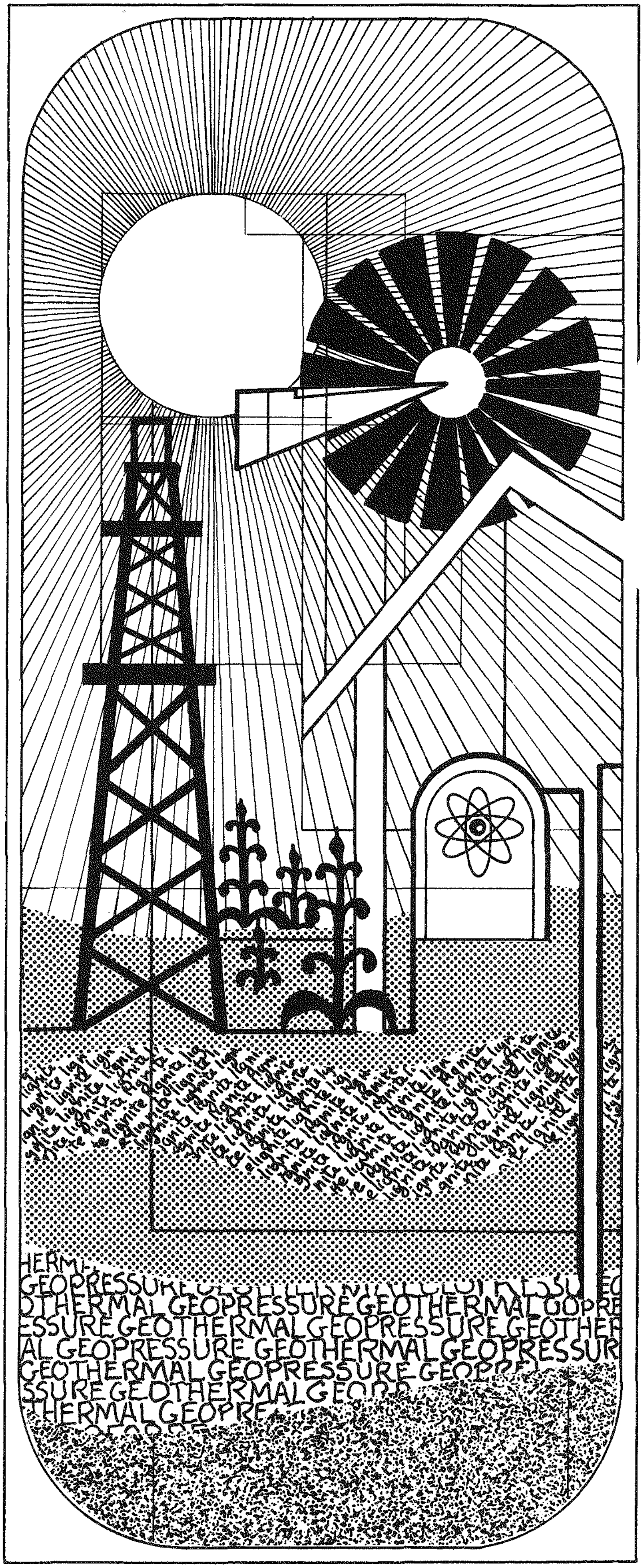

Texas Energy Development Fund

TENRAC/EDF--062

DE83 900825

USE OF WIND POWER TO ASSIST IN STRIPPER (OIL) WELL PUMPING

TENRAC/
EDF-062

TEXAS ENERGY
& NATURAL RESOURCES
ADVISORY COUNCIL

AUGUST, 1981

MASTER

USE OF WIND POWER TO ASSIST IN STRIPPER (OIL) WELL PUMPING

by

Earl H. Gilmore

951 5667

Alternative Energy Institute
West Texas State University
Box 248
Canyon, Texas 79016

INTERIM REPORT

August 31, 1981

Prepared for
Texas Energy and Natural Resources Advisory Council
Energy Development Fund
Project # 80-W-4-1

Report # EDF-062

EXECUTIVE SUMMARY

A wind-electric generator designed and constructed by United Technologies Research Center in East Hartford, Connecticut, was selected for a wind-assist to stripper (oil) well pumping experiment. The field, containing 100 wells, is northeast of Borger, Texas, and is leased by Phillips Petroleum Company. The machine is rated at 8 kw in a 20 mph wind. The foundation was poured early in March of 1981, but assembly and erection was delayed until mid-August at the request of the manufacturer. Two UTRC machines failed during the winter of 1980-81, which necessitated additional study and developmental work.

This emphasizes characteristic problems being faced by the developing wind machine industry. Manufacturers and entrepreneurs are clearly unable to provide all of the required technical expertise for successful new system development because of a lack of performance data. It should be recognized that no wind machine available today should be considered fully developed and field testing is essential for revealing design flaws, omissions, etc., as well as for evaluating application potential.

The UTRC 8 began operation on August 14, 1981, and between that date and September 2, 1981, 880 kwh of electrical energy were produced. From this it is projected that at least 30,000 kwh per year may be produced assuming continuous operation. Of considerable significance is that no problems were encountered as a consequence of electrical connection to the grid in the stripper well field. Since only about nineteen days of operation were recorded, continuation of data collection is required to satisfactorily determine system efficiency, reliability, and economics.

Preliminary results indicate a cost for electrical energy at the site of about 14 cts/kwh, and a payback period of about 12 years. The available data are far too limited, however, to merit much confidence. The Phillips project manager indicated that payback periods of less than 6-7 years are commonly accepted. One year of reasonably continuous data should provide the information necessary for Phillips to make its own economic assessment.

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ACKNOWLEDGEMENT

We are grateful for the assistance of Mr. Seth Thomason, Industrial Representative of Southwestern Public Service in Borger, who provided a pole for the anemometer and made arrangements for it to be set. He also supplied the detented kilowatt-hour meters for the directional metering required.

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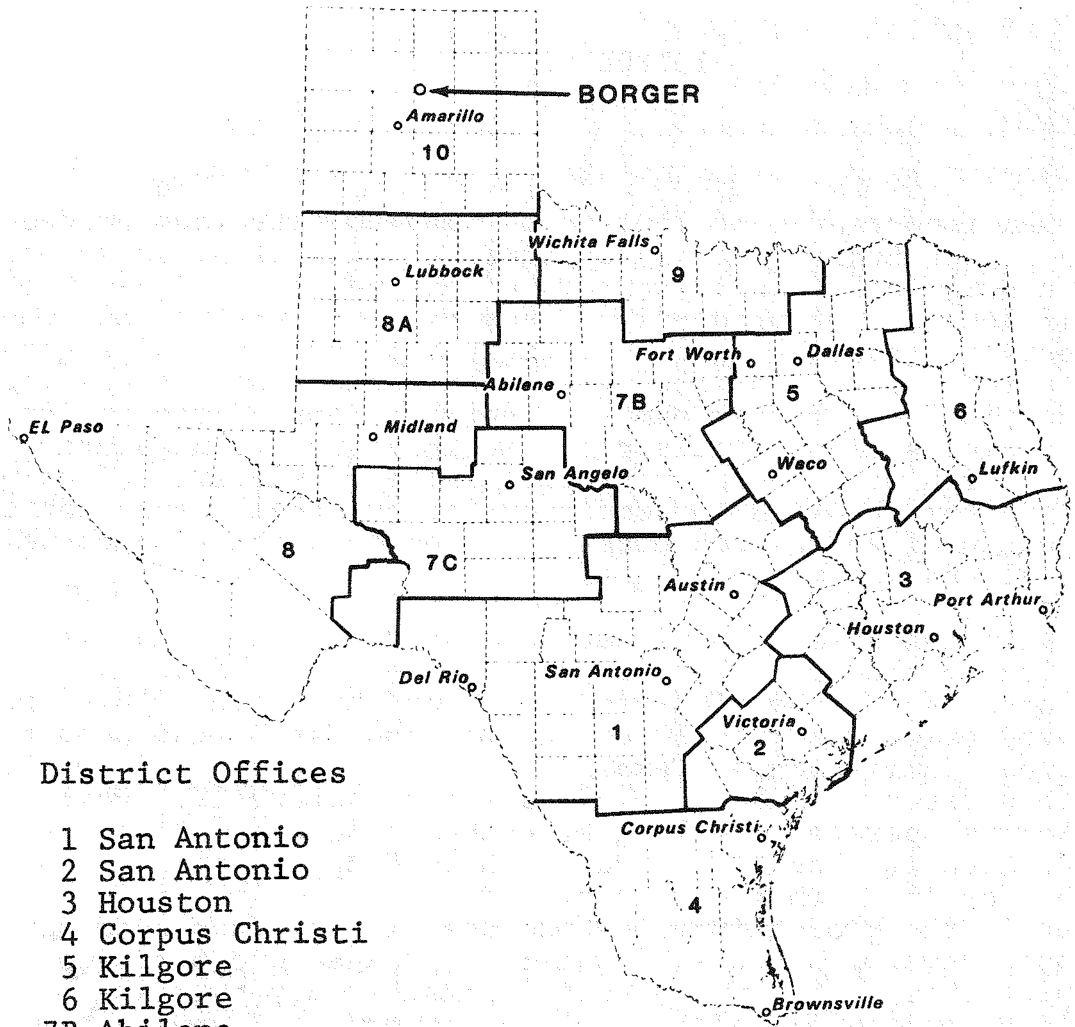
INTRODUCTION

Background

An important contribution is made to petroleum production in the State of Texas by stripper oil wells, those wells which pump less than 10 barrels of oil per day. Because of their low rate of production, they can be operated only under especially favorable economic circumstances, such as a good price for oil, and/or low production costs. One escalating production cost is for pumping energy. Some of the fields containing stripper wells also lie in parts of the State having high wind energy potential. The possibility of using energy from the wind to complement or eventually supplant the conventional energy resources now used to pump stripper wells is real and worth investigating.

