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INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research and Development of Wind Turbine Systems
ANNEX XI

39th IEA Topical Expert Meeting

Power Performance of Small Wind Turbines not connected to the Grid

CEDER Soria Spain, April 2002

Organised by: CIEMAT

FOI
SWEDISH DEFENCE RESEARCH AGENCY

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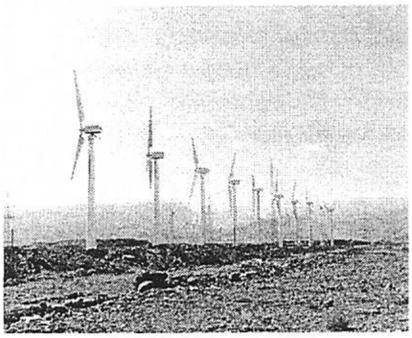
BASE TECHNOLOGY INFORMATION EXCHANGE



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The objective of this Task is to promote wind turbine technology through cooperative activities and information exchange on R&D topics of common interest. These cooperative activities have been part of the Agreement since 1978.

The task includes two subtasks. The objective of the first subtask is to develop recommended practices for wind turbine testing and evaluation by assembling an Experts Group for each topic needing recommended practices. For example, in 1999 the Experts Group on wind speed measurements published the document titled "Wind Speed Measurement and Use of Cup Anemometry".

The objective of the second subtask is to conduct joint actions in research areas identified by the IEA R&D Wind Executive Committee. The Executive Committee designates Joint Actions in research areas of current interest, that requires an exchange of information. So far, Joint Actions have been initiated in *Aerodynamics of Wind Turbines, Wind Turbine Fatigue, Wind Characteristics, and Offshore Wind Systems.* Symposia and conferences have been held on designated topics in each of these areas.

In addition to Joint Action symposia, Topical Expert Meetings are arranged once or twice a year on topics decided by the IEA R&D Wind Executive Committee.

Since these activities were initiated in 1978, 32 volumes of proceedings from Expert Meetings, 13 volumes of proceedings from the symposia on Aerodynamics of Wind Turbines, 5 from the symposia on Wind Turbine Fatigue, and two from the symposia on Wind Characteristics have been published. In the series of Recommended Practices 11 documents were published and five of these have revised editions.

The Annex was extended in 1999 until 2001. In January 2000, Sven-Erik Thor of FFA, Sweden, replaced the Technical University of Denmark as operating agent.

Four meetings took place in 1999. At the 32d Expert Meeting on *Wind Energy under Cold Climate Conditions* in Helsinki, Finland, 13 participants from 7 countries made eleven presentations. At the 2nd Symposium on *Wind Characteristics* at RISØ National Laboratory in Denmark, twelve papers were presented by 11 participants from 5 countries. At the 5th Symposium on *Wind Turbine Fatigue* at DTU Delft in the Netherlands, 14 participants from 4 countries gave 10 presentations. Finally, the 13th Symposium on *Aerodynamics of Wind Turbines* at FFA in Stockholm, Sweden, had 19 participants from 6 countries that presented 15 papers.

All documents produced under Task XI and published by the Operating Agent are available from the Operating Agent, and from representatives of countries participating in Task XI.

The Operating Agent of Annex XI also acts as the official IEA observer on Technical Committee No. 88, Wind Turbine Generator Systems, of the International Electrotechnical Commission (IEC TC88). The IEC is an international body that generates international standards in cooperation with ISO. The emerging standards often take the IEA Recommended Practices as precursors.

IEA TOPICAL EXPERT MEETING ON POWER PERFORMANCE OF SMALL WIND TURBINES NOT CONNECTED TO THE GRID

INTRODUCTORY NOTE

Felix Avia Aranda, Autonomous Wind System Project
Department of Renewable Energies- CIEMAT, Spain

and

Hal Link
National Renewable Energy Laboratory, USA

BACKGROUND

Sometimes lost behind the attention given to multi-megawatt wind farms, the market for autonomous electrical systems using small wind turbines is becoming an increasing attractive business. However, in spite of the maturity reached on the development of the wind technology for grid connected power plants, the state of the art of wind autonomous systems is far away from technological maturity and economical competitiveness. Average costs for current wind stand-alone installations vary from \$3500 to 10000 US per installed kW, which contrasts with \$1000-1300 per installed kW corresponding to grid-connected installations. If we just talk about the cost of the wind turbine itself, the specific cost (cost per kilowatt) varies from \$1500-5000 for stand-alone machines contrasted with \$675 for grid-connected ones.

In relation to the performance analysis for both kinds of systems, we find values of average specific energy produced for stand-alone around 0,15 kW/m^2 whereas the average value for grid-connected systems is 0,5kW/m^2. This is mainly due because grid-connected systems are used in higher wind speeds sites, but also shows that there is a wide range for improving the present technology for stand-alone wind turbines.

The technology for stand-alone wind systems, and more specifically for the wind turbines, is clearly different from the one used in grid-connected systems. These differences affect all of the subsystems, mainly the control and electrical system, but also the design of the rotor of the wind turbines. Small Wind Turbines (SWT) existing in the market are machines that have developed in a nearly "hand-crafted" way, with a maturity which is far from the one corresponding to the wind turbines for grid-connection.

There is a lack of norms, standards and guidelines applied to wind-powered autonomous systems, as well as to wind turbines that are not grid-connected. In particular the wind energy community needs a standard method for determining the power performance characteristics of turbines that are not connected to the grid. Such an effort is currently underway in the International Electrotechnical Commission (IEC). The TC88/MT12 group of the IEC is revising the IEC standard, IEC 61400-12, "Power performance testing." Although most of the revisions to IEC61400-12 are concerned with grid-connected wind turbines, an Annex has been proposed that addresses testing of small turbines that are not connected to the grid. That Annex, with brief comments, is attached to this document.

Many of the researchers and test engineers whose contributions led to the Annex are concerned that the proposed methods are not well founded in scientific and practical experience. This feeling persists even though several programs have been concluded in the United States and Europe in which testing issues were investigated. It is the intent of this symposium to address these issues and to identify appropriate follow-on activities.

INTENDED AUDIENCE

The audience should be engineers working at research centres, universities, manufacturing, suppliers, and installers of wind-driven autonomous systems.

The meeting will cover the following topics:

- Testing site conditions
- Measuring Instrumentation
- Position of the Meteorological Sensors
- Data Acquisition Systems
- Data collecting procedures
- Analysis of Data
- Procedures for air density correction

PROPOSED ANNEX TO IEC 61400-12

Note to the following text. This procedure is drafted as though it would appear in IEC 61400-12, Ed 2 as an Annex. The maintenance team responsible for drafting Edition 2 of that standard agreed that this annex could be incorporated into Edition 2 if it obtains sufficient support from members of the small wind turbine community. If adopted, it will probably be listed as Annex H or I, since Annex G is likely to cover another issue. The text in *blue Italics* would not be in the final annex. It is included here as explanatory. H. Link, 20Sep01.

ANNEX G

(normative)

POWER PERFORMANCE TESTING OF SMALL WTGS

Draft 8/15/01

Small WTGS (as defined by the most recent edition of IEC61400-2) have features that required special provisions for power performance testing. When testing a small WTGS, all requirements described in this document shall be met except as noted below:

The scope of this annex includes grid-connected wind turbines as well as battery charging tubines.

1. In Section 2.1, Wind Turbine Generator System: In addition to the information listed in clause 6, the description of the WTGS shall include:

a) wiring sizes, conductor material, types, lengths and connectors used to connect the wind turbine to the battery bank and or the electrical grid

For battery charging applications, the description of the WTGS shall also include:

a) nominal battery bank voltage (e.g., 12, 24, 48 volts)

b) battery bank size, battery type and age

c) description including make, model, and specifications of the device used to maintain the battery bank voltage.

d) voltage setting(s) for any over or under-voltage control devices used in the WTGS.

Additional information is needed to confirm conditions and requirements for testing small turbines.

2. Also in Section 2.1, Wind Turbine Generator System: The WTGS shall be installed using the manufacturer's specified mounting system. If a wind turbine is not supplied with a specific mounting system, the generator should be mounted at a hub height of at least 10 meters.

Wind shear close to the ground adds uncertainty to the power curve. Ten-meter towers should are a reasonable compromise between installation cost and measurement uncertainty.

3. Also in Section 2.1, Wind Turbine Generator System: The WTGS shall be connected to an electrical load that is representative of the load for which the turbine is designed. In the case of battery-charging applications, this load shall be comprised of a battery bank and a device suitable for controlling battery bank voltage as specified below.

A typical load for battery charging applications would be a battery bank and a variable load (lights, appliances, etc). For power performance measurements the variable load must have the capability of *matching the output of the turbine (inverter connected to the grid, Enermaxer™ with resistive load, etc). This permits performance to be defined at any desired voltage.*

4. Also in Section 2.1, Wind Turbine Generator System: The battery bank, if used, shall be positioned as close as possible to the wind turbine but outside of the fall zone of the turbine (i.e., a radial distance from the tower base equal to hub height plus 1/2 the rotor diameter). Wiring between the WTGS and the battery bank and/or the electrical grid shall be in accordance with the manufacturer's specifications. If the specifications provide for a range of wire sizes, wires shall be sized as close as possible to the average of that range. If no specifications are provided, the wiring shall be sized such that voltage drop between the wind turbine generator and the battery bank and/or inverter is equivalent to 10% of nominal voltage at rated power.

Most manufacturers provide guidance on wire size and can do so easily if the default sizing is undesirable. If no guidance is provided, 10% is a reasonable balance between wiring cost and overall system efficiency since losses would be closer to 5% at common wind speeds.

5. Also in Section 2.1, Wind Turbine Generator System: For battery-charging applications, the voltage regulation device shall be capable of maintaining the battery bank voltage within 10% of the settings given in Table G1 over the full range of power output of the turbine. The 1-minute average of the battery bank voltage must be within 2% of the settings given in Table G1 to be included in the usable data set.

This performance specification on the voltage regulation device enables selection of several commercial devices or use of a custom fabrication. It was based on NREL's experience with the Enermaxer™ and a relatively small battery bank.

6. In Section 2.2.1, Distance of meteorological mast: The anemometer mounting may be attached to the turbine tower. The anemometer and it's mounting boom and mast shall be at least 3 meters away from the WTGS even if such a separation distance is greater than 4 rotor diameters. In addition, the anemometer mounting should be configured to minimize its cross-sectional area above the level that is 1.5 rotor diameters below hub height to prevent tower wake effects on the turbine.

This is the minimum safe distance to avoid wake effects from the anemometer and its mounting on the test turbine. Correlation of wind speeds at a distance of 3 meters should be excellent.

7. In Section 3.1, Electric Power: If the WTGS is configured for battery charging, electric power (measurement): WTGS output power shall be measured at the connection of the WTGS to the battery bank.

This provision reduces the arbitrary effect of test setup on power production while being a reasonable characterization for situations where the battery bank is at the base of the turbine tower. Loss in wires can be easily estimated for other installations.

8. In Section 3.4, Air density: The air temperature sensor and the air pressure sensor shall be mounted such that they are at least 1.5 rotor diameters below hub height even if such mounting results in a location less than 10 m above ground level.

Required to prevent wake effects from these sensors on the test turbine.

9. In Section 3.5, Wind turbine generator status: Monitoring of WTGS status is recommended only when the turbine controller provides an indication of turbine faults.

Small turbine controls often do not include fault indications.

10. In Section 4.2, Wind turbine generator system operation: If, in the case of battery charging applications, the turbine's voltage controller reduces turbine output at the optional, high voltage setting, it may be adjusted to a higher value. If it is adjusted, the test report shall document the settings before and after adjustment. No other adjustments to the turbine's controls are permitted.

Voltage controllers are not likely to be set below the high voltage setting. However, if they are, any data obtained with the voltage controller active would indicate very low performance that is not representative of the effect of voltage change on turbine output.

11. In Section 4.3, Data collection: Preprocessed data shall be of 1-minute duration.

One-minute preaveraging a) provides a more detailed view of the turbine's response to wind speed and b) enables the power curve to be defined in a shorter time period. Ten-minute preaveraging: a) provides consistency with large turbine performance testing, b) will give a more accurate prediction of annual energy production when combined with a MEASURED wind speed distribution (assuming, of course, that the measured wind speeds are preaveraged on a 10-min or longer basis as well, and c) ease of data processing especially when power performance data are being collected at the same time as duration test data. NREL has found that the differences between performance based on the two preaveraging periods are small at moderate (7 m/s) wind sites. Further, the cost advantages of 1-minute preaveraging are large especially when considering the optional measurement at high and low voltage settings.

12. In Section 4.4, Data selection: Select data sets shall be based on 1-minute periods.

Included to be consistent with Section 4.3.

13. In Section 4.6, Database: The database shall be considered complete when it has met the following criteria:

a) Each bin includes a minimum of 10 minutes of sampled data

b) The total database contains at least 60 hours of data with the WTGS within the wind speed range.

Based on NREL test experience that less time is required to define a smooth and consistent power curve when using 1-minute preaveraging.

14. In Section 5.1, Data Normalization: For turbines with passive power control such as furling or blade fluttering, wind speed shall be normalized using Equation 5.

NREL has judged that passive power control will most likely result in furling occurring at a lower wind speed as air density increases. This is roughly equivalent to active power control in large turbines. Adjustment of wind speed rather than power is the appropriate method for normalization in this case.

15. In Section 5.3, Annual energy production: In cases where the WTGS does not shut down in high winds, AEP calculations shall be calculated as though cut-out wind speed were the highest, filled wind speed bin or 25 m/s, whichever is greater.

We need some provision for turbines with no cut-out. Twenty-five m/s seems a reasonable value.

16. In Section 6, Reporting Format: The report shall clearly state the calculated annual energy production for a wind site with an average Rayleigh wind speed of 5 m/s.

This parameter is arguably the most important single number resulting from the power performance characterization. It's emphasis should draw attention to the overall performance of the wind turbine and, hopefully, deemphasize such parameters as peak power output, peak Cp, and cut-in wind speed. Also suggested is the energy production level of at other wind speeds and for other lengths of time. Five m/s is representative of wind conditions at hub height for typical installations at residences where wind levels tend to be lower than for commercial wind farm installations. Annual (vs. monthly or daily) energy production is consistent with characterizations used for large wind turbines and for consumer appliances in the US. In addition, it avoids the implication that the turbine will provide projected average energy every day or month during the year.

17. It is recommended that additional performance data be obtained to quantify the effect that changes of battery bank voltage have on turbine performance. These additional power curves should be obtained by setting the battery bank voltage to the optional low and high settings listed in Table G1, and by obtaining at least 30 hours of data using 1-minute pre-averaging.

Table G1. Battery Bank Voltage Settings

Nominal Voltage	Required Setting	Optional Low Setting	Optional High Setting
12	12.6	11.4	14.4
24	25.2	22.8	28.8
36	37.8	34.2	43.2
48	50.4	45.6	57.6
Other	2.1*	1.9*	2.4*

*volts per cell

The required setting is based on several sources that relate lead acid battery voltage to state of charge. 2.1 volts per cell is about 80% SOC when current is zero. It is also the median of voltage at 60% SOC and 100% SOC -- a range over which many battery banks might be expected to operate. Charging (and discharging) current has a large effect on battery voltage. However these effects work both directions and have a minor effect on the average voltage.

The optional settings were selected to represent reasonable voltage levels and yet to be far enough from the required setting to quantify the effect.

The quantity of data required is half of that required for the power curve at the required voltage level because the accuracy is not required to show this secondary effect.

18. In Annex B, the specifications for maximum terrain variations from a plane shall be determined based on the turbine's hub height, not its rotor diameter.

This requirement was originally specified for large turbines with a hub height equal to the rotor diameter. For small turbines, where hub height is usually much larger than the rotor diameter, small variations in terrain are less likely to cause disturbances to the wind passing through the rotor plane.

IEA R&D Wind Annex

POWER PERFORMANCE OF SWT NOT CONNECTED TO THE GRID
Expert Meeting #39

Prepared by :

L. Arribas

F. Avia

Renewable Energies for Decentralised Systems.

CEDER-CIEMAT 25-26 April 2002

The lack of norms and standards applied to SWTS, and in particular to Decentralised Wind Systems is one of the main barriers for development of the market

There is an urgent necessity of a standard procedure for characterisation of SWT´s for operation non connected to the grid, accepted for the whole wind market

- **The target is to define a procedure for generating the Power Curve of a SWT , useful for assessment of the Energy produced for the WT, when operating in an autonomous system for energy supply.**

- **Target of the symposium is to addres the important issues of the procedure and to identify appropiate follow-on activities**

Ciemat

Key Issues for Procedure Definition

•The test procedure developed will be a repeatable method for producing a power versus wind speed curve. The procedure will only be effective if it supplies repeatable results.

•The curve will form the basis for a Guarantee of Performance.

•The test procedure aims to be as simple as possible to encourage its use by manufacturers

Some of the Previous Actions:

•IEC TC88 WG6/1 : Working Group 6 (Performance Evaluation) SubCommittee 1 (Small Systems), preparing a standard for the assessment of performance of small wind turbine systems (1995-1997?)

•"Stand Alone Wind Systems: Developing a Methodology for Standardising Performance Claims"- ALTENER Project - IT Power, NEL, Marlec and Proven -(1997-1999)

•PEMSWECS: Performance Evaluation Methods for Autonomous, Application Orientated Wind Turbine Systems - JOULE Project - ECN, NEL, DEWI - (1998-2000)

Key Issues

•Scope of application (WT size, use)

•Testing site conditions

•Measuring Instrumentation

•Position of the Meteorological sensors

•Test configuration. Loads

•Data Acquisition Systems

•Analysis of Data

•Procedures for air density correction

Scope of Application

•SIZE:

- •WT up to 40 m^2 of sweep area (present IEC 64000-12 Standard)
- • WT up to 200 m^2 of sweep area (draft of up-dated IEC 64000-12 Standard)

•APPLICATION:

- •Only for not grid connected systems
- •Grid and not grid connected systems

Scope of Application

•The present IEC 64000-12 Standard for "Power Characterisation of WT" is fully applicable to WT connected to the grid with sweep area between 40 to 200 m^2. (When the AIE recommendations for WT testing where prepared, the size of wind turbines in the market was around 200 m^2 of sweep area).

•For WT connected to the grid with a sweep area lower than 40 m^2, the IEC 64000-12 Standard for "Power Characterisation of WT" has to be modified. In particular the situation of the meteorological mast, and the rules about the size of obstacles and slope of the terrain, should be referred to the hub height instead to the rotor diameter.

Scope of Application

- For WT connected to the grid with a sweep area lower than 40 m^2, the IEC 64000-12 Standard for "Power Characterisation of WT" has to be modified.
- In particular the situation of the meteorological mast, and the rules about the size of obstacles and slope of the terrain, should be referred to the hub height instead to the rotor diameter.

Scope of Application

For WT not connected to the grid a new procedure for Power Characterisation has to be developed. The procedure should be applicable to WT with sweep area lower than 40 m^2 (?)

Testing Site Conditions

- Terrain conditions:
  - Slope
  - Obstacles
  - Others
- Meteorological mast position
- Meteorological mast configuration
- Measurement Instrumentation

Key Issues for the Test Configuration

- Test configuration
  - Resistors
  - Batteries
  - Voltage regulation
  - Loads
- Measurement point
- Other: Cable sizing, length and connectors

Key Issues for Data Acquisition

- **Scanning frequency**
- **Pre-averaging time**
- **Number of data per bin required**
- **Total number of data required**
- **Width of the measured range**

Power perfomance evaluation of Autonomous Wind Turbine Systems

Jan Pierik (ECN)
Robert Dunlop, Wai-Kong Lee (NEL)
Joachim Gabriel (DEWI)

1. Introduction
2. Test systems, measurements and simulations
    - System 1: PM generator, rectifier and resistive load
    - System 2: PM generator, rectifier and batteries
    - System 3: PM generator, resistive load and speed control
3. Recommendations

ECN

Introduction

Objective: **develop methods for power performance evaluation for autonomous systems 100 W - 30 kW for electricity production**

Focus:

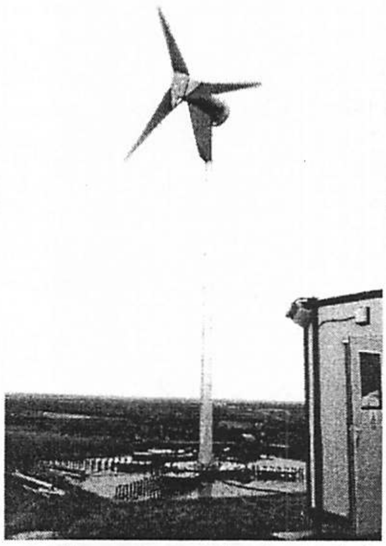
- How does electrical load influence energy production?
- What is best pre-averaging time?

Method:

- power performance measurements
    - standard loads
    - real loads
- model calculations to understand effect of load impedance
- three different types of systems

ECN

EWEC 2001, Copenhagen, JTG Pierik et al



System 1: tested by NEL

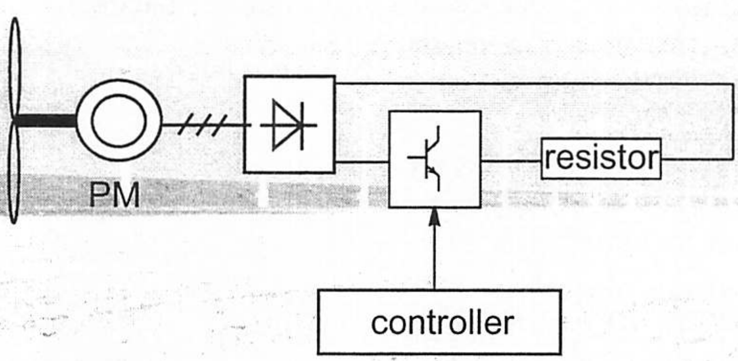
PM generator
Diode rectifier
Resistive load

Proven WT6000 (6 kW)
Rotor diameter 5.6 m
Hub height 9 m
Down wind
Passive pitching/coning
Rated speed 200 rpm

ECN

EWEC 2001, Copenhagen, JTG Pierik et al

System 1: Proven WT6000



ECN

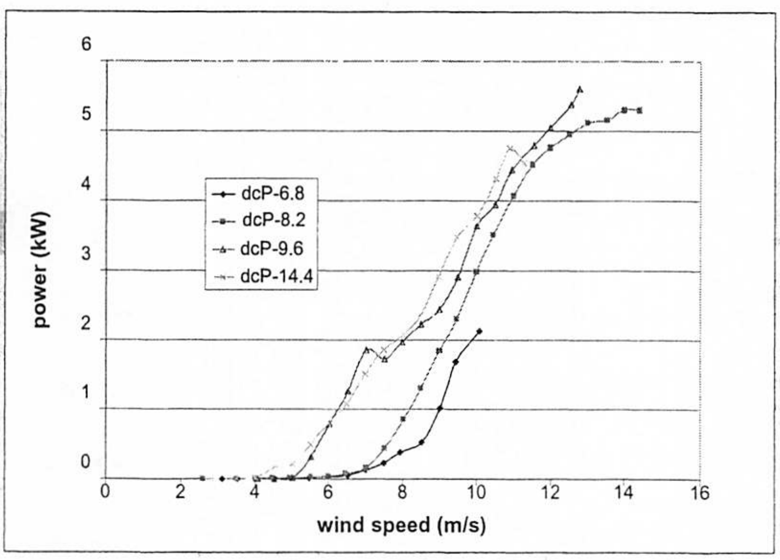
System 1: PM generator, rectifier, resistive load

- Measurements:
  - Power-wind speed curves different loads:
    - ∗ without voltage control
    - ∗ with voltage control
  - Transfer function
  - Power-wind speed curve at end user
- Simulations:
  - Generator characteristics

ECN

EWEC 2001, Copenhagen, JTG Pierik et al

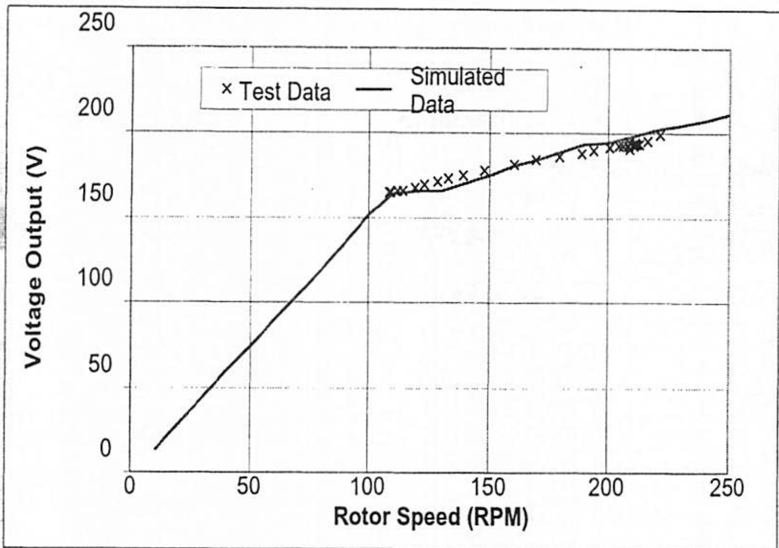
System 1 without voltage control



ECN

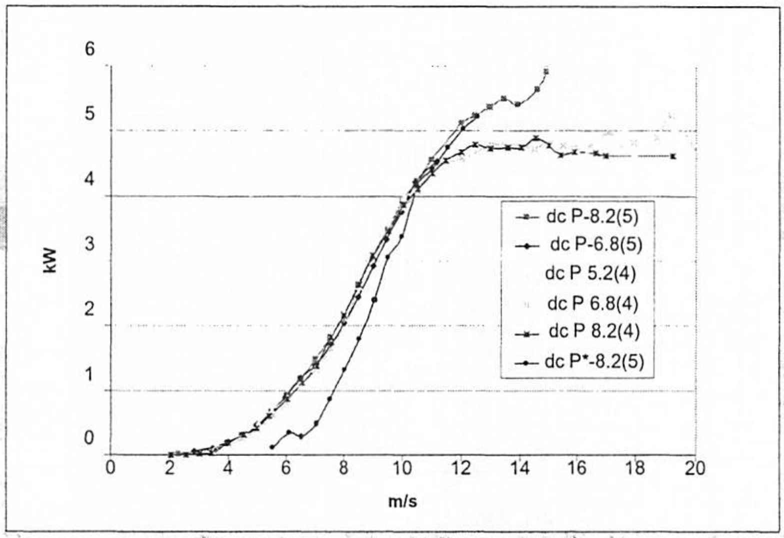
EWEC 2001, Copenhagen, JTG Pierik et al

System 1 with voltage control



EWEC 2001, Copenhagen, JTG Pierik et al

System 1 with voltage control



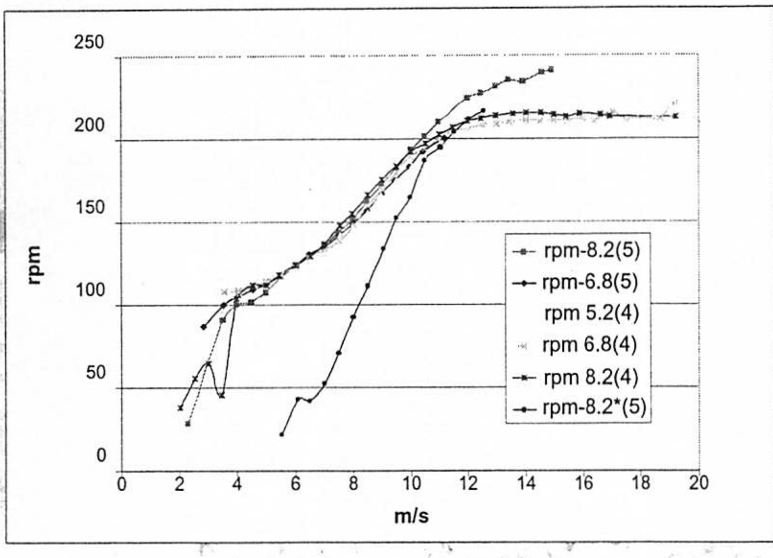
power

versus

wind speed

EWEC 2001, Copenhagen, JTG Pierik et al

System 1 with voltage control



rotor speed

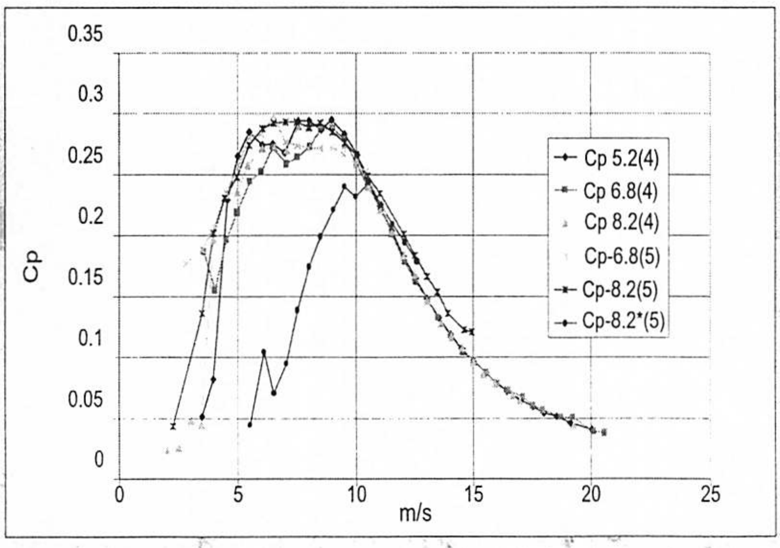
versus

wind speed

ECN

EWEC 2001, Copenhagen, JTG Pierik et al

System 1 with voltage control



power coefficient

versus

wind speed

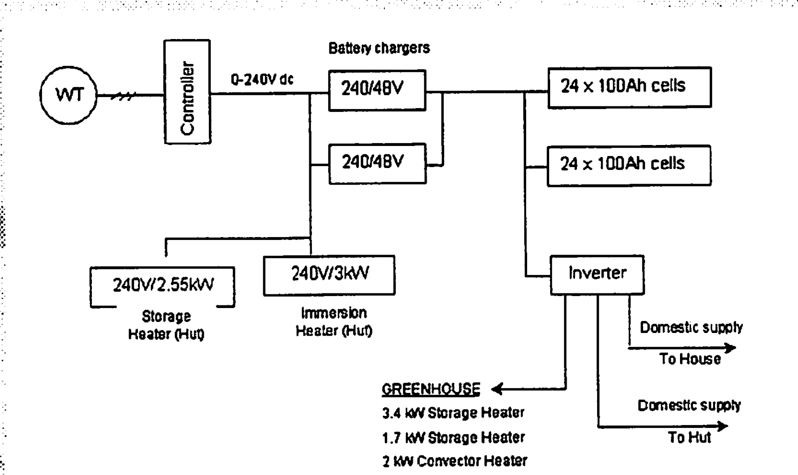
ECN

System 1: Conclusions

- without voltage control:
  - strong effect of the (size of the) load on power performance
- with voltage control:
  - no effect of load on power performance
  - tuning of voltage control will influence power performance

ECN

System 1: End User



ECN

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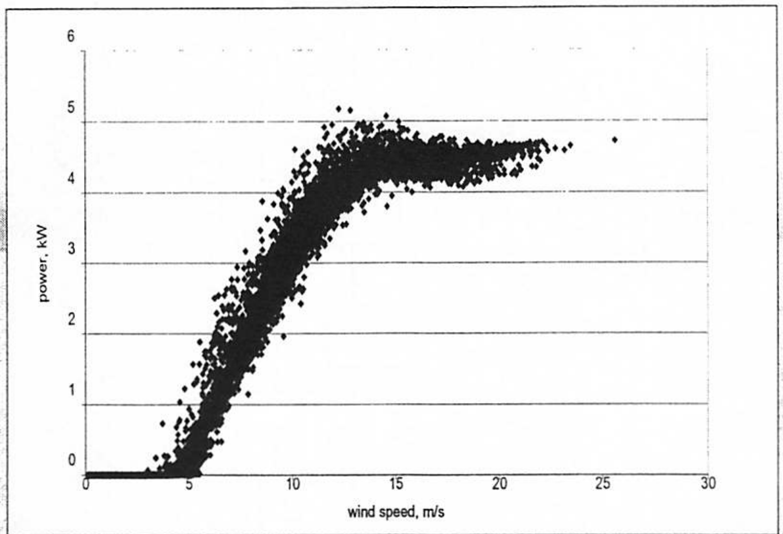
System 1: End User measurement



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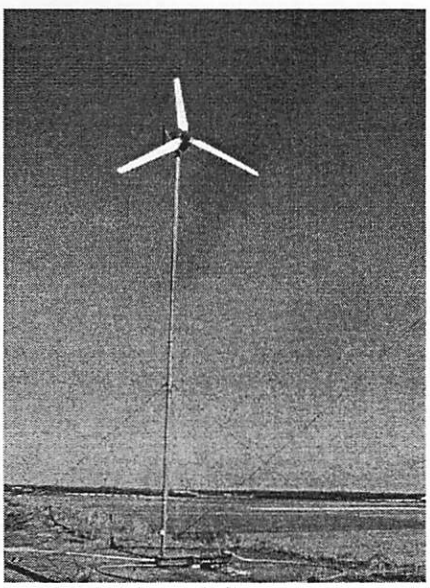


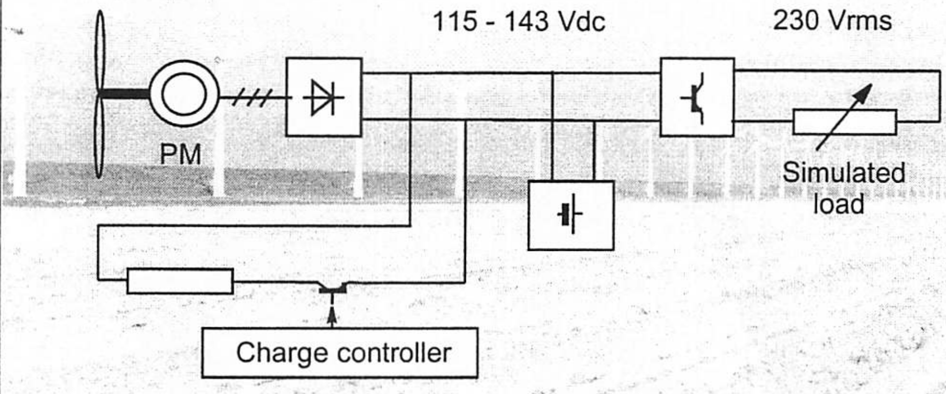
System 2: tested by ECN

PM generator
Diode rectifier
Batteries

Fortis Montana (4 kW)
Rotor diameter 5 m
Hub height 12 m
Up wind
Inclined hinged tail vane
Rated speed 300 rpm

