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OPERATIONAL EXPERIENCE ON THE MP-200 SERIES  
COMMERCIAL WIND TURBINE GENERATORS

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ABSTRACT

Since incorporation in 1975, WTG Energy Systems, Inc. has dedicated itself to designing and manufacturing intermediate scale wind turbine generators. To date, we have installed three such generators, with a fourth scheduled to go on line by January 1982. Having accumulated thousands of operating hours in diverse utility environments, the MP-200 System wind turbines have demonstrated their potential as a viable commercial generating source. This presentation will describe some of the experience gained in the operation of these machines.

INTRODUCTION

WTG Energy Systems, Inc. was incorporated under the Laws of the State of New York in April, 1975 and is engaged in the design, fabrication, assembly and marketing of utility grade wind turbine electrical generating systems.

To date, the Company has fully designed, assembled and field tested the MP1-200, a 200 kilowatt wind turbine generator prototype. This machine is installed as part of the utility network of the Town of Gosnold on Cuttyhunk Island, Massachusetts. The MP1-200 was installed in July, 1977. The Company has entered into an agreement with the Gosnold Power and Light Commission which allows the Company to use the Town's electric power network as a test bed for performance evaluation, demonstration and advertising for its prototype unit.

WTG Energy Systems, Inc. sold their first production unit to the Nova Scotia Power Corporation. The MP2-200 System was installed at the Nova Scotia Power Corporation's Wreck Cove site in November, 1980. Nova Scotia Power Corporation will use this unit to pump water from a lake at a lower elevation to the reservoir at the Wreck Cove Hydro Plant, thereby increasing the capacity of the hydro facility.

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Also in competitive bidding, WTG Energy Systems, Inc. was awarded the contract to furnish Pacific Power & Light Co. with the MP3-200 System. This unit was delivered to Pacific Power & Light's Whiskey Run site on the Pacific coast in December, 1980. The MP3-200 has been in operation since the Spring of 1981 and is being used by Pacific Power & Light as a research unit to determine the feasibility of wind generated electricity for the utility.

WTG Energy Systems, Inc. has recently completed the detailed design of a 600 kW wind generator. Production of this unit is anticipated to begin in the Fall of 1981.

The Company's progress, to date, has been governed by a design philosophy that incorporates the following guidelines:

The design and marketing of the Company's wind generators must be economically viable when compared to conventional generating sources.

The Company's products must incorporate off-the-shelf components and these products must be fabricated using conventional manufacturing techniques.

The product design must lend itself to field erection to both easy access and remote sites and this design must be flexible to meet various interface requirements.

Recognizing that field maintenance and repairs are a prime life cycle cost consideration, a product design must evolve that minimizes O & M requirements, permits service by technicians familiar with conventional generating equipment, and anticipates a product life of 30 years.

The wind generator and its electrical system must impose no hazard to the public, its operators or the interconnected system.

These considerations have been the driving parameters in the design and development of the MP-200 System design.

#### MP-200 SYSTEM DESIGN

The MP-200 System mechanical, hydraulic and electrical control systems are briefly described as follows.

## Mechanical System

The MP-200 System is illustrated in Figure 1, and consists of a three-bladed steel rotor, upwind, which is supported by a shaft integral to the transmission. The constant 30 RPM rotor speed is increased through a 40:1 gear box and delivers 1200 RPM to a 6-pole, 350 KVA synchronous alternator. Hydraulic power is supplied from a high pressure system mounted in the machine cabin, and is delivered to the tip flaps through a rotating union in the low speed shaft. Hydraulic power also operates the disc brake(s) on the high speed shaft and the yaw motors. Alignment with the wind is maintained by dual harmonic transmissions driving a bull gear. Yaw brakes lock the drive train to the tower. Details of the mechanical system are summarized in the MP-200 System Wind Turbine Specifications.

The tip flaps control the aerodynamic torque of the rotor by varying the aerodynamic lift and increasing the drag on the airfoil. In the deployed position, the flaps are 60 degrees out of the airfoil plane. The tip flaps operate in one of three modes; deployed during shutdown, in plane during normal operation, and position control during start-up until electrical synchronization is achieved. Position control is also used to limit the power production to 350 kW (maximum continuous rating of the major driveline components) in wind velocities over 35 mph up to shutdown at 50 mph.

