THE UNIVERSITY OF MISSOURI BULLETIN

ENGINEERING EXPERIMENT STATION SERIES
VOLUME IV NUMBER 1

ECONOMICS OF RURAL DISTRIBUTION OF ELECTRIC POWER

BY

L. E. HILDEBRAND

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PREFACE.

This bulletin is intended to be of interest to three classes of people; farmers, central station managers and engineers concerned with rural distribution of electric power. While all parts may not be clear to all three classes yet it is believed that the bulletin as a whole will be well understood by all if the few technical discussions are assumed to be correct. The entire paper is primarily a discussion of the economic problems of rural distribution rather than a handbook of rural electrical construction and practice.

We have, in the preparation of the manuscript, freely consulted the various technical periodicals and the reports of the various engineering societies. Much valuable information has been obtained from the **Electrical World, The Electrical Review and Western Electrician, The Proceedings of the American Institute of Electrical Engineers** and the **Proceedings of the National Electric Light Association.** Various text books of electrical engineering such as Sheldon, Mason & Hausmann's **Alternating Current Machines,** Franklin & Esty's **Elements of Electrical Engineering,** Steinmetz's **Alternating Current Phenomena,** Foster's **Electrical Engineering Pocket Book;** and the catalogues and bulletins of General Electric Company, Westinghouse Electric & Manufacturing Company, Western Electric Company, American Steel & Wire Company, and Central Electric Company, have been freely used.

We wish to thank Messrs. M. P. Weinbach, E. W. Kellogg and S. M. Hardaway for valuable assistance in correcting the manuscript and for general advice.

LEE E. HILDEBRAND.

University of Missouri,
Columbia, Missouri,
December 18, 1912.

INTRODUCTION.

Within the past few years there has developed a persistent desire in the mind of the American farmer for the conveniences of urban life. Throughout the country we find many instances of the gratification of this desire in the extended use of the comforts which a few years ago were considered luxuries on a farm. The rural mail delivery connects the farm daily with the entire outside world; the telephone keeps the farm continuously in touch with the immediate community while good roads promote both the business interests and the social intercourse of the rural population. The present large use of these and many other conveniences has made rural life more desirable and has lessened the migration of our farmers, and farmers' sons and daughters to the cities. At the present time we find everywhere the idea that city comforts should be brought to the farmer and not the farmer to the city conveniences.

Electricity on the Farm.—Among the various sources of comfort and convenience to be found in large towns and cities is the use of electricity for lighting, household purposes and power. The use of electric power in rural districts can and should be extended largely as it is a direct means of effecting a large saving of both money and time. Farmers realize the necessity of using labor saving devices. This more than any other factor has caused the large increase in the use of gasoline engines on farms. This bulletin is a discussion of a substitute for the gasoline engine which is as cheap if not cheaper than the engine, everything considered. It is not intended to depreciate the usefulness of a gasoline engine as it is indeed almost indispensible in some places, but rather to show a better means of obtaining mechanical power.

There is no doubt but that wherever possible it is generally preferable to employ power to do a certain task rather than to use manual labor. There are few at the present time who deny that electric power is the safest, most convenient and most economical means of doing work, if the electric power is obtainable at a fair price, but obtaining the power is often the stumbling block in the way of using electricity in rural regions. It must be shown that its conveniences and economy are so great that it would be wise, economical and expedient to distribute electricity for lighting and power to the rural districts.

Advantages of Electricity for Lighting.—Except those engaged in the sale of gas or gas-lighting fixtures, few deny that the electric incandescent lamp is the safest and most convenient means of illuminating residences that has yet been discovered. This statement is confirmed by its extensive use in all cities where electric power is obtainable. How many times have you seen advertisements for hotels, apartment houses and residences for rent, which state as an added inducement, "Electric Lights" or "Thoroughly wired for electric light"? The number of large buildings without electric light is extremely small and most of the smaller ones have complete equipments if electricity is obtainable at a reasonable rate.

There are a number of desirable qualities possessed by the electric light which are not to be found with any other illuminant. When a house is wired in accordance with the present standards, the fire risk can be considered as negligible, whereas with any lamp which depends on an open flame for its incandescence and a match for its ignition there is always some danger of fire. The number of fires caused by matches which are not extinguished when thrown away, possibly on a carpeted floor or in a waste basket, is certainly large. The danger of an accident with the ordinary portable kerosene lamp is especially large. Electric light is safest and most convenient since it is only necessary to turn a switch to instantly flood the room with light. The electric light is not dirty and requires extremely little attention. Contrast this with any other known source of light and the relative merits of the different illuminants are easily seen. Since the electric lamp operates in a closed bulb and very little heat is thrown off, it is easy to see that, in winter when the rooms are more or less closed, the ventilation will be much better, and in summer the rooms will be cooler. There are other advantages, too numerous to mention in this paper, which make electric lighting universal where power is obtainable.

Household Use of Electricity.—There are many operations in the daily routine of housekeeping in which a small amount of power conveniently applied would be very advantageous. A small motor can be used to operate the washing machine or the sewing machine, to clean the room by means of a vacuum cleaner, to pump water, to clean and polish the silverware and even to wash the dishes. These tasks and many others which can be easily and expeditiously performed by electric power, are the ones which keep the housekeeper busy from morning until night, whereas, if a small motor is used, some leisure time is afforded for relaxation and the actual labor is made very much lighter. The electric flat iron is in daily use in thousands of homes, making ironing day very much less disagreeable. There are many electric heating and cooking devices on the market which find appreciative users in all parts of the country. A few of these devices are coffee percolators, toasters, chafing dishes, frying pans, ovens, curling irons, water heaters, shaving mugs, small heaters for halls and bathrooms, and glue pots. Some of these would undoubtedly be useful in rural homes.

Farm Motors.—A large motor can be used by the farmer in many operations which now require manual labor or the use of a gasoline engine. Grinding feed, cutting ensilage, pumping water for live stock or for irrigating during drouth, sawing wood, baling hay, threshing and many other tasks of similar nature are easily, quickly and cheaply accomplished by the use of an electric motor.

The farmer will say at once, "Can not all these things be done with a gasoline engine?" They can, but a motor possesses many advantages over the engines usually found on a farm. It is no trouble to start a motor—just close a switch and the machine is in operation. We all know the amount of trouble and exertion required to start a gasoline engine, especially in cold weather. If a motor is used there is no cooling water to attend to or to keep from freezing and no dangerous supply of gasoline is required which will be constantly wasted by evaporation. Ignition troubles are entirely absent. The first cost of a motor is lower than that of a high class engine and the yearly repair bills are very much less. A motor is always ready to give reliable and steady service at any time and at large overloads with high efficiency, whereas an engine must be in first class condition to deliver even its normal full load rating. Less space is required for a motor than for an engine. Insurance is always high on any building containing a gasoline engine while the proper installation of a motor will not affect the rates. A motor continues to give satisfactory, reliable and cheap service, with only a small supply of oil a few times a year long after two engines have been discarded. The popularity of the motor is due particularly to its cheapness but mostly to its ease of application, operation and control.

This comparison is not made to show the faults of the gasoline engine, but rather to show the many good qualities possessed by electric motors. Gasoline engines can not be recommended too highly for farm use where electric service is not available. Any task which an electric motor can perform, can also be done by an engine, but with less convenience, more trouble and, quite often, greater expense. If the advantages of using a gasoline engine on the farm are admitted, it follows that an electric motor would be even more advantageous.

Costs of Farm Operations.—Table 1 gives the cost of performing many farm operations with electric power at various rates. The

TABLE 1

Operation	Remarks
Grinding corn	Large grinder, about 40 bu. per hour
Grinding corn	Small grinder, about 10 bu. per hour
Threshing barley	
Cutting ensilage	6 tons per hr. cut and elevated with blower
Husking	4 bu. per hr.
Grinding feed	one ton per hr. of heavy grains
Shredding fodder	2 tons per hr.
Clover cutting	41 lbs. per hr. finely cut—90 coans
Milking	30 qts. per hr.
Corn sheller	26.5 bu. per hr.
Washing	1/8 hp. motor per washer full
Sawing wood	4 cords per hr.
Pumping water	72 gallons per hr.
Threshing rye, wheat, oats, barley	
Washing	1/4 hp. motor per washer full
Shredding and husking corn.	6 wall 3 header and husker
Vacuum cleaner	per 100 sq. ft. carpet or rug
Horse groom	1 hp. motor
Cream separator	
Butter churn and worker	
Sausage grinder	large
Sausage stuffer	3/8 hp. motor
Beet and turnip cutter	6 tons per hr.
Rolling oats	25 hp. mill
Cracking corn	
Oat crusher	
Milking	

figures are from various sources, most of them being obtained from tests under actual operating conditions, the results of which have been published in the several engineering magazines and reports of the engineering societies. No attempt has been made to substantiate these results except to give them a superficial examination. They are not intended to be used for the calculation of costs with any and all types of machines on the market, but rather to give a fair idea of the cost of doing some farm tasks with electric power.

TABLE 1

Unit	KW hrs.	Cents per Unit at following cost of power in cents per K. W. hour.						
		4	5	6	8	10	15	20
bu.	.4	1.6	2.	2.4	3.2	4.	6.	8.
bu.	.8	3.2	4.	4.8	6.4	8.	12.	16.
bu.	.125	.5	.625	.75	1.	1.25	1.875	2.5
ton	.66	2.64	3.3	3.96	5.28	6.6	9.9	13.2
bu.	.105	.42	.525	.63	.84	1.05	15.75	2.1
100 lbs.	.66	2.64	3.3	3.96	5.28	6.6	9.9	13.2
ton	5.5	22.	27.5	33.	44.	55.	82.5	110.
100 lbs.	.87	3.48	4.35	5.22	6.96	8.7	13.05	17.4
qt.	.004	.016	.02	.024	.032	.04	.06	.08
bu.	.028	.112	.14	.168	.224	.28	.32	.64
.. ..	.023	.092	.115	.138	.184	.23	.345	.46
cord	1.25	5.	6.25	7.5	10.	12.5	18.75	25.
hr.	.5	2.	2.5	3.	4.	5.	7.5	10.
bu.	.22	.88	1.1	1.32	1.76	2.2	3.3	4.4
.. ..	.061	.244	.305	.366	.488	.61	.915	1.22
tons	5.37	21.48	26.85	32.22	42.96	53.7	70.55	107.4
.. ..	.023	.092	.115	.138	.184	.23	.345	.46
horse	.106	.424	.53	.636	.848	1.06	1.59	2.12
100 lbs.	.04	.16	.2	.24	.32	.4	.6	.8
lb.	.0006	.0024	.003	.0036	.0048	.006	.009	.012
100 lbs.	.44	1.76	.22	.264	.342	4.4	6.6	8.8
100 lbs.	.05	.2	.25	.3	.4	.5	.75	1.
ton	.158	.632	.79	.948	1.264	1.58	2.37	3.16
bu.	.06	.24	.3	.36	.48	.6	.9	1.2
bu.	.1	.4	.5	.6	.8	.1	1.5	2.
bu.	.2	.8	1.	1.2	1.6	2.	3.	4.
can	.02	.08	.1	.12	.16	.2	.3	.4

The cost of energy for motor service on most farms will be between 4 and 8 cents per kilowatt hour, so these are the figures which should be taken for comparison in most places. Only the actual cost of energy is considered and all such charges as interest, depreciation, repair and taxes are omitted. This is the basis on which such work is usually compared.