EWEC 2001, Copenhagen, JTG Pierik et al

System 2: Fortis Montana



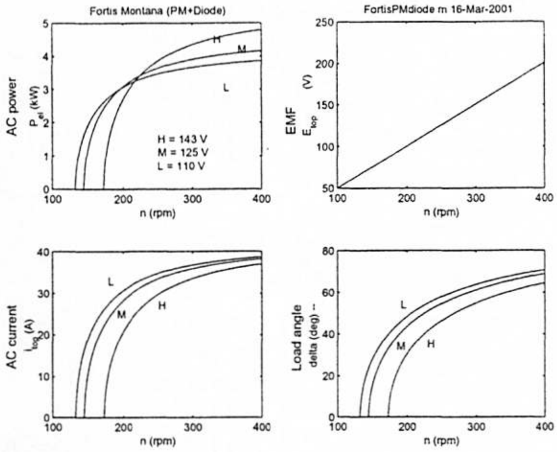
EWEC 2001, Copenhagen, JTG Pierik et al

System 2: PM generator, rectifier, batteries

- Measurements:
  - Generator parameters
  - Power-wind speed curves different DC voltages
  - Transfer function
- Simulations:
  - Generator characteristics (power-speed curves, DC current)
  - Power performance system with batteries

EWEC 2001, Copenhagen, JTG Pierik et al

System 2: Simulations for 3 DC voltages

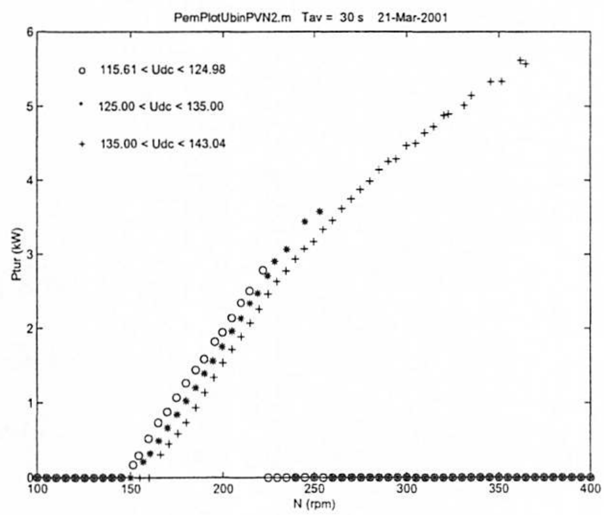


power,
EMF,
AC current
and load angle

against rotor speed

EWEC 2001, Copenhagen, JTG Pierik et al

System 2: measurements 3 DC voltage levels



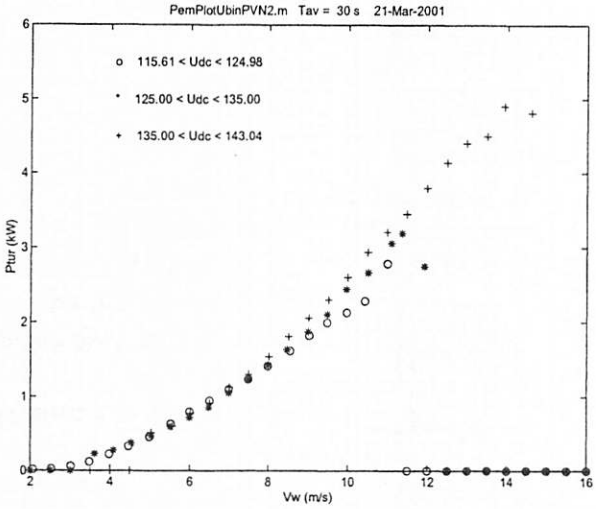
power

versus

rotor speed

EWEC 2001, Copenhagen, JTG Pierik et al

System 2: measurements 3 DC voltage levels



power

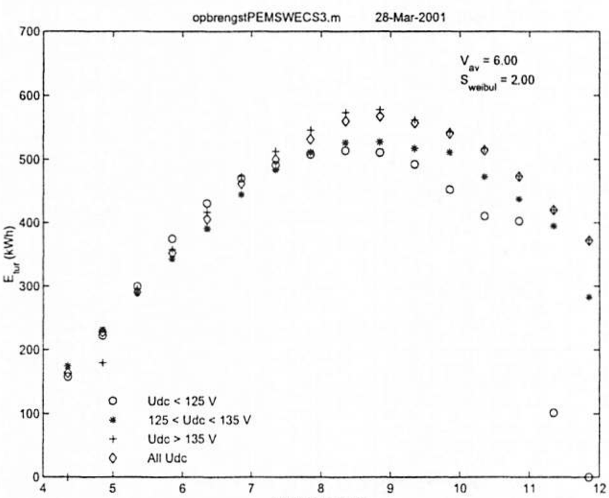
versus

wind speed

ECN

EWEC 2001, Copenhagen, JTG Pierik et al

System 2: measurements 3 DC voltage levels



Energy production

versus

wind speed

ECN

EWEC 2001, Copenhagen, JTG Pierik et al

System 2: Power performance 3 voltage levels

Weibull parameters			
$V_{w,av}$	5	6	7
k	2	2	2
Yearly energy production E (kWh/y)			
U < 125V	4087	5359	5959
125 < U < 135V	4093	5455	6128
U > 135V	4374	5849	6582
all U	4296	5753	6482
Deviations			
$\frac{E_{U>135} - E_{U<125}}{E_{U<125}}$	7%	9%	10%
$\frac{E_{U>135} - E_{allU}}{E_{allU}}$	2%	1.5%	1.5%
$\frac{E_{allU} - E_{U<125}}{E_{allU}}$	5%	7%	8%

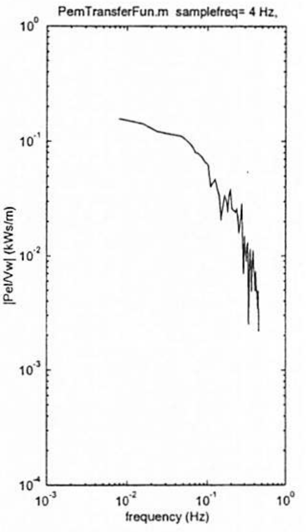
ECN

EWEC 2001, Copenhagen, JTG Pierik et al

System 2: Conclusions

- Effect of voltage variations:
  - 30% variation in DC voltage due to wind speed and load changes
  - significant effect on power-rotor speed curve (0.5 kW)
  - small effect on power-wind speed curve
  - small effect on estimated power performance (5%)
- Pre-averaging period:
  - from transfer function 20 s
  - confirmed by comparision of power curves

ECN



Transfer function from measurements

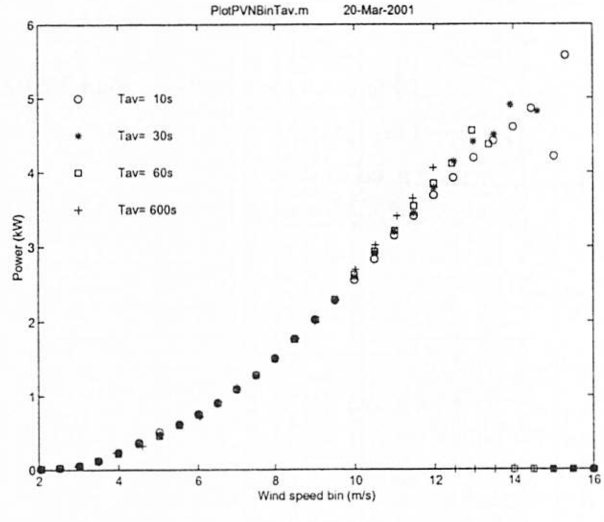
Power variation
devided by
wind speed variation
as function of the
frequency of the variation

cut-off frequency 0.05 Hz

estimated
pre-averaging time 20 s

EWEC 2001, Copenhagen, JTG Pierik et al

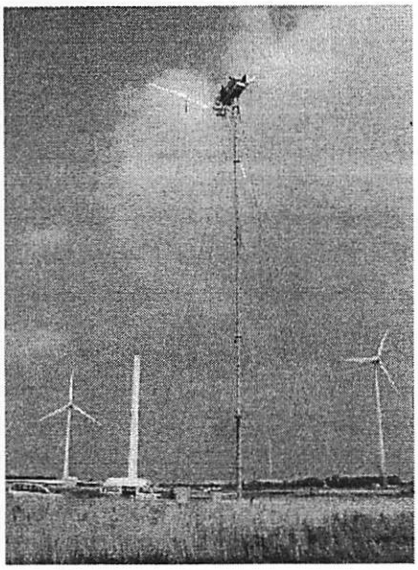
System 2: Validation pre-averaging time



power

versus

wind speed



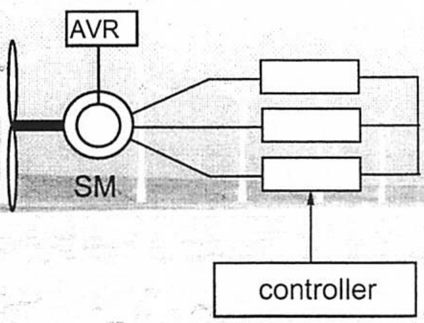
System 3: tested by DEWI

SM generator
Resistive load

Südwind E/N 1230 (30 kW)
Rotor diameter 12.5 m
Hub height 30 m
Down wind
Stall/flap hinges
Rated speed 71 rpm

ECN

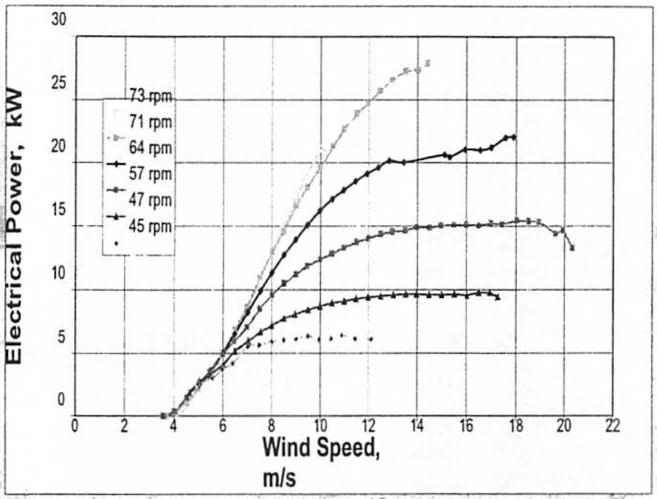
System 3: Südwind



ECN

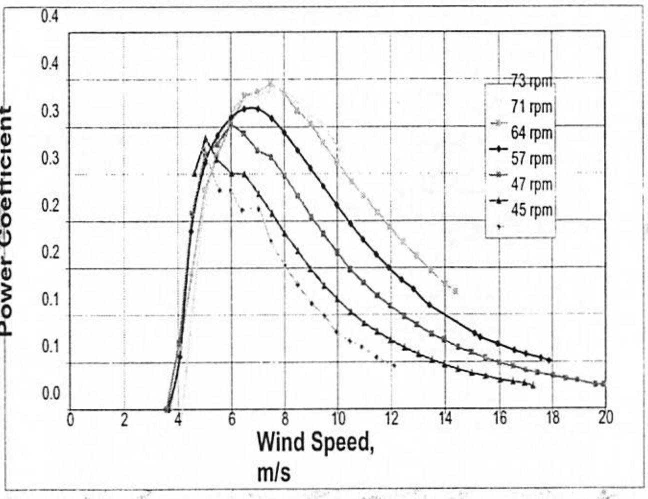
EWEC 2001, Copenhagen, JTG Pierik et al

System 3: Measurements at 6 rotor speeds

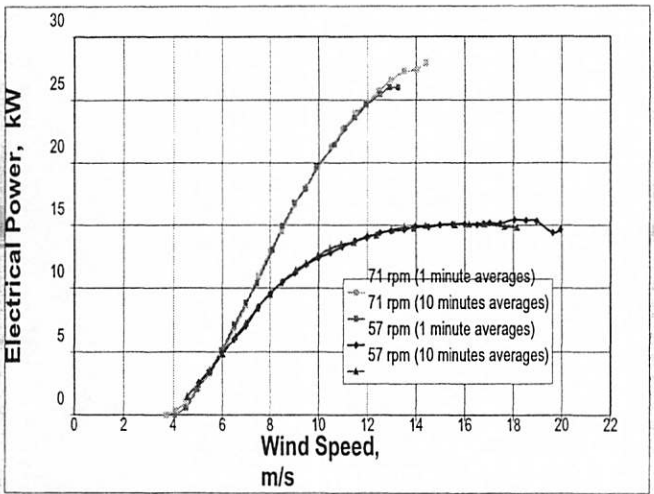


EWEC 2001, Copenhagen, JTG Pierik et al

System 3: Measurements at 6 rotor speeds



System 3: Measurements pre-averaging



ECN

System 3: Conclusions

- Effect of load on power performance:
  - significant effect of speed setpoint
  - no effect of load
  - similar conditions to grid connected
- Pre-averaging period:
  - 60 s confirmed by comparision of power curves

ECN

Recommendations (1)

Measurements:

- required measurements:
  - wind speed and direction;
  - electric power;
  - ambient temperature and pressure.
- optional measurements:
  - DC voltage and current;
  - turbine rotational speed;
  - yaw angle.
- use a sample frequency of 2 Hz or higher;
- archive the raw 2 Hz data;
- measured electric power should include wind power dissipated in a dump load.

ECN

Recommendations (2)

Systems with PM generator, diode rectifier and resistive loads

- without voltage control:
  measure power curve for minimum and maximum load
- with voltage control:
  - document setpoint(s) of the voltage control
  - measure power curve for randomly changing real load
  - instantaneous load value or type is less relevant

ECN

Recommendations (3)

Systems with PM generator, diode rectifier and batteries

- quantify voltage variation
- variation below 30%:
  - need not to be taken into account (effect about 5%)
  - measure power-windspeed curve under random load conditions
- variations exceed 30%:
  - either include voltage measurement
    bin measurements against 3 voltage levels
    evaluate effect on power performance
  - or measure power-wind speed curves
    at two extreme values of DC voltage
    and evaluate effect on power performance

ECN

EWEC 2001, Copenhagen, JTG Pierik et al

Recommendations (4)

Systems with synchronous generator, resistive load and speed control:

- similar to grid connected turbines:
  no effect of load on power performance
- apply same method

ECN

Recommendations (5)

Evaluation of measurements:

- pre-averaging time of 30 s for rotor diameters less than 6 m
- 60 s for diameters of 6-12.5 m
- perform pressure and temperature correction

ECN

PERFORMANCE EVALUATION METHODS FOR AUTONOMOUS, APPLICATIONS ORIENTATED WIND TURBINE SYSTEMS

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[1] Energy research Centre of the Netherlands (ECN)
[2] National Engineering Lab (NEL), Scotland
[3] Deutsches Wind Institute (DEWI), Germany

ABSTRACT This paper describes the development of methods for the power performance evaluation of autonomous wind turbine systems designed for electricity production. Three system types have been investigated. The emphasis was on the evaluation of the effect of the electrical load on the power production of the turbine. Measurements and simulations showed that, if certain conditions are met, a straight forward method similar to the method applied for grid connected systems is feasible.
Keywords: autonomous wind turbine systems, power performance evaluation, electrical systems.

1 INTRODUCTION

Autonomous, application orientated wind energy systems vary in design, size (from about 100 W to several times 10 kW) and loading characteristics. This poses particular difficulties in evaluating their power performance, when compared to grid-connected machines, for a number of reasons:

- the wind speed is not the only significant independent parameter; other climatic factors are also relevant, especially the turbulence level. Small wind turbines in particular, are more affected by turbulence than larger ones;
- aerodynamic effects may not completely dominate system efficiency, relatively poor mechanical and electrical efficiencies are also possible;
- the complete system has to be considered, not only the wind turbine; System performance will depend strongly on matching the electrical load with the turbine characteristics.

The primary objective of the PEMSWECS project is to provide a technical basis for the standardisation of power performance evaluation methods of autonomous wind turbine systems for the generation of electricity, in the range of 100 W to about 30 kW. This can serve as the basis for commercial warranties for autonomous, application orientated wind turbine systems. The project is largely testing based. It is complemented by analytical modelling, to provide a better understanding of system characteristics as well as to assist in performance prediction.

2 TEST SYSTEMS

The following stand alone wind turbine systems have been investigated:

- a 6 kW Proven system, equipped with a permanent magnet (PM) generator, diode rectifier, voltage controller and resistive load. This system is mainly intended for domestic heating and was tested and analysed by NEL;

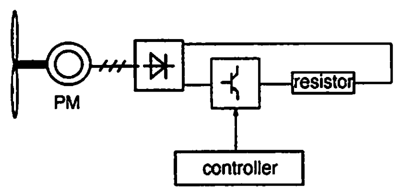


Figure 1: *Proven System with permanent magnet generator, rectifier, resistor and voltage controller*

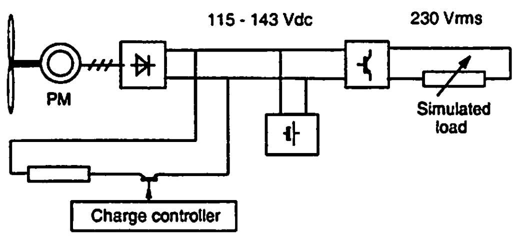


Figure 2: *Fortis system with permanent magnet generator, batteries, charge controller, inverter and AC load*

- a 4 kW Fortis Montana system with a permanent magnet generator, a diode rectifier and batteries. Its main purpose is the supply of domestic appliances through a single phase 230V-50Hz inverter. It was tested and analysed by ECN;

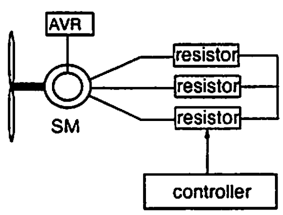


Figure 3: *Südwind system: synchronous generator, resistive load, voltage and speed control*

- a 30 kW Südwind system with synchronous generator and resistive load. This system can be used for the supply of domestic and small industrial appliances and produces heat as a by-product. It was tested and analysed by DEWI.

The actual analysis for the development of a power performance method concentrates on two aspects:

- the effect of the electrical load on the power-windspeed curve of the turbine;
- the choice of the pre-averaging time for the determination of the power curve.

3 SYSTEMS WITH PM GENERATOR, RECTIFIER AND RESISTIVE LOAD

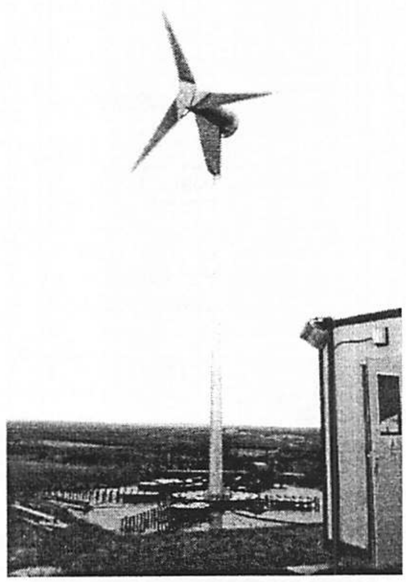


Figure 4: *Proven turbine installed at NEL test site*

The Proven turbine at NEL is a 6 kW down-wind turbine with passive pitching/coning to limit the aerodynamic power. It is a three bladed machine with a rotor diameter of 5 m and a hub height of 10 m. The passive pitching/coning can be tuned by applying either 4 or 5 springs. The three phase AC power is fed through a diode rectifier to resistors of 5.2, 6.8, 8.2, 9.6 or 14.4 Ω. The system is equipped with an IGBT switch, which is controlled by the generator voltage.
Figure 5 demonstrates the strong effect of the load on the power performance of the system without voltage control. Since the load is connected to the turbine regardless of the voltage, a low value resistor will present a high load, which will prevent the turbine from producing power at low wind speeds. If the wind speed increases, the power produced with the low value resistor is also significantly less than at higher resistor values. These measurements clearly demonstrate the effect of the electrical load on the energy production of an autonomous system and the need to consider the load and its control (if any) in the evaluation of these systems.

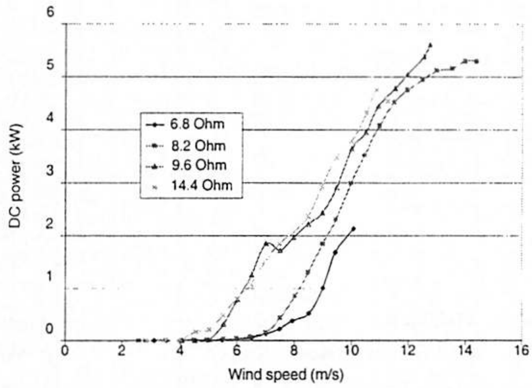


Figure 5: *DC power vs wind speed at different loads for the Proven turbine (no control of the DC voltage)*

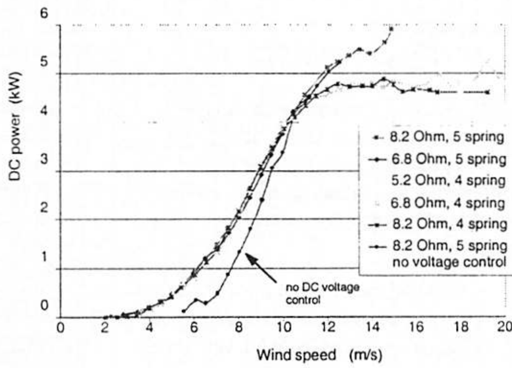


Figure 6: *DC power vs wind speed at different load for the Proven turbine (4 or 5 rotor springs)*

The effect of controlling the DC voltage is demonstrated in figure 6. The effect of the different resistive loads now almost has disappeared. The differences above 12 m/s are caused by a different number of rotor springs, which changes the coning behaviour and the maximum aerodynamic power. In systems with voltage control the tuning of the controller will influence the power performance of the autonomous system, while the influence of the load on the power performance is small.

4 SYSTEMS WITH PM GENERATOR, RECTIFIER AND BATTERIES

The Fortis Montana turbine tested at ECN is a three bladed, up-wind turbine with a rated power of 4 kW, a rotor diameter of 5 m and an inclined hinged tail vane to limit the aerodynamic power (figure 7). The three phase AC power is fed through a diode rectifier to a string of ten 12 V batteries (see figure 2). Battery charging is limited by a FET which switches on a dumpload if the DC voltage reaches 143 V. The DC voltage depends on the DC current and direction and varies between about 115 V and 143 V. The AC load is supplied by a single phase IGBT inverter.
With regard to the effect of the load on the power performance figure 8 shows that, although the influence of the load on the DC voltage is substantial, the effect on the power-windspeed curve is relatively small. In the range

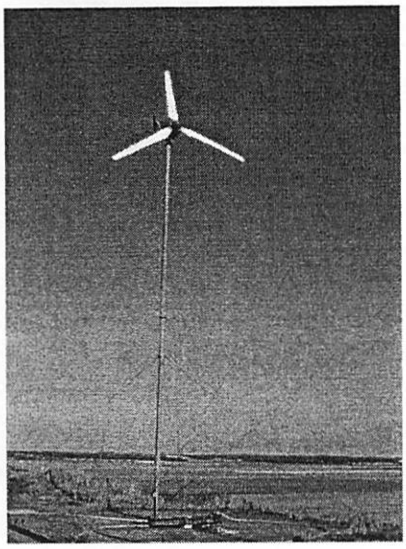


Figure 7: *Fortis Montana Turbine at ECN test site*

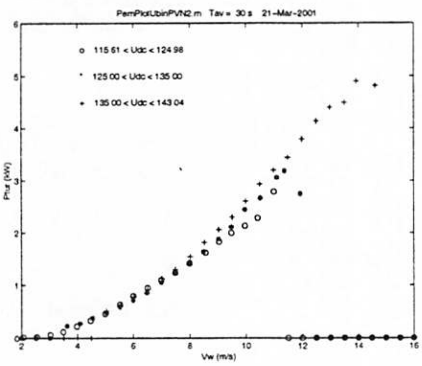


Figure 8: *Measured power-wind speed curves for 3 DC voltage levels*

above 10 m/s there is some difference, but the number of values per bin was relatively small. The small effect suggests the feasibility of a simplified method for the determination of the power curve for systems with batteries which fulfill the conditions in the measurements. The combined effect of the wind speed distribution and differences in P(V) curve on the actual energy production over a long period will now be quantified.
Figure 9 gives the energy production for the 3 DC voltage levels and the average over all voltage levels for a Weibull distribution with an average wind speeds of 6 m/s and a shape factor of 2. The deviations from the average over all voltages is small. Table 1 shows the cumulative results, also for 5 and 7 m/s average wind speed. The maximum deviation is 10%, under real conditions an average value of the listed deviations of about 5% is expected. This deviation seems to present unsufficient justification for a complicated measurement procedure which takes the effect of DC voltage variations into account. Therefore, it is recommended to perform the measurements under real load conditions, implying randomly changing DC voltage, and make no correction for the DC voltage changes.

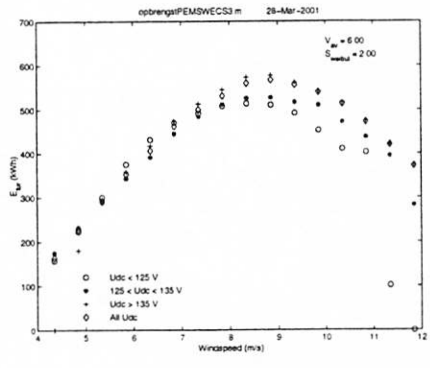


Figure 9: *Energy production for 3 DC voltage levels and the average over all voltages: Vav =6 m/s, k=2*

Table 1: *Yearly production in wind speed interval 5-11 m/s*

Weibull parameters			
$V_{w,av}$	5	6	7
k	2	2	2
Yearly energy production E (kWh/y)			
$U < 125V$	4087	5359	5959
$125 < U < 135V$	4093	5455	6128
$U > 135V$	4374	5849	6582
all U	4296	5753	6482
Deviations			
$\frac{E_{U>135}-E_{U<125}}{E_{U<125}}$	7%	9%	10%
$\frac{E_{U>135}-E_{allU}}{E_{allU}}$	2%	1.5%	1.5%
$\frac{E_{allU}-E_{U<125}}{E_{allU}}$	5%	7%	8%

5 EFFECT OF THE PRE-AVERAGING TIME

IEC 61400-12 suggests a pre-averaging time of 10 minutes for the evaluation of grid connected wind turbines. For small autonomous systems, this is probably too long. Time averaging reduces the effects of poor point-to-point correlation and inertial lag, acting as a low pass filter. High frequency wind fluctuations are filtered out and the inertial lag is masked if the pre-averaging time exceeds the response time constant. The averaging time should be chosen in relation to the system's response time. Hansen and Hausfeld [1] analysed this problem by deriving a transfer function for an arbitrary turbine. This transfer function is a low pass filter as well. They suggest to choose the averaging time of the measurements equal to the cutoff frequency of the turbine transfer function, since this will guarantee the best information transfer in the measurements.
Figure 10 gives the transfer function from wind speed to electric power for the Fortis Montana turbine, estimated from an 8 hour measurement with a sample frequency of 4 Hz and a length of the measurement sample used in the FFT of 512 data points (128 s). A reduction by a factor 2 is reached at a frequency of 0.05 Hz, suggesting an optimal averaging time of 20 s. This estimate should be taken as an indication, since it will depend on the operating conditions. To verify this result, the power curves of the Fortis turbine have been determined for a number of sampling

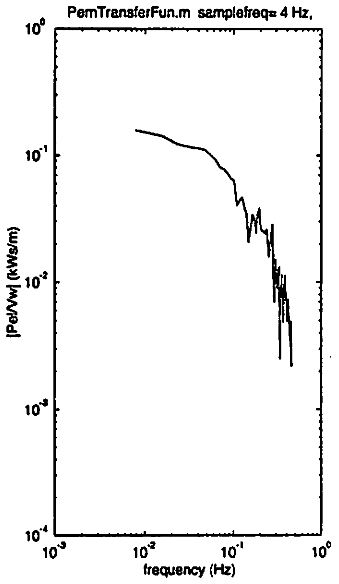


Figure 10: *Fortis Montana transfer function* $\mathrm{d}P_{el}/\mathrm{d}V_w$

frequencies and that confirmed the result.

6 SUMMARY OF RECOMMENDATIONS

Measurements for the power performance of autonomous systems:

- required measurements:
  - wind speed and direction;
  - electric power;
  - ambient temperature and pressure.
- optional measurements:
  - DC voltage and current;
  - turbine rotational speed;
  - yaw angle.
- use a sample frequency of 2 Hz or higher;
- archive the raw 2 Hz data;
- measured electric power should include wind power dissipated in a dump load.

Systems with PM generator, diode rectifier and resistive loads at the DC side:

- without voltage control: perform a measurement of the power curve for the minimum and the maximum load. This will determine the best and worst performance of the system;
- with voltage control: document the setpoint(s) of the voltage control and measure the power curve for real load conditions. The load value and type are less relevant.

Systems with permanent magnet generator, diode rectifier and charge limitation:

- consult the manufacturer or perform a scoping measurement to quantify the variation, due to load changes, of the DC voltage at the diode rectifier;
- if the voltage deviations are 30% or less, voltage changes need not to be taken into account in the power performance measurement and evaluation procedure;
- if voltage variations are not taken into account, take measurements for the power-wind speed curve under random load conditions, comparable to end user conditions;
- if the voltage deviations exceed 30%:
  - either include voltage measurement in the data acquisition and bin measurements against 3 voltage levels and evaluate the effect on the power performance;
  - or measure power-wind speed curves at the two extreme values of the DC voltage and evaluate the effect on the power performance.

Systems with synchronous generator, resistive load and speed control:

- these systems are similar to grid connected turbines and the same method for performance evaluation applies.

Evaluation of measurements:

- use a pre-averaging time of 30 s for rotor diameters less than 6 m and 60 s for diameters of 6-12.5 m;
- perform a pressure and temperature correction.

End user performance prediction:

- for systems without batteries: use a statistical evaluation method;
- for systems with batteries: use a time domain model and include battery characteristics. A simple model was developed for this purpose [2];
- the effect of the battery size and battery losses is not included in the proposed measurement procedure for systems with batteries. It is proposed to evaluated this aspect separately, since it is dependent on the demand pattern of a given application;

ACKNOWLEDGEMENTS

This work has been executed in the JOULE programme on Renewable Energy, on a partial grant of the European Commission and Generic R&D programmes financed by the participating countries.

REFERENCES

[1] A.C. Hansen and T.E. Hausfeld. Frequency response matching to optimize wind-turbine test data correlation. *Transactions of the ASME*, pages 246, Vol. 108, 1986.

[2] J.T.G. Pierik. Pemswecs - performance evaluation methods for autonomous, applications orientated wind turbine systems - systems with batteries. Technical Report ECN-C-01-032, ECN, 2001.

POWER PERFORMANCE OF SWT NOT CONNECTED TO THE GRID:

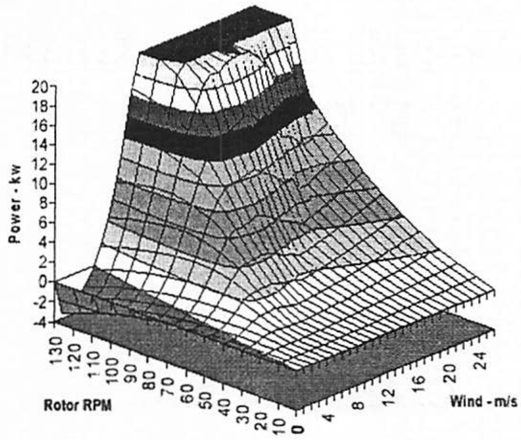
EFFECT OF THE LOAD

Luis Arribas, Felix Avia
CIEMAT - Spain
Alexandre C. Araujo da Costa
UPM

Aspects:

- Influence of the voltage on the power curve
- Characterization method

Understanding the problem: the rotor



Variable speed

Power "Surface"

From: P.W. Carlin, A.S. Laxson, E.B. Muljadi, *"The History and State of the Art of Variable-Speed Wind Turbine Technology"*, NREL/TP-500-28607, Feb. 2001

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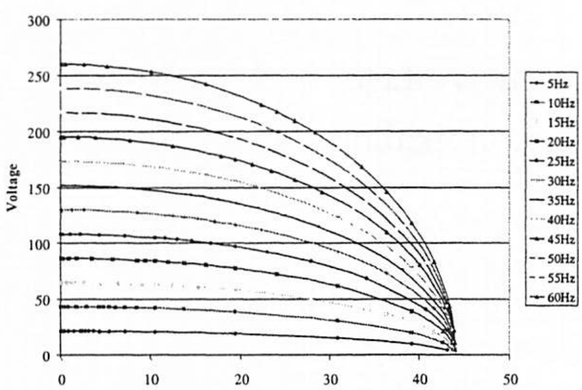
Understanding the problem: the generator



PMG connected directly to different resistors (theoric)

Permanent Magnet Generator

Variable Voltage and Frequency

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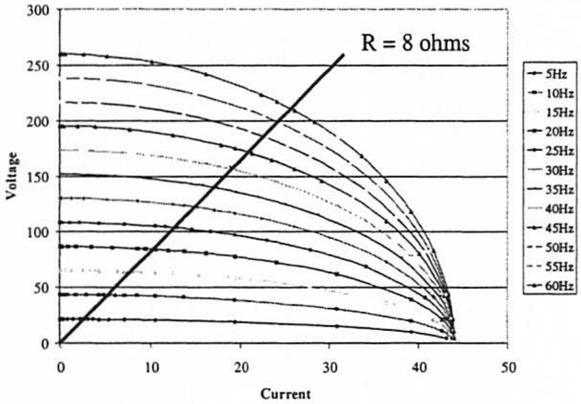
Understanding the problem: the load



The working point of the generator is fixed by the load

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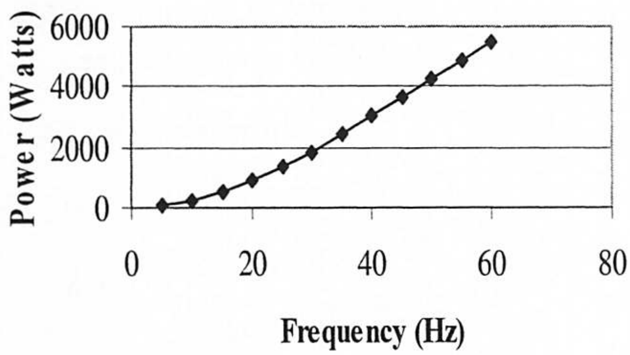
Understanding the problem: the load



For each load

One Generator Curve

Get the Power Curve from the "Power Surface"

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Understanding the problem:

- The Power Curve depends on:
  - the rotor characteristics (Pe, Vv, rpm)
  - the generator characteristics (V, I, rpm)
  - the load (R)

Usually not viable!

