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UTILITY EXPERIENCE WITH TWO DEMONSTRATION WIND TURBINE GENERATORS

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ABSTRACT

Southern California Edison's interest in wind energy started prior to 1975 and has been spurred by the Company's large proportion of oil-fired generation, an excellent wind resource and the belief that wind would be the first alternate energy source to reach commercialization.

Edison has committed 360 MW of nameplate generating capacity to wind energy by year 1990 in its long-range generation plan. To reach this goal the Company's wind energy program focuses on three areas: the continuous evaluation of the wind resource, the hands-on demonstration of wind turbine generators (WTG) and an association with wind park developers.

Two demonstration WTGs have been installed and operated at Edison's Wind Energy Center near Palm Springs, California: a 3 MW horizontal axis Bendix/Schachle WTG and a 500 kW vertical axis Alcoa WTG. They are part of a one to two year test program during which the performance of the WTGs will be evaluated, their system operation and environmental impact will be assessed and the design criteria of future WTGs will be identified.

Edison's experience with these two WTGs is summarized and the problems encountered with the operation of the two machines are discussed in this paper. The information needs of a utility planning to use WTGs as a cost-effective and reliable resource are also briefly addressed.

INTRODUCTION

The demonstration testing of two large WTGs is only one aspect of Southern California Edison's wind energy program. As illustrated in Figure 1, other aspects include a continuing evaluation of the wind resource on Edison's service territory with particular emphasis on the San Gorgonio Pass region, evaluation of WTG designs proposed by the DOE and others, system integration and economic studies. Recently, the development of cooperative commercial wind projects, an activity not shown in the figure, has become an important part of the program.

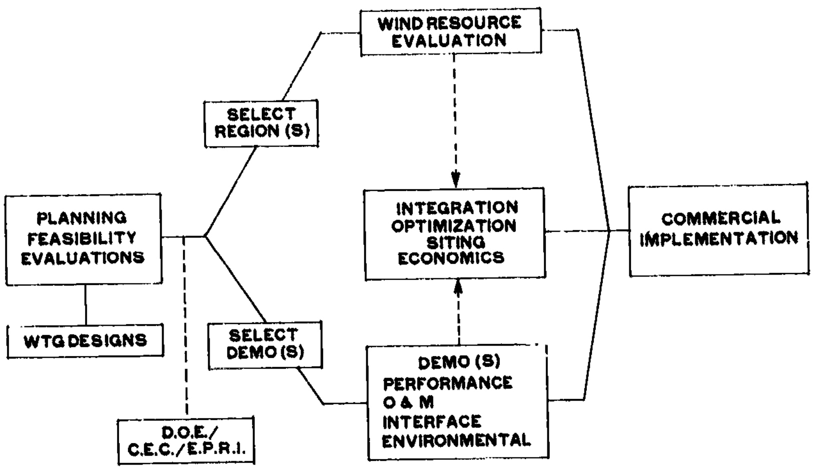

Figure 1: The Edison Wind Energy Program

The evaluation of WTG designs and systems are aimed at determining the technical, economic, socio-economic, land use and environmental factors associated with the installation of multi-unit wind farms.

The evaluation of the wind resource, stated in 1975, has continued with the installation by the DOE of a 150 foot meteorological tower near the Edison Devers Substation, the monitoring of winds in the San Gorgonio Pass through the installation of 19 monitoring stations as part of a study sponsored by Edison and the California Energy Commission, and the installation of a 330 foot meteorological tower.

The development of cooperative commercial wind projects was initiated with the preparation of a Wind Park Opportunity Announcement (WPOA). Response by private entrepreneurs and corporations was excellent, leading to promising negotiations. Through the purchase of energy produced by wind parks Edison hopes to meet a significant portion of its wind-generated resource goal.

The demonstration testing of large WTGs originated when Edison identified the Schachle variable rotor rpm WTG concept as a promising design. A joint effort with Bendix Corporation resulted in the installation of a 3 MW horizontal axis machine placed in first operation in December 1980. Edison's interest in alternate concepts included the vertical axis designs and led to the installation in March 1981 of a 500 kW machine designed and fabricated by Alcoa (Figure 2).

