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Electric Light and Power Systems for the Farm

H. H. Delong

Electric
LIGHT and POWER SYSTEMS FOR THE FARM

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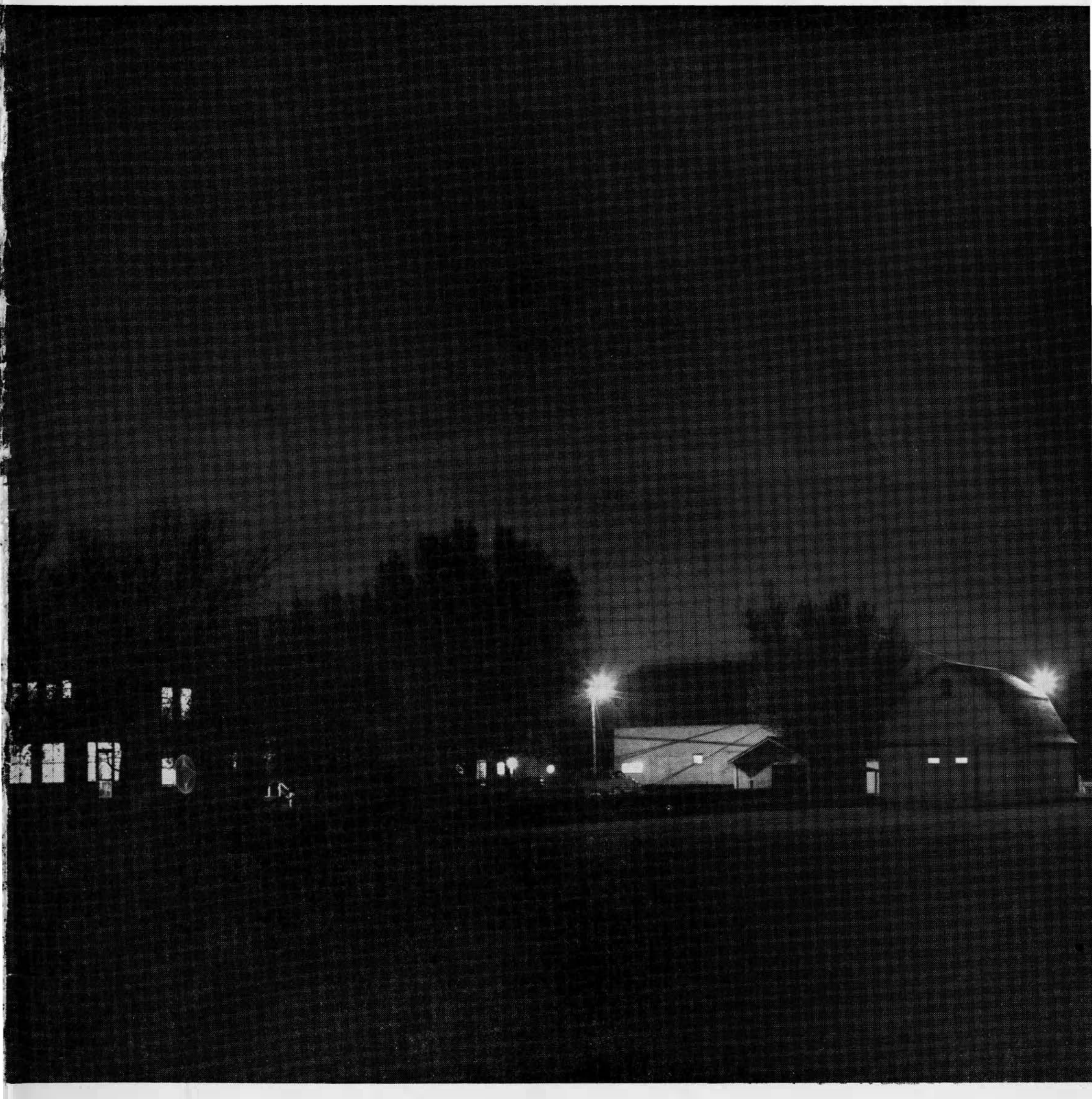

Agricultural Engineering Department

AGRICULTURAL EXPERIMENT STATION

SOUTH DAKOTA STATE COLLEGE · BROOKINGS

Developments In the Use of Electricity On the Farm

The coming of electric light and power for use in farm homes has been acclaimed one of the four or five greatest developments for the farmer in the last two centuries. Like most other inventions, or developments, it has not been the work of one man or one agency, but rather the accumulation of the efforts of many.

The early use of city gas for lighting prompted experimental work in farm lighting plants of acetylene gas and also generator gasoline plants before 1920. These plants, while moderately successful, did not compare favorably with electricity for lighting and home appliances.

Soon after 1915 the first gasoline engine-driven electric plants, with their complement of 32-volt battery sets, were being installed in many South Dakota farm homes. The number of these plants increased and some farms are still served by this type of small but dependable farm electric plant.

By 1930 the wind-electric plant became a common sight on prairie farmsteads. These were usually the 32-volt battery model, but some were very small and were suited to 6-volt current only, for charging radio batteries and for very limited home lighting. Large-size batteries were installed on the larger plants to carry over electrical energy on days when there was no wind.

Electricity from central power stations was slow in development in South Dakota as compared to states farther east and on the Pacific coast. Some farms near towns and cities were served by the extension of short lines from the city system. Also a few farms along large transmission lines were served, but costs were usually prohibitive. Perhaps the pioneer farm line in South Dakota was that of the Renner test line which was in operation as early as 1927 and which served some 20 farms between Renner and Sioux Falls.

The National Emergency Act of 1935 made rural electrification one of its projects, and the Congressional Acts of 1936 and 1937 firmly established the Rural Electrification Administration and its plans and policies. The rural electric cooperatives were started in South Dakota in 1939 and 1940 and now number more than 30. Many farmers anticipated having 110-volt current from highlines, but not yet having it, have purchased 110-volt AC manual control or automatic plants to hurry the electrification of their farms. The 110-volt, wind-electric plants were also introduced, thus allowing some of the standard 110-volt equipment on the market for city customers to be used also with the wind-electric plants.

The wide-spread use of liquefied petroleum (propane-butane) mixtures, for kitchen ranges, water heaters, and even home furnaces must not go unmentioned. These gas appliances have brought many modern conveniences to thousands of farm homes not yet served by central electric service.

Figures quoted on the percent of farms electrified hardly give the correct picture for South Dakota, as they consider electrified farms only those served by a central station. South Dakota was rated 47th in percent of farms electrified as compared to other states in the United States.

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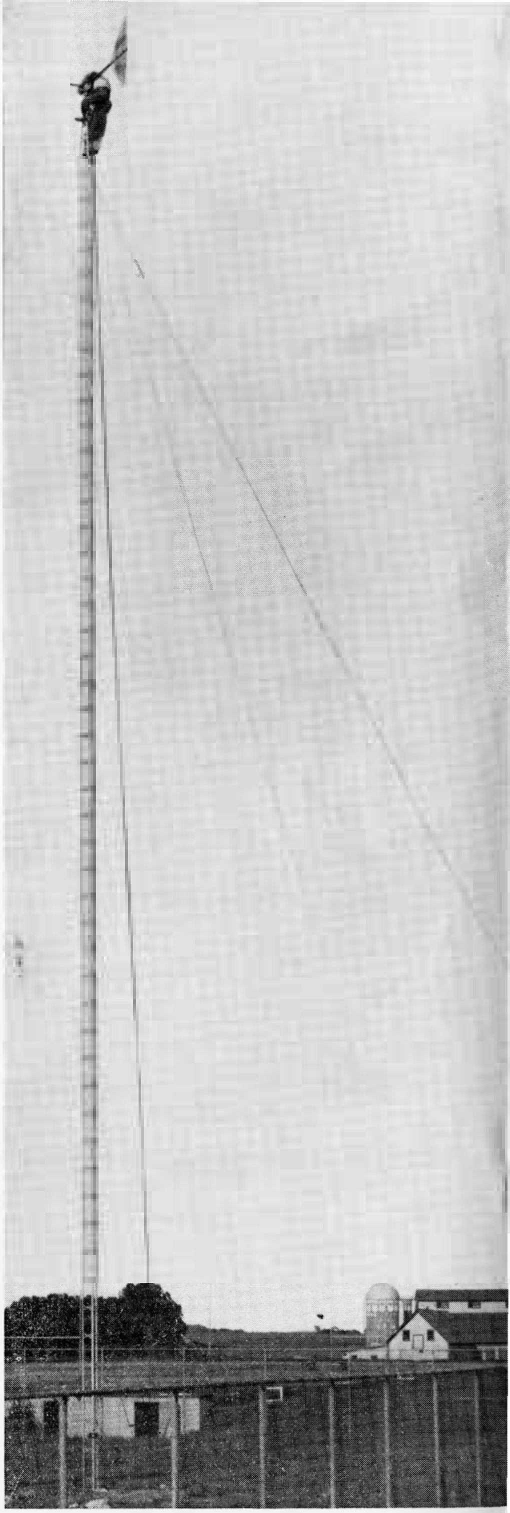

Fig. 1. Workmen assembling the wind-electric tower and plant at Brookings, South Dakota

Electric Light and Power Systems For Your Home

By H. H. DeLong[1]

Many farms await modern facilities and the coming of electric light and power. Eventually they may have central service, but some may be in territory so thinly populated as to make such service very expensive. Some have possibilities of using gasoline-electric plants, or other types of electrical plants, a few years while they wait for highline service. Others may wish to know the cost of maintaining a standby plant, even after they have highline service, to give added security against line damage from storms.

