile of line

$\cos\phi$ = power factor at load end

$\sin\phi = \sqrt{1 - \cos^2\phi}$ = reactive factor of the load and is positive for a lagging and negative for a leading current

r = conductor resistance per mile in ohms (from wire tables)

x = " reactance " " " " " "

$z = \sqrt{r^2 + x^2}$ " impedance " " " "

Q = % power loss in terms of delivered power

D = % voltage " " " " " voltage

From Fig.(6·b) it is seen that

$$V_g = \sqrt{(V \cos\phi + rlI)^2 + (V \sin\phi + xlI)^2} \qquad (23)$$

$$= V \sqrt{\left(\cos\phi + \frac{r}{Z}\right)^2 + \left(\sin\phi + \frac{x}{Z}\right)^2} \qquad (24)$$

since the current at load end is the same as at generator end the % power loss is:

$$Q = \frac{100\ rlI}{V\ \cos\phi} = \frac{100\ r}{Z\ \cos\phi} \qquad (25)$$

and the % voltage loss is:

$$D = \frac{100(V_g - V)}{V}$$

$$= 100\left[\sqrt{\left(\cos\phi + \frac{r}{Z}\right)^2 + \left(\sin\phi + \frac{x}{Z}\right)^2}\,\right] \qquad (26)$$

the power factor at generator end is:

$$\cos\phi_g = \frac{100 + Q}{100 + D}\cos\phi \qquad (27)$$

the % impedance drop is:

$$100\ \frac{\sqrt{r^2 + x^2}}{Z} \qquad (28)$$

Care should be taken to differentiate between voltage drop $(V_g - V)$ and the impedance drop (zlI). For a given impedance drop the generator voltage may be any thing from A % greater to A % less than that at the receiving end depending on whether the current be leading or lagging.

A graphical method of obtaining the voltage loss is from a chart devised by Mershon and known as Mershon's Diagram. To use the chart calculate;

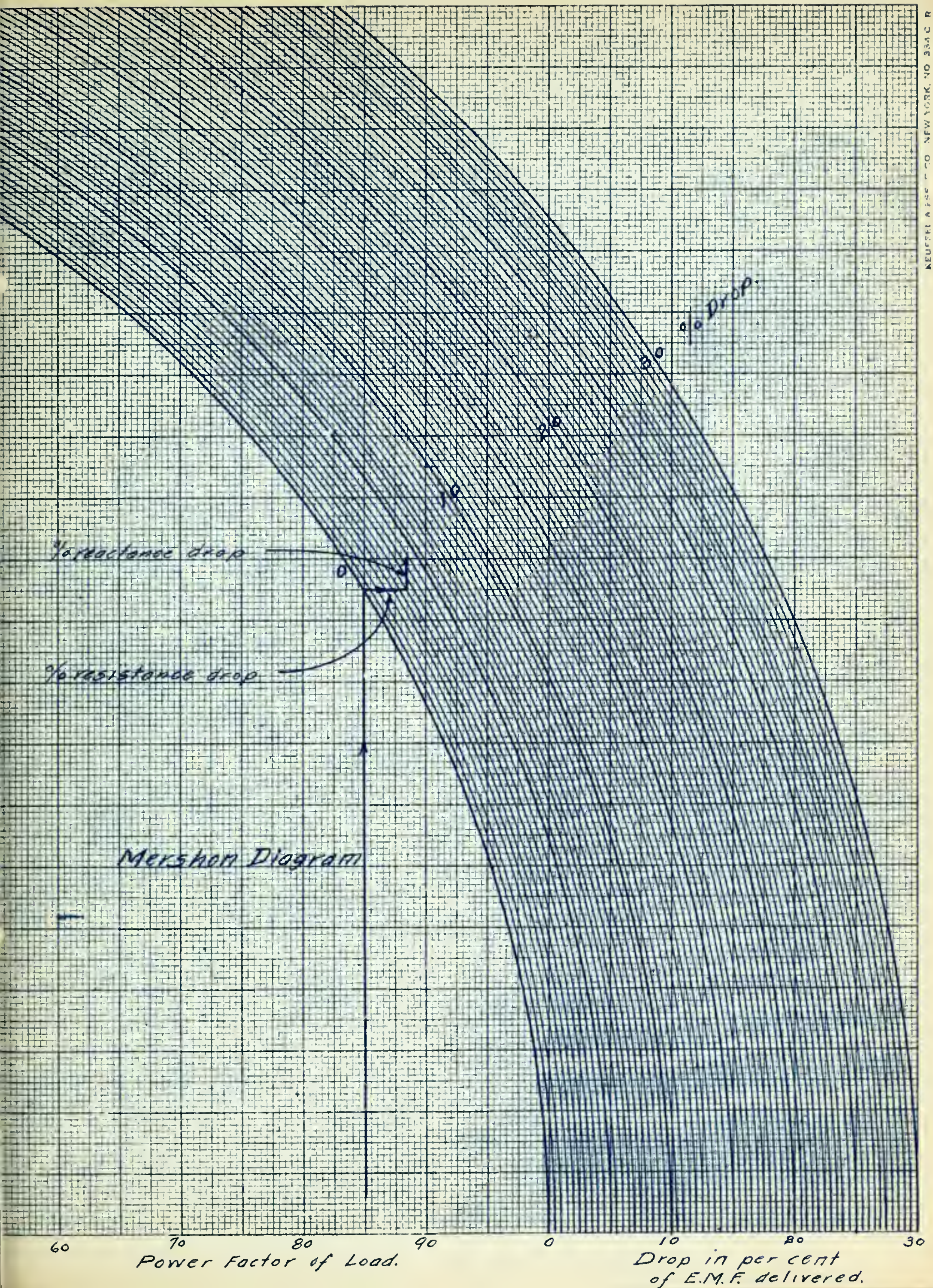
the per cent resistance drop

$$= r\left(\frac{100\ lI}{V}\right) \qquad (29)$$

the per cent reactance drop

$$= x\left(\frac{100\ lI}{V}\right) \qquad (30)$$

and from a point on the curve marked 0 corresponding to the power factor of the load lay off in a horizontal direction



Mershon Diagram

the per cent resistance drop (29) and from the end of this line in a vertical direction lay off the per cent reactance drop (30). The per cent voltage loss is then given by the curve passing through the end of this line.

To express these values in terms of the generated voltage we have:

$$V = A\sqrt{1 \pm \sqrt{1 - \frac{(R^2 + X^2)P^2 \times 10^6}{A^4 \cos^2 \phi}}} \qquad (31)$$

where

$$A = V_g\sqrt{\frac{1}{2} - \frac{1000\,P(R\cos\phi + X\sin\phi)}{V_g^2 \cos\phi}} \qquad (32)$$

and

V_g = volts to neutral at generator end

R = ohms resistance per wire

X = " reactance " "

P = K.W. load " "

= $\frac{1}{2}$ total K.W. delivered in a single phase line

= $\frac{1}{3}$ " " " " " 3 - " "

= $\frac{1}{4}$ " " " " " 2 - " 4-wire line

Practical considerations.