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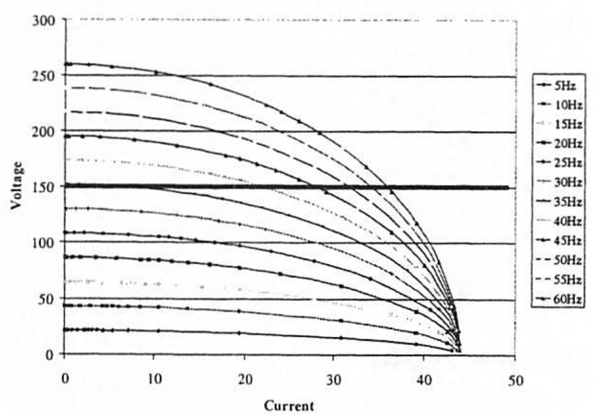
Understanding the problem: Battery Charging Applications



For each different voltage

One Generator Curve

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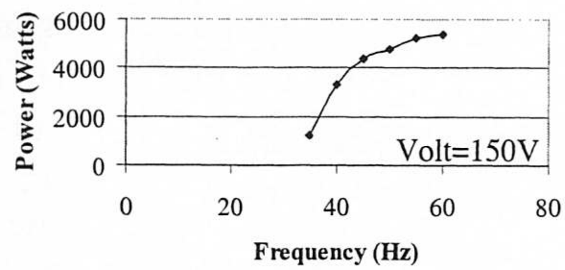
Understanding the problem: Battery Charging Applications



With this generator curve

Get the Power curve from the Power "Surface" from the rotor

Usually not viable, again!

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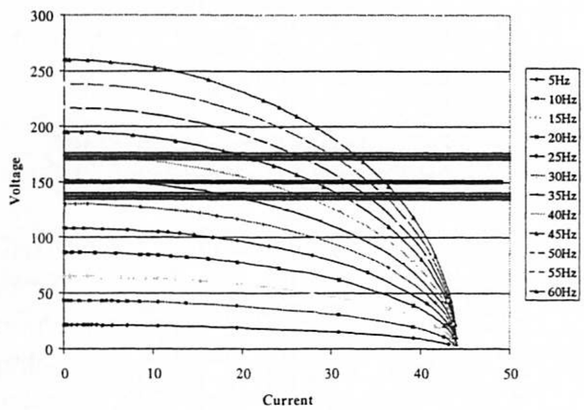
Understanding the problem: Battery Charging Applications



Objective

Characterization of the Power Generation for a specific voltage range

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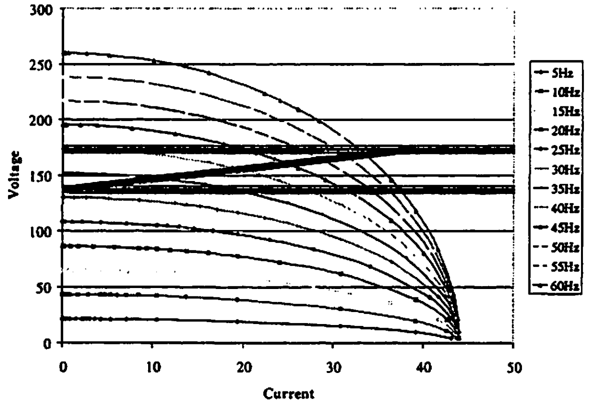
Understanding the problem: Battery Charging Applications



But also taking into account the effect of the load!

(impedance of the battery + load)

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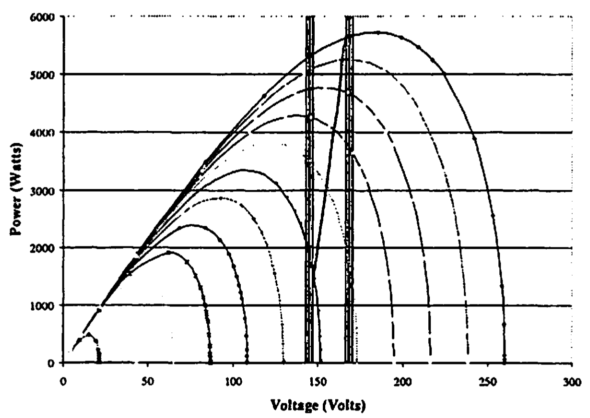
Understanding the problem: Battery Charging Applications



Objective

Characterization of the Power Generation for a specific voltage range and a specific use

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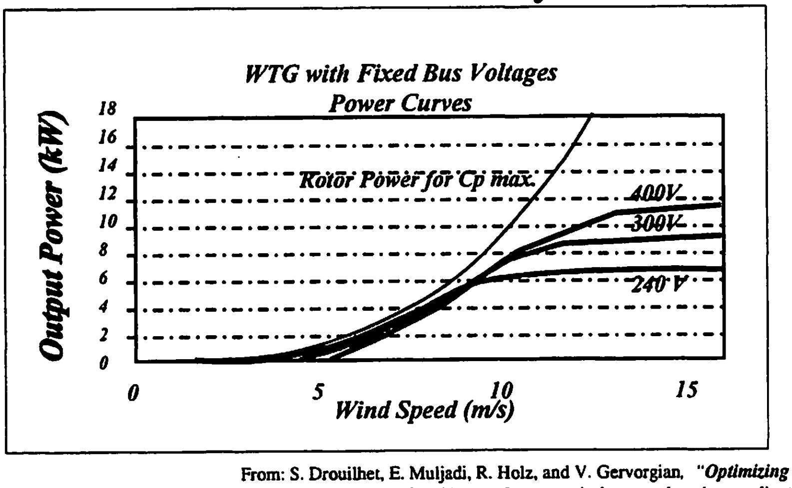
Issues on the influence of the voltage: Theoretical study



From: S. Drouilhet, E. Muljadi, R. Holz, and V. Gervorgian, "***Optimizing small wind turbine performance in battery-charging applications***", Windpower '95

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Approaches on the influence of the voltage: Annex G, IEC-61400-12 (proposal):

- Additional Power curves should be obtained by setting the battery bank voltage to the optional low (1.9 V/cell) and high settings (2.4 V/cell), apart from the power curve for the required setting (2.1 V/cell).

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Approaches on the influence of the voltage: ITPower

- Power curves will be determined on the basis of the following conditions:
  - SOC = 0; 96% of nominal voltage (23.04 V for a 24 V battery)
  - SOC = 100; 112 % of nom. volt. (26.88 V for a 24 V battery)

From: F. Crick, P. Fraenkel, P. Cowley, M. McCourt, I. Fawkes, P. Fitches & B.Reid, "***Small stand-alone wind systems: developing a methodology for standardising performance claims***", EWEC 1999, Nice

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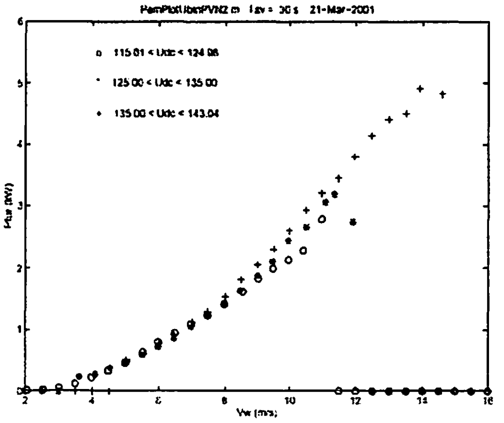
Approaches on the influence of the voltage: PEMSWECS Project;



Influence on the Power Curve

- The general impression is that the effect of the DC voltage on the power curve **under real load conditions** is relatively small

From: J.T.G. Pierik , R.W. Dunlop, W.K. Lee, J. Gabriel, "***Performance evaluation methods for autonomous,applications Orientated wind turbine systems***", EWEC 2001, Copenhaguen

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IEA Topical Expert Meeting, 2002

Approaches on the influence of the voltage: PEMSWECS Project;

Influence on the power-rotor speed curve:

- Substantial

This surprising behaviour (influence on the power-rotor speed but not on the power-wind speed curve) can be explained be the strongly nonlinear behaviour of the rotor.

Approaches on the influence of the voltage: PEMSWECS Project:

Influence on the Annual Energy Output

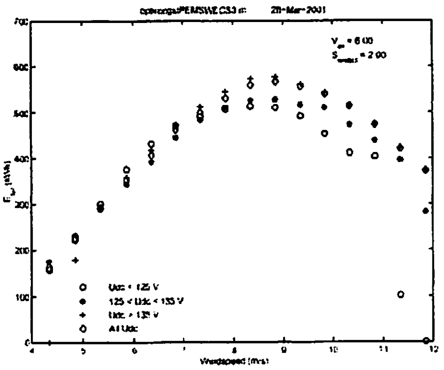


Table 1: *Yearly production in wind speed interval 5-11 m/s*

Weibull parameters			
$V_{w,av}$	5	6	7
k	2	2	2
Yearly energy production E (kWh/y)			
$U < 125V$	4087	5359	5959
$125 < U < 135V$	4093	5455	6128
$U > 135V$	4374	5849	6582
all U	4296	5753	6482
Deviations			
$\frac{E_{U>135} - E_{U<125}}{E_{U<125}}$	7%	9%	10%
$\frac{E_{U>135} - E_{allU}}{E_{allU}}$	2%	1.5%	1.5%
$\frac{E_{allU} - E_{U<125}}{E_{allU}}$	5%	7%	8%

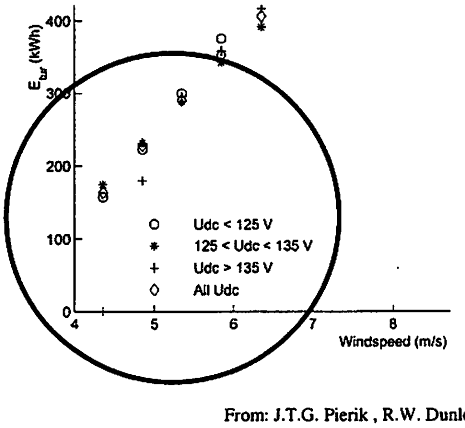
From: J.T.G. Pierik , R.W. Dunlop, W.K. Lee, J. Gabriel, "***Performance evaluation methods for autonomous,applications Orientated wind turbine systems***", EWEC 2001, Copenhaguen

Approaches on the influence of the voltage: PEMSWECS Project;

Recommendations:

- If the voltage deviations are 30% or less, voltage changes need not to be taken into account in the power performance measurements and evaluation procedure: take measurements for the power-wind speed curve under random load conditions, comparable to end user conditions;

Approaches on the influence of the voltage: PEMSWECS Project.

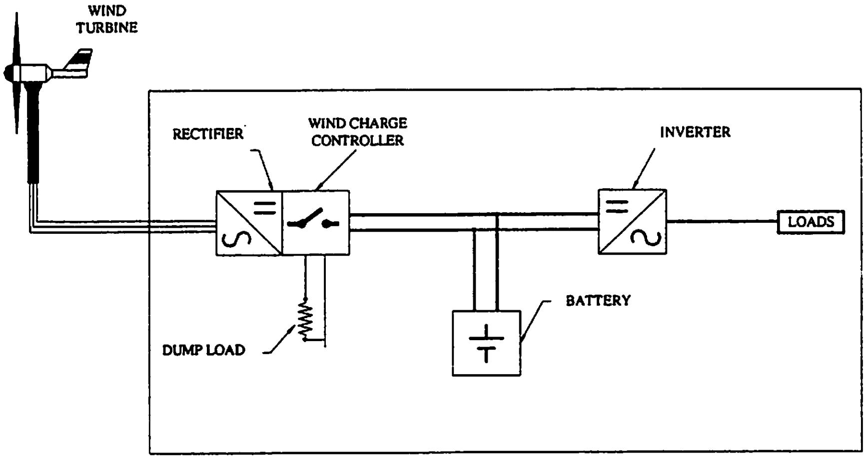


Some comments

- Little influence on energy production: OK
- Quality of service (LOLP) issues? (the influence would be bigger for lower average wind speeds)
- Good enough for characterization using batteries

From: J.T.G. Pierik, R.W. Dunlop, W.K. Lee, J. Gabriel, *"Performance evaluation methods for autonomous,applications Orientated wind turbine systems"*, EWEC 2001, Copenhaguen

Key Items for the Test Configuration:



Power Performance of Small Wind Turbines not connected to the Grid
IEA Topical Expert Meeting, 2002

Approaches on the test configuration: Annex G, IEC 61400-12 (proposal):

- The WTGS shall be connected to a load comprised of a battery bank and a device suitable for controlling battery bank voltage.
- The voltage regulation device shall be capable of maintaining the battery bank voltage within 10% of the test settings over the full range of power output of the turbine
- The 1-minute average of the battery bank voltage must be within 2% of the test settings, and should be included in the usable data set

Power Performance of Small Wind Turbines not connected to the Grid
IEA Topical Expert Meeting, 2002

Approaches on the test configuration: PEMSWECS

- Uses a battery bank; no general suggestions on the size of the battery
- The voltage is allowed to vary freely in the working range, connected to real load conditions: no voltage control is made, apart from the overvoltage protection.
- If the voltage deviation exceeds 30% of the nominal voltage:
  - **either include voltage measurement** in the data acquisition and bin measurements against 3 voltages and evaluate the effect on the power performance;
  - **or measure power-wind speed curves at the two extreme values** of the DC voltage and evaluate the effect on the power performance.

Approaches on the test configuration: ITPower

- It is suggested that the allowable voltage fluctuation should not exceed 2 % of test voltage.
- In order to maintain the state of charge at appropriate levels, it is proposed to use a shunt regulator (or array of shunt regulators) to emulate battery performance.
- The benchmark test should as a minimum define the turbine performance at extreme values of SOC.
- Considerable thought has been given to devising a readily available alternative which could be used to simulate the primary characteristics of a battery over a representative range of states of charge.

CIEMAT's Practices on the test configuration

- Voltage fluctuation does not exceed 2 % of test voltage.
- In order to maintain the battery voltage at appropriate levels, it is used the regulator that was sent together with the turbine. The desired voltage setting is achieved through the adjustment of the variable resistor included in the regulator's circuit.
- Battery banks are big enough for the voltage not to vary quickly.

Suggestions on the test configuration for WT in battery charging applications (I)

- Various difficulties arise in using a battery as a load, since factors such as the size of the battery, the type of battery, its temperature and state of charge can influence its impedance. A standard battery has too many variables associated with it to provide a stable, repeatable benchmark test. (ITPower document)
- All necessary efforts should be made in order to **avoid the use of a battery** in the power performance characterization.

Power Performance of Small Wind Turbines not connected to the Grid
IEA Topical Expert Meeting, 2002

Suggestions on the test configuration for WT in battery charging applications (II)

- A possible solution appears to be the use of voltage controllers.
- This voltage controller can be connected either to a resistive load or to the grid.
- With these voltage controllers, at least three power curves should be obtained, for the voltages corresponding to the extreme SOC, and one for the nominal voltage.
- This way, the WT would be characterized as an independent element, apart from the application

Suggestions on the test configuration for WT in battery charging applications (and III)

- From this information, that defines the WT, the information on the particular power curve for a specific equivalent impedance.
- More measuring campaigns are needed to improve (and surely simplify) this suggested method

Suggestions on the test configuration for WT for general use

- If the method described before (the use of voltage controllers so as to obtain power curves for different voltages) results valid, the voltage range could be opened to the whole range of variation of the generator. This way, the turbine performance would be defined for any application (battery charging, grid connection, pumping systems) where a rectifier is used.

IEA R&D Wind Annex XI

POWER PERFORMANCE OF SWT NOT CONNECTED TO THE GRID

Data Acquisition and Processing

Prepared by :
L. Arribas
F. Avia

Renewable Energies for Decentralised Systems.
CEDER-CIEMAT 25-26 April 2002

Key Topics

- **Scope of application (WT size, use)**
- **Testing site conditions**
- **Measuring Instrumentation**
- **Position of the Meteorological sensors**
- **Data Acquisition Systems**
- **Analysis of Data**
- **Procedures for air density correction**

Issues for Data Acquisition

- **Scanning frequency**
- **Pre-averaging time**
- **Number of data per bin required**
- **Total number of data required**
- **Width of the measured range**
- **Density correction**

Key Items for Data Acquisition:
Scanning frequency

<u>IEC 64000-12:</u>

Data shall be collected continuously at a sampling rate of *0,5 Hz or faster*. Air temperature, air pressure and precipitation, and WTGS status may be sampled at a slower rate, but at least once per minute.

<u>PEMSWECS:</u>

Use a sample frequency of *2 Hz or higher*. Archive the 2 Hz raw data

<u>ItPower:</u>

A data sampling rate of *0.5 Hz* is recommended for performance evaluation purposes.

Key Items for Data Processing:

Pre-averaging time

IEC 64000-12:

The data should be pre-processed with a duration *between 30 s and 10 minutes* and shall be 10 min divided by an integer number.

Annex G:

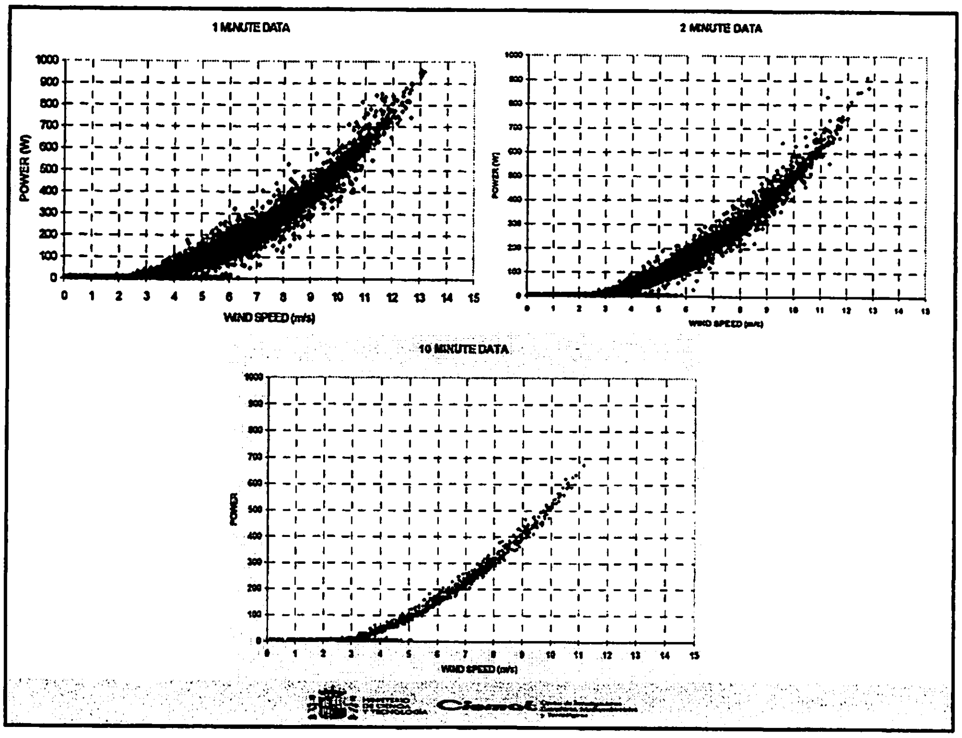
Pre-processed data shall be of *1 minute* duration

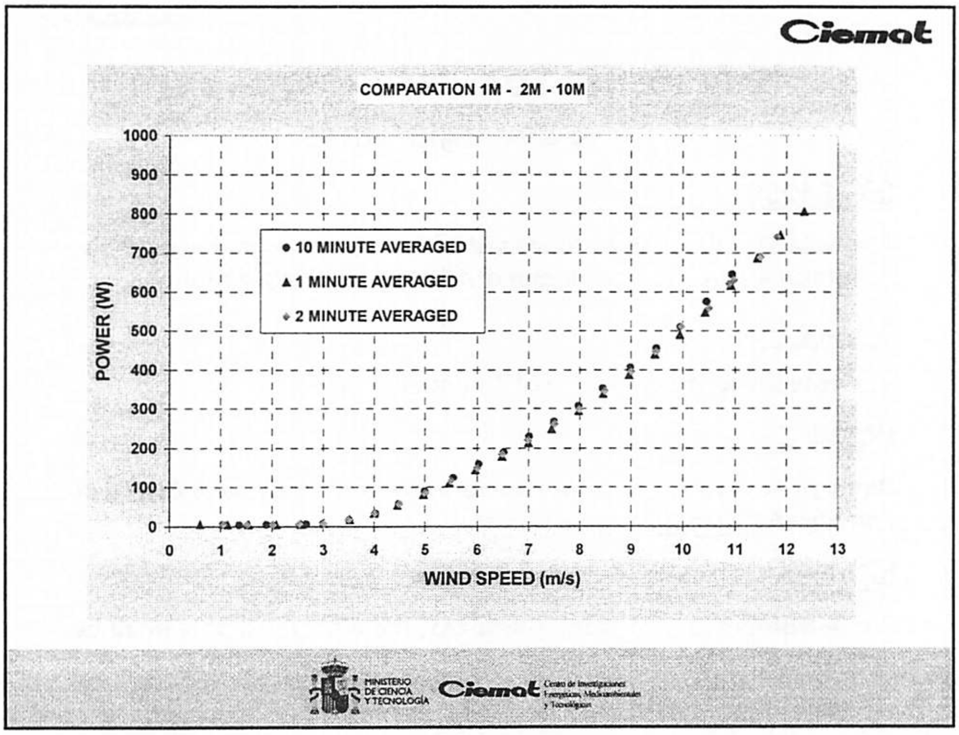
PMWECS

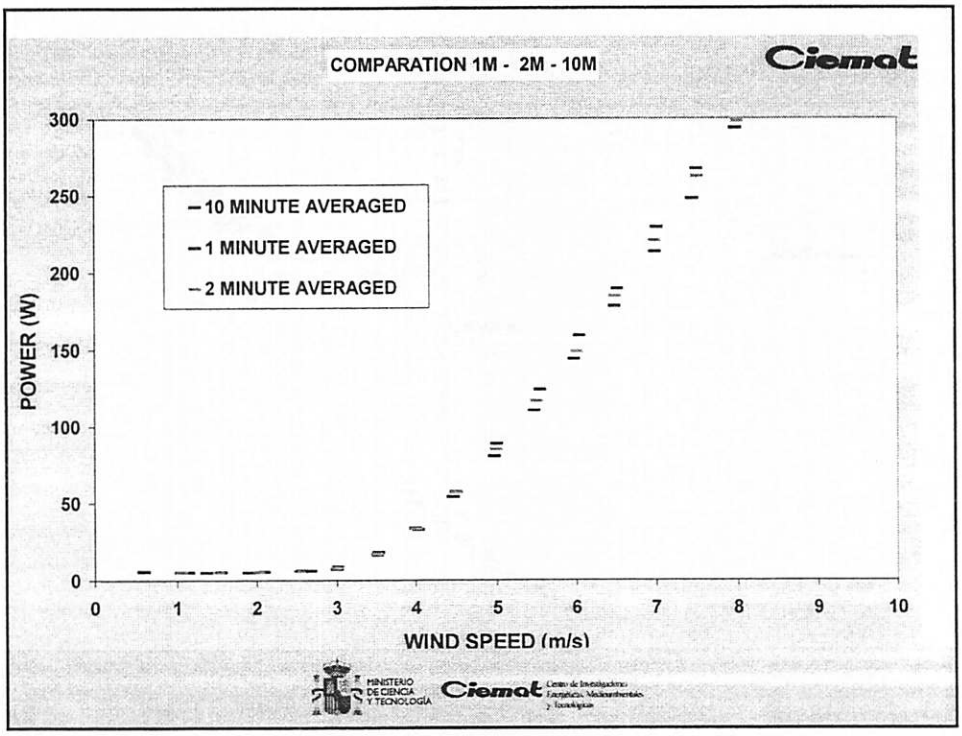
Use a pre-averaging time of *30 s for rotor diameters less than 6 m, and 60 s for diameters of 6-12.5 m*

ItPower

For performance evaluation purposes, the measured data shall be time-averaged every *10 minutes.*




Ciemat
COMPARATION 1M - 2M - 10M
POWER (W)
WIND SPEED (m/s)
10 MINUTE AVERAGED
1 MINUTE AVERAGED
2 MINUTE AVERAGED
MINISTERIO DE CIENCIA Y TECNOLOGÍA
Ciemat


COMPARATION 1M - 2M - 10M
Ciemat
POWER (W)
WIND SPEED (m/s)
10 MINUTE AVERAGED
1 MINUTE AVERAGED
2 MINUTE AVERAGED
MINISTERIO DE CIENCIA Y TECNOLOGÍA
Ciemat

Ciemat

Key Items for Data Processing

Pre-averaging Time: Sensibility to the AEP

Rayleigh	10 MINUTES kWh/Year		1 MINUTE kWh/Year	%	2 MINUTE kWh/Year	%
4 m/s	638,5		615,8	-3,56	628,0	-1,64
5 m/s	1030,6		989,1	-4,03	1008,4	-2,15
6 m/s	1305,3		1252,0	-4.06	1274,7	-2,34

Ciemat

Key Items for Data Processing

Number of data per bin required
Total number of data required

IEC 64000-12:

Each bin includes a minimum of *30 minutes* of sampled data. The total duration of the measurement period includes a minimum of *180 hours* with the WTGS available within the wind speed range.

Annex G:

Each bin includes a minimum of *10 minutes* of sampled data. The total data base contains at least *60 hours* of data with the WTGS within the wind speed range

ItPower

Each wind speed bin must contain a minimum of *30 minutes* of sampled data. The entire valid data set must contain at least *90 hours* of data.

Ciemat

Key Items for Data Processing

Width of the measured range

<u>IEC 64000-12:</u>

- **From Cut-in minus 1 m/s to 150 % the wind speed where the power reach 85 % of the rated power.**
- **From Cut-in minus 1 m/s to the wind speed from which the "AEP measured" is > or = to the "AEP extrapolated" (A what wind speed?).**

<u>ItPower</u>

The minimum permissible range of valid data bins is zero to *12 m/s*

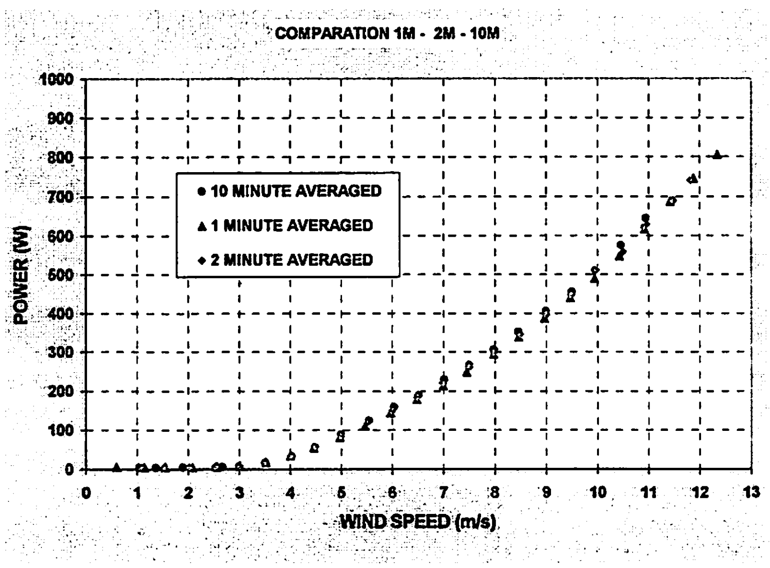
Ciemat

Key Items for Data Processing

Width of the measured range: % of the AE produced for the upper part of the CP

Rayleigh	> 12 m/s		>14 m/s		>16 m/s	
	Time (%)	Energy (%)	Time (%)	Energy (%)	Time (%)	Energy (%)
4 m/s	0.1	**1.4**	0.01	**0.14**	-	-
5 m/s	1.08	**7.7**	0.21	**1.5**	0.03	**0.21**
6 m/s	4.31	**19.2**	1.38	**6.1**	0.37	**1.6**

Time = Cumulative Probability



Ciemat

Key Items for Data Processing

Width of the measured range covered from a 15 days testing period vs the preaveraing time

	10 MINUTES	2 MINUTES	1 MINUTE
MINIMUM	0	0	0
MAXIMUN	11 m/s	12 m/s	12.5m/s

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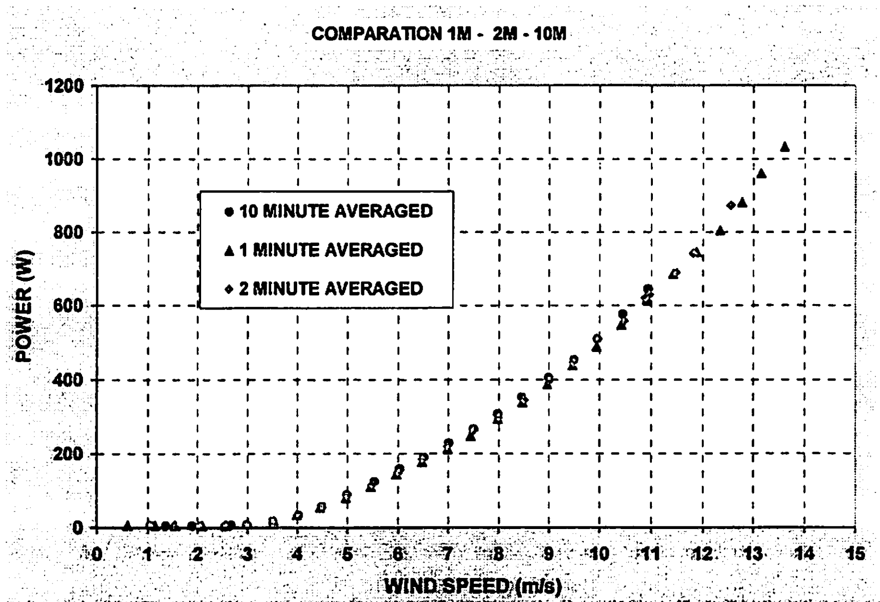

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Key Items for Data Processing

Density Correction

IEC 64000-12 . Annex G:

For WT with passive`power control, such as furling or blade fluttering, wind speed shall be normalized using equation 5:

$$(V_n=V_{10}(r_{10}/r_0)^{1/3})$$

ItPower

Given the variable speed and in some cases variable geometry nature of the rotors on the SWT being tested, the density corrections stated in IEC 61400-12 cannot be assumed to be valid. Indeed, application of an invalid density correction may only add further scatter to results.

Key Items for Data Processing

Uncertainty analysis

?

PROPOSAL

✓A data sampling rate of *1 Hz* is recommended for performance evaluation purposes. Air temperature, air pressure and precipitation, and WTGS status may be sampled at a slower rate, but at least once per 10 minute.

✓For performance evaluation purposes, the measured data shall be time-averaged every *10 minutes.*

✓The minimum permissible range of valid data bins is *0 - 14 m/s*

✓Between 0-14 m/s each bin shall include a minimum of *30 minutes* of sampled data. The total duration of the measurement period includes a minimum of *120 hours* with the WTGS available within the wind speed range.The bins over 14 m/s could be completed with data using pre-averaging time of 1 minute

✓Density corrections cannot be made. The power curve shall clearly indicate the average density measured during the testing procedure.

✓Uncertainty analysis shall be performed

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The Influence of Atmospheric Turbulence on the Kinetic Energy Available During Small Wind Turbine Power Performance Testing

IEA Expert Meeting on:
Power Performance of Small Wind Turbines
Not Connected to The Grid
CEDER-CIEMAT
Soria, Spain

BCochran@CPPwind.com

Introduction:

- **Influence of atmospheric turbulence on kinetic energy has been discussed for many year.**

  (Putman showed that he was underestimating total kinetic energy by up to 14% by using a hourly average wind speed.)