A prime area for initiating a study of this kind is in the Texas Panhandle where a large number of stripper wells are operated in the windiest region of the State. This area is production District 10 of the Oil and Gas Division of the Railroad Commission of Texas (Fig. 1). Of the 12,500 wells in this district, about 11,500 are stripper wells. Phillips Petroleum operates the largest number of these wells. Average production is about 3 bbl/day in Gray County, and less than 2 bbl/day in Hutchinson County. This oil is emulsified with water in the production zone, so that it is often necessary to pump several barrels of water to produce one barrel of oil. Pumping costs are thus increased considerably over what they would be if the oil alone could be pumped.

The earliest effort to identify the regions in the continental U.S. having the greatest windpower potential was made by Thomas in 1946 (1). He identified the Texas Panhandle region as one having an extraordinarily high potential, probably the best of any region of comparable size in the nation. Later studies, the first for Texas only (ref. 2, Fig. 2), and another for the entire U.S. (ref. 3, Fig. 3), generally confirm Thomas' findings. The data available for making these assessments are admittedly sparse, particularly for a state the size of Texas. The data have been gathered at a relatively few widely separated National Weather Service stations. The function of sensing and recording windspeed data was only one of a number of similar duties, moreover, the data were taken with anemometers at various heights and in some questionable locations. Nevertheless, general studies



District Offices

1 San Antonio
2 San Antonio
3 Houston
4 Corpus Christi
5 Kilgore
6 Kilgore
7B Abilene
7C San Angelo
8 Midland
8A Lubbock
9 Wichita Falls
10 Pampa

Figure 1. Texas Railroad Commission Map of Oil and Gas Production Districts.

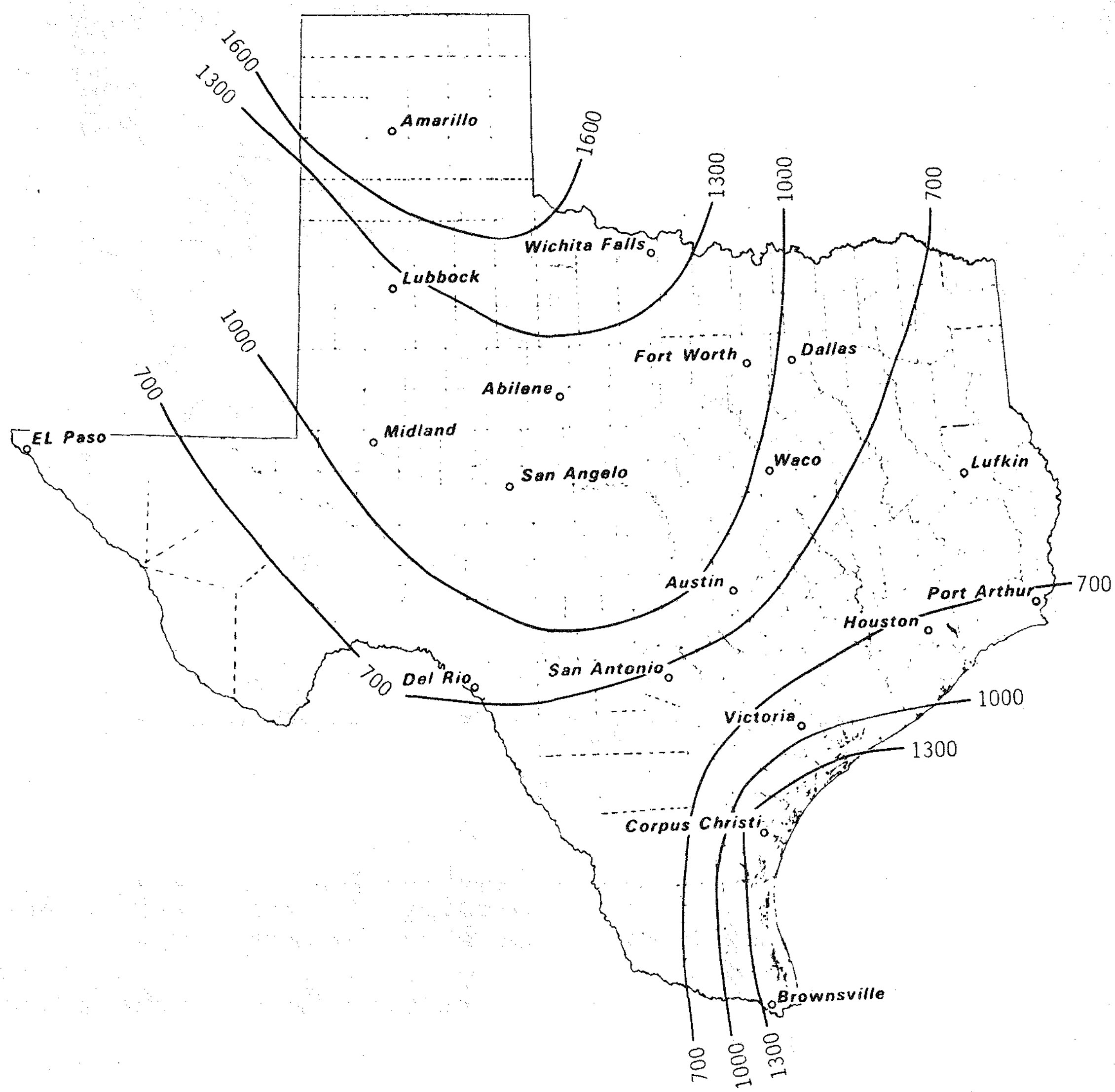


Figure 2. Map of Windpower Potential in Texas. Numbers on the contour lines are average annual energy in kwh per square meter at a height of 23 ft (7 m). For flat country, these values must be multiplied by 2.6 to obtain values for the 50 m level.

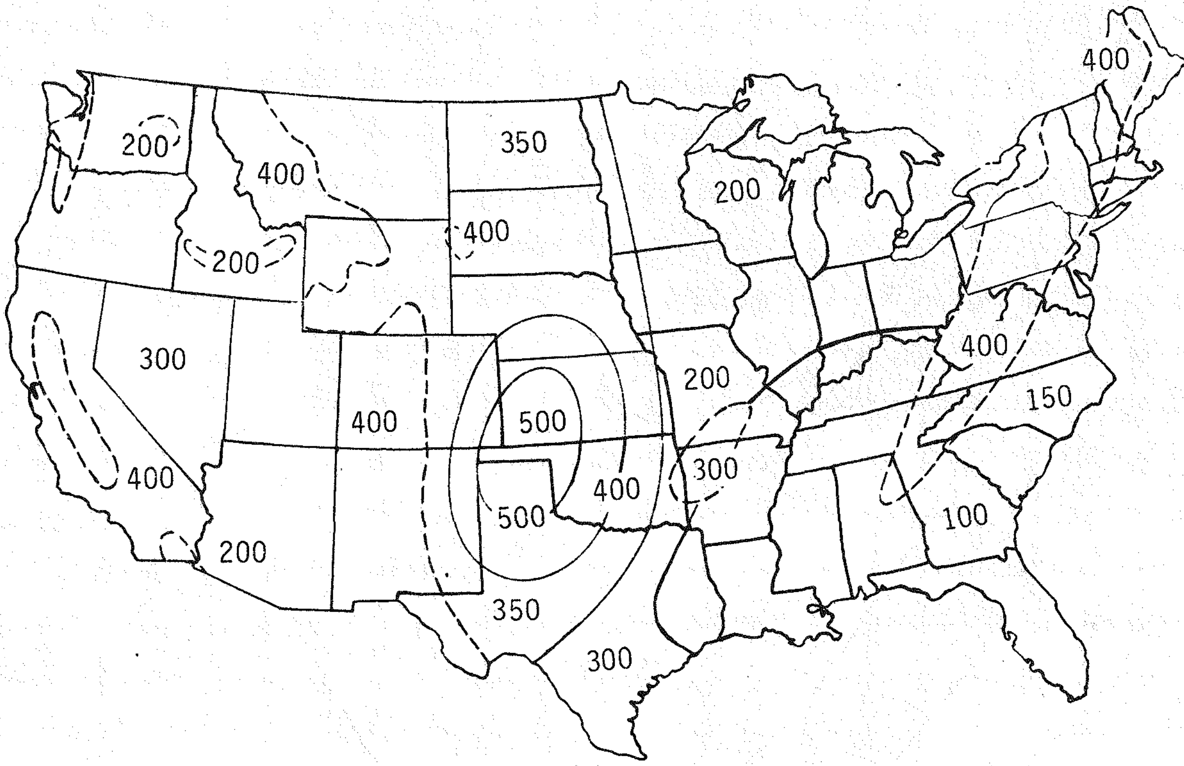


Figure 3. Map of National Windpower Potential. Numbers are estimates of average annual power, watts per square meter, at a height of 50 m above ground level.

provide an undeniable basis for identifying the Texas Panhandle as a prime region for developing the windpower potential, even if many important details are absent. The Alternative Energy Institute data collection program will improve the data base for the northwestern part of the state.

Objectives

The objectives of this project can be broadly classified into those which should be accomplished in three years, and those that would need to be paralleled by the development of new production technologies. The latter could conceivably lead to a total incorporation of wind energy into the energy output of favorably situated oil fields. Only the first (short-term) objectives will be presented here.