Motors for general farm use are quite often mounted on skids or trucks so that they can be moved from place to place easily. The truck should have mounted on it not only the motor, but also a switch, a fuse for each wire and any starting device which is required. Fig. 1 shows a small motor mounted on skids with its

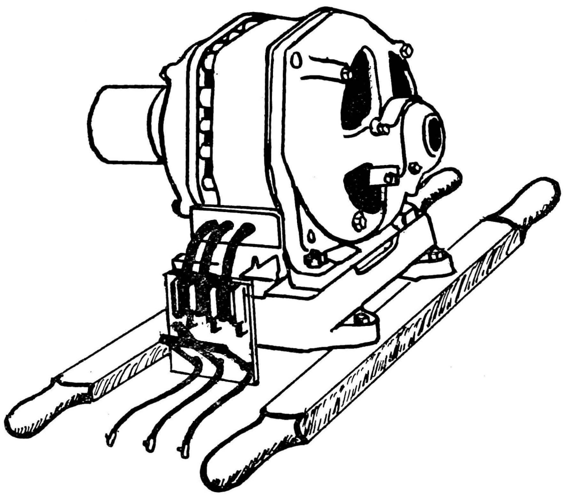


Fig. 1.

fuses and switch on a small upright board. Fig. 2 shows a large motor placed on a truck. If the motor is large enough to require a starting device it can be placed just behind the small switchboard.

Development of Rural Use of Electricity.—Within the past few years we find a remarkable development in the use of electricity in rural districts for both light and power. The progress has proceeded most rapidly in the more thickly settled communities in the states of the Mississippi valley. However, there is a greater aggregate of power used in the arid western states. In the central states, electric power is already used for performing almost every operation of farm life which requires power, while large tracts of land in the western states are made productive by irrigation with electrically driven pumps when otherwise they would be sandy wastes. Ohio, Illinois, Michigan and Indiana have numerous installations of transmission lines serving rural districts. Some western water power plants depend to a large extent for their income upon the power sold to ranchers for irrigation purposes.

The development has proceeded even further in Enropean districts. In Italy and Germany are to be found many interesting installations, the power even being used for tilling the fields very much as we use a steam or gasoline traction engine. A complicated construction is used to deliver electric power to the tractor through a system of cables. The system used is very expensive, but the results obtained more than compensate for the expense, so that the use of electric power is made economical even in the complicated system used for tillage. If this use of electric power has proved economical when we take into account the difficulties and the elaborate apparatus required, how much more would the use of electric power for stationary machines with very simple installations, prove advantageous? Americans have boasted of progressiveness for so long that we are rather inclined to believe that we are first in all things, but here is one matter in which Europeans are far ahead of us. These countries are more densely populated than the United States in the rural districts; this accounts for some of our lack of development. American rural communities are now rapidly improving in this respect and many farms where the work is done by the efficient electric motor are to be found. When the great convenience of the electric power and the service which the motor will give at a cost lower in most cases than that of other kinds of power which are available to farmers are considered, we can predict great progress in the use of electric power on farms during the next few years. All engineering magazines have articles on this subject from time to time, and central station managers are beginning to consider this field seriously as a means of extending their business. In fact there are few power systems in the western states which do not have considerable load consisting of motors connected to pumps for irrigation purposes; and a few derive the major portion of their income from farming communities.

Reasons for Development.—In the early days of electric power the more densely populated districts of large cities were the first markets to be developed, as a greater number of customers could be reached with little capital. As there were plenty of customers to be found in cities, the greater effort was exerted to obtain those from whom the largest profit could be derived with the least investment. Now that nearly all of the people of this class who will ever use electricity are already paying customers, an effort is being made to secure those customers from whom a fair profit can be derived, but who are harder to serve. One class of these customers is composed of factory power users, who are hard to serve because they require reliable and continuous power at a very low rate. Another class consists of those customers who are users of but little energy, and who are far from the central plant.

The remoteness of farmers from stations has kept the development of rural distribution of electric energy in the rear for some time, but now that the possibilities of the large field for extension with prospects of fair returns is realized, more effort is being made to secure these many thousands of customers who were once thought to be entirely outside the zone of practical and economic distribution.

That it is both possible and profitable for central electric stations to extend service to at least some of the farmers can be seen

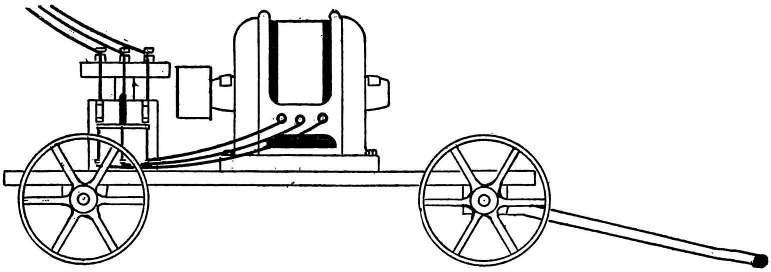


Fig. 2.

by considering the fact that a large number of "off peak" customers can be served from a relatively cheap line with voltages very seldom above 6600. It is the fact that the farmers will furnish a good day motor load which makes them particularly desirable customers.

It should not be hard for the farmer to see the desirability of using electric power when the many advantages and the low cost are considered. The central station man will see the advantages of serving these customers in those cases where the cost of construction of the line can be kept low enough to make the distribution of a small amount of power at a low unit cost profitable to the station. We shall therefore proceed to investigate the distribution of power in farming districts keeping before us at all times the economic side of the question.

Securing Electric Power on Farms.—Electric power can be made available in almost any rural district, but it is not always economical or practical to use electric power, especially in very thinly settled communities, and where each customer uses a very small amount of power. Most cases will need the exercise of considerable judgment to secure the best and most economical installation when more than one type of installation is feasible. In other cases it will require much consideration to determine whether or not an installation of any type is feasible. The various localities, having materially different conditions, necessarily present entirely different problems for solution. The amount of power used, measured in kilowatt hours per year per mile of line, is a factor in the selection of the system. Thus if there are four customers per mile, and each customer uses 2000 kilowatt hours per year there would be 8000 kilowatt hours sold every year for each mile of line. Under these conditions it might be feasible for a central electric power plant to install a distribution system; whereas if the customers are so far apart that only 1000 kilowatt-hours would be sold per year for each mile of line it would be impracticable to install a transmission line. In the case of a few isolated customers each one of whom use a fair amount of power, a separate plant for each farm is necessary.

Thus it appears that there are two sources of electric power for the farmer: first, isolated plants, and second, distribution systems from central electric plants. The former usually consists of a small generator driven by an internal combustion engine, continuity of service being obtained by the use of a storage battery to deliver stored energy when the engine and generator are not in operation. The second source includes distribution lines built from the near by plants, either by the cooperation of the farmers, or by the station itself; distribution lines supplied from high voltage transmission lines; and distribution lines from centrally located power plants for farmers only, such as are found in Germany. Each of these different phases of the problem will be studied separately in different parts of this bulletin.

Isolated Plants.—When a farmer desires electric service and when he is the only one in the community who wishes to use electric power, the isolated plant is the only solution, unless he is able to furnish an extremely large load. In the case of the isolated plant, a gasoline or oil engine is used to drive a small direct current generator which charges a storage battery, the energy for lighting and power being taken from the battery, or the battery and generator combined. Power can be obtained from the battery at all times, while the plant need be operated only occasionally for a few hours at a time. The number of hours that it will be necessary to use the engine and generator will of course depend entirely on the amount of energy that is used, as the battery has only a limited capacity, and must be charged frequently by the generator. This installation is suitable for supplying a small amount of power only, and is best adapted to lighting and household use, although power motors may be used if desired.

Most installations of this character use a one or two horsepower engine, with a one-half or one-kilowatt generator, and a storage battery which will store sufficient energy to light from 10 to 25 tungsten lamps, of 16 candle power each, continuously for 8 hours. If fewer lamps are used the battery charge will last longer. Therefore the average farm house can be lighted from three to seven days without the engine being used. A three horsepower motor can be used about two hours on the larger plant taking its power from the engine and battery together, but the power which can be used continuously is less than that of the engine, in most cases only about one-half, because it is only the stored energy in the battery which makes it possible to use the large motor even for a short time. The small isolated plant is intended to be used only for lighting purposes. There is little advantage in using a gasoline engine to drive a generator which would in turn operate the motor, when the engine itself could be used to drive the machine, obtaining more power for the same expenditure by eliminating the losses in the transmission line and motor. If an isolated plant is to be installed, a portable engine should be purchased so that it can be used for other power work, and the electric power be used for lighting only. There is no doubt that an isolated plant will give satisfactory service if a reasonable amount of attention is given to it, but the cost is liable to be very high for the service rendered. The operating expenses are seldom excessive, but the fixed charges such as interest on the investment and depreciation of the machine make the overall expense high. From the standpoint of cost, an isolated plant compares favorably with the other means of obtaining light on the farm, such as acetylene or gasoline outfits, and about the same amount of attention is required for satisfactory operation. However electric light has several advantages which make it more desirable. No system therefore, can be recommended in preference to the others, but the cost and service rendered by each must be considered in every case.

A Typical Isolated Plant.—As an example of what may be expected from isolated plant installations we give two examples of typical plants. The first plant described is a small one for lighting only, while the second is larger and has some advantages not included in the first. Figure 3 shows the general appearance of the small outfit while figure 4 shows a diagram of electrical connections.

The initial cost of the apparatus is approximately as follows:

Switchboard	$ 65.00
Engine, 1 horsepower	90.00
Generator ½ kilowatt at 50 volts	85.00
Belt, foundation, piping, etc	25.00
Battery 40 ampere hour, 16 cells	85.00
	$350.00

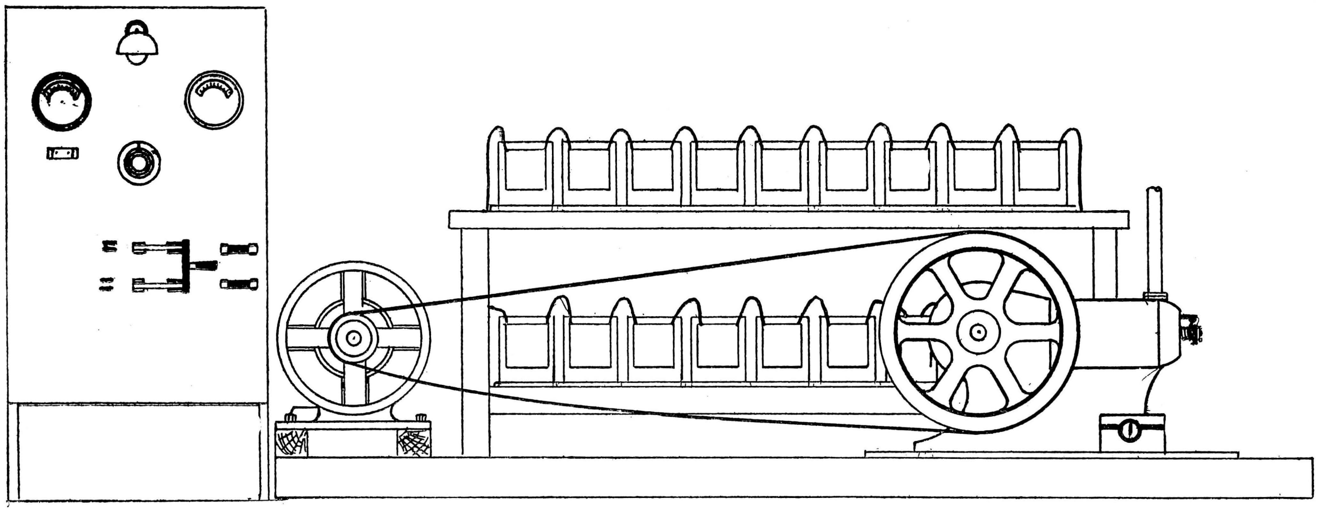


Fig. 3.

The cost of installation has been omitted as the plant can be set up by the farmer himself in his spare time. An expert wireman can make the electrical connections for the plant in a day. The cost of wiring a six room house, including two lamp fixtures in two rooms and pendent lamps in the other rooms and on the porches, with flush switches on the wall to control the lamps will be about $50.00. The total cost of the installation is then $400.00.

