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16. Abstract

This report describes the site selection, initial cost and installation of a Small Wind Energy Conversion System. A description of the first two years of operation is also included. A 25 kwh system was selected and installed at Wichita Falls on the grounds of the District Office. The system operated trouble free for the first two years and produced approximately 40,000 kwh of electrical energy.

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Installation of a SWECS at the Wichita Falls District Office

by

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and

Frank S. Craig

Research Report 545-3F

Research Study 1-3D-81-545

Conducted by

District 3 Office
Wichita Falls, Texas
and
Transportation Planning Division
Research Section
State Department of Highways
and Public Transportation

In Cooperation With the

U.S. Department of Transportation
Federal Highway Administration
Demonstration Projects Division

May, 1984

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

The United States Government and the State Department of Highways and Public Transportation do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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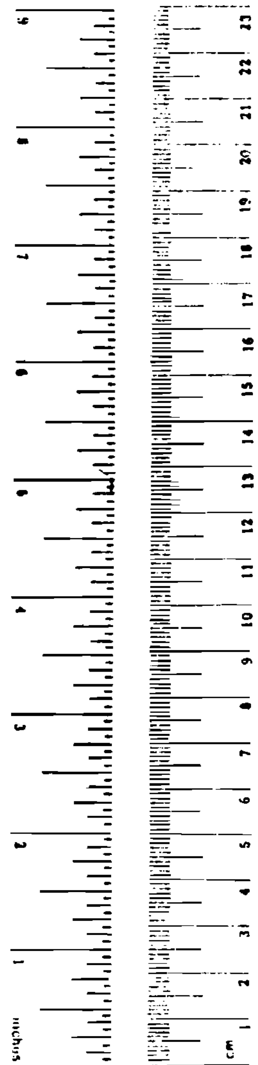
The personnel from the Wichita Falls District (District 3). These personnel not only assisted in the site selection, equipment selection and installation of the equipment, but prepared the grounds, constructed the foundation, laid conduit and cabling, installed the monitoring instruments and collected data produced by the instruments. The District is under the general supervision of Mr. Jimmy L. Stacks, District Engineer. Supervision of the work was performed by Mr. Frank S. Craig and Mr. Frank L. Ragland. Special thanks are given to Mr. Robert Fenoglio and Mr. Jerry Harris who performed much of the work mentioned above and who monitored the daily operation.

Texas Electric Service Company, particularly Mr. Jack A. Harris, Marketing, Research, and Training Manager, and Mr. R.D. Vickers, Customer Representative, for the suggestions, information and aid received in the installation and operation of the SWECS unit.

METRIC CONVERSION FACTORS

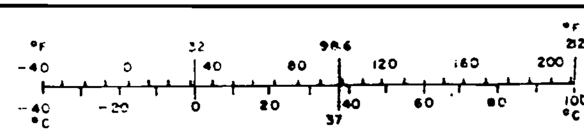
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Implementation Statement

The implementation of this report is inherent in that a Small Wind Energy Conversion System (SWECS) is to be installed. This project will demonstrate the capabilities of a SWECS. The project is open to the public and a display area showing actual operation, and past and present power production has been made available. Continuous print-outs of wind velocity, wind direction, power consumed by the facility and power produced are on display. Small written articles and advertisements have been forwarded and used by several newspapers. Therefore, it is believed the implementation of this project will be that of providing knowledge to interested parties concerning future use of such systems.

Summary

This report describes the site selection, equipment cost and installation methods of a Small Wind Energy Conversion System (SWECS). After considerable study, discussions with knowledgeable people, and observations of working systems a 25 kw unit was selected for installation and demonstration. The unit was installed at the maintenance and storage area at the Wichita Falls District Office. The initial cost of the equipment was approximately $25,000 including the equipment, installation, periodic inspection and minor modifications by the manufacturer. Only a few manufacturers of this size unit were found, but the manufacturer with the lowest cost, meeting the requirements proposed, was Jay Carter Enterprises, Inc., at Burkburnett, Texas. The unit was installed May 12, 1982, and put on line at 3:40 p.m. At the completion of a surveillance period of about two years, the unit had performed satisfactorily and produced about 40,000 kw of electrical energy.

[On April 29, 1984, the SWECS unit was found to be inoperable with one blade slightly feathered or twisted out of alignment. Further investigation indicated the possibility of a broken tendon in the edge of the fiberglass blade causing a relaxation of the shape of the blade. Jay Carter Enterprises indicated both blades should be replaced with a matched set. This was accomplished at a cost of $1500. The problem occurred about two weeks before the unit had been on line for two years (age--102 weeks). Because this report had been nearing completion at the time of occurrence, this information will not be repeated in the report.]

Recommendations

It is important to note that about one half of the electric service company charge stems from the "demand" term (peak use period or largest use in a 15-minute period). If demand could be reduced, savings would be significant. Peak use of electricity in the office complex should be studied and reduced if possible by staggering the activation of equipment. Also, it may be desirable to consult with companies which specialize in providing energy management techniques.

This project has demonstrated the feasibility of installing and using SWECS units. It is recommended units be installed and used where District personnel believe such use would be beneficial.

INSTALLATION OF A SWECS AT THE

WICHITA FALLS DISTRICT OFFICE

I. Background

At the initiation of this project the United States had just experienced a period of critical shortage of fossil fuels at the retail market level. Even though more stable supplies are presently available, attempts are being made to study alternate or so-called renewable energy sources for present and future use. This project was initiated to demonstrate one form of such an energy source - the power gleaned from the wind.

After considerable study, it was decided to select a Small Wind Energy Conversion System (SWECS) in the 25 kw range. It was reasoned that this size unit would be the size most used by the more isolated Departmental field offices and a size most economically priced for small businesses or small rural groups of say three to four dwellings to a unit.

Several visits were made to sites having operating equipment and discussions were held with people knowledgeable in the SWECS field. These visits produced excellent information. For example, Dr. R.N. Clark working with the U.S. Department of Agriculture and in cooperation with DOE was developing information on SWECS.(1) A visit with Dr. Clark at Bushland, Texas, proved very beneficial. The DOE study at Bushland involved several vertical axis "egg beater" type units along with a down wind horizontal axis unit which was used to provide power for agricultural purposes. Also a visit with Dr. Vaughn Nelson and the personnel at the Alternative Energy Institute, West Texas State University in Canyon, Texas, was helpful not only in providing information on SWECS units but also in providing wind velocity and direction information.(2)

II. Object

The object of this report is to provide information concerning the site selection, equipment costs and installation methods in setting up a SWECS, along with performance information of the SWECS selected.

III. Site Selection

The basic criterion in the site selection was that the site be on Departmental grounds. Also, the site should be in a position to receive the best available wind velocity with consideration of the dominant wind direction if possible. The site should be such that noise and other distractions to the surrounding houses or public be non-existent; however, the unit should be highly visible to the public in order that inquiry and demonstration could occur. Considerable monitoring of the unit was planned; therefore, the unit should be

(Numbers in parentheses are related to publications in the References.)

sited at a location within easy access by monitoring personnel. After considerable planning and discussion, a request was made to the FHWA and permission received to locate the unit on the maintenance and storage yard at the Wichita Falls District Office. It had originally been planned to set up wind and weather monitoring equipment at two or more locations where Departmental offices were located. Wind data would have been collected for approximately one year while the SWECS was being fabricated. The site having the best wind velocity information would be selected for installation. But as it developed the SWECS was available prior to receiving the weather monitoring equipment. It was necessary to accept the SWECS or experience a lengthy delay. However, a procedure of studying the wind information prior to site selection is recommended for future use.

The storage yard at the Wichita Falls District Office is several hundred feet back of the warehouse. The warehouse in turn is approximately 300 feet back of the main portion of the complex. The main office faces a highway which is a major city street in Wichita Falls. The storage yard is at or near the crest of a long rolling hill; therefore, the SWECS is highly visible to the public passing on the street and the unit is in an excellent position to receive the winds from every direction without excessive turbulence. The nearest housing or dwelling is approximately 1000 feet from the SWECS.

Studies were made of the effects of noise to the surroundings by obtaining readings with a meter which measures noise in decibels. This testing was obtained prior to site selection by visiting sites having a SWECS unit similar to that being purchased. Values were obtained at one location on more than one occasion. Readings were obtained in four directions at various intervals beginning at the SWECS tower and moving out until the values did not change (obtained a common or background noise level). In no case was the reading greater than 71 dBA with a 60-foot tower. A background noise level of 48 to 52 dBA was achieved about 150 to 200 feet from the tower. Therefore, a difference of 15 to 20 dBA can be attributed to the SWECS; however, little effect of noise was noted at a distance of 150 feet from the tower.

IV. The SWECS Unit

After considerable study, which included reports from the DOE experiments at Rocky Flats, Colorado, it was decided to select a horizontal axis, downwind, SWECS.[3] It developed that only a small number of manufacturers (3 companies in 1980) produce a SWECS unit in the 25 kw size range. Therefore, requests for price information and operational details were forwarded and received from manufacturers which had 25 kw SWECS units available. The manfacturer with the lowest cost meeting the requirements proposed was Jay Carter Enterprises, Inc., at Burkburnett, Texas. Specifications for the required unit may be found in Appendix A.

V. Equipment Costs

Jay Carter Enterprises bid $25,000 for the SWECS unit complete with 80-foot tower and installation. It was necessary for the Department to construct the foundation and provide the conduit and cabling from the meter near the office complex to the SWECS. The Department also provided the services of an electrician to connect the system to the service company grid. The following are costs associated with the installation of the system:

1.	Carter Wind Generator Model 25 with 80-foot tower	$25,000
2.	System components and delivery costs	1,410
3.	Conduit and Cabling	550
4.	Electric Work	200
5.	Foundations (Material, Equipment and Labor)	750
	Total	$27,910

VI. The Electric Utility Company

During the initial planning, Texas Electric Service Company (TESCO), which supplies power to the Wichita Falls area, was contacted. From the initial contact a high degree of interest and aid has been received. The company supplied watt meters and pulse generators (purchased) for monitoring energy outputs. TESCO also offered to share digital type data from a pulse generator attached to a watt meter used to monitor the generator output.

