PROCEEDINGS OF THE 23rd INTERSOCIETY ENERGY CONVERSION ENGINEERING CONFERENCE

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FOREWORD

The world has seen tremendous changes in the energy situation over the last twenty years. We have gone from plentiful and cheap oil supplies in the sixties to the scarcity in the seventies and another, probably temporary, oil glut in the eighties. Conventional power and alternative power have seen their ups and downs. Research and development in both space and terrestrial power has also seen its ups and downs. All of these trends can be seen so clearly in the proceedings of the Intersociety Energy Conversion Engineering Conference (IECEC). The IECEC conference has served as a barometer for the energy situation in the U.S.A. and the world.

A thorough analysis of the energy scenario makes two things very clear. One is the constant need for research and development in energy resources and energy conversion technologies, and the second is the much needed international cooperation in developing and sharing these technologies. These needs have served as the basis and the theme of the 23rd IECEC: "International Cooperation for the Advancement of Energy Conversion Technologies." We, the conference organizers, have tried to make this truly an international conference. To this end, we are especially grateful to our international conference coordinators, namely, Professor Sergio Stecco, the European Coordinator, Professor Naotsugu Isshiki, the Pacific Area Coordinator, and Dr. Anil Rajvanshi, the Asian Coordinator.

At the 23rd IECEC, more than 400 technical papers are being presented in 85 sessions, including panel discussion sessions. The topics of the sessions include almost every imaginable area of space and terrestrial power. The papers have been organized into a four-volume Proceedings. The volumes are organized by topical areas for the convenience of the readers.

We would like to acknowledge the efforts of all the session organizers, session chairpersons, and co-chairpersons who worked so hard to make this conference a success. Special thanks are due to Bill Billerbeck who coordinated all the Aerospace Power sessions. Thanks are also due to the ASME staff, especially Marisa Scalice, Herb Tinning, and the Technical Publishing Department for the conference arrangements and publication of the Proceedings. Most importantly, we would like to recognize the efforts of all the authors who contributed their papers to this conference.

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Dedicated to the Memory of Charles C. Badcock
Chairmen: W. C. Hwang and B. J. Carter *Organizer:* S. Gaston

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Chairman: W. Billerbeck *Vice-Chairman:* R. M. Nelms

Session 18—Space Station Power Generation and Storage I—Photovoltaic Power System
Chairmen: D. W. Sheibley and T. Dougherty *Organizer:* J. H. Ambrus

Session 19—Heat Engine Session I—Thermochemical Heat Engines
Co-Chairmen: J. B. Moreno and C. P. Bankston *Organizer:* J. Abbin

Session 20—Stirling Cycle Modeling
Chairman: T. Finkelstein *Organizer:* D. A. Renfroe

Session 21—Fuel Cells II—Fuel Cells Applications and Development
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Chairman/Organizer: R. O. Warrington *Co-Chairman:* M. Weaver

Session 24—Energy Conservation III
Chairman/Organizer: R. R. Johnson *Co-Chairman:* H. Othieno

Session 25—Aerospace/Terrestrial Mechanical Energy Storage II
Chairmen: H. K. Asper and F. J. M. Thoolen *Organizer:* M. Olszewski

Session 26—Nuclear Power III—MHTGR: Developing a Reactor with 20-20 Foresight
Co-Chairmen: A. C. Millunzi and S. R. Penfield *Organizer:* S. M. Cho

Session 27—Space Nuclear Power System Application Studies
Chairman/Organizer: M. Swerdling *Co-Chairman:* M. Shirbacheh

Session 28—Space Station Power Generation and Storage II—Solar Dynamic System
Co-Chairmen: T. L. Labus and T. H. Springer *Organizer:* J. H. Ambrus

Session 29—Space Nickel-Hydrogen I
Chairman/Organizer: S. F. Schiffer *Co-Chairman:* S. J. Gaston

Session 30—Computer Simulation of Spacecraft Power Electronics II
Co-Chairmen: J. Barton and E. Baumann *Organizer:* W. J. Billerbeck

Session 31—Space Power Automation Techniques and Systems II—Applications from Terrestrial Systems
Chairmen: L. L. Grigsby and R. Touchton *Organizers:* D. J. Weeks and L. F. Lollar