Microprocessor Controller: The microprocessor based controller represents an integrated approach to system control. The four primary elements of this system are:

Data Display & Logging: All the operating parameters of the wind turbine are continuously updated and displayed on a large screen CRT terminal. This display serves to replace a large number of meters and indicators normally found on generator control systems. The extensive use of visual attributes, enhances the readability of operating data, calling attention to improper conditions. The remote control printer console (TTY) provides hard copy "LOGS" of the operating parameters every hour or as requested (Figure 2). This terminal also provides the means for entering supervisory commands. Certain types of alarms can be cleared from the TTY remote from the wind turbine station if so equipped. Detailed alarm messages are printed with the exact time of day and date of an alarm condition.

Supervisory Control: These routines schedule the operation of the wind turbine based on commands, wind conditions, alarms, etc. Machine start, run up, synchronize and shutdown sequences are also performed by the supervisory logic.

Machine Control: This includes the control of azimuth (yaw) position, speed/acceleration, synchronizing and power. Direct digital control used in these routines offers the advantages of flexibility, speed and accuracy. Parameters may be modified by WTG, Inc. as required for specific applications.

Machine Protection: A comprehensive alarm program included in the control software duplicates the functions of numerous protective relay devices as well as providing protection for many fault conditions generic to wind turbines which would otherwise not be available. Normal alarm response sequences (tripout, shutdown) are also contained in the logic of the alarm program.

Hardware backup protection of critical operating parameters is employed, providing baseline protection in the event of a computer malfunction. Elaborate fault diagnostics and error checking routines were designed into the control program, assuring that conditions leading to system faults are detected quickly and appropriate safety mechanisms can be brought into action.

All safety shutdown systems are inherently failsafe, in that aggregate component failures will not defeat shutdown actuators (tips and brakes). All elements in this system are mechanically stored energy devices. Faults resulting in a lockout relay trip automatically lead to a relay initiated emergency shutdown, which in effect interrupts the power to the shutdown devices needed to maintain an operating (run) condition. A coded alarm message is displayed on the CRT and TTY terminals providing a record of the fault(s) and facilitating diagnostics by operation and maintenance personnel.

#### MP1-200 OPERATIONAL EXPERIENCE

Beginning shortly after incorporation in the Spring of 1975, WTG Energy Systems, Inc. developed the MP-200 System design based on the design configuration of the Danish Gedser machine. The 200 kW size range was selected keeping in mind the engineering and manufacturing capabilities of the Company. It was believed at that time, that this intermediate size machine would have a marketing application in remote, diesel fired utilities where the cost of fuel would make the economic considerations feasible. Cuttyhunk Island, Massachusetts was selected for the site of the prototype MP1-200 unit as this small, diesel utility would be typical of the future applications for commercial wind generators.

In July, 1977 the MP1-200 prototype was interconnected to Cuttyhunk Island's grid of an installed capacity of 465 kW. It was noted in the initial operation of the MP1-200 that much developmental work was required to evolve a control system that would allow the machine to be compatible in performance, with small diesel/generator sets. A high gain governing system needed to be developed to operate stability with the existing diesel governors without modifying the diesel generator controls. Pitch control could not be used in this grid as its response time was not adequate to operate within the required frequency tolerances.

Over a two year period, a load modulation control system was developed utilizing a load bank with very fast switching action to regulate the effective load applied to the generator as part of a speed feedback control system. By the Summer of 1980, the Cuttyhunk machine was operating stably with the grid at penetration levels of over 100%, maintaining frequency regulation of less than  $\pm 0.5$  Hz (of power line frequency) in wind speeds of up to 40 mph. Power variations when operating on line can be maintained within  $\pm 10\%$  of nominal. At this time the MP1-200 has generated over 2,500 electrical hours into the Cuttyhunk grid.

The prototype has provided us with valuable operational experience which has led to the upgrading of subsequent machines. Based on results from numerous tests and operational experience on the MP1-200, the yaw drive has been modified, a yaw brake system has been retrofitted, valuable experience has been gained with operating in a corrosive salt water environment, and the surface coating specifications have been updated.