1. To identify and solve the principal problems involved in the mechanics of installing, interconnecting, protecting, metering, and operating a wind-electric generator into a grid supplying power to stripper well pumps.

2. To meter over a significant time period the output of a wind turbine located within a stripper well field in the Texas Panhandle. The information sought will include: a) annual energy production, b) power vs wind-speed curves for the UTRC 8 kw wind turbine, c) average power and maximum power, d) determine whether items a) and c) can be calculated with the use of item b) and wind histograms taken at the site.

3. To record enough wind data on site to a) allow the determination described in "2,d" above, and b) to provide a data base from which accurate performance predictions can be made for other wind turbines that might be considered for use in the same area.

4. To determine the extent to which wind turbine output matches the intermittent loads of stripper wells (no change in pumping schedules).

5. To determine the technical and economic feasibility of modifying stripper well pumping schedules to coincide with power availability from the wind. The effect on well productivity must obviously be given careful consideration.

6. To determine the technical and economic feasibility of using stand-alone wind turbines to pump stripper wells. In addition to its cost comparison value, this information will be valuable to those with the problem of operating wells that must be powered by something other than electricity.

Objectives 4, 5, and 6 will be completed by a continuation of this project authorized for the 82-83 biennium.

The subtle benefits of a project of this kind are often overlooked. Wind turbine technology is still in the early stages of development wherein a considerable input of technical expertise is still required. The manufacturers and entrepreneurs are clearly unable to provide all that is required; indispensable information will have to come from critical evaluations of field tests and experiences. The oil field is operated and maintained by personnel with technical training and experience, and whose daily tasks involve the operation and servicing of large machinery. Although many aspects of wind turbines and wind turbine operation are not in their areas of expertise, many are. The participation of Phillips personnel cannot help but advance the practical utilization of wind turbines, not only in the oil field, but in general as well.

The technical staff at UTRC is especially desirous of having a power vs windspeed curve for this machine made at a site other than at the U.S. Government small wind machine test site, in Rocky Flats, Colorado, where the initial acceptance tests were made.

Overview of Contents

A general description of the nature of this project and of progress made to August 31, 1981 - the end of the contract period - is presented in this report. The general background and motivating objectives have already been discussed. This list of the objectives and their presentation is the most complete and detailed to date.

General features of the UTRC-8 wind turbine are described, and a list of its technical specifications is given in the Appendix. The foundation design and its minor modifications are discussed along with a brief account of the construction. Turbine modifications made by the UTRC technician during assembly and just prior to its erection are discussed. Information concerning the erection of the wind turbine is also provided.

A view of the total instrumentation also is given with a description of what has been accomplished at the end of this contract period. The small amount of data collected within the short time interval between the erection of the machine and the end of the contract period is presented and briefly discussed.

PROJECT PLAN

Description of Project

The general plan has been to procure and set up an appropriately sized and sufficiently reliable wind turbine in a producing oil field, and to tie it into the local electrical grid that provides power to the pump motors. Coincident with and immediately following installation of the wind turbine and all its associated equipment, the instrumentation necessary for accomplishing the stated objectives would be installed.

An extended period of data collection will then follow. The time required to accumulate the quantity of data adequate for answering the major questions is, of course, difficult to predict. Data analysis will begin as soon as any significant quantity of data is available and will continue throughout the remainder of the contract period.

The last three of the objectives listed will necessitate frequent consultation and collaboration with Phillips personnel. Some of the data they must have will take some time to obtain. It is probable that most of the economic analyses will take place during the last few months of the contract.

The UTRC-8 kw Wind Turbine. This wind turbine was designed and assembled in the United Technologies Research Center at East Hartford, Connecticut. A picture of this unit is shown in Fig. 4. The unit was developed with funding from one of four competitive contracts offered by the DOE in 1977. Two important specifications were that it would produce an output of at least 15 kw in a 27 mph wind, and that it would produce from 45,000 to 55,000 kwh of electrical energy per year at sea level in a wind regime having a 12 mph (5.4 meters/sec) average wind speed (4,5). Three manufacturers each delivered a unit which was tested at the Rocky Flats Small Wind Machine Test Center in Colorado. The UTRC 8 kw performed well in those tests, but the wind regime at that site leaves much to be desired when it comes to producing reliable power vs windspeed curves within a reasonable time span. As a consequence, the power vs windspeed curves available from these tests require verification before they can be used with confidence to predict machine performance in other wind regimes, especially in regimes with good potential for energy production. Nevertheless, those tests indicated that this wind turbine is sufficiently tough, reliable, and efficient to justify further testing in the Texas Panhandle. It must be realized, of course, that no machine available today should be considered fully developed, and that field testing is essential for revealing the remaining design flaws, omissions, etc., as well as for evaluating application potentials. The UTRC 8 kw unit selected for the Borger project presently represents the only design resulting from the original DOE contract that has much prospect of being mass-produced.

The UTRC-8 kw is a two-bladed, horizontal-axis, down wind machine designed to be yawed by forces resulting from blade coning. Rotor diameter is 32 ft (approx. 10 meters), giving a swept area of about 800 sq. ft. (74 sq. meters). The machine has been equipped with a 60 Hz, 3-phase, induction generator. Its stators are connected to give a 480 volt (nominal) output. Because the generator windings are excited by the 480 volt grid voltage in the stripper well field, it, in turn, supplies power to that grid at 480 volts, operating as an asynchronous generator.

The most unusual feature of the turbine is the extraordinary flexibility of the blades and of their supporting structure. The blades are affixed to a flexbeam which has nonisotropic deformation constants such that the blades can be more easily twisted than deflected as cantilevers, either in or perpendicular to the plane of the rotor. This

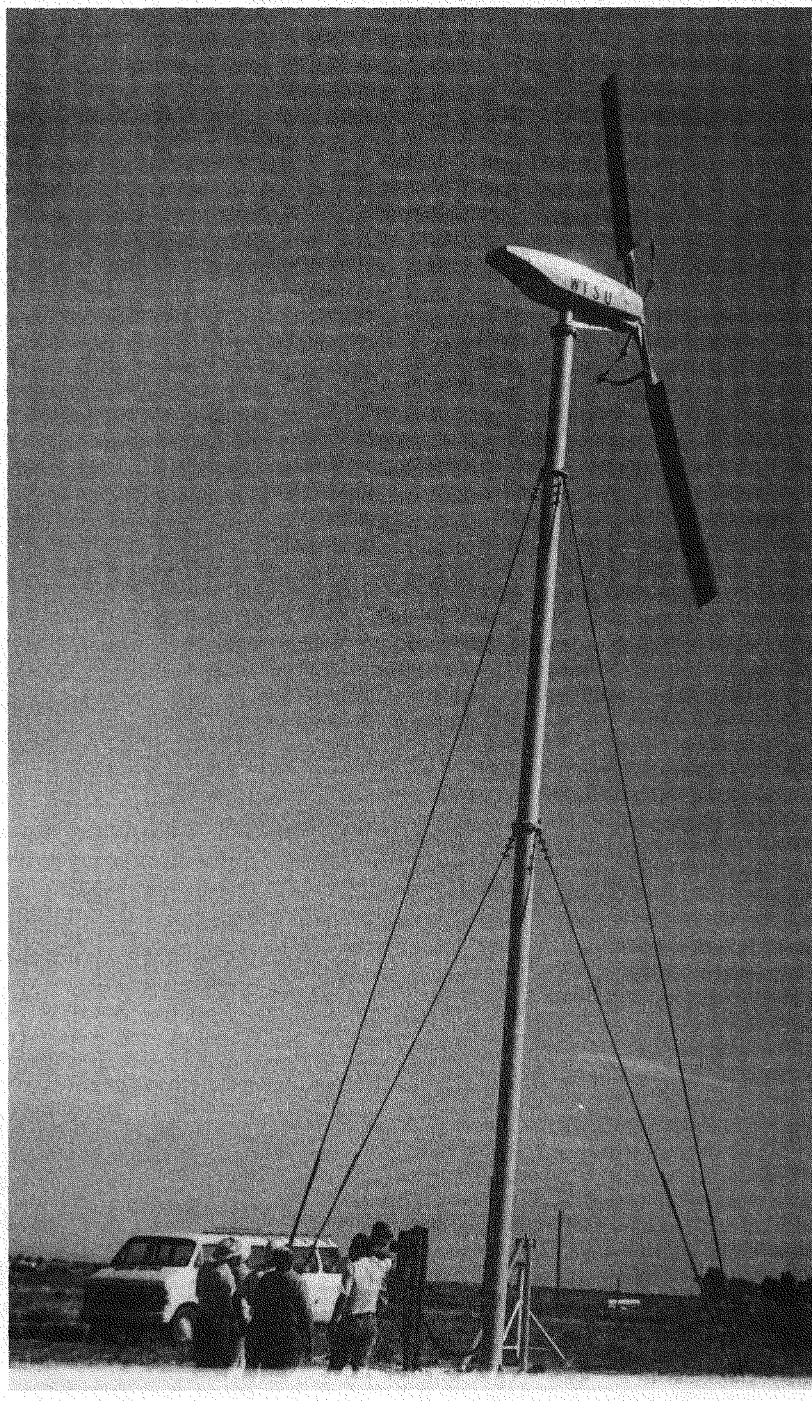


Figure 4. UTRC-8 Wind Turbine.

feature was to have provided sufficient feathering for the turbine to operate in very high winds without the need of a brake. Two pendulum masses are attached to the blades by a linkage that controls the pitch as a consequence of the centrifugal force acting on these attached masses (Fig. 5). The nacelle also houses a speed increaser gear train and a brake. The brake was added after two other prototype machines were damaged in tests in Wisconsin. Power and control circuit slip rings, and several safety sensors are also housed within the nacelle.