Session 32—Heat Engine Session II—Heat Engine Technology Development
Co-Chairmen: J. E. Boretz and W. D. Batton *Organizer:* J. Abbin

Session 33—Stirling Engine Component Modeling and Testing
Chairman: C. D. West *Organizer:* D. A. Renfroe

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Chairmen: J. W. Suitor and D. R. Glenn *Organizer:* B. R. Will

Session 35—Solar Energy Conversion
Chairman/Organizer: F. Kreith *Vice-Chairman:* D. E. Klett

Session 36—Thermionic Power I
Chairman: D. L. Jacobson *Organizer:* G. L. Main

Session 37—Battery Energy Storage—Terrestrial Applications I
Chairman/Organizer: S. M. Schoenung *Co-Chairman:* S. W. Eckroad

Session 38—Aerospace/Terrestrial Mechanical Energy Storage III
Chairman: J. A. Kirk *Co-Chairman:* G. E. Rodriquez

Session 39—Nuclear Power IV—MHTGR Components and Technology
Chairman: A. C. Millunzi *Co-Chairman/Organizer:* S. R. Penfield

Session 40—Space Nuclear Reactor Technology
Chairman: R. Harty *Organizer:* M. Swerdling

Session 41—Space Power Automation Techniques and Systems III
Chairmen: T. M. Cook and G. Sheble *Organizers:* D. J. Weeks and L. F. Lollar

Session 42—Space Nickel-Hydrogen II
Chairman: S. J. Gaston *Co-Chairman/Organizer:* S. F. Schiffer

Session 43—Computer Simulation of Spacecraft Power Electronics III
Chairman: B. Bechtel *Vice-Chairman:* M. Liffring

Session 44—Space Station Power Management and Distribution System I
Chairman: R. J. Frye *Vice-Chairman:* J. W. Mildice

Session 46—Advanced Cycles and Systems
Chairman/Organizer: W. D. Jackson

Session 47—Design Procedures for Stirling Cycle Machines
Chairman: D. Berkowitz *Organizer:* D. A. Renfroe

Session 48—Electrical Propulsion
Chairman/Organizer: P. D. Agarwal *Co-Chairman:* F. A. Wyczalek

Session 49—Solar Heating and Cooling I—Solar Energy Fundamentals
Chairman/Organizer: J. T. Beard *Vice-Chairman:* T. Min

Session 50—Thermionic Power II
Chairman: L. R. Woff *Organizer:* G. L. Main

Session 52—Aerospace/Terrestrial Mechanical Energy Storage IV
Chairmen: H. K. Asper and F. J. M. Thoolen *Organizer:* H. K. Asper

Session 53—Innovative Concepts I
Chairman/Organizer: T. M. Levinson *Co-Chairman:* R. L. Watts

Session 54—SP-100 Nuclear Reactor Technology
Chairman: A. D. Schnyer *Organizer:* M. Swerdling

Session 55—Space Power Automation Techniques and Systems IV—Space Station
Chairmen: D. Herman and R. J. Spier *Organizers:* D. J. Weeks and L. F. Lollar

Session 56—Space Nickel-Cadmium Batteries
Chairman: C. W. Koehler *Organizer:* S. Gaston

Session 57—Panel on Issues and Applications of High Tc Components
Chairman/Organizer: S. Schoenung *Co-Chairman:* D. Palmer

Session 58—Heat Engine III—Heat Engine Technology Development
Co-Chairmen: K. L. Linker and J. B. Kesseli *Organizers:* J. Moreno and J. Abbin

Session 59—Stirling Cycle Test Results
Chairmen: D. Gedeon and A. Ross *Organizer:* D. A. Renfroe

Session 60—Alternative Fuels
Chairman: D. K. Walter *Co-Chairman/Organizer:* C. J. Wallace

Session 61—Solar Heating and Cooling II—Innovative Solar Energy Systems
Chairman: T. Min *Vice-Chairman:* J. T. Beard

Session 62—MHD I—Status of Commercial MHD
Chairman: J. T. Lineberry *Organizer:* E. S. Pierson