If fully charged at the start the battery will supply lamps with energy as shown in Table 2.

TABLE 2.

Hours	Number of 16 C. P tungsten lamps	Number of 16 C. P. carbon filament lamps
3	15	5
4	12	4
6	9	3
8	8	3
10	7	2

A six room house could probably be lighted two or three days without recharging the battery. It takes eight hours to charge the battery, so that the engine need be operated only about 3 hours per day or eight hours every two or three days.

The annual cost of operation is as follows:

Interest, $400 at 6%	$24.00
Depreciation of engine and battery, $175 at 10%	17.50
Depreciation of other equipment, $225 at 5%	11.25
Lamp renewals	5.00
Gasoline, oil and supplies	20.00
Repairs and taxes, $400 at 2%	8.00
	$85.75

The cost of light per month is $7.15. In the above calculations we have assumed that no motors are to be used. It is perhaps unfair to charge all the investment costs of the engine to the lighting installation as the engine can and probably will be used for other purposes. Again the fire insurance on the buildings that have electric lights would probably be reduced so that the cost of light may be reduced on this account. However we do not believe that it is possible to light a country residence with an isolated electric plant for less than $5.00 per month when all the cost factors are considered.

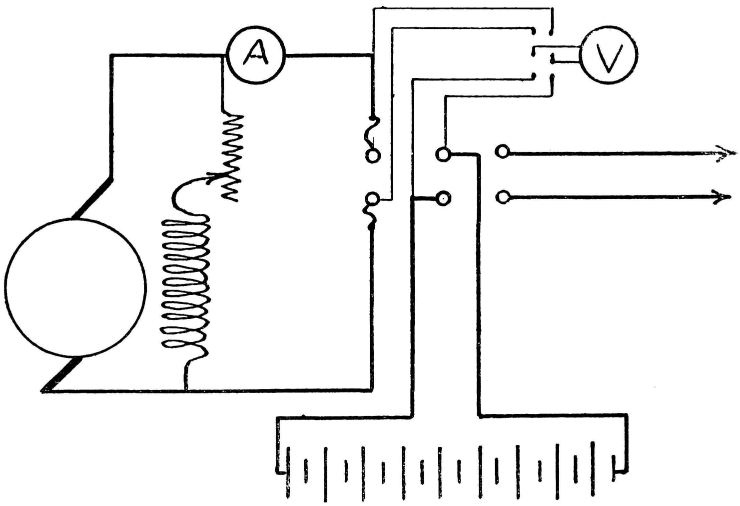


Fig. 4.

A somewhat larger plant with more refinements than the one just considered and some added advantages will now be considered. This plant can be started from the switchboard, without the necessity of "cranking" the engine, by using the battery to operate the dynamo as a motor. The motor turns the engine and with the ignition switch closed an explosion results after a few revolutions. By the use of counter E. M. F. cells, it is possible to charge the battery while power is being used for lighting or to use the combined capacity of the battery and generator to operate a large motor for a short time. Thus it is possible to obtain full 24 hour service and also to carry large loads for a short time if it is desired. The initial cost of the installation is about as follows:

Switchboard	$120.00
Engine, 2 horsepower	150.00
Generator, 1 kilowatt	100.00
Battery	290.00
Belt, foundation, piping, etc	25.00
House and barn wiring	75.00
	$760.00

The battery has the following capacity:

Hours	No. of 16 C. P. Tungsten lamps	No. of 16 C. P. carbon filament lamps	Watts
3	45	16	900
4	37	13	750
6	27	10	550
8	22	8	450
10	19	7	380

If the combined capacity of the battery and generator is used, the output is increased 1000 watts, which is enough to supply 50 16-C. P. tungsten lamps or 18 16-C. P. carbon filament lamps. A two horsepower motor can be used three or four hours before the battery is exhausted, after which all the power will have to come from the generator, and the plant can then supply only about a 1-horsepower motor. It is very evident from this that there is no economy in using the isolated plant for motor service. Driving the generator requires a two-horsepower engine which can just as well be of the portable type so that it can be used for other farm work when not required to charge the battery. This makes the full two-horsepower of the engine available for power instead of only one-half of this amount which the electric motor will deliver.

The annual expenses of the plant just described are:

Interest, $760.00 at 6%	$ 45.60
Depreciation of engine and battery, $440 at 10%	44.00
Depreciation of other equipment, $320 at 5%	16.00
Taxes and repairs, $760 at 2%	13.20
Lamp renewals	10.00
Gasoline, oil and supplies	40.00
	$168.80

Summary—Isolated Plants.—The cost of supplying electric power by an isolated plant is low when only the actual costs of production, or manufacturing costs, are considered, and the interest on the investment, and depreciation of the machines are neglected. This is what most advertisements and catalogues do whenever they show a low cost for lighting country homes by this method.

As a summary we may state that the isolated electric plant is satisfactory from the standpoint of convenience, reliability, safety, low operating expenses and general utility. However the first cost is high and this makes the yearly charge, or fixed cost, higher than that of either gasoline or acetylene lighting outfits. Electric lighting has many advantages over gas lighting, which makes it unfair to figure the relative merits of different systems from economic standpoints only. The added advantages of electric lights somewhat compensate for the higher first cost of the plant, so that the service and merits of all systems should be carefully weighted and balanced against their respective costs.

In all cases where the best system is wanted regardless of cost, the isolated electric light plant is most satisfactory. In many other cases we believe that it will be chosen, not because of its cheapness, but because of its many advantages.

RURAL DISTRIBUTION OF ELECTRIC POWER.

An earlier part of this bulletin shows the advantages and economy of using electric power in rural districts and also that its use has increased in the past few years; a large increase in the next decade is predicted. Inasmuch as isolated plants are unsatisfactory for power purposes and usually are not economical for lighting purposes, means of obtaining electrical energy on farms must often be obtained elsewhere.

The author of this bulletin believes that the solution of the problem of obtaining electric power on the farm lies in the purchase of energy from a central electric station. The only disadvantage of this is the fact that a long transmission line is needed to serve only a few customers. The farmers can either co-operate to build this line past their several homes and connect with a nearby city plant, or preferably they can influence the central station to build the line by a promise of sufficient business to make the enterprise profitable for the station. In the first case, the energy would be purchased and measured at the city limits. The price per unit of energy would be very low as the character of the load makes it desirable for the central station to serve this class of customers. The farmers corporation would pay for line losses, transformer losses, line repairs and all superintendence. They would also pay fixed charges on the investment such as taxes, interest and depreciation, so that the cost of power at their several homes would be considerably higher than at the city plant. If the central station were to build the line, they would have to receive all the above items as well as a fair profit on the investment from the farmers in their monthly bills, but as the larger company could probably install and maintain the system more economically, the cost of power to the farmer would be about the same as if they owned the distribution system. As the yearly cost of energy is about the same in either case, it is of course preferable for the farmers to induce the central station to build the line so that the initial investment will be a minimum.

Rural Distribution from Viewpoint of Power Plants.—From the viewpoint of the central station we may say that rural lines have proven profitable to many central stations in the Mississippi valley. The load is well distributed throughout the day, motors being used during "off peak" periods. The lighting peak, which is usually small, does not exactly coincide with the city lighting peak due to the differences in the habits of the two classes of customers. Because of the fact that rural lines help to increase the load factor, the business is very desirable, while the cost of developing the power will in general be little more than operating expenses as no additional plant equipment is needed. Some companies require the customer to pay part of the cost of the pole line, but this joint ownership of property by customers and utility corporations may lead to future difficulties. The company may require an advance payment equal to all or part of the cost of line construction, this money to be applied on future power bills. The company may require that each farmer build his own branch line from the main distribution line, and furnish his own transformer and meter, or pay rental on the same to the central station. In general, the more the customer furnishes, the lower the unit cost of power must be, while if the equipment paid for by the farmer is excessively large few customers will be secured. If the power plant furnishes everything, the price of power per unit may be so high that there will be difficulty in securing many customers. These two factors must be balanced to suit local conditions.

The first year's business may not, and probably will not, show any profit, but after the advantages are once seen by the farmers a fair income is the natural result. This has been the experience of several small central stations in neighboring states, and also of the large western plants which supply power for irrigation. The entire matter hinges on whether enough power can be sold to take care of the high investment charges. Each power plant operator must judge for himself what his market conditions will be. Later in this paper there are given some examples of typical lines under different load conditions, with costs completely analyzed. From these, some idea of the feasibility of rural distribution can be obtained after the market conditions have been studied.

General Scheme.—Regardless of whether the distribution system is paid for by the farmers, by the station or by both, the general design and construction will be the same. If the line passes through the city, it is necessary to transmit the power to the outskirts of the city at the regular city distributing voltage, which in most cases for small cities is 2200 volts. A special line may be built from the plant or the city mains may be used if they have sufficient capacity to give good regulation on the long rural lines. It is best to use a separate line from the power house, as complete control of the long system is then afforded at the station switchboard, and any trouble on the rural line, which is very susceptible to interference, will not affect the city customers. The disadvantage of this plan lies in its increased cost.

Voltage.—In the case of many systems, distribution may be effected at 2200 volts while in some cases where the load is large, or the distance great, 6600 volts must be used. In the latter case, an outdoor pole type transformer with a simple outdoor oil switch, and high tension fuses must be installed at the city limits, unless permission can be secured to run a 6600 volt line through the city streets, in which case the transformer and protective apparatus may be installed in the plant. It is not desirable to use a higher voltage than 6600 for direct distribution, as transformers are not made in the very small capacities for higher voltages. As each customer must have a separate transformer at his home, many small transformers will be required. If it becomes advisable to use a higher voltage than 6600, it is preferable to make two transformations. Thus the main transmission line voltage will perhaps be 16500. Branch circuits will be extended to several customers at 2200 volts and again transformed to 110 or 220 volts at the farmers' homes. This makes a complicated system, but one that has proven satisfactory to a few central stations which transmit power from their main plant to small towns near by and supply power to farmers located along their transmission lines.

Three Phase vs. Single Phase Systems.—The fact that rural distribution of electrical power can be effected economically and profitably is generally conceded, provided farmers can be induced to make use of motors for the many operations in which power can be advantageously applied, and if no unusual features are necessary in the distribution system.

From the farmer's standpoint, a three phase system is preferable. A single phase motor and one transformer costs more than a three phase motor and a bank of transformers for three phase use. The three phase motor is best adapted to farm use because it is simpler, more rugged and has electrical and mechanical characteristics which make it more suitable to the farmer's particular use.

As the central station's profit depends to a great extent upon the amount of the motor load, and as a large motor load can be best secured by extending satisfactory service at a reasonable cost, it seems highly advisable to gain the good will of the customers by giving them the advantages of the use of three phase motors. Since it is always advisable, and in many cases essential, to secure a large motor load, it follows naturally that a three phase transmission line should be used under all except extreme conditions.

If a small motor load, and a large lighting load can be secured at the time of installation, it may be wise to erect a single phase system at first which will later be changed to three phase when there is a possibility of increasing the motor load. The saving of copper and insulators made by using the one phase instead of the three phase system will be about $60 per mile for very lightly loaded lines, where sufficiently good regulation can be secured with a single phase line using No. 8 or No. 10 copper wire and 2200 volts. In case a large wire or a higher voltage must be used to secure good regulation with a single phase system, it is economical to change to a three phase system. If the cost of power lost is a deciding factor in selecting the size of conductor, then three phases will be most economical, since to transmit the same amount of power with the same line loss the three phase system requires only three-fourths as much copper as the single phase system.

It is thus seen that a three phase system is the most economical to use in all except very lightly loaded lines. As it is very doubtful if lightly loaded rural lines could be profitably installed, it appears that in all cases where a rural line is feasible, three phase systems should be used.