Perhaps the first requisite of a distributing system is that it shall be reliable under all conditions that may arise except those entailed in a wide spread fire or flood. This presupposes good construction which means good material and workmanship in the first place and the following out of some definite plan for extensions to the system already constructed, together with a well balanced scheme as a groundwork. In this connection it is well to bear in mind the tendency of all municipalities toward an elimination of unnecessary poles and it is well for the various companies,- telephone, light and street railroad - operating in any one district to make their plans toward this end before being forced into it at a greater expense. This is accomplished by a system of joint pole ownership where the various companies having lines on the same street, combine their systems on the same pole line e.g., the poles supporting trolley spans being used for supporting street lighting fixtures, and the main or auxilliary feeder of the light company's or the light and telephone companies combine on one lead of poleset cet.

Troubles from the existence of two sets of poles on one street may arise from objections by the property owners to the congestion of poles, and should the two lines be on the same side of the street it is sometimes found that the services taken from the poles of one line may tend to pull them over until the wires of the other company come into contact with a pole, and either burning the pole off if the lines be high voltage or of making trouble if they carry telephone lines.

Routes should be selected that are practicable for all

parties using them and care must be taken to select streets that are free, or nearly so from trees, for all lines carrying primary lines. This tree problem is one of the worst which confronts the operating company and must be handled with tact on account of the property owners who are always beautifying the streets by setting out trees which constitute a continual menace to continuous operation by the electric company.

The arrangement of wires on the pole is governed mainly in the distributing system by mechanical and practical considerations among which are the following:

That the largest wires be on the lowest possible cross arm in order to reduce the bending stress on the pole to a minimum.

That the largest wires be on the pins nearest the pole in order to reduce the bending on the cross arm to a minimum.

That the wires be arranged symmetrically on either side of the pole, especially where they are dead-ended, in order toreduce the twisting stress on the pole to a minimum.

That the highest voltage wires be on the upper cross arms with the lower voltages, the secondary, and the telephone wires arranged down the pole in the order named.

That the arrangement be systematic throughout.

It is customary to allow 1000 volts per mile of line, with the minimum for primary distribution at 2300 volts. (The use of 1100 volts is not now considered good practice and is practically obsolete.) Due to an increase of load on a system and a desire to take care of it without increasing the copper may lead to the standard of 2300 volts growing, by the use of the "Y" connection of transformers, to approximately 4500 volts and then by use of the standard 6600 volt parties being thus all care must be taken to select streets that are free, or nearly so, from trees.for all lines carrying primary lines . This tree problem is one of the worst which confronts the operating company and must be handled with tact on account of the property owners who are always beautifying the streets by setting out trees which constitute a continual menace to continuous operation by the electric company..

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Over-head distribution transformers are usually hung as pole top transformers in one of two ways: either near the top of the pole where the primary leads are short, being connected to the transformer thru fuse boxes or other suitable disconnecting and protecting device, or they may be

hung below the secondary leads where the primary leads are brought down the pole either in conduit or open. This latter method makes for a more accessible installation and is easier to install tho the objection of course lies in bringing the primary leads down the pole which introduces a source of danger to the linemen.

There is a great deal of discussion regarding the relative merits of the use of two single phase transformers connected in open delta and three single phase or one three-phase forming the closed delta. A selection of either scheme is based on local conditions. A comparison of the two schemes is as follows:

The total transformer capacity required for an open delta bank to carry a given load is 15% greater than for a closed delta. This total capacity is in two units instead o of three - or its equivalent , one three-phase transformer.

The voltage drop in the open delta bank is unsymmetrical which causes a slight unbalance in the three full load voltages, which is however negligible in most cases.

When one transformer in the closed delta bank is injured the two remaining will carry 58 % of the load with the same heating but with slightly poorer regulation on two phases. Should the closed delta be in one unit, that circuit is at once shut down.

When transformers are chosen for a given load the above objections to the open delta bank partially disappear on account of the larger units used. In addition transformers of different sizes may be used on a mixed power and light load -- one to carry the lighting and in open delta with the other , the power load.