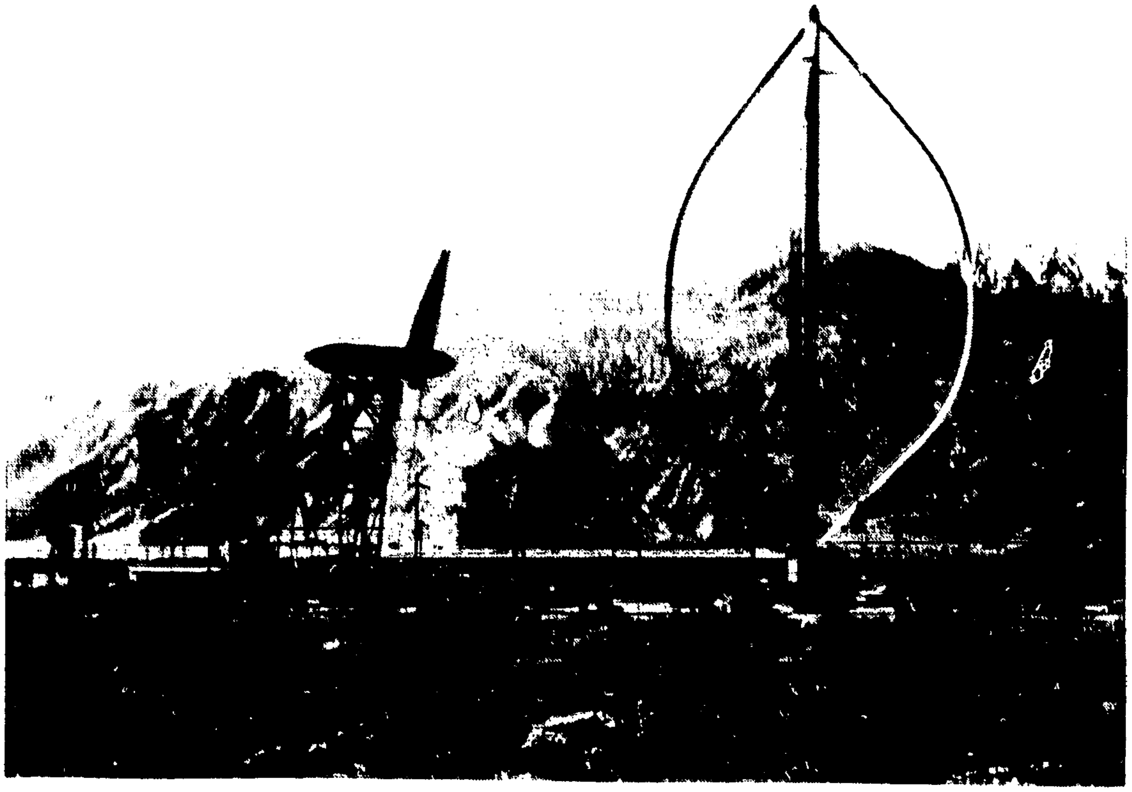

Figure 2: Alcoa and Bendix/Schachle WTGs

THE EDISON WTG TEST PROGRAM

The test program was designed to provide, over a period of two years, the data needed to support the planning, installation and operation of WTGs on a commercial scale. Although originally developed for the testing of two specific WTG designs, the program was designed to accommodate any wind turbines aimed at the utility market.

The overall scope of the program is to document the performance of the WTGs being tested, to train Edison personnel as WTG operators, to assess the operation and maintenance requirements and to evaluate the system impact of the WTGs. The environmental issues associated with WTGs will also be explored and the design criteria of commercial units will be identified. The key questions to be answered by the program in the areas of performance and system impact are outlined in Tables 1 and 2 respectively.