With so many competitive ways of farm electrification available it was considered timely to determine the comparative size, dependability, and cost per kilowatt-hour of some of the above-mentioned methods. For the study, two types of plants were chosen: the 110-volt AC automatic gasoline-electric plant, and the 110-volt DC wind-electric plant with battery. The capacities, dependability, and cost per kilowatt-hour were then compared with existing rates and figures as reported by various rural electric cooperatives in South Dakota and several other states.

Electric service provided by a central station is conceded best for thickly settled areas. No doubt there is an economic limit to how many miles of line can be run to serve one farm. However, there are alternate ways for isolated farms to use gasoline engines or wind energy to supply electric power. It is a problem of distances, current prices and the initial cost of the various plants or highlines, the life of the plant, and care and labor involved.

Minor considerations in choosing the project for research were to study the possibilities of using wind-electric or gasoline plants for standby service for those who have invested heavily for an electrical farm water system, freezers, and refrigerators, or heating equipment which depends on electric current for its controls. Also to be considered are the home appliances that a farm family has already purchased for use with liquefied petroleum gas. Some farms and ranches prefer their electric welding equipment to be belt-driven from the tractor so that it can be portable and taken to the fields. Many farms have already developed their systems of grinding and elevating in terms of tractor power rather than that of using electric motors.

The future may hold many possibilities for developments in all phases of farm power and lights. Discovery of oil and gas in South Dakota could alter the price of liquid petroleum gas. Hydroelectric power from the Missouri river will soon lower the wholesale cost of electricity, but the problems of delivering power to the farm will remain until better methods of transmission are developed. With improvements which may come, wind-electric plants may be made to generate in lower wind velocities, or in new ways, to carry over the stored energy, other than with batteries.

[1]Agricultural Engineer, South Dakota Agricultural Experiment Station. Acknowledgment is made to Frank Wiersma, graduate assistant, for his help on this project.

Much of this work was made possible through the aid of the Wincharger Corporation, Sioux City, Iowa, which provided the Wincharger plant, the funds for a research assistant, and lent the gasoline-electric plants, roto-switch and other small motors.

Methods Used in the Test

Kilowatt-Hours Used Per Farm

The amount of current needed or used per farm is dependent on many factors, such as size of farm, type of farm business, purchasing power, cost of equipment and many others. The United States Department of Agriculture through the Rural Electrification Administration presents in its 1948 Statistical Report the following figures: Average kilowatt-hours per consumer per month in rural electric groups of 1 to 36 months of operation, 110; and average kilowatt-hours per consumer per month in groups of over 97 months of operation, 202. These are figures representing REA Co-ops from all parts of the United States. For 1948, the same report gives 21,207 South Dakota consumers using 31,568,956 KWH's, or an average of 124 KWH's per month. An examination of more recent reports from the various South Dakota cooperatives shows an increasing amount per month per farm, but it is still well below 200 KWH's.

Plants for Test in Keeping with Average Farm Demand

The plants selected for the experimental tests were those of a size to provide a steady and dependable load for the average farm. A glance at Table 1 will show that not all of the plants would be large enough. However, there are many gasoline-electric plants and diesel-electric plants of larger sizes than could be used for the typical farm.

The first plant selected for the trial was a 1500-watt gasoline-electric plant of the fully automatic 110-V AC type. Governing controls held frequency at the common 60-cycles per second, and regular lights and appliances for central station service were used as loads. The motor was a two-cylinder, air-cooled engine, directly connected to the generator.

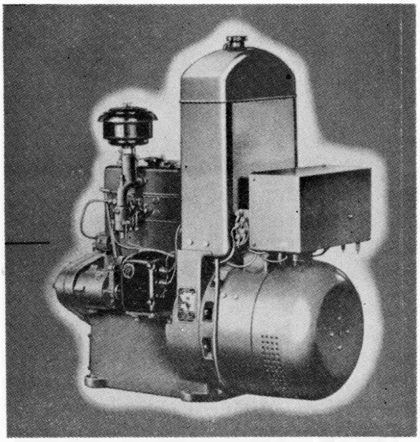

Fig. 2. A gasoline-electric farm light plant.

Two 6-volt starting batteries were used for automatic starting and ignition. Whenever a 60-watt light load, or its equivalent in appliances was turned on, the plant would automatically crank itself and start to supply the current required. The generator automatically adjusted itself to the wattage turned on, up to its rated load. An overload would shut off the plant in a short time, and too heavy a starting load would also cause the overload mechanism to turn off the plant.

The second plant selected was much like the first except in size. It was a 3000-watt, gasoline-electric, fully automatic of the 110-V AC, 60-cycle type. In design it had all the features of the first plant, but had twice the full load capacity.

The wind-electric plant was of the 110-V DC type with a set of 56 glass jar storage batteries of 180-ampere hour capacity. At the Brookings' test location, it was mounted on a 105-foot guyed steel tower. The following year, when placed on the South Dakota Agricultural Experiment substation farm at Cottonwood, it was mounted on a 65-foot tower.

Table 1. Initial Costs of Various Farm Electric Light Plants

Plant size and description	Approximate first cost
350-watt gasoline-electric, 32-V, DC, manual control	$ 400–$ 500
1000-watt gasoline-electric, 32-V, DC	$ 400–$ 525
1000-watt gasoline-electric, 32-V, DC, complete with battery set	$ 540–$ 600
2000-watt gasoline-electric, 32-V, DC, complete with battery set	$ 650–$ 700
350-watt gasoline-electric, 110-V, 60c, AC, manual controls	$ 175–$ 225
750-watt gasoline-electric, 110-V, 60c, AC, manual controls	$ 200–$ 250
1000-watt gasoline-electric, 110-V, 60c, AC, manual controls	$ 250–$ 300
1500-watt gasoline-electric, 110-V, 60c, AC, automatic controls	$ 400–$ 550
3000-watt gasoline-electric, 110-V, 60c, AC, automatic controls	$ 475–$ 575
12-V small size wind-electric, 20′ tower, automobile type battery set	$ 160–$ 200
32-V small size wind-electric plant, guyed tower 60′ high, 180-amp. hour battery set	$ 700–$ 800
32-V large size wind-electric, guyed tower 60′ high, 400-amp. hour battery set	$1400–$1600
110-V large size wind-electric, guyed tower 60′ high, 180-amp. hour battery set	$1700–$1900

The wind-electric plant was automatically controlled from a panel near the batteries, and the plant was turned on at all times. The propeller turned the generator at any time the wind was sufficient. A governor prevented excessive speeds in high wind, and the automatic controls regulated the charging rate to fit the needs of the battery.

Thus all three plants selected for the study were fully automatic and provided electric power when any load was connected to them.