An extensive load and stress analysis program was conducted on the rotor and tower system to experimentally verify the initial design assumptions. Data was compiled and analyzed for the rotor's in plane bending moments, flapwise bending moments, low speed shaft bending and torsion, tower tension and torsional stresses, and the natural frequency calculations were verified experimentally. The theoretical performance calculations correlated very well with original design data.

Discussions are presently underway with the Town of Gosnold to sell the output of the MP1-200 to the town. It is anticipated that a contract will be finalized by September, 1981, and the MP1-200 will no longer be used as a research tool, but will be a fully operational on-line power source.

## MP2-200 OPERATIONAL EXPERIENCE

In the late Fall of 1979, WTG Energy Systems, Inc. was awarded a contract by the Nova Scotia Power Corporation for the first commercial MP-200 System unit. The MP2-200 machine was delivered and installed by the Winter of 1981. The severe winter at the Wreck Cove site delayed the commissioning schedule, so that it was not until late February, 1981 that the MP2-200 first generated power into the Nova Scotia grid.

The following modifications from the prototype have been incorporated into the MP2-200:

The ribs and skin of the rotor are fabricated from 304 stainless steel to provide increased corrosion protection.

The tip flap area was extended to from 13.3% to 16.7% of the airfoil area to provide greater drag during shutdown, and a lower idle speed.

The tip flaps are centrifugally augmented to insure failsafe operation in the event of rotor overspeed without loss of hydraulic pressure.

Blade skin thickness was optimized using 22 ga. stainless steel at the tip, progressing to 16 ga. stainless steel at the root end.

The root end spar weldment was moved outboard to decrease the bending moment and lower stresses transferred through the weldments.

Corrosion protection was improved on surface finishes.

The machine cabin and spinner were redesigned to provide greater access to machinery, and a tighter drive train enclosure.

Dual high speed shaft braking systems were incorporated.

The thermal rating of the generator was increased to compensate for peak power production approaching 400 kW on the prototype.

A complete manual control panel within the machine cabin was included.

Software modifications to permit tip control to replace load modulation (load bank) for speed and power control functions.

A remote supervisory control terminal to provide remote operation and the facility to reset alarms.

The Nova Scotia Power Corporation machine is used at the Wreck Cove Hydro Plant to pump water a height of 40 feet from a lower elevation lake to the main surge lake. As the hydro plant operates with a head of 1200 feet, the effective power of the 50 HP pump is greatly amplified. Pending the success of this unit, it is proposed that this demonstration unit serve as a model for similar installations within the Nova Scotia Power Corporation grid.

At this time, the MP2-200 has operated in the grid less than 100 hours due to schedule delay. The schedule presently calls for the wind generator to be in full production by mid-August.

#### MP3-200 OPERATIONAL EXPERIENCE

As the Nova Scotia Power Corporation unit was nearing completion of fabrication, WTG Energy Systems, Inc. received a contract to furnish Pacific Power & Light Co. with the MP3-200 for their Whiskey Run location. The fabrication and delivery of this machine was singularly unique in that the order was received the second week in September and the final shipment left the plant on December 16th of that year. The length of time from receipt of order to delivery was 14 weeks. The first on line operation of the MP3-200 occurred the third week of January, 1981, four work weeks after delivery.

Pacific Power & Light Co. plans to use this unit as a research tool, in cooperation with WTG Energy Systems, Inc. to "increase the knowledge of wind machine operation, wind turbine grid integration analysis and design features that impact allowable energy capture". Specific areas of study include power quality analysis, performance analysis, power dynamics, aerodynamic and airflow disturbance and control and dispatch strategies.

As of this date, the MP3-200 has been formally turned over to Pacific Power & Light and is approaching 500 hours of routine on line operation.

#### MP-600 SYSTEM DEVELOPMENT

Recently, WTG Energy Systems, Inc. received a contract to develop the detailed design of a 600 kW machine suitable for a commercial windfarm application. The final report will be submitted this week.

The MP-600 System is based on the MP-200 Systems experience and consists of a 125 foot rotor diameter mounted on a 115 foot tower. A 1000 HP transmission with a 48:1 gear ratio will drive a 750 kW, 4160 VAC generator. Details of this unit are summarized in the MP-600 System Wind Turbine Specifications.