In efficiency and weight the open delta bank is on a par

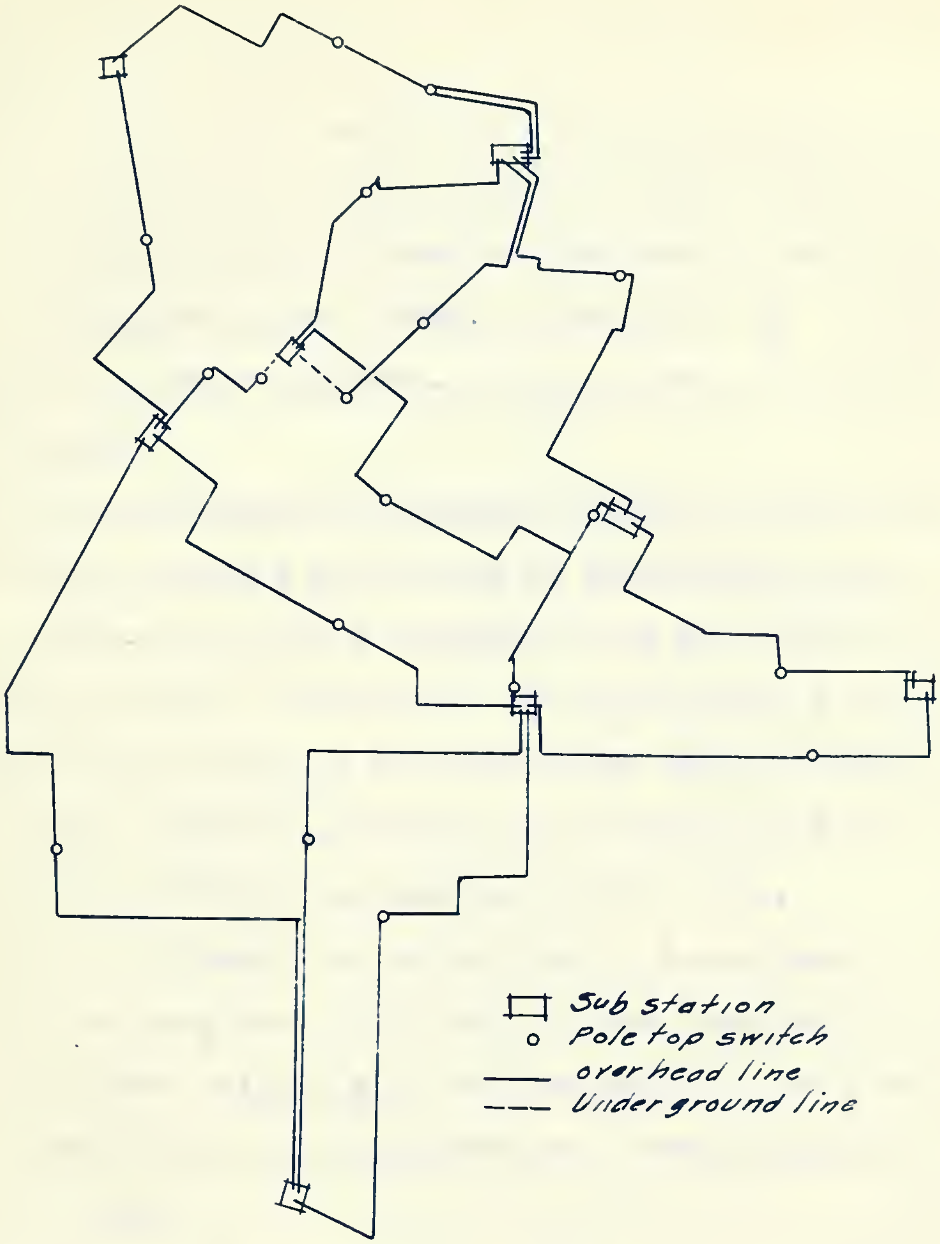

Fig. 7.

Diagram showing a particular case of the arrangement of feeder circuits.

with the closed delta,. while in cost it shows a slight advantage over three transformers in closed delta but is inferior on both counts to the single three phase transformer..

The open delta is made up of two units and hangs on the pole better than three,though not so readily or cheaply as one three phase transformer..

The tendency is that the use of three phase transformers will become more general and ultimately gain the popularity they enjoy in European practice - tho at present there are so many minor advantages to be claimed for each that any one of them may become the ruling factor in a given case and throw the decision..

Assuming then that the lines have been constructed in a sturdy and safe manner we can take up the arrangement of circuits to best accomplish the result of continuous operation.. A method in general use is to so arrange circuits between substations that with the operation of a tie switch located approximately midway between stations the lines which ordinarily are used as main feeder circuits are used to tie the two districts together and any station may be cut out to allow for changes in transformers or wiring or to make repairs in case of trouble.. (See Fig.. (1) for such a system..) The high voltage lines supplying the stations should be brought in over separate routes in so far as possible to minimize the danger of a general shut down from trouble on any one of them.. For the tie switches used on these circuits a 2200 volt three pole oil break switch may be used and on the 10,000 or 15,000 volt lines a type of switch similar to the Baum #413 may be used which is an air break switch, either disconnecting or fused with the three poles operated by a lever extending

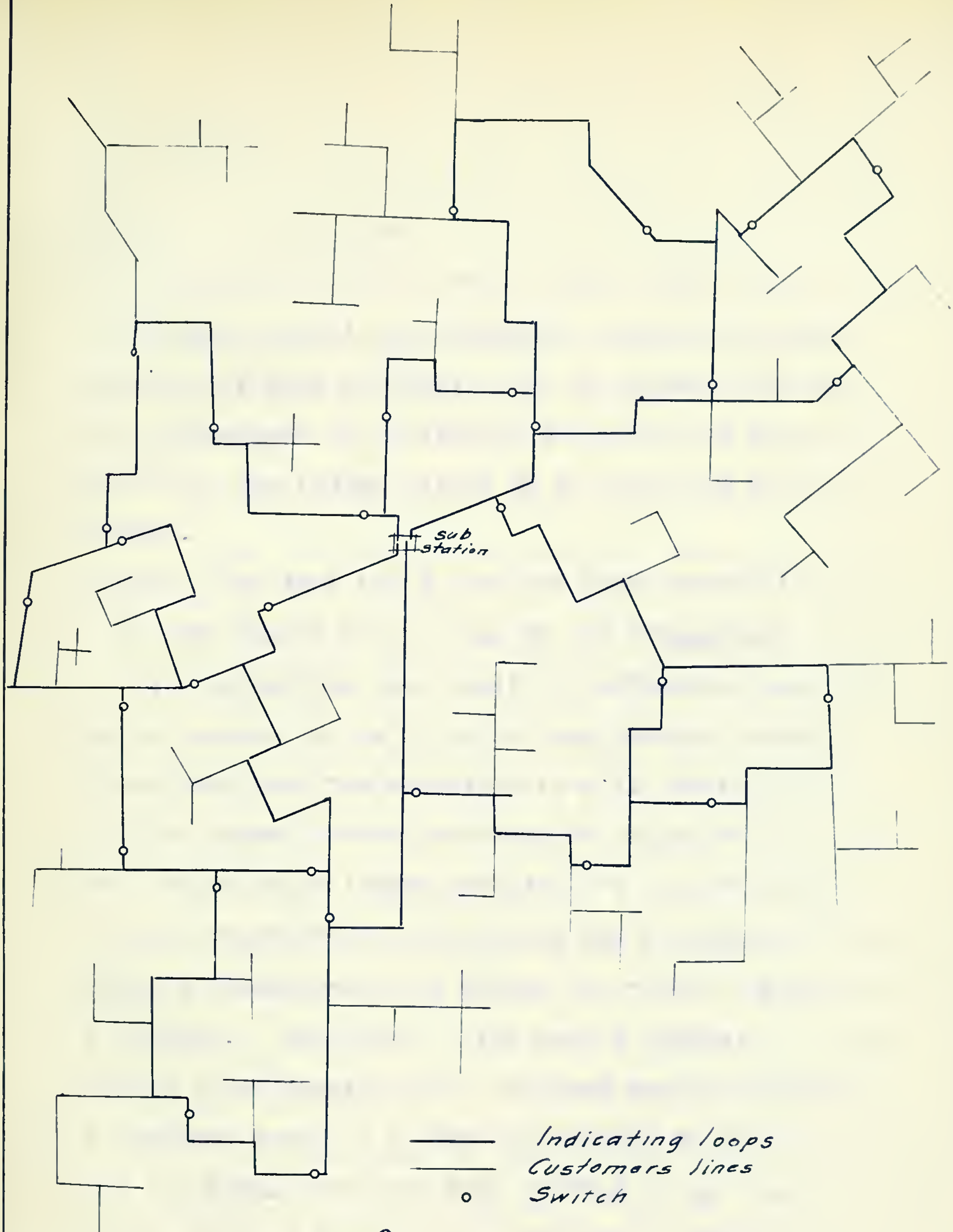

Fig. 8.

Sketch showing arrangement of Loop System for Feeders.

down the pole which may be locked in either open or closed position.

In cases where there is but one supply station - sub-station or generating plant - in the district, this scheme is applied to the feeder circuits and tie points are arranged so that sections of the feeder may be cut out in case of need or emergency. Fig. 8.

Due to the usual system of Y-delta connected transformers trouble may ~~ar~~rise when paralleling feeders from the so called "right and left connection" on the Y side which produces a reversed polarity in the delta which will not parallel. See Fig. (9) It is necessary to phase out and change connections where necessary. This trouble developed in the earlier three phase transformers put out by some of the manufacturers and caused some trouble before being located.