Tests of the 1500-Watt and 3000-Watt Gasoline-Electric Plant

The 1500-watt gasoline-electric plant was mounted on a solid concrete base, but rubber support bushings dampened vibrations when the motor was cranking or starting. The automatic control box was placed on an instrument panel just above the plant. On the same base and instrument panel was mounted the 3000-watt plant and control box. From each control panel several leads were run out to load outlets. Some of the loads,

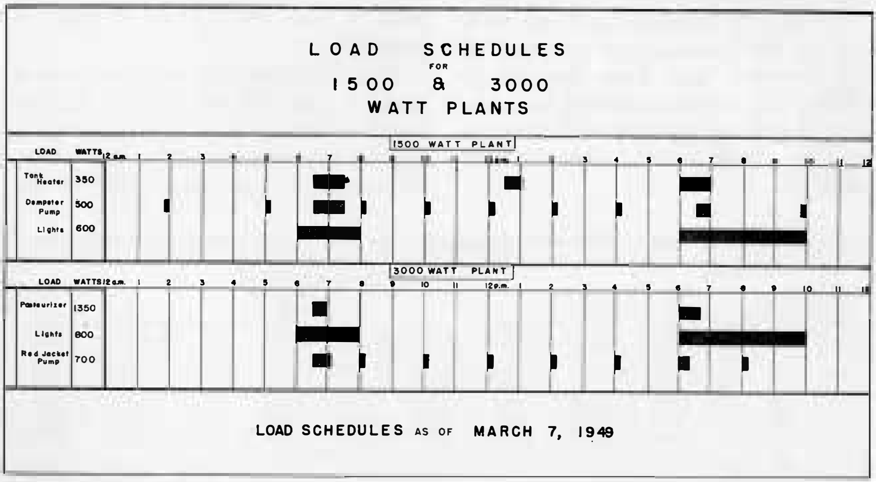

Fig. 3. Time chart showing the "on" periods during the day for the gasoline-electric plants.

such as a refrigerator, had their own automatic starting switch, so that when they started, the light plant to which they were attached started. At least one outlet was left to manual control for test and checking purposes. All other controls were run to relay switch outlets.

A large roto-drum mechanism was used to turn the remainder of the loads on and off through relay switches. The roto-drum was driven by a synchronous motor and revolved once every 24 hours. Lobes were placed on this drum in locations to simulate a typical farm load; that is, lights were turned on for a short time in the morning, and from 5 p.m. in the evening. Figure 3 shows the pattern of daily loads for the plants. Each was loaded with three appliances: namely lights, a heating appliance, and a motor.

Preliminary tests were first run to adjust this automatic load to about 6 KWH's per day. Actually on the longer tests the large plant averaged nearer 7 KWH's per day. It was neither essential nor possible to keep the plants running at an exact number of kilowatt-hours per day.

Fuel costs seemed to be a major item with the gasoline plants and Figures 4 and 5 give the kilowatt-hours per week and the fuel consumption per week of the extended tests from January to March. The time for refueling and servicing the plants, together with notes on servicing, tuneups, etc., were carefully recorded.

Special tests were then run with gasoline-electric plants to test their dependability and ability to handle loads. A refrigerator was added to the 3000-watt plant load for one month. The plant handled this additional load above its average of 6 KWH's per day. Fuel costs increased sharply due to the much more frequent starting and stopping of the plant. Daily consumption increased from 6 to 8 KWH's and daily fuel consumption from 2½ to 5 gallons.

The 3000-watt plant was then given a series of trials with loads of 4, 5, 6, 7 and 8 KWH's per day. The cost per kilowatt-hour in each case included the costs of fuel, labor, oil, repairs, services of labor for repairs, depreciation, and interest on investment. Table 2 gives the data for these calculations.

The 1500 watt plant was also loaded with the refrigerator for a 30-day test. It would not always start when two heavy loads came on at once, so the pump motor had to be taken off. Thereafter the plant handled its load satisfactorily except for a few times when several switches were turned on at once; the safety switch at the refrigerator would disconnect the machine, leaving it turned off until it was noticed and turned on manually.

The 1500-watt plant was also given a series of trials of loads, varying in kilowatt-hours per day of 3, 4, 5, 6 and 7. Cost figures were kept in the same manner as with the larger plant. Data for the

Table 2. Operating Costs for 3000-Watt Gasoline-Electric Plant with Various Daily Consumption

Daily consumption KWH	Totals: KWH generated	Totals: Hours run	Totals: Cost of Fuel consumed	Costs per Kilowatt Hour: Fuel consumed	Labor for refueling	Oil	Repairs	Service and repair labor	Depreciation	Interest on investment	Total cost
4	48	84	$ 6.43	$0.13396	$0.0125	$0.0245	$0.0044	$0.0188	$0.1312	$0.0206	$0.3478
5	110	154	13.49	.12264	.0099	.0158	.0035	.0150	.1050	.0164	.2883
6	210	245	21.38	.10181	.0083	.0163	.0029	.0125	.0875	.0137	.2431
7	56	56	5.19	.09264	.0071	.0139	.0025	.0107	.0750	.0117	.2137
8	24	21	2.08	.08670	.0062	.0121	.0022	.0094	.0656	.0103	.1924
Operating costs for all loads during entire period Jan. 8—May 26											
	840	957		.10844	.0083	.0138	.0018	.0071	.0833	.0138	.2366

Note: Daily running time assumed constant at 7 hours

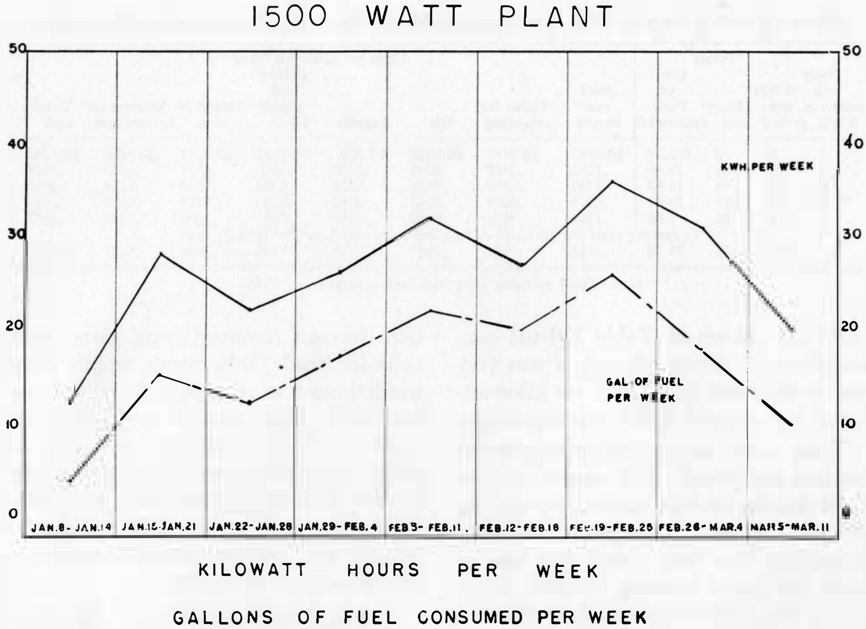

Fig. 4. Kilowatt-hour production and fuel consumption for the 1500-watt plant.

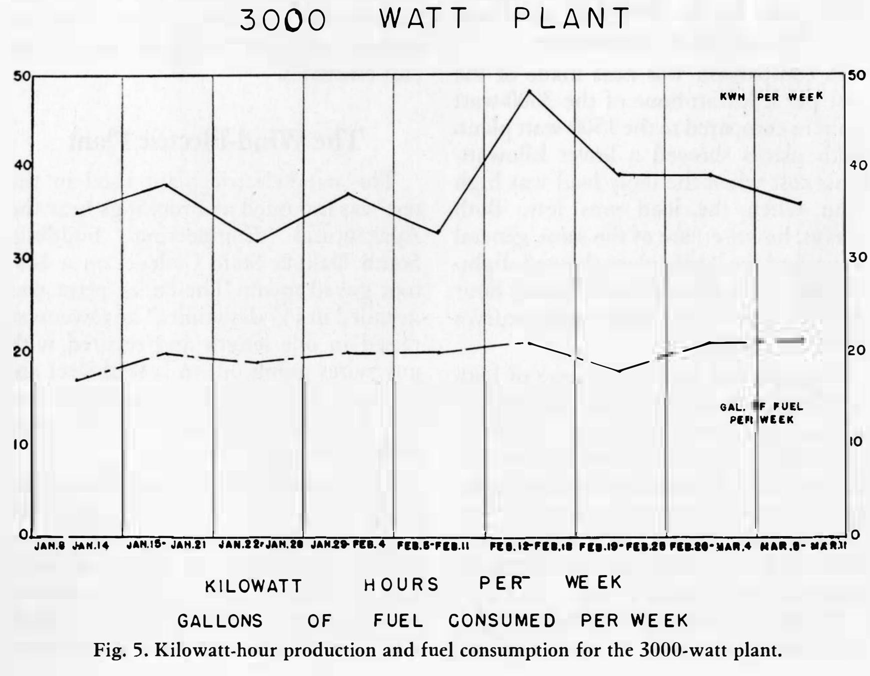

Fig. 5. Kilowatt-hour production and fuel consumption for the 3000-watt plant.