- **Influence often ignored because of dual impact on turbine power production.**

  (Increases kinetic energy, decreases turbine efficiency)

- **Current IEC 61400-12 standard does not adequately address turbulence at the test site.**
- **Omission specifically impacts testing of small wind turbines because of the potential variety of sites**

Turbulence in the Atmospheric Boundary Layer:

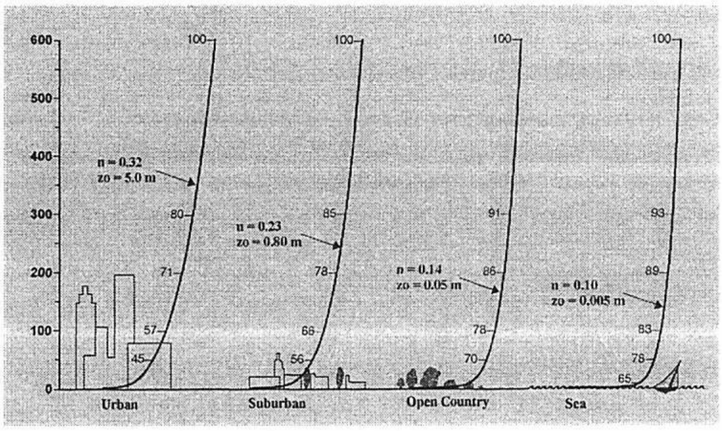
- **Vertical wind shear created by aerodynamic friction and thermal gradients**
- **Resulting velocity profile can be described by the following relationship:**

$$U_z = U_{ref} \times \left(\frac{z}{z_{ref}} \right)^n$$

Where:

n = *power law coefficient;*
U_z = *longitudinal mean velocity at height, z;*
U_{ref} = *longitudinal mean velocity at a reference height, z_{ref};*
z = *height above local grade; and*
z_{ref} = *reference height above local grade.*

Longitudinal Velocity Profiles Over Uniform Terrain in Neutral Flow:



Turbulence in the Atmospheric Boundary Layer:

- **Aerodynamic friction and thermal gradients also create atmospheric turbulence**
- **The lower portion of the ABL can be described from the relationship:**

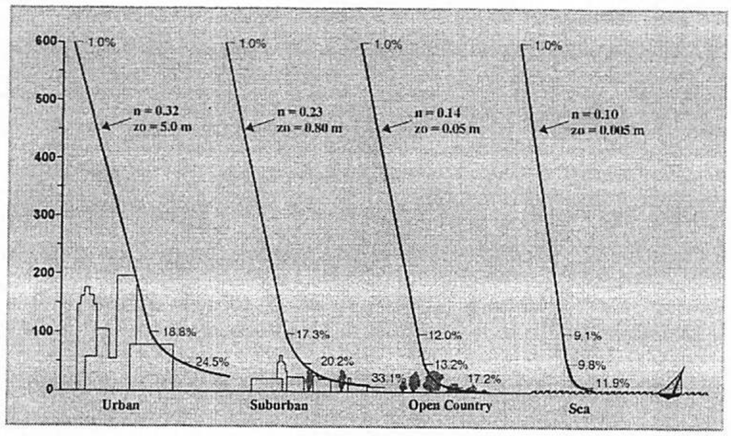
$$\left(\frac{U_{rms}}{\overline{U}}\right) = T.I. = n\ln\left(\frac{30}{z_0}\right) \div \ln\left(\frac{z}{z_0}\right)$$

Where:

U_{rms} = **root mean squared longitudinal velocity; and**

= **mean longitudinal velocity.**

Turbulence Intensity Profiles Over Uniform Terrain in Neutral Flow:



Approach:	Sea	Open Country	Suburban	Urban
n =	0.104	0.14	0.23	0.31
zo =	0.005	0.05	0.80	5.00
Height Above Grade (m)	Turbulence Intensity (T.I.)			
10	11.9%	17.2%	33.1%	81.4%
15	11.3%	15.9%	28.5%	51.4%
20	10.9%	15.2%	26.0%	40.7%
25	10.6%	14.6%	24.3%	35.1%
30	10.4%	14.2%	23.1%	31.5%
35	10.2%	13.9%	22.1%	29.0%
40	10.0%	13.6%	21.4%	27.1%
45	9.92%	13.4%	20.8%	25.7%
50	9.81%	13.2%	20.2%	24.5%
75	9.39%	12.4%	18.4%	20.8%
100	9.12%	12.0%	17.3%	18.8%

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Distribution of Wind Speeds:

- **Hourly Average Wind Speeds Over Long Time Periods:**
  - **Macro, Meso, and Micro Scale Motion**
  - **Rayleigh (or Weibull) Distribution**

- **1-Second Wind Speeds within 10 second to 1 hour averaging times**
  - **Micro Scale Motion Only**
  - **Gaussian Distribution**

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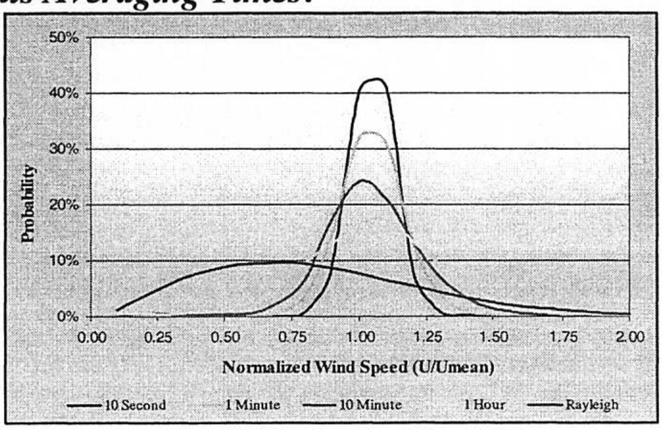
Distribution of 1 Second Wind Speeds Within Various Averaging Times:



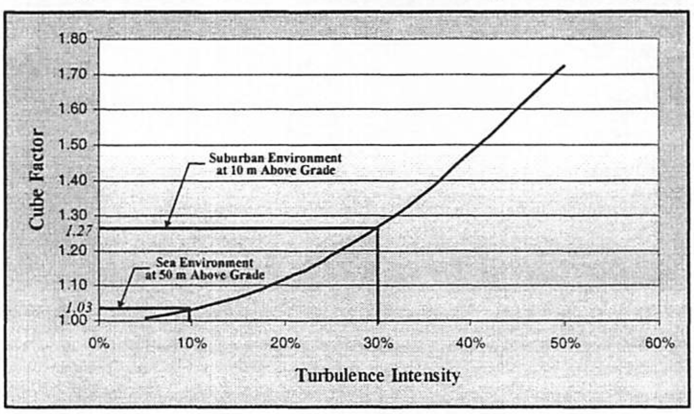
Data at 10 m above grade at CPP's Test Site in Fort Collins, CO, USA

Calculating the Cube Factor as a Function of T.I.:

- Gaussian distribution can be defined by its mean and rms values.
- Normalize measured wind speeds by the 1 or 10 minute mean wind speed, .
- U_{rms} / = Turbulence Intensity
- / = Unity

$$\text{cube factor} = \left(\frac{\overline{U^3}}{\overline{U}^3} \right) = \sum_{i=0}^{\infty} \left(\frac{U}{\overline{\overline{U}}} \right)^3 \times P\left(\frac{U}{\overline{\overline{U}}} \right)$$

The Cube Factor as a Function of the Local T.I. Assuming a Gaussian Distribution of Wind Speeds:



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***Results*:**

- **The kinetic energy approaching a small wind turbine, for the same mean wind speed, may vary by as much as 23% at different test sites.**

(Cube factors ranging from 1.27 to 1.03)

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***Potential Mitigation*:**

- **Define power curve using a cubic averaged wind speed, $\overline{U^3}^{(1/3)}$**

Pros:

Properly accounts for the total kinetic energy approaching the wind turbine.

Cons:

Charts or statistics are generally not available for a cubic average wind speed.

Power curves may not be repeatable because it does not account for variations in turbine efficiency resulting from different levels of atmospheric turbulence.

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Potential Mitigation:

- **Minimize averaging times.**

Pros:

The variations in turbulence intensity decrease with decreased averaging time. Data from the CPP test site indicates that the cube factor is reduced from 1.14 to1.04 with a 1-minute averaging time.

Cons:

Decreasing the averaging time will decrease the correlation between the measured wind speed and the wind speed present at the wind turbine.

Power curves may still not be repeatable because it does not account for variations in turbine efficiency resulting from different levels of atmospheric turbulence.

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Potential Mitigation:

- **Specify allowable hub height T.I. values within the site characterization standard.**

Pros:

Variation in cube factors could be maintained within E3% by limiting hub height T.I. Values between 13% and 18%. Thus, power curves will be much more repeatable.

Cons:

Would limit the sites that could be used for power performance testing (For example: Very smooth sites may not meet T.I. standards at any tower height above 10m).

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Potential Mitigation:

- **Combine 1-minute averaging time with the specified hub height T.I. values.**

Pros:
Variation in cube factors could be further reduced.

Cons:

Would only provide consumer an estimate of turbine performance for one level of atmospheric turbulence. Thus, will provide no indication as to which turbine will provide the best return on investment at their specific location.

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Potential Mitigation:

- **Expand testing procedure to include power performance curves at multiple levels of atmospheric turbulence.**

Pros:
Will allow customer to define the best turbine for their specific environment.

Cons:

Time and Expense

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Conclusions:

- The current site specification standards are not sufficient to ensure that accurate and repeatable power performance curves for small wind turbines.
- The results indicate that the kinetic energy present at the hub height can vary by as much as 20 percent depending upon the level of turbulence present at the test site.
- Variation in kinetic energy can be somewhat mitigated by reducing the averaging time from 10 minutes to 1 minute and by setting specific standards for allowable hub height turbulence intensity levels
- It is also suggested that the testing procedure may be expanded to include power performance curves at multiple levels of atmospheric turbulence.

The Influence of Atmospheric Turbulence on the Kinetic Energy Available During Small Wind Turbine Power Performance Testing

By

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IEA Expert Meeting on:
Power Performance of Small Wind Turbines
Not Connected to The Grid

CEDER-CIEMAT
Soria, Spain

April 2002

1. Introduction

The influence of atmospheric turbulence on the total kinetic energy available in the wind has been discussed for many years. Putman (1948) discussed this concept in his synopsis of the experiments carried out on the 1250 kW Smith-Putman wind turbine at Grandpa's Knob, Vermont in the early 1940's. Putman demonstrated through the use of the cube factor, the ratio of $\overline{U^3}/\overline{U}^3$, that using an hourly average wind speed to calculate the total kinetic energy available to the turbine would underestimate the actual kinetic energy by up to 14%, at the Grandpa's knob site.

Engineers have often ignored the influence of atmospheric turbulence because of its dual influence on turbine power production. The presence of atmospheric turbulence not only increases the kinetic energy available to the wind turbine; it also tends to decrease the efficiency of the turbine at converting the kinetic energy into mechanical or electrical power. While each of these two characteristic effects of turbulence can be significant, they also have the potential to cancel each other out. This may lead one to inappropriately diminish the importance of turbulence when evaluating turbine performance.

Currently the only discussion of turbulence in the IEC 61400-12 (1998) international standard for wind turbine power performance testing is a requirement that the site characterization documentation should include a scatter plot of the turbulence intensity as a function of wind direction. No guidance or standards are included which either state an acceptable range for the approach turbulence or provide any indication of any corrections that may need to be applied to account for the local turbulence.

This paper will demonstrate that the presence of atmospheric turbulence at the test site is particularly important when evaluating small wind turbines. Unlike utility grade wind turbines, the smaller wind turbines are often placed on shorter towers, in a wide variety of landscapes, and often in less than optimal locations. These factors combine to create a wide range of turbulent environments in which the wind turbines are expected to perform. Therefore, it is important that the power performance testing standard for small wind turbines should adequately address the influence that the atmospheric turbulence has on expected power performance.

2. Turbulence in the Atmospheric Boundary Layer

The atmospheric boundary layer is created by aerodynamic friction resulting from the motion of the air relative to the earth's surface and thermal gradients between the upper atmosphere and the surface. The resultant is a vertical wind shear that varies not only in magnitude but also in structure. The variation in mean wind speeds with height above grade is often defined using a power law relationship where:

$$U_z = U_{ref} \times \left(\frac{z}{z_{ref}} \right)^n$$

where:

n	=	power law coefficient;
U_z	=	longitudinal mean velocity at height, z;
U_{ref}	=	longitudinal mean velocity at a reference height, z_{ref};
z	=	height above local grade; and
z_{ref}	=	reference height above local grade.

The magnitude of the power law coefficient may vary between 0.1 in exceptionally smooth terrain to approximately 0.35 in very rough terrain such as built-up urban areas (Snyder, 1981). An estimate for the value of the power law coefficient can be obtained from the surface roughness length, z_o, using the following relationship from Counihan (1975):

$$n = 0.24 + 0.096\log_{10} z_0 + 0.016(\log_{10} z_0)^2$$

There are several references which site values for the surface roughness length based on descriptive characterizations of the local terrain. Three of the more common references are Davenport (1965), Simiu and Scanlan (1978), and Weiringa (1992). While there is some disagreement about specific values of z_0 for a particular terrain, in general, values range from less than 1 cm for smooth surfaces up to several meters for the middle of urban areas. Figure 1 shows typical values for n and z_0 for various terrains ranging from seas to highly built-up urban areas, along with plots of the associated vertical velocity profiles.

In addition to producing a velocity deficit near the surface, the presence of aerodynamic friction and thermal gradients are also responsible for the creation of atmospheric turbulence. The variation in the longitudinal turbulence intensity, T.I., within the lower portion of the atmospheric boundary layer, from 0 to 100m above grade, can be defined from the following relationship from Snyder (1985):

$$\left(\frac{U_{rms}}{\overline{U}}\right) = T.I. = n\ln\left(\frac{30}{z_0}\right) \div \ln\left(\frac{z}{z_0}\right)$$

where:

U_{rms}	=	root mean squared longitudinal velocity; and
$\overline{U}$	=	mean longitudinal velocity.

At heights above 100m, Snyder (1981) suggests that the turbulence intensity can be estimated by assuming a T.I. value of 0.01 at 600m and assuming a linear relationship between 100m and 600m.

Figure 2 shows the corresponding variation in longitudinal turbulence as a function of height above grade for the same terrain features shown in vertical velocity profiles indicated in Figure 1.

The current site characterization requirements included in the IEC 61400-12 (1998) standard only include limitations on the presence of topographical variations near the site, the presence of nearby operating wind turbines, and the location of significant obstacles in the direct vicinity of the test site. All of these criteria could potentially be met for site descriptions ranging from a sea environment to a suburban environment. Assuming that hub heights may also vary between 10m (the minimum hub height referenced in the proposed small wind turbine annex) to 50m above grade, Figure 2 indicates that the T.I. values may range from less than 10 percent up to values over 30 percent. The influence that this wide range of hub height T.I. values may have on the level of kinetic energy approaching a test unit is discussed in the following section.

3. Increase in Kinetic Energy Associated with Turbulent Flow

The first step in calculating the increase in kinetic energy associated with various levels of turbulent intensity is to define the distribution of wind speeds within the sample period used for evaluating small wind turbine power performance curves.

Three characteristic forces define the airflow within the atmospheric boundary layer: macro, meso, and microscale motions. Macroscale motion features scales in excess of 2000 km created by synoptic troughs, ridges, highs, lows and frontal boundaries. Mesoscale features range from near macroscales down to individual cloud cells with dimensions of 1–20 km. Microscale motions are those that are influenced by smaller obstacles and terrain features and are considered to be the turbulent portion of the approach flow. One defining characteristics of the microscale flow is that the magnitude of the velocity fluctuations within each of the three Cartesian cordinates are of the same magnitude, whereas in both the macro and meso scales the longitudal components of the flow dominate the lateral or vertical fluctuations.

The distribution of mean wind speeds is often assumed to follow a Rayleigh (or Weibull) distribution. Such a distribution is used in the IEC 61400-12 standard for calculating the estimated annual energy production (AEP) for a site based on an annual average wind speed. As such, the Rayleigh distribution includes the influence of macro, meso, and microscale motion, as discussed above. When evaluating the distribution of wind speeds over a shorter averaging time period, such as the 10 minute average identified in the IEC61400-12 standard, or the 1 minute average proposed for the small wind turbine annex to this standard, a different wind speed distribution may be warranted. At the 1 to 10 minute time intervals, the influence of macro and mesoscale motion is limited. Rather, the motion is dominated by the microscale or turbulent motion. Panofsky and Dutton (1984) indicate that the Gaussian distribution can be used to approximate the probability density function for turbulent motion despite the fact that turbulence is not specifically a Gaussian process.

Figure 3 shows the distribution of 1-second wind speeds within various averaging times ranging from 10 seconds to 1 hour. The data was collected at CPP's test site at 10m above grade. The site can be characterized as "open-country" and has the classical $1/7^{th}$ power law velocity profile. The plot clearly indicates that, at least up to the 10 minute averaging time, the distribution of wind speeds is indeed Gaussian in nature. At the 1 hour averaging time the distribution comes less symmetric and begins to approach the Rayleigh distribution. However, even at the 1 hour averaging time period the Gaussian distribution still more closely defines the wind speed distribution.

The fact that a Gaussian distribution can be used to define the wind speed distribution is quite fortuitous since a Gaussian distribution can be fully defined by its mean and rms values. If the measured wind speeds, U, are normalized by its short term average, $\overline{U}$, as shown in Figure 3, the Gaussian distribution can defined by $U_{rms} / \overline{U}$, the definition of the turbulence intensity, and the normalized mean wind speed, which by definition equals unity. Therefore, the relationship between the mean wind speed cubed and the mean cubed wind speed, i.e., the cube factor can be empirically determined by integrating the area under cubed wind speed probability distribution such that:

$$\left(\frac{\overline{U^3}}{\overline{U}^3}\right) = \sum_{(U/\overline{U})}^{\infty} \left(\frac{U}{\overline{U}}\right)^3 \times P\left(\frac{U}{\overline{U}}\right)$$

where:

$P\left(\frac{U}{\overline{U}}\right)$ = probability of the normalized wind speed $U/\overline{U}$, assuming a Gaussian distribution.

The resulting relationship between the cube factor and the local T.I. is shown in Figure 4. As stated in the previous section, the T.I. values that might be present at the hub height for a small wind turbine test unit may vary between 10 and 30 percent. Figure 4 indicates that the cube factor at 10 percent turbulence is only approximately 1.03, however, at 30 percent turbulence the cube factor increases to approximately 1.27. Therefore, with the same mean wind speed the kinetic energy approaching a turbine set at 10m above grade in a suburban environment would be 23% greater than that approaching a turbine set at 50m above grade in a sea environment. Although both of these potential test locations would meet the IEC 61400-12 site characterization standards, it is obvious that significantly different power performance results would be obtained at the two sites.

4. Potential Mitigation

There are various potential methods for mitigating this noted discrepancy in the kinetic energy present at different test sites. The most obvious might be the use of a cubed average wind speed, $\overline{U^3}^{(1/3)}$. Rather than comparing the wind turbine output against the 1-minute or 10-minute mean wind speed, the measured power curve could relate power production as a function of the averaged cubed wind speed. With this method the measured power production would be directly compared to the total kinetic energy approaching the wind turbine. The problem with such a procedure is two fold. First, an averaged cubed wind speed would be meaningless to the consumer. Charts or statistics are not generally available that provide any indication of the averaged cubed wind speed. And, since the presence of turbulence is a local phenomenon, it is unlikely that site-specific values could be obtained without collecting actual hub height wind speed data at each potential site. Second, if the goal of the specification is to provide an accurate and repeatable result, this procedure will fail. Since this procedure would not address the potential reduction in efficiency associated with increased atmospheric turbulence, different test locations could still result in different measured power curves.

A second means for mitigating the potential discrepancy in kinetic energy at various test sites involves evaluating the averaging times used to produce the power curves. Referring back to Figure 3, one will note that the deviation in wind speed decreases with decreased averaging time. At the CPP test site the measured T.I. at 10m for a 30-minute averaging time is approximately 22%. The cube factor for a T.I. value of 22% is approximately 1.14. If the averaging time is shortened to 10 minutes the T.I. value decreases slightly to approximately 18%, where the cube factor is approximately 1.10. If the averaging time is further shorted to 1 minute the T.I. value decreases to approximately 12% and the corresponding cube factor is reduced to 1.04. Thus, at least at the CPP test site, using a one-minute average would reduce the discrepancy between the recorded kinetic energy and the actual kinetic energy from 10 percent down to approximately 4 percent. Similar reductions would be expected for other test bed locations; however, the reductions may be very site specific.

A third method for minimizing the variation in kinetic energy from site to site would be to include a specific requirement for the hub height T.I. value within the site characterization standard. For example, the variation in kinetic energy could be maintained within +/-3 percent by limiting the hub height T.I. values between 13 and 18 percent. For an open country environment this would mean that the hub heights should be between approximately 10m and 50m. In a suburban environment the hub heights would need to be raised to a minimum height of approximately 50m. Note: this standard would likely restrict testing at extremely smooth sites.

These results suggest that the repeatability of the power performance measurements may be greatly enhanced, strengthening the integrity of the power performance standard, by combining the 1-minute averaging time and specific hub height T.I. requirement. However, this still will not provide any specific information to the consumer related to how a particular turbine will behave at various levels of T.I. Ultimately the consumer needs this information to assess the which turbine will provide the best return on investment at their specific local. Therefore, it may be advantageous to eventually expand the testing procedures to include power performance curves at multiple levels of T.I.

5. Conclusions/Recommendations

The results presented in this paper indicate that the current site specification standards are not sufficient to ensure that accurate and repeatable power performance curves for small wind turbines. The results indicate that the kinetic energy present at the hub height can vary by as much as 20 percent depending upon the level of turbulence present at the test site.

The variation in kinetic energy can be somewhat mitigated by reducing the averaging time from 10 minutes to 1 minute and by setting specific standards for allowable hub height turbulence intensity levels. It is suggested by the author that the hub height turbulence intensity values should be required to be within the range of 13 to 18 percent. An empirical formula, which relates turbulence intensity to height above grade for various types of local terrain, indicates that this standard could be achieved for most potential test sites with hub heights between 10m and 50m above grade.

6. References

Counihan, J., "Adiabatic Atmospheric Boundary Layer: A Review and Analysis of Data from the Period 1880-1972," Atmos. Envir., v.9, no. 10, p. 871-905, 1975

Davenport, A.G., "The Relationship of Wind Structure to Wind Loading," Proc. Conf. On Wind Efffects on Buildings and Structures, Nat. Phys. Lab, London, 1965.

IEC 61400-12, "Wind turbine generator systems – Part 12: Wind turbine power performance testing," First edition 1998-02, International Electrotechnical Commission, Geneva, Switzerland, 1998.

Panofsky, H.A. and J.A. Dutton, "Atmospheric Turbulence, Models and Methods for Engineering Applications," John Wiley & Sons, Inc., NY, NY, 1984.

Putnam, P.C., "Power from the wind," Van Nostrand Reinhold Company, NY,NY, 1948

Simiu, E., and R.H. Scanlan, "Wind Effects on Structures," John Wiuley & Sons, Inc., NY, NY, 1978.

Snyder, W.H., "Guidelines for Fluid Modeling of Atmospheric Diffusion," US Environmental Protection Agency, Office of Air Quality, Planning and Standards, Research Triangle Park, NC, EPA 600/8-81-009,April 1981.

Weiringa, J., "Updating the Davenport Terrain Roughness Classification," Journal of Wind Engineering and Industrial Aerodynamics, V. 41, pp 357-368, 1992.

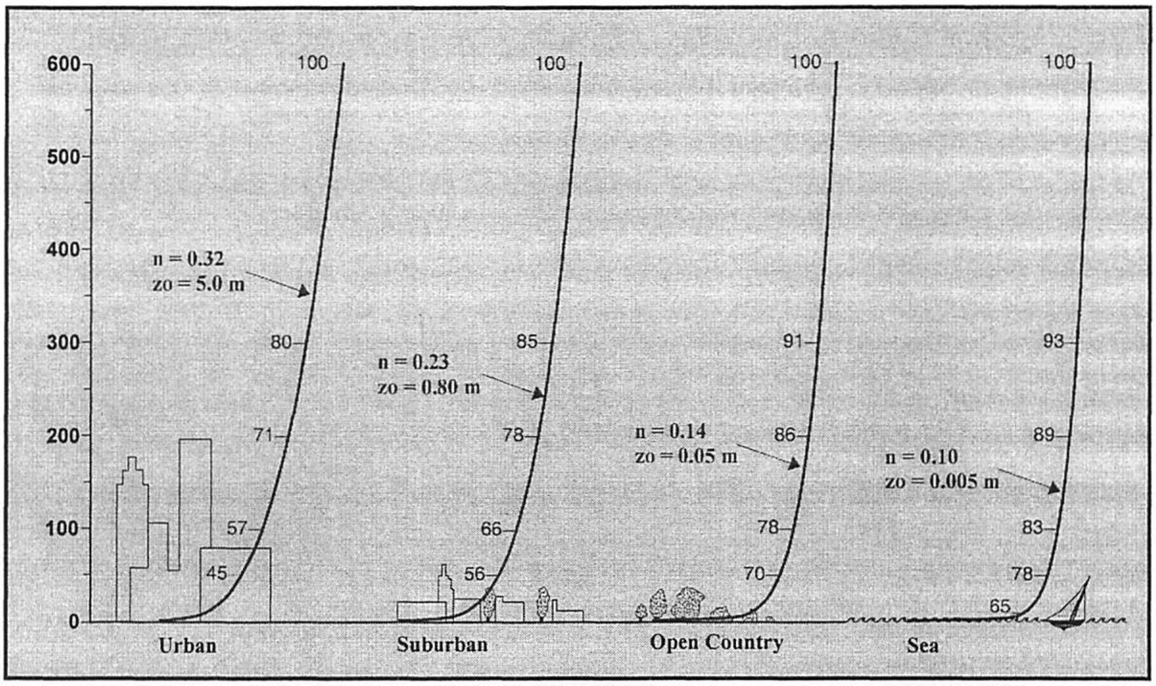


Figure 1. Longitudinal Velocity Profiles Over Uniform Terrain in Neutral Flow

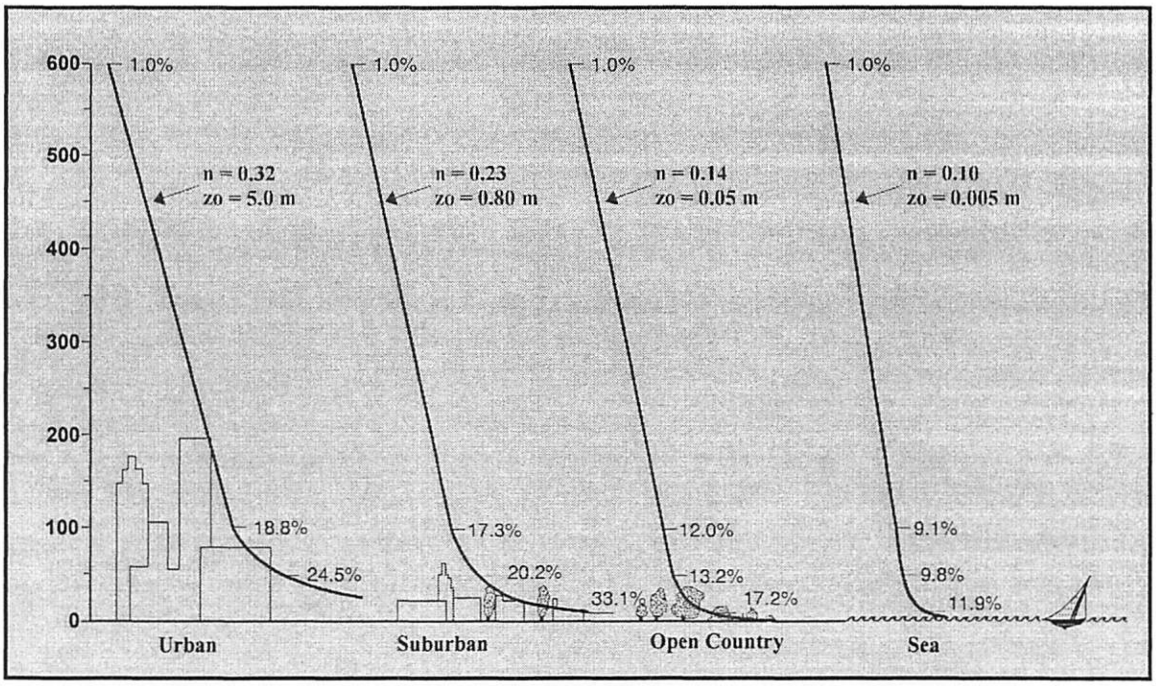


Figure 2. Turbulent Intensity Profiles Over Uniform Terrain in Neutral Flow

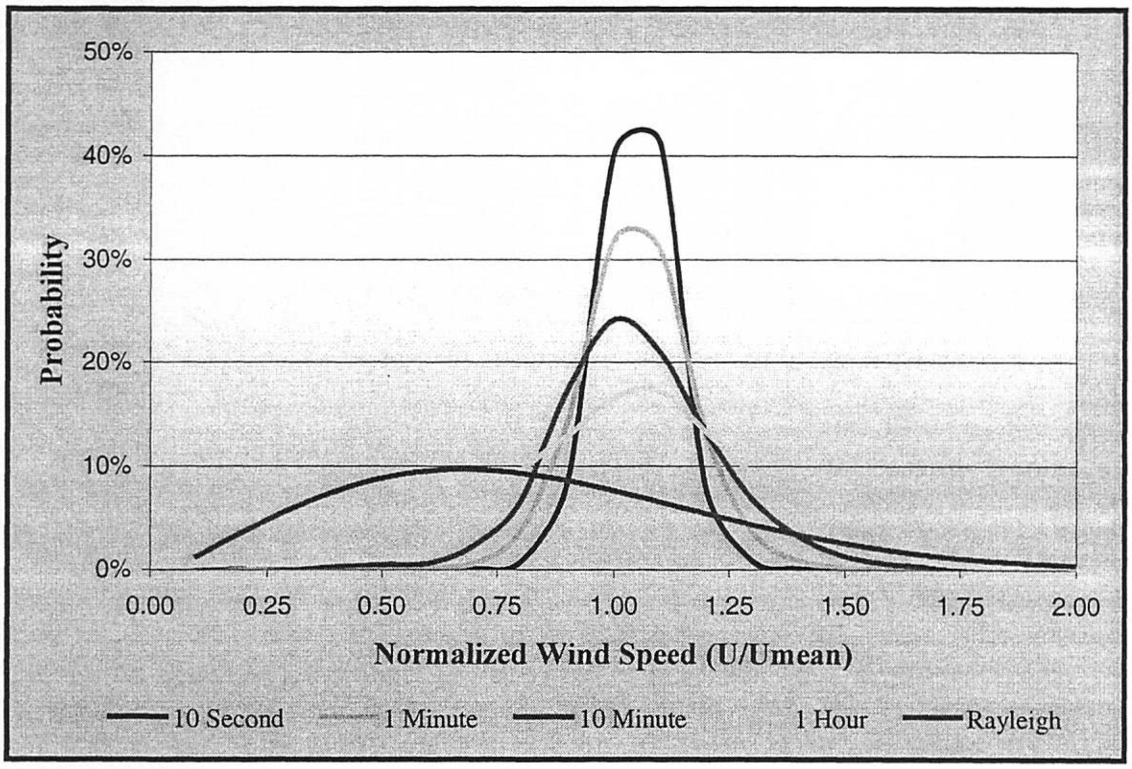


Figure 3. Distribution of 1 Second Wind Speeds Within Various Averaging Times

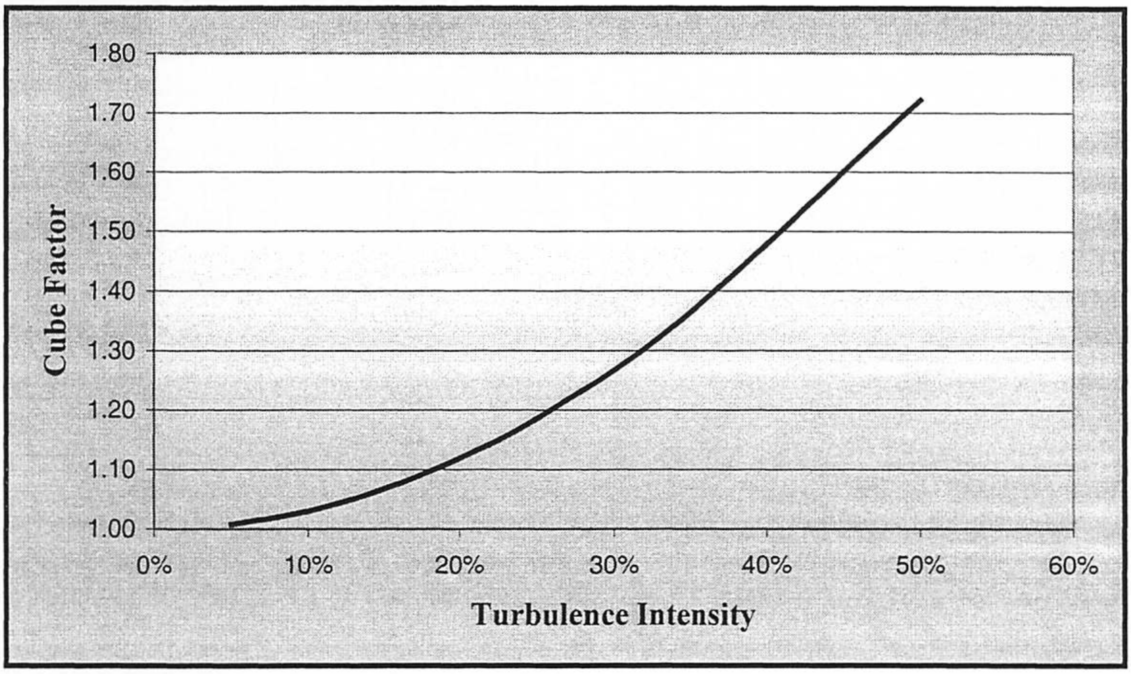


Figure 4. The Cube Factor as a Function of the Local Turbulence Intensity Assuming a Gaussian Distribution of Wind Speeds

NREL

Quantification of Preaveraging Interval on Three Small Wind Turbines

By
Hal Link
Charles Newcomb
Mark Meadors
Jeroen van Dam

for

IEA Experts Meeting
Soria, Spain
April 25 & 26, 2002

NREL

Objective

- Determine the effects of preaveraging interval on power curves and estimates of annual energy production

4/22/02
National Wind Technology Center

NREL

Method

- Obtain power performance data on three small wind turbines:
  - AIR 403, 1m rotor diameter, 400 W rated
  - Bergey XL.10, 7m rotor diameter, 10 kW rated
  - AOC 15/50, 15m rotor diameter, 65 kW rated
- Tests in accordance with IEC Power Performance Testing Standard (IEC 61400-12) except for preaveraging interval

NREL

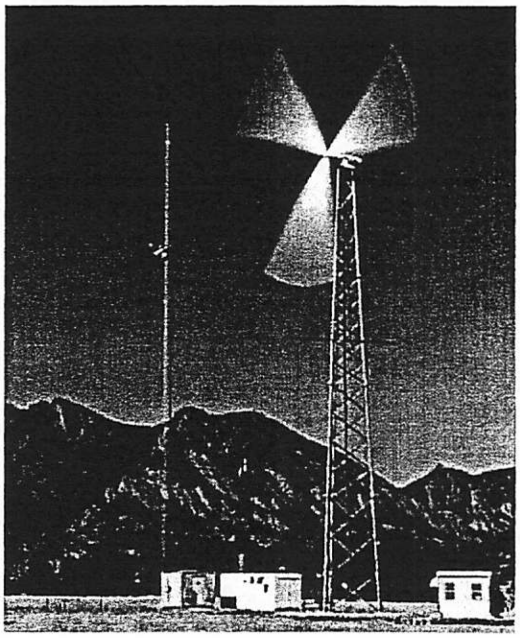
Method (continued)

- Obtain data using low preaveraging interval
  - AIR 403: 1-second
  - Bergey XL.10: 10-second
  - AOC: 1-minute
- Combine data to obtain 1-min and 10-minute data sets
- Determine power curves and AEP per standard methods