VII. Installation Methods

The SWECS was delivered and installed on May 12, 1982. The installation was performed by a well-trained crew using well-endowed and specialized equipment. The unit was delivered on a trailer especially equipped with mountings to contain the components while in transport. The trailer was towed by a medium-size truck (see Figure 1).

Prior to installation departmental personnel had constructed the foundation for the unit as directed by Jay Carter Enterprises, Inc. The foundation consisted of six small concrete pads. The top of the pads was finished close to ground level and the remainder of the pad was constructed so as to be relatively deep in the ground. Figure 2 shows one of the pads and the installation of hardware by the contractor.

One of the pads was in the center or surrounded by four other pads which were at the north, south, east, and west positions and at a uniform distance from the center pad. The center pad contained the mounting for the tower (See Figure 3) and the other four pads were used as tie downs or "dead men" for cable bracing. The sixth pad contained a brace to hold the generator off the ground

Figure 1 - SWECS Transport

Figure 2 - SWECS Foundation

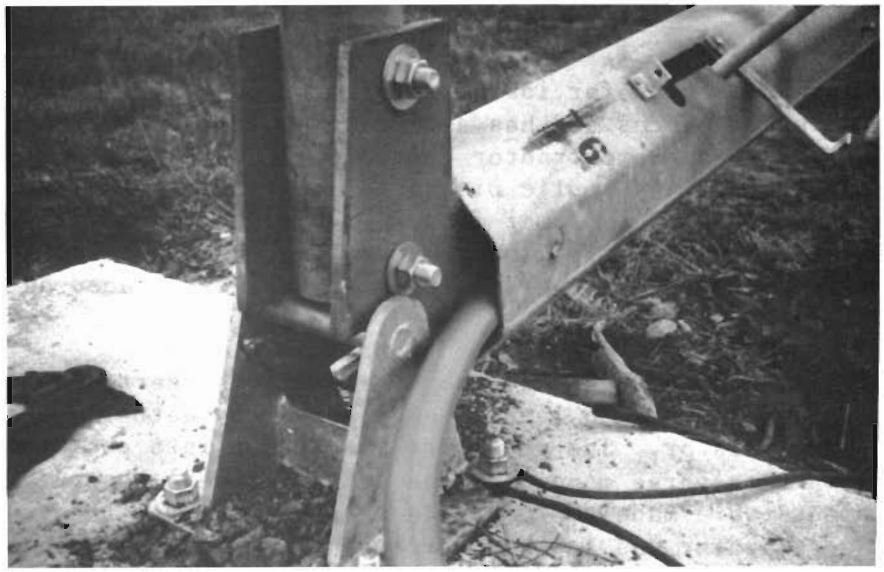

Figure 3 - Tower Mounting

Figure 4 - Connection of Tower Lengths

when it is in a lowered position for installation or maintenance. The 80-foot tower was delivered in two pieces and has a larger diameter at the top than at the bottom. Figure 4 shows the contractor connecting the two parts of the tower which is accomplished using a hydraulic piston attached to a preprepared clevis on each part. One end of the tube tower fits into the other end with a close tolerance in the end dimensions. The lower end of the tower was fitted to the support on the center pad and the tower, with generator, was placed on the brace on the sixth pad.

The cable braces were attached and some tension was exerted on the "side" cables. Provision has been made to level the generator by actually observing a level mounted on the generator. The generator was raised into position and the two levels mounted in a traverse manner on the generator were observed using a telescope. Adjustments were made to the cable lengths to level the generator. After leveling, the generator was lowered for further work. Figure 5 shows a view of the generator with the top cover removed to mount the transverse levels. Figure 6 shows the contractor observing the levels so the cabling can be adjusted to level the generator horizontally. When complete the side cables remain in position and the "front" cable has received a set length. The rear cable and a gin-pole arrangement allow the generator and tower to be raised and lowered using a pulley system. The truck was used to pull the tower and generator up and also to lower the unit. This operation is shown in Figure 7.

The blades were installed and adjusted as shown in Figures 8 and 9. When complete the tower was again raised with the gin-pole, pulley-cable, and truck as shown in Figure 10. Instrumentation provided by Jay Carter Enterprises was mounted near the generator as shown in Figure 11. After the electric cabling was attached and checked out, the system was initiated. The unit was put on line at 3:40 p.m.

At a later date a winch mechanism was purchased and installed. The winch replaced the truck method of lowering the tower and generator. Also at a later date a lightning rod was purchased from and installed by Carter personnel.

VIII. Data Collection System

A microprocessor system was installed to monitor the performance of the SWECS unit and to collect weather information. Figure 12 shows the equipment as installed in the District Office. The system obtains weather information from a digital weather monitor and energy information from the pulse generators on the watt meters described previously. The data was processed, stored on a cassette, and hourly reports printed for display as part of the demonstration of the system. A listing of the program used to process the data at the District Office may be found in Appendix B.

Figure 5

SWECS with Cover Removed

Figure 6

Leveling the Generator

Figure 7 - Raising the Unit

Figure 8 - Blade Installation

Figure 9 - Blade Adjustment

Figure 10

Completed Unit

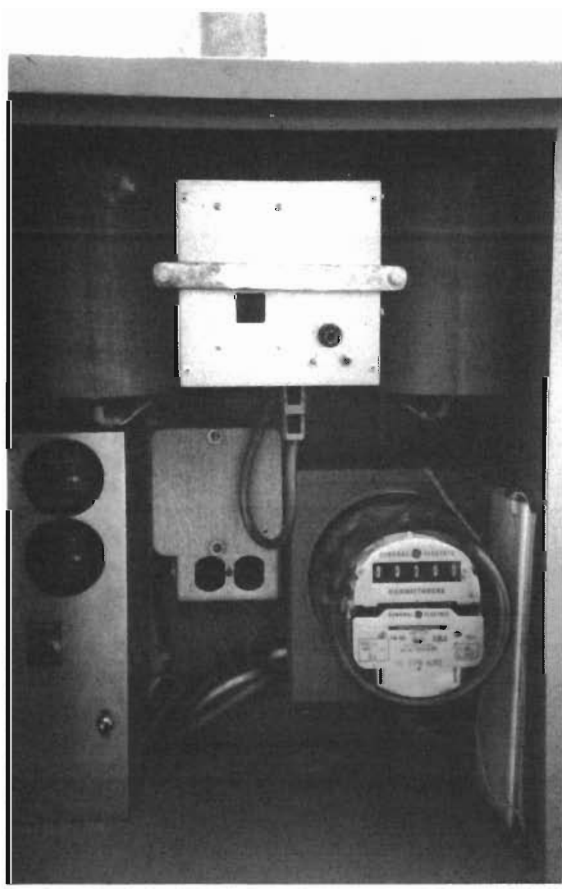

Figure 11

Instrumentation

Figure 12

Data Collection Unit

Later, three reports were prepared from data stored on the cassette. One of these reports was a daily plot of the hourly averages or summaries. An example of this plot is shown in Figure 13. Note, two days are shown with hourly time intervals on the vertical axis and two different scales on the horizontal axis. Four plots are used showing energy output by the generator, total energy consumed by the District Office complex (note the scale value should be multiplied by ten), average wind velocity, and the cubed average wind velocity. The average wind velocity is the arithmetic average of velocities obtained at one-second intervals. The cubed average wind velocity was calculated by obtaining one-second wind velocities, cubing the one-second velocities, and summing the cubes for a one-hour interval. The one-hour sum of the cubes was then divided by the number of one-second observations and the cube root of this value found. This cube root value is the cubed average wind velocity for the hour in question.

An example of the second report is found in Figure 14. This report is a monthly summary composed of daily values. The daily values were obtained from the hourly data similar to that explained in the plot of Figure 13. In addition, the average daily temperature is shown along with the Theoretical Wind Power generator efficiency and (dominant) wind directions. The Theoretical Wind Power is a calculated value based on the measured wind velocity cubed, air density, the swept area of the blades of the generator, and a "pile-up factor" of 59.2 percent. The Efficiency of the Generator is the quotient of the power produced by the SWECS divided by the Theoretical Wind Power. It should be noted that a watt meter for the SWECS output malfunctioned and was removed on October 1 through 5, 21 and 22, and 27 through 28, 1982. Also the microprocessor was down for several hours on October 6, 1982, which affected the value shown for Power Used by Facility.

An example of the third report is shown in Figure 15. The third type of report contains wind information and allows the observer to study the wind velocity and directions in tandem. Note the wind directions are listed vertically and observed in rows. For example, during the month of October 1982 some 18.3 percent of measurements were from the east-southeast. The columns are wind velocities in mph. For example, the third column is the information for an 8- to 12-mph wind. About 8.4% of the time this velocity was observed from the ESE and 28.4% of the observed measurements in October were in the 8 to 12 mph group.

IX. Wind Information

Wind information was collected by two anemometers and a directional indicator. One anemometer was mounted at 30 feet but the information reported following was collected by a second anemometer mounted on a radio tower approximately 300 feet from the SWECS. The equipment on the radio tower was mounted at a height of 80 feet. This elevation was the same height as the center of the swept area of the SWECS. The data was collected and processed as described previously and comparisons were made with the energy produced. However, general summaries follow.