Table 3. Operating Costs for 1500-Watt Gasoline-Electric Plant with Varying Daily Consumption

Totals				Costs per Kilowatt Hour							
Daily consumption KWH	KWH generated	Hours run	Cost of Fuel consumed	Fuel consumed	Labor for refueling	Oil	Repairs	Service and repair labor	Depreciation	Interest on investment	Total cost
3	30	70	$ 3.74	$0.1245	$0.0167	$0.0326	$0.0207	$0.0213	$0.2352	$0.0230	$0.4740
4	152	266	19.09	.1256	.0125	.0245	.0156	.0160	.1764	.0172	.3877
5	150	210	18.68	.1245	.0100	.0196	.0124	.0128	.1414	.0138	.3392
6	246	287	24.07	.0978	.0083	.0163	.0103	.0106	.1176	.0115	.2726
7	56	56	7.06	.1260	.0071	.0140	.0088	.0091	.1008	.0099	.2757
Operating costs for all loads during entire period Jan. 11—June 3, 1949											
	645	1225	74.28	.1152	.0136	.0087	.0136	.0140	.1940	.0187	.3750

Note: Daily running time assumed constant at 7 hours

trials are shown in Table 3. Fuel consumption for the smaller plant was very nearly the same in gallons per kilowatt-hours in 3, 4 and 5 KWH per day range.

Tests were run on various degrees of loading the plants. This served only to demonstrate the fuel economy of having the plant loaded to capacity when it was operating. It is very wasteful of fuel to have the plant running steadily when only a few lights are turned on. Figures 6 and 7 show the kilowatt-hours per gallon for continuous running on given watt loads, for the 3000-watt plant and the 1500-watt plant, respectively.

A comparison was next made of the cost per kilowatt-hour of the 3000-watt plant as compared to the 1500-watt plant. Both plants showed a lower kilowatt-hour cost when the daily load was high than when the load was low. Both curves, however, are of the same general slope, and the larger plant showed slightly lower costs for a given kilowatt-hour per day load. The performance curves are shown in Fig. 8.

One operator had full charge of both light plants. A careful record was kept of all time spent with the plants. At times, daily refueling was necessary, because the original fuel tanks of 5-gallon capacity were used. This need not be the size of tank used on regular farm installations. Oil was changed according to manufacturer's instructions.

At the manufacturers' specified times, the engine heads were removed and carbon deposits removed from piston and cylinder head. Only minor repairs were needed, such as repairing an oil leak on the small plant, one fuel pump replacement, governor resetting to keep the plants on 60 cycles per second, and slight trouble with the breaker point assembly. Only one minor replacement was necessary in the automatic control cabinet—that of an electrical relay.

Although not needed on the test plants during the test period, a periodic overhaul is advisable in the life of any frequently-run gasoline engine. Cost of such an overhaul was included in total cost estimates.

The Wind-Electric Plant

The wind-electric plant used in the test was mounted at Brookings near the Agricultural Engineering building, South Dakota State College, on a 105-foot guyed tower. The entire plant was installed in 1½ days time. The tower was raised in one length and secured with guy wires going out to special steel anchorages. The propeller, vane, and generator were then assembled at the turntable on the top of the tower.

The propeller used at the Brookings' trials, was a wood four-blade type, two blades of which had a governor controlled pitch. Thus the generator could turn at charging rate in a very low wind, yet not turn at an excessive speed in high wind. The generator was gear-driven

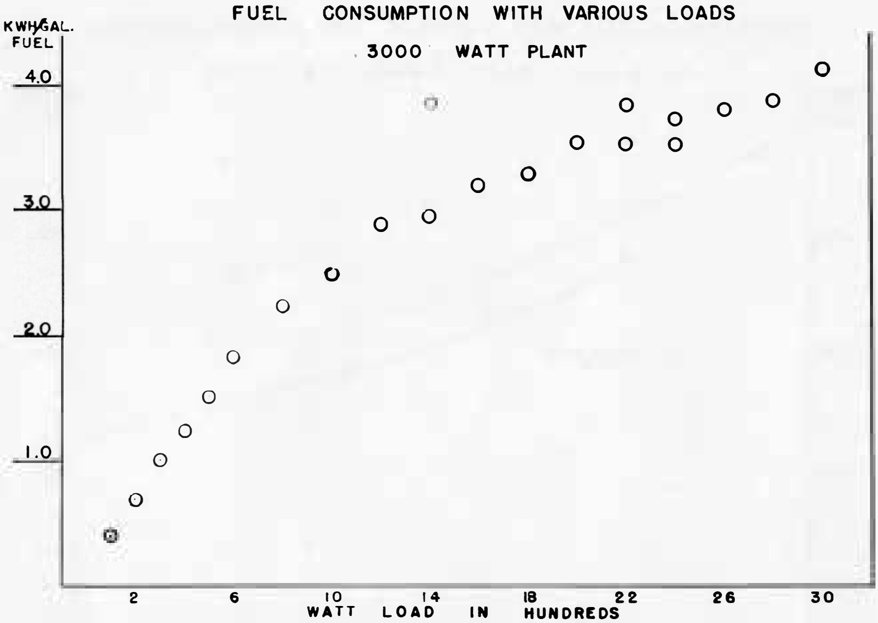

Fig. 6. Maximum loading of the 3000-watt plant gave highest KWH per gallon of fuel.

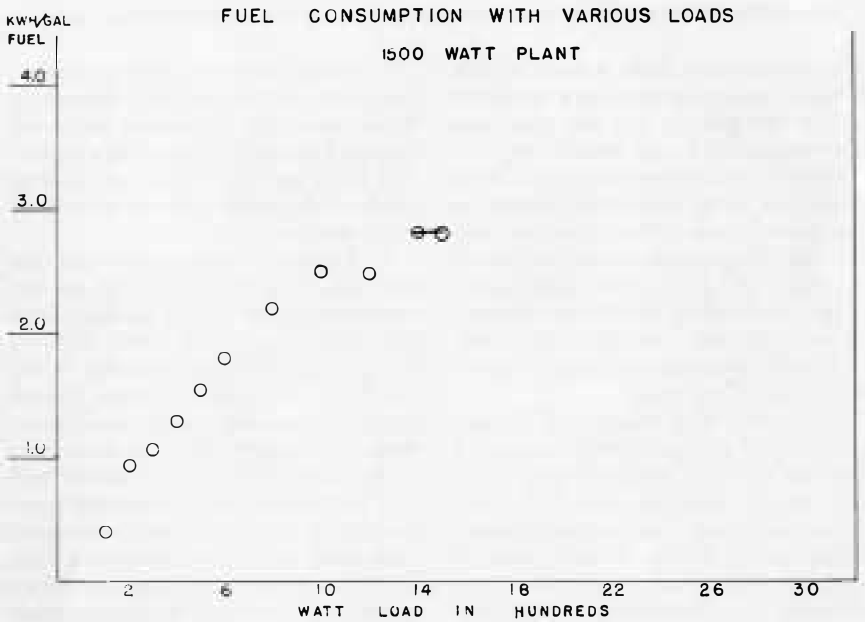

Fig. 7. Maximum loading of the 1500-watt plant gave greatest KWH per gallon of fuel.

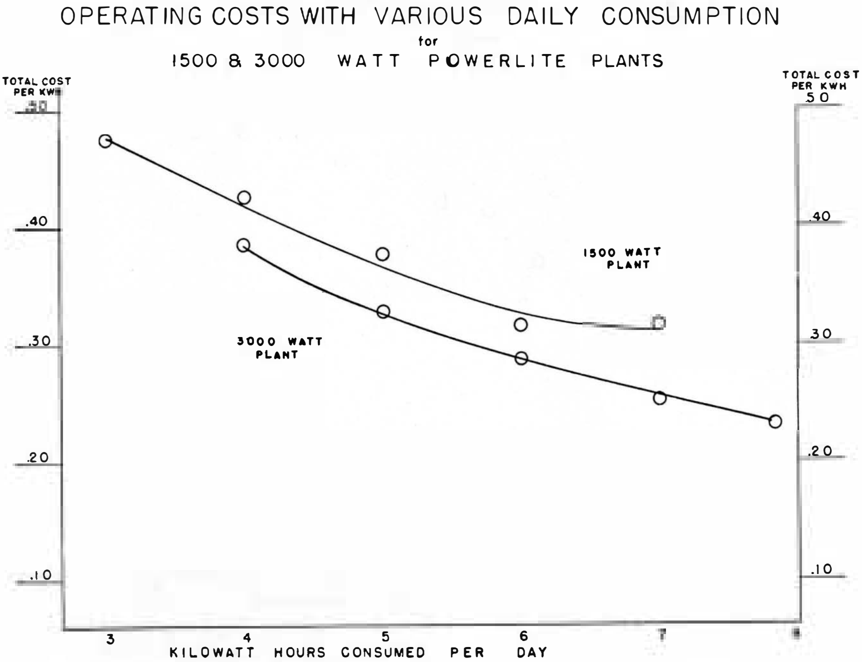

Fig. 8. The 3000-watt plant produced current at a lower cost than did the 1500-watt plant.

from the propeller shaft. A shut-off cable extended down the tower to a hand control at the ground, but the plant was never turned off except for servicing.