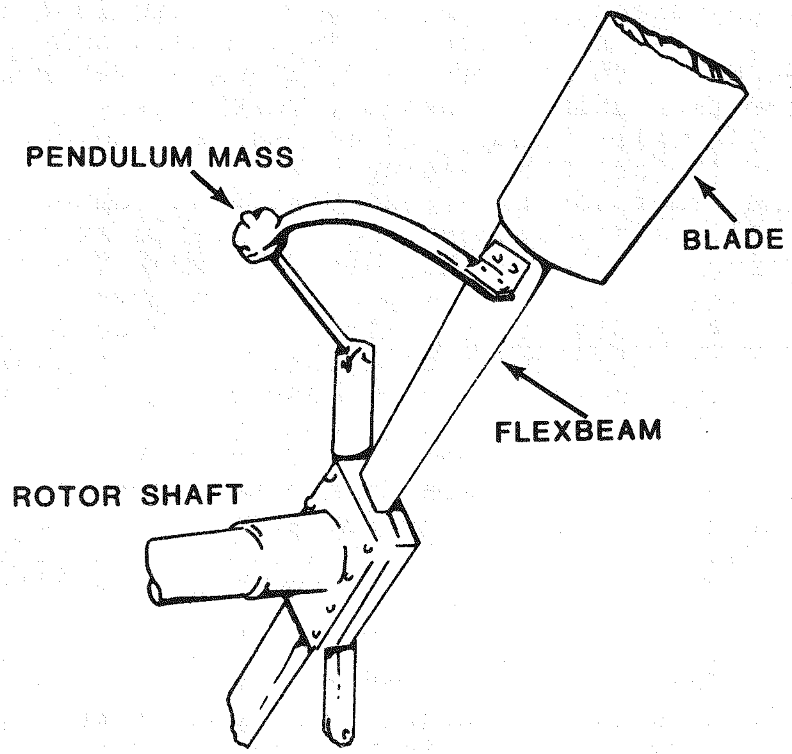


Figure 5. Flexbeam with Pendulum Masses.

The nacelle is mounted on a tower providing a hub height of 50 ft. This tower was designed and tested by UTRC. It is fabricated from 10 inch standard pipe and flanges, and is guyed at each of two levels with three lengths of 7/8 inch cable. Tower design permits lowering and raising with the aid of an A frame and a cable and pulley system. Motive power can be supplied by a 12 volt dc motor driving a winch, or by a heavy vehicle to which cables can be attached.

Two early models of the UTRC 8 kw wind turbine feeding into the distribution system of Wisconsin Power and Light were severely damaged during ice storms in December of 1980. These units were operating on towers provided by the utility which were somewhat taller than the towers designed and tested by UTRC. The failures resulted in part, if not wholly, from resonances set up between rotor frequencies and tower frequencies. Nevertheless, the plan to rely exclusively on blade feathering to control rotor speeds in high winds was abandoned. Several new safety features were introduced to minimize the chances of damage not only during severe weather conditions, but for other conditions occasionally encountered. The decision was made to include a disk brake as a permanent part of the power train instead of using it as an extra safety feature in test models only. The brake is actuated by 1) rotor overspeed, 2) excessive rotor vibration, 3) low (including a loss of) line voltage, 4) phase reversal, 5) single phasing, 6) excessive load currents, and 7) generator (motor) overheating. Whenever the brake is applied, the generator is automatically disconnected from the line. All safety sensors are resettable at the control box except for the sensor that detects excessive vibration.

The Stripper Well Oil Field. The stripper well field where this project is in progress is located about six miles ENE of Borger on the Cockrell Ranch Lease of the Phillips Petroleum Company (Sect. 6, Blk M21, TCRR Survey) in Hutchinson County, Texas (Fig. 6). The overall average of stripper well production in Hutchinson County was reported to be less than two barrels per day. Considerable quantities of water must be pumped as well because this oil is emulsified with salt water.

The field is located in an area between the level ground of the plains country and the Canadian River. The terrain is considerably rougher than most of the rest of the Panhandle country; the soil is primarily a mixture of coarse sand with smaller amounts of gravel. Because the land is unsuited to farming, agricultural use is limited to the grazing of cattle. The natural vegetation is mostly short grass and some scrubby mesquite. Several ravines cross the area, generally from east to west. As a consequence, the land slants upward from the west, which will probably cause wind coming from anywhere within the sector from the southwest to the northwest to be accelerated. The openness from the southwest around to the northwest is attested by the fact that many topographical features at least eight to ten miles distant can be seen in this view. The site selected for the foundation is on a rise between two fairly deep ravines; one to the north, and one to the south. The base of the tower is at an elevation of about 3060 ft (933 meters) above sea level.

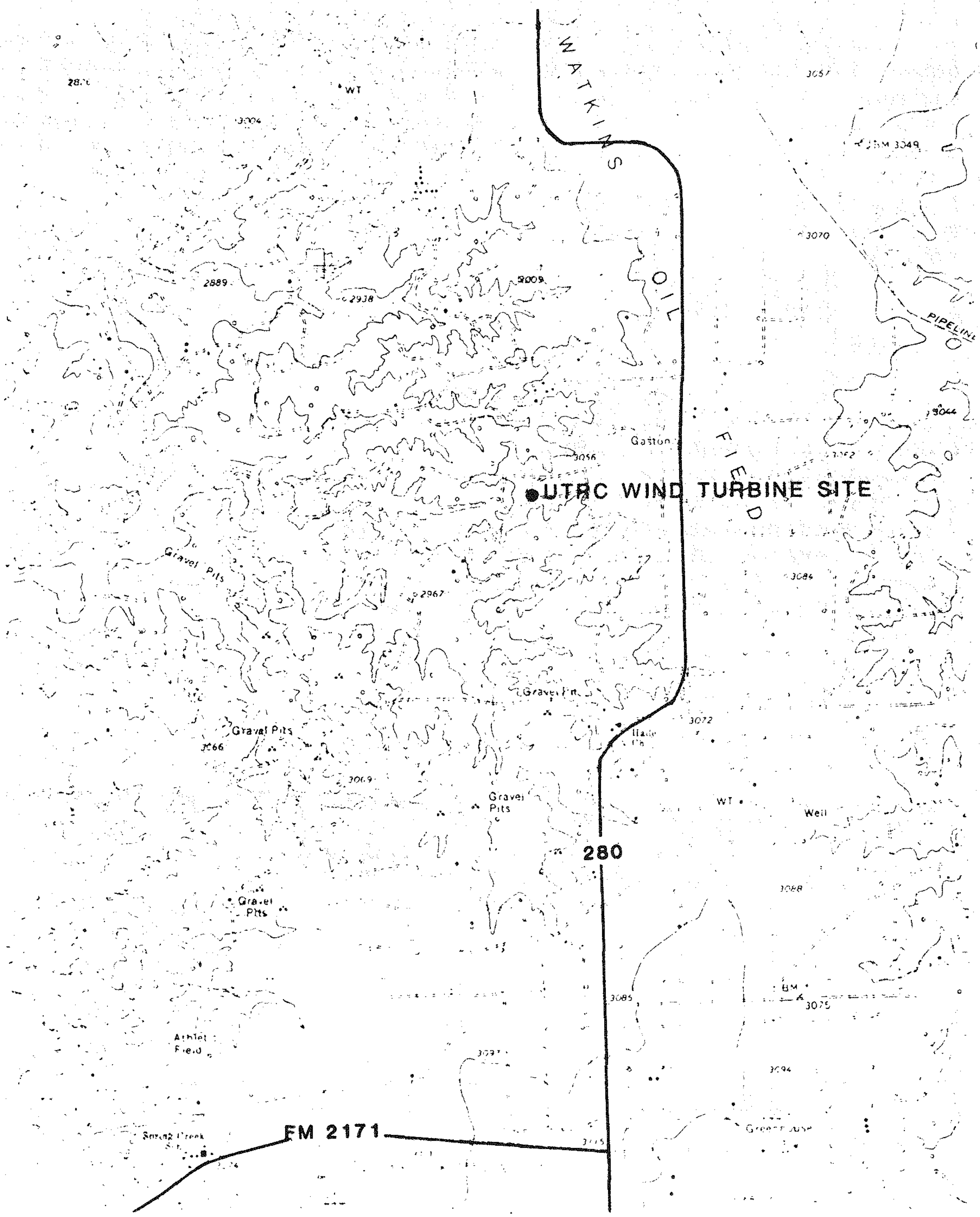


Figure 6. Topographical Map of Area Around Site.

Approximately 100 oil wells are operated in this lease. Some have been in operation since the late 1920's. Their depths average about 3000 ft (1000 meters). They produce some gas along with oil and (salt) water, and must be serviced periodically to remove paraffin that accumulates in the barrel and in the delivery pipe. The piping system that collects production from the wells appears to have evolved in a way dictated by existing circumstances and the topography. Production is collected in a way unrelated to the power distribution system. For some of the tests that are planned, some repiping and meter insertion will be required.

Most of the wells are powered with 3 hp, 480V, 3-phase, 60 Hz electric induction motors, but a few have motors with higher horsepower ratings. Phillips owns all the electrical distribution lines and equipment on the lease. The electrical power is supplied by Southwestern Public Service Company to connections at the south end of the lease, where it is also metered. Line voltages on the lease are maintained at about 480 volts. Power is supplied to the area where the wind turbine is installed through an open delta connection from two transformers. Approximately 14 wells are served from this transformer bank. The schematic arrangement of this local grid is shown in Fig. 7.