PLOT OF POWER & WIND SPEED VS TIME
CARTER-25 WICHITA FALLS, TEXAS
OCTOBER 1982

* = WIND SPEED MEASURED AT 80 FT # = WIND SPEED CUBE FUNCTION
\+ = POWER GENERATED BY CARTER-25 X = (POWER USED BY FACILITY)X10 IN KWH

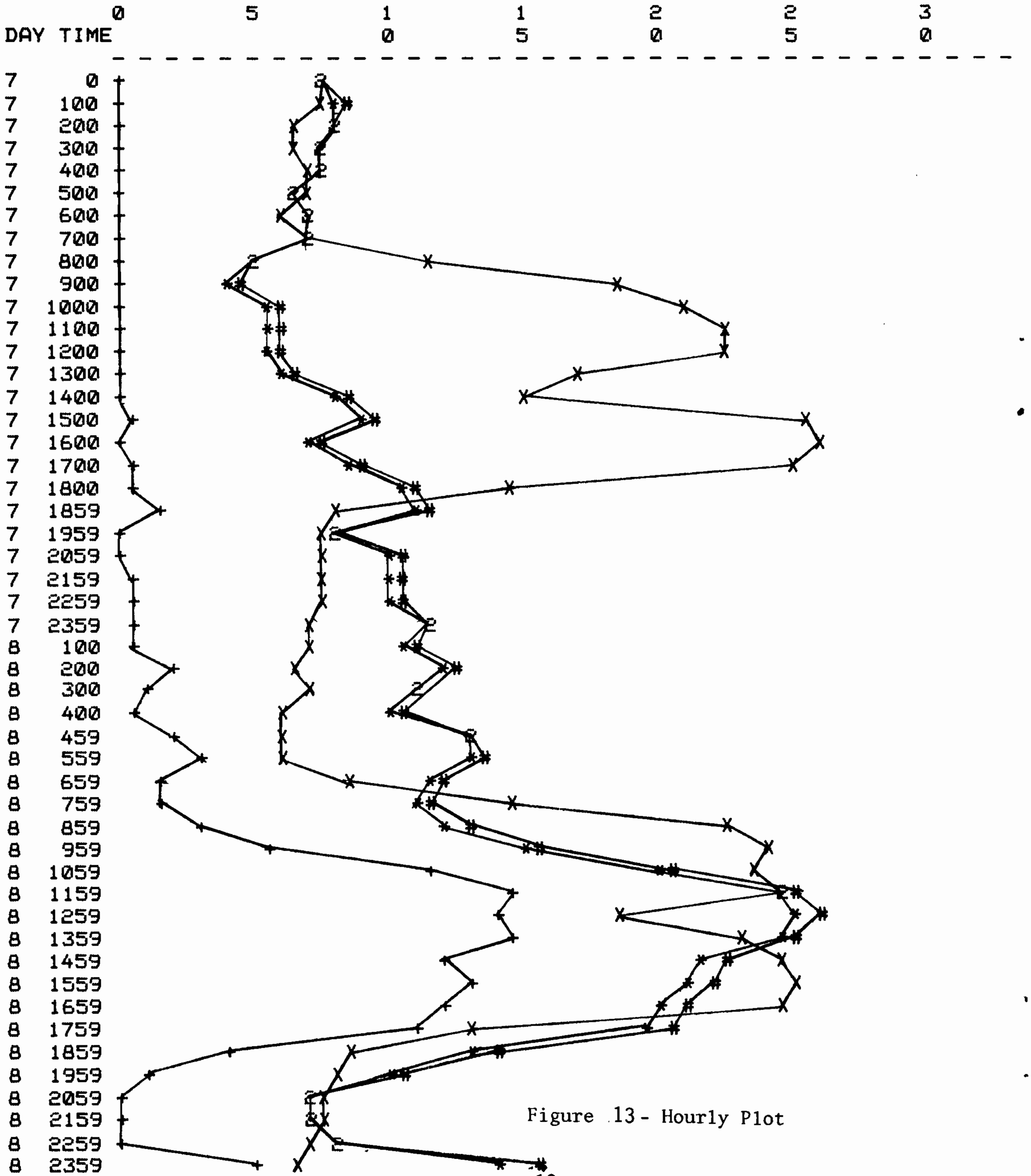

Figure 13 - Hourly Plot

SWECS CARTER-25 WICHITA FALLS
MONTHLY SUMMARY
OCTOBER 1982

DAY	WIND DIR	AVG WIND VEL (MPH)	AVG WIND CUBE (MPH)	SWECS POWER PRODUCED (KWH)	POWER USED BY FACILITY (KWH)	THEORETICAL WIND POWER (KWH)	EFF. OF GENERATOR (%)	AVG TEMP
1	SE	14.9	15.3	0.0	2615.9	149.8	0.0	79
2	ESE	10.4	11.3	0.0	1251.1	106.9	0.0	76
3	N	4.0	4.3	0.0	1207.9	7.9	0.0	74
4	ESE	7.3	7.7	0.0	3235.3	49.6	0.0	77
5	SE	12.1	12.5	0.0	2666.9	98.5	0.0	77
6	N	11.1	11.6	10.7	564.0	23.9	44.7	78
7	E	7.7	8.1	4.7	3193.2	37.6	12.5	77
8	S	14.8	15.3	131.9	3279.8	302.9	43.5	77
9	WNW	9.9	10.4	51.2	1293.8	97.4	52.6	76
10	WNW	8.4	8.8	21.6	1151.6	53.3	40.5	75
11	N	6.6	7.1	1.7	1460.5	22.0	7.7	74
12	NNE	6.4	6.8	4.2	1938.9	22.6	18.6	66
13	SW	6.4	6.7	4.9	1913.2	22.8	21.5	63
14	SSW	6.4	6.8	4.5	2077.3	25.1	17.9	64
15	WNW	7.1	7.6	11.6	2323.0	38.4	30.2	67
16	N	7.2	7.6	3.7	1155.1	30.2	12.3	67
17	ESE	11.5	11.8	51.8	1232.1	112.7	46.0	68
18	ESE	13.6	13.9	99.7	2744.7	180.5	55.2	72
19	NNW	16.6	17.3	182.9	2405.8	379.1	48.2	68
20	NNW	6.4	6.7	4.9	1393.1	23.0	21.3	52
21	E	3.7	4.1	0.0	1484.2	5.0	0.0	54
22	NE	3.0	3.4	0.0	2314.2	3.6	0.0	59
23	ESE	6.7	7.0	1.1	1224.1	28.5	3.9	58
24	ESE	7.5	7.8	1.8	1162.4	34.7	5.2	58
25	ESE	9.6	9.8	14.5	2273.7	60.7	23.9	57
26	ESE	14.8	15.1	14.9	2244.8	231.4	6.4	60
27	SE	16.8	17.2	0.0	2353.9	351.8	0.0	67
28	WNW	11.4	12.0	0.0	2651.0	165.6	0.0	65
29	SSE	8.6	8.9	23.7	2523.6	55.7	42.5	60
30	ESE	12.3	12.7	88.9	1360.6	141.4	62.9	65
31	SSE	14.0	14.4	128.6	1548.0	193.8	66.4	73

Figure 14 - Monthly Summary

SWECS CARTER-25 WICHITA FALLS
WIND DIRECTION/VELOCITY SUMMARY
OCTOBER 1982

WIND DIR	<--PERCENT OF THE TOTAL-BASED ON ONE HOUR PREDOMINANT DIRECTION--> 0-4	4-8	8-12	12-16	16-20	20-24	24-28	28-32	32+	TOTAL
N	0.3	4.2	2.0	0.6	0.1	0.1	0.0	0.0	0.0	7.3
NNE	1.1	3.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	5.2
NE	2.4	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5
ENE	0.3	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0
E	1.0	1.7	3.2	0.4	0.1	0.0	0.0	0.0	0.0	6.5
ESE	1.1	2.4	8.4	5.8	0.4	0.1	0.0	0.0	0.0	18.3
SE	0.1	1.4	4.8	4.6	1.8	0.4	0.0	0.0	0.0	13.2
SSE	0.4	1.5	3.0	3.4	2.7	1.1	0.0	0.0	0.0	12.1
S	1.5	1.0	1.0	1.0	1.0	0.6	0.4	0.0	0.0	6.5
SSW	1.4	1.7	0.6	0.8	0.1	0.1	0.0	0.0	0.0	4.8
SW	1.0	1.7	0.1	0.1	0.0	0.0	0.0	0.0	0.0	3.0
WSW	0.1	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.7
W	0.7	1.4	1.0	0.3	0.1	0.0	0.0	0.0	0.0	3.5
WNW	0.3	2.7	2.1	1.7	0.1	0.0	0.0	0.0	0.0	6.9
NW	0.3	1.4	0.1	0.0	0.1	0.0	0.1	0.0	0.0	2.1
NNW	0.3	1.4	1.0	0.3	0.1	0.4	0.0	0.0	0.0	3.5
TOTAL	12.4	29.7	28.4	19.1	6.9	3.0	0.6	0.0	0.0	100.0

****TOTAL NUMBER OF HOURS ANALYZED = 711

Figure 15 - Monthly Wind Summary

Wind Direction. Table I shows a summary by month of all the wind direction information collected. The table contains the percent of the hours of occurrence during the month, for the month and direction in question. It may be noted that the dominant directions are from the southeast moving toward the northwest, with the east, east-southeast, southeast and the south-southeast having the largest percentages of time. However, the fall and winter months tend to have dominant wind directions from the northerly directions. The northerly directions could be associated with storm systems which occur during these months. These storm systems tend to have short periods of very high winds as do the spring months.

Wind Speed. Table II contains a summary of the wind speed information for each month studied. The percent of the hours of occurrence during the month are again shown. It should be recalled that the power produced increases in proportion as the cube of the wind velocity and the SWECS generator is generally not activated at wind velocities less than about 8 mph.

The wind speeds tend to be variable with different quantities found during the same month on succeeding years. However, the spring months tend to have higher more productive winds. Lower speeds are found during the hot summer months. Note windspeeds in excess of 32 mph tend to occur during February, March, April and May.

X. SWECS Performance

At the completion of this project, observations of the SWECS were obtained for about two years. During this period the SWECS has operated with very little down time. The system has been shut down for short periods in order to perform the suggested maintenance. In addition, on two occasions rather violent storms have activated the "Out of Balance" control system which stopped the generator when the brake engaged. On these occasions it was necessary to lower the generator and reset the control. However, the unit has performed well with no operational difficulties.

The wind has not cooperated as well as the generator. During the summer after installation the wind velocities were lower than normal, and this trend seemed to continue throughout the observation period. For example, the average wind velocity for October 1982 was 10.6 mph, measured by the National Weather Service, whereas the October 1983 value was 9.6 as measured with project equipment at the District Office.