WTG PERFORMANCE

- POWER OUTPUT
- ENERGY OUTPUT
- AERODYNAMIC EFFICIENCY (C_P)
- MECHANICAL EFFICIENCY (POWER TRAIN LOSSES)
- OVERALL EFFICIENCY
- WAKE CHARACTERIZATION (SPACING)

Table 1: Key WTG Performance Questions

WTG SYSTEM OPERATION IMPACT

- CAPACITY FACTOR
- DYNAMIC RESPONSE TO WIND GUSTS
- POWER FACTOR CONTROL
- VARS CONSUMPTION
- ADEQUACY OF ELECTRICAL PROTECTION DEVICES
- START/STOP IMPACT

Table 2: System Operation Aspects of WTG Operation

The Edison WTG test site is located at the eastern end of the San Gorgonio Pass, approximately eight miles north of the city of Palm Springs, California. The site is adjacent to Edison's Devers Substation which has a long history of data collection. Partial wind speed and direction records were kept as early as 1962 as part of an effort to solve wind-related problems with distribution lines in the Palm Springs area. In mid-1976 the site was proposed to ERDA as a candidate site for the MOD-OA WTG. The site was later selected by the DOE to be one of the 17 candidate sites in the program and was instrumented with a 150-foot meteorological tower. The location of the tower with respect to the WTGs is shown in Figure 3. The close proximity of the substation to the WTGs afforded a cost effective electrical connection to the Edison grid. Recent data have shown that average wind velocities are in the order of 18 mph at 150 feet. Maximum wind velocities of 90 mph have been recorded.

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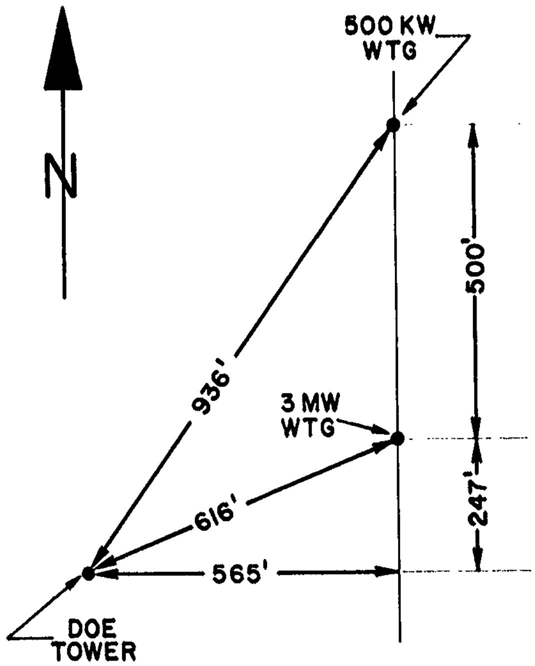

Figure 3: DOE Meteorological Tower Location

Three major sources of data will be used during the test program: continuous performance, special test and manually logged data. The nature of the data is outlined in Table 3. The data acquisition system illustrated in Figure 4 uses a data logger and a magnetic tape drive to sample and record performance parameters at predetermined time intervals. Computer programs have been developed to process the data and summarize performance statistics under three tabulation formats: daily wind data, daily WTG performance summary and monthly performance analyses. Tables 4, 5 and 6 illustrate these three formats.

EDISON'S EXPERIENCE TO DATE

The Bendix/Schachle WTG is a horizontal axis machine with a 165 foot, three-bladed rotor operating at variable speed to control the tip speed versus wind speed ratio.

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A. CONTINUOUS PERFORMANCE DATA