Control of charging rates was always taken care of by automatic controls on the control panel. When batteries were low, the charging rate would be allowed to go as high as the wind supplying the power would allow. When batteries were well-charged, the controls would allow only a trickle to enter the battery, regardless of velocity of wind.

The battery bank consisted of 56 glass-jar, lead-cell storage batteries connected in series to provide approximately 110-V DC current. Batteries were of the 180-ampere hour size. The batteries were observed every day as to their state of charge, and every month given an extra charging or "equalizing charge" by turning the controls to a higher rate.

The plant performed without mishap, except for a broken insulator due to a defective part. One instrument panel was damaged by carelessness of the operator. The plant was able to ride out all high winds of the period without wind damage to tower or plant.

At Brookings, where tests were run from July 1947 until July 1948, the batteries were placed in a dry building, with good circulation of air. This building did get slightly below freezing in the winter. It was a good location, though battery tops needed dusting and battery water needed to be added occasionally.

The character of the load did not need to be the same as for the automatic gasoline-electric plants, because the batteries were ready at all times to carry a little load or a big one. Light bulbs turned on continuously served as the major portion of the load and could be set at about 5 to

6 KWH's per day. On days of excess wind, motors, or some tank heaters, were turned on for increased load. A home refrigerator was run almost all of the time as part of the load.

A typical monthly operation record for the wind-electric plant is shown in Fig. 9. This shows how the battery kept its charge well above the 1.200 specific gravity point, and that the daily kilowatt-hour consumption was 7.6 (av.) although on some days high wind enabled it to go to nearly 15 KWH's per day. Such lavish use of current, however, also allows the batteries to get low and may result in a day or two without use of normal current. A steady load of 6 KWH's per day would have assured one of a more even consumption curve.

A year's results on the wind-electric plant at Brookings are shown in Fig. 10. The two plotted lines follow the same pattern—and should—because the top line is kilowatt-hours per month, while the lower line is average daily kilowatt-hours, for the period of that month. There is some variation, one month with another, in the amount of wind available. There seems to be no set or predictable pattern of wind behavior for South Dakota. On one occasion July was a low month, and on another, November was low.

On the second year's trial the wind-electric plant was moved from the Brookings' location to the Agricultural Experiment substation at Cottonwood, S. D. There the plant was mounted on a 65-foot tower. The same battery set was used and the same generator. However, a new experimental alumnium propeller was placed on the plant. The batteries

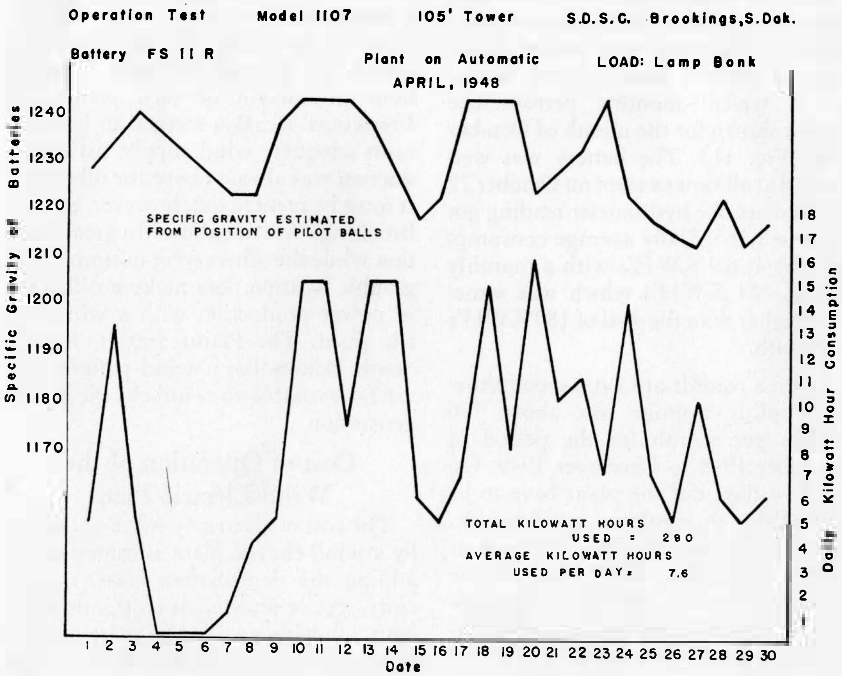

Fig. 9. Battery gravity readings and current consumption records for a typical month of the wind-electric plant.

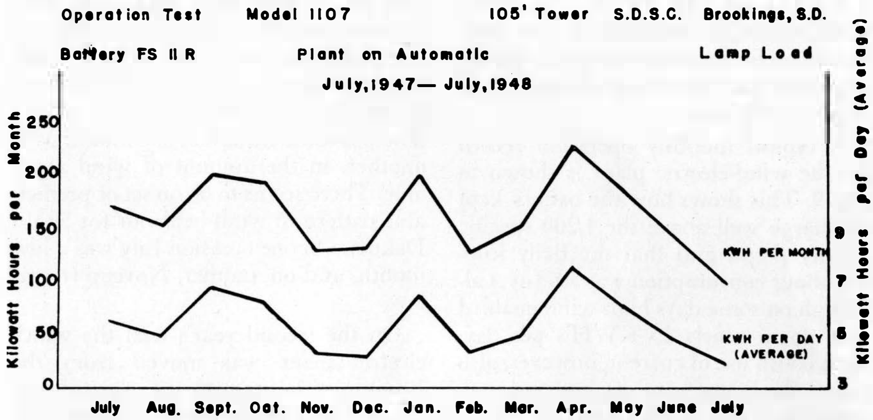

Fig. 10. Daily average KWH, and total monthly KWH, of the wind-electric plant at Brookings.

and the control panel were placed in the basement of the substation manager's home.

The load was a typical farm home load consisting of lights, radio, water-system motor, refrigerator, and added appliances of washer, iron, radiant heater, etc. A typical monthly performance curve is shown for the month of October 1948 (Fig. 11). The battery was well charged at all times except on October 27 and 28 when the hydrometer reading got down to 1.165. Daily average consumption was at 6.9 KWH's with a monthly total of 214 KWH's which was somewhat higher than the goal of 180 KWH's per month.

A year's records at Cottonwood show the monthly average just above 150 KWH's per month for the period of December 1948 to December 1949. On only two days did the plant have to be shut off due to regulator panel trouble. None of the months from December 1948 to December 1949 equalled the month of October 1948 in energy production. Figure 12 shows the year's energy pattern for Cottonwood.

During the summer of 1947 and following, records were kept on three 110-V wind-electric plants at three different locations. The plants were all the same kind as that used for the Brookings' test. One plant was located at Lincoln, Neb.; a second at Sioux City, Iowa, with the third at Brookings, S. D. Figure 13 shows the average monthly kilowatt-hour production of each plant. The Brookings' location seemed to have the most adequate wind supply, as its production was always above the other two. It must be pointed out, however, that the Brookings' test line showed a great variation while the others were uniform. Geographic location does make a difference in power production with a wind-electric plant. The Plains area in western South Dakota has a wind pattern definitely favorable to wind-electric power generation.

Cost of Operation of the Wind-Electric Plant

The cost of electricity when generated by a wind-electric plant is calculated by adding the depreciation costs, interest costs, service and repair costs, and labor costs, allowing an average share of these total costs to be charged against a given period of time, and then dividing by the kilowatt-hour generated in that period.