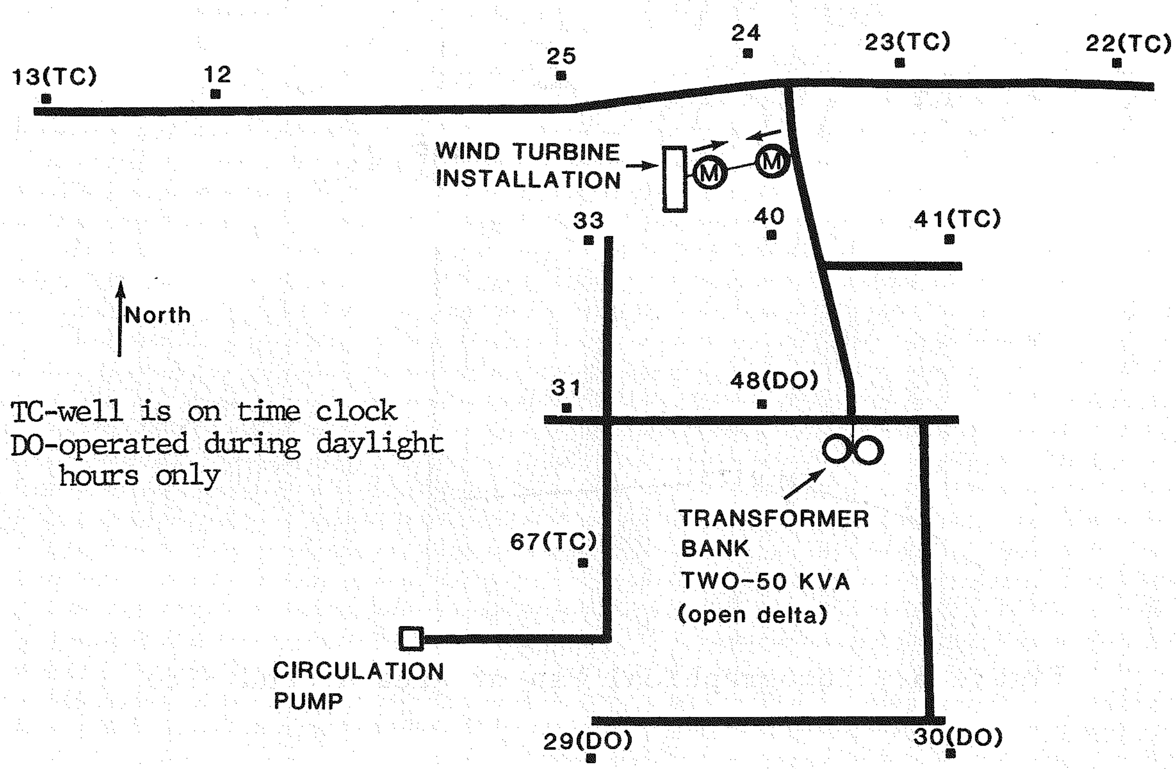


Figure 7. Local Electrical Supply Grid.

Tower Foundation. Figure 8 is a diagram of the foundation actually constructed. It differs slightly from the original plan which called for cable anchor pads spaced 120° apart, all at the same distance of 11 ft. from the center of the tower pad. The hoist anchor pad is positioned to the geographic north of the tower pad to permit the tower to be lowered into the prevailing wind. The system of cable anchor pads is displaced 7° from the direction of the hoist pad in order to allow the passage of a hoisting cable to the bottom of the tower. We substituted a simpler and more easily constructed anchor pad for the UTRC design. The UTRC engineers concurred in this change. A comparison of the two designs is made in Fig. 9. The primary performance advantage of the modified design (Fig. 9a) is that it minimizes opportunity for metal fatigue. In the UTRC design (Fig. 9b) the long rods extending from the blocks of underground concrete will be subjected to flexing forces by action of the cables connected to their ends. The possibility of metal fatigue at the point at which the rod enters the concrete block is, therefore, much greater. Excavation is much simpler as well. It is necessary only to drill a cylindrical hole in the soil. We had originally intended to drill and bell, but the soil was not sufficiently compacted to permit a bell to be formed. Fig. 10 is a picture of the tie plate that was designed and fabricated to tie the cables, through turnbuckles, to the concrete anchor.

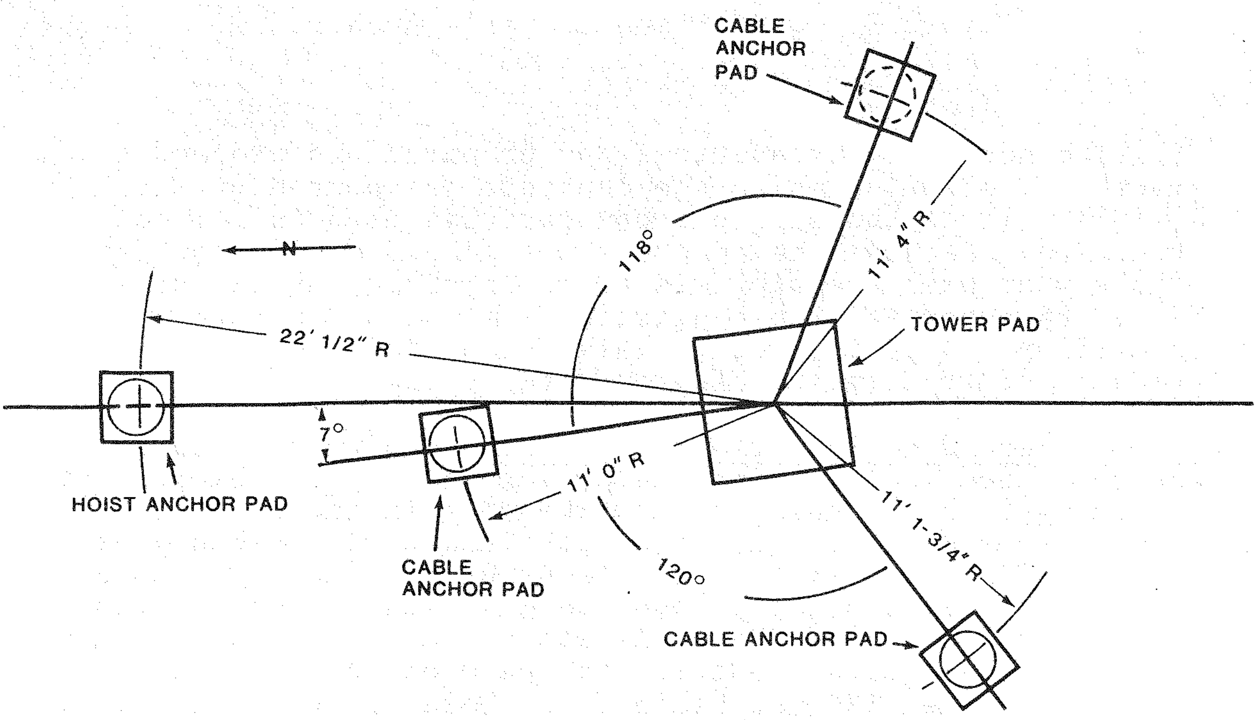
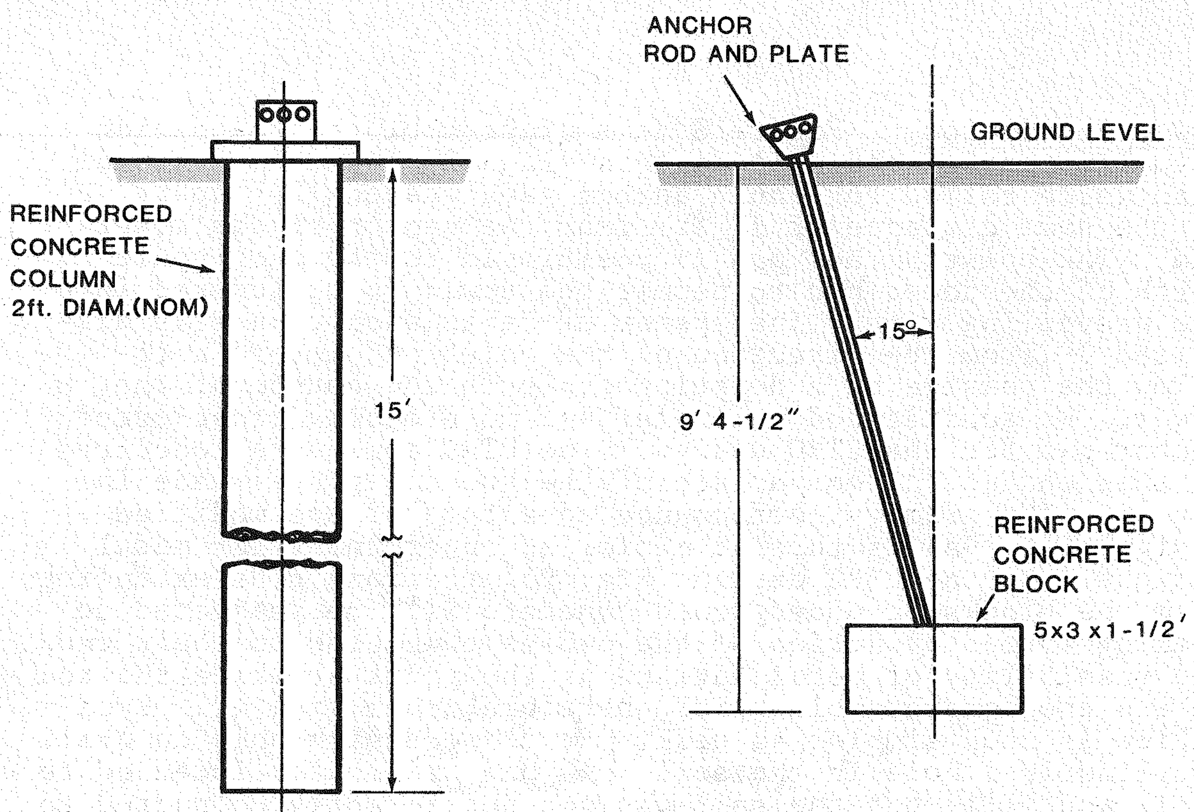


Figure 8. Foundation Plan for UTRC-8.



a) Cable anchor used on stripper well project.

b) Original design by UTRC.