- DATA LOGGER
- COMPUTER TABULATIONS

B. SPECIAL TEST DATA

- DYNAMIC TESTS
- SOUND DATA
- OTHER

C. MANUALLY LOGGED DATA

- STATION LOG
- O&M COSTS
- SHUTDOWN CAUSES

Table 3: Data Sources for Test Program

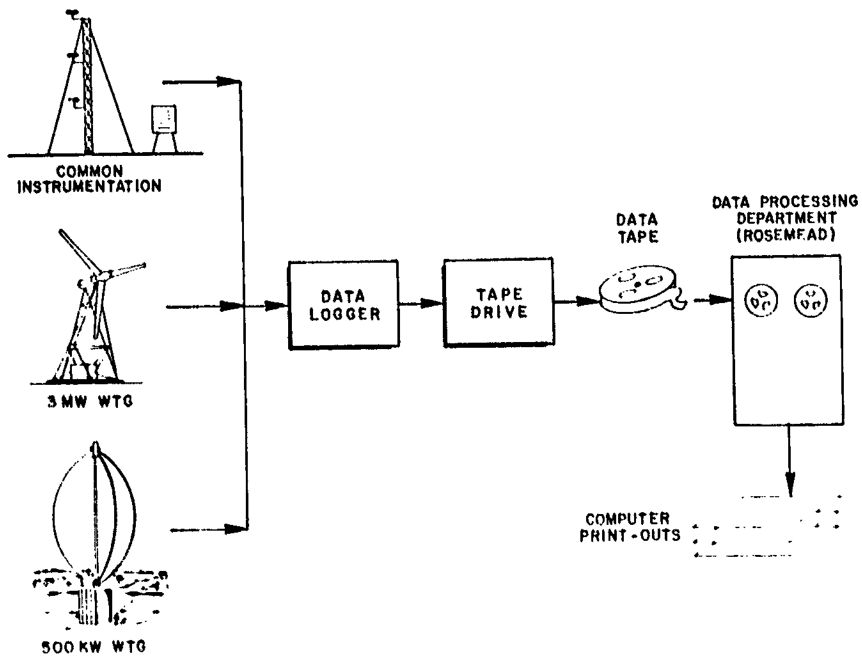

Figure 4: Edison Data Acquisition System

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DAILY WIND DATA SUMMARY
DEVERS WTG TEST SITE
DATE: 111

HOUR ENDING AT	WIND SPEED AT DOE TOWER MILES PER HOUR 30 FEET	100 FEET	150 FEET	WIND SPEED SHEAR COEFFICIENT	PREVAIL WIND DIRECTION AT 100 FEET	DRY BULB TEMPERATURE DEGREES FAHR.	BAROMETRIC PRESSURE INCHES HG.	POWER AT 100 FEET KW/ SQ FOOT
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
10:00	20.0	24.0					9.92	0.068
10:00	20.0	24.0					9.92	0.068
10:00	20.0	24.0					9.92	0.068
10:00	20.0	24.0					9.92	0.068
10:00	20.0	24.0					9.92	0.068
10:00	20.0	24.0					9.92	0.068
10:00	20.0	24.0					9.92	0.068
10:00	20.0	24.0					9.92	0.068
10:00	20.0	24.0					9.92	0.068
10:00	20.0	24.0					9.92	0.068
10:00	20.0	24.0					9.92	0.068
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
10:00	20.0	24.0	26.0	0.163	2	80.0	29.92	0.068
DAILY AVERAGES	20.0	24.0	26.0	0.163	4	80.0	29.92	0.068

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TOTAL ENERGY IN THE WIND FOR THIS DAY -- 1.628 KWH PER SQUARE FOOT
EQUIVALENT AVERAGE WIND SPEED FOR THE DAY -- 24.0 MILES PER HOUR

Table 4: Daily Wind Data Summary

DAILY WTG PERFORMANCE SUMMARY
3 MEGAWATT BENDIX/ SCHACHLE
DATE: 111

HOUR ENDING AT	WIND SPEED AT HUB MILES PER HOUR	WIND POWER FOR SWEPT AREA KILOWATTS	ELECTRICAL POWER PRODUCED KILOWATTS	ELECTRICAL POWER ABSORBED KILOWATTS	NET ELECTRICAL POWER KILOWATTS	COEFFICIENT OF PERFORMANCE
10:00	24.4	1594.6	800.0	100.0	700.0	0.4390
10:00	24.4				0.0	0.4390
10:00	24.4				0.0	0.4390
10:00	24.4				0.0	0.4390
10:00	24.4				0.0	0.4390
10:00	24 4				0.0	0.4390
10:00	24.4				0.0	0.4390
10:00	24.4	1594.6	800.0	100.0	700.0	0.4390
DAILY AVERAGES	24.4	1594.6	800.0	100.0	700.0	0.4390