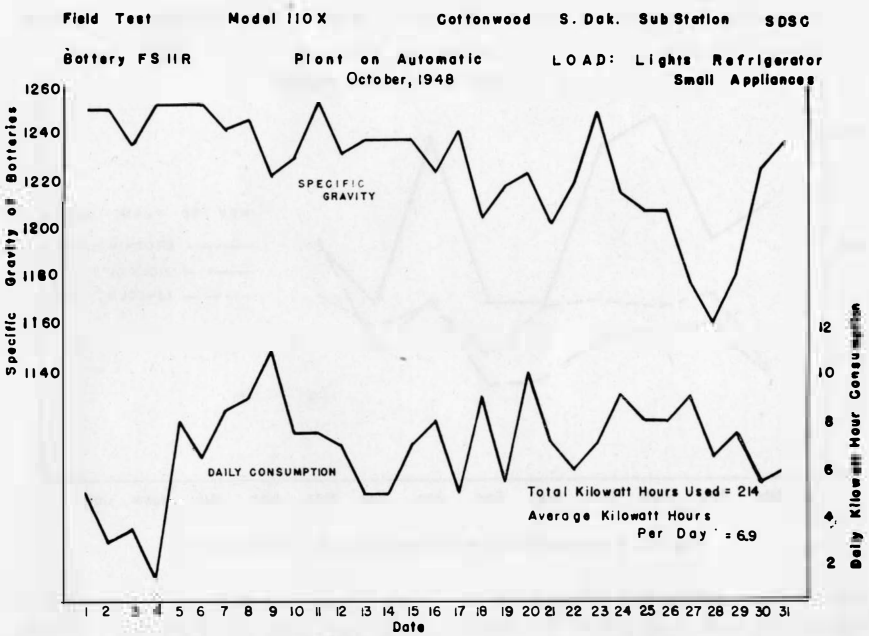

Fig. 11. A typical month for the wind-electric plant at Cottonwood, South Dakota.

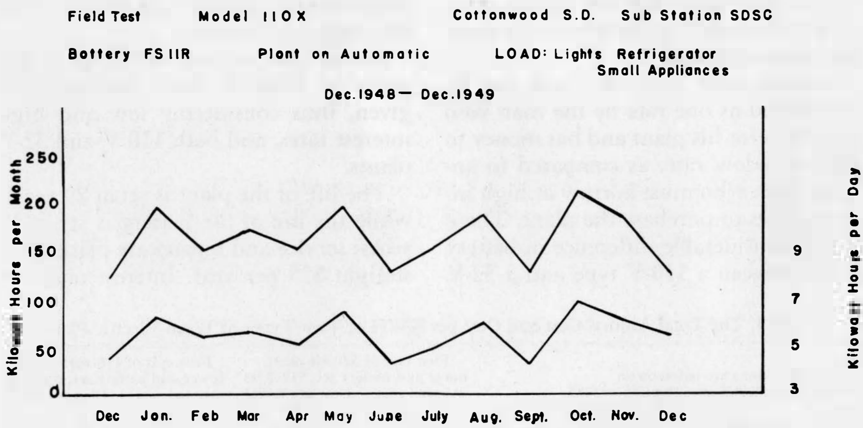

Fig. 12. Electric energy production of the wind-electric plant at Cottonwood, South Dakota for a 1-year period.

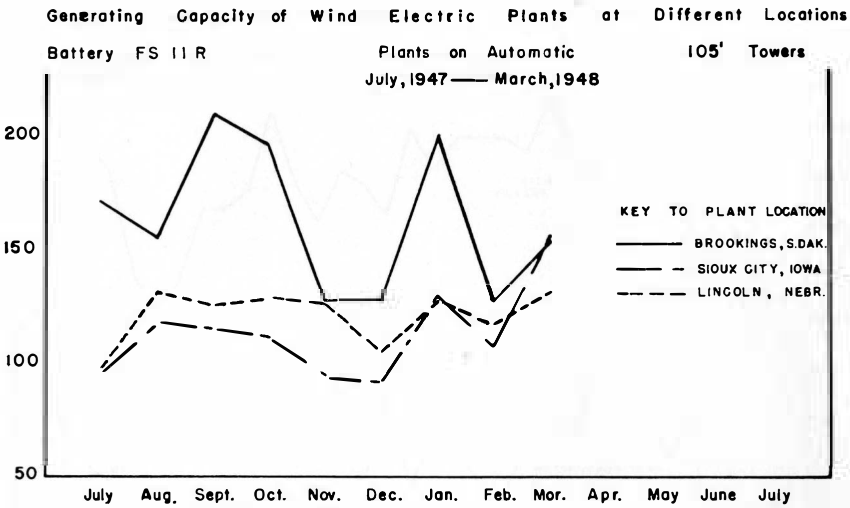

Fig. 13. A comparison of wind conditions in three localities.

Several assumptions and estimates have to be made, such as length of life, insurance cost, annual repair cost, and service costs. Not every owner will want to do the tower work necessary to change oil in the gear case; thus his service costs may be increased by the service call from the territory dealer.

Interest costs may vary and can be considered as one rate by the man who pays cash for his plant and has money to lend at a low rate, as compared to another man who must borrow at high interest rates to purchase the plant. There is also considerable difference in battery costs between a 110-V type and a 32-V type. Some advantages for the 110-V plant were pointed out earlier, but some saving can be had by using the 32-V type. Those batteries which are purchased with the 32-V plant should be of a larger ampere-hour capacity to have the "carry over capacity" needed.

Calculations on cost of electricity are given in Table 4. Four alternates are given, thus considering low and high interest rates, and both 110-V and 32-V plants.

The life of the plant is set at 20 years, while the life of the battery is set at 10 years; service and repairs are placed at a straight $25 per year. Interest rates are

Table 4. The Total Annual Cost and Cost per KWH of Two Types of Wind-Electric Plants

Calculations are based on an average daily KWH consumption of 5.55	First cost of 32-volt plant, tower and battery set, $1448.00		First cost of 110-volt plant, tower and battery set, $1670.00	
	Annual cost	Cost per KWH	Annual cost	Cost per KWH
Depreciation of plant—20 years	$ 52.52	$0.026	$ 52.52	$0.026
Depreciation of battery—10 years	44.30	.0219	66.50	0.0329
Interest on investment—at 3 percent	21.63	.0107	25.05	.0124
Interest on investment—at 7 percent	50.50	.0272	58.50	.0290
Service and repair costs	25.00	.0124	25.00	.0124
Labor costs at 1 hr. per mo. and 1.00 per hr.	12.00	.0059	12.00	.0059
Total costs at 3 percent	133.82	.0769	181.07	.0896
Total costs at 7 percent	184.32	.0934	214.52	.1062

figured at 7 percent in one case and 3 percent in the alternate case. The daily kilowatt-hour consumption was taken as 5.55, or 169 KWH's for an average month, or 2020 KWH's for the year.

Rural Electric Service from the Central Power Plants

The number of farms served by rural electric farm lines has had a very rapid growth since 1935. There were some systems distributing electric current to farms prior to that, but the major growth in rural electrification has come since the REA was created in 1935. Since then, consumers connected to systems made possible by REA loans have grown to 2,500,000.[2] Loans have been made to 952 groups for the nation, and 28 of these groups were in South Dakota (1948). The number of borrowers continues to increase and latest figures give 31 cooperatives for South Dakota with 38 per cent of the farms served. Actually the figures change monthly, and it is impossible to report the exact figures for a certain date.

Patterns have been developed as the many distribution systems have been worked out. In national averages the young cooperatives (1 to 36 months) have 2.25 consumers per mile, and $13.01 monthly revenue per mile. Those systems that have operated 97 months, and over, have 3.69 consumers per mile and a revenue per mile of $26.49. People use more electricity when they have time and money to buy more appliances and plan more ways in which to use it.

In size, the most common operating system has 500 to 700 miles of line. In number of consumers, the most common sizes are those from 2000 to 3000 and 3000 to 5000 consumers.

The 1948 National Summary shows that for every dollar of revenue paid in by the consumers about 33 percent goes for power cost, 17 percent for depreciation, 10 percent for interest, with the remainder for other operating and miscellaneous costs, plus a 10 percent net margin.

The obvious reason why central service power for farm home use is popular is that it gives electric power without the care or supervision of the farmer, and the supply is usually abundant for all needs. A few minor disadvantages have been noted such as low-line voltages at peak-load periods, and temporary outages when storms damage the highlines. The former disadvantage of high cost has been partially overcome by lower cost construction and the long-time loans at low interest rates made by the national government to the cooperatives.