Session 63—Space Nickel Hydrogen III
Chairman: D. Pickett *Co-Chairman/Organizer:* S. F. Schiffer

Session 64—Thermal Energy Storage I
Chairman: J. J. Tomlinson *Co-Chairman/Organizer:* M. Olszewski

Session 65—Innovative Concepts II
Chairman/Organizer: T. M. Levinson *Co-Chairman:* R. L. Watts

Session 66—Pulse/Megawatt Space Power
Chairman: R. J. Sovie *Co-Chairman/Organizer:* A. W. Adam

Session 67—Space Power Automation Techniques and Systems V
Chairmen: W. D. Miller and T. M. Trumble *Organizers:* D. J. Weeks and L. F. Lollar

Session 68—Space Lithium Batteries
Chairman: G. Halpert *Co-Chairman:* H. Frank *Organizer:* S. J. Gaston

Session 69—Superconducting Technology Applications to Space Power
Chairman/Organizer: J. S. Fordyce *Co-Chairman:* C. E. Oberly

Session 70—Space Station Power Management and Distribution II
Chairmen: J. J. Biess and I. G. Hansen *Organizer:* J. H. Ambrus

Session 71—Heat Engine Session IV—European Heat Engine Technology Development
Chairman: E. Carnevale *Vice-Chairman:* D. Florjancic

Session 72—Applications of the Stirling Cycle as an Engine
Chairman: M. A. White *Organizer:* D. A. Renfroe

Session 73—Energy From Municipal Solid Waste
Chairman/Organizer: B. Goodman *Co-Chairman:* D. K. Walter

Session 74—Solar Heating and Cooling III—Solar Heating and Cooling Systems
Chairman: G. Meckler *Co-Chairman:* D. E. Klett

Session 75—MHD II—MHD for Space
Chairman: R. R. Holman *Organizer:* E. S. Pierson

Session 76—Space Nickel-Cadmium and Advanced Silver-Zinc Batteries
Chairman/Organizer: C. W. Koehler

Session 77—Aerospace/Terrestrial Mechanical Energy Storage V
Chairman/Organizer: J. A. Kirk *Co-Chairman:* G. E. Rodriquez

Session 78—Nuclear V—Nuclear Design Aspects of Advanced Fission Reactors
Chairman: S. Anghaie

Session 79—Space High Voltage
Chairman: W. G. Dunbar *Vice-Chairman:* S. R. Yadavalli

Session 80—Spacecraft Power Systems
Chairman: M. J. Milden *Vice-Chairman:* T. L. Bavaro

Session 81—Space Fuel Cells
Chairman/Organizer: L. H. Thaller *Co-Chairman:* J. Fellner

Session 82—Superconductivity Developments and Terrestrial Applications
Chairman/Organizer: S. Schoenung *Co-Chairman:* D. Palmer

Session 83—Thermal Energy Storage II
Chairman: J. J. Tomlinson *Co-Chairman/Organizer:* M. Olszewski

VOLUME FOUR — CONTENTS

WIND ENERGY

ENERGY CONSERVATION

ENERGY CONVERSION TECHNOLOGIES FOR DEVELOPING COUNTRIES

SOLAR HEATING AND COOLING—SOLAR HEATING AND COOLING SYSTEMS

SOLAR HEATING AND COOLING—INNOVATIVE SOLAR ENERGY SYSTEMS

SOLAR ENERGY CONVERSION

SOLAR HEATING AND COOLING—SOLAR ENERGY FUNDAMENTALS

ELECTRICAL PROPULSION

INNOVATIVE CONCEPTS

ALTERNATIVE FUELS

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THE DESIGN OF CHINESE 200 KW WIND TURBINE GENERATOR

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Abstract

The goal of the Chinese medium-sized wind turbine program, 200 KW, 32 m diameter, 3 bladed horizontal axis machine is to explore innovative WECS methods for an experimental project to increase public awareness and acceptance of wind systems.

The paper will describe the design features of blades, rotor, gearbox, induction generator and full-span pitch control system. Methodology includes a computer program for blade calculation, finite-element analysis for component rigidity, and structural dynamic consideration.