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DAILY STATISTICS

ENERGY PRODUCED (KILOWATT-HOURS)	19200.0
ENERGY ABSORBED (KILOWATT-HOURS)	2400.0
NET ENERGY (KILOWATT-HOURS)	16800.0
NUMBER OF MACHINE STARTS	0
NUMBER OF WIND-RELATED SHUTDOWNS	0
NUMBER OF NON-WIND-RELATED SHUTDOWNS	0
NUMBER OF HOURS BETWEEN MACHINE CUT-IN AND CUT-OUT SPEEDS	0
HOURS OF WIND TURBINE OPERATION	0
WTG AVAILABILITY (PERCENT)	0.0
WTG CAPACITY FACTOR (PERCENT)	23.3

CUMULATIVE STATISTICS TO DATE

ENERGY PRODUCED (KILOWATT-HOURS)	0.
HOURS OF MACHINE OPERATION	0
WTG AVAILABILITY (PERCENT)	0.0
WTG CAPACITY FACTOR (PERCENT)	0.0

Table 5: Daily WTG Performance Summary

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MONTHLY WTG PERFORMANCE ANALYSIS
3 MEGAWATT BENDIX/ SCHACHLE
DATE : 800101

WIND SPEED AT 100 FEET	NUMBER OF HOURS	CONTROL ANEMOMETER MPH	ROTOR RPM	GENERATOR VOLTS	GENERATOR AMPS	WIND POWER AVAILABLE KILOWATTS	REAL POWER KILOWATTS	REACTIVE POWER KILOVARS	POWER FACTOR	COEFFICIENT OF PERFORMANCE	YAW ERROR DEGREES	BLADE PITCH DEGREES
BELOW CUT-IN	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.0	0.0
33	0.0	0.0	0.							0.0	0.0	0.0
34	0.0	0.0	0.							0.0	0.0	0.0
35	0.0	0.0	0.							0.0	0.0	0.0
36	0.0	0.0	0.							0.0	0.0	0.0
37	0.0	0.0	0.							0.0	0.0	0.0
38	0.0	0.0	0.							0.0	0.0	0.0
39	0.0	0.0	0.							0.0	0.0	0.0
40	0.0	0.0	0.							0.0	0.0	0.0
41	0.0	0.0	0.							0.0	0.0	0.0
42	0.0	0.0	0.							0.0	0.0	0.0
43	0.0	0.0	0.							0.0	0.0	0.0
44	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
45	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
46	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
47	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
48	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
49	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
51	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
52	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
53	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
54	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
55	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
56	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
57	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
58	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
59	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
60	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
ABOVE CUT-OUT	0.0	0.0	0.0	0.	0.0	0.	0.	0.	0.0	0.0	0.0	0.0
AVERAGES/ TOTALS	12.5	17.0	23.0	2000.	100.0	1595.	800.	100.	0.992	0.502	5.0	45.0

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Table 6: Monthly WTG Performance Analysis

The proprietary blade design and tip speed control are expected to yield high rotor wind energy conversion efficiencies. Fixed displacement pumps and variable displacement motors are used to maintain a constant 1200 rpm generator speed. The WTG nacelle is supported by a 110-foot rotating tower. Electrical power is transmitted from the WTG to the test site substation through slip rings mounted at the base of the tower. The rotor is designed to operate at a constant blade pitch angle up to the rated wind speed. At and above rated wind speed the rotor blades are moved toward their feathered position. A diagram of the power drive train is shown in Figure 5.