While average figures can be quoted for all cooperatives and states, a more careful study brings out the effect of size, mileage, age, density, etc., on the final cost of electric service to the consumer. For instance, a large group of individual cooperatives can be arranged in order of size, to see if the rates to the consumers become lower as the operating unit size gets larger. The "rate" to the consumer is calculated by dividing the item "KWH's billed" into "operating revenues." This gives an average rate for the year for an average consumer, but it is not necessarily the actual rate for a given consumer.

Most rate scales start with a minimum payment per month, or a sliding rate such as: First 40 KWH's, 6 cents; next 50 KWH's 4 cents; next 210 KWH's 3¾ cents, and all above 300 KWH's, 3¼ cents. Special rates of 1½ cents or 2 cents a KWH may also be given for off-peak water heater rates. Every one shares in the high beginning rates, although the users of large quantities attain the lowest average rates.

In an effort to determine the condi-

[2]1948 Annual Statistical Report, Rural Electrification Administration.

tions in existence that affect the retail rates of individual REA cooperative associations, the rates were plotted against various conditions. Four of those used were (1) the age of the co-op versus rate, (2) the size of the co-op (total number of consumers) versus rate, (3) the density of the line (consumers per mile) versus rate, and (4) the consumption per mile versus rate.

In the study made on the effect that the age of a co-op has on the rate, it is safe to conclude that up to the time a co-op reaches the age where it is no longer growing and the consumption and output are no longer increasing, the rates decrease as the co-op becomes older. In the study, seven states were included, and five co-ops were taken from each state. The general run of curves showed a definite decrease in rates with an occasional increase for a short period of time. At no time did any one co-op show an increase for more than one year.

The total number of consumers in a co-op apparently has no appreciable effect on the rates which that co-op charges. Six states from various parts of the country were used in this study with about seven co-ops used from each state. The lines representing the points plotting the size of the co-op versus the rate showed very little increase or decrease. There appeared to be no marked relationship between the two.

It would seem logical to assume that the greater the density of the line, that is the number of consumers per mile, the cheaper the rates they would have to pay. This is in general true, but does not hold in all cases. The assumption holds true in the western and more sparsely settled states such as Kansas and Idaho where there is a larger variation in densities of consumers between different co-ops. However, in the midwestern states of Illinois, Indiana, and Iowa, the variation in density is small and no relationship to the rates is shown. Still, from the 13 states studied it was observed that the greater the variation in densities of co-ops, the greater the variation of rates, and in general, the co-ops in more densely populated areas charged lower rates.

A more definite relationship was noted when the consumption per mile was plotted against the rates charged. Here again, a more marked relationship was observed in the more sparsely settled states, but the states of Iowa, Illinois and Indiana also showed a definite decrease in rates as the consumption per mile increased. This was true in all of the 13 states studied.

It appears that the greatest factor determining the rate is the amount of electricity that can be sold on a given length of line. In other words, the more electricity a co-op can sell for a given amount of line that it has to build and pay for, the less it is necessary to charge for each kilowatt-hour in order for the line to pay for itself. This is, in part, a combination of two of the other factors, that is, the density of the line and the age of the co-op. As a co-op grows older, the consumers on a given line increase their individual consumption by the addition of electrical appliances. This, of course, increases the consumption per mile, and in turn decreases the rates.

There are other factors which affect the rates, an important one being the wholesale rate which the co-op has to pay. An added mill per kilowatt-hour on the wholesale rate will naturally cause an added mill per kilowatt-hour on the retail rate, regardless of density, age, or consumption.

Other factors which determine the cost of line construction and maintenance such as land terrain, soil, transportation costs, and extremes in weather conditions, will also have an indirect effect on the retail rates. These factors will vary in different localities and have no relation

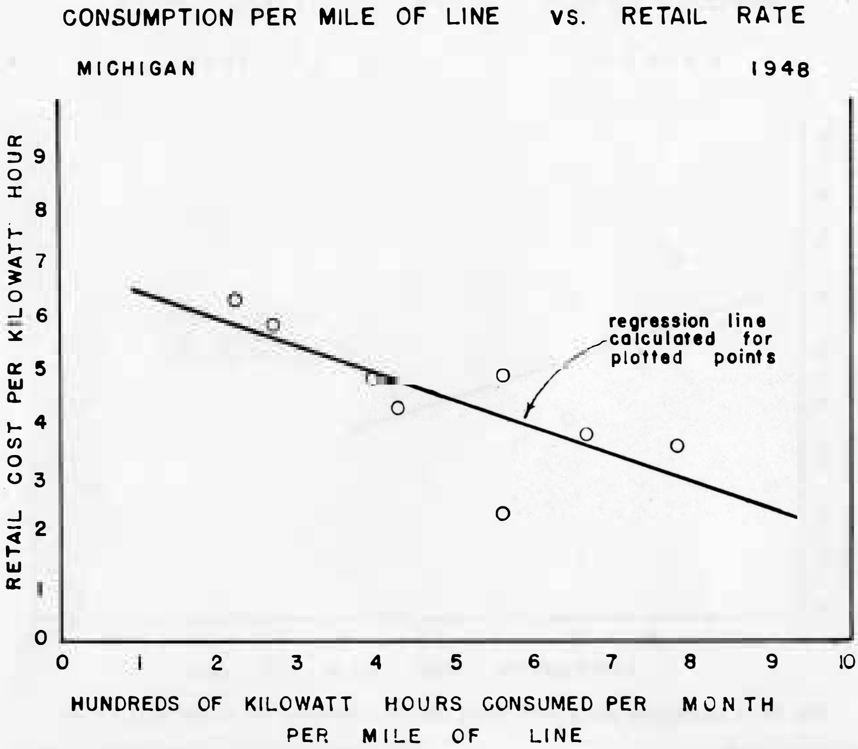

Fig. 14. A state group-study graph showing consumption per mile and corresponding retail rates.

to the other four main conditions used in this study.

Figure 14 shows how revenue per mile affects rates on REA lines. It is probably not possible always to predict the revenue per mile of potential rural electric territory by knowing only the average customers per mile. Something must be known of their farming enterprise and the size of the farm and home units. Certainly the size of income and the potential buying power has much to do with the quantity of current used on a given farm. Farmers in a dairying community could expect to use profitably more electrical energy in the production, processing, and storing of milk products, than farmers in a grain farming area.

The density of the REA line, or the consumers per mile is known, however, from the start of survey work for a project. Although density versus rate does not coordinate as closely as revenue-per-mile versus rate, it is a fair indicator. Figure 15 shows such a relation. The national average of density is 3.09 consumers per mile (1948). At that same time the average density of 7 cooperatives in southeastern South Dakota was 2.75 consumers per mile of line. In the newer projects of northeastern and central South Dakota, line density averages 1.32 consumers per mile. Those scattered sections of western South Dakota which had REA lines showed a density of 2.03 consumers per mile, not counting one cooperative with many city customers connected, which had 8.97 consumers

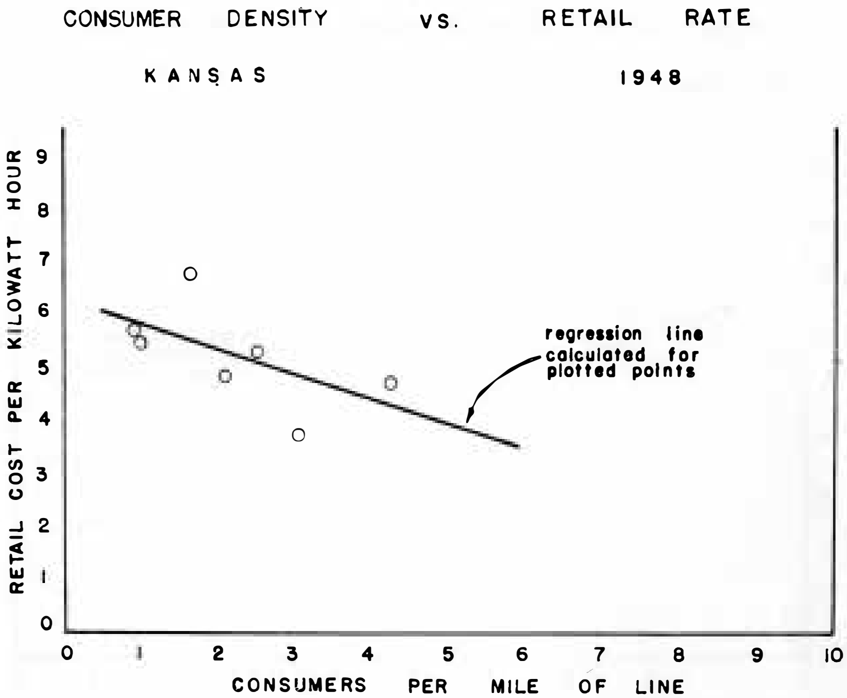

Fig. 15. A typical state group-study graph showing relation of line density to retail rates.

per mile listed.