Pending approval of the detailed design, production of this unit is scheduled to begin in the Fall of this year.

## CONCLUSIONS

### Systems Design

The rotor on the MP1-200 has successfully sustained  $5 \times 10^6$  completely reversing cycles, verifying conservative high-cycle fatigue criteria.

Improvements have been made in areas of high local stress concentrations providing additional assurances of "infinite life" fatigue considerations.

The protection and control system has proved to be a reasonable, cost effective approach.

None of the MP-200 Systems have encountered a major component failure.

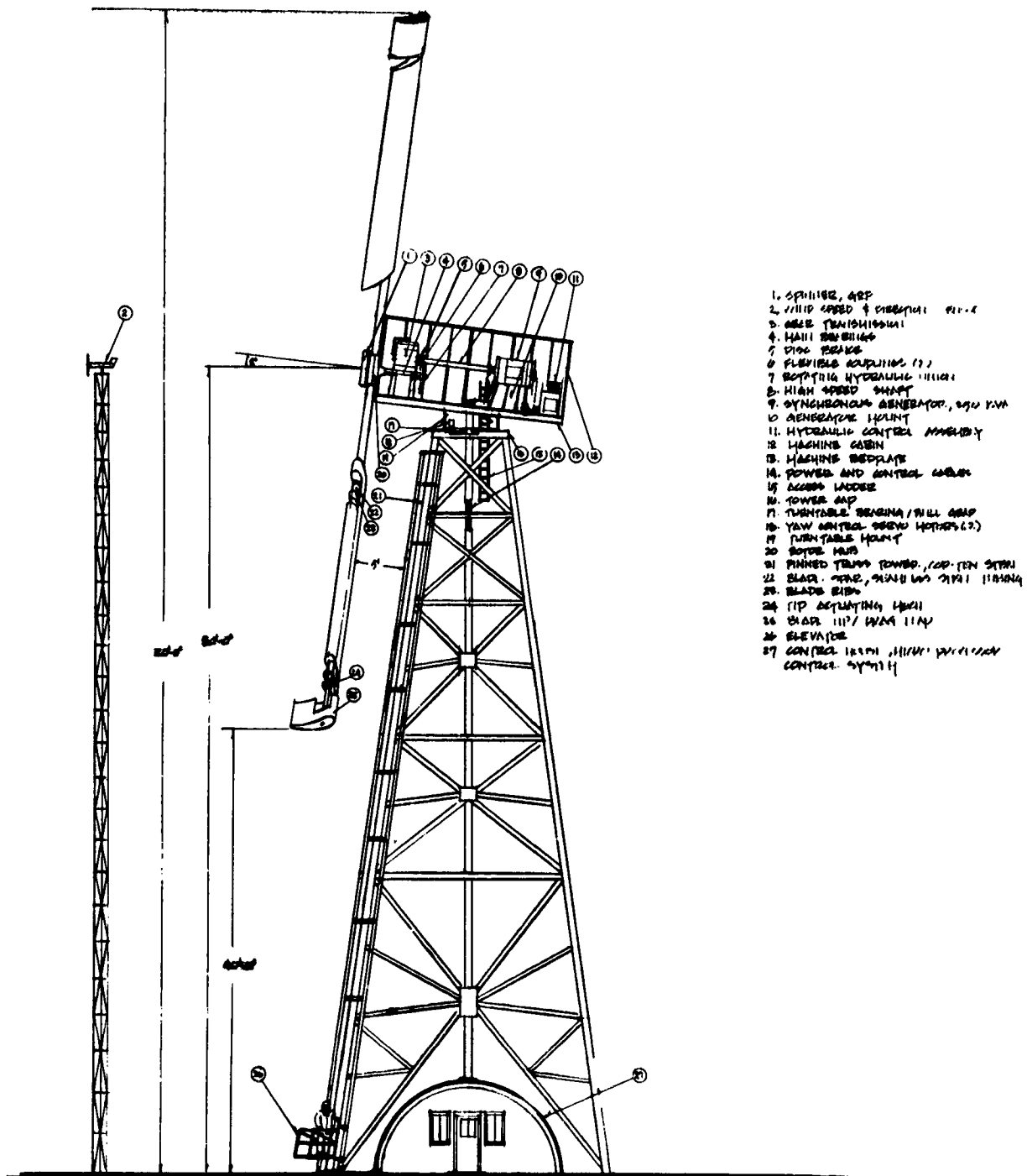
### Marketing

The marketplace has not verified our initial projections. Our two production units have both been purchased by "infinite bus" utilities, not remote diesel grids. We believe a cooperative relationship between the utility industry and "third party" investors will develop as the major marketplace for commercial units. The MP4-200, scheduled for installation in New England later this year, was purchased by such an investment group. In fact, the support of a major "third party" investment group has been critical to the development of the MP-600 unit.

However, our initial market assessment may develop at some future date. The international markets appear to be increasingly aware of our progress, namely, those remote, isolated diesel utilities. To quote from a recent study: "The WTG machine has the advantage that it has been specifically designed for isolated island environments and in fact has operated on an island ... for several years".