Another precaution found very usefu~~l~~l is a portable sub-station of a convenient size mounted - in the case of a rotary converter station for street railway work - on a flat or box car, or if for lighting or power work on a truck which can be drawn by horses or automobile, and fitted with proper high tension switch, meters, regulator, et. cet. It is well to note that all high tension apparatus is being perfected for use on out door installations so that it is becoming more and more general that buildings for sub-stations are being replaced, particular~~l~~ly for small installations, by out door sub-stations, and it is no t uncommon to see out door installation as large as 50,000 k.v.a. and operating at as high as 150,000 volts.

In the early stages of the electrical industry no partic-ular attention was paid to the regulation of the system but

but of late as the bad effects of poor regulation are being better understood and the public is more critical this is receiving much more attention and it is becoming the aim of an operating company to make "service first" their slogan. Some of the bad effects of poor regulation are, for too high a voltage;

decreased life of electric lamps,
excessive speed of D.C. motors,
excessive field current of A.C. motors resulting in burnouts or over heating.

Some of the bad effects of low voltage are;

decreased efficiency and life of electric lamps,
decreased power out put of motors and a corresponding increase of current, resulting in heating.

These effects of poor regulation are much more noticeable on lighting than on power circuits so that special devices are in use on the former which are omitted on the latter. Where the voltage varies from a higher to a lower levelthan normal these effects are cumulative on lamp service, since when the voltage is high the lamps are blackened and their life shortened and when the voltage drops below normal the lamps appear to be very much further from their normal candle power than before. Part of this is psychological but the effect on the power company is just as bad as tho it were all real. For a variation of 5 % above or below normal the following gives an idea of the effects produced:

Each % decrease in voltage decreases the
candle power of carbon lamps ______________5 %
Decreases torque of induction motors --------------2 %

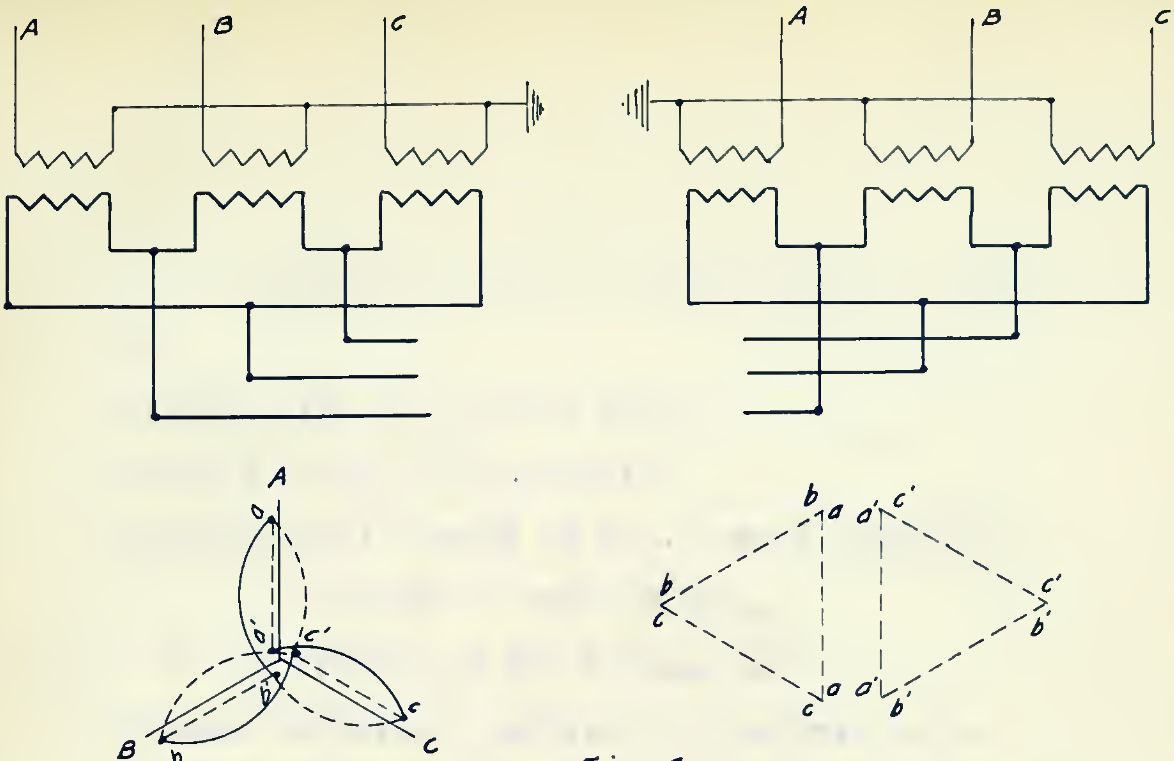

Fig. 9.

Paralleling two banks of transformers Y-Δ connection.

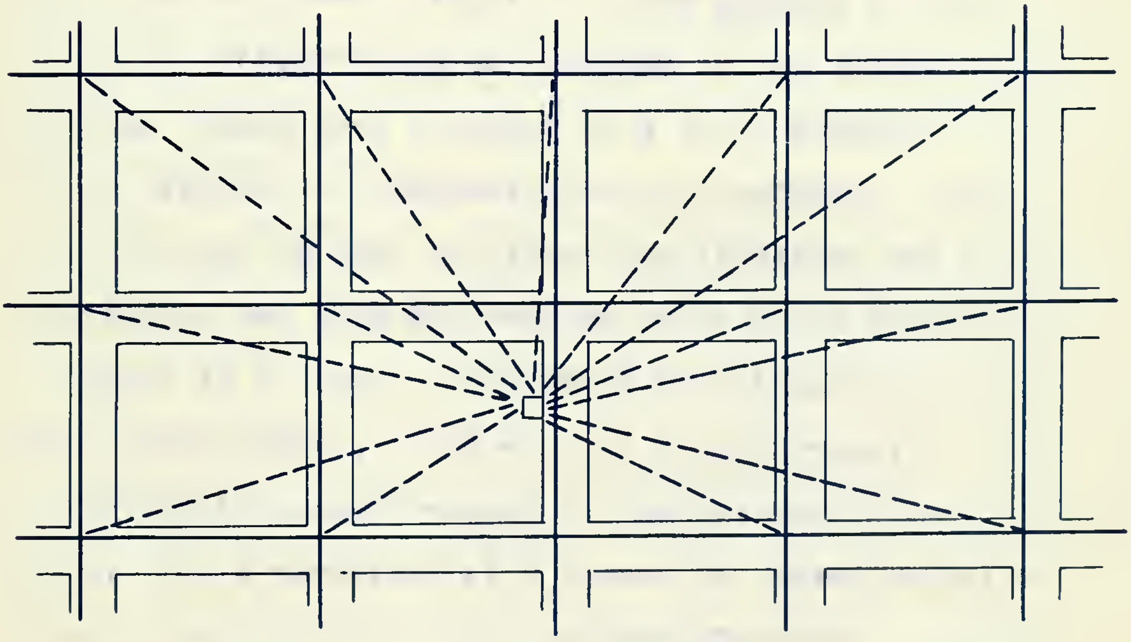

Diagram of Feeder System for an underground net work.