The maximum efficiency during a 24-hour period when calculated as shown in Chapter VIII occurred on December 14, 1982 and was found to be 81.2%. Efficiencies of 50 and 60% were common. The efficiency calculation is based on data from a one-hour time period and is very dependent on a calculated energy value. The calculated energy value is based on theoretical priciples and is sensitive to wind velocity. Wind velocities can vary widely during an hour period, so the efficiencies fluctuate depending on the consistency and strength of the wind velocity.

Table I
WIND DIRECTION
(% of Time During the Month)

YR MO	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	TOTAL HOURS
82 Jul	2.0	3.2	6.9	2.0	9.4	15.3	18.9	20.4	10.4	5.4	2.6	0.5	1.2	1.1	0.3	0.5	652
Aug	5.2	6.1	8.1	2.9	11.1	11.5	12.8	19.4	10.6	7.1	1.4	0.5	0.3	0.8	0.0	2.0	592
Sep	17.9	5.3	4.3	0.8	10.6	19.3	17.9	11.8	4.7	2.6	1.2	0.8	0.6	0.6	0.6	1.2	509
Oct	7.3	5.2	5.5	1.0	6.9	19.0	12.7	11.4	6.5	4.8	3.0	0.7	3.5	6.9	2.1	3.7	711
Nov	14.8	1.3	3.8	1.3	8.4	10.8	15.5	9.5	8.0	6.3	3.8	1.5	1.5	2.9	2.2	8.4	715
Dec	12.5	0.5	1.4	1.1	5.3	5.3	6.8	8.8	9.6	7.4	7.4	3.9	9.0	9.0	3.1	8.8	622
83 Jan	10.6	4.8	6.8	3.0	12.1	3.2	6.5	7.3	3.4	9.1	5.1	3.0	4.3	9.8	4.3	6.6	725
Feb	9.9	3.2	4.9	3.2	13.4	8.1	9.2	4.7	3.2	4.0	5.4	1.0	5.4	13.3	3.7	7.4	595
Mar	4.8	4.3	4.5	2.9	13.4	10.2	8.4	6.8	5.9	4.8	3.5	3.5	4.5	10.5	7.1	5.2	694
Apr	6.8	2.8	3.8	2.0	9.5	8.9	9.3	9.6	3.8	8.4	5.4	1.1	3.1	13.9	4.7	6.8	717
May	8.0	4.8	6.6	1.7	14.3	12.7	12.6	11.7	3.6	5.0	1.7	1.2	3.0	5.2	1.5	6.3	725
Jun	6.3	5.0	9.9	2.7	18.6	19.8	13.5	11.5	3.6	2.2	1.6	0.5	0.7	0.7	0.9	2.3	555
Jul	1.1	2.2	3.6	1.2	14.3	24.9	17.1	23.7	7.0	4.4	0.1	0.0	0.0	0.1	0.0	0.3	743
Aug	2.1	2.4	7.0	1.3	14.8	24.8	14.3	14.5	6.4	8.1	2.3	0.7	0.0	0.6	0.3	0.6	705
Sep	5.8	4.8	3.5	0.7	7.9	23.9	22.8	18.6	5.5	2.7	0.8	0.0	0.1	0.1	0.6	2.0	706
Oct	4.9	3.2	6.4	2.4	10.5	12.7	11.6	15.4	7.0	8.1	4.5	2.7	2.9	4.5	1.7	1.6	629
Nov																	
Dec	19.1	4.8	2.7	1.7	7.0	6.6	6.3	4.7	4.4	5.3	4.4	1.7	5.2	7.8	4.1	14.4	640
84 Jan	9.9	9.6	0.6	0.6	1.2	5.0	7.5	5.0	6.2	18.9	8.4	2.2	1.9	5.9	4.3	12.7	322
Feb	4.9	1.6	1.3	0.6	6.8	6.1	10.3	10.7	6.7	9.5	9.5	4.2	4.6	10.7	6.4	6.0	672
Mar	10.6	7.4	10.5	4.9	12.8	5.3	7.5	4.4	2.2	5.4	5.8	3.8	4.0	8.4	3.1	3.9	741
Apr	4.4	4.3	7.1	2.0	11.2	7.4	7.9	8.2	2.4	6.0	7.2	4.3	7.7	13.1	3.3	3.6	635
May	10.3	10.0	6.5	1.3	18.3	12.7	6.9	10.1	3.1	5.2	2.1	0.5	1.1	6.9	1.0	3.9	612
Total Hours	1133	606	761	272	1563	1791	1633	1628	799	876	550	248	421	867	357	630	14217

(Based on dominant direction in one-hour intervals.)

Table II
WIND SPEED
(% of Time During the Month)

YR MO	0-4	4-8	8-12	12-16	16-20	20-24	24-28	28-32	+32	TOTAL HOURS
82 Jul	20.9	42.8	21.8	14.0	0.6	0.0	0.0	0.0	0.0	652
Aug	19.9	50.7	25.7	3.7	0.0	0.0	0.0	0.0	0.0	592
Sep	4.7	26.9	33.0	22.8	9.0	3.5	0.0	0.0	0.0	509
Oct	12.4	29.8	28.3	19.3	6.8	3.0	0.6	0.0	0.0	711
Nov	5.2	22.8	31.3	24.3	11.2	3.9	1.1	0.1	0.0	715
Dec	13.0	29.3	23.6	22.7	9.5	1.6	0.3	0.0	0.0	622
83 Jan	7.7	33.9	35.3	14.8	6.3	1.5	0.4	0.0	0.0	725
Feb	35.0	27.7	17.8	11.1	6.2	1.7	0.5	0.0	0.0	595
Mar	55.3	8.8	15.3	13.4	5.6	1.6	0.0	0.0	0.0	694
Apr	11.2	26.1	22.2	13.1	11.9	6.3	4.6	2.6	2.1	717
May	7.6	31.0	30.1	13.2	8.6	2.6	1.9	1.8	3.2	725
Jun	41.8	20.7	20.9	10.8	4.5	0.9	0.4	0.0	0.0	555
Jul	21.8	13.3	37.6	17.2	5.7	3.6	0.8	0.0	0.0	743
Aug	14.3	31.9	38.4	13.5	1.8	0.0	0.0	0.0	0.0	705
Sep	3.7	16.3	38.5	30.6	7.9	1.7	1.1	0.1	0.0	706
Oct	9.5	25.4	41.0	18.3	3.8	1.0	1.0	0.0	0.0	629
Nov										
Dec	5.9	31.4	30.2	19.4	11.6	1.6	0.0	0.0	0.0	640
84 Jan	5.3	36.3	32.0	14.0	4.3	6.5	1.6	0.0	0.0	322
Feb	6.7	20.4	25.4	21.3	13.2	7.4	3.1	1.8	0.6	672
Mar	3.1	22.8	31.0	20.2	15.2	5.3	1.6	0.7	0.1	741
Apr	3.6	17.0	25.8	23.1	17.2	9.4	3.1	0.6	0.0	635
May	3.6	18.3	33.5	26.0	12.6	5.1	1.0	0.0	0.0	612
Total Hours	2016	3714	4141	2520	1142	434	153	54	43	14217
Cum. %	14.2	40.3	69.4	87.1	95.1	98.2	99.3	99.7	100.0	
Cum. %	100.0	85.7	59.7	30.6	12.9	4.9	1.8	0.7	0.3	

The maximum power produced by the SWECS during a 24-hour period was measured on November 11, 1982 at 333 kw. The lowest wind velocity during this 24 hours was 14 mph, and the largest was 29 mph. Power production during the 24-hour intervals for the two-year study was larger than 200 kw on several occasions.

XI. Energy Production and Benefits

Normally, a study of the energy produced by the SWECS would include the total amount of energy produced, the amount of energy stored or returned to a utility grid, and the amount used by the office facility. However, the size of the SWECS influenced the analysis of the subject study.

The Carter SWECS units are constructed such that the alternating current produced by the generator has the same frequency and is synchronized with the line current. The unit has no stationary energy storage such as batteries. The excess energy produced is transmitted to the service company grid. Because the Department is not in the business of producing electricity and only desired to demonstrate the use of alternate energy systems, a SWECS was deliberately selected to be of a small size so that minimal quantities would be returned to the service grid. From Figure 13, it may be noted that the hourly use of electricity by the District Office complex in October 1982 ranged from about 40 kw to 260 kw. Since the generator is rated at 25 kwh and the minimum hourly use is 40 kw, one would suspect little energy would be returned to the grid. This proved to be the case. All energy produced by the unit was used by the facility and no energy was returned or sold to TESCO. This fact should simplify an analysis of cost benefits. However, the electric service company bases charges on multiple factors.

An electric service company has the responsibility of providing a constant source of power to its customers. Many of the customers will demand power at the same time and peak use periods occur. Because of this peak use the service company is forced to design its power plants with such capacity as to produce sufficient power at these peak periods. During non-demand periods the power plant can cut back on the fuel used to produce electricity and operate much more economically. In seeking equitable methods of charging its user customers, a service company may have a very complex system. The Texas Electric Service Company used the following method to calculate charges for the service delivered to the District Office complex during the study period:

$ 10.00	Customer charge
3.61	per kw of demand in excess of 10 kw, and
.0425	per kwh for first 2500 kwh
.0250	per kwh for next 3500 kwh
	(Add 150 kwh per kw of demand in excess of 10 kw)
.0049	per kwh for all additional kwh

The term "demand" was defined as:

"The current month maximum kw, provided, however, that for customers having not less than one full month of on-peak kw history the kw thus determined may not exceed the sum of the maximum on-peak kw plus 30% of the amount by which the current month maximum kw exceeds the maximum on-peak kw; but not less than 80% of the amount by which the maximum on-peak kw exceeds 15 kw; nor less than 50% of the amount by which the contract kw exceeds 15 kw.

Current month maximum kw is the kw recorded during the 15-minute period of maximum use during the current month.

Maximum on-peak kw is the highest kw recorded at the premises during the billing months of June, July, August, September or October in the 12 months ending with the current month.