NREL

AOC 15/50 Wind Turbine

Configuration:	
Rotation Axis (H / V)	H
Orientation	Downwind
Number of Blades	3
Rotor Hub Type	Non-Teetered
Rotor Diameter (m)	15.0
Hub Height (m)	24.4
Performance:	
Rated Electrical Power (kW)	50
Rated Wind Speed (m/s)	12
Cut-in Wind Speed (m/s)	3.8
Cut-out Wind Speed (m/s)	25
Extreme Wind Speed (m/s)	59.5
Rotor:	
Swept Area (m^2)	17
Coning Angle (deg)	6
Tilt Angle (deg)	0
Rotor Speed (rpm)	65 NREL 62.5 RISO
Pitch Angle (deg)	0.9 NREL 0.45 RISO



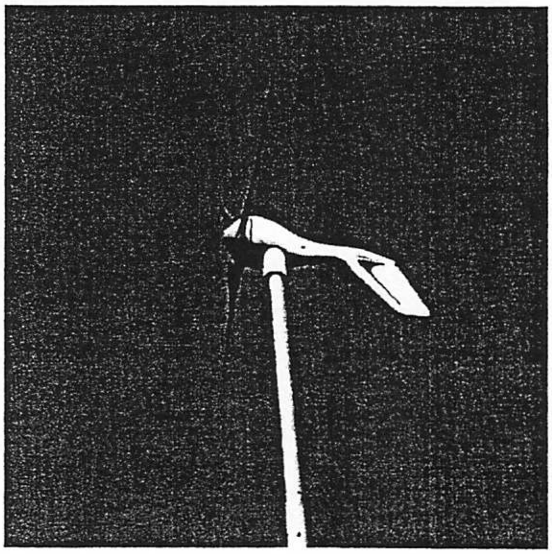
4/22/02

National Wind Technology Center

NREL

AIR 403 Wind Turbine

Make, Model	SouthWest WindPower, AIR 403
Rotation Axis	Horizontal
Orientation	Upwind
Number of Blades	3
Rotor Diameter (m)	1.17 meters (46")
Hub Height (m)	13.7 m (45 feet)
Rated Electrical Power (W)	400
Rated Wind Speed (m/s)	12.5
Cut-in Wind Speed (m/s)	3.6
Cut-out Wind Speed (m/s)	None
Extreme Wind Speed (m/s)	44.7
Swept Area (m^2)	1.8
Min On-line Rotor Speed	840 rpm
Max On-line Rotor Speed	2,800 rpm
Coning Angle (deg)	2.5 (forward)
Tilt Angle (deg)	4
Blade Pitch Angle (deg)	2.5
Direction of Rotation	Clockwise



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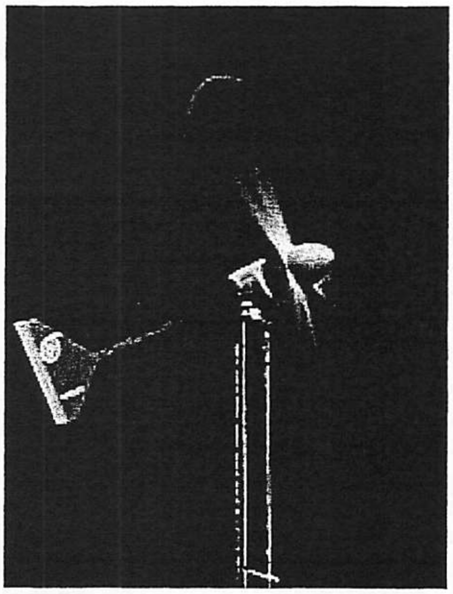
Bergey XL.10 Wind Turbine

Make, Model	Bergey, EX.10
Rotation Axis (H / V)	Horizontal
Orientation	Upwind
Number of Blades	3
Rotor Hub Type	Rigid
Rotor Diameter (m)	7.0
Hub Height (m)	37
Rated Electrical Power, kW	10
Rated Wind Speed (m/s)	13.0
Cut-in Wind Speed (m/s)	3.1
Cut-out Wind speed (m/s)	none
Swept Area (m^2)	38.4
Blade Pitch Control	Powerflex
Direction of Rotation	Clockwise
Rotor speed (rpm)	0-350
Power Regulation	Passive
Tower Type	Bergey guyed lattice
Height (m)	36.6
Controller: Make, Type	Bergey Gridtek inverter
Electrical Output Voltage	240-volt single phase
Yaw System	Tail vane



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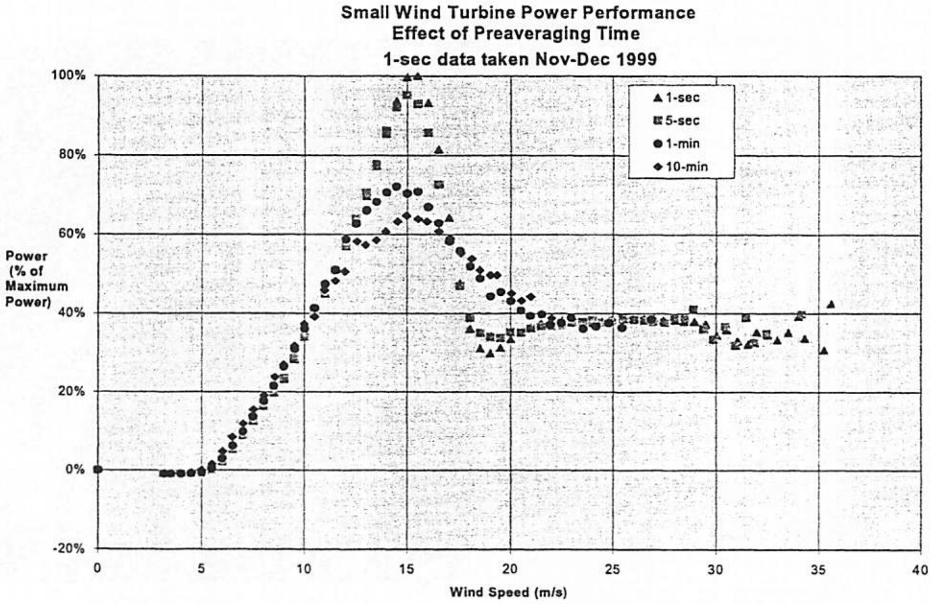
AIR 403, 1 m Rotor



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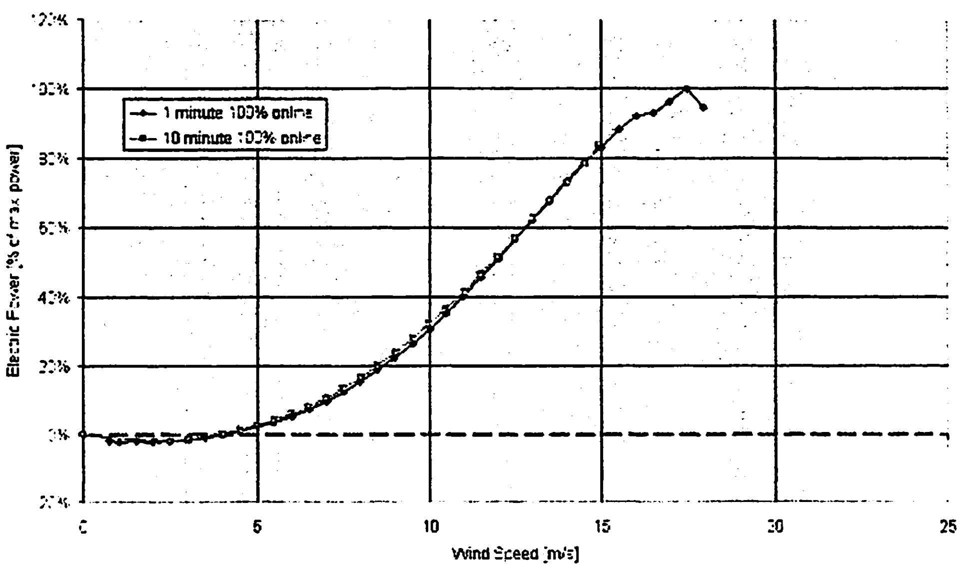
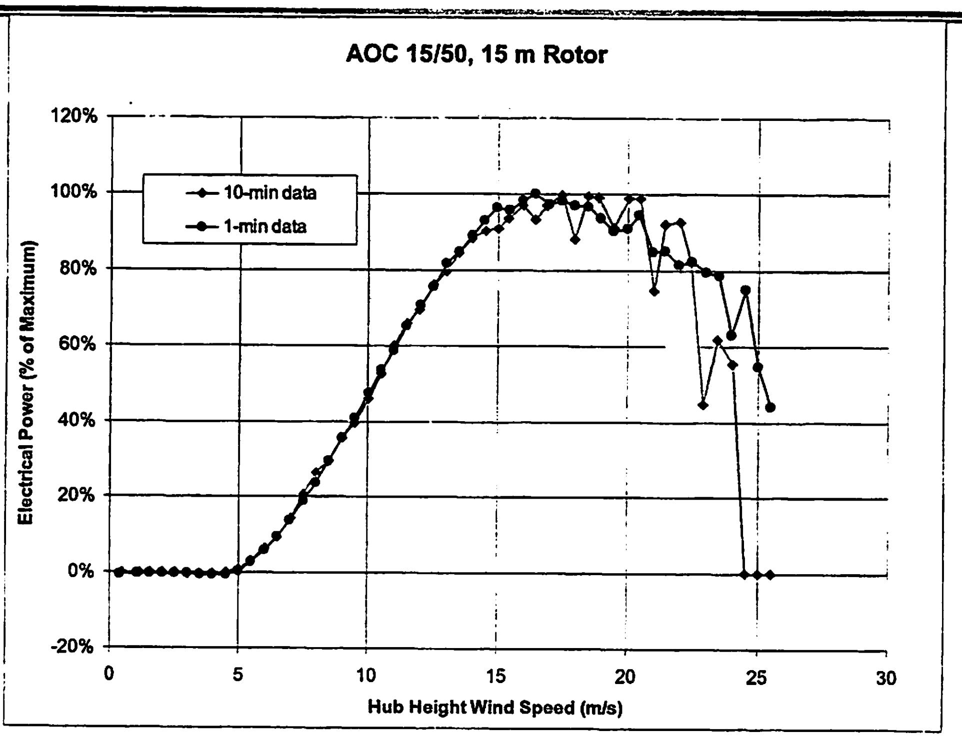
Annual Energy Production AIR 403, 1 m Rotor			
Average Wind Speed (m/s)	AEP(1-min)/ AEP(10-min)	AEP(1-sec)/ AEP(10-min)	Uncertainty in AEP (10-min)
4	-15%	-26%	149%
5	-6%	-12%	66%
6	-1%	-3%	40%
7	2%	3%	29%
8	3%	6%	23%
9	3%	9%	20%
10	4%	10%	19%
11	4%	10%	18%

Bergey Excel 10-kW, 7 m Rotor



Annual Energy Production Bergey XL10, 7 m Rotor		
Average Wind Speed (m/s)	AEP(x)/ AEP(10-min)	Uncertainty in AEP (10-min)
4	-23%	120%
5	-9%	53%
6	-1%	35%
7	9%	26%
8	19%	22%
9	29%	19%
10	39%	18%
11	47%	17%



Annual Energy Production, AOC 15/50, 15 m Rotor		
Average Wind Speed (m/s)	AEP(x)/ AEP(10-min)	Uncertainty in AEP (10-min)
4	-8%	56%
5	-1%	26%
6	1%	16%
7	2%	12%
8	3%	11%
9	3%	11%
10	3%	12%
11	2%	13%

Conclusions

1. Longer preaveraging interval "flattens" curvature in power curve
   - Tends to increase indicated power at low wind speeds
   - Tends to decrease indicated power at high wind speeds

Conclusions (continued)

2. 1-minute power curves tend to be smoother and include more high wind speed bins
3. 1-minute AEPs indicate lower performance in low wind regimes than 10-minute AEPs
4. 1-minute AEPs indicate higher performance in high wind sites than 10-minute AEPS
5. Differences in AEP are less than standard uncertainty levels

Small Wind Turbine Preaveraging Study

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16 May, 2000
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Introduction

The National Renewable Energy Laboratory is participating in an international effort to develop measurement and analysis techniques appropriate for the definition of the power performance characteristics of small wind turbines. As part of this effort, NREL conducted a special test of a small turbine in which several weeks of data were recorded at a once per second sample and record frequency. NREL staff analyzed these data in a variety of ways to evaluate the effects of "preaveraging." Preaveraging is the process by which power and wind speed samples are time-averaged during data acquisition. Preaveraging is advantageous because it improves the correlation between wind speed measured at a meteorological tower located some distance from the wind turbine. It also reduces the size of the data sets that must be stored and analyzed.

A difficulty with preaveraging is that it tends to distort the resulting power curve. This distortion has been described as "tilting" because it tends to push the power curve upwards at low wind speeds and pull it downwards at moderate to high wind speeds. A more appropriate description is that it "smoothes" the power curve. Any curvature tends to be flattened by preaveraging. In low wind speeds, where the power increases roughly as a function of wind speed cubed, the power curve is concave upward. Preaveraging flattens the curve by pulling the belly of the curve up. In moderate wind speeds, where the turbine transitions to regulated power output through blade pitch, stall, furling, or flutter, the curve is concave downward. Preaveraging smoothes and flattens the curve by pulling the curve downward.

This distortion can be quite large for small turbines that exhibit radical changes in power output due to furling or blade fluttering. The turbine tested at NREL uses blade flutter to control power. We found dramatic differences in the maximum power level when solely due to preaveraging effects.

Approach

NREL installed a small turbine at our National Wind Technology Center outside of Boulder, Colorado in the autumn of 1999. The turbine was instrumented for power performance testing as part of a project to certify the wind turbine in accordance with IEC 61400-22, Certification of Wind Turbines. NREL modified the data acquisition system slightly during November and December, 1999 in order to record one-second samples of wind speed and power.

Wind speed was measured using a Met One Instruments, Model 010 cup anemometer with aluminum cups. This anemometer has a distance constant of approximately 4.6 meters. It was mounted 3.1 meters toward the prevailing wind direction (305° true) at this site in accordance with the standard, IEC 61400-12, Power Performance Measurements of Wind Turbines.

Power was measured with an Ohio Semitronics Incorporated, Model PC8-002-01EY44 power transducer that sensed voltage at the turbine's yaw-axis slip rings in such that voltage drop through the wiring between turbine and battery bank was not included in the measurements. The turbine was connected to a constant-voltage load consisting of a capacitor and an Enermaxer load controller. For this study, load voltage was set at 28.2 volts and was maintained with about 0.2 volts.

The test site is relatively flat close to the turbine but has some hillocks and drainages within 100 meters of the turbine. The terrain gradually increases in complexity to the west with 3000 meter mountains several kilometers upwind of the test site. Winds are quite turbulent at the site with an average turbulence intensity of 15% at average wind speeds of 15 m/s.

Data were taken over a period of 3 weeks from 25 Nov 99 through 16 Dec 99. Over 125 hours of data were taken during this period.

The data were analyzed using a combination of Excel™ and Qbasic™ programs. The Excel program was used to plot results but was not able to handle the large quantity of data obtained during the test. For that purpose we used Qbasic programs to bin data by wind speed and to preaverage the 1-sec data into 5-sec, 1-minute, and 10-minute data sets. The preaveraging method was identical to that used in the Campbell Scientific dataloggers that we normally uses for power performance tests.

The Qbasic programs were also used to calculate expected energy. Expected energy is the energy that the turbine would have produced during each data set if it had operated exactly on its power curve. Since, as will be shown, the turbine has a different power curve for each preaveraging interval, different quantities of expected energy were calculated for each data set.

Results

Figure 1 shows the dramatic difference in power curves obtained using different preaveraging periods. Note that the 1-sec power curve shows the most detail. It also indicates performance at wind speeds up to 35 m/s whereas the 10-min power curve ends at 21 m/s. Although the differences between the curves appears largest in winds around 15 m/s, differences at 6 m/s are even larger when expressed in terms of the ratio of 10-min power to 1-sec power.

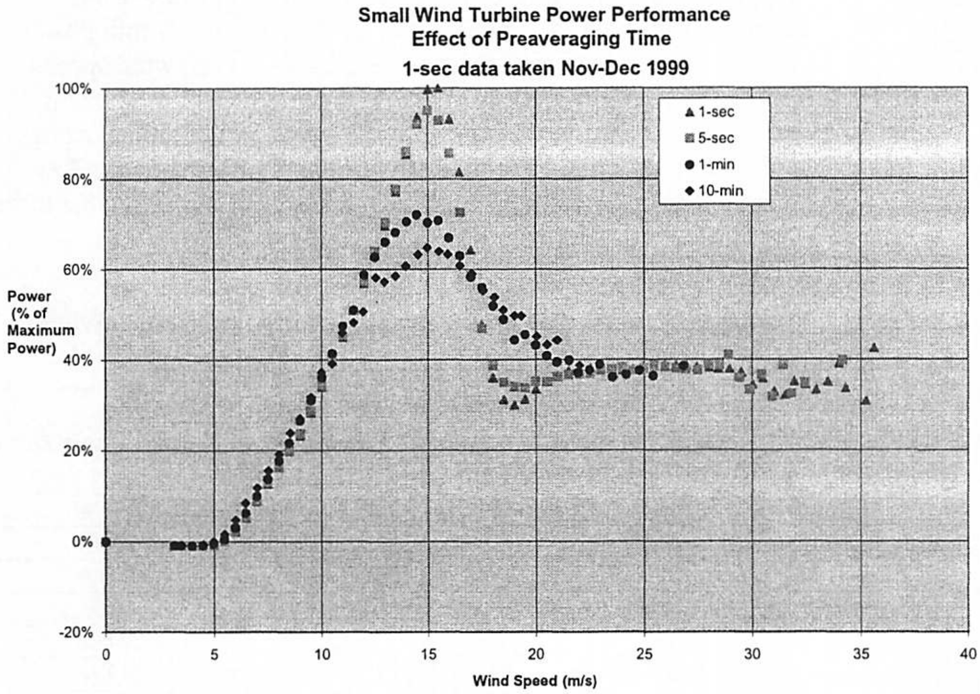


Figure 1. Effect of Preaveraging Time on Power Curves

To evaluate the effect of these power curve differences on energy production, we used the 1-sec, 1-min, and 10-min power curves and wind speeds of 21 m/s and lower to calculate expected energy for all of the data sets. The expected energy values for the 1-sec data sets were summed to yield a total expected energy for the test. Then the total expected energy was divided by the total measured energy for the test. As anticipated for the 1-sec data set, total expected energy using the 1-sec power curve was 100% of measured energy. However, when the 1-min and 10-min power curves were used, the expected energy was only 95% and 90% of measured energy, respectively. (See Table 1.) Conversely, when 10-min data sets were combined with 1-sec and 1-min power curves, expected energy was 111% and 103%.

This relationship indicates that combining a power curve with wind resource data taken with a different preaveraging time can lead to substantial errors in predicting energy production.

Table 1. Effect of Preaveraging on the Ratio of Expected Energy to Measured Energy

	1-sec power curve	1-min power curve	10-min power curve
1-sec data set	**100%**	95%	90%
1-min data set	106%	**100%**	96%
10-min data set	111%	103%	**100%**

To evaluate the effect of the preaveraging time on annual energy production using theoretical wind speed distributions, we combined the 1-sec, 1-min, and 10-min power curves with several Rayleigh wind speed distributions. We used average wind speeds from 4 m/s through 11 m/s, as specified in the IEC power performance measurement standard. As shown in Table 2, longer preaveraging times overestimates annual energy production in high wind regimes and underestimates annual energy production in low wind regimes. The differences of +35% and –9% seem quite large considering that there is no measurement error in these calculations.

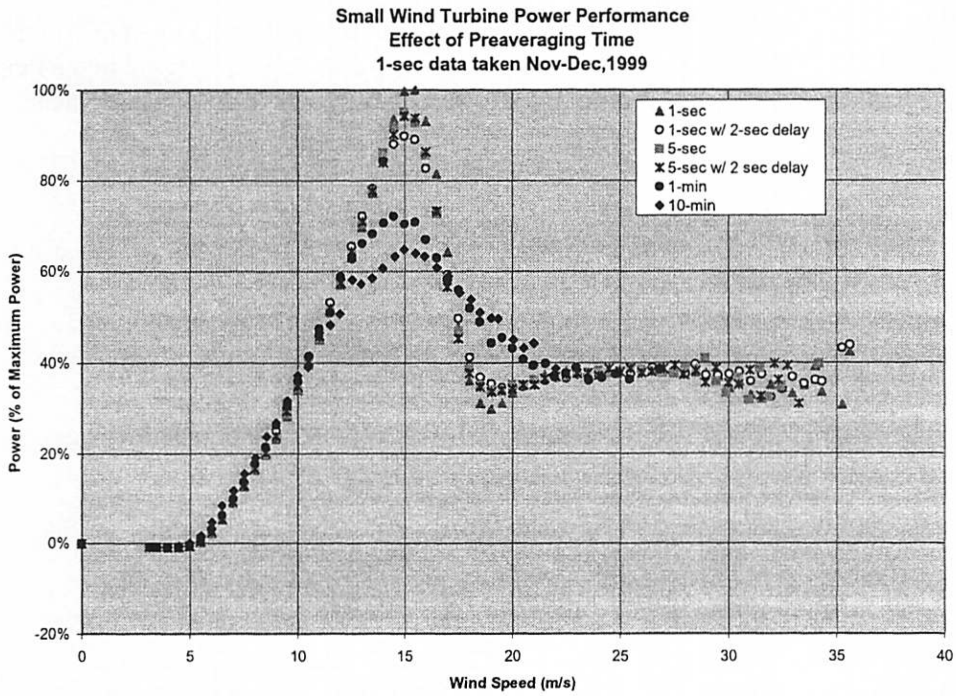
Table 2. Effect of Preaveraging on the Annual Energy Production using Rayleigh Wind Speed Distributions

	AEP(x) / AEP(1-sec)		
Average wind speed (m/s)	1-sec power curve	1-min power curve	10-min power curve
4	100%	115%	135%
5	100%	107%	114%
6	100%	102%	103%
7	100%	99%	97%
8	100%	97%	94%
9	100%	95%	92%
10	100%	95%	91%
11	100%	95%	91%

Finally we attempted to quantify how some of these results may have been different had the anemometer been located farther away from the turbine. For the largest small turbine permitted by the IEC standard 61400-2, Safety of Small Wind Turbines, a typical anemometer placement would be 18 meters from the turbine. At a wind speeds of 8-10 m/s, there would be an average time difference of about 2 seconds from the time that a change in wind speed would be measured by the anemometer until it affected the turbine. This would be much different for the test conditions we have been considering where there is probably less than a 1-sec delay between anemometer measurements and turbine responses. We anticipated that a larger distance between the anemometer and the turbine would degrade the correlation between wind speed and power shown in the 1-sec power curve.

To evaluate this effect, we offset the wind speed measurements relative to the power measurements by two seconds. Figure 2 shows that the 2-sec delay has an effect similar to use of a 5-sec preaveraging time. Also of interest is that this figure shows that better detail is obtained when with a 5-sec preaveraging time when the 2-sec delay is present than using 1-sec preaveraging.

Table 2. Estimated Interaction of Anemometer Placement and Preaveraging Times on Power Curves



Discussion

This section seemingly should list the conclusions we have drawn from these results. Other than to conclude that preaveraging has a significant effect on power curves and energy production calculations, it is not clear how to act upon these findings. At first, it would seem appropriate to conclude that preaveraging degrades and distorts the results of power performance testing.

However, there are serious practical difficulties with obtaining, storing, and processing 1-sec data sets. The robust dataloggers that NREL and others use for power performance measurements do not have the onboard processing and memory capability required. For this test we did not record wind direction, air temperature, air pressure, or statistical information. Even so we had to download the data files almost daily. There is also the consideration that there are errors associated with using 1-sec wind speed measurements using an anemometer with a 4.6-meter distance constant. Finally, there is the effect associated with larger anemometer spacing than was used in this test.

However, the reasons to use the 10-min preaveraging specified in the IEC standard for power performance measurements of large turbines (IEC 61400-12) seem to be limited to: a) maintain consistency with methods used for large wind turbines and b) maintain consistency with wind resource measurements obtained using 10-min preaveraging. It is not clear that either reason would be sufficient to justify the distortion that results from such a long preaveraging period.

In between these two extremes probably lies the appropriate preaveraging period to use. The authors intend to investigate the practicality and effects of preaveraging in the range from 5 seconds to 1 minute. We welcome the observations and experience of others.

Small Wind Turbines On Flat Roofs

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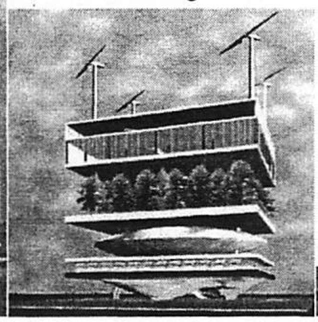
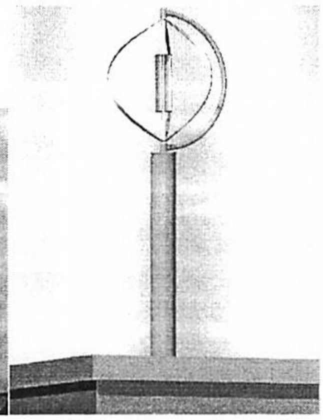




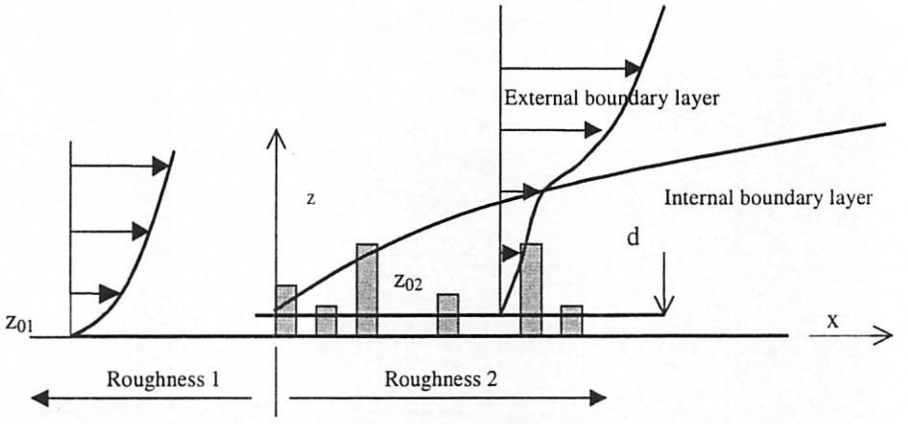
Topics

- Wind in the built environment
- Wind on a flat roof
- Power production of small wind turbines in skewed flow
- Conclusions
  - Overall
  - Example

Small Wind Turbines On Flat Roofs

DUWIND TU Delft

Wind in the built environment



Topical Expert Meeting no. 39, 25 - 26 April 2002 slide no. 3

Small Wind Turbines On Flat Roofs

DUWIND TU Delft

Wind in the built environment

Displacement length: $d=0.75h_{gem}$

$z < d=0.75h_{gem}$ $V \sim 0$

- $d < z < 20z_0+d$ no log law
- $z > 20z_0+d$ log law

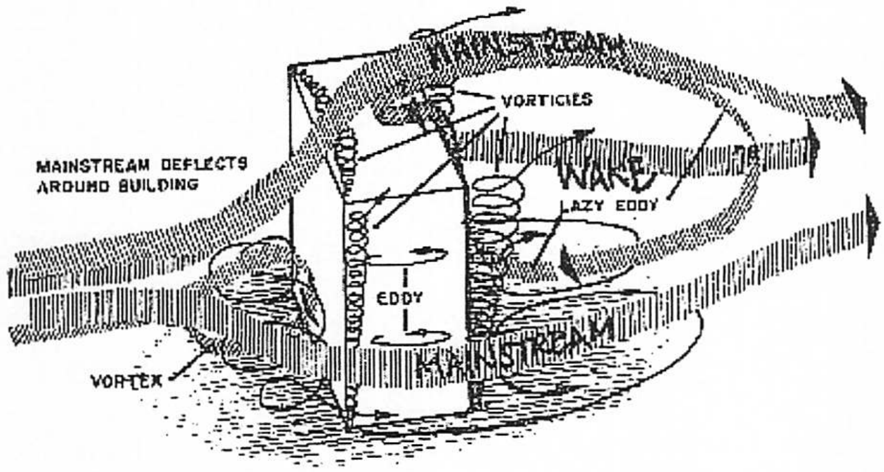
Conclusion: **wind is very location dependent in the built environment!**

Topical Expert Meeting no. 39, 25 - 26 April 2002 slide no. 4

Small Wind Turbines On Flat Roofs

DUWIND TU Delft

Wind on a flat roof

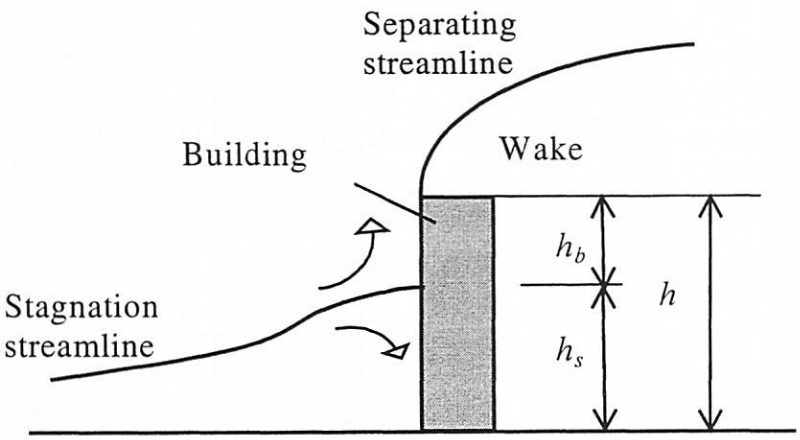


Topical Expert Meeting no. 39, 25 - 26 April 2002 slide no. 5

Small Wind Turbines On Flat Roofs

DUWIND TU Delft

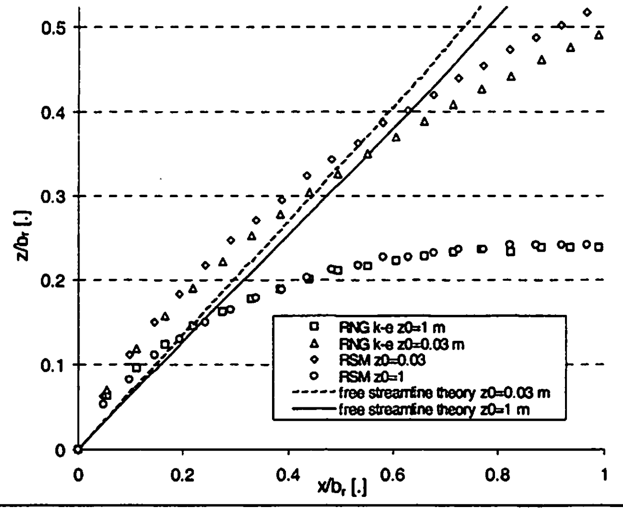
Wind on a flat roof



Topical Expert Meeting no. 39, 25 - 26 April 2002 slide no. 6

Small Wind Turbines On Flat Roofs — DUWIND TU Delft

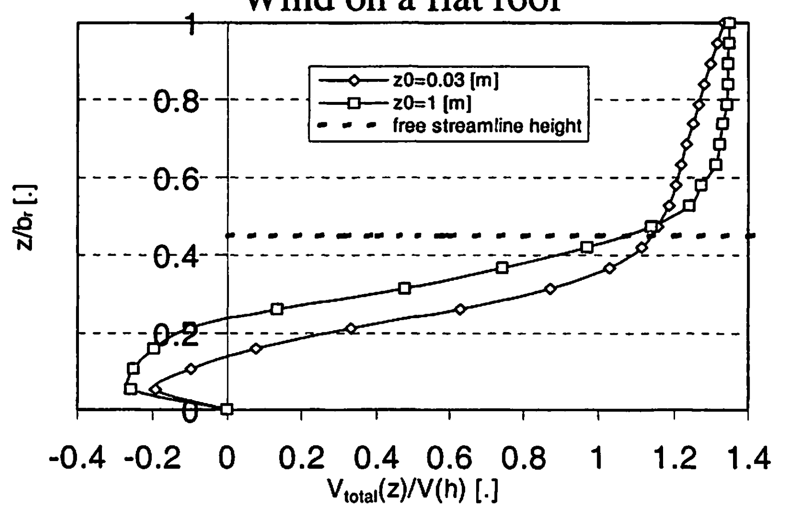
Wind on a flat roof



Topical Expert Meeting no. 39, 25 - 26 April 2002 — slide no. 7

Small Wind Turbines On Flat Roofs — DUWIND TU Delft

Wind on a flat roof



Topical Expert Meeting no. 39, 25 - 26 April 2002 — slide no. 8

Wind on a flat roof

Building in urban area (z_0=1 [m]) of 20 [m] height. Wind Turbine in the middle of the roof. Than:

•lowest rotor tip above 4 [m] from the roof,

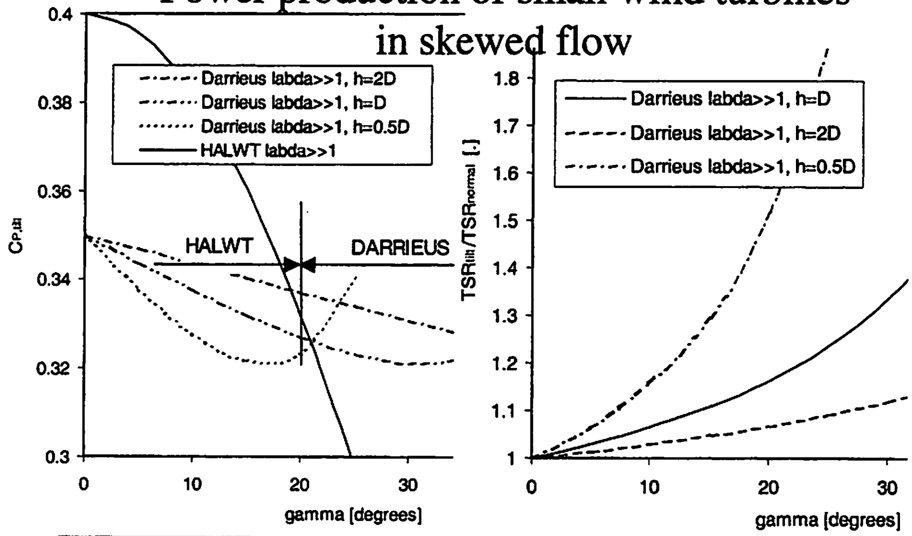
•flow makes an angle of about 20 degrees with the horizontal roof.