Figure 9. Comparison of Cable Anchors.

The necessary excavations and preparations proceeded smoothly, following which the concrete was poured on March 4, 1981. Three-thousand psi concrete was used in all construction. Because the concrete was poured during the part of the year when freezing was to be expected, it was protected by covering with a plastic film which, in turn, was covered by a layer of soil. This foundation shows no evidence of freezing or of premature drying.

Assembly and Erection of Wind Turbine. When the foundation was completed, only a minor delay was anticipated because of the changes that needed to be worked out in the wind turbine. We were soon notified that modifications would probably be completed in time for the unit to be erected in May. More time was required however, and the installation date moved on into the summer of 1981. It was not until August 11 when the additional parts required for the modifications and Mr. Tom Murrin, the UTRC technician, had both arrived. The modifications were completed, the tower assembled and the unit was erected August 11-14.

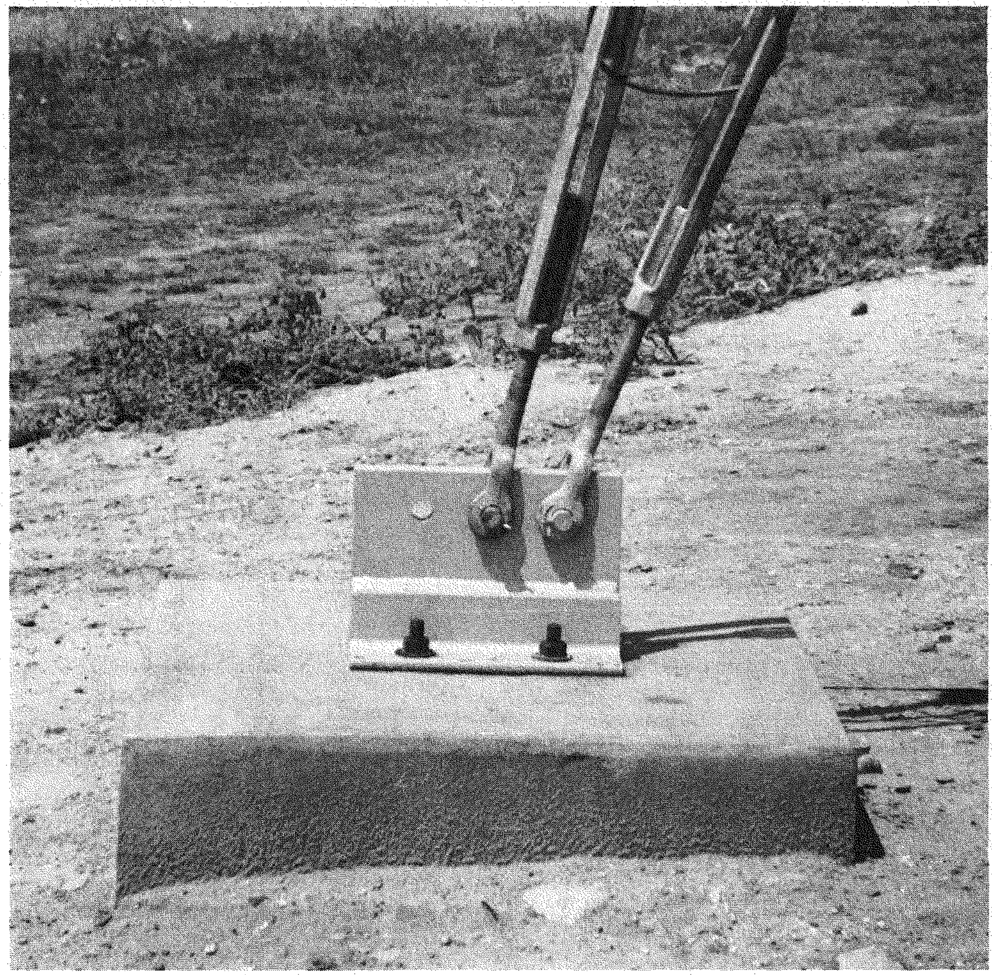


Figure 10. Tie Plate on Anchor.

The primary decision to permanently install a brake on the drive train led to decisions to use this brake to stop the rotor for any one of several conditions regarded as threatening to the turbine. Several other changes became necessary as a consequence. The brake installed was a pressure plate type of a fail-safe design. It is applied whenever its electrical supply is interrupted, otherwise it is released. A rotor overspeed sensor was installed on the high speed shaft and a vibration sensor was installed in the nacelle. Both these sensors have the capacity to interrupt the supply power to the brake. The necessary changes in the control circuitry had been made in the control panel before it was shipped from UTRC. It was necessary, however, to install additional slip rings in order to connect the new sensors in the nacelle to the circuitry in the control box.

Some modifications of the mechanical systems were made as well. The yaw housing was replaced with a modified design because cracks had developed on one of the earlier models. In addition, the rotor shaft was changed, because the UTRC engineers wanted to use a shaft with increased hardness. In addition, changes were made that necessitated an additional keyway in the shaft. The thread for the hub bolt in the new shaft was different from the one in the old shaft. The new hub bolt required was inadvertently omitted in the shipment from UTRC. Phillips personnel sought out a machine shop in Borger and had the required bolt manufactured - a 7/8 inch diameter, Grade 5 bolt with left-handed thread - so that assembly could continue on schedule. All the electrical and mechanical modifications were made at the warehouse in Borger where the unit had been stored since its arrival early in 1981. All bearings requiring grease were serviced at this time, and a non-detergent 30 weight oil was added to the sump of the geared speed-increaser.

The turbine components were transported to the site on August 13 on trucks provided by Phillips. The tower was assembled, the yaw assembly on the nacelle was bolted to the tower, and the motor and its pitch control mechanism were assembled and attached to the rotor shaft. At this point, the generator was properly phased with the local grid. The guying cables were attached to the tower and to the cable anchors, the "A" frame was fitted to the shaft on the tower base, and the hoisting cable properly attached. The free end of the latter was connected to a winch on one of the trucks and the tower hoisted into place without event. Cable tensions were set by Mr. Murrin and the turnbuckles were secured with small locking cables provided by UTRC. Power connections were checked and the rest of the required wiring was completed at this time. The rotor brake was released and the unit began to produce power at about 9:40 am on August 14, 1981. Photographs of the assembly and erection activities are provided in Figs. 11 through 14. A view of the installation from the southeast is given in Fig. 15.

<u>Instrumentation</u>. The instrumentation consists of three general types. The first and most extensive consists of the meters that measure electrical quantities. When the turbine was installed at the site, two kwh meters with detents were wired into the line between the wind turbine and the local grid to measure 1) energy delivered to the grid by the turbine, and 2) energy consumed by the turbine. Elapsed (running) time indicators were installed in order to measure the total time that the turbine is available for producing power, and the total time that the turbine delivers power to the line. An Electro Industries Model WH201GD meter was chosen for use at the installation. It will provide an

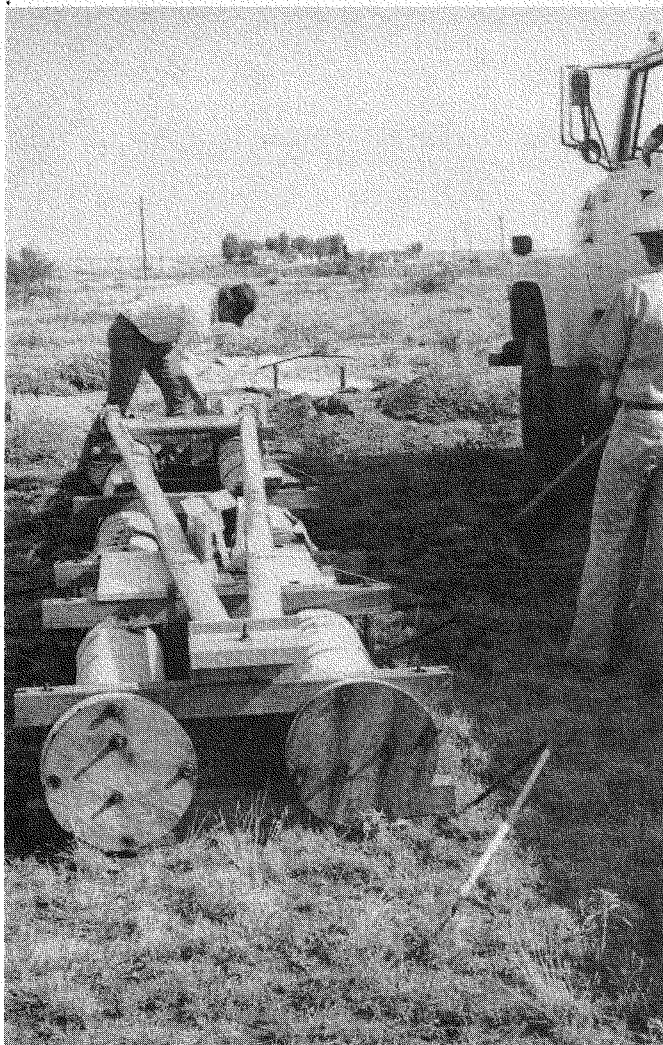


Figure 11. Tower Sections at Site Before Assembly.