Contract kw is the greater of (a) the maximum electrical load specified in the agreement for electric service, or (b) the kw recorded at the premises during the 15-minute period of maximum use at any time during the 12 months ending with the current month."

Electric service charges to the District Office complex for the period from October 1981 to October 1982 may be found in Table III. Note the charges for October 1982. The total charge was $4,078. The actual demand was 272 kw, however the demand used for charges was 295 kw [(384 - 15) X .8]. The 295 kw demand was used throughout the winter months of 1982-83. The cost breakdown for August 1982 and October 1982 may be found on Table IV.

The average cost per kwh used in August was $6,981.18/116,800 kwh or $0.060 per kwh. The average cost in October 1982 was $4,078/70,400 kwh or $0.058 per kwh. Note the fuel adjustment cost for August 1982 was 3.2164 cents per kwh whereas the fuel adjustment for October 1982 was 2.3740 cents per kwh.

About one half of the total charges originate with the demand term; therefore, it is important to consider this term when studying cost benefits. However, it is difficult to determine the effect of the SWECS on reducing the demand. Observing Figure 13, it does appear that some increase in wind velocity occurs during the peak use period of the complex (afternoon hours, especially during the summer). This velocity is probably due to the thermal movement of air when the land mass is heated.

A small analysis and comments by Texas Electric Service Company have been included in Appendix C. TESCO indicates in a one-year period from May 1983 to April 1984 the SWECS unit produced about 19,930 kwh with a maximum output of 23.35 kw. The unit used 950 kwh and 55,350 kvar of reactive power.

Table III
Use History for the District 3 Office

MO.	YEAR	ACTUAL-KW	BILLING	KWH	CHARGES
Oct.	1982	272	295	70,400	$4,078
Sept.	1982	368	368	109,600	$6,084
Aug.	1982	384	384	116,800	$6,981
July	1982	376	376	106,400	$6,880
June	1982	360	360	81,600	$5,610
May	1982	272	276	56,000	$3,819
Apr.	1982	224	276	72,000	$4,214
Mar.	1982	192	276	61,600	$3,890
Feb.	1982	192	276	64,480	$3,755
Jan.	1982	192	276	71,520	$3,818
Dec.	1981	230	276	60,480	$3,345
Nov.	1981	288	288	55,680	$3,371
Oct.	1981	360	360	71,040	$4,161
TOTAL				997,600	$ 60,006

Table IV
Billing Examples

October, 1982 — Actual Demand - 272 KW
Billing Demand - 295 KW — Use- 70,400 KWH

Customer Charge	$ 10.00
Demand 295 KW minus 10 KW = 285 KW at $ 3.61 per KW	1,028.85
2500 KWH at 4.25¢/KWH	106.25
3500 KWH at 2.50¢/KWH	87.50
(*Add 150 kwh per kw of demand in excess of 10kw)	
295 kw - 10 kw = 285 kw times 150 kwh per kw =	
42,750 kwh at 2.50¢/KWH	1,068.75
All additional kwh = 70,400 kwh minus 2500 kwh minus 3500 kwh minus 42,750 kwh = 21,650 kwh at 0.49¢ per kwh	106.09
Fuel Adjustment - 70,400 kwh at 2.3740¢ per kwh	1,671.30
TOTAL	$4,078.74

August, 1982 — Actual Demand - 384 kw
Billing Demand - 384 kw — Use - 116,800 kwh

Customer Charge	$ 10.00
Demand 384 kw minus 10 kw = 374 kw at $ 3.61 per kw	1,350.14
2500 kwh at 4.25¢ per kwh	106.25
3500 kwh at 2.50¢ per kwh	87.50
*384 kw - 10 kw = 374 kw x 150 kwh/kw = 56,100 kwh at 2.5¢ per kwh	1,402.50
Additional kwh = 116,800 kwh - 2500 kwh - 3500 kwh - 56,100 kwh = 54,700 kwh at 0.49¢ per kwh	268.03
Fuel Adjustment - 116,800 kwh at 3.2164¢ per kwh	3,756.76
TOTAL	$6,981.18

Production

In approximately two years (from May 1982 to April 1984) the SWECS produced some 40,465 kw of electricity. Based on continuous monitoring of energy used and produced it is estimated that the SWECS will reduce the monthly demand an average of about one to four percent.

Benefits

Probably the best method of predicting a monetary benefit for the subject unit is to use the average cost per kwh. The average cost per kwh was reported earlier in Chapter XI and was obtained by dividing TESCO's total monthly charge by the kwh used during the month. When this was accomplished the mean monthly value was found to be $0.06 per kwh. Therefore, the monetary benefit derived from the first two years of operation was $2427.90 or $1213.95 per year. The annual values will be influenced by increases in fuel and service costs. Therefore, Table V was prepared to show a listing of estimated annual costs and benefits. Note, the fuel costs and electric service has been estimated to increase at a rate of ten percent per year. The unit is expected to pay off the initial cost of $25,000 in approximately 12 years.

XII. Conclusion

The SWECS unit used in this study appears to be extremely well designed and has shown good performance that has been relatively maintenance-free. Rather than the usual start-stop-debug routine of much new equipment, the subject SWECS was installed, immediately began producing electricity, and has been producing power since that time. The pay off period for the unit must involve a relatively long time period and little is known about long-term maintenance costs. But it is concluded that Small Wind Energy Conversion Systems are relatively trouble-free, will not cause excessive use of personnel time for equipment maintenance, and are economically feasible with payoff on initial and maintenance costs of about 14 years.

Table V
Investment Return Period
(Based on an Energy Cost Increase of 10% per Year)

YEAR	SAVING (DOLLARS)	CUMULATIVE SAVING (DOLLARS)	COST (DOLLARS)
1983	$1,214	$ 1,214	
1984	1,335	2,549	
1985	1,469	4,018	
1986	1,616	5,634	
1987	1,777	7,411	
1988	1,955	9,366	
1989	2,151	11,517	
1990	2,366	13,883	
1991	2,602	16,485	
1992	2,863	19,348	
1993	3,149	22,497	
1994	3,464	25,961	$25,000
1995	3,810	29,771	27,910
1996	4,191	33,962	34,000

Note: Assuming a maintenance cost of $750 per year, some $34,000 would be involved ($25,000 initial plus $9,000 maintenance) for an investment return in 1996.

References

1. Clark, R.N., and Schneider, A.D., "Irrigation Pumping with Wind Energy," ASAE, Vol. 23, No. 4, pp. 850-853, 1980.

2. Nelson, Vaughn, and McGaughey, David, "Consumer's Guide for Wind Energy in Texas," Alternative Energy Institute, West Texas State University.

3. "Is the Wind a Practical Source of Energy for You?" Special publication - DOE Rocky Flats Wind Systems Program, September 1980.

4. Park, Jack, and Schwind, Dick, "Wind Power for Farms, Homes and Small Industry," Report No. RFP-2841/1270/78/4, September 1978.

5. Proceedings - National Conference American Wind Energy Association, Summary 1980, Pittsburgh, Pennsylvania, Hosted by ALCOA, June 1980.

Appendix A

Specifications for a Wind Generator

and

Mounting Tower

Specifications for a

Wind Generator

and

Mounting Tower

General

The wind generator shall be so designed and fabricated to have low maintenance, good reliability, long life, pleasing esthetics, and high efficiency. The unit shall contain an induction-type generator producing 3-phase, 440-volt, 60-cycle AC current. The unit shall be a horizontal, down-wind system which naturally weather vanes. The blades shall be fabricated to stall in a high wind condition to protect the generator from overloading. An overspeed control shall cause the blades to pitch up and stall. The blade design shall contain a self-start feature.

The blades shall be formed basically of fiberglass and shall be very strong but highly flexible. In a non-rotating condition, in winds of 125 mph, the blades will "unload" by bending to an angle of 45 degrees without damage.

Output

The generator shall be capable of producing 25 kw in a 26-mph wind. The maximum output will be 30 kw in approximately a 30- to 40-mph wind and the minimum output will occur at a 7½ mph wind. The system shall be capable of being "tied in" with parallel operation in an electric utility company line with appropriate safety and operational features, meeting the attached "Guidelines for the Parallel Operation of a Customer-Owned Small Wind Energy Conversion System (SWECS) at the Utility Company Service Voltage Level." (Obtained from Texas Electric Service Company.)

Blades

The rotor diameter shall be 32 feet. The blade chord shall be 13 inches at the tip and 42 inches at the root. The blade shall be fabricated primarily from fiberglass and PVC foam. The spar shall be composed of a continuous filament-wound unidirectional glass structure with a 25 to 1 safety factor.

Tower

The tower shall be 80 feet high and fabricated from galvanized pipe. It shall be a single pole structure supported with four guy wires. The tower shall contain a single gin pole arrangement which will permit the tower (and generator) to be raised or lowered by one or two persons by rotating the tower about the base from a vertical to horizontal position (or vice versa). This tower and generator arrangement shall permit maintenance functions to be accomplished at ground level.

Yaw Control

The yaw control shall be a free yaw system but with dampening. The yaw control shall be a passive system and shall not contain a yaw servo system or other devices for monitoring and evaluating wind direction before controlling the yaw with the servo system.

Overload Control

The overload control shall also be a passive system in which the blades automatically stall in high winds to prevent generator overload. However, the system shall still be capable of generating electricity in winds of 100 mph. Servo system and monitoring equipment which change blade pitch to control rpm or kw output shall not be used.

Overspeed control

The overspeed control shall be accomplished through the design characteristics of the spar and blade which will cause the blade to pitch up and stall in an overspeed condition to limit maximum rpm. If the overspeed was due to the utility break or malfunction, causing generator turn-off, then the generator will automatically reset and come back on when power is restored to the line.

Braking

The system shall contain a mechanical or disc brake capable of stopping the rotor in 125-mph winds under extremely high rotational velocities by manual control from ground level.

Out-of-Balance Control

Should the blade(s) or rotor become out of balance to a dangerous level, the system shall be equipped with a mechanical brake which shall be activated. This brake shall be capable of stopping the rotor in any wind under any rotational velocity.