Field testing and operational performance results will be introduced during the conference. Economic analysis for manufacture, energy production, and price of electricity are to be assessed for future prospecting of commercialization.

Introduction

China today is concentrating her efforts on the drive for modernization. Energy has first priority among industrial developments. In 1987, 920 million tons of coal, 134 million tons of petroleum, and 496 TWH of electricity (hydro-power 99.5 TWH sharing 20%) were produced. Nevertheless, the shortage of electrical power severly hampers China's economic growth.

Furthermore, there are vast remote areas in Inner Mongonia and Northwest China that are isolated from an electrical power grid but favored with good wind. The demand for electricity in these areas is even more serious than anytime before. For the past years, through demonstration and financial subsidy, the use of small windmills has grown by leaps and bounds. Up to the present, more than thirty thousand new wind machines have been installed and owned by individuals in Inner Mongonia. Wind electricity brings comfort and joy to herdsmen's families.

Wind Resources and Siting

China's southeast coastal region faces the Pacific Ocean. Wind power is very strong especially on the islands. Effective wind energy density in this region is more than 200 watts/sq.m and may reach 300 watts/sq.m or more on the islands. In an entire year, there are more than 6000 hours with a wind speed of 3 - 20 m/s and over 4000 hours with 6-20 m/s.

Ping Tan Island, located on the east coast of Fujian Province, has been selected for installation of the 200 KW wind turbine. There are rich wind resources, convenient transportion, and a local diesel grid for interconnection. Anenometer towers are set up for wind speed measurement. It has been calculated that with a 32 m diameter 200 KW wind turbine generator, at hub height of 30 meters, 750,000 Kwh of electricity can be produced per year. The average annual wind speed in Ping Tan is 8.1 meters per second.

Project Development

The development program is aimed at harnessing the wind in those areas with favourable resources on the coastland and offshore islands of the Southeast China, Shandong and Liaoning Peninsulas. Within these regions, though large electrical power networks feed electricity to agriculture, industry, and livelihood, the power supply cannot satisfy the increasing demand. Besides, hundreds of islands are now depending on diesel generators. Diesel fuel is in short supply. Therefore, the prospect of using wind/diesel generator systems to reduce fuel is very attractive.

Keeping in mind the engineering and manufacturing capability, we selected the 200 KW size range. The objective is to gain experience in the design, construction, and operation of wind turbine grid integration. It is not designed to be cost-effective in prototype, but rather strong enough for grid integradion.

Machine Description

The 200 KW wind turbine generator is a horizontal axis 3-bladed downwind machine as shown in Figure 1, 2 and photo 1. The tower is a stepped tubular structure. The hub height is 30 meters. The hub houses the full-pitch link drive mechanism and spindle bearing, which support the blades in a 7 degree coned position. The low speed shaft, to which the rotor is attached, is supported by two roller bearings. The 3-stage parallel shaft gearbox is designed to carry 360 KW. The low speed shaft is hollow to allow placement of the push-pull rod which connects the ball thread actuated by a DC servo motor for pitch control. The induction generator is coupled to the high speed shaft of the gearbox. The 41 rpm rotor speed is increased to 1500 rpm. The speed ratio is 36.6. A disc brake is incorporated on the high speed side of the gearbox for maintanenence and emergency shutdown.

The bedplate is a box beam structure tilted at 4 degrees. The yaw drive uses two hydraulic motors. A strong disc brake provides yaw axis stiffness and damping. The present control system is an analog electronic circuit with logic relays. A micro-processor control system will be added subsequently.

Design Description

Rotor Blade

Several blade designs have been developed to determine the aerodynamic and structural properties and costs of tooling and fabrication. A computer program using Glauert blade-element/momentun strip theory is used. The inputs are chord length, thickness ratio, twist angle, and lift-drag characteristics of airfoils at different stations along the blade. The main outputs are power, thrust, CP value, and aerodynamic loads at different wind speeds.

For a 32 m diameter turbine operating at 41 rpm, with a 2° pitch setting in a wind of 11.5 m/s, the theory predicts:power=311 KW, thrust=4280 kgs, CP=0.4135. At a wind speed of 13 m/s: P=412.6 KW, thrust=4884 and CP=0.3812. The wind turbine can be uprated to 350 KW without much alteration.