Power production of small wind turbines in skewed flow

- HALWT: Momentum theory
- Darrieus: Momentum and blade element theory under assumption of high TSR

Small Wind Turbines On Flat Roofs — DUWIND TU Delft

Power production of small wind turbines in skewed flow



Topical Expert Meeting no. 39, 25 - 26 April 2002 — slide no. 11

Small Wind Turbines On Flat Roofs — DUWIND TU Delft

Conclusions; overall

Wind turbines on the middle of flat roofs:

- Shall be positioned with the lowest rotor tip above the separation bubble,
- Shall be a HALWT for skew angles below 20 degrees and a Darrieus for skew angles above 20 degrees.

Topical Expert Meeting no. 39, 25 - 26 April 2002 — slide no. 12

Conclusions; example

Building in urban environment z_0=1 [m]

•For building height 20 [m], lowest rotor tip more than 4 [m] above the flat roof,

•30% higher wind velocities,

•Darrieus for building height above 20 [m],

•HALWT for building height below 20 [m]

Influence of skewed flow on the aerodynamic efficiency of roof wind turbines

A comparison with of the aerodynamic efficiency of lift wind turbines under skewed flow.

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ABSTRACT

The flow over a flat roof of a building makes an angle with the roof. Wind turbines sited on the roof thus operate in a skewed flow. Most wind turbines produce less power if the flow makes an angle with the normal vector at the actuator disk. However, the aerodynamic efficiency of a Darrieus suffers less from skewed flow than a Horizontal Axes Lift Wind Turbine. This is partly due to an increased projected area of the Darrieus and partly by the different behavior of a Darrieus under skewed flow. This result is used to point out the optimal working area in skewed flow of a Darrieus and a Horizontal Axes Lift Wind Turbine. It is showed that a HALWT can be best used to operate in small skew angles (up to about 20 degrees) and a Darrieus can be used for the higher angles (above 20 degrees). Furthermore it is showed that the Darrieus undergoes a growth of the TSR for a 20 degrees skewed flow of about 55% for a Darrieus with $h = 0.5D$ and about 8% for a Darrieus with $h = 2D$.

1 INTRODUCTION

Wind Turbines on flat roofs of mid to high-rise buildings are sited in the skewed flow above the roof [2]. The skew angles of the flow can vary from 0 to 90 degrees depending on the roughness, height of the building and position on the roof of the building. A high rise building in a low roughness area gives a high skew angle of the flow to the horizontal roof [2].

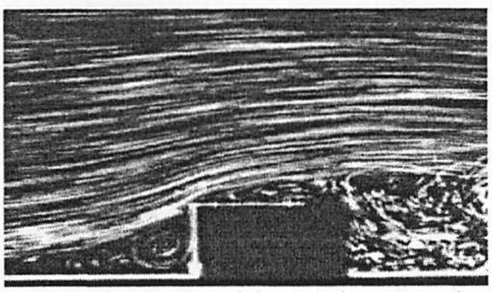


Fig. 1. Visualization of the turbulent separation on a wind tunnel model of a low-rise building.

It is interesting to calculate the influence of the skewed flow on the performance of potential roof wind turbines. Which wind turbine for instance gives the highest power output in the skewed flow on the flat roof?

2 THE HORIZONTAL AXES LIFT WIND TURBINE IN SKEWED FLOW

Depending on the position at the roof there is a skewed flow. In the middle of the roof of a mid-rise building (about 20 m height) the skew angle of the flow to the horizontal roof varies from 20 to 45 degrees depending on the roughness of the area around the building. A high roughness gives a small skew angle and vise versa.

The aerodynamic efficiency of a horizontal axes wind turbine in skewed flow $C_{P,HAWT,tilt}$ will decrease according to [1]

$$C_{P,HAWT,tilt} = C_{P,perp} \cos^3 \gamma , \qquad (1)$$

where $C_{P,perp}$ is the aerodynamic efficiency under normal -parallel to the axes- flow conditions.

2 THE DARRIEUS WITH HIGH TIP SPEED RATIO IN SKEWED FLOW

For a Darrieus with high Tip Speed Ratio in skewed flow it shall be assumed that according to the model of Strickland [3]:

- The flow is attached to the blades during the revolution,

- the skew angle of the resulting velocity vector on the blades does not influence the lift coefficient.

Schematically a Darrieus consists of two actuator disks. One at the windward (a and c) and one at the leeward side (d and b) of the Darrieus (see figure 2, next page). For skewed flow the edges of the Darrieus consist of just one, the windward (a) and the leeward (b), actuator disk. The middle consists of two actuator disks (c and d) behind each other.

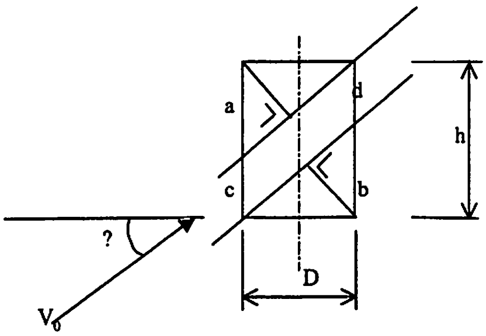


Fig 2. Schematical division of flow regions on a H-Darrieus in skewed flow.

Then the blade force in the direction of the stream tube can be found from blade element and momentum theory resulting in an induction factor for the double actuator disk a_d of [3]

$$a_d = \frac{Bc}{2R}\frac{R\Omega}{V_\infty}\left|\sin\theta\right| \qquad (2)$$

with number of blades B, cord length of the blades c, diameter of the Darrieus $2R$, rotational frequency *O*, undisturbed wind velocity V_8, and rotational angle *?* (*? =0* corresponds to a blade moving parallel to the wind direction)

and for the single actuator disk a_s of

$$a_s = \tfrac{1}{2} a_d . \qquad (3)$$

In these relations the induction factor a_i with $i=d$ or $i=s$ is defined by

$$V_t = V_\infty (1 - a_i) \qquad (4)$$

where V_t is the velocity at the actuator disk and V_∞ is the undisturbed velocity at the leeward side of the actuator disk. The aerodynamic efficiency for a double actuator disk can be found from [3]

$$C_P = 2\pi\zeta\left[\tfrac{1}{2} - \frac{8}{3\pi}\zeta + \frac{12}{32}\zeta^2\right] \qquad (5)$$

with

$$\zeta = \zeta_d = \frac{BC\lambda}{2R} \qquad (6)$$

for the double actuator disk in the middle of the Darrieus. The maximum aerodynamic efficiency of 0.554 can be found by differentiating equation (5) with respect to *?* resulting in

$$\zeta_d = 0.401 . \qquad (7)$$

The single actuator disks at the upper (a) and lower position (b) of the Darrieus can be taken together which gives an aerodynamic efficiency of

$$C_{P,s} = C_{P,d}(\zeta = \zeta_s) \qquad (8)$$

with, because of the halve blade force,

$$\zeta = \zeta_s = \tfrac{1}{2}\zeta_d . \qquad (9)$$

The upper (a) and lower part (b) of the actuator disk can be combined for a calculation of the aerodynamic efficiency with equation (9) as the input. The total aerodynamic efficiency for a Darrieus in skewed flow can now be found from

$$C_{P,tilt} = \frac{A_d}{A_t} 2\pi\zeta\left[\tfrac{1}{2} - \frac{8}{3\pi}\zeta + \frac{12}{32}\zeta^2\right] + \frac{A_s}{A_t}\pi\zeta\left[\tfrac{1}{2} - \frac{4}{3\pi}\zeta + \frac{3}{32}\zeta^2\right]. \qquad (10)$$

where the projected area of the "single actuator disk Darrieus" can be found from

$$A_s = D^2 \tan\gamma \qquad (11)$$

and the projected area of the "double actuator disk Darrieus" can be found from

$$A_d = D(h - D\tan(\gamma)) \qquad (12)$$

and the total projected area of the Darrieus can be found from

$$A_t = Dh . \qquad (13)$$

The maximum aerodynamic efficiency can be found by differentiating equation (10) with respect to *?*, which results in an optimal aerodynamic efficiency depending on the skew angle of the flow.

RESULTS

The relations (1) and (10)-(13) can be plotted as a function of the skew angle of the flow (see figure 3). Figure 3 shows that the aerodynamic efficiency of a Darrieus suffers less from skewed flow for higher skew angles than the aerodynamic efficiency of a HALWT in skewed flow.

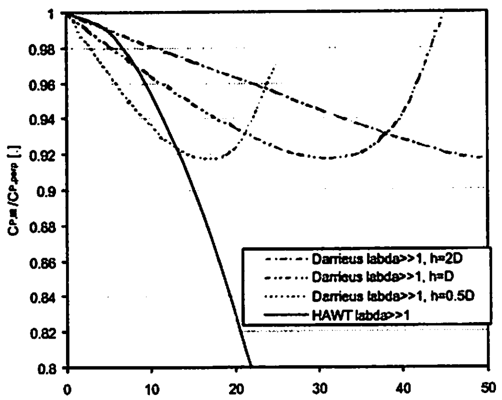


Fig. 3. Aerodynamic efficiencies of a HAWT and a Darrieus (with different height h, diameter D combinations) for different skew angles of the flow.

The increase in aerodynamic efficiency for growing skew angle of the flow is partly caused by the response of the Darrieus but more important, the increase of projected area for the skewed flow. The aerodynamic efficiency remains concerned with the frontal projected area A_f this explains the growth in aerodynamic efficiency.

The projected area for the skewed flow increases, so the solidity (ratio blade area and projected area) also changes. In order to compensate this the Darrieus has to turn faster, so the TSR will increase. Related to the formulas in this paper, the change in the value of the parameter ? for optimal aerodynamic efficiency results in a change in Tip Speed Ratio for a certain configuration of a Darrieus (dimensions B, c, R) for different skew angles of the flow (see figure 4).

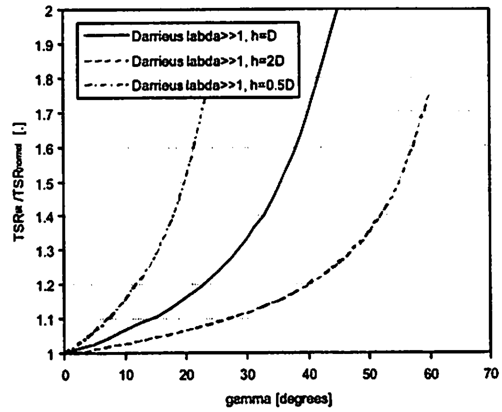


Fig.4 Change of the TSR for a certain configuration of a Darrieus (dimensions B, c, R)

CONCLUSIONS

Under normal flow conditions (no skewed flow) the aerodynamic efficiency of a smaller HALWT and Darrieus can be up to respectively 0.4 and 0.35. The result mentioned in figure 3 can be used to make a plot of the absolute aerodynamic efficiency in skewed flow based on the aerodynamic efficiency in normal flow conditions (see figure 5).

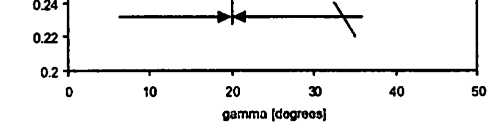


Fig.5 Absolute aerodynamic efficiency of a HALWT and a Darrieus in skewed flow.

Figure 5 makes clear that a Darrieus with high TSR suffers less from skewed flow than a HALWT. The aerodynamic efficiency decrease in tilted flow is less. Furthermore figure 5 makes clear that the aerodynamic efficiency in skewed flow of a Darrieus compared to a HALWT will be higher for skew angles of the flow above about 20 degrees.

In [2] it is showed that a skew angle of the flow of about 20 degrees is reached at the middle of flat roofs for buildings in urban areas (roughness 1 [m]) higher than about 20 [m]. So, if we look at the aerodynamic efficiency, it is desirable to choose a Darrieus for buildings in urban areas higher than about 20 [m]. Below this height a HALWT is preferred.

A 55% growth of the TSR of a Darrieus with h=0.5D in skewed flow can be expected. For a Darrieus with h=2D this growth in TSR will be limited to about 8%.

REFERENCES

[1] T. Burton, D. Sharpe, N. Jenkins, E. Bossanyi, Wind Energy Handbook, J. Wiley & sons Ltd, England, 2001

[2] S. Mertens, Proceedings Global Wind Power conference and exhibition, 2002

[3] R.E. Wilson, P.B.S. Lissaman, Applied Aerodynamics of Wind Power Machines, Aerovironment, Inc. Pasadena, California 1974

[4] van Dyke, Milton, An album of fluid motion, Stanford, Parabolic, 1982


DIRECCIÓN TÉCNICA
ITC
Description of a test platform for small wind turbine
Dunia Mentado Rodríguez
Penélope Ramírez Gonzáles
ITC
energías renovables y agua


DIRECCIÓN TÉCNICA
ITC
ITC - Description & Objectives
ITC (Instituto Tecnológico de Canarias) is a company owned Canarian Government, under direct dependence of the Presidency and Technological Innovation Department
Its main objective is to foster the industrial development of the Canarian Archipelago, by means of R+D activities, services to SMEs and close contact with canarian administration agencies, universities and companies
Offices in Gran Canaria, Tenerife, La Palma and El Hierro
ITC current staff: 180 people
ITC
energías renovables y agua

Technical Direction

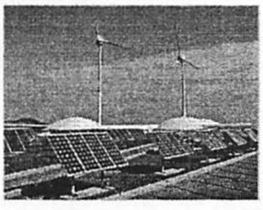
GENERAL OBJECTIVES :
To develop, to foster and to lead R+D activities and technical services which support the Industrial Development of the Canaries.

EMPHASIS:
- Applied Research.
- R+D Transfer to Canary Islands-based Enterprises.

AREAS:
- Renewable Energies.
- Desalination and Water treatment.
- Biotechnology.
- Medical Engineering.

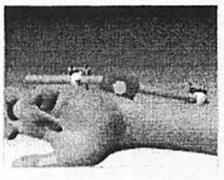
DEPARTMENTS TECHNICAL DIRECTION

- Renewable Energies and Water Department

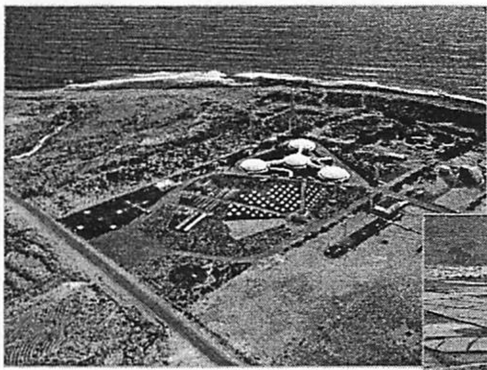


- Biotechnology Department

- Medical Engineering Department



GENERAL FACILITIES



POZO IZQUIERDO
(Gran Canaria)

Area: 109.000 m^2

Mean wind speed: 7,5 m/s
Annual solar irradiation :
2.000 kWh/m^2

GENERAL FACILITIES

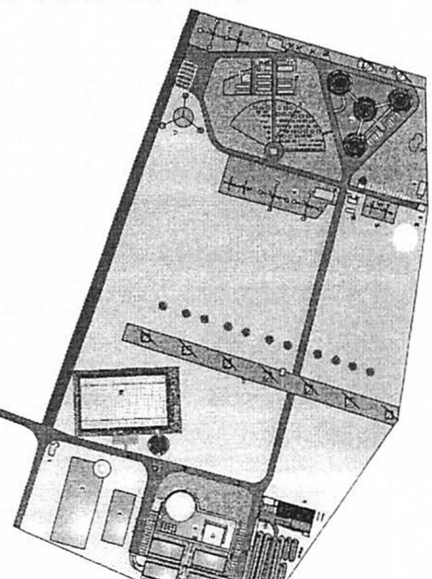
1. Control Room
2. Building for Training courses (projected)
3. Biotechnology
4. Main building of the ITC
5. Buildings Service area (purifying plant, green-point, etc)
6. Biotechnology Laboratories
7. Domes - Workshops
8. Sea water pumping room
9. Desalinated water tank

Field Installations

10. Wind area I
11. Wind area II
12. Wind area III
13. Wind area IV
14. Photovoltaic Solar area I
15. Photovoltaic Solar area II
16. Thermal solar area I
17. Climatological Station

Installations Associated to specific Projects

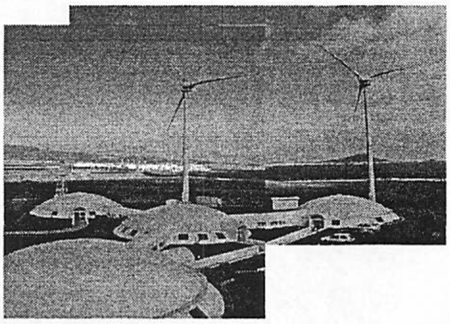
18. Aeroponic Greenhouse supplied 100% by renewable energies (projected)
19. Algae growing Pools
20. Isolated Desalination Systems house
21. PLASOLTER House
22. Water Reservoir
23. SODESA house
24. Inverters and batteries house
25. Wind-diesel systems house
26. Contedes Container
27. MORENA Container
28. Liquid LENS Installations

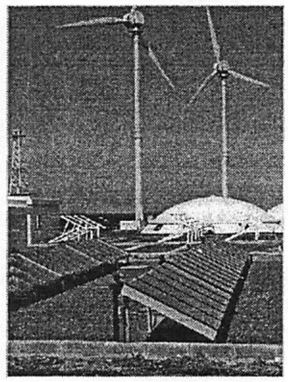


RENEWABLE ENERGIES AND WATER DEPARTMENT

OBJECTIVES:

Development of specific applications based on the utilisation of renewable energies, especially water desalination in off grid systems and electricity production, heat and cold production in remote areas.





RENEWABLE ENERGIES AND WATER DEPARTMENT

R+D Lines

- Electricity production from renewable energies
- Drinking water production (water desalination) from renewable energy systems
- Cooling, ice-production and air-conditioning from renewable energy systems
- Application of renewable energies in buildings and agriculture
- Development of low and medium power wind systems (wind-diesel included)
- Penetration of renewable energies in weak electrical grids
- Development and evaluation of systems linked to desalination and water treatment
- Hydrogen production from renewable energies

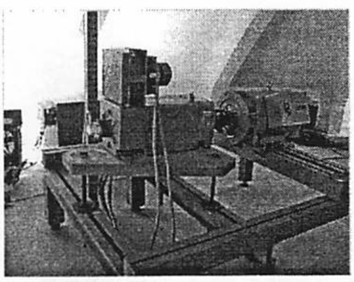
RENEWABLE ENERGIES AND WATER DEPARTMENT

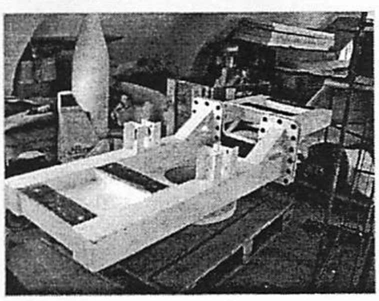
Developed Products

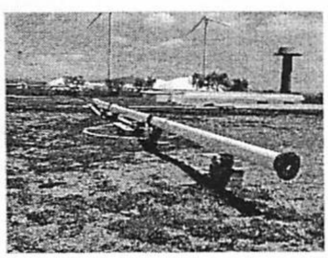
- ➢Modulated reverse osmosis desalination plant driven by an off-grid wind farm
- ➢Reverse osmosis desalination plant driven by a small wind turbine.
- ➢Reverse osmosis desalination plant driven by an off-grid photovoltaic system
- ➢Container with hybrid system (wind-photovoltaic-diesel) for electricity production
- ➢Container for water desalination (no electrical connection to the grid needed)
- ➢Ice production systems driven by small wind turbines and photovoltaic systems
- ➢Cold storage plant driven by a small wind turbine

EODIESEL 15-20 20 kW Wind-Diesel System

- ➢Wind-Diesel System for villages not connected to the grid
- ➢20 KW Synchronous wind turbine, 20 KW diesel generating set and flywheel
- ➢Control system with PLC
- ➢The whole system will be designed as compact modules, containers, in order to facilitate its installation in isolated areas without constructions

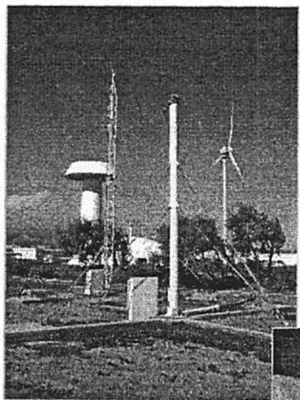


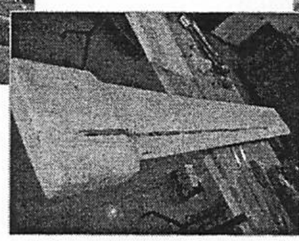


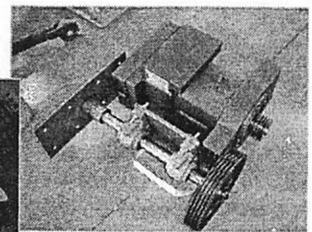


AEROBATEC Small Wind Turbine Prototype

- Small wind turbine made of standard components available in the market, with objectives of simplicity and minimum cost
- Suitable for manufacture in developing regions
- Easy maintenance

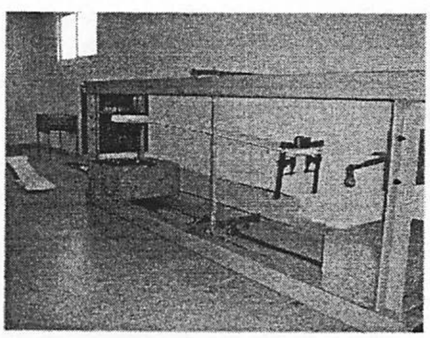


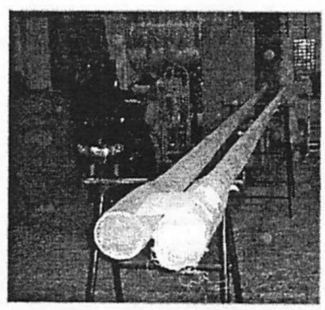




PALAS Test platform for wind turbine blades

Development and manufacturing of a test platform for wind turbine blades up to 10m length

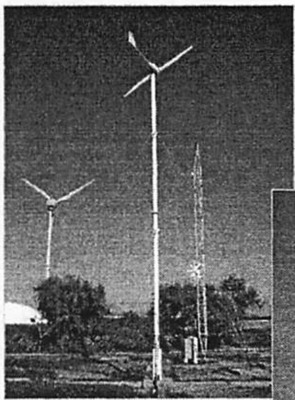


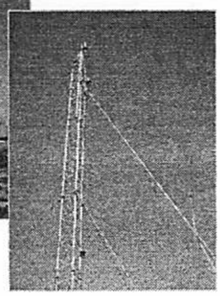


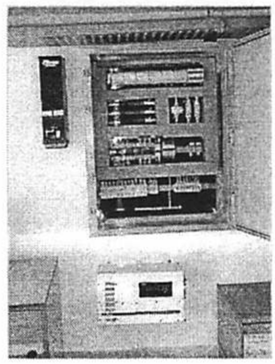
AEROBANC

OBJECTIVES

- Test platform for power performance of small wind turbine not connected to the grid
- Determination of procedures for air density correction.

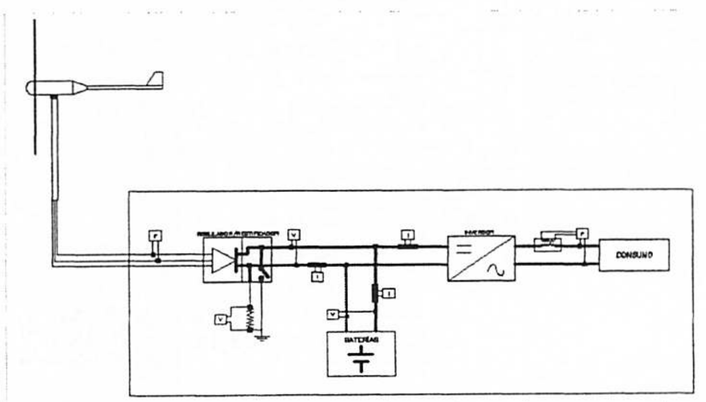




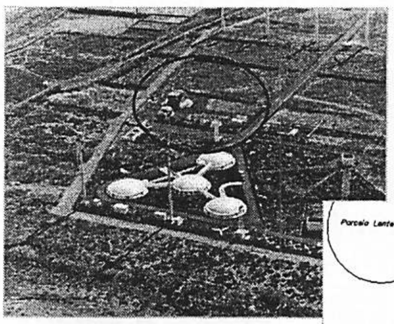


SYSTEM DESCRIPTION

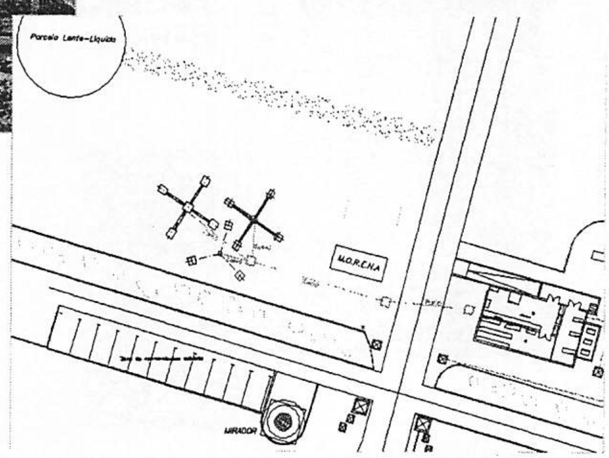
- Wind Turbine: Bornay Inclin 1500 W || 24 Vac || two bladed rotor || diameter = 2,86 m || hub-height = 9,22 m
- Regulator: Bornay 150 A || 24 V
- Batteries: 24 V ⇒ 2 V x 12 elements Tudor type 5 EAN 70
- Inverter: Trace Engineering 24 Vdc to 220 Vac
- Load: resistance from 1000 W up to 3000 W



TESTING SITE CONDITIONS: terrain description

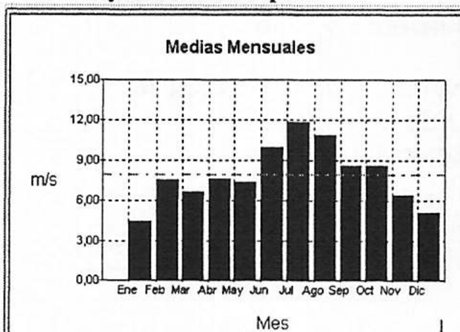


- Plain terrain with small bushes
- 100 m from the sea
- No high buildings in the surroundings



TESTING SITE CONDITIONS: Wind conditions

Monthly mean wind speed



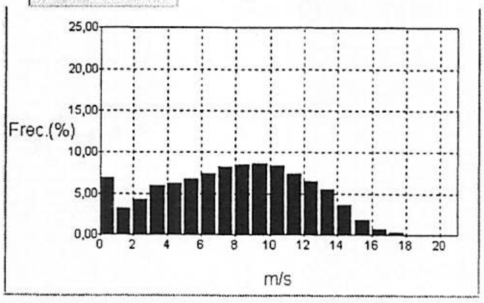
Mes	m/s	Desv.	%D
Ene	4,46	2,74	10
Feb	7,54	3,74	10
Mar	6,61	3,38	10
Abr	7,65	3,86	10
May	7,38	4,36	10
Jun	9,95	4,85	10
Jul	11,89	3,31	10
Ago	10,89	3,44	10
Sep	8,62	2,98	10
Oct	8,57	2,85	10
Nov	6,43	3,35	10
Dic	5,07	2,99	10

Med. anual = 7,92

POZO IZQUIERDO Year 2000

Annual mean wind speed = 7,92 m/s

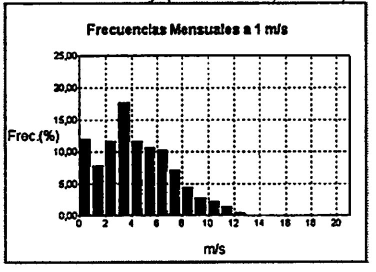
Frequency distribution



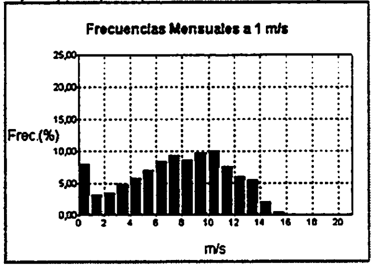
TESTING SITE CONDITIONS: Wind Conditions

Seasonal wind frequency distribution: Year 2000

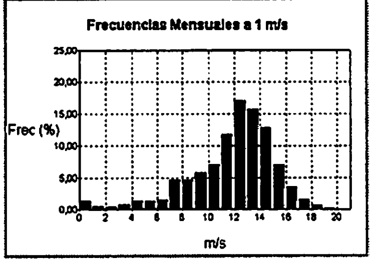
Winter: January (Vmean= 4,45 m/s)



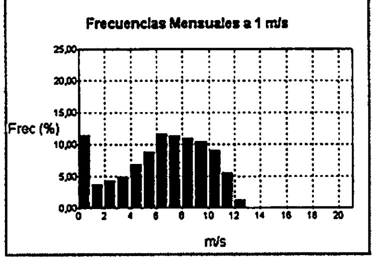
Spring: April (Vmean= 7,65 m/s)



Summer: July (Vmean= 11,89 m/s)

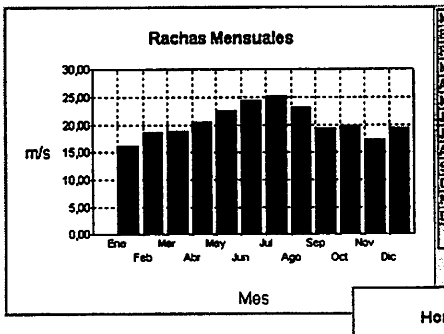


Autumn: November (Vmean= 6,43 m/s)



TESTING SITE CONDITIONS: Wind conditions

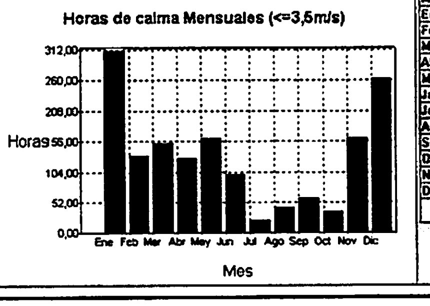
Wind Gusts



Mes	m/s
Ene	16,10
Feb	18,60
Mar	18,90
Abr	20,50
May	22,60
Jun	24,40
Jul	25,10
Ago	23,10
Sep	19,30
Oct	19,80
Nov	17,40
Dic	19,30

POZO IZQUIERDO
Year 2000

Wind speed ≤ 3,5 m/s (Lulls)

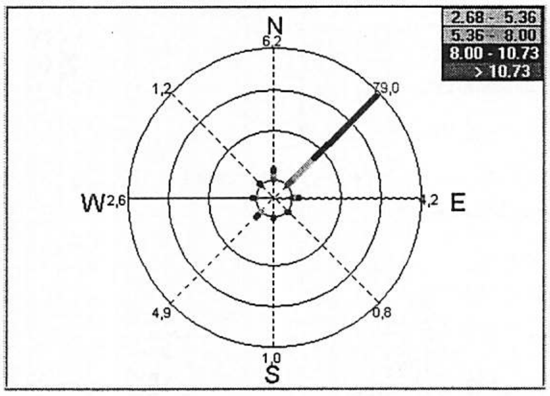


Mes	Horas	%Hor.Pos
Ene	311	42%
Feb	132	19%
Mar	153	21%
Abr	126	18%
May	161	22%
Jun	99	14%
Jul	21	3%
Ago	43	6%
Sep	58	8%
Oct	36	5%
Nov	161	22%
Dic	262	35%

TESTING SITE CONDITIONS: Wind conditions

POZO IZQUIERDO
Year 2000

Wind Rose



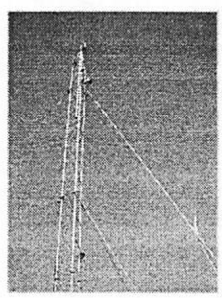
MEASURING INSTRUMENTATION

METEOROLOGICAL SENSOR

➢Anemometer and wind vane: power supply: 24 Vdc
output: 4-20 mA
wind speed range: 0-65 m/s, accuracy: 2%, resolution: 0'01 m/s
wind direction range: 0-359°, accuracy : ±2°, resolution: 1°

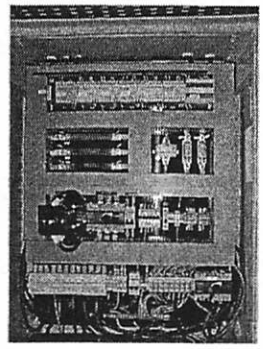
➢Temperature and humidity sensor: power supply : 24 Vdc
output: 4-20 mA
accuracy: ±2%
temperature range: -30°C to +70°C
humidity range: 0-100%

➢Barometric pressure sensor: power supply : 12 Vdc
range: 800-1100 mbar
output: 4-20 mA
accuracy: <±0,25%



MEASURING INSTRUMENTATION

SIGNAL CONVERTERS

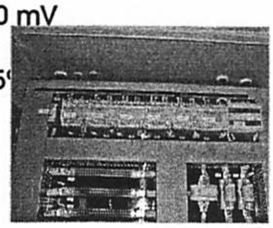


➢Frequency converter: power supply: 220 Vac
range: 0-80 Hz
output: 4-20 mA
accuracy: 2%

➢Voltage converter: power supply : 24 Vdc
range: 0-30 V
output: 4-20 mA
accuracy: 0'5%

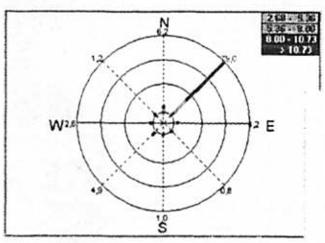
➢Shunt : + Voltage converter: power supply : 24 Vdc

Shunt	Voltage converter
range: 0-150 A	range: 0-150 mV
output: 0-150 mV	output: 4-20 mA
accuracy: 0'5%	accuracy: 0'5



➢Power converter: power supply : 24 Vdc
range: 0-5000 W
output: 4-20 mA
accuracy: 0'5%

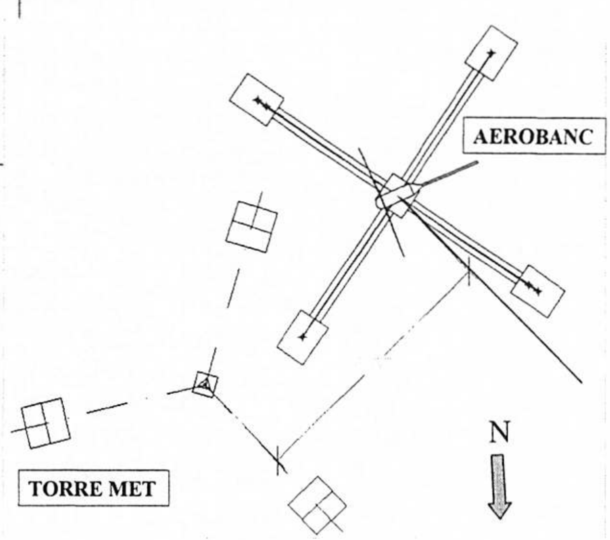
POSITION OF THE METEOROLOGICAL SENSORS



➢North-East position

➢Distance to the wind turbine=6,57 m

➢Anemometer at hub height = 9,22 m



DATA ACQUISITION SYSTEMS

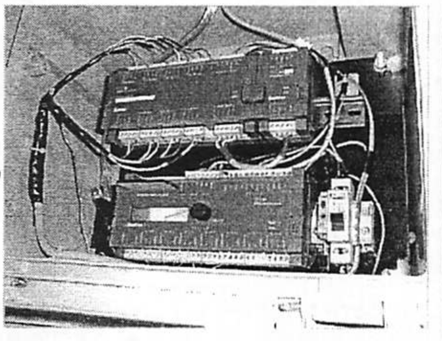
➢Datalogger GANTNER IDL 100: 8 analogue inputs
6 digital inputs
256K RAM
Display

➢Multiplexor IMX 102: 8 analogue inputs

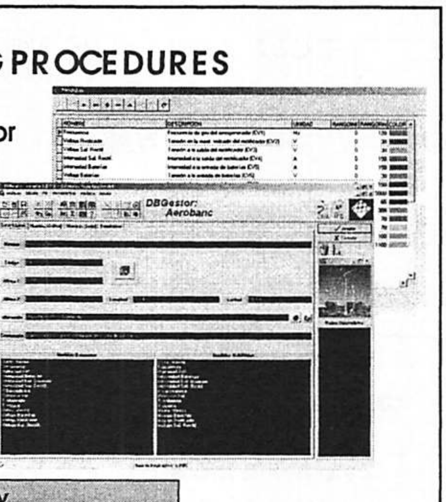
➢Converter module Bus-Profibus ISM 101/M to communicate the datalogger with the multiplexor

➢A PCMCIA memory card Flash 8 Mb

➢The data stored in the PCMCIA memory card are transferred periodically to a PC



DATA COLLECTING PROCEDURES



➢Data collected in Database DB Gestor

➢Database DB Gestor is a software developed by ITC

➢It is a tool for the control and management of Data measured fro[m] the research projects: wind and sol[ar]

➢Variables are sampled and recorde[d] every second:

❖Wind speed ❖Wind direction ❖Temperature ❖Humidity ❖Barometric pressure	❖Frequency ❖Dump Load Voltage ❖Regulator Output Current ❖Regulator Output Voltage ❖Batteries Current ❖Batteries Voltage ❖Inverter Input Current ❖Consumption Load

Conception of a test bench for small wind turbine not connected to the grid.