Fig. 10.

Each % increase in voltage decreases the life of carbon lamps 13%

(This is an average. The variation of 5 % giving for the first % a decrease of 18 % and for the fifth 8 %)

Increases the magnetizing current in induction motors------2 %

The first attempts at regulation were made by hand from either the single buss ~~or~~ in connection with the "end cells" on a battery kept floating on the line for D.C. distribution. Then was developed the multiple bus which fed long feeders from the "high" bus and short feeders from the "low" bus, both being operated in parallel for light loads and separated on heavy loads. One system developed a scheme shown in Fig.(10) for their under-ground D.C. system when confronted with the problem of more than two sets of busses, which consists of using a single bus and pulling out or throwing in feeders as the load increases or decreases so as to maintain uniform voltage on the network. Pressure wires are run to the station from each center of distribution so that the operator is at all times in touch with the conditions of voltage at each center.

With the circuits of a system arranged on the tree system Fig.(1) regulation can only be accomplished for the average condition and wide variations will be found on the various branches. With the use however of the feeder system Fig.(2) the voltage can be kept well within any prescribed limitson practically the entire network. On A.C. circuits use is made of the automatic induction type of regulator which serves every requirement of voltage regulation admirably. This is usually a station type of apparatus, tho there is now on the market a pole type A.C. voltage regulator suitable for small single phase circuits that is good. With these

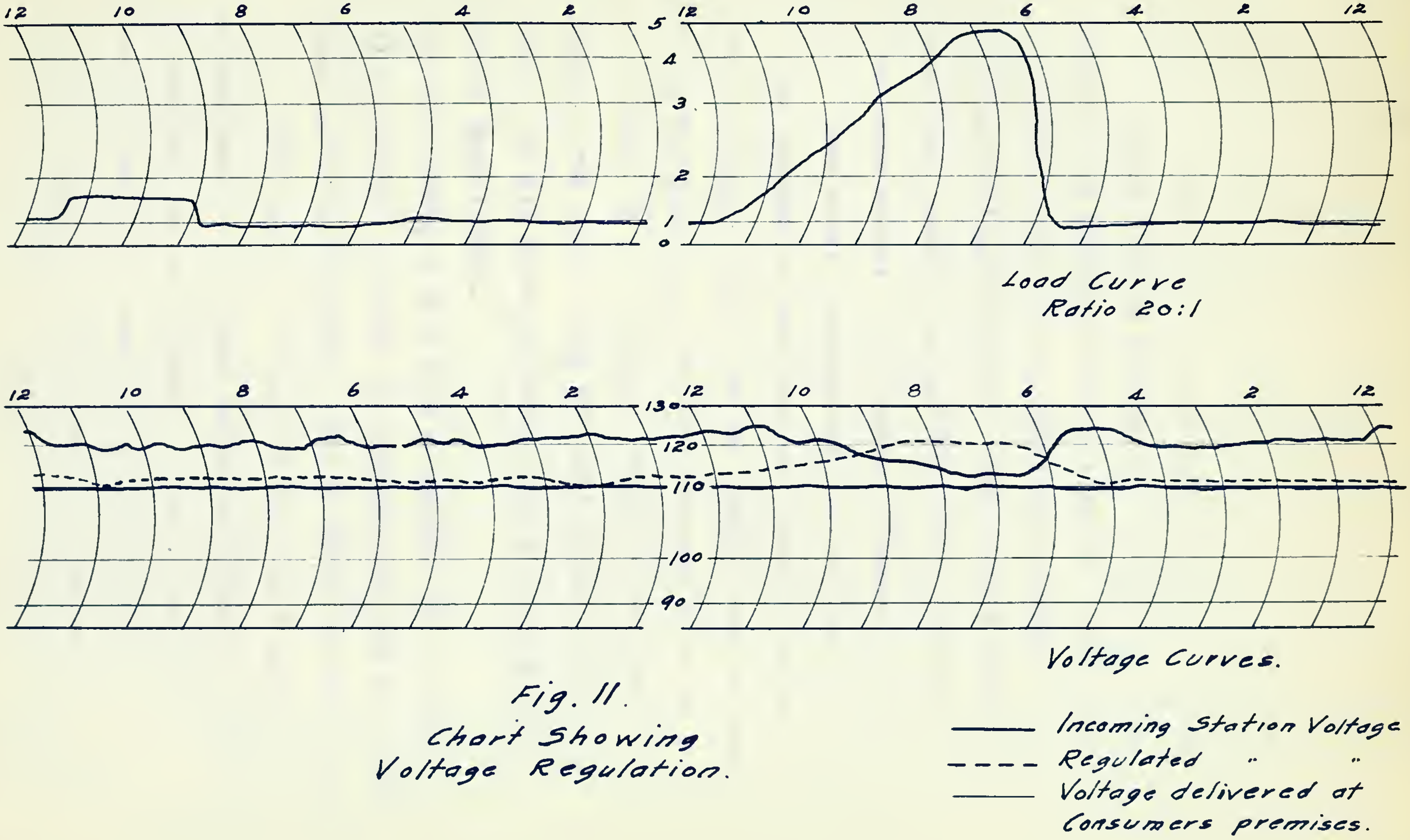

Fig. 11.
Chart Showing
Voltage Regulation.

regulators it is possible to maintain a regulation that is much better than could possibly be obtained by the hand method. See voltage chart Fig.(11). These charts were obtained from the ~~symiltaneous~~ simultaneous readings of recording instruments showing the load in amperes on this feeder, the incoming station voltage, regulated station voltage, and voltage at the consumers premises.

Assuming that these conditions of successful operation have been fulfilled we must take into account the fact that investors will not be attracted to the securities of the company unless the returns seem adequate. This means efficiency in every departmentand it can be obtained in the distributing end the same as in all others by a careful~~l~~ attention to details.

Reference has been made to Kelvin's Law applied to the selection of size of conductor and it may be noted that applying it to the case of the circuit from which the above charts were taken that the loss of power in this case was $124.00 per year and the interest on the investment at 6 % was $150. These items are sufficiently close so that allowing for a reasonable increase in the power to be distributed over this circuit, it complies with the law.

In addition to the copper losses in the line there are the losses in the line transformers and the line losses due to the exciting current of the line transformers. These may be minimized by the careful~~l~~ selection of transformers with regard to the load carried, diversity factor, distribution of the load, and by exercising care in the location and proportion of load carried by each transformer, it be-regulators it is possible to maintain a regulation that is much better than could possibly be obtained by the hand method. See voltage chart fig.( ). These charts were obtained from the symltaneous readings of recording instruments showing the load in amperes on this feeder, the incoming station voltage, regulated station voltage, and voltage at the consumers premises.