As the shape of the blade airfoil has a great influence on the performance of the rotor power, accurate dimensions and surface smoothness are emphasized during the fabrication process. One blade has been tested in the shop as shown in photo 2. Bending moment, deflection, torque, stress and strain, and natural frequency coincide with design predictions.

Rotor Hub

The rotor hub is designed as a pyramid structure of welded steel plates. The hub is rigid, and flanged directly onto the main shaft. The blades are supported by the hub. Due to weight, aerodynamic loads, strong centrifigul forces are exerted on the hub. The stresses vary cyclically on each revolution. Numerical calculation by the finite-element method have been used to compute the stress and strain on the hub body. It has been identified that the critical stress of 11.68-15.12 kg/mm^2 and maximum strain of 0.065-0.39 mm are within the safe limits.

Gearbox

A 3-stage parallel shaft gearbox increases the 41 rpm of the main shaft through a toothed coupling to 1500 rpm at the generator. Helical gears are used to connect the parallel shafts, and Herringbone gears are used to balance the thrust of the shaft. The gear material is $40CrNi_2Mo$, which was chosen for strength. The tooth surface is heat-treated to increase hardness. The gearbox casing is made of cast steel. Test runs have demonstrated that 360 KW can be achieved. Photo 3 shows the machine was assembled and tested in the shop.

Generator

Induction and synchronous generators have been compared for electric utility applications. On costs, they are nearly the same. The induction generator behaves in a very similar fashion to a fluid coupling. The damping results in a dramatic reduction in dynamic loads. The induction generator must draw all its excitation from the grid, so capacitors are provided on line.

Tower

The tower is a rigid and stepped tubular structure made of sheet steel. The top diameter is 160 cm. The clearance between the blade tip and tower is nearly four times the tube diameter. The tower shadow should not be significant. The rotor and tower interaction has been checked to avoid potential dynamic effects which could result in resonance. The tower surfaces are protected with anti-corrosion coating. Photo 4 shows the tower was being pre-assembled in the shop.

Pitch Change Mechanism

It is a full span pitch control system. Pitching of the blade is performed by a push rod through the hollow main shaft acting crank arms attached to each of the blade shafts. The push rod is moved by a ball screw driven by a DC motor actuated by a speed and power loop with position feedback. The maximum pitch rate is 8°/sec. The pitching angle range is 2° to 84°. At 84° the blades are feathered.

Control System

The wind turbine generator is designed for automatic operation with the grid. The wind turbine starts at 5 m/s and produces 200 KW at 11.5 m/s; above 11.5, the generator continues to produce rated power by adjusting the pitch angle of the blades. When the wind velocity exceeds 20 m/s or drops below 5 m/s, the generator is taken off the grid, and the blades are feathered to bring the rotor to a halt. The four control systems are: pitch control,yaw control,start/shutdown,and safety monitor system.

Specification

Performance

Rated Power	200 KW
Wind speed at hub height	30 m
Cut-in	5 m/s
Rated	11.5 m/s
Cut-out	20 m/s
Maximum design speed	60 m/s

Rotor

Type	Horizontal-axis
Number of blades	3
Diameter	32 m
Speed	41 rpm
Rotation(looking upwind)	Counter-clockwise
Location	Downwind
Cone angle	7 deg.
Tilt angle	4 deg.

Blade

Length	15 m
Weight	1500 kgs
Material	Fiberglass
Airfoil at 75% span	NACA 4415
Twist angle, tip to root	10 deg.
Solidity	8 %
Root chord	1.77 m
Tip chord	0.6 m
Root thickness	0.52 m
Tip thickness	6.3 cm