The range country presents a problem of very low line density and, therefore, a reduced revenue per mile. Of the consumer's dollar (1948) spent for electrical energy 17 percent went for depreciation of the lines, 10 percent for interest on line building loans, 5 percent for maintenance, and 14 percent for other expenses, and these do not include cost of power, net margin, or operation costs. This was a national average figure with 3.09 consumers per mile and an average retail rate of $.0318 per kilowatt-hour.

Starting with these average figures, an attempt has been made to predict the increase in retail rate as density per mile decreased, other figures remaining constant. Table 5 shows the summary of a series of calculations.

While the 46 percent of the revenue dollar, representing line costs, repayment and interest, might not increase in direct proportion to the miles of line per customer, there would have to be a substantial increase in rates to retire a heavier line cost per customer in the same length of time. Line construction costs vary with the times but usually run from $800 per mile to $1200 per mile. From Table 5, it can be seen that line costs would become economically unsound in territories where from 3 to 5 miles of line were needed per consumer. The alternate ways of providing electric service would be less costly than highline service.

Ranch Country Survey

During the fall of 1949 a survey was made in the central and western parts of South Dakota concerning the status of farm utilities and the wishes of the farmers as to the kind of utilities they would like to have. The surveyors visited 62

Table 5. Relationship of Rate Increase to Line Mileage Increase*

	Miles of Line per Consumer					
	¼	½	1	2	3	5
Basic rate	.0318	.0318	.0318	.0318	.0318	.0318
Extra rate cost due to linear increases of line costs	.0000	.0146	.0252	.0730	.1170	.2040
Resulting rate	.0318	.0464	.0570	.1048	.1488	.2358

*Estimated.
Density 3.09
Rate—.0318 KWH

Consumers dollar	
Dep.	17%
Int.	10%
Main.	5%
Other	14%
	46%

farms in 21 counties and discussed the utility situation with the farm owners. A questionnaire was filled out by the survey man, although it was not always possible to secure a complete set of answers.

When the survey blanks were tabulated and summarized, the following answers were obtained:

1. Twenty-three of the 62 farms still used kerosene lights, and had never had electricity.
2. Seventeen of the group had used, or now use, gasoline generator and 32-V battery light plants.
3. Three used automatic gasoline-electric plants of 110-V AC current.
4. Two had 6-V wind-electric plants, 27 had 32-V wind-electric plants, and 3 had 110-V wind-electric plants. One farm had a diesel-electric plant.
5. Forty-three of the 62 farms had propane-butane as a fuel for kitchen range, 10 used this fuel in their furnaces, 25 used gas refrigerators, and 6 had gas water heaters.
6. For the farms where kerosene or distillate was used, 10 were heating homes with this fuel and 2 had kerosene burning refrigerators.
7. Of the 62 farms, 15 had flowing wells, 11 had windmills with gravity tank system, 5 had windmills only, 2 used engines for pumping, 6 used cisterns, 1 used spring water, 1 used water from pond, and one had no source of water.

The group interviewed did not know all the details of organizing an REA cooperative, but most understood the organization to be a cooperative, and that the National REA loaned money to construct the lines. Many had paid the $5 application fee and understood that to be one share and one membership in the coming cooperative organization, when and if it could be organized. These potential REA patrons estimated that their current might cost them from 6½ cents a KWH to 15 cents a KWH, though some were entirely uninformed about rates.

1. Prospective users estimated that they could, or would, like to pay $5 to $10 per month.
2. The average distance of the farm from town was 11.35 miles, but actual distances varied from 1 to 40 miles.
3. Miles to the next farm averaged 1.68, but varied from one-half mile to 8 miles. Seven out of the 62 farms were 3 miles or more from a neighboring farm.
4. The average for the 62 farms was 10½ miles to a hard-surfaced road.
5. It was an average of 10½ miles to the nearest known electric highline. In this last respect some farms were 40, 50, or 60 miles away from a known highline.
6. Many stated that preliminary steps had been taken in this community to organize an REA.

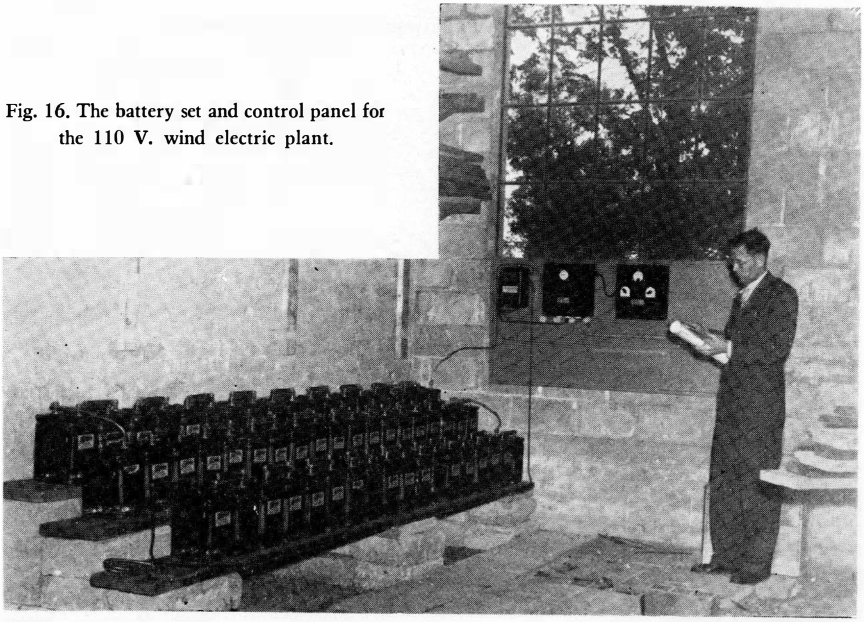

Fig. 16. The battery set and control panel for the 110 V. wind electric plant.

Summary

1. Studies of REA annual statistical figures of 1948 show that the average kilowatt-hours per month per farm is 110 for the new cooperatives and 202 for those that have been in operation 8 years or more. In South Dakota the average KWH per month per farm in 1948 was 124.

2. Tests showed that the gasoline-electric plants can generate current for the average farm at 24 cents per KWH. The wind-electric can provide current for 7½ to 10½ cents per KWH. The existing REA Co-op rates are near 3½ cents per KWH.

3. The 3000-watt gasoline-electric plant of the 110-V, AC automatic control proved adequate to handle loads up to 180 KWH's per month on typical farm pattern loads.

4. The 1500-watt automatic gasoline-electric plant proved capable of carrying a similar 180 KWH per month load, but sometimes gave trouble in starting several heavy loads that came on simultaneously.

5. The 110-V, DC, wind-electric plant, with the 180-ampere hour battery size proved its ability to generate a daily load of 5 to 6 KWH's and a monthly load of 150 to 180 KWH's. Larger battery sizes are available to carry over energy for longer periods when the wind is not adequate to run the plant.

6. Geographic location makes a difference in the output of a wind-electric plant, and the wind velocities of western South Dakota are favorable to this type of plant.

7. Approximately 33 percent of the revenue paid by the REA consumer is for the wholesale purchase of power. Average wholesale rates in South Da-

kota are 1⅓ to 1½ cents, and average retail rates are 3 to 4 cents per KWH.

8. REA retail rates decrease slightly as the co-op gets older, and more current is used.

9. The very large REA cooperative has no advantage in lower retail rates over smaller cooperatives.

10. In states where there is a density contrast in consumers per mile, the operating systems with the greater density have the lower retail rate, but there is almost no data available for systems with densities less than one farm per mile.

11. In all cases studied the greater the KWH consumption per mile, the lower the retail rate.

12. Calculations would indicate that, other costs remaining the same, if line costs were increased by having only one customer in 3 or more miles, alternate ways of generating farm electric power would be cheaper than central station service. There are areas in western South Dakota where line density would fall below the limit of 1 farm to 3 miles of line.