Francis Pelletier, Master student

ÉCOLE DE TECHNOLOGIE SUPÉRIEURE
Département de génie mécanique
Montréal, Québec, Canada

OUTLINE

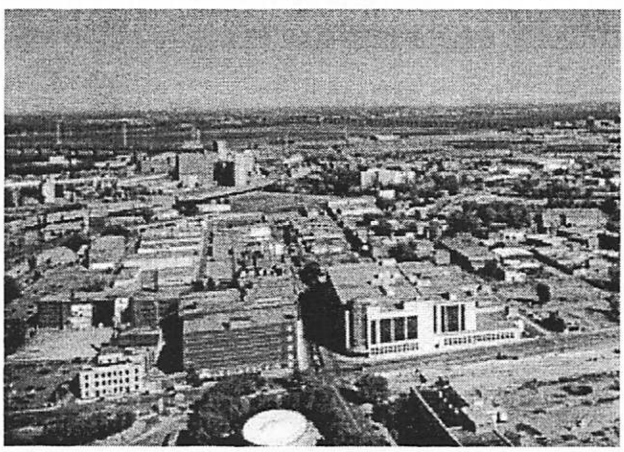
- Conception of the test bench.
- Uncertainty analysis.
- Data analysis and results.
- Future work.

I Conception of the test bench

- ✓ Location.
- ✓ Mechanical design\analysis.
- ✓ Instrumentation and data acquisition system

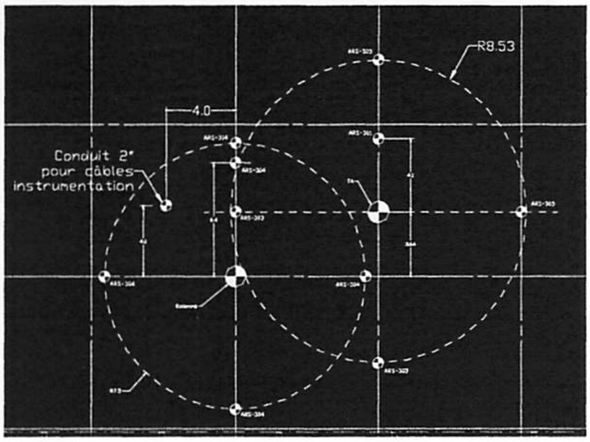
I Conception of the test bench

Location: Downtown Montréal
(average speed 6 m/s)



I Conception of the test bench

Location: ETS roof



Distance = 9m
(Dia: 9/4 meters
to 9/2 meters)
•Same heights

I Conception of the test bench

Location: ETS roof - MOTIVATION

- Proximity
  - Fluid mechanics related topics analysis
  - Test bench for mechanical lab
  - Test bench for electrical lab
- Evaluate the potential of a wind turbine in an urban environment.

I Conception of the test bench

WE NEED A SITE
CALIBRATION

- Site calibration via modeling (FLUENT)
- Site calibration via data acquisition system (IEC 61400-12)

I Conception of test bench

Mechanical design\Analysis

✓ Design -> Pro Engineer.

✓ Analysis - > Ansys (finite element analysis)

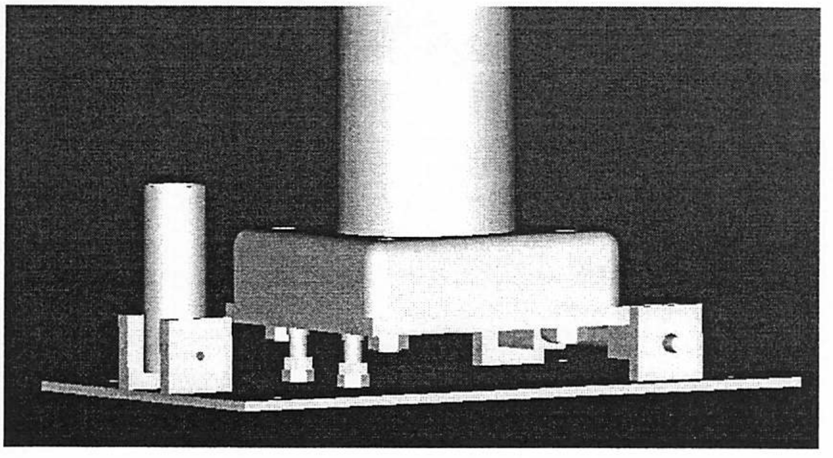
RESULTS:

✓ Tilting tower.

✓ Maximum diameter = 5 meter.

I Conception of the test bench

Mechanical design\Analysis



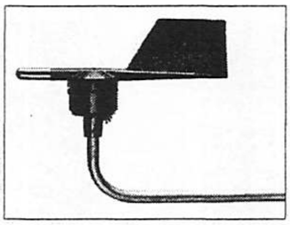
I Conception of the test bench

Instrumentation and data acquisition system

- 2 anemometers
- NRG TYPE 40 Calibrated
- Distance constant = 3m

I Conception of the test bench

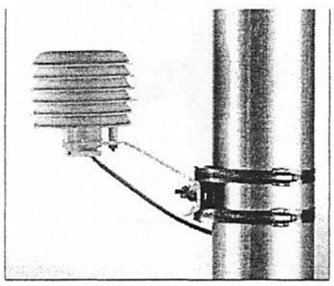
Instrumentation and data acquisition system



- 2 wind direction vanes
- NRG 200 series

I Conception of the test bench

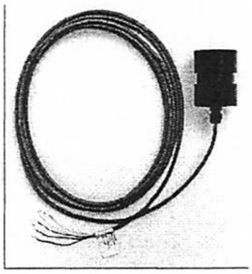
Instrumentation and data acquisition system



- 1 Temperature sensor
- NRG #110S

I Conception of the test bench

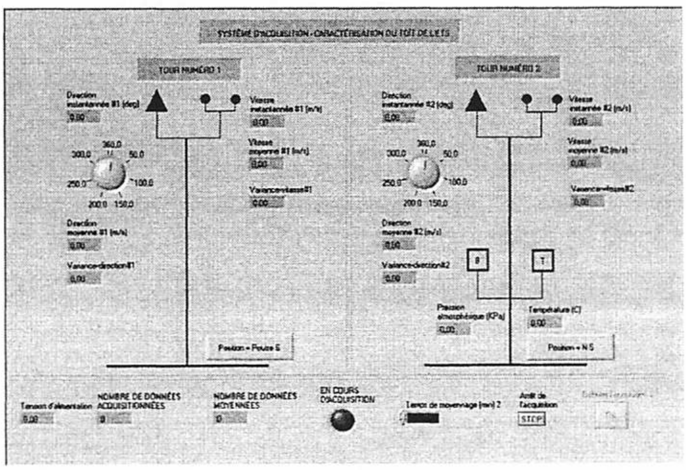
Instrumentation and data acquisition system



- 1 Pressure sensor
- NRG #BP20

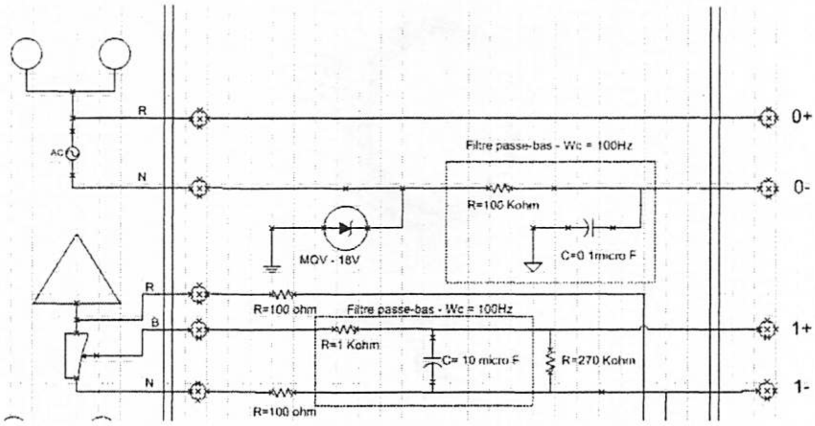
I Conception of the test bench

Instrumentation and data acquisition system



I Conception of the test bench

Instrumentation and data acquisition system



II Uncertainty analysis

Uncertainty of the anemometer:
$\Delta V=\pm sqrt((0.1)^2+(0.0074*v_i)^2)$

TYPE B - ERRORS

- Steady state calibration: ± 0.1 m/s *
- Variation in time: ± 0 m/s
- Turbulence ($E = I^2 * (1.8 * d - 1.4)$: ± 0.36%
- Flow inclination effect on calibration: ± 0.65% *
- Temperature effect (if T>0°C): ± 0 m/s
- Flow distortion (mast, boom & others): ± 0 m/s
- DATA ACQUISITION SYSTEM (T.I.)
  - Offset: ± 0 m/s
  - Span ± 0 m/s
  - Resolution ± 0 m/s
  - Data treatments (FFT) ± 0 m/s

II Uncertainty analysis

Uncertainty of wind vane direction:

③D = sqrt ($(3.6)^2 + (0)^2 + (5^2) + (0.5)^2$) = ± 6.2°

TYPE B - ERRORS

- Steady state calibration: ± 3.6°
- Flow distortion (mast, boom & others): ± 0°
- Installation: ± 5° *
- DATA ACQUISITION SYSTEM (T.I.)
  - Offset: ± 0°
  - Span (Class 0.5) ± 0.01 V *
  - Resolution ((10 / 4095) / 2) : ± 1.22mV
  - Data treatments (same as Span): ± 0.01 V *

±sqrt($(0.01)^2+(0.00122)^2+(0.01)^2$) = ± 0.014 V

± (360/10) * 0.014 = ± 0.5°

25th of April 2002 Francis Pelletier 17

II Uncertainty analysis

Uncertainty of thermometer:

③T= ± sqrt ($(1.16)^2 + (2)^2 + (1.43)^2 + (0.6)^2$) = ± **2.8 °C**

TYPE B - ERRORS

- Steady state calibration: ± 1.16°C
- Radiation: ± 2°C
- Installation (if L < 10 meter): ± 1.43°C
  Installation (if L > 10 meter): ± 0.43°C
- DATA ACQUISITION SYSTEM (T.I.)
  - Offset: ± 0 V
  - Span (Class 0.5) ± 0.01 V *
  - Resolution ((10 / 4095) / 2) : ± 1.22mV
  - Data treatments (none): ± 0 V

±sqrt($(0.01)^2+(0.00122)^2$) = ± 0.01 V

± (0.01*55.55) = ± 0.6°C

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II Uncertainty analysis

Uncertainty of barometer:

$\Delta p = \pm$ sqrt ($(1.5)^2 + (0.028)^2 + (0.22)^2$) = ± **1.5 kPa**

TYPE B - ERRORS

- Steady state calibration: ± 1.5 kPa
- Installation: ± 28 Pa
- DATA ACQUISITION SYSTEM (T.I.)
  - Offset: ± 0 V
  - Span (Class 0.5) ± 0.01 V *
  - Resolution ((10 / 4095) / 2) : ± 1.22mV
  - Data treatments (none): ± 0. V

±sqrt($(0.01)^2+(0.00122)^2$) = ± 0.01 V

(0.01*21.79) = ± 0.22 kPa

II Uncertainty analysis

Uncertainty for Power in wind:
(From anemometer tower)

$$P=\frac{1}{2}\rho A V^3$$

$$\Delta P=\sqrt{\left(\frac{\partial P}{\partial \rho}*\Delta\rho\right)^2+\left(\frac{\partial P}{\partial A}*\Delta A\right)^2+\left(3*\frac{\partial P}{\partial V}*\Delta V\right)^2}$$

$\Delta A \rightarrow 0$

$$\rho=\frac{p}{R*T}$$

$$\Delta V=\sqrt{(typeA)^2+(typeB)^2}$$

II Uncertainty analysis

Uncertainty for wind turbine power:

$$P=(V^3,E,I,TI,\theta,var(\Lambda),Load,\dots)$$

$$\Delta P=\sqrt{\left(3*\frac{\partial P}{\partial V}*\Delta V\right)^2+\left(\frac{\partial P}{\partial E}*\Delta E\right)^2+\left(\frac{\partial P}{\partial I}*\Delta I\right)^2+\left(\frac{\partial P}{\partial TI}*\Delta TI\right)^2+\left(\frac{\partial P}{\partial \theta}*\Delta \theta\right)^2\dots}$$

III Data Analysis and results

(Calibration of complex site (temporary masts))

Data selection considering:

- Direction (30° Sectors)
- Wind speed (24 hours min (5-10m/s)

  (BIN = 0.5 m/s)

- 3D computer modelling

- Turbulence (TI < TI15 (15/Uhub + a) * (1 + a)

  where a=2 and TI15=18[%]

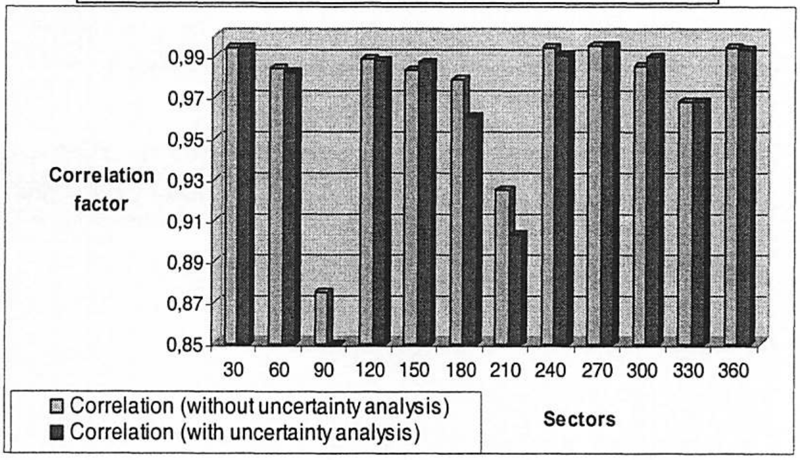
  -> IEC turbulence model - Class A)
- Uncertainty analysis
- Variance in direction (Future work)

IEC-61400-12

ETS

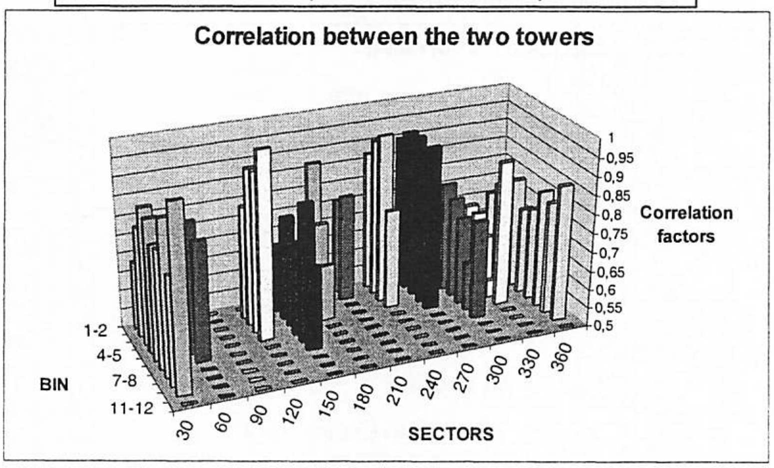
III Data Analysis and results

Correlation of speeds between 2 towers
Results (1 week of data !!!)



III Data Analysis and results

Correlation of speeds between 2 towers
Results (1 week of data !!!)



IV Future work

- ✓ Fatigue & vibration Analysis.
- ✓ Installation.
- ✓ Measurement and data analysis.
- ✓ Modification of the acquisition system for the performance test of a wind turbine.
- ✓ Installation and performance test of a wind turbine.

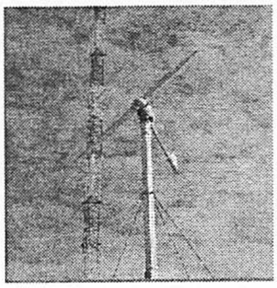
Conception of a test bench for small wind turbine not connected to the grid.

Francis Pelletier, Master student

ÉCOLE DE TECHNOLOGIE SUPÉRIEURE
Département de génie mécanique
Montréal, Québec, Canada

Grid Isolated Wind Systems
R&D&D Working Group Acticities

Grid Isolated Wind Systems
R&D&D Working Group Activities



Ignacio Cruz
RES Department

IEA Topical Expert Meeting
Soria 25-26 April 2002

"Power Performance of Small Wind Turbines not connected to the grid"

Grid Isolated Wind Systems
R&D&D Working Group Acticities

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1. Introduction
2. CENTER description
3. PROJECT Objectives
   - Collecting the data
   - Working with the data
4. TEST FACILITY Description
   - Small Wind Turbines available
   - Instrumentation and DAS available.
5. DATA BROWSER Developed
   - Collecting the data
   - Working with the data
   - Operation modes (Query, average…)
6. Results
7. Conclusions

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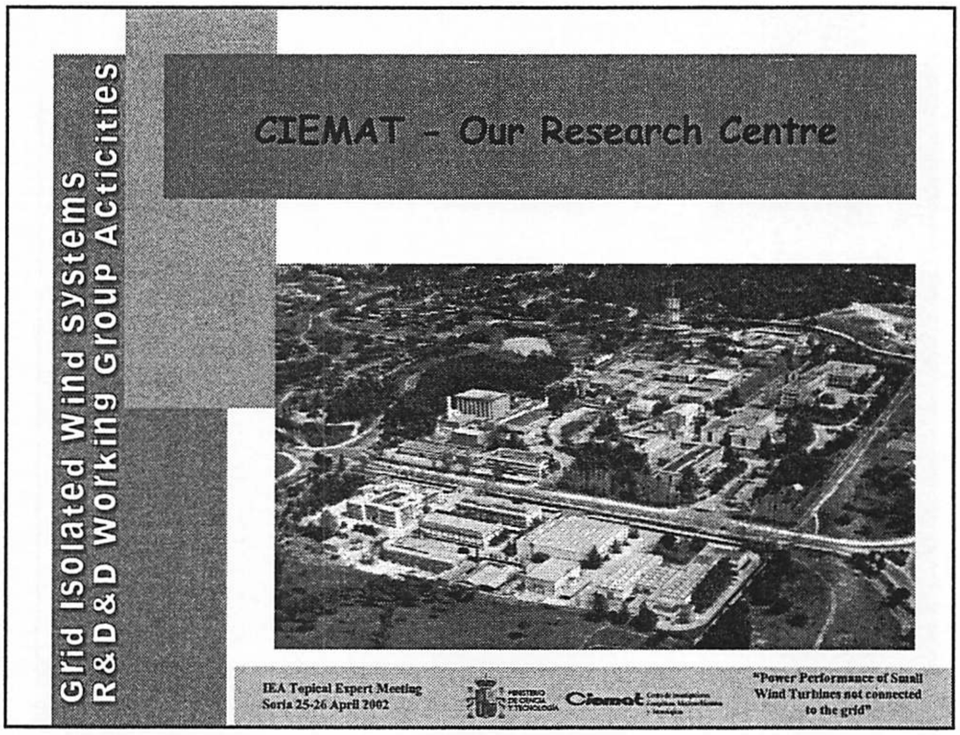
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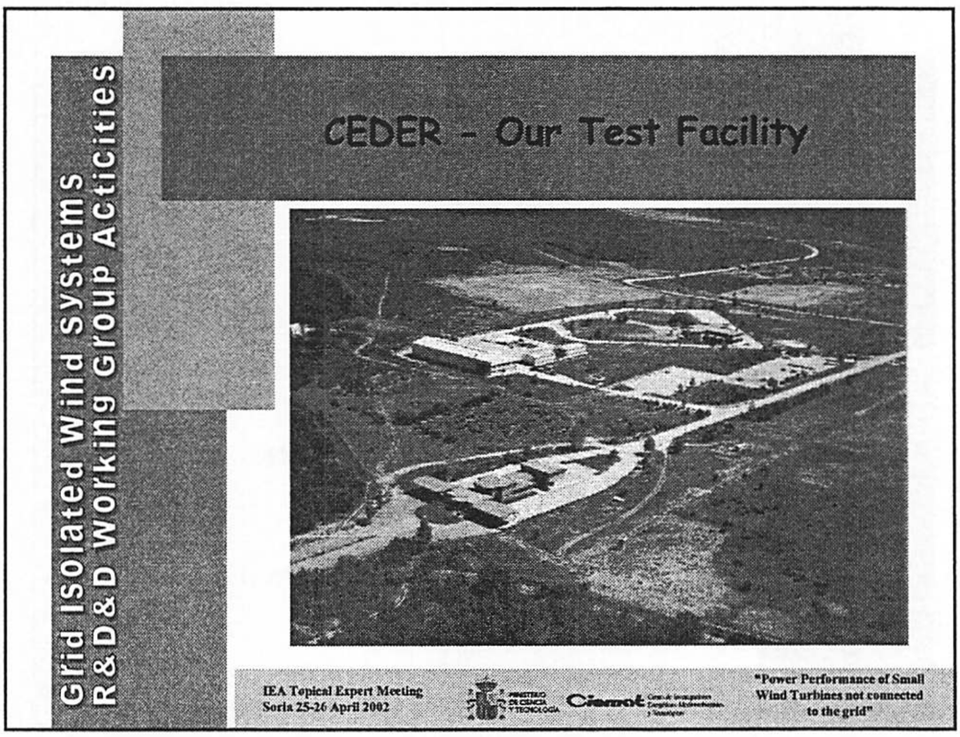
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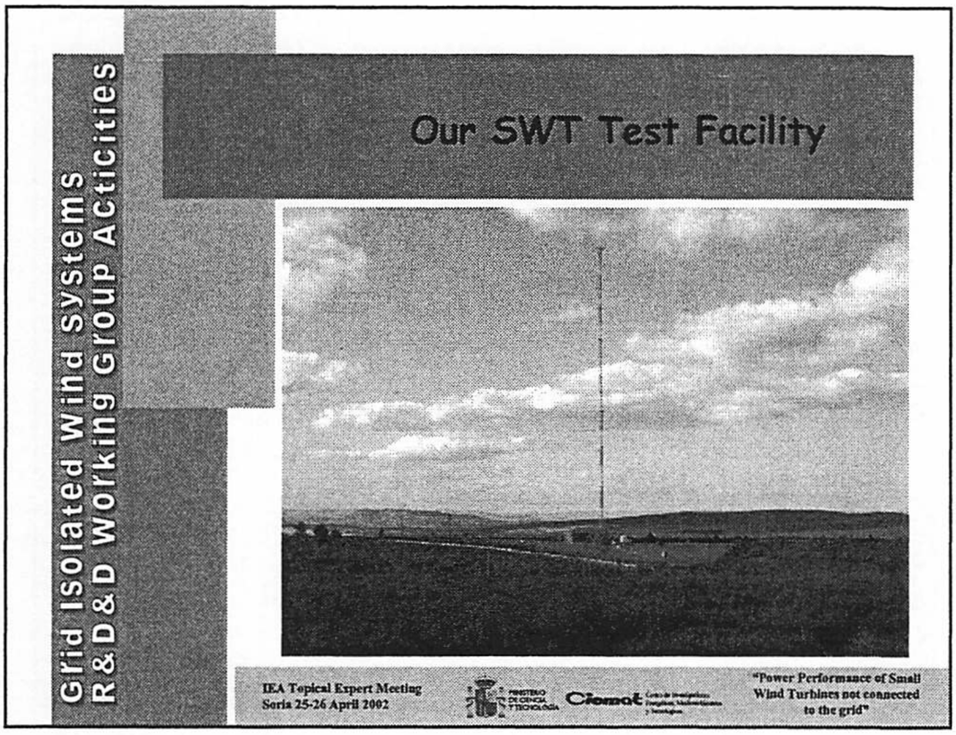
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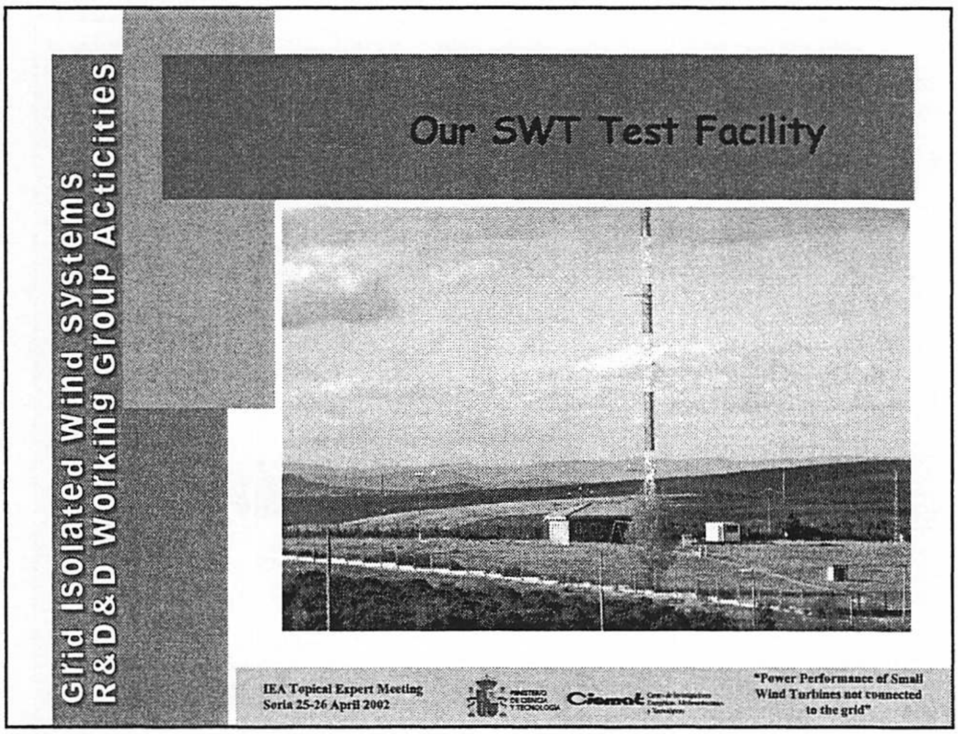
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Grid Isolated Wind Systems
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Our SWT Test Facility

- Full instrumented 100 m height tower with 5 measure levels.
- 2 x 10 m height meteorological towers totally instrumented.
- 1 x 40 m height meteorological tower totally instrumented.
- Battery banks (24 V, 48 V, 110 V, 220 V, 330 V).
- Small generators test bench (up to 12 kW, 1000 rpm).
- Different power converters (rectifiers, inverters, battery charge regulators etc.)
- Programmable loads, dump loads etc
- 2 diesel generators (4 kW, 50 kW).
- 3 data acquisition systems.
- Loads analysis system.
- Power Quality analysis system.
- Special tools and standard instrumentation.