Generator

Type	Induction
Rating	200 KW
Voltage	400 volts
Speed	1515 rpm
Frequency	50 Hz

1. Installation completed

Project Cost

	Item			Percentage
I	Turbine		¥ 1,067,000	73 %
	1 Blades	225,000	21%	
	2 Hub	32,000	3%	
	3 Pitching mechanism	40,000	3.8%	
	4 Drive system	170,000	16%	
	Gearbox	90,000		
	Main shaft & bearing	55,000		
	Coupling & brake	25,000		
	5 Yaw drive system	49,000	4.6%	
	6 Hydraulic system	39,000	3.7%	
	7 Tower	220,000	21%	
	8 Bedplate & nacelle	50,000	4.7%	
	9 Generator & auxillary	92,000	8.6%	
	10 Control system	50,000	4.6%	
	11 Anti-corrosion	25,000	2 %	
	12 Accessories	75,000	7 %	
			100 %	
II	Transportation		30,000	2 %
III	Installation		70,000	4.7 %
IV	Foundation		100,000	6.8 %
V	Design & research		200,000	13.5 %
	Total		¥ 1,467,000	100 %

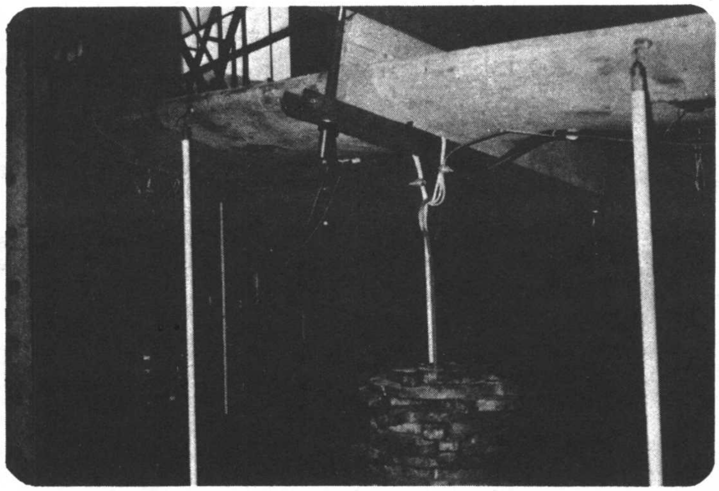
The total development cost for this 200 KW wind turbine generator is about one and half million Chinese Yuan which is equivalent to US$750,000 at 1985 dollar value. Since then the prices of material and labor have increased; but the exchange rate has also increased.

It is estimated that one 200 KW wind turbine generator in Ping Tan Island can produce an average of 750,000 Kwh electricity annually. The current diesel electricity is averagely 0.25 Yuan per Kwh, the average diesel fuel consumption is 0.275 kg/Kwh. Consequently, one 200 KW wind turbine could produce a revenue of ¥187,000 and save 200 tons of diesel oil per year.

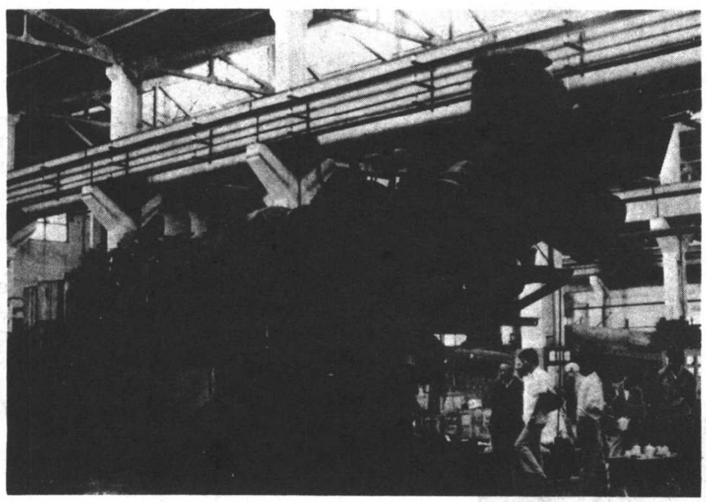
Conclusion

The aim of the Chinese 200 KW wind turbine generator is to obtain design and operational experience to evaluate the technology of a large wind turbine. The other purpose is to provide the cost and performance data to evaluate wind as an energy source. Facing the rapid progress of the country's economy and the increasing demand of electrical power, the prospect of developing wind energy in China's coastal area looks very promising. The immediate task is to establish a good demonstration project so as to pave the way for future utilization.

2 Blade tested in the shop



3 Machine test run in the shop



4 Tower assembled in the shop