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This means that all extensions to a system must be carefully planned and be forwarded under some definite plan which looks to the ultimate betterment of the system ,tho it may appear at the time that the income from a particular extension does not warrant such heavy construction, If it is in the general scheme of betterment that the more expensive type be used, it will be found cheaper than to use the alternative and then later rebuild. It is well to remember that cheap construction at any point on the distributing system where the constant effort is for continuity of service, does not pay - either in the so called "temporary job" which may be left for years before getting back to put in permanently, or in the case that the business to be taken on does not warrant the expense of standard construction. Either do it right or not at all, for either an accident may occur or business may develop on the line so as to make it necessary to strengthen the line and the cost of changes more than equals the interest on the investment saved by the cheaper construction.

Street illumination is a science in itself and deserves more than the brief reference which it is possible to accord it here. It is well to go over the ground and outline the requirements and the most common methods of meeting them.

An idea of the increasing im portance of street lighting may be gathered by noting the greater amount of space given to it in the engineering publications during the past few years as compared to that given it ten years ago.

The determination of the intensity of illumination required and the best method of producing it with a minimum cost forms the fundamental problem of street lighting. The area to be lighted is a long narrow strip with an approximately uniform illumination its full length except at street intersections where a higher intensity is desirable. The cost involves the energy expended, maint~~ai~~enance of lamps, interest and depreciation on the lamps, plant and auxilliary equipment.

The intensity of illumination at any point is proportional to the light intensity of the unit usedand inversely proportional to the square of the distance from the light source - where this may be considered as a point, which is true of the arc lamp or the incandescent as used in street lighting. It is evident that to secure a given illumination the energy to be supplied will vary directly with the separation of the lamps, i.e., if the distance between lamps be doubled, each lamp must have four times the light flux and the energy per unit of length of street will be doubled. If the problem could be solved on the basis of energy alone, it would be advisable to use a maximum number of lamps with a corresponding reduction in their light flux and energy consumption. Increasing the number of light units however increases the in-

stallation and maintenance costs, and a spacing must be selected where the saving of energy is balanced by the cost of the increased number of lamps. A general solution is impossible on account of the numerous variables involved such as difference in intensity requirements, obstacles such as trees which prevent the proper locating and spacing of poles and lamps, energy costs, et/ cet. When considered from the standpoint of economy only, if the cost of energy is low large units spaced at larger intervals are advisable, and if the energy cost is high smaller units more frequently spaced are advisable.

It should be noted that this only applies to the lighting of long narrow areas where the area lighted varies with the distance between units. It does not apply to the illumination of large areas, parks et/ cet. where the lights are placed on the square as the unit, since here the area lighted by each unit varies with the square of the distance between units and the light efficiency is independent of the spacing of the units used.

The requirements for good street illumination may be considered from the following standpoints:-

Uniform intensity distribution; diffusion; intrinsic brilliancy of the lamp used; and shadows.

Experience has shown that good street lighting attracts traffic and stimulates trade which accounts for the more general lighting of the business districts - tho from the standpoint of design the problem is complicated by the lighting effects from the stores and building fronts which are lighted with a view toward decoration. This idea of attracting trade to these districts calls for a higher intensity

than is necessary for the residence or more sparsely settled districts where the need is for sufficient light to clearly reveal persons, vehicles, obstructions, inequalities in the pavement and to allow the reading of addresses and watches. The primary reason for street lighting is safety for the public and illumination that is sufficient for the above purposes is sufficient for protection.

The development of the "white ways" is almost entirely dependent on their value as an advertisement. The average annual cost per front foot of the store frontage for these white ways is about $.90 or $45.00 per year for a 50 foot store front. The displaced system cost from $.10 to $.40 per foot, say an average of $.25 or $12.50 for the 50 foot store front. Assuming that the profits on the business done in this store are 10 % of the total business, the merchant must expect an increase of more than $325.00 in his sales due directly to the increased lighting effects.

From this intense illumination the gradations proceed down thru the stages of separated lights with the attendant multiplicity of types of units from which to choose and the varying degrees of illumination sought,- parks, boulevards, residential districts, wholesale districts et cet. all of which makes the problems each one to be solved by itself and each a problem for a specialist on illuminating engineering. There is no definite system which will apply to different cities or to different streets in any one city.

In the business districts if arcs are to be used they should be hung above the middle of the streetand not less than 25 feet above it. In residential districts the most serious

problem is the trees. For the majority of cases the use of low candle power units along the curb line will give satisfactory illumination. It is necessary to hang the lamps low in order to clear the trees which results in spots and an objectionable glare in the eyes making the darker areas even more pronounced,due to the contraction of the pupil of the eye. If the lamps can be hung near the middle of the street they may be hung higher and still the light will not be obstructed by the trees. A further handicap in parks , boulevards and residential streets is found in the selection of ornamental standardswhich are not always of a design to help in the distribution of the light, and whose cost is too often a large part of the appropriation leaving too little to be expended in getting light.

A consideration of the units from which to select is confined to either arcs or incandescent lamps with a wide range in either type, both as regards the lamp itself but its mounting type of reflector, or diffusing glassware et/ cet.

Arc lamps are divided into the following general classes:

Multiple - 110 and 22o volt D.C. and A.C.
Series - both D.C. and A.C.
Multiple - series.

This latter is for use in such cases as where it is desired to use five or six lamps in series over the 550 volt railway service the lamp being provided with an auxilliary compensating resistance that is cut in automatically if the lamp is put out of service. It is not in extensive use for street lighting.

The multiple lamp for either D.C. or A.C. is available

for industrial plants and local street or yard work, but is unreliable in outdoor installations where a slight film of oxide on the contact clips due to exposure to the weather will render the lamp inoperative because the low 110 voltage will not jump over it. It is built with a resistance in series with the arc to cut down the voltage over the arc to the proper value.

The series arc in both D.C. and A.C. in one of its many forms is better suited to street lighting than either of the former. The D.C. lamp is more efficient than the A.C. lamp but has its disadvantages in that it requires a specialmachine at the plant to energize it - either a D.C. arc generator or mercury arc rectifier outfit - either of which is a source of trouble and operates at a comparitively low efficiency. The use of the constant current regulating transformer to be connected across the constant potential mains of the A.C. station makes possible a much more general use of the A.C. series arc lamp.

The carbon flame arc lamp gives off a yellow light with a high efficiency but due to this yellow light, special expensive carbons which are cored with calcium, and the fact ~~t~~ that quantities of gas are given off when burning, this lamp is restricted in its use and is generally used for advertising purposes.