Besides the three wire three phase system, there is another which might be profitably used, namely the three phase four wire system. The primaries of the transformers are delta connected to the 2200 volts 3 phase circuit, while the secondaries are arranged in star and the fourth wire connected to the neutral, which is usually grounded. This gives with three 2200 volt primary 2200 volt secondary transformers a voltage of 2200 volts from any wire to the neutral, or to ground, with 3800 volts between any two outside wires. The copper economy and regulation are almost as good as in a 3800 volt 3 wire 3 phase system, while the voltage strains to ground which have to be met are only those of a 2200 volt circuit. Since the size of the conductors vary inversely as the square of the voltage a large saving in line material can sometimes be made by using this system.

Design of Distribution System.—In the design of a rural distribution system, the engineer is confronted by several economic problems which are different from those encountered in either a city distribution system or in a long distance power transmission line. The load will in general be small and widely distributed and will be subject to large fluctuations. The lighting load will, of course, obey the same general laws that apply in any distribution system, but motors will be used at infrequent intervals, and consequently high peaks may occur at unexpected times, while the average load will be low. These peaks will not affect the station as they will generally occur at times when the plant is lightly loaded. Also they will be far below the capacity of the plant, but they may tax the ability of the distribution system to deliver power with good regulation.

As the average load is small and as absolute continuity of service is not essential a construction of a light character is permitted and even necessary if the central station is to realize a profit. The fixed charges on the cost of the conductors will usually exceed the cost of the line loss. Therefore the smallest conductors that will give good regulation should be used. To keep down investment charges, the first pole line should be constructed as cheaply as is compatible with safety. An interruption in the service of a few hours, while being undesirable is permissible, as farmers do not need absolute continuity of service so much as service itself. The line need not be made more expensive to secure uninterrupted service although in some instances repairs could be greatly reduced by a little better initial installation.

In the long run a cheaply constructed line would probably be more expensive than one of better construction on account of its high maintenance costs. In constructing a line into new territory there is some uncertainty as to the revenue which may be derived, and a possibility that the project may be abandoned entirely after a few years trial. A line of low first cost will minimize the financial loss in such an event.

Once the business is established, however, the line must be regarded as a permanent installation and all permanent installations should be designed to secure the lowest total annual cost, including depreciation and maintenance charges as well as the interest on the initial investment.

Poles.—In general the pole line should resemble that now used for rural telephone lines. A twenty-five or thirty foot wooden pole should be used as it is sufficiently long and much cheaper than longer ones. If twenty-five foot poles set five feet in the ground are used the lowest part of the span will be at least 15 feet from the ground. This is sufficient for any place except road or railroad crossings. At road crossings thirty or thirty-five foot poles should be used and at railroad crossings the poles should be larger and set close to the right of way on each side. Many different kinds of wood are used for poles, such as cedar, pine, chestnut, cypress, redwood, fir, spruce and juniper, but the engineer can easily be guided in his choice by considering the cost. The cheapest pole should be selected for the initial installation, but for later lines, after the system has become a profitable enterprise a pole should be selected for which maintenance and depreciation charges are a minimum. This selection is made by dividing the first cost of the pole by the number of years of life and adding the yearly cost of repair and attendance, such as painting or resetting.

The life of poles, according to various authorities, is given in Table 4.

TABLE 4.

Material	Life in years
Cedar	12 to 20
Pine	6 to 10
Redwood	15 to 20
Fir	15 to 20
Chestnut	12 to 15
Cypress	9 to 10
Juniper	8½
Steel	25
Structural Iron	25
Concrete	Indefinite except for mechanical injury

It has been proven beyond any possibility of doubt that a pole which has been treated with the proper preservative has a much longer life than an untreated pole of the same material. The usual preservative is creosote. This material is introduced into the pores of the wood by several different methods, which may be divided into three general classes, namely: vacuum process, open tank process and painting. The vacuum process requires expensive apparatus and is utilized only by companies using a large number of poles. Poles treated by this method however can be purchased from some companies. The other two methods are directly appliable for use by small companies and farmers. In the open tank process, the butts of the poles are placed in heated preserving materials contained in an open tank of proper size. The cost of treating poles in this manner is low and very good results are obtained. In many cases painting the poles with the proper preservative will greatly lengthen their useful life. It is claimed by some engineers that these two cheaper processes are just as good if not better than the more expensive vacuum process. We are not in a position either to prove or to disprove this statement. Line poles usually decay first at about the level of the ground and this part of the pole at least should be painted since the cost is low and much useful life is added to the pole. Whether the pole should be treated more than this

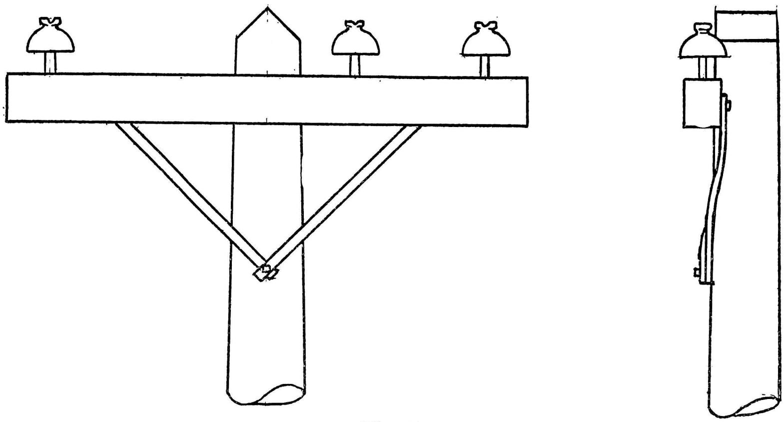


Fig. 5.

depends entirely upon the cost and the added life. If the added life will more than pay for the treating, then the poles should be treated if possible.

Cross Arms.—Cross arms as well as poles are made from several different woods and the same general rules apply in their selection. They need not be treated, but should be rounded on top and well painted. Their life is usually less than that of the pole because they are sawed from large logs and so the grain is exposed to the elements. To secure the cross arm to the pole, a gain is cut in the pole into which the arm is fitted and a bolt is passed through both; or lag screws may be used passing through the arm into the pole. Sometimes iron braces are added to make the cross arm more secure in its position. Cross arms, braces and pins for insulators should be placed in position on the poles before erection. Figure 5 shows pole top construction.

Cross arms on two adjacent poles face in opposite directions.

Insulators.—Insulators are usually made of glass or porcelain, pin type insulators always being used for low voltages. Glass insulators are very much used on low voltage distribution systems for both the secondary and the high tension lines while porcelain is used on all very high tension systems. Glass is cheaper but it is not as strong, or as good an insulator as porcelain. For 2200 volt systems glass insulators will probably be used because of their cheapness. For 6600 or 13200 volts glass or porcelain may be used while for voltages above this porcelain should be used. The difference in cost of line using different kinds of insulators will not be great since all low voltage insulators are comparatively cheap.

The insulators are secured to the cross arms or poles by wooden pins, steel pins, or wooden brackets. On rural lines wooden pins are best for use on cross arms.

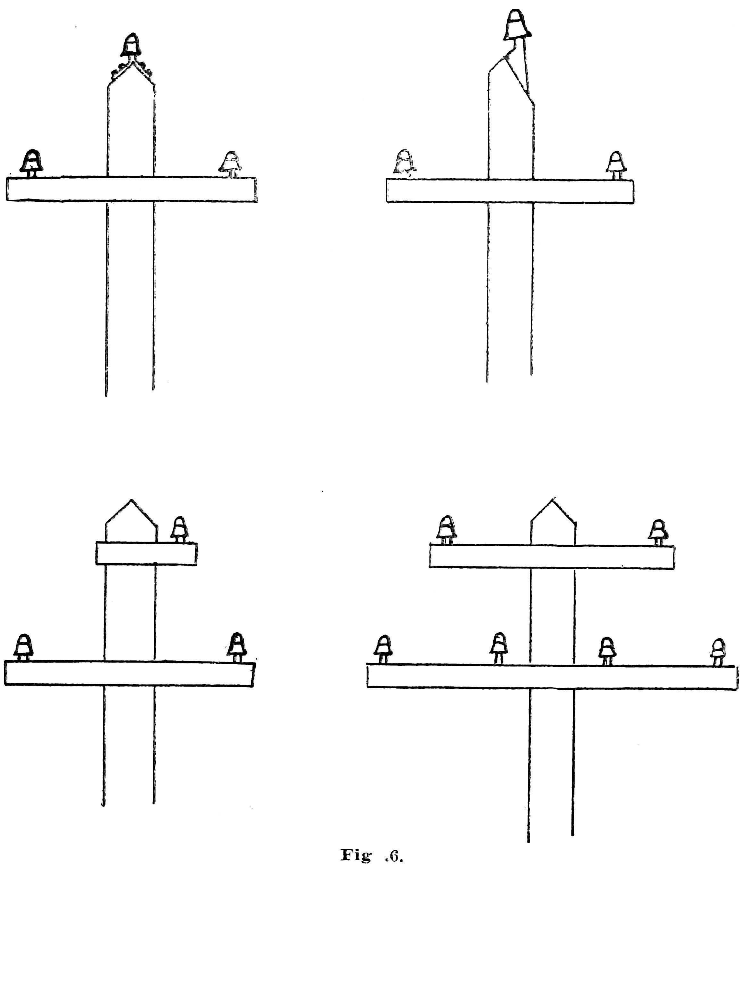


Fig .6.

Arrangement of Conductors.—A single phase system requires but two wires and two insulators per pole which should be placed on the ends of a short cross arm placed near the top of the pole. This arrangement is the same as is shown in figure 5 except that the center insulator is to be omitted.

A three phase system requires three wires and three insulators per pole which may be placed in the form of an equilated triangle or all in one plane as shown in figure 5. The triangular construction is best, several forms of which are shown in figure 6.

If the three conductors are secured in one plane on a long cross arm they should be transposed every mile to keep the voltage the same on all three phases.

If there are telephone lines near the distribution system, the wires should be transposed frequently even with the equilateral triangular arrangement.

Line Conductor Calculations.—The selection of the proper size of conductor, and the proper voltage is a complex and rather difficult problem. There are three factors which must be considered; mechanical strength, voltage regulation and total annual cost. The regulation must be sufficiently good for the service. The cost of supplying all distribution losses, plus the fixed charges on the installation should be a minimum. For some new installations the line losses may be greatly increased to reduce the first cost thus making the sum more than the minimum. But either mechanical strength or voltage regulation is usually the controlling factor in determining the size of conductors, the line losses being a secondary consideration since the cost of supplying them is usually far less than the fixed charges on the equipment.

Assuming sufficiently close regulation for the service expected, we shall proceed on the basis of securing the cheapest installation. The line which is at first selected may be somewhat modified later to reduce distribution losses. There are several factors which affect the regulation of an alternating current distribution system such as size of conductors, kind of system (one phase or three phase), voltage, spacing of conductors, load and power factor. The costs which are varied by changing either the size of conductor or the voltage are: the cost of conductors, insulators, protective devices, switches and transformers. A change in the voltage or size of conductor also affects the line copper loss, the transformer copper loss and the transformer iron loss.

Of these several factors, some can be eliminated by inspection. The load and power factor are fixed by the customers. The use of single phase or three phase system is determined by several factors as discussed on page 21; a three phase system should be used in most cases. The spacing of conductors is determined by the liability of accidental contact. We thus have left only the size of conductors and voltage to be considered in the design of the system.

To secure a given regulation, we may use a small wire and high voltage or a large wire and low voltage. In the former case, the line copper cost is small and the cost of transformers, insulators, switches and protective devices is high. The transformer iron loss is also high. In the latter case these relations are reversed. It is evident that there is a certain size wire and voltage which will give a minimum cost for all the elements concerned.