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1. SPHERE, 400
2. 1/110 SPEED & DIRECTION
3. GEAR TRANSMISSION
4. MAIN BEARING
5. DRUM BEARING
6. FLEXIBLE COUPLING (2)
7. ROTATING HYDRAULIC MOTOR
8. HIGH SPEED SHAFT
9. SYNCHRONOUS GENERATOR, 400 VAC
10. HYDRAULIC MOTOR
11. HYDRAULIC CONTROL ASSEMBLY
12. MACHINE CABIN
13. MACHINE BEDPLATE
14. POWER AND CONTROL CABLES
15. ACCESS LADDER
16. TOWER CAP
17. TURNABLE BEARING / FULL GEAR
18. YAW CONTROL DRIVE MOTOR (2)
19. TURNABLE MOUNT
20. ROTOR HUB
21. PINNED TOWER TOWER, 100-TON STEEL
22. BLADE TRAP, 21/2" DIA. 21/2" THICK
23. BLADE BUSH
24. TIP ACTUATING LINK
25. BLADE 111/2" DIA. 11/4"
26. ELEVATOR
27. CONTROL 120V, 110V, 220V, 240V  
CONTROL SYSTEM

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MACHINE STATUS PRINTOUT

MP3-200 WIND TURBINE GENERATOR STATUS PRINTOUT

DATE: 041 TIME: 13:39

OPERATION MODE: AUTO RUN - ON LINE

COMPUTER ERROR CODE: 0000

ALARM STATUS: CLEAR ALARM CODE: 000.00

WIND VELOCITY: 24.2 MPH WIND DIRECTION: 198 DEG.

AVG. WIND VELOCITY: 23 MPH AZIMUTH POSITION: 198 DEG.

CABLE TURNS: 1 CW

LINE VOLTS (1-2): 494 TURBINE VOLTS (1-2): 494 TURBINE AMPS(1): 180

(2-3): 493 (2-3): 493 (2): 185

(1-3): 494 (1-3): 494 (3): 175

KILO-VOLTAMPS: 154 POWER FACTOR: .89 LAG KILOWATTS: 137 OUT

KILO-VOLTAMPS REACTIVE: 78 OUT

MILL FREQ: 60.01 HZ GEN. SPEED: 1201 RPM GEN.TEMP.: 30 DEG.C

\*\*\*\*\* ALARM \*\*\*\*\*

TYPICAL ALARM PRINTOUT

ALARM STATUS: CURRENT

ALARM CODE WORD: 000.20 (HYD.)