Figure 12. Preparation of Nacelle Section Prior to Assembly.

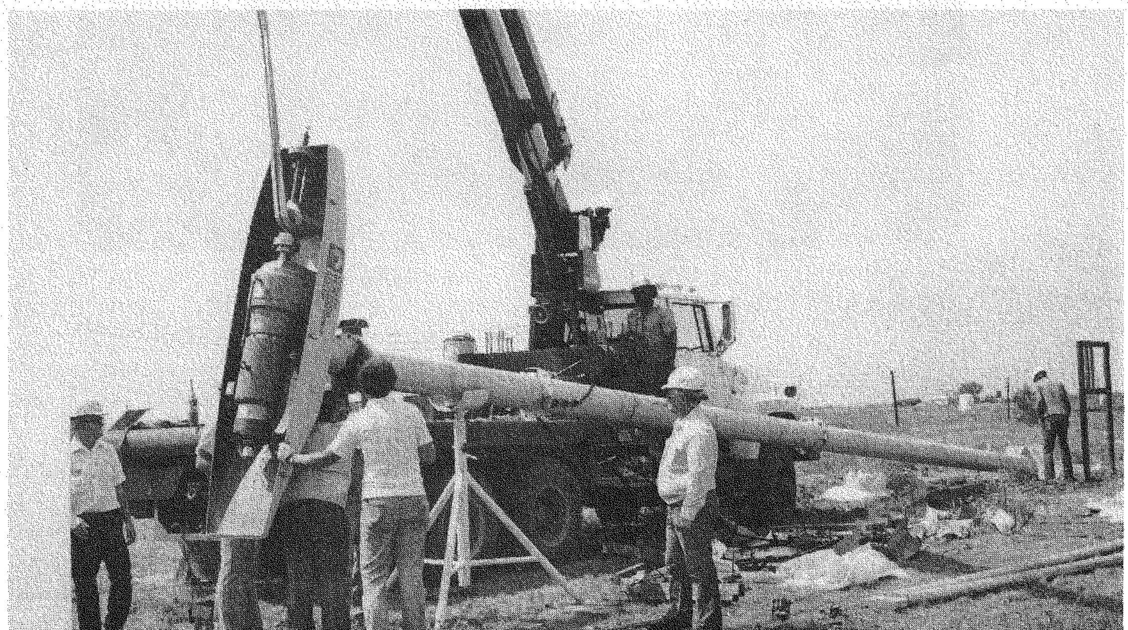


Figure 13. Nacelle Section Being Bolted to Tower.

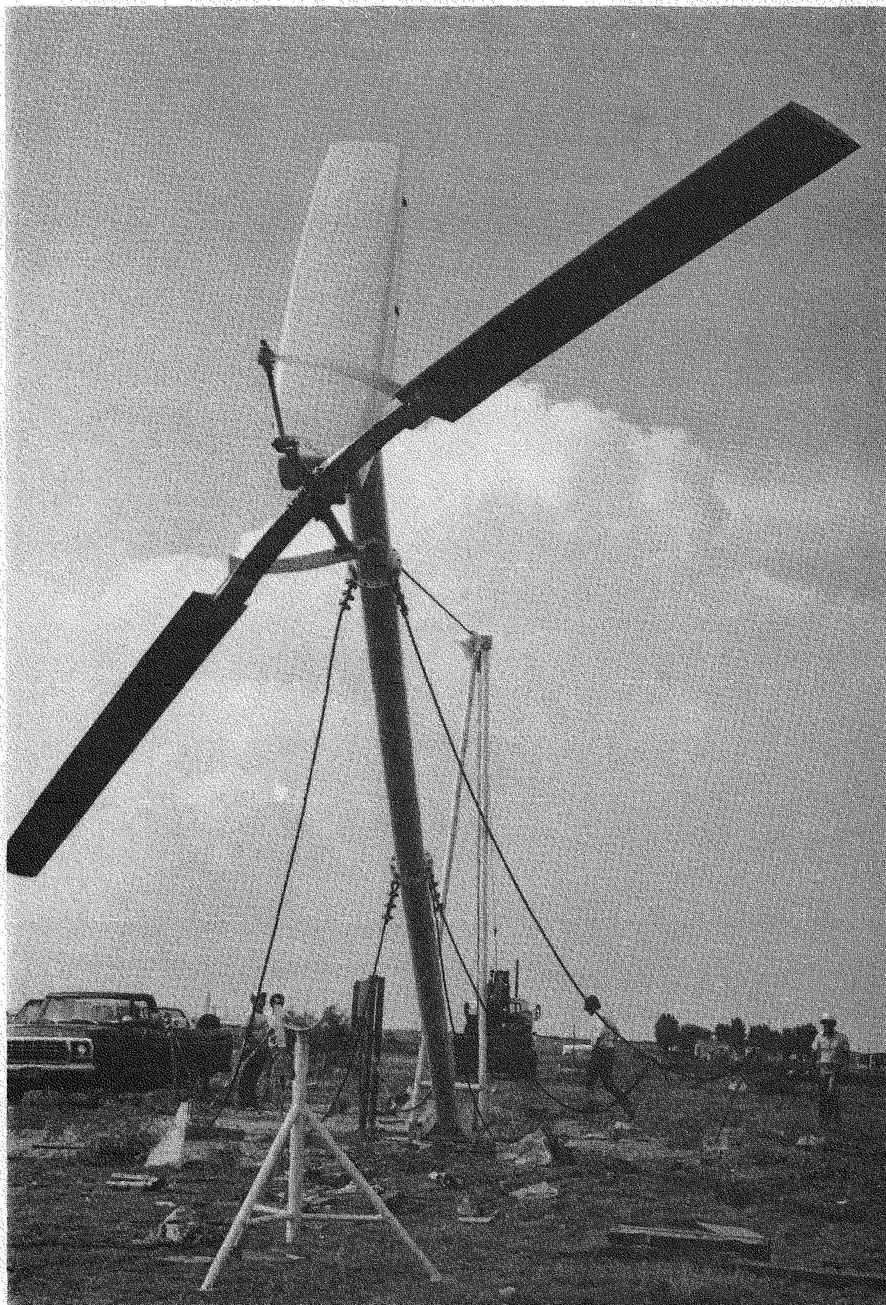


Figure 14. Hoisting of Assembled Unit into Position.

LED readout of instantaneous power as well as a cumulative record of kwh produced by the machine. The output of this meter can be interfaced with data acquisition systems. It will provide electrical power output readings while the meteorological instrumentation will provide simultaneous windspeed readings. These readings will provide the data necessary to produce power vs windspeed curves for the turbine.

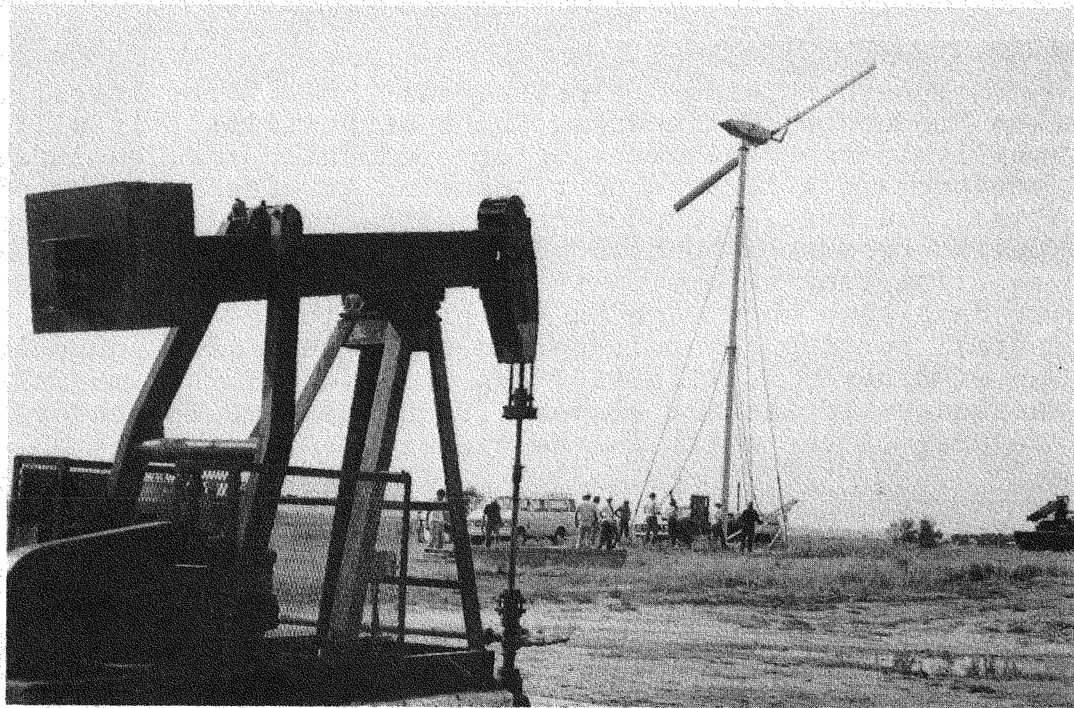


Figure 15. UTRC-8 Wind Turbine as seen from Well No. 40.