The most satisfactory method of determining the proper size of the conductors and the proper voltage is by trial. First assume that No. 8 or No. 10 wire is to be used, depending upon the mechanical strength necessary. Then find the standard voltage which will give sufficiently good regulation and compute the costs of all variable elements. Next consider the next lower standard voltage and select the proper conductor for the required regulation, again computing the cost of all variable elements. The distribution losses and the cost of supplying them are also calculated for both installations. After all these are tabulated the proper selection may be made.

The following formulae have been found to be valuable. For a certain conductor (No. 8 or No. 10) the voltage which gives the required regulation is

$$E = a\,b\,c\,\sqrt{D\,P}$$

Where E = Voltage between conductors
D = Distance in thousand feet to the center of distribution
P = Total K. V. A. which may be connected to line at one time

a, b and c are constants

"a" takes into account the kind of system. For

1 phase, $a = \sqrt{2} = 1.414$
3 phase, $a = 1$
2 phase, 3 wire, $a = 1$ (common conductor must be larger than outside conductors)
2 phase, 4 wire, $a = 1$
3 phase, 4 wire, $a = 1$ (where E = voltage between two outside wires)

$$b = \left(\frac{\text{Reg}}{1000\ R}\right)^{1/2}$$

Where **R** = resistance of 1000 ft. of conductor as given in the table below.

Reg = required regulation expressed as a decimal (thus: 3% regulation = .03)

b for different size conductors and different regulations is plotted in the curves on page 30.

c is a constant which takes into account the reactance of the line and the power factor of the load. In other words it is a constant to change the regulation which would be obtained in a direct current system to the regulation which is obtained with an alternating current system. For 100% power factor **c** is always unity and for most rural lines at any expected power factor is sufficiently accurate if assumed equal to unity. The exact value of **c** is found from the curve on page 32 as explained later.

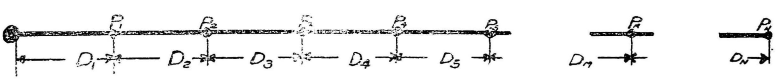
D = distance in 1000 of feet to the center of distribution of the system

$$D = [(P_1+P_2+P_3+P_4+ \ldots +P_n)D_1 + (P_2+P_3+P_4+ \ldots +P_n)D_2 + (P_3+P_4+ \ldots P_n)D_3 + (P_4+ \ldots +P_n)D_4 + \ldots + (P_m+ \ldots +P_n)D_m + P_nD_n] \div [P_1+P_2+P_3+P_4 + \ldots +P_n]$$

Where P_1, P_2, P_3, P_4, ... P_m, ... P_n are the connected loads of individual customers in KVA, and D_1, D_2, D_3, D_4, ... D_m, ... D_n, are the distances between them in thousands of feet.

The proper size of conductors for a certain voltage and a required regulation, may be determined by the use of the following formula:

$$R = \frac{1}{a^2 c^2} \cdot \frac{E^2\,Reg}{1000\,DP}$$



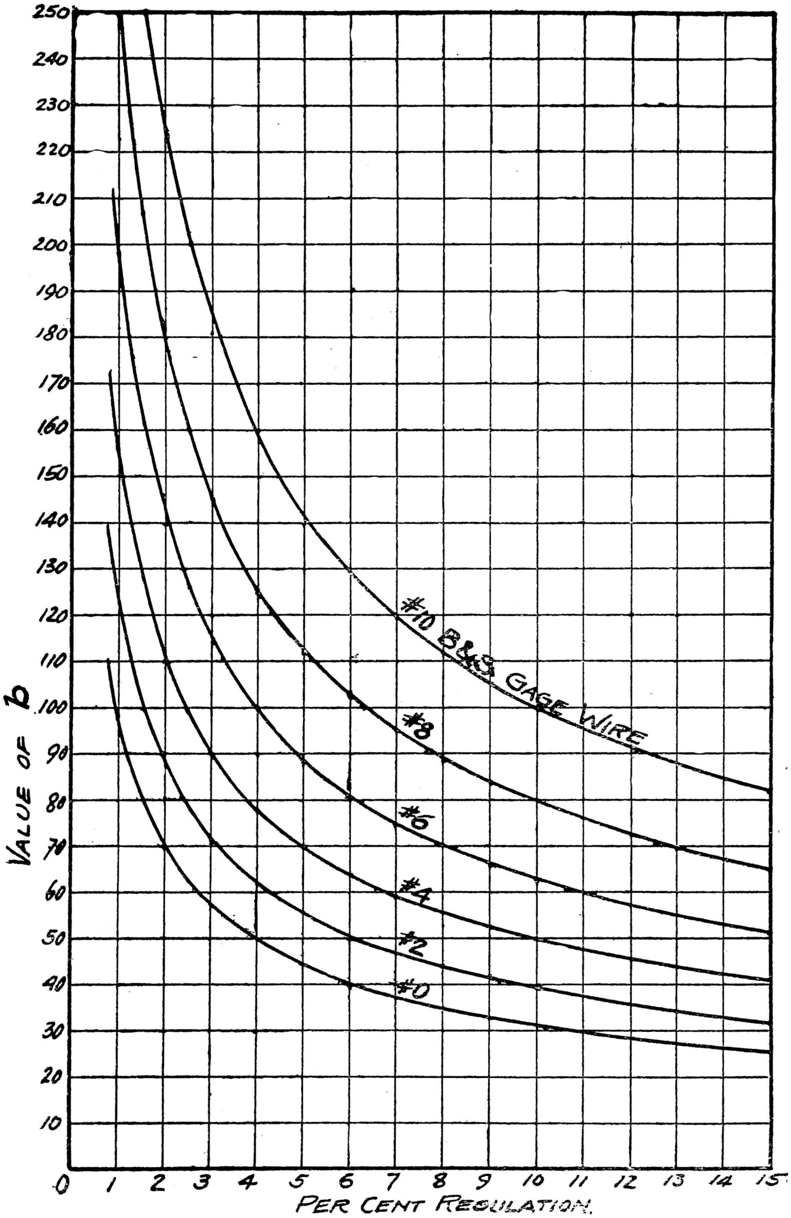
Supply end of line

Fig. 7.

The value of **R** per 1000 feet of commercial copper wire is shown below:

Size wire B & S Gauge	10	8	6	4	2	0	00	000	0000
R	.9972	.6271	.3944	.248	.156	.09811	.0778	.0617	.04893

To find **c** from the curve on page 32 proceed as follows: Draw a vertical line through the points which correspond to the spacing of the wires, and at the point where this line intercepts the curve corresponding to the size of the wire used, draw a horizontal line until it intercepts the curve corresponding to the power factor of the system. From this intersection draw a vertical line to the top of the figure and read the value of "c" from the scale. This gives



Value of b
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Per Cent Regulation.
#10 B&S Gage Wire
#8
#6
#4
#2
#0

Fig. 8.

the proper value of **c** to use. As an example: find the value of **c** for a system using No. 6 wire spaced three feet apart and having 80% power factor. The vertical line through the three foot point is the heavy line about the center of the page. This intersects the No. 6 curve at a ratio factor of .37. Through this point draw a horizontal line which intersects the 80% power factor curve at a value of **c** equal to 1.03 which is the proper value for these conditions.

A Special Distribution System.—As an example of the design of a distribution system for rural communities let the following problem be assumed: A city plant has a three phase 2200 volt generating equipment of ample capacity to supply the load for a line as given in the following table. The manufacturing cost of power is one cent per kilowatt hour. At the switchboard the selling price of power for off peak service is one and one-half cents per kilowatt hour and the selling price of power for peak service is six cents per kilowatt hour. The customers and the individual connected loads are as follows:

Customer	Distance from city in 1000 feet.	Connected Light load in K. W.	Connected Motor load in H. P.	Required Transformers		Remarks
				No.	K.V.A. rating each.	
A	1	1	0	1	1	
B	2	½	0	1	½	
C	3	½	3	2	2	Motor used 20 hrs. per day 3 months per year to irrigate truck farm
D	5	1	0	1	1	
E	5	1	5	2	3	General service motor
F	5	½	0	1	½	
G	6	½	0	1	½	
H	8	1	10	2	7½	General service motor
I	10	½	0	1	½	
J	11	1	3	2	2	General service motor
K	11	½	0	1	½	
L	13	1	2	2	2	Motor used 10 hrs. per day throughout yr. for pumping water
M	14	½	0	1	½	
N	16	½	10	2	7½	General service motor
		10	33			

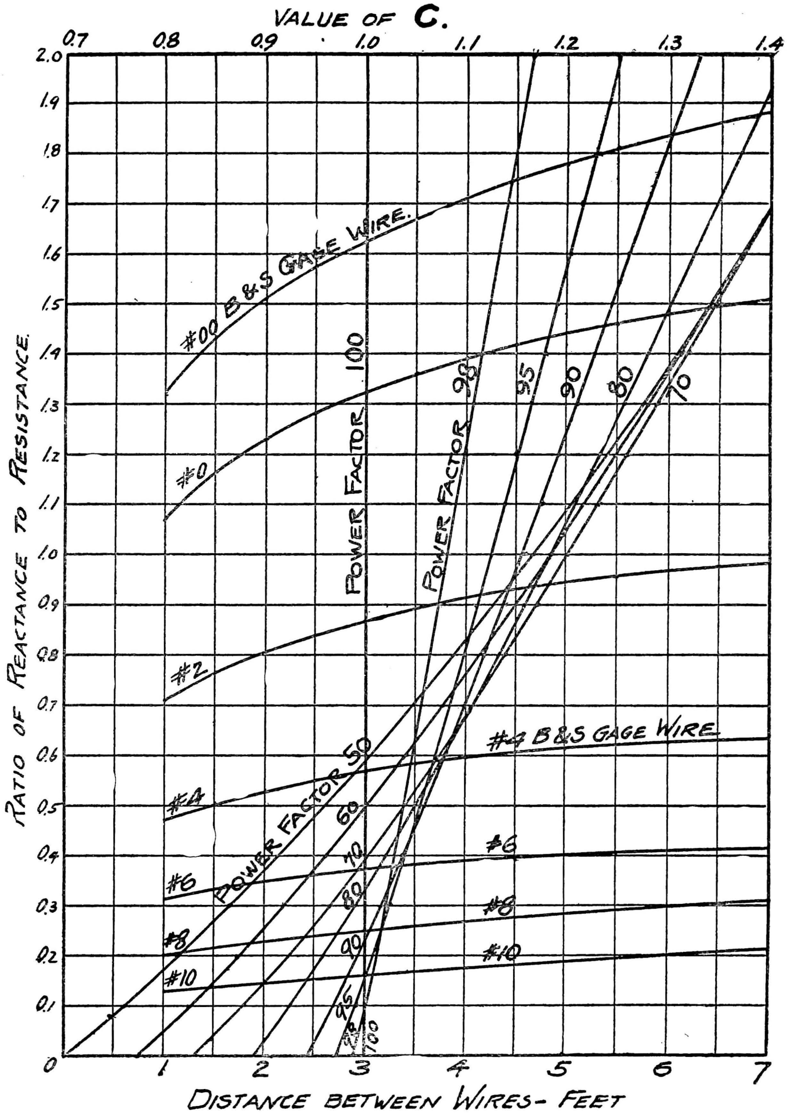

VALUE OF C.
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RATIO OF REACTANCE TO RESISTANCE
#00 B&S GAGE WIRE.
#0
#2
#4
#4 B&S GAGE WIRE
#6
#8
#10
POWER FACTOR 100
POWER FACTOR 98
95
90
80
70
POWER FACTOR 50
60
70
80
90
95
98
100
1
2
3
4
5
6
7
DISTANCE BETWEEN WIRES - FEET

Fig. 9.