COMPUTER ERROR CODE WORD: 0000

MODE: EMERGENCY SHUTDOWN - LOCKED OUT

DATE: 041 TIME: 13:44

SUPERVISORY  
COMMAND MENU

KEYIN CODES: SE - SUPERVISORY ENABLE SS - SUPERVISORY STOP

ES - ENABLE SYNCHRONIZATION DS - DISABLE SYNCHRONIZATION

SD - SET DATE ST - SET TIME

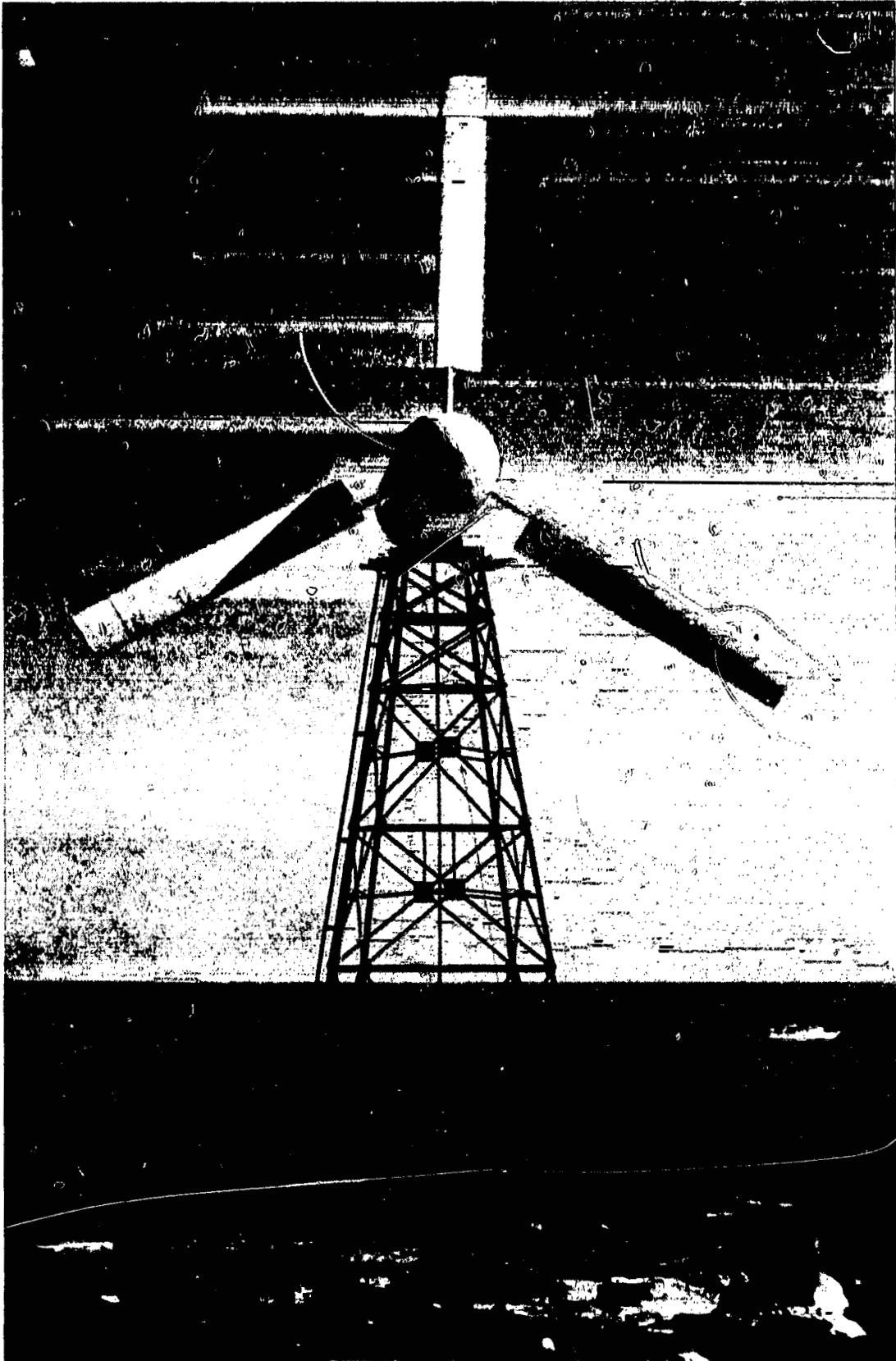
CA - CLEAR ALARM PS - PRINT STATUS

SP - SET POWER

ENTER 2 CHARACTER CODE FOLLOWED BY THE RETURN KEY. BELL INDICATES

THE ENTRY WAS NOT ACCEPTED. TRY AGAIN.

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MP1-200 WTG Energy Systems, Inc.  
Cuttyhunk Island, MA.

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MP2-200 Nova Scotia Power Corp.  
Wreck Cove, NS

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MP3-200 Pacific Power & Light  
Whiskey Run, OR