The metallic flame arc lamp overcomes some of these objections. It gives a white light at an extremely high efficiency and is excellent for street lighting purposes. It operates on D.C. and with a mercury rectifier set is a very desirable solution of the street lighting problem. The outfit

for supplying the D.C. from the constant potential A.C. bus consists of a constant current regulator (which can be wound for any voltage up to 13000 volts) a rectifier bulb and tank, together with a switchboard and instruments, switches et. cet. The regulator is similar to the repulsion automatic regulator in use for constant current A.C. series carbon lamps. The current is rectified between the secondaries of the regulator and the lamps. In the mercury rectifier, it is necessary to maintain the vapor in a conducting condition and to reduce the fluctuations of current in the arc to such an extent that flickering of the light is prevented. This is accomplished by constructing the regulator so that it receives energy from the primary circuit and gives it out during the period of zero value of the current in the primary. In addition then to providing a constant current in the circuit it stores up sufficient energy to maintain a current flow over the zero point of the A.C. wave. The use of a choke coil or other inductance in either lead is thus made unnecessary. The regulator and bulb are enclosed in an iron tank filled with oil which affords good insulation and a more even temperature of each. The efficiency of this outfit at full load is in the neighborhood of 90 % and the power factor on 60 cycle current is about 70 %. The average life of the bulb is 1500 hours.

If it is desired to furnish an arc circuit from the 60 cycle A.C. bus bars the energy consumption for various types of arc lamps at the bus bars - neglecting line losses - will be as follows:-

Assuming the arc machine supplying the 6.6 amp. D.C. open arcs and the 6.6 amp. D.C. enclosed arcs to be driven by an

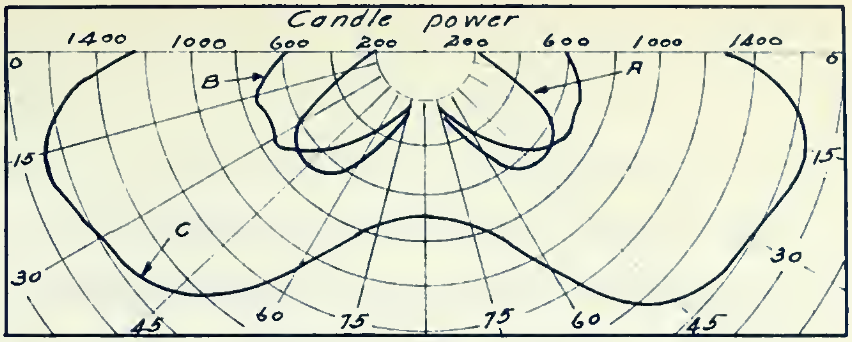

Fig. 12. Light distribution for various arc lamps.
A- Series D.C. 6.6 amp enclosed.
B- Series A.C. 6.6 amp. enclosed.
C- Series D.C. 6.6 amp metallic flame.

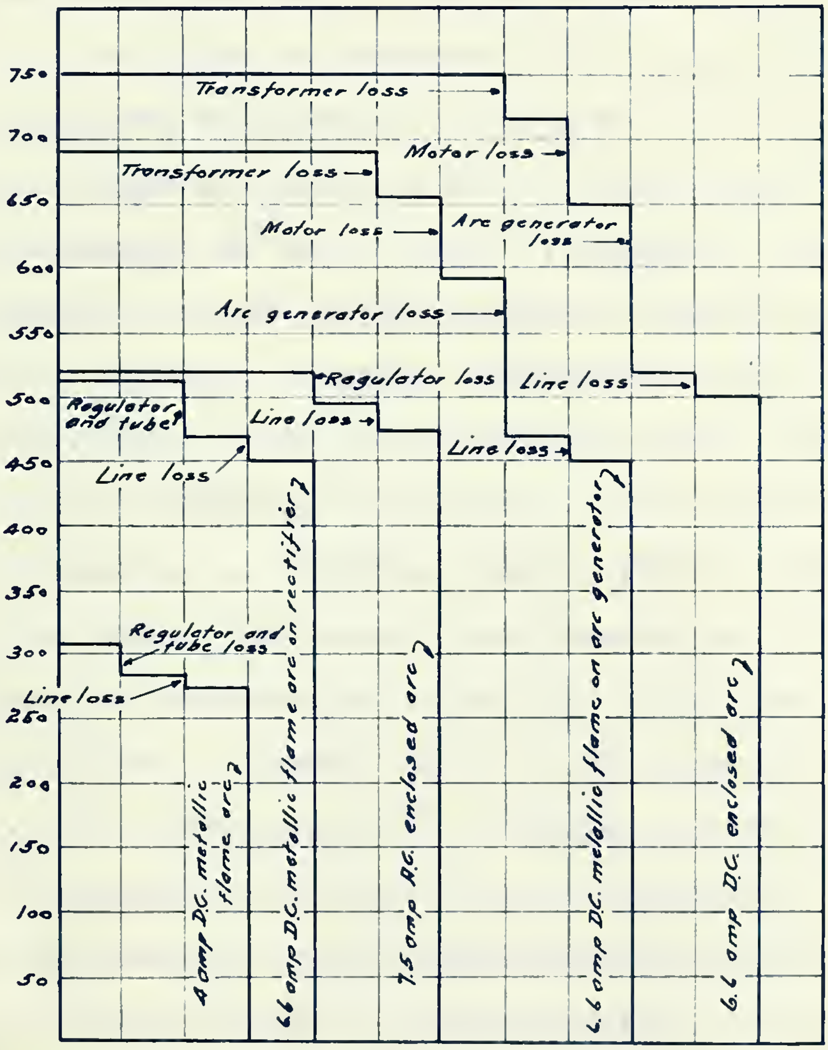

Fig. 13. Analasis of distribution losses for various types of series arc light systems.

induction motor, the efficiency of the set will be 70 %.

The efficiency of an A.C. constant current regulating transformer and mercury rectifier is 90 %.

The energy required at the lamp terminals is;

for the 6.6amp. D.C. open arc ------------ 480 watts
" " 6.6 " " enclosed arc ---------- 480 "
" " 7.5 " A.C. " " ---------- 475 "
" " 4 " D.C. metallic flame arc --- 275 "

and the energy per lamp at the A.C. bus will be;

for the 6.6 amp. D.C. open arc ---------- 685 watts
" " 6.6 " " enclosed " ---------- 685 "
" " 7.5 " A.C. " " ---------- 495 "
" " 4 " D.C. metallic flame arc -- 301 "

If the metallic flame arc is compared to the 7.5 amp. A.C. enclosed arc it will be found that the increased cost of the metallic flame electrodes is offset by their longer life over that of the carbons. The life of a trim of the metalic flame arcs is 165 - 170 hours and can be increased by sacrificing efficiency - depending on the proportion of the light giving materials used in the electrodes.

Other considerations in the problem of street lighting besides the source of light are the light intensity, distribution of light flux, et cet. Fig.(12) gives a comparison of the values of light intensities and their distribution showing a marked superiority in the metallic flame arc thru the useful angle. This remarkable light distribution of the metallic flame arc is only eclipsed by the high efficiency of the entire system. An analysis of the losses in a system employing various types of lamps is given in Fig. (13).

Great improvements in the manufacture of all types of arc lamps together with the care of design of all parts has led to ruggedness and dependability of the mechanical and electrical parts and increased their useful~~l~~ness and application. Special care has been expended in perfecting the ventilation of the type of lamp such as the metallic flame arc where much gas and heat are evolved.