D for motor service is calculated as follows:

$P_1 = 3$,	$D_1 = 3$	$(P_1 + \ldots. + P_5)D_1 = 33 \times 3 = 99$	
$P_2 = 5$,	$D_2 = 2$	$(P_2 + \ldots. + P_5)D_2 = 30 \times 2 = 60$	
$P_3 = 10$,	$D_3 = 3$	$(P_3 + \ldots. + P_5)D_3 = 25 \times 3 = 75$	
$P_4 = 3$,	$D_4 = 3$	$(P_4 + \ldots. + P_6)D_4 = 15 \times 3 = 45$	
$P_5 = 2$,	$D_5 = 2$	$(P_5 + \ldots. + P_6)D_5 = 12 \times 2 = 24$	
$P_6 = 10$,	$D_6 = 3$	$(P_6 + \ldots. + P_6)D_6 = 10 \times 3 = 30$	
			333

$$\mathbf{D} = \frac{333}{33} = 10.09$$

D for lighting service is found as follows:

$P_1 = 1$,	$D_1 = 1$	$(P_1 + \ldots. + P_{11})\ D_1 = 10 \times 1 = 10$	
$P_2 = \frac{1}{2}$,	$D_2 = 1$	$(P_2 + \ldots. + P_{11})\ D_2 = 9 \times 1 = 9$	
$P_3 = \frac{1}{2}$,	$D_3 = 1$	$(P_3 + \ldots. + P_{11})\ D_3 = 8\frac{1}{2} \times 1 = 8.5$	
$P_4 = 2\frac{1}{2}$,	$D_4 = 2$	$(P_4 + \ldots. + P_{11})\ D_4 = 8 \times 2 = 16.$	
$P_5 = \frac{1}{2}$,	$D_5 = 1$	$(P_5 + \ldots. + P_{11})\ D_5 = 5\frac{1}{2} \times 1 = 5.5$	
$P_6 = 1$,	$D_6 = 2$	$(P_6 + \ldots. + P_{11})\ D_6 = 5 \times 2 = 10.$	
$P_7 = \frac{1}{2}$,	$D_7 = 2$	$(P_7 + \ldots. + P_{11})\ D_7 = 4 \times 2 = 8.$	
$P_8 = 1\frac{1}{2}$,	$D_8 = 1$	$(P_8 + \ldots. + P_{11})\ D_8 = 3\frac{1}{2} \times 1 = 3.5$	
$P_9 = 1$,	$D_9 = 2$	$(P_9 + \ldots. + P_{11})\ D_9 = 2 \times 2 = 4.$	
$P_{10} = \frac{1}{2}$,	$D_{10} = 1$	$(P_{10} + \ldots. + P_{11})\ D_{10} = 1 \times 1 = 1.$	
$P_{11} = \frac{1}{2}$,	$D_{11} = 2$	$(P_{11})\ D_{11} = \frac{1}{2} \times 2 = 1.$	
			76.5

$$\mathbf{D} = \frac{76.5}{10} = 7.65$$

From an examination of the load conditions it is evident that the motor load which may occur at one time is 5 H. P. plus a part of the 28 H. P. in general motors. Let it be assumed that one-half of the general service motors may at some time be connected.

$$\text{Then } \mathbf{P} = 5 + \frac{28}{2} = 19 \text{ H. P.}$$

1 H. P. in an induction motor requires about 1 KVA.

Then **P** = 19KVA

For induction motor service 10% regulation is sufficiently good. The values found above may now be substituted in equation (1).

$$\mathbf{E} = \mathbf{abc}\sqrt{\mathbf{DP}}$$

a = 1 for 3 phase system

b = .79 for No. 8 wire and 10% Reg. from the curve on page 30.

c = .98 for a system using No. 8 wire spaced 28″ and with 80% power factor, from curve, page 32. This gives

$$E = 1 \times 79 \times .98 \sqrt{10.09 \times 19} = 1074 \text{ volts.}$$

As 2200 volts is the next higher standard voltage, and is also the voltage of the city system, No. 8 wire and 2200 volts may be considered as being suitable for the motor service.

For lighting service the voltage is found as follows:

a = 1

b = 145 for No. 8 wire and 3% regulation from the curve on page 30.

c = 1.01 for 98% power factor and No. 8 wire spaced 28″.

$$E = 1 \times 145 \times 1.01 \sqrt{7.65 \times 5} = 906 \text{ volts.}$$

and

It has been assumed in the above that one-half of the total connected lighting load will be supplied at one time. Therefore if the line is constructed of No. 8 wire spaced 28″ and the power is distributed at 2200 volts, the proper regulation will be given. This regulation has been assumed to be 10% for induction motor service, and 3% for lighting service. The motor and lighting load will not occur at the same time so that we are safe in designing the system for the one load which presents the severest conditions. There is no need to consider any other voltage than 2200 since the cost can not be lessened by changing any of the factors. However, it may be interesting to consider the financial condiitons and the economic feasibility of a distribution system such as this one which is fairly typical of a small line after a few years operation.

Assuming that the customer purchases his own transformer and meter and also builds his own branch line from the main distribution system, the initial cost of this system is composed of the folfolwing items:

2390 lbs. No. 8 bare hard copper wire at $20 per 100 lbs.	$478.00
120 25-ft. poles, 40 per mile, at $3.50 each	420.00
120 3-ft. cross arms, at $0.25 each	30.00
360 2200 volt insulators, at $0.04 each	14.40
120 sets pole hardware, bolts, braces, pins, etc	18.00
Labor, setting poles, placing cross arms and insulators	240.00
Labor, stringing wires	75.00
Incidentals	75.00
Switches, fuses and lightning arresters	149.60
3 mile line complete costs	$1500.00

This distribution system can be cheapened by using ¼″ galvanized steel strand in place of No. 8 copper wire the regulation still being better than the standards which have been set, but the future capacity will not be quite so large. The system as now designed will take care of several times the present assumed load and with ¼″ galvanized steel strand about 1.3 times the present assumed load. Under these new conditions the cost will be

4800 ft. ¼″ galvanized steel strand, at $0.75 per 100 ft.	$320.00
90 30-ft. poles, 30 per mile, at $4.50 each	405.00
90 3-ft. cross arms, at $0.25 each	22.50
270 insulators, at $0.04 each	10.80
90 sets pole hardware	13.50
Labor, setting poles, placing arms and insulators	180.00
Labor, stringing wires	100.00
Incidentals	75.00
Switches, fuses and lightning arresters,	149.60
3 miles line complete costs	$1276.40

This saving is made because of the lower cost of the steel wire and because ¼″ steel strand has several times the mechanical strength of No. 8 copper wire so that we can space the poles farther apart.

The yearly cost to the central electric company will be as follows:

Fixed charges composed of 6% interest, 7% depreciation and 3% taxes and repairs, total 16% of $1276.40	$204.23
Iron loss in transformers, 4664 Kw hrs. at $0.01	46.64
Copper loss in line and of transformers, 300 Kw hrs	3.00
Supervision, attendance and clerical	100.00
Total yearly cost	$353.87

The total power sold is found as follows:

If one-third of the connected lights are used three hours per day, then 3650 Kw hrs. will be sold for lighting purposes. The use of general purpose motors is assumed as 5 hours per day for one-seventh of the motors, or each motor will be used 5 hours per week. The motor load is:

Irrigation	$3 \times 20 \times 90$	5400 hp. hrs.
Pumping	$2 \times 10 \times 365$	7300 hp. hrs.
General	$\frac{-}{7} \times 5 \times 365$	7300 hp. hrs.
Total		20000 hp. hrs.

And 20000 horsepower hours delivered at the motor shaft requires about 18000 kilowatt hours motor input. From the sale of this amount the central station must receive the cost of power at the switchboard, the cost of distributing it, and a profit on the cost of the distribution system. The distribution cost is $353.87, a 10% profit is $127.64, and $481.51, or 2.22 cents per Kw. hr., must be added to the price of power at the switchboard. This makes the cost of electric power to the farmer for motor use, 1.5 + 2.2 = 3.7 cts. per Kw. hr. and for lighting purposes 6 + 2.2 = 8.2 cts. per Kw. hr.

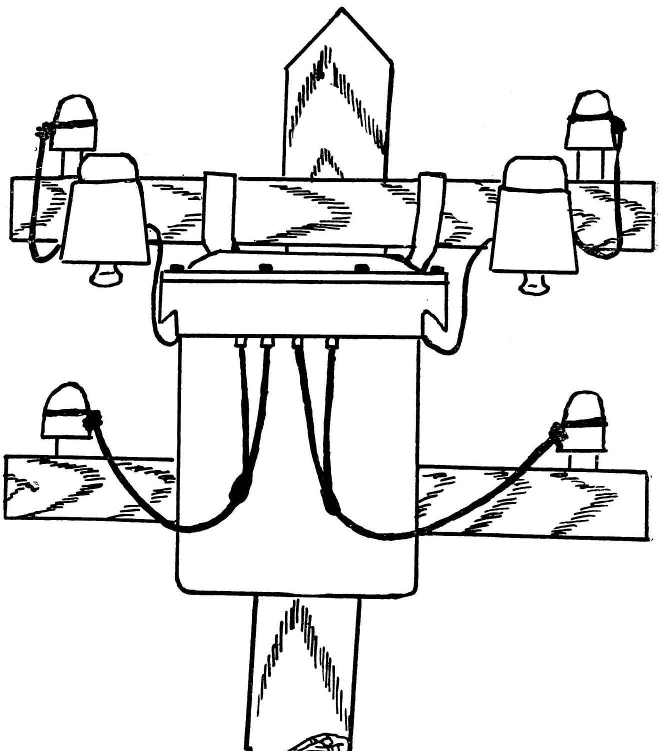


Fig. 10.—Mounting of a Transformer

Cost of Electric Service to Farmer. — It may be interesting to see what the farmer actually pays for the use of electric power. First, consider the case of a farmer who uses electricity for lighting a small residence, taking Mr. B. of the preceding problem as a fair example. He has an installation of twenty 25-watt tungsten lamps to light his six room residence. His investment is as follows for two 2-lamp fixtures and six pendant lamps, first class installation:

Wiring	$50.00
Meter	10.00
Transformer, ½ KVA	20.00
Branch line from his home to line, ¼ mile	80.00
Total	$160.00

His yearly expenses are as follows:

Fixed charges, 14% of $160.00	$22.40
Lamp renewals	3.00
Current, 180 Kw. hrs. at $0.082	14.76
Total	$40.16

His actual yearly expense will be $40.16, but he will pay the central electric company an average of only $1.20 per month.

As a typical example of the cost of motor service, consider the case of Mr. E. who has twenty-five 40-watt tungsten lamps in his residence, barn and other buildings and uses a five horsepower motor for general service. The total power used is:

Lighting, 1/3 x 3 365 = 365 Kw. hrs. at $0.082	$29.95
Motor, 4.4 x 5 x 52 = 1144 Kw. hrs. at $0.037	42.30
Total yer year	$72.25
per month	6.00

His investment is as follows:

House and barn wiring	$75.00
Meter	10.00
Two 3 KVA transformers at $35.00	70.00
Branch line, home to line, ¼ mile	80.00
Motor, 5 H. P. 3 phase, 1800 RPM	80.00
Total	$315.00

The total cost is as follows:

Fixed charges, $315.00 at 14%	$41.10
Power	72.25
Oil, waste and sundries	5.00
Lamp renewals	5.00
Total	$126.35

The cost for the lighting system is..........................$50.75
The cost for motor service is 75.60

Compare the above motor cost with the cost of doing the same work with a gasoline engine.