Gear Box

The gear box shall be fabricated for long life and to resist the effects of weather. The gear box shall be of Tenzaloy aluminum alloy with cast-in-place steel inserts for bearing supports. The gears shall be hardened to insure long life.

Appendix B

Program Listing - Used to Process Data for Demonstration and Display at the Site

File name = "SWECS.WS"

JUNE 11, 1982
SEMI-FINAL PROGRAM FOR SWECS WIND ENERGY SYSTEM FOR DIST. 3, WICHITA FALLS, TEXAS.

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION.
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THIS PROGRAM IS A COMBINATION OF ASSEMBLY LANGUAGE AND BASIC TO OPERATE AN AIM 65/HEATHKIT WEATHER MONITOR/TEXAS INSTRUMENTS ASR-733 AND ASSOCIATED INTERFACE EQUIPMENT .

```
5 POKE 4,00:POKE 5,10              (0A00 Hex)
7 XX=USR(UU)
10 A0=0:A1=1:A2=2:A3=3:A4=15:A5=21
20 DIM Z(21),Y(3),WD$(16)
30 DATA"N","NNW","WNW","NW","SSW","SW","W","WSW","NNE","NE"
35 DATA"E","ENE","S","SSE","ESE","SE"
40 FOR I=A0 TO A4:READ WD$(I):NEXT I
50 INPUT"   YEAR-    ";YR
60 INPUT"   DAY OF YEAR(EX: 159)-    ";DAY
65 PRINT"   ":PRINTTAB(20)"SWECS-CARTER 25 - WICHITA FALLS"
70 PRINTTAB(20)"YEAR - ";YR;"    DAY OF YEAR - ";DAY
75 PRINT"   TIME  WIND   WIND   WIND   WIND   WIND   INPUT   OUTPUT";
77 PRINT"   TOTAL   TEMP"
80 PRINT"         SP-1   SP-2   SP-1   SP-2   DIR.";
82 PRINT"   POWER   POWER    POWER"
85 PRINTTAB(9)"AVG    AVG    CUBE   CUBE";
87 PRINTTAB(44)"(KWH)    (KWH)     (KWH)":PRINT"   "
99 POKE 4,105:POKE 5,10                              (0A69 Hex)
100 X=USR(NN)
105 FOR I=A1 TO A5:M=I+3343:Z(I)=PEEK(M):NEXT I
110 FOR I=A1 TO A3:M=I+3327:Y(I)=PEEK(M):NEXT I
115 WS=0:WV=0:W1=0:W2=0
120 WA=((Z(16)+Z(17)*256)*0.00625)+0.05
122 WB=((Z(18)+Z(19)*256)*0.00625)+0.05
125 WC=((Z(20)+Z(21)*256)*0.12)+0.05
127 WA=WA*10:WA=(INT(WA))/10:WB=WB*10:WB=(INT(WB))/10
128 WC=WC*10:WC=(INT(WC))/10
130 FOR I=A0 TO A3:I1=I+1:I2=I+5
135 WS=WS+Z(I1)*256^I:WV=WV+Z(I2)*256^I:NEXT I
137 WS=WS/3600:WV=WV/3600
140 WS=WS^(1/3)+0.05:WV=WV^(1/3)+0.05
145 FOR I=A0 TO A2:I1=I+9:I2=I+12
150 W1=W1+Z(I1)*256^I:W2=W2+Z(I2)*256^I:NEXT I
155 W1=(W1/3600)+0.05:W2=(W2/3600)+0.05:K=Z(15):W$=WD$(K)
160 WS=WS*10:WS=(INT(WS))/10:WV=WV*10:WV=(INT(WV))/10
165 W1=W1*10:W1=(INT(W1))/10:W2=W2*10:W2=(INT(W2))/10
```

```
168 TT=Y(1)*100+Y(2)
170 PRINTTAB(0);TT;TAB(6);W1;TAB(13);W2;TAB(20);WS;
175 PRINTTAB(27);WV;TAB(36);W$;TAB(42);WA;TAB(50);WB;TAB(59);WC;
178 PRINTTAB(67);Y(3)
180 IF TT<=2300 GOTO 99
182 DAY=DAY+1
183 IF DAY<366 GOTO 65
184 YR=YR+1:DAY=1
185 GO TO 65
190 END
```