The second type of instrumentation is meteorological. An anemometer was installed on a pole located 100 ft. to the southwest of the turbine tower. The anemometer height was set at the same level as rotor hub height, which is 50 ft. A Mark IV Natural Power compilator was installed to record the wind data from the anemometer. Thirty-two separate windspeed bins are available in the compilator for each of the 24 hours in a day. The sensitivity of the compilator is set at 1 meter per second (m/s), consequently the mean bin windspeeds are 0.5, 1.5, 2.5, etc. m/s in bins 0, 1, 2, etc. All windspeeds 32 m/s and greater are logged into bin 32. A visual readout of windspeed will be provided at the base of the tower where a readout of turbine power will also be provided. These signals will also be input to data acquisition system that simultaneously record windspeed and turbine power.

Two different kinds of data acquisition systems will be used. The first will be a two channel Sangamo recorder of the same type used by utilities to record electrical energy demand. The second is a system owned by the USDA Research and Conservation Center at Bushland, Texas. It is installed in a trailer that can be moved from location to location. Although it will be available on a limited basis for use in the stripper well field, it will be available long enough to get the data required to develop power vs windspeed curves for the machine.

The third kind of instrumentation will be installed by the Production Engineering Group at Phillips. It will primarily involve the metering of production from an individual stripper well located near the wind turbine. At the present time, the available production data applies to groups of wells, because production is combined and conveyed to a settling tank before it is metered. It will be necessary to have some knowledge of the production of one well on its normal pumping schedule before the effect of a schedule based on wind power availability can be assessed. It may also be necessary to install elapsed (running) time indicators on several of the wells in the vicinity.

RESULTS

The long delay in getting the UTRC-8 into operation deprived us of the opportunity to collect more than a modicum of data during the initial contract period. The time was insufficient for installing more than standard electrical metering, and no meteorological data could be collected. Nevertheless, a rough calculation of some of the economics involved can be made.

The unit produced 880 kwh of energy during the period August 14 - September 2. The average energy in August winds is about 60% of the overall monthly average. On this basis we can estimate that the annual output for the unit will be about 30,000 kwh. A calculation of the cost of energy in the manner of Clark, et al. (6, page 52) gives 13.8 cts/kwh, based on a $21,000 initial cost, an annual interest rate of 16 percent, and a maintenance and operation cost of 3 percent per annum. A calculation of years to payback using Wolfe's method (7, page 304) and the above figures plus a fuel inflation rate of 16 percent and an initial fuel cost of $0.05/kwh, gives 12 years.

Of considerable significance is that no problems were encountered as a consequence of the electrical connection to the grid in the stripper well field. The interface worked well even though the grid supply voltage was somewhat higher than the nameplate 440 volt rating.

All the wind turbines of this size that are equipped with two blades are noticeably noisy, but in our opinion, the UTRC-8 is quieter than the others we have been around.

The tower sections did not align perfectly because the planes of the flanges were not as near perpendicularity to the axes of the tower section as they should have been, but it does not appear that there will be any problem on this account. Mr. Murrin set the guy cables with only slight tensions. There is a minor tower shake of no consequence when the unit operates.

CONCLUSIONS

Significant progress on addressing the primary objectives of this project, system installation, power production metering and production, load matching, stand alone system development, and economic analysis, have been accomplished. A lengthy delay was encountered because of required modifications in the overspeed control system. This was not considered unusual for a product of new technology being set up for testing in service-type situations. A considerable number of technical and organizational problems, as well as communication problems, including wind turbine shut-down retrofit, electrical system control adjustments, structural modifications, instrumentation installation, and interfacing with Phillips and United Technologies, have been overcome. Rapid progress on completion of data collection and analysis is expected.

The acquisition, installation and operation of a commercially available wind turbine by a state university in cooperation with a major oil company and the machine manufacturer provided a unique interface which has not typically been experienced in the past. Problems which were encountered emphasize the need for more technical support of this sort. It would have been especially difficult for individuals or small businesses to have accomplished the objectives of this project without strong engineering and technical support. Manufacturers and entrepreneurs are clearly unable to provide all of the required technical expertise for successful new system development because of a significant lack of reliable performance data. It should be recognized that no wind machine available today should be considered fully developed, and field testing is essential for revealing design flaws, omissions, etc., as well as for evaluating application potential.

The UTRC-8 is a two-bladed, horizontal-axis, downwind machine with a 440-volt, 60-Hz, 3-phase induction generator rated at 8 kw at 20 mph. The foundation for the unit was constructed on March 4, 1981, but due to manufacturer's delays, the unit was not erected until August 14, 1981. For the nineteen-day period between August 14 and September 2, 880 kwh were generated. Based on a projection assuming continuous operation, approximately 30,000 kwy per year should be developed. It is significant to point out that no problems were encountered as a consequence of the electrical connection to the grid in the stripper well field.

The results thus far have provided only the sparest insight to the economic aspects of the project. The figures of about 14 cts/kwh for electricity and a payback of 12 years are based on ten year averages of wind data taken at a station 50 miles distant. In addition, the standard deviation for the August wind energy figure is 35 percent (2, page 41), a fact which injects a considerable additional uncertainty. Mr. Bartel of Phillips Petroleum stated that they look favorably on systems that will pay back in as few as 6 to 7 years. Phillips buys electricity on an industrial rate schedule, which necessitates a more sophisticated cost/benefit analysis than a direct comparison of costs per kwh. They have indicated that their decision will, understandably, be based upon the analyses made by their cost analysis group.

The advantages associated with a cooperative project of this kind have been evidenced in how ideas develop and plans are improved in the course of discussions between AEI and the Phillips personnel of their Production Department. In many instances, good solutions have been found to some bothersome problems much more quickly than would have been possible by either group alone.

RECOMMENDATIONS

Long-term data collection is required in the continuation project. Data from metering power production, load requirements, and wind availability will provide a strong basis for determining the economic applications for this system. Also, long-term operation will help define overall system reliability.

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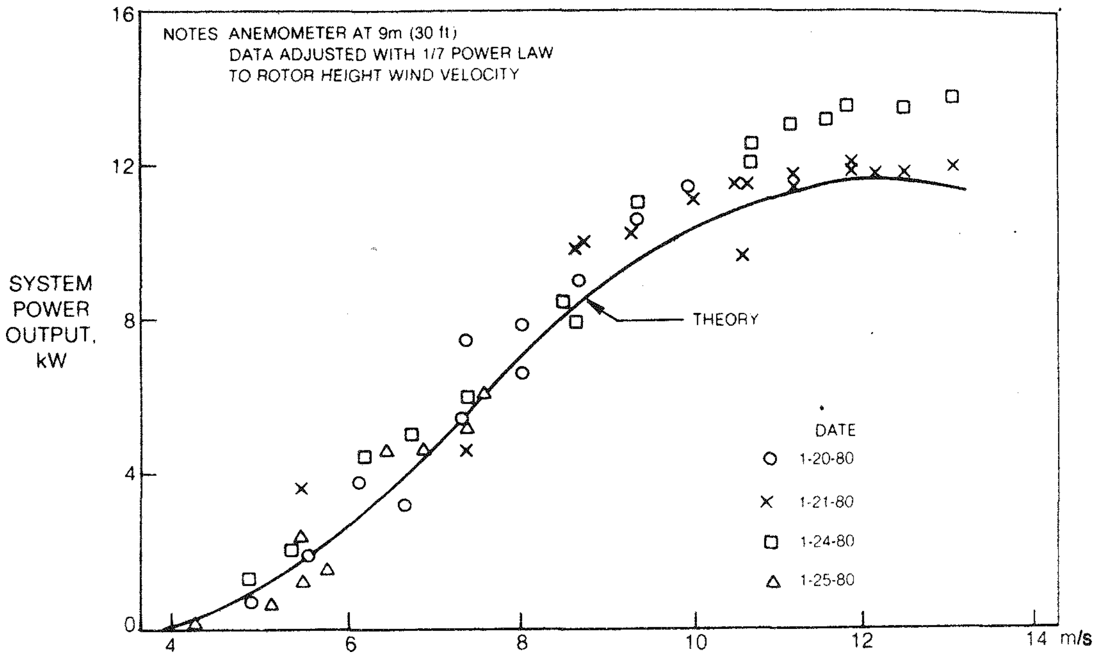
APPENDIX A

SPECIFICATIONS OF UTRC-8 WIND TURBINE

Rated Power	8 kw
Rated Wind Speed	20 mph
Rotor Speed	105-112 rpm (175 fps)
No. of Blades	2
Diameter	32 ft.
Chord	15 in.
Airfoil Series	23112
Taper	None
Twist	0^{o}
Start-up Blade Angle	12^{o}
Operating Blade Angle	0^{o}
Pre-Cone	0^{o}
Generator Rating	15 kw
Synchronous Speed	1800 rpm
Gear-reducer Ratio	17/1
Tower Height	50 ft.

APPENDIX B

EXPERIMENTAL AND THEORETICAL POWER VS WINDSPEED FOR UTRC-8.
(Experimental tests performed at Rocky Flats, Colo.)*



*From UTRC Report "UTRC 8 kW Wind System, Phase II - Fabrication and Test, Technical Report." R. B. Taylor and M. C. Cheney, Contract No. DE-AC04-76DP03533, Subcontract No. PF68186F, February 4, 1981, p. 68.