A 5 H. P. engine complete costs..........................$250.00
The fixed charges are, interest 6%, depreciation 10%, taxes and repairs 4%, a total of 20% on $250.00................ 50.00
Gasoline, 1/6 gallon per horsepower hour with 10% for leakage and waste, amounts to 238 gal., at $0.18 per gal...... 42.80
Oil, waste, batteries and sundries............................ 15.00

The total for a gasoline engine is...................$107.80
The total for electric motor is...................... 75.60

The electric motor is thus much cheaper as well as safer and far more convenient and reliable.

Typical Large Rural Distribution System.—Let it be assumed that a central electric company, having a three phase 2200 volt plant, wishes to supply power for a rural line as outlined in Table 17. The company is to supply transformers and branch circuits, but each customer must purchase his own meter. The manufacturing cost of power is one cent per kilowatt hour and the profitable selling price at the switchboard is one and one-half cents per kilowatt hour for "off peak" and six cents per kilowatt hour for peak load power.

Customer	Distance in 1000 of ft.	Lighting load in K.W.	Motor load in H. P.	Remarks
A	1	1	3	Gen'l purpose motor 5 hrs. per wk.
B	1	1	5	Truck farm, used 20 hrs. per day in summer.
C	2	½	3	Gen'l purpose motor 5 hrs. per wk.
D	3	1	Two 5 H.P.	Truck farm used 20 hrs. per day in summer.
E	4	1	0	
F	6	½	Two 5 H.P.	Truck farm used 20 hrs. per day.
G	8	1	3	Gen'l purpose motor 5 hrs. per wk.
H	9	1	10	Pumping 10 hrs. per day through the year.
I	10	1	10	3 H.P. motor pumping 5 hrs.per day
			3	
J	13	½	0	
K	14	1	0	
L	16	1	5	Gen'l purpose motor 5 hrs. per wk.
M	17	2	0	
			5	5 H.P. motor general purpose 5 hrs per week
N	18	½	3	3 H.P. motor pumping 5 hrs. per dy
O	21	1	10	Gen'l purpose motor 3 hrs. per wk.
P	23	1	3	Gen'l purpose motor 5 hrs. per wk.
Q	25	1	4	Gen'l purpose motor 5 hrs. per wk.
			10	10 H.P. motor general purpose 4 hour per week.
R	26	½	3	3 H.P. motor pumping 5 hrs. per dy
S	28	1	5	Gen'l purpose motor 5 hrs. per wk.
T	29	½	0	
U	33	1	Two 10 H.P.	Power 5 hrs. per week.
V	34	1	5	General purpose motor.
W	35	½	10	Power.
X	37	15	10	Power.
Y	40	1	5	Gen'l purpose motor 5 hrs. per wk.

From an inspection of the table it is evident that the line must be designed to take care of the motor load as it presents decidedly the worst conditions. We shall therefore proceed to find **D** for the motor load.

$P_1 = 8$,	$D_1 = 1$	$(P_1 \ldots P_{19})D_1$	$= 157 \times 1 = 157$
$P_2 = 3$,	$D_2 = 1$	$(P_2 \ldots P_{19})D_2$	$= 149 \times 1 = 149$
$P_3 = 7$,	$D_3 = 1$	$(P_3 \ldots P_{19})D_3$	$= 146 \times 1 = 146$
$P_4 = 10$,	$D_4 = 3$	$(P_4 \ldots P_{19})D_4$	$= 139 \times 3 = 417$
$P_5 = 3$,	$D_5 = 2$	$(P_5 \ldots P_{19})D_5$	$= 139 \times 2 = 258$
$P_6 = 10$,	$D_6 = 1$	$(P_6 \ldots P_{19})D_6$	$= 126 \times 1 = 126$
$P_7 = 13$,	$D_7 = 1$	$(P_7 \ldots P_{19})D_7$	$= 116 \times 1 = 116$
$P_8 = 5$,	$D_8 = 6$	$(P_8 \ldots P_{19})D_8$	$= 103 \times 6 = 618$
$P_9 = 8$,	$D_9 = 2$	$(P_9 \ldots P_{19})D_9$	$= 98 \times 2 = 196$
$P_{10} = 10$,	$D_{10} = 3$	$(P_{10} \ldots P_{19})D_{10}$	$= 90 \times 3 = 270$
$P_{11} = 3$,	$D_{11} = 2$	$(P_{11} \ldots P_{19})D_{11}$	$= 80 \times 2 = 160$
$P_{12} = 4$,	$D_{12} = 2$	$(P_{12} \ldots P_{19})D_{12}$	$= 77 \times 2 = 154$
$P_{13} = 13$,	$D_{13} = 1$	$(P_{13} \ldots P_{19})D_{13}$	$= 73 \times 1 = 73$
$P_{14} = 5$,	$D_{14} = 2$	$(P_{14} \ldots P_{19})D_{14}$	$= 60 \times 2 = 120$
$P_{15} = 20$,	$D_{15} = 5$	$(P_{15} \ldots P_{19})D_{15}$	$= 55 \times 5 = 275$
$P_{16} = 5$,	$D_{16} = 1$	$(P_{16} \ldots P_{19})D_{16}$	$= 35 \times 1 = 35$
$P_{17} = 10$,	$D_{17} = 1$	$(P_{17} \ldots P_{19})D_{17}$	$= 30 \times 1 = 30$
$P_{18} = 15$,	$D_{18} = 2$	$(P_{18} \ldots P_{19})D_{18}$	$= 20 \times 2 = 40$
$P_{19} = 5$,	$D_{19} = 3$	$(P_{19})D_{19}$	$= 5 \times 3 = 15$
			3355

$$D = \frac{3355}{157} = 21.35$$

In estimating the value of **P** the conditions governing the use of the motors must be carefully considered. Let it be assumed that all truck farm motors are connected, that 75% of the pumping motors are connected at one time and that one-third of the general purpose motors may be connected. Near the end of the line are three power installations for rock quarries and rock crushers, and all of these may be connected at one time so that the maximum possible load is:

Truck farms		22.00 H. P.
Pumping	19 x .75 =	14.25 H. P.
General	71 x 1/3 =	23.65 H. P.
Power		45.00 H. P.
Total	**P** in H. P. =	104.9 H. P.

As one H. P. in motor capacity requires about 1 K. V. A., **P** in K. V. A. = 104.9

It is now necessary to find the voltage which is necessary to transmit this power at 80% power factor over a three phase system using No. 8 copper wire spaced 28 inches apart.

$P = 104.9$
$D = 21.35$
$a = 1$
$b = 79$ for 10% regulation curve page 30.
$c = .98$ curve page 32.

$$E = abc \sqrt{DP}$$

$$E = 1 \times 79 \times .98 \sqrt{21.35 \times 104.9} = 3670 \text{ volts}$$

As 6600 volts is the next higher standard voltage it must be selected if it is desired to use a straight three phase system. A four wire, three phase, star connected system with 2300 volts between any wire and the neutral or 3980 volts between outside wires may also be used. This necessitates three transformers at each motor. The use of this latter system provides for 18% future growth while a 6600 volt three phase system allows a future load of 3.2 times the present load. As this load is hardly to be expected, 5/16″ steel strand wire may be substituted and still allow for considerable future business. A three phase, 2200 volt system requires No. 3 B. & S. copper wire and allows 15% future business. This gives three possible designs to choose from: 6600 volts three phase 5/16″ steel strand; 3980 volts three phase, four wire, with No. 8 copper wire conductors and ¼″ steel strand for the neutral; and 2200 volts three phase with No. 3 copper wire. To make a selection between these three the cost of each should be considered.

Items	Cost of a 7½ mile line		
	6600 volts 3 phase 5/16" steel strand	3980 volts No. 8 copper wire ¼" steel strand neutral	2200 volts 3 phase No. 3 copper wire
400 30' poles spaced 100 ft., at $4.50......		$1800.00	
300 35' poles spaced 40 per mile, at $7...	$2100.00		$2100.00
400 cross arms and set of pole hdw'r @45c		180.00	
300 cross arms and set of pole hdw'r @45c	135.00		135.00
1600 2200-volt insulators, at 4c..........		64.00	
1200 2200-volt insulators, at 4c..........			48.00
1200 6600-volt insulators, at 5c..........	60.00		
Labor setting poles	650.00	800.00	650.00
Labor stringing wires	225.00	225.00	225.00
40000' ¼" steel strand..................		300.00	
120000' 5/16" steel strand..............	1200.00		
5390 lbs. No. 8 bare copper wire.........		1079.00	
10900 lbs. No. 3 bare copper wire........			3635.00
Switches, lightning arresters and fuses..	600.00		
Total 7½ mile line....................	$4970.00	$5948.00	$7193.00
Total per mile	$663.00	$792.00	$959.00
Total Costs			
Step up transformers, 3 phase...........	$ 600	$ 560	
Distributing transformers, all single phase	3400	2300	$2300
Branch lines, averaging ⅛ mile..........	1800	2250	1800
Main line	4970	5948	7193
Total	$10770	$11058	$11293

There is very little difference in the cost of the three different systems for this installation so other than financial factors must be considered in making the selection. The third system is probably the best because it can be changed to a 3 phase 4 wire system having three times its present capacity if the future business becomes large or if it is desirable to extend the line. Futhermore, 2200 volts is the most common distribution voltage.

The total amount of power sold annually is as follows:

Lighting	6155 Kw. hrs.
Truck farms	34600
Pumping	44500
Power	59000
General	16200
	160455 Kw. hrs.

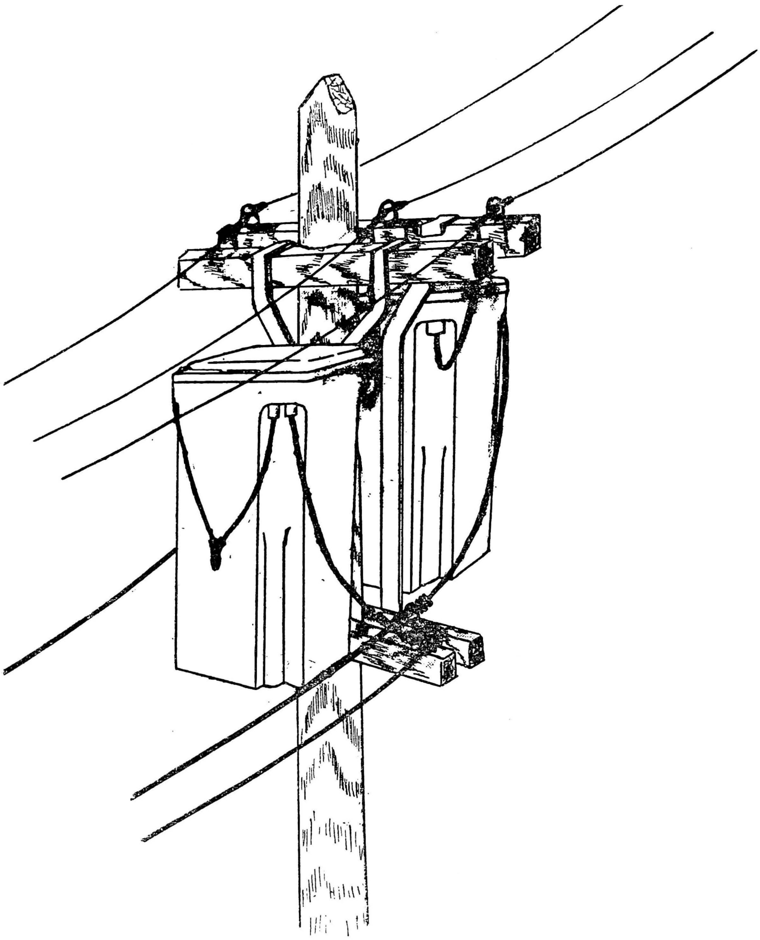


Fig. 11.—Two Transformers on a Three-Phase System.