NEXT IS AN ASSEMBLY LANGUAGE LISTING.

```
<K>*=0A00
/
 0A00  EA  NOP  ------THE PROGRAM IS ENTERED FROM BASIC AT THIS
                      ADDRESS.
 0A01 EA NOP
 0A02 78 SEI
 0A03 EA NOP
 0A04 A9 LDA #40     ----------------------------------------------
 0A06 8D STA A400     This routine loads up the interrupt
                     vectors.
 0A09 A9 LDA #0E
 0A0B 8D STA A401    ----------------------------------------------
 0A0E EA NOP
 0A0F EA NOP

 0A10 A9 LDA #0C     ----------------------------------------------
 0A12 8D STA A417     This routine sets up the Serial Baud rate.
 0A15 A9 LDA #C2
 0A17 8D STA A418    ----------------------------------------------
 0A1A EA NOP

 0A1B A9 LDA #80     ----------------------------------------------
 0A1D 8D STA A002     Make port B an input port with the
                     exception of PB-7  (T-1 output)
 0A20 A9 LDA #C0     ----------------------------------------------
 0A22 8D STA A00B     Set up auxiliary control register.
 0A25 8D STA A00E     Set up interrupt enable register.
 0A28 A9 LDA #D0
 0A2A 8D STA A004     Timer 1 (write)
 0A2D A9 LDA #B1
 0A2F 8D STA A005     Timer 1 (write)
 0A32 EA NOP         ----------------------------------------------


 0A35 EA NOP
 0A36 A9 LDA #00     ----------------------------------------------
 0A38 8D STA A003     Make port A an input, and set up the PCR
 0A3B A9 LDA #00     for correct transition sensing.
 0A3D 8D STA A00C    ----------------------------------------------
```

```
0A40 A9 LDA #80      ---------------------------------------------
0A42 8D STA A002 Make port B an input, with the exception of PB-7
0A45 A9 LDA #46      Set interrupt "disable" bits
0A47 8D STA A00E
0A4A A9 LDA #B9      Set interrupt "enable" bits
0A4C 8D STA A00E
0A4F A9 LDA #E3      Set Aux. Control Register
0A51 8D STA A00B
0A54 A9 LDA #00      PCR
0A56 8D STA A00D
0A59 EA NOP


0A5B EA NOP
0A5C EA NOP
0A5D A9 LDA #09       --------------------------------------------
0A5F 8D STA A008       Timer #2 locations.
0A62 A9 LDA #00
0A64 8D STA A009
0A67 60 RTS --------      RETURN TO BASIC.


0A68 EA NOP
0A69 A9 LDA #00      -----  ASSEMBLY PROGRAM REENTERED FROM BASIC
0A6B A2 LDX #40          HERE.
0A6D CA DEX            Zero out memory locations 0D00 through
0A6E 9D STA 0D00,X     0D39, for data storage.
0A71 D0 BNE 0A6D
0A73 EA NOP ----------------------------------------------------

0A74 A9 LDA #3C      Load 60 seconds into 0CF1
0A76 8D STA 0CF1
0A79 A9 LDA #3C      Load 60 minutes into 0CF2
0A7B 8D STA 0CF2
0A7E EA NOP -----------------------------------------------------

0A7F 58 CLI   -------      CLEAR INTERRUPT.

0A80 EA NOP        ----------------------------------------------
0A81 EA NOP         Store port A in one of the following locations
0A82 A0 LDY #0F       (0E01-0E0F) by using the value in Port B
0A84 AD LDA A00D      to determine which location.
0A87 29 AND #02
0A89 F0 BEQ 0A84      Use A00D for CA1 interrupt.
0A8B AD LDA A000      Read port A at A001
0A8E 29 AND #0F       Read port B at A000
0A90 AA TAX
0A91 AD LDA A001
0A94 8D STA 0D39
0A97 29 AND #0F
0A99 9D STA 0E00,X
0A9C 88 DEY
0A9D D0 BNE 0A84       ------------------------------------
```

```
0A9F EA NOP        ------------------------------------------
0AA0 EA NOP          Shift the 10's digit of Wind Speed-1 in
0AA1 AD LDA 0E04   location 0E04, four places to the left, then
0AA4 0A ASL .A     OR it with the 1's digit in location 0E0C.
0AA5 0A ASL .A       Store the results in 0D03.
0AA6 0A ASL .A       This puts 2 BCD digits in 0D03.
0AA7 0A ASL .A
0AA8 0D ORA 0E0C
0AAB 8D STA 0D03
0AAE EA NOP        ------------------------------------------

0AB3 EA NOP
0AB4 A9 LDA #E0    ------------------------------------------
0AB6 CD CMP 0D03
0AB9 90 BCC 0ABE
0ABB 4C JMP 0AD3      If 0D03 > #0E, then AND 0D03 with #0F,
0ABE A9 LDA #0F      otherwise continue.
0AC0 2D AND 0D03     This removes the F from 0D03, if necessary.
0AC3 8D STA 0D03

0AC6 EA NOP        ------------------------------------------
0AD3 D8 CLD        -------   Clear decimal.
0AD4 AD LDA 0D03
0AD7 AA TAX
0AD8 29 AND #0F
0ADA 8D STA 0FA0     This routine changes Wind speed #1 (Heathkit
0ADD 8A TXA          Anemometer -5%- at 30 ft.) from BCD to HEX
0ADE 29 AND #F0      numbers.
0AE0 4A LSR .A
0AE1 8D STA 0FA1
0AE4 4A LSR .A
0AE5 4A LSR .A
0AE6 18 CLC
0AE7 6D ADC 0FA1
0AEA 6D ADC 0FA0
0AED 8D STA 0D03
0AF0 EA NOP          ------------------------------------------

0AFF EA NOP        ------------------------------------------
0B00 AD LDA 0D03
0B03 20 JSR 0EDA   ---Jump to Cube subroutine.
0B06 A0 LDY #04
0B08 A2 LDX #00
0B0A 18 CLC
0B0B BD LDA 0D10,X
0B0E 7D ADC 0F54,X    This routine sums the #1 cubed wind speed
0B11 9D STA 0D10,X    (Heathkit Anemometer -5%- at 30 ft) per
0B14 E8 INX            second.
0B15 88 DEY
0B16 D0 BNE 0B0B
```

```
                                  --------------------------------------------
0B18 AD LDA 0D03
0B1B 20 JSR 0EC4
0B1E BD LDA 0D18,X     This routine sums the #1 wind speed (Heathkit
0B21 7D ADC 0F54,X     Anemometer -5%- at 30 ft) per second.
0B24 9D STA 0D18,X
0B27 E8 INX
0B28 88 DEY
0B29 D0 BNE 0B1E     ---------------------------------------------


0B2B AD LDA 0D05     ---------------------------------------------
0B2E 20 JSR 0EDA    ---- Jump to CUBE subroutine.
0B31 AD LDA 0D14
0B34 A0 LDY #04
0B36 A2 LDX #00
0B38 18 CLC
0B39 BD LDA 0D14,X   This routine sums the #2 cubed wind speed
0B3C 7D ADC 0F54,X   (Texas Electronics- 1% Anemometer at 80 ft)
0B3F 9D STA 0D14,X   per second.
0B42 E8 INX
0B43 88 DEY
0B44 D0 BNE 0B39
                     ------------------------------------------
0B46 AD LDA 0D05
0B49 20 JSR 0EC4
0B4C BD LDA 0D1B,X
0B4F 7D ADC 0F54,X    This routine sums the #2 Wind speed (Texas
0B52 9D STA 0D1B,X    Electronics- 1% - Anemometer at 80 ft) per
0B55 E8 INX           second.
0B56 88 DEY
0B57 D0 BNE 0B4C
0B59 EA NOP          -------------------------------------------

0B5A 4C JMP 0BE5     Skip the next 139 locations  (jump to 0BE5)

0BE5 A9 LDA #00      ------------------------------------------
0BE7 8D STA 0D05     Zero the #2 wind speed location every second.
0BEA EA NOP           0D05 is Wind speed #2 storage location.


0BEF EA NOP          -------------------------------------------
0BF0 CE DEC 0CF1      Decrement the seconds count. Has it been 60
0BF3 AD LDA 0CF1      seconds? If no, then go back to 0A80.
0BF6 D0 BNE 0BFB      If yes, then jump to 0C09.
0BF8 4C JMP 0C09
0BFB 4C JMP 0A80
0BFE EA NOP         ---------------------------------------------

                    ---------------------------------------------
0C09 A9 LDA #3C   ----  Re-load the seconds count with 60 at end of
0C0B EA NOP             each minute.----
0C0C 8D STA 0CF1
0C0F EA NOP
```

```
0C11 EA NOP
0C12 20 JSR 0D80   ----Jump to wattmeter service routine.---
                       (output, Excitation, & total consumption)

0C18 AD LDA 0D39    ----------------------------------------
0C1B 4A LSR .A      Shift wind direction to the left. and store
0C1C 4A LSR .A     in 0D04.
0C1D 4A LSR .A
0C1E 4A LSR .A
0C1F 8D STA 0D04    ----------------------------------------

0C25 AE LDX 0D04    ----------------------------------------
0C28 FE INC 0D25,X   At the end of each minute, increment the wind
                    direction in one of the following locations
                    (0D25 thru 0D34). This sums the number of
                    minutes the wind was in each direction for
                    the given hour.
                    ----------------------------------------

0C30 CE DEC 0CF2----Decrement minutes----,
0C33 AE LDX 0CF2 -- check for zero--
0C36 D0 BNE 0BFB -- if not zero, then branch to 0BFB.
                    if yes then continue.

0C40 AD LDA 0E05     ---------------------------------------
0C43 0A ASL .A        Put 2 BCD digits in 0D00 for the hours.
0C44 0A ASL .A
0C45 0A ASL .A
0C46 0A ASL .A
0C47 0D ORA 0E0D
0C4A 8D STA 0D00
0C4D EA NOP          ---------------------------------------

0C50 A9 LDA #E0      ---------------------------------------
0C52 CD CMP 0D00
0C55 90 BCC 0C5A     This routine removes the F from the hours.
0C57 4C JMP 0C64
0C5A A9 LDA #0F
0C5C 2D AND 0D00
0C5F 8D STA 0D00
0C62 EA NOP          ---------------------------------------

0C6A AD LDA 0E06     ---------------------------------------
0C6D 0A ASL .A          This routine puts 2 BCD digits into
0C6E 0A ASL .A       0D01 for the minutes.
0C6F 0A ASL .A
0C70 0A ASL .A
0C71 0D ORA 0E0E
0C74 8D STA 0D01
0C77 EA NOP          ---------------------------------------
```

```
0C7A AD LDA 0E01        ----------------------------------------
0C7D 0A ASL .A              This routine puts 2 BCD digits into
0C7E 0A ASL .A          0D02 for the temperature.
0C7F 0A ASL .A
0C80 0A ASL .A
0C81 0D ORA 0E09
0C84 8D STA 0D02
0C87 EA NOP             ----------------------------------------


0C90 A0 LDY #03         ----------------------------------------
0C92 D8 CLD
0C93 B9 LDA 0CFF,Y          This routine changes Hours, Minutes,
0C96 AA TAX             and temperature from BCD to HEX.
0C97 29 AND #0F
0C99 8D STA 0FA0
0C9C 8A TXA
0C9D 29 AND #F0
0C9F 4A LSR .A
0CA0 8D STA 0FA1
0CA3 4A LSR .A
0CA4 4A LSR .A
0CA5 18 CLC
0CA6 6D ADC 0FA1
0CA9 6D ADC 0FA0
0CAC 99 STA 0CFF,Y
0CAF 88 DEY
0CB0 D0 BNE 0C92
0CB2 EA NOP             ----------------------------------------


0CC0 A0 LDY #00         ----------------------------------------
0CC2 A2 LDX #10
0CC4 B9 LDA 0D25,Y          This routine determines the predominate
0CC7 8C STY 0D1E        wind direction for the hour.
0CCA 8D STA 0D35
0CCD CA DEX
0CCE F0 BEQ 0CE5
0CD0 C8 INY
0CD1 B9 LDA 0D25,Y
0CD4 CD CMP 0D35
0CD7 90 BCC 0CCD
0CD9 F0 BEQ 0CCD
0CDB 8D STA 0D35
0CDE 98 TYA
0CDF 8D STA 0D1E
0CE2 4C JMP 0CCD
0CE5 60 RTS             RETURN TO BASIC PROGRAM AT THE END OF EACH HOUR
0CE6 EA NOP             ----------------------------------------
```

```
0D80 A0 LDY #03     ------------------------------------------
0D82 A2 LDX #00
0D84 8E STX 0D53        This routine accumulates the wattmeter
0D87 18 CLC          count at the end of each minute.
0D88 BD LDA 0D1F,X
0D8B 7D ADC 0D50,X
0D8E 9D STA 0D1F,X
0D91 BD LDA 0D20,X
0D94 6D ADC 0D53
0D97 9D STA 0D20,X
0D9A E8 INX
0D9B E8 INX
0D9C 88 DEY
0D9D D0 BNE 0D87
0D9F A9 LDA #00  -Zero temporary locations to start the  next minute.
0DA1 8D STA 0D50  ---- Temporary storage for Excitation watt meter
                       (1 minute)
0DA4 8D STA 0D52  ---- Temporary storage for Output of Carter-25
                       (1 minute)
0DA7 8D STA 0D54  ---- Temporary storage for Total consumpt. meter
                       (1 minute)
0DAA 60 RTS         ------------------------------------------



0E40 EA NOP    ---- Beginning of interupt sevice routines.
0E41 EA NOP
0E42 EA NOP
0E43 EA NOP
0E44 48 PHA
0E45 8A TXA
0E46 48 PHA          Save stack.
0E47 98 TYA        ************
0E48 48 PHA
0E49 EA NOP


0E4A EA NOP
0E4B AD LDA A00D --- check for interupt flag
0E4E 2D AND A00E --- AND with interrupt enable register.
0E51 0A ASL .A
0E52 0A ASL .A
0E53 30 BMI 0E90  ---  Branch to 0E90, (Wind speed #2) (1% Anemometer)
0E55 0A ASL .A
0E56 30 BMI 0EA4  ---  Branch to 0EA4, (Output of Carter-25)
0E58 0A ASL .A
0E59 30 BMI 0EAE  ---  Branch to 0EAE, (Total Consumption meter)
0E5B 0A ASL .A
0E5C 0A ASL .A
0E5D 0A ASL .A
0E5F 30 BMI 0EBA  ---  Branch to 0EBA, (Excitation wattmeter)
```

```
0E60 68 PLA
0E61 A8 TAY
0E62 68 PLA                  Restore the stack.
0E63 AA TAX                 **********************
0E64 68 PLA
0E65 EA NOP          ----------------------------------------------

0E66 EA NOP
0E67 40 RTI     ---    Return from interrupt sevice routines.

0E90 A0 LDY #09   ---- Interrupt service for Wind speed #2
                        (1% Anemometer)
0E92 8C STY A008
0E95 A0 LDY #00
0E97 8C STY A009
0E9A EE INC 0D05
0E9D EA NOP

0E9F EA NOP
0EA0 4C JMP 0E55  --- Return for next priority interrupt.

0EA3 EA NOP
0EA4 EE INC 0D52   ---  Interrupt service for Output wattmeter.
0EA7 AC LDY A000
0EAA 4C JMP 0E58   ---  Return for next priority interrupt.
0EAD EA NOP
0EAE EE INC 0D54   ---  Interrupt service for Total consumption meter.

0EB1 AC LDY A000
0EB4 4C JMP 0E5B   --- Return for next priority interrupt.
0EB7 EA NOP
0EB8 EE INC 0D50   --- Interrupt service for Excitation meter.
0EBB AC LDY A001
0EBE 4C JMP 0E60   --- Interrupt routines finished, return to
0EC1 EA NOP            stack restore at 0E60

0EC3 EA NOP        -------------------------------------------
0EC4 A0 LDY #03
0EC6 A2 LDX #00
0EC8 18 CLC              This routine is called when summing
0EC9 8D STA 0F54         the wind speeds.
0ECC 8E STX 0F55
0ECF 8E STX 0F56
0ED2 60 RTS
                   -------------------------------------------
```

```
0EDA 8D STA 0F59
0EDD 8D STA 0F50
0EE0 8D STA 0F52
0EE3 A9 LDA #00
0EE5 8D STA 0F51
0EE8 8D STA 0F53
0EEB A0 LDY #02
0EED A9 LDA #00
0EEF 8D STA 0F56
0EF2 8D STA 0F57
0EF5 A2 LDX #10
0EF7 4E LSR 0F51
0EFA 6E ROR 0F50
0EFD 90 BCC 0F0F
0EFF AD LDA 0F56
0F02 18 CLC
0F03 6D ADC 0F52
0F06 8D STA 0F56
0F09 AD LDA 0F57
0F0C 6D ADC 0F53
0F0F 6A ROR .A
0F10 8D STA 0F57
0F13 6E ROR 0F56
0F16 6E ROR 0F55
0F19 6E ROR 0F54
0F1C CA DEX
0F1D D0 BNE 0EF7
0F1F 88 DEY
0F20 F0 BEQ 0F3C
0F22 AD LDA 0F59
0F25 8D STA 0F50
0F28 A9 LDA #00
0F2A 8D STA 0F51
0F2D AD LDA 0F54
0F30 8D STA 0F52
0F33 AD LDA 0F55
0F36 8D STA 0F53
0F39 4C JMP 0EED
0F3C 60 RTS
```