It may be useful~~l~~ to review the units in use in reference to lighting calculations. The unit universally used in expressing light intensity is the candle. From recent researches it has been determined that the mechanical equivalent of white light is approximately .07 watts per candle. Light intensity usually varies in different directions from the source and it is therefore customary to refer to distribution curves similar to fig. (12) and in some cases to the mean spherical candle power. The use of the candle power for expressing the value of the light intensity at any angle characterizes the value of the distribution of the light flux for a particular purpose but does not indicate the total flux from the source. This distribution may be varied in innumerable ways - by var~~y~~iations in the design of the lamp, location of the carbons, type of reflector or globe used, et~~.~~ cet.

Flux density is expressed in lumens and is the flux of light in a beam of one unit solid angle (one square meter at a radius of one meter) in which the intensity is .88 of a standard British candle. The light flux is often expressed in foot candles, as this is a function of the intensity and distance in feet.

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In as much as the result desired in street lighting is a uniform illumination of low intensity the light flux should be distributed in a particular manner. When the height of the lamp and the distance between units is considered, that source of light is preferred which gives the most of the light flux between the horizontal and 25 degrees below. For the sake of economy it is of course desirable to select a lamp whoseinitial distribution of light flux is as near the desired value as possible, thus making it unnecessary to use reflectors.

A correct theoretical arrangement of reflectors does not necessarily mean a satisfactory illumination since the results are judged by the effects produced. It is necessary to so place the lamps that the eye of the observer will not be exposed to their direct rays. It is thus advisable to decrease the brilliancy of the source of light and place it as high as possible but this ordinarily means more frequent spacing of lamps and an additional initial expense, and unfortunately it is often the oase that first cost is of more importance than effective lighting.

A source of light giving best results for street lighting is one producing no light in the upper hemisphere and whose maximum candle power is at an angle of approximately 15 degrees below the horizontal and whose minimum candle power is directly beneath the lamp. Such a distribution makes it possible to hang the lamp high above the direct line of vision, thus eliminating the glare in the eyes of the observer at the street level and at the same time maintain a more nearly uniform illumination. In addition, the lamp being hung high/ shortens the shadows, the illumination directly under the lamp is decreased and eye fatigue elimin-

ated in that it then becomes unnecessary for it to adjust itself to alternate light and dark spots.

In comparing the various types of light sources for street illumination they should be judged by the effective illumination produced at a point midway between adjacent lamps i.e., at a point where the intensity is at its lowest value.

An examination of incandescent lamps available for street lighting shows a marked increase in the number available types with efficiencies that compare with those of arc lamps when maintenance costs are considered. This lamp has progressed thru the stages of carbon filament, specially fired carbon, tantalum, tungsten and nitrogen filled tungsten;- these two latter, due to the refinements in their manufacture and the scientific design of reflectors, have solved many of the problems of street lighting. The tungsten lamp has been improved until it is now given ratings as follows:

110 volt type	25 - 40 watts	131 watts per mean horizontal candle power.
	60 - 150 "	1.18 " " "
	250 - 500 "	1.13 " " "

and the nitrogen filled lamp in the larger sizes is rated at approximately .6 watt per mean horizontal candle power.

Incandescent lamps are used for street lighting on both series and multiple circuits - being in the latter case abaptable to the ornamental type of cluster standard, when they may be fed from the commercial low voltage mains eliminating trouble in having the high tension wires of the series circuit in the metal standards.

The principal defect in street illumination is improper

diffusion of light and the use of units with a high intrinsic brilliancy so placed that they violate the physiological requirements. The introduction of the series tungsten lamp has made available a highly efficient light source which is to a large extent free from these defects. Suitable reflectors are available to deflect the light into the useful~~l~~ angle, thereby increasing the effective candle power and further reducing the cost for a given intensity. Furthermore the tungsten lamp has the proper color value for use with low intensities of illumination, and a large list of sizes is available for use under varying conditions, and by the use of lamps of a moderate candle power equipped with suitable reflectors the lamps may be so spaced and hung at such an angle that there will be no interference with trees and at the same time will not produce a glare even approximating that of the arc lamp.

Incandescent series lamps can be used very successfully in cases where the results to be obtained are to be at a minimum expense, and where the conditions will not permit the use of high candle power units of the arc lamp type.

The requirements of a series system of incandescent lamps is as follows:

An efficient series lamp.

An efficient and reliable device for automatically regulating the current.

An automatic device for cutting out a lamp when the filament breaks.

The recent developments of the series tungsten lamp has provided the first in sizes ranging from 25 to 80 candle power with a life of from 1500 to 2000 hours. They show but little reduction in candle power during normal life and the quality diffusion of light and the use of units with a high intrinsic brilliancy so placed that they violate the physiological requirements. The introduction of the series tungsten lamp has made available a highly efficient light source which is to a large extent free from these defects. Suitable reflectors are available to deflect the light into the usefull angle, thereby increasing the effective candle power and further reducing the cost for a given intensity. Furthermore the tungsten lamp has the proper color value for use with low intensities of illumination, and a large list of sizes is available for use under varying conditions, and by the use of lamps of a moderate candle power equipped with suitable reflectors the lamps may be so spaced and hung at such an angle that there will be no interference with trees and at the same time will not produce a glare even approximating that of the arc lamp.

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There are two systems of series tungsten lighting in general use known as the "adjuster socket" and the "regulator" systems - the choice depending on local conditions and to some extent on the number of lamps installed.

The adjuster socket system consists of a series of lamps connected across the high tension mains with an impedance coil in shunt with each lamp for maintaining the continuity of the circuit if a lamp burns out. The ampere capacity of each lamp in series must be the same and the sum of the voltages of the lamps must be equal to the voltage across the mains to which they are connected.

The regulator system differs from this in that the current in the series of lamps is controlled by a constant current regulating transformer acting automatically. In this system each socket is insulated between the clips with an insulation of such strength that it withstands the pressure due to the normal voltage across the lamp but should the filament burn out the entire voltage of the system would be thrown across these clips and puncture the insulating film. Since the tungsten lamp circuit is practically an ohmic resistance load, the ordinary series arc regulator is not satisfactory as it does not regulate sufficiently close to prevent flickering of the lamps. There has been developed a regulator for use on these circuits of the repulsion coil type which are made very sensitive by the use of two coils suspended in such a way that they just balance each other under normal current conditions. This type will keep the lamp current within one per cent of normal under most conditions.

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The series incandescent lamp does not come into direct competition with the arc lamp - its field being in outlying districts, parks and districts where the tree problem is a serious one. It is replacing to a large extent gas lighting and is found superior to it on nearly all counts.

In conclusion it is well to call attention to the fact that the author is well aware that it is in no sense a complete review of a distributing system but it is hoped that enough has been said to show the interest that this portion of the field should command and that its proper design will call for as high a degree of engineering skill as the plant or transmission system and that its importance in the system entitles it to as much consideration as the other departments.