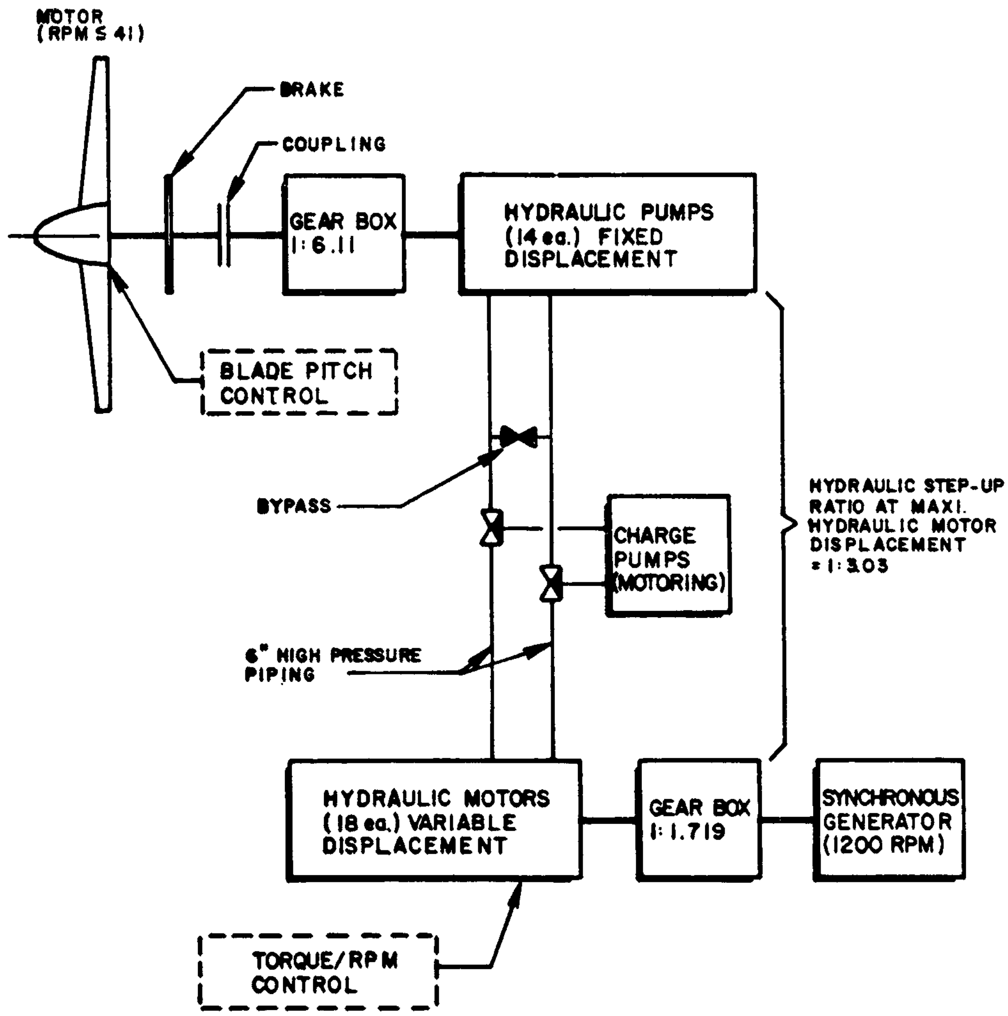

Figure 5: Bendix/Schachle WTG Power Drive Train

The WTG was first operated on-line on December 15, 1980. A gearbox bearing failure and low winds prevented operations until March 3, 1981. The bearing failure was caused by a lack of lubrication traced to the omission of an oil line.

Problems were encountered during synchronization of the generator with the Edison grid. No generator field was applied prior to closing of the main breaker in the original synchronizing method. Recurring diode failures in the exciter led to a change of method and the installation of a synchronizing relay. The generator and grid voltages are now matched prior to the closing of the main breaker by the synchronizing relay.

The WTG is rated at 3 MW in 40 mph winds at hub height. However, the current operating envelope is limited to lower power and wind speed values to allow for measurement and analysis of blade stresses.

Problems have also been experienced with the Edison data acquisition system mainly related to poor quality control. The computer programs used to process the performance data are being tested as the WTG operating time is building up.

To date, power levels in excess of 1 MW have been reached. Development efforts are currently focused on the implementation of automated controls, the expansion of the operating envelope and the training of operators.