This routine cubes the wind speed readings each second.

The routine is called when summing the cubed wind speeds.

Return from subroutine.

END OF ASSEMBLY LANGUAGE PROGRAM

****

Appendix C

TESCO Information

TEXAS ELECTRIC SERVICE COMPANY

May 9, 1984

Mr. Kenneth D. Hankins, P.E.
Supervising Research Engineer
State Department of Highways
and Public Transportation
P. O. Box 5051
Austin, Texas 78763

Dear Kenneth:

Enclosed for your use and information is a billing record for the year May 1983 to April 1984 pertaining to your facility at 1601 Southwest Parkway in Wichita Falls. Included on the billing record is the test metering information for the 25 Kw Jay Carter wind generator.

During these twelve months, the wind generator produced 19,930 kilowatt-hours of energy with a maximum output of 23.35 Kw. The unit used 950 kilowatt-hours and 55,350 Kvar of reactive power. This still indicates to us a relatively low power factor for the output of the generator.

We are sorry to hear of your problems in April. Enclosed is a copy of the report pertaining to April 29. This is apparently the day the unit failed since the output has been "0" since that day. Please let me know when you have the blades replaced and other maintenance completed. We intend to leave the metering equipment in place and recording so we are ready when you resume operation of the wind generator.

We would appreciate receiving any reports you prepare regarding operation of this unit and the cost of repairs and maintenance. We have enjoyed the opportunity of working with you on this project. If we can be of any help, please call on us.

Sincerely,

Jack A. Harris
Marketing Research & Training Manager

jvh
enclosure

CUSTOMER ANALYSIS
TESCO 735-001
REV. 10-75

ACCOUNT NUMBER: 71-026-22000-1 / 71-026-22006-0

DELIVERY VOLTAGE:

ADDITIONAL DATA

25 Kw Jay Carter Wind Generator

CUSTOMER NAME: Texas Highway Department

SERVICE ADDRESS: 1601 Southwest Parkway

TOWN OR AREA: Wichita Falls, Texas

CLASS OF BUSINESS:

PREPARED BY: Jack A. Harris

DATE PREPARED: 5-9-84

YEAR: 1983-84

RATE: General Service Rate G

Wind Generator

Test Tape Change Date	MONTH 1983	KW ACTUAL	KW BILLING	KWH	AMOUNT	KWH Input	Reactive Max. Demand	Power KVARH	KW Output	KWH Output
5- 9-83	May	224	295	72,000	$ 4,711.94	100	16.64	6,350	19.82	2,750
6- 8-83	Jun	344	344	90,400	5,773.30	50	15.96	5,050	21.00	1,700
7-11-83	Jul	368	368	122,400	7,079.31	100	15.04	4,150	20.15	1,250
8- 5-83	Aug	320	320	135,200	7,122.20	50	14.72	4,100	13.95	850
9- 7-83	Sep	328	328	117,600	5,882.01	100	15.66	4,800	12.70	1,000
10- 6-83	Oct	360	360	76,800	5,005.84	100	15.05	5,650	19.40	1,730
11- 1-83	Nov	224	282	66,400	4,148.83	50	15.21	4,200	21.95	1,100
12- 2-83	Dec	248	282	71,200	4,305.87	100	16.11	5,150	23.35	2,600
1- 4-84	1984 Jan	208	290	72,800	4,595.98	100	15.43	4,000	19.52	1,500
2- 2-84	Feb	232	290	67,200	4,495.47	100	15.86	3,250	21.38	1,250
3- 5-84	Mar	272	290	72,800	4,693.25	50	15.34	5,200	21.10	2,500
4- 3-84	Apr	168	290	67,200	4,495.47	50	14.33	3,450	20.85	1,700
	TOTALS			1,032,000	$62,309.47	950		55,350		19,930

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RR16002 STUDY NO 705-603-9 TEXAS HWY DEPT CHANNELS A B C PAGE NUMBER 0027

ACCT NO 71-026-22006-0 1601 SOUTHWEST PKWY RECORDED IN KW KQ KW REPORT DATE 05/04/84

MULTIPLE-CHANNEL LOAD WICHITA FALL PRINTED IN KW KVAR KW INTERVAL TIME 15 MIN

DATE 04/29/84 SUN PULSE MULT .0062500 .0062500 .0062500

TIME ENDG	M-1,C-A KW	M-2,C-B KVAR	M-3,C-C KW	TOTAL KW	CALC KVA	PF FLAG	TIME ENDG	M-1,C-A KW	M-2,C-B KVAR	M-3,C-C KW	TOTAL KW	CALC KVA	PF FLAG
15	1	13	0	1	13	6.9	1215	0	2	23	23	24	99.7
30	0	4	0	0	4	8.9	30	0	2	24	24	24	99.7
45	0	3	0	0	3	8.8	45	0	2	24	24	24	99.8
0100	0	10	0	1	10	6.3	1300	0	2	24	24	24	99.8
15	0	14	1	1	14	6.8	15	0	2	24	24	24	99.7
30	0	9	1	1	9	8.4	30	0	2	24	24	24	99.7
45	0	14	1	1	14	8.8	45	0	2	24	24	24	99.7
0200	0	13	3	3	13	23.6	1400	0	2	23	23	23	99.7
15	0	13	3	3	13	26.3	15	0	2	24	24	24	99.7
30	0	12	4	4	13	33.1	30	0	2	24	24	24	99.7
45	0	11	5	5	13	40.6	45	0	2	24	24	24	99.7
0300	0	10	7	7	12	55.6	1500	0	2	23	23	23	99.5
15	0	10	7	7	12	57.2	15	0	2	24	24	24	99.7
30	0	10	6	6	12	51.6	30	0	2	23	23	23	99.6
45	0	11	6	6	12	48.9	45	0	2	24	24	24	99.7
0400	0	8	9	9	12	75.9	1600	0	2	24	24	24	99.7
15	0	11	6	6	12	46.9	15	0	2	24	24	24	99.8
30	0	12	2	2	12	16.1	30	0	2	24	24	24	99.8
45	0	7	11	11	13	83.7	45	0	2	23	23	24	99.8
0500	0	3	17	17	18	98.0	1700	0	2	24	24	24	99.8
15	0	2	20	20	20	99.4	15	0	2	22	22	22	99.5
30	0	3	18	18	18	98.1	30	0	2	23	23	23	99.7
45	0	4	17	17	17	97.6	45	0	2	22	22	22	99.5
0600	0	4	16	16	17	96.9	1800	0	3	21	21	21	99.0
15	0	4	16	16	16	96.5	15	0	3	20	20	20	98.7
30	0	4	16	16	16	96.6	30	0	3	20	20	20	98.8
45	0	5	15	15	16	95.7	45	0	3	20	20	20	98.9
0700	0	4	16	16	17	96.6	1900	0	4	18	18	18	97.8
15	0	4	17	17	17	97.4	15	0	4	18	18	18	97.9
30	0	3	17	17	18	98.1	30	0	5	15	15	16	94.7
45	0	4	16	16	16	96.6	45	0	7	12	12	14	84.6
0800	0	4	16	16	17	97.2	2000	0	9	9	9	13	72.9
15	0	4	16	16	16	96.4	15	0	13	3	3	14	21.5
30	0	4	15	15	16	96.0	30	0	13	3	3	13	23.8
45	0	5	15	15	16	95.8	45	0	14	2	2	14	12.8
0900	0	4	16	16	16	96.4	2100	0	14	2	2	14	14.4
15	0	3	18	18	18	99.5	15	0	13	2	2	14	12.7
30	0	2	21	21	21	99.5	30	1	14	1	1	14	9.5
45	0	2	24	24	24	99.7	45	0	12	4	4	13	30.7
1000	0	2	23	23	23	99.7	2200	0	11	5	5	12	40.4
15	0	2	22	22	22	99.5	15	0	13	3	3	14	19.5
30	0	2	24	24	24	99.7	30	1	15	0	1	15	8.5
45	0	2	24	24	24	99.6	45	1	15	0	1	15	9.0
1100	0	2	24	24	24	99.7	2300	1	15	0	1	15	8.3
15	0	2	24	24	24	99.7	15	1	15	1	1	15	9.9
30	0	2	24	24	24	99.7	30	0	14	1	2	14	11.8
45	0	2	23	23	23	99.6	45	1	15	1	1	15	8.5
1200	0	2	22	22	22	99.5	2400	2	15	0	2	15	14.9

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