The amount to be realized over and above selling price of power at switchboard is:

Fixed charges	$1810.00
Transformer iron loss	152.00
Copper loss	21.00
Profit 10%	1130.00
Supervision, clerical and attendance	800.00
Total	$3963.00

Additional cost per KW hr....................2.47 cents

The proper selling price of power at farmer's residence is thus:

1.5 + 2.47 = 3.97 cts. per KW. hr. for day load and

6 + 2.47 = 8.47 cts. per KW hr. for lighting service.

This selling price is higher for the heavily loaded line because the central electric station owns not only the transmission line but also the branch circuits and transformers.

Economics of Rural Distribution.—The only argument which will influence central electric stations to extend their service to rural districts must be based on income and profit. Examples of two distribution circuits have been given which show the selling price of electrical energy must be in order to make a profit on the entire investment. The first example is a short line with a medium load, built to keep down first costs. The second is a large heavily loaded rural line constructed in a first class manner, and designed for most economic operation. Neither line shows the conditions encountered on very lightly loaded rural lines.

A rural distribution system must earn a certain profit over and above all expenses including fixed charges, and this profit must be as large as can be earned by investing the same capital in other enterprises having the same degree of uncertainty. The expenses are: interest on the line investment, taxes, repairs and depreciation of the system, clerical and supervisional charges and cost of supplying all distribution losses (of which transformer iron losses are the largest) as well as the profitable selling price of electrical power at the switchboard. This price of power at the switchboard is less than the city selling price, as city distribution expenses do not have to be met. The actual profitable selling price of power at the switchboard varies through very wide limits at the different times of the day due to the varying load on the plant. At "off peak" times during the day when farm motors are mostly used, the equitable price of power may be less than one-fourth the price at the evening lighting peak time, so that a low rate for motor service is always justified if there is a high peak caused by some other load. It must not be thought that because this energy is sold at a low price there is no profit. Considering the profit on the investment required to serve the customers, motor service at a low unit price is just as profitable if not more so that the high priced lighting load.

With the exception of copper loss, which is very small, and clerical work, all the cost of distributing power over a given line is constant regardless of the amount of power which the customers use. Therefore the distributing charge per kilowatt hour varies inversely as the number of kilowatt hours sold. A line which has a heavy load usually has a better type of construction, so that this relation does not hold strictly true for two different lines.

An analysis of the cost of rural distribution shows that the following is approximately true: Copper loss is generally a negligable factor and will seldom exceed one per cent of the power sold. Transformer iron losses are usually high unless high tension disconnecting switches are provided to disconnect the transformers where they are not in use and this may be economical in some instances. For 2200 volt distribution, transformer iron losses will amount to about one per cent of the connected transformer capacity continued 24 hours per day, which amounts to 88 kilowatt hours per year per K V A in connected transformer capacity. For higher voltages, the iron losses are higher than this. Fixed charges on the investment are usually high considering the amount of power sold. A fair estimate of them is as follows:

Item	Per cent
Interest, (at current rate)	4-6
Depreciation of pole line (depends on type)	5-15
Depreciation of conductors	3-8
Taxes (at current rate)	
Repairs	1-5

A central station should consider nothing less than 10% profit on the investment as the business is slightly hazardous and 15% would probably be a better figure to use in preliminary computations for new lines.

To find the economical selling price of power at the farmer's homes the following formula will apply.

$$P = \frac{FC + pC + L}{\text{KW hrs. per year per mile}} + S$$

Where **P** is the selling price per kw. hr.,

F is the fixed charges in percent of total investment, assumed as 16% in our previous calculations,

p is the percent profit,

L is the cost per mile of supplying line losses.

C is the average cost per mile of all the apparatus and lines owned by the electric power company,

S is the profitable selling price of power at the switchboard varying for different service plus a small amount for clerical and supervision work.

The total amount which must be added per kilowatt hour to the economic price of power at the switch board is

1000 KW hrs. per year per mile	15.0 cents
2000 KW hrs. per year per mile	8.5 cents
4000 KW hrs. per year per mile	5.0 cents
10000 KW hrs. per year per mile	2.5 cents
20000 KW hrs. per year per mile	1.5 cents
40000 KW hrs. per year per mile	1.0 cents

This table is based on a line costing about $650 per mile, and a connected load about ten times the average load. The values given vary but little with different lengths of transmission. It is probable that the cost of lines for lightly loaded systems can be reduced below $650 per mile, so that the selling price of power for these lines can be reduced.

Distribution from High Tension Transmission Lines.—The trouble and expense of many small substations make it unwise to serve small customers from high voltage transmission lines, unless enough customers can be supplied from one transformer station to warrant the construction of a substation of the best type, with constant attendance to secure reliability of serve to the customers, and with the best protective apparatus to protect the main transmission line from disturbances originating on the customer's circuits. The income from isolated customers is seldom large enough to be profitable even after the element of risk of interruption of the main transmission service by local disturbances on the branch circuits has been subtracted. To secure full protection to the substation apparatus, a reliable and positive lightning arrester must be placed at each station; to protect the transmission system, reliable circuit breakers must be installed to interrupt the service in case of trouble. Since both of these protective devices must be designed for the transmission voltage, they are necessarily expensive. Small high voltage transformers are also costly. If uninterrupted service is to be extended to the customers, there must be constant attendance. To secure all these qualities the apparatus should preferably be enclosed in a building. All of these factors make it uneconomical and unprofitable to serve small isolated customers.

If, however, a number of customers who do not require absolute continuity of service can be connected to one substation, and

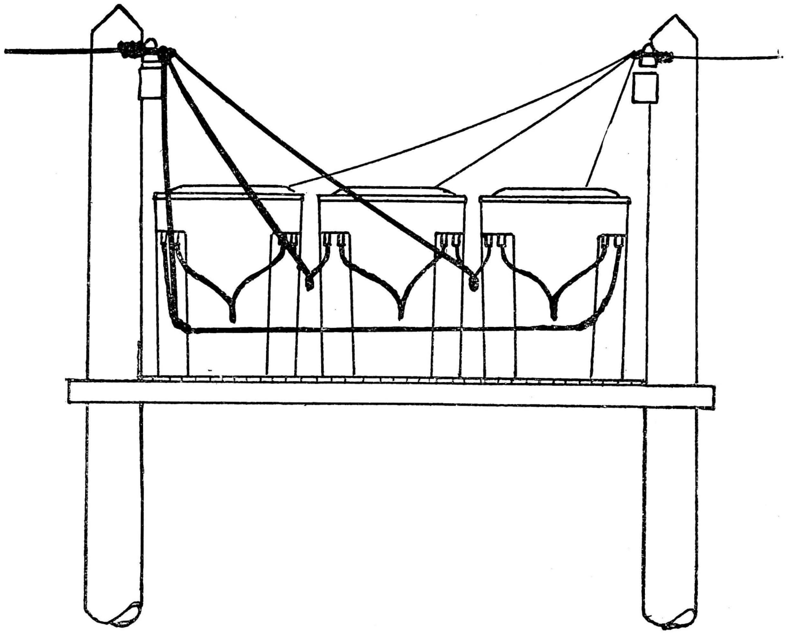


Fig. 12.—Bank of Three Transformers on a Three Phase System.

the company is willing to assume the risk of interruption of the main service, there is no reason why these customers should not be provided with electrical power. This is the case with farmers. A rural distribution system such as is described in the second problem discussed in the preceding pages could be economically and profitably served with an outdoor transformer station of 100 KVA capacity from a 33,000 or possibly a 44,000 volt transmission line. Constant attendance can be dispensed with since farmers do not require continuity of service as much as the service itself. Several companies now design outdoor transformers in small capacities for high voltages, using cheaper types of apparatus than are used for large transformer stations.

Notwithstanding the fact that the apparatus available for this service leaves something to be desired, many power companies use, and several manufacurers make sets for the protection of small outdoor transformer stations. These sets are composed of a disconnecting switch, a high tension fuse of a special design, a chokc coil, and a horn gap lightning arrester. In case of a short circuit on the branch the fuse is blown. A lightning disturbance entering from the line is reflected by the choke coil to the horn gap where it discharges, the arc being broken by the natural operation of the horn gap. In case the arc is not extinguished at once, the high tension fuse which is in series with the arrester as well as the other apparatus, is blown. Thus in case of a short circuit or in some cases of lightning discharge, the circuit is opened by the fuses until they are replaced by an attendant. Whenever any work is to be done on the station, the station can be made dead by opening the disconnecting switches after the low tension switches have been opened. While this system does not secure continuity of service to the customers, and does not fully protect against transient disturbances, yet it is the best cheap installation that can be made under present conditions. A substation which would serve the customers on the farmers' line described under problem 2 would cost about $1800.

The annual expenses are:

Amount to be realized from distribution line	$3963.00
Fixed charges, 16% of $1800	288.00
Profit, 10% on $1800	180.00
Transformer iron loss	100.00
Supervision and attendance	200.00
Total	$4731.00

The amount to be added to the selling price of power to defray distribution costs is 2.94 cents per kilowatt hour, which is a very reasonable figure. Therefore, if a sufficiently good load can be connected to one substation, and if the customers do not demand absolute continuity of service, as is the case with farmers, and if the power company is willing to assume the risk of interruption of the main transmission service and to keep the transformer station in satisfactory operation, a fair revenue at a good profit is derived from serving farmers, even from a 33000 volt transmission line.

Special Central Electric Plants.—In several European countries, for example Germany, Italy and Norway, there are now in operation many small central electric plants situated in the centers of well developed farming countries. These plants have distribution systems extending to the homes of the farmers within a reasonable radius. Some of the larger plants are steam driven, many of the small ones are gasoline or oil engines, while a few utilize water power. Many of them are direct current plants using a storage battery to secure continuous service to the farmers with intermittent operation of the generator and prime mover.

While we do not know all the conditions surrounding the establishment of these plants, it appears that they are less economical than distribution from city plants or high voltage transmission lines. The satisfactory method of securing electric power on farms in America does not lie in the direction of small isolated plants. If, however, it is not possible to secure power from a large central plant, it is better and more economical for two or more farmers living near each other to use one isolated plant such as described earlier in this bulletin rather than for each farmer to have his own separate plant. The isolated plant described under problem 2 on page 17 would satisfactorily supply two small residences with light at a cost about the same as that given by supplying one residence. The cost to each farmer would be little more than one-half of the cost given previously. But this is a refinement of the isolated plant rather than a central station of the kind used in Europe.

A central plant for the use of farmers would need to be a small installation of the same type as the large city plants. There is no need of multiplying the number of small plants in a country when in general one large station can supply energy more economically than several small ones. The large plants are already installed and they will need little extra equipment to serve a large number of farmers by means of a few distribution lines. They should be used wherever possible.

CONCLUSION.

It is undisputed that farmers will find as much satisfaction in the use of electric light as any other customers. Electric motors can be profitably used almost daily in many farm processes because of their convenience, ease of operation, flexibility, lack of noise and dirt, long life, small repair charges and general overall economy. It is usually uneconomical for farmers to own and operate isolated plants since the fixed charges are high, and such plants are not well adapted to supplying motors with power. It therefore seems preferable to distribute power from a central electric plant by means of a high voltage distribution system. This is economical to the farmer and profitable to the central station if a good motor load can be secured. The best system will usually be found to be a three phase system, either three wire or four wire, with a voltage such that standard 2200 volt or 6600 volt distributing transformers can be used. The entire line should be designed for as low a first cost as is consistent with durability and general engineering practice. In the selection of the system for a particular line, the cost of all applicable systems should be considered. It is sometimes profitable for power companies to install small outdoor transformer stations to supply rural lines.

Small central stations supplying power to farmers only, and with no other market, are not likely to prove successful financially. Distribution from a city central electric station or a long distance high voltage transmission line is always to be recommended where feasible as being the most satisfactory to all concerned in obtaining electricity for lighting and power in rural districts.

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