The Alcoa WTG is a vertical axis machine with a 123 foot, three-bladed rotor driving a 500 kW induction generator through a fixed ratio gearbox. The rotor is held by 6 guy cables anchored 165 feet away from the generator enclosure. The aluminum blades have a 29 inch cord and a symmetrical NACA 0015 airfoil. The WTG is started by a 30 hp motor and stopped by a service brake and emergency brake mounted on the generator shaft. A diagram of the power drive train is shown in Figure 6.

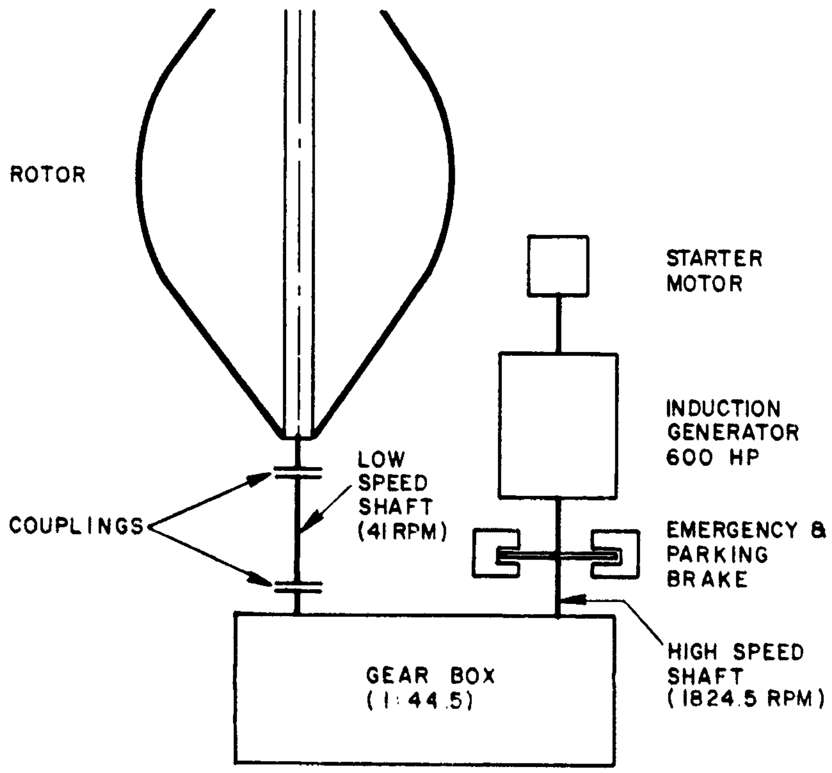

Figure 6: Alcoa WTG Power Drive Train

The WTG was first operated on-line on March 17, 1981 by Alcoa personnel and started preacceptance tests. On April 3, 1981 the rotor failed and was destroyed. The cause of failure was an overspeed condition related to controls software and a malfunction of the brakes. At approximately 60 rpm the blades separated from the torque tube and hit the guy cables. The overspeed was 50% of the 40 rpm normal rotor speed. Test data and analyses have indicated that the aerodynamic performance of the rotor notably exceeded Alcoa's predictions and contributed to the overspeed condition.

Plans are being formulated to rebuild the WTG following testing of a modified WTG installed in Oregon. The new WTG will be extensively redesigned.

UTILITY PLANNING NEEDS

A general concern expressed by the utilities when they investigate WTGs as a generation resource relates to the lack of operating data. Although this situation is rapidly changing, the need for accurate information will remain during the coming years. Assistance to utilities from the wind power community should be focused on providing information on reliability, O&M costs, operating constraints and system interface requirements. Performance guarantees and field support will be deciding factors in the selection of WTG. Acceptance criteria also need to be developed and consistent methods for predicting energy production need to be agreed upon. Given the wind regimes of their selected sites, the utilities need to be in a position to assess the energy costs of WTGs with a good level of confidence.

The key to obtaining their information will be the continuation of existing, and the creation of new WTG demonstration programs designed to generate the appropriate actual operating data while providing the necessary utility experience.