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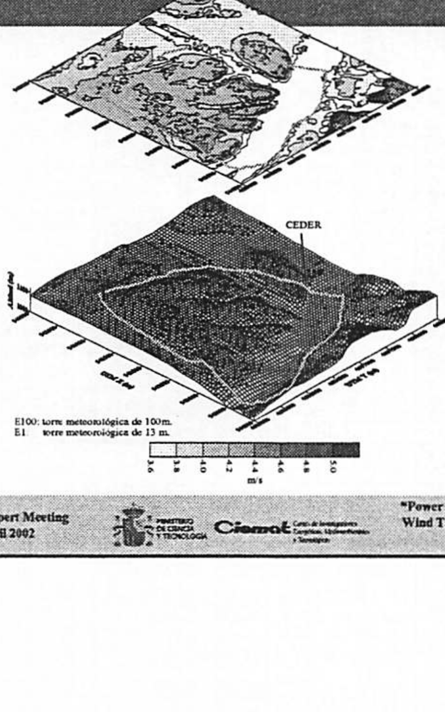
PLANTA DE ENSAYO DE AEROGENERADORES (CEDER) CAMPO DE VIENTO (4 x 5.5 Km) A 30 m a.g.l. MODELO WASP



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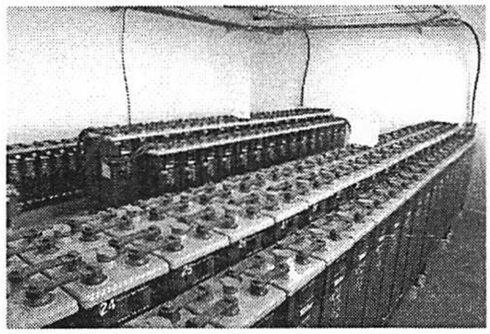

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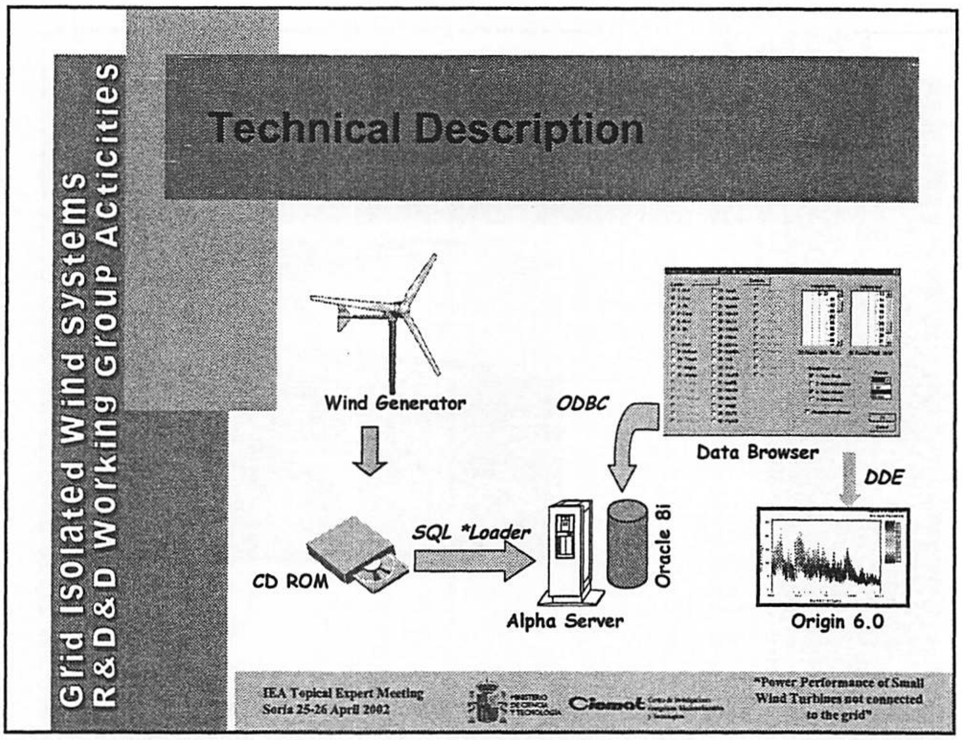
Development of a data browser connected to a partitioned database SITMA

Sistema Informático para el Tratamiento de Medidas de Aerogeneradores

Computer System for the Handling of Wind Turbine Generator Measures

Characteristics:

- Handling of a large amount of data which come from Wind Turbine Generator
- An easy and a friendly way to access the data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Technical Description
Wind Generator
ODBC
Data Browser
DDE
SQL *Loader
Oracle 8i
CD ROM
Alpha Server
Origin 6.0
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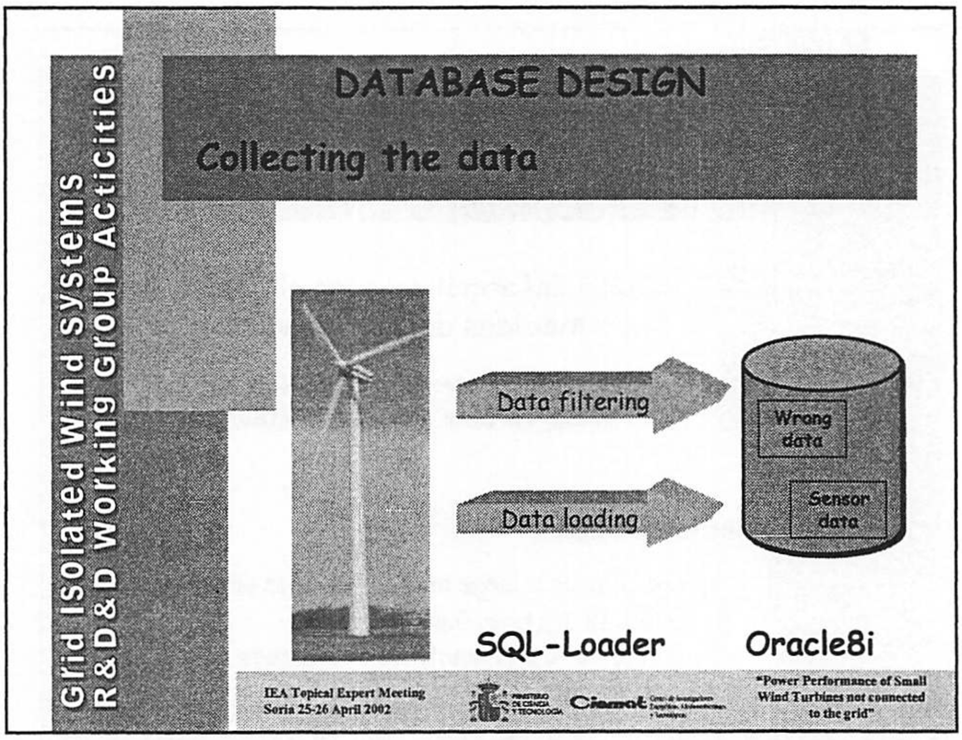
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DATABASE DESIGN
Collecting the data
Data filtering
Data loading
Wrong data
Sensor data
SQL-Loader
Oracle8i
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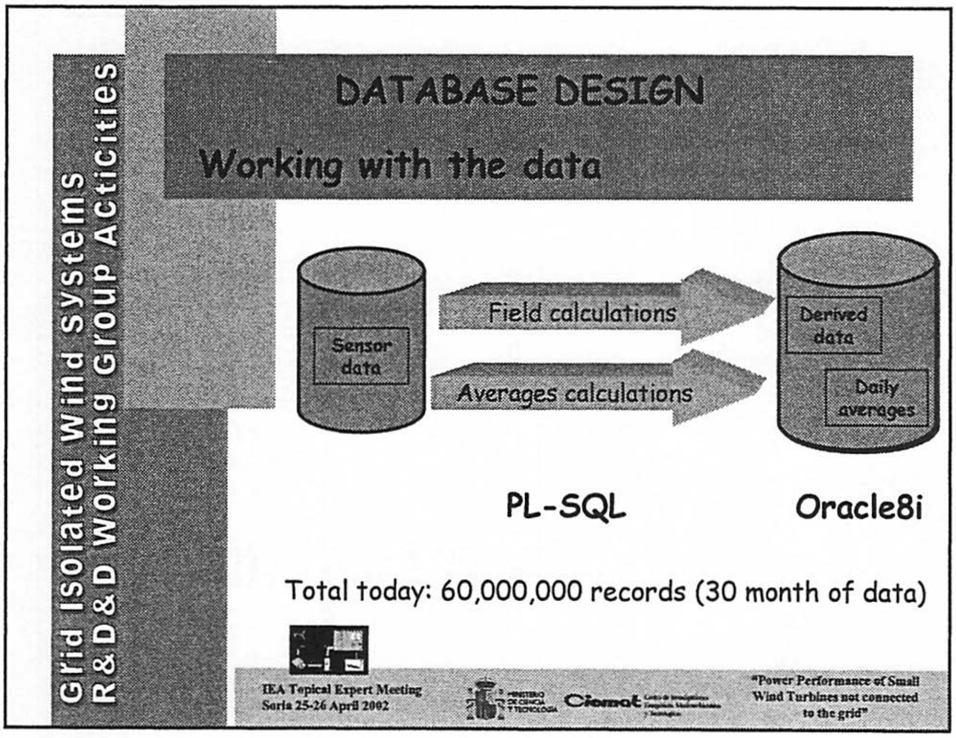
Grid Isolated Wind Systems
R&D&D Working Group Acticities
DATABASE DESIGN
Working with the data
Sensor data
Field calculations
Averages calculations
Derived data
Daily averages
PL-SQL
Oracle8i
Total today: 60,000,000 records (30 month of data)
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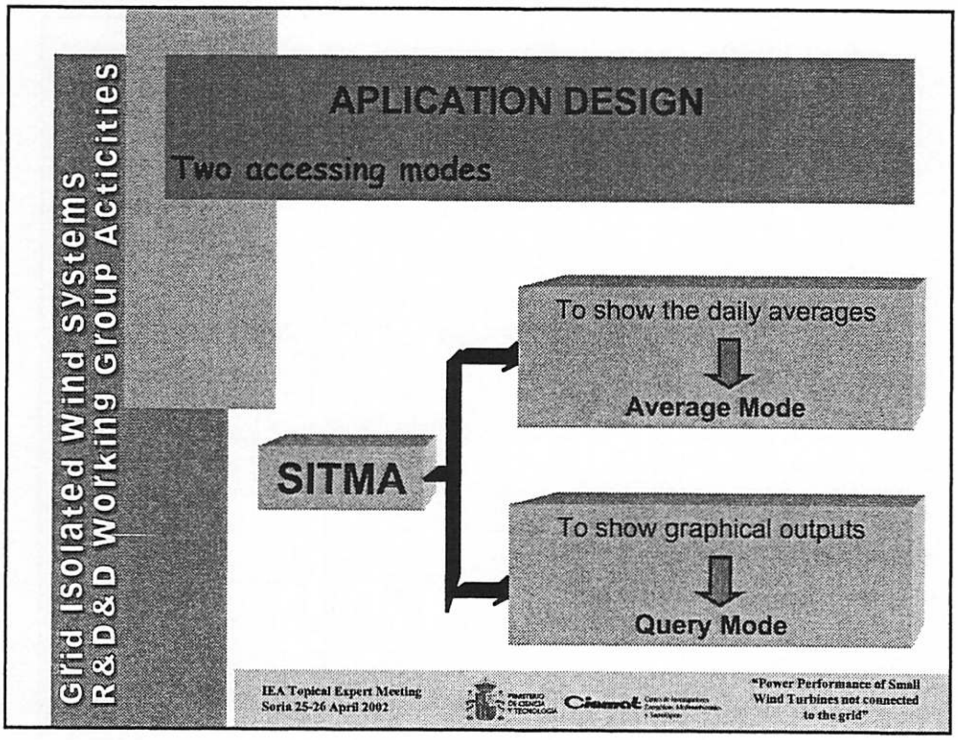
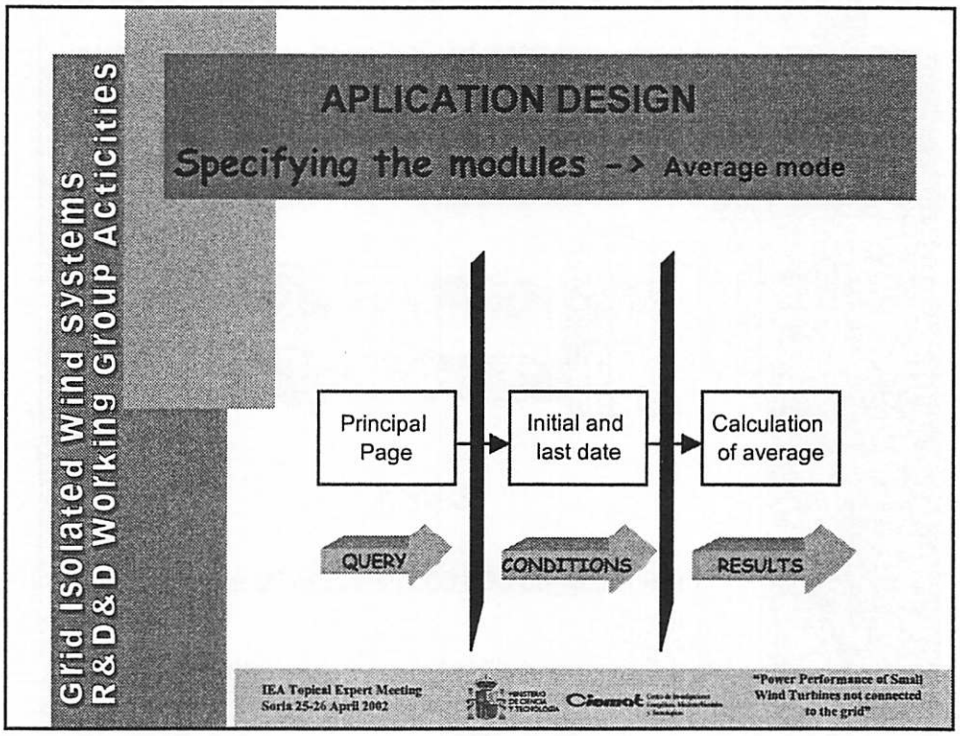
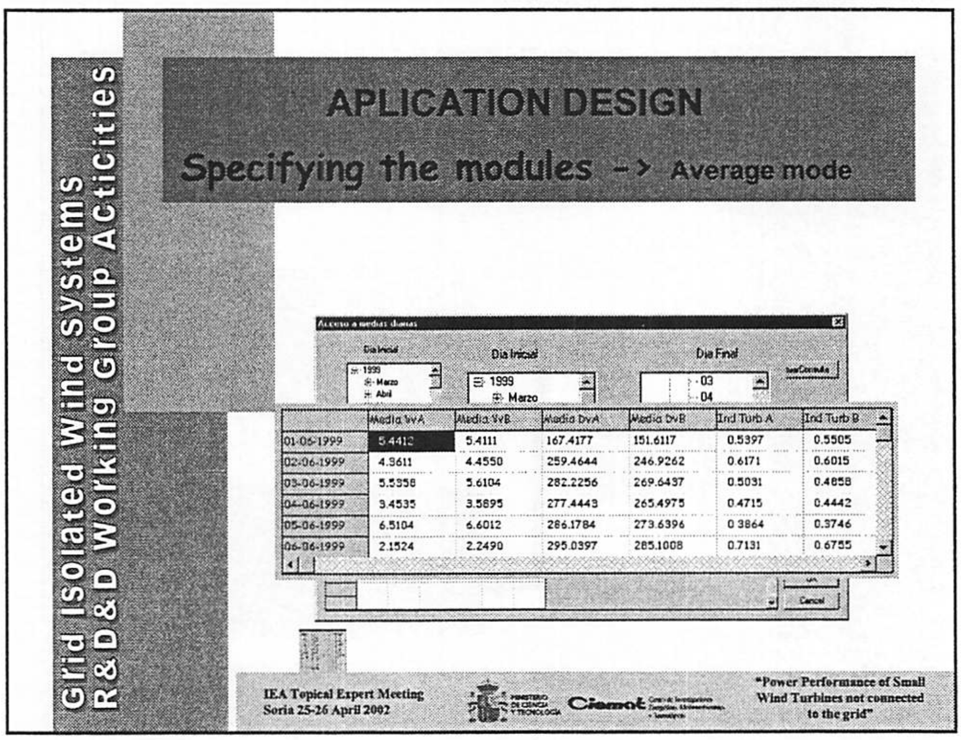
Ciemat
"Power Performance of Small Wind Turbines not connected to the grid"


Grid Isolated Wind Systems
R&D&D Working Group Acticities
APLICATION DESIGN
Two accessing modes
SITMA
To show the daily averages
Average Mode
To show graphical outputs
Query Mode
IEA Topical Expert Meeting
Soria 25-26 April 2002
Ciemat
"Power Performance of Small Wind Turbines not connected to the grid"


Grid Isolated Wind systems
R&D&D Working Group Acticities
APLICATION DESIGN
Specifying the modules -> Average mode
Principal Page
Initial and last date
Calculation of average
QUERY
CONDITIONS
RESULTS
IEA Topical Expert Meeting
Soria 25-26 April 2002
"Power Performance of Small Wind Turbines not connected to the grid"


Grid Isolated Wind systems
R&D&D Working Group Acticities
APLICATION DESIGN
Specifying the modules -> Average mode
Dia Inicial
Dia Final
1999
Marzo
Abril
03
04
Media VvA
Media VvB
Media DvA
Media DvB
Ind Turb A
Ind Turb B
01-06-1999 5.4412 5.4111 167.4177 151.6117 0.5397 0.5505
02-06-1999 4.3611 4.4550 259.4644 246.9262 0.6171 0.6015
03-06-1999 5.5358 5.6104 282.2256 269.6437 0.5031 0.4858
04-06-1999 3.4535 3.5895 277.4443 265.4975 0.4715 0.4442
05-06-1999 6.5104 6.6012 286.1784 273.6396 0.3864 0.3746
06-06-1999 2.1524 2.2490 295.0397 285.1008 0.7131 0.6755
Cancel
IEA Topical Expert Meeting
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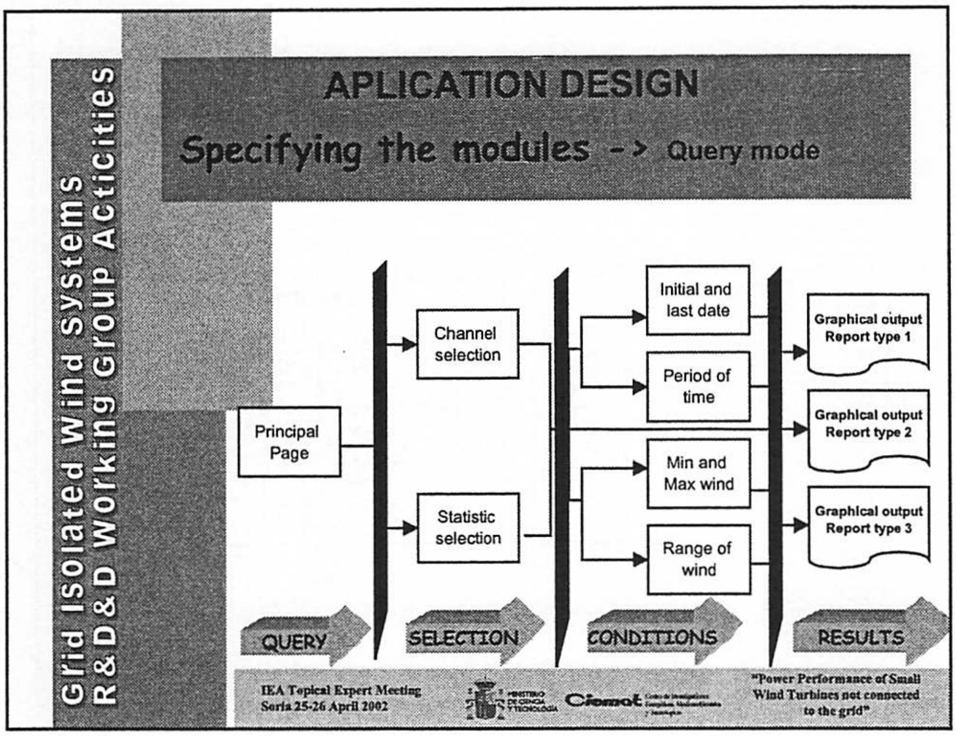
"Power Performance of Small Wind Turbines not connected to the grid"


Grid Isolated Wind Systems
R&D&D Working Group Acticities
APLICATION DESIGN
Specifying the modules -> Query mode
Principal Page
Channel selection
Statistic selection
Initial and last date
Period of time
Min and Max wind
Range of wind
Graphical output Report type 1
Graphical output Report type 2
Graphical output Report type 3
QUERY
SELECTION
CONDITIONS
RESULTS
IEA Topical Expert Meeting
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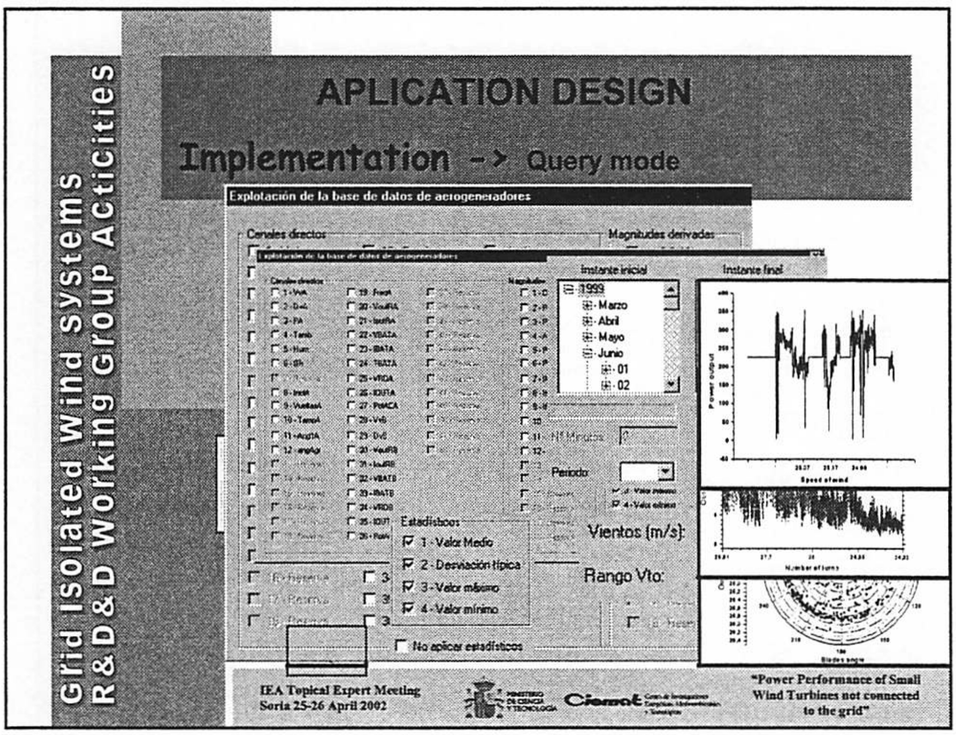
"Power Performance of Small Wind Turbines not connected to the grid"


Grid Isolated Wind Systems
R&D&D Working Group Acticities
APLICATION DESIGN
Implementation -> Query mode
Explotación de la base de datos de aerogeneradores
Canales directos
Magnitudes derivadas
Instante inicial
Instante final
1999
Marzo
Abril
Mayo
Junio
01
02
Periodo
Estadísticos
1 - Valor Medio
2 - Desviación típica
3 - Valor máximo
4 - Valor mínimo
No aplicar estadísticos
Vientos (m/s):
Rango Vto:
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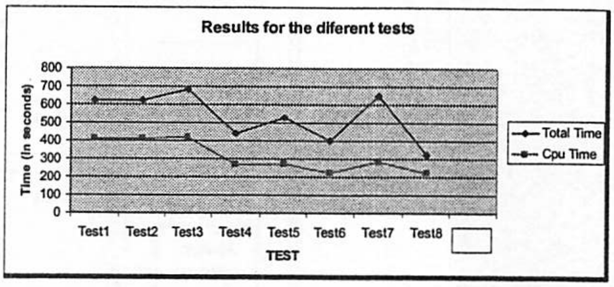
Results of the tests



IEA Topical Expert Meeting
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"Power Performance of Small Wind Turbines not connected to the grid"

Grid Isolated Wind Systems
R&D&D Working Group Acticities

Final considerations

- Optimising by costs: ORACLE not always uses the best execution plan
- Indexes aren't always a good solution when the number of records is high
- The statistical functions don't affect the time spent by the query.

IEA Topical Expert Meeting
Soria 25-26 April 2002

"Power Performance of Small Wind Turbines not connected to the grid"

Summary of IEA R&D Wind - Topical Expert Meeting 39
Power Performance of Small Wind Turbines not connected to the Grid

25th and 26th of April 2002, CEDER, Soria, Spain

Hal Link and Sven-Erik Thor

1 Background

Sometimes lost behind the attention given to multi-megawatt wind farms, the market for autonomous electrical systems using small wind turbines is becoming an increasing attractive business. However, in spite of the maturity reached on the development of the wind technology for grid-connected power plants, the state of the art of wind autonomous systems is far away from technological maturity and economical competitiveness. Average costs for current wind stand-alone installations vary from $3500 to 10000 US per installed kW, which contrasts with $1000-1300 per installed kW corresponding to grid-connected installations. If we just talk about the cost of the wind turbine itself, the specific cost (cost per kilowatt) varies from $1500-5000 for stand-alone machines contrasted with $675 for grid-connected ones.

In relation to the performance analysis for both kinds of systems, we find values of average specific energy produced for stand-alone around 0,15 kW/m^2 whereas the average value for grid-connected systems is 0,5kW/m^2. This is mainly due because grid-connected systems are used in higher wind speeds sites, but also shows that there is a wide range for improving the present technology for stand-alone wind turbines.

The technology for stand-alone wind systems, and more specifically for the wind turbines, is clearly different from the one used in grid-connected systems. These differences affect all of the subsystems, mainly the control and electrical system, but also the design of the rotor of the wind turbines. Small Wind Turbines (SWT) existing in the market are machines that have developed in a nearly "hand-crafted" way, with maturity that is far from the one corresponding to the wind turbines for grid-connection.

There is a lack of standards and guidelines applied to wind-powered autonomous systems, as well as to wind turbines that are not grid-connected. In particular the wind energy community needs a standard method for determining the power performance characteristics of turbines that are not connected to the grid. Such an effort is currently underway in the International Electrotechnical Commission (IEC). See www.iec.ch or directly http://www.iec.ch/cgi-bin/procgi.pl/www/iecwww.p?wwwlang=E&wwwprog=dirwg.p&ctnum=1914. The TC88/MT12 group of the IEC is revising the IEC standard, IEC 61400-12, "Power performance testing." Although most of the revisions to IEC61400-12 are concerned with grid-connected wind turbines, an Annex has been proposed that addresses testing of small turbines that are not connected to the grid.

Many of the researchers and test engineers whose contributions led to the Annex are concerned that the proposed methods are not well founded in scientific and practical experience. This feeling persists even though several programs have been concluded in the United States and Europe in which testing issues were investigated. This symposium addressed these issues and to identified appropriate follow-on activities.

2 Summary

The meeting was a successful sharing of information by sixteen particapants from twelve organizations representing seven countries. The meeting covered three main topic areas:

1. Recent findings on methods to measure power performance of non-grid connected wind turbines,
2. Present activities being conducted by other participants
3. Feedback on current proposal for the IEC standard

The most salient points in each topic area are summarized below from the organizers' perspective (which may not represent the views of other participants). Overall the meeting was very instructive on a technical basis and usefull by providing contacts for future cooperative research. It was especially important to obtain concurrence from the participants that the proposed Annex to IEC 61400-12 (the international standard for power performance testing of wind turbines) should be recommended for approval.

The group decided to communicate future developments this area through an email group of limited size with the potential to convene another meeting if appropriate. See also paragraph 4 Continuation below.

3 Discussion

3.1 Recent findings on measurement of the power performance of non-grid connected wind turbines

3.1.1 Jan Pierik, ECN, the Nederlands

Pierik reported on the PEMSWECS project. They found:

1. if voltage variations of the battery bank are less than 30 %, they may have a large effect on some parts of the power curve but do not have a large effect on AEP (annual energy production)
2. sampling rates of at least 2 hz (vs current requirement of 0.5 hz in grid connected turbines) should be used
3. preaveraging should be 30sec for turbines with rotor diameters less than 6 m and 30 sec for rotors less than 10 meters
4. battery voltage should be allowed to vary over wide ranges of SOC and then the data should be binned to show the effect of voltage variations.
5. voltage variations can be obtained using a voltage regulator and so batteries do not need to be part of the experimental set up.
6. raw data should be saved

3.1.2 Felix Avia, Ciemat, Spain

Avia reported on the methods that Ciemat plans to use for testing:

1. since shorter preaveraging time increases data scatter in the power versus wind speed curve and indicates lower AEP for low wind speed sites, 10-minute preaveraging should be used.
2. wind speed range should be from 0 to 14 m/s
3. no normalization should be done for air density

3.1.3 Brad Cochrane, CERMAK PETERKA PETERSEN, Inc.. USA

Cochran reported on an analytical study that he conducted concerning the influence that wind turbulence has on kinetic energy. He found that when using a 10-minute pre-averaging time, the variation in kinetic energy between two test sites could vary by as much as 23% for the same mean wind speed. This effect is more important for small wind turbines because they are closer to the ground and are likely to be placed in more varied locals, thus, exposed to winds of higher turbulence. For certain turbines this effect may be offset by a decrease in turbine efficiency with high turbulence levels, however, each turbine will react differently. In addition, a shorter averaging time, such a 1-minute, was shown to reduce the deviation in kinetic energy between to sites with different wind turbulence. Therefore, to produce repeatable power production curves, power should be shown as a function of turbulence intensity and, perhaps, standardized power curves should be based on a specified, limited range of turbulence intensity.

3.1.4 Hal Link, NREL, USA

Link reported on work at NREL where they have quantified the effect of different preaveraging intervals on the power performance of three wind turbines

1. Longer preaveraging flattens power curves. This leads to higher indicated power levels at low wind speeds and lower indicated power levels at high wind speeds for most turbines.
2. Longer preaveraging indicates higher AEP at low wind speed sites and lower AEP at high wind speed sites. The difference is usually small compared to the uncertainty in AEP calculations

3.2 Present activities being conducted by other participants

3.2.1 Ignacio Cruz Cruz, Ciemat, Spain

Ciemat is embarking on a strong program to test small wind turbines and to investigate wind diesel systems.

3.2.2 Ermen Llobet, Ecotecnia, Spain

Ecotecnia is interested in developing small turbines and will begin by developing several electrical conversion devices.

3.2.3 Sanders Mertens, Delft University of Technology, The Nederlands

University of Delft is investigating wind turbines installed on roofs as this is a configuration that is frequently requested in the Nederlands. Inititial work using models indicates that vertical axix turbines would be superior to HAWTs in many cases due to the inclined flow typical of wind flow over flat roofs.

3.2.4 Dunia Mentado Rodríguez & Penélope Ramírez Gonzáles, Technical Institute of Canary Islands, Spain

Researchers on the Canary Islands are developing a test facility for small wind turbines. They have a very windy site with average winds of 11,9 m/s in July. In cooperation with Ciemat, they will investigate the effect of air density on furling wind turbines.

3.2.5 Francis Pelletier, École de technologie Supérieure, Canada

Researchers in Quebec, Canada, are preparing to test wind turbines on a roof-mounted facility. They have developed instrumentation and will soon conduct a site calibration test to characterize flow over the roof.

3.3 Comments on IEC standard

Hal Link gave a presentation of some items for discussion on the present version of the IEC standard. The version discussed was the draft of 11 March, 2002. The items for discussion are included in the introductory note in chapter 1 in the beginning of the document. Eighteen of the 19 items in the annex were discussed.

3.3.1 Scope

Felix proposed that the standard is only valid for wind turbines not connected to the grid. But on the other hand it can be the situation that the system also is connected to the grid with some electrical equipment. Cochran noted that there might be a need for a standard for small wind turbines connected to the grid. The participants agreed that the annex should address only non-grid connected wind turbines. Special provisions for small turbines that are connected to the grid should be incorporated into the main body of the standard.

3.3.2 Item 1. Definition of the turbine system

Accepted as written.

3.3.3 Item 2. Minimum turbine and anemometer height of 10 meters

Accepted as written.

3.3.4 Item 3. Load requirements

Some participants felt that no batteries were necessary or, at least they did not need to be as large as would normally be used because the voltage regulator should prevent any current from flowing to the battery. A small battery or other device might be needed to maintain load voltage when the turbine is below cut-in and not producing any power. It was agreed that the first sentence should be softened to permit a smaller battery bank than would normally be used for purposes of power performance testing.

3.3.5 Item 4. Location of the battery bank

No strong feelings were aired. Acceptable percentage voltage drop could be a possible way to handle this. Another possibility is to specify the cable length.

3.3.6 Item 5. Requirements for the voltage regulation device

Accepted as written.

3.3.7 Item 6. Location of meteorological mast/tower

Accepted as written.

3.3.8 Item 7. Position to measure power output

Pierik noted that some turbines are equipped with dump load systems. He felt that it is appropriated to measure power before the dump load when the voltage is allowed to vary and the voltage protection system is set low enough that significant power is consumed by the dump load instead of being used to charge batteries or power external loads. It was agreed, since this procedure requires that voltage be regulated within tight limits and that the voltage protection device be adjusted to a high enough setting to eliminate powering the dump load, that the proposed text was acceptable.

3.3.9 Item 8. Requirements for air density measurements

Accepted as written.

3.3.10 Item 9. Requirement for monitoring wind turbine status

Accepted as written.

3.3.11 Item 10. Allowance for adjusting the charge controller (voltage protection device)

Accepted as written.

3.3.12 Item 11. Pre-averaging time 1-minute

Avia is in favor of 10 minute averaging. However he and other participants concurred that 1-minute pre-averaging was acceptable for this standard.

3.3.13 Item 12. Data set based 1-minute periods

Not specifically discussed because this requirement is a function of the preaveraging time whose discussion is noted above.

3.3.14 Item 13. Rules for a complete database

Avia proposed, and the participants agreed that the standard should include the following provisions:

a) All wind bins between 0 and 14 m/s shall be complete, and

b) The complete wind speed range should include characterization of turbine performance when the turbine is furled.

3.3.15 Item 14. Data normalization

Two possible methods are power normalization, which shifts the power curve in a vertical direction and wind speed normalization, which shifts the power curve in a horizontal direction. Avia proposed that neither method should be performed since neither has been validated for small wind turbines. Other participants shared this concern. There was weak support expressed for normalizing only the energy production.

3.3.16 Item 15. Provision for no specification of cut out wind speed

Accepted as written.

3.3.17 Item 16. Reporting requirements

Arribas de Paz noted that the text did not explain how multiple power curves should be presented when data are obtained at three battery bank voltages. He proposed that a single power curve should be presented with the variations due to battery bank voltage differences shown as part of the uncertainty bands.

3.3.18 Item 17. Reporting requirement for annual energy production at 5 m/s sites

Accepted as written.

3.3.19 Item 18. Battery bank voltage settings

Accepted as written

3.3.20 Summary

Overall the group felt that the standard should go forward even though there were several points on which no consensus was reached. It was the group's opinion that it was better to have an imperfect, yet common method, than to continue with the present situation where no consistant method is being used. The standard can always be modified if better methods are demonstrated.

4 Continuation

It was concluded that quite extensive work is conducted within the IEC MT12 subgroup on non grid connected wind turbines. However, there is still a need to exchange information and discuss different topics with a broader group of people. This can be achieved through a news server on Internet or an email list operated by a moderator.

The latter approach was considered to be a useful way to continue the discussion. Hal Link and Felix Avia were assigned the task to find a moderator and to draw up the objectives and practical thing around such an email discussion network.

Media coverage

LUBIA·

El Ceder certificará la calidad de los sistemas eólicos autónomos

A. I. P. Soria

El Centro de Desarrollo de Energías Renovables (Ceder), ubicado en Lubia , será un centro de referencia para certificar la garantía de pequeños aerogeneradores. Este centro acoge un encuentro de los miembros de la Agencia Internacional de la Energía Eólica, formada por 20 organizaciones de 17 países de todo el mundo, para intercambiar información entre estos expertos y los técnicos de Lubia, que desde 1998 están investigando. El objetivo es modificar la normativa para probar la calidad de estos *molinos domésticos*, certificación que se podrá realizar en Lubia.

Encontrar en España una explotación ganadera o una granja alejada del medio urbano que se suministre de forma autónome con energía eólica es algo excepcional. Sin embargo, en el centro de energías renovables de Lubia trabajan desde el año 1998 para certificar la garantía de los pequeños aerogeneradores que sirvan para producir energía para consumo individual y en lugares aislados, al contrario que los comerciales que evacúan la energía a una red general.

Una vez que la Agencia Internacional de Energía Eólica haya aprobado el procedimiento de ensayos para probar estos pequeños aerogeneradores, el control de calidad se podrá realizar en el centro de Lubia.

El Ceder es el único centro de España y de los pocos del mundo, sólo hay otros dos, Estados Unidos y Dinamarca, en el que se realiza en la actualidad investigaciones sobre el aprovechamiento energético con aerogeneradores pequeños.

El ingeniero industrial Luis Cano, investigador del Ceder de Lubia, explicó que el objetivo de este encuentro con expertos internacionales es intercambiar información con ellos y exponerles los resultados de los ensayos que se han desarrollado en el centro de Lubia sobre este tipo de aerogenarodores, máquinas que se utilizan, sobre todo, para uso doméstico en otros países.

No obstante, la falta de normativa y estándares que garanticen la calidad y fiabilidad de este tipo de sistemas de pequeña potencia es una de las principales barreras para el desarrollo de esta tecnología, apenas desarrollada en España.

MARIANO CASTEJO

Reunión de expertos en energía eólica en el Ceder de Lubia.

Luis Cano considera que los fabricantes de grandes aerogeneradores, para parques eólicos, tienen que disponer de una normativa que puedan seguir y que recoja la fabricación de los *molinos* pequeños. Este investigador explica que en España está muy extendida la utilización de la energía solar para uso doméstico, en lugares donde no se pueden conectar a la red eléctrica, sin embargo apenas se conocen casos de propiedades con sistemas eólicos autónomos.

Los presentes, llegados desde Estados Unidos, Italia, Canadá, Suecia y Brasil, elaborarán un documento técnico que refleje los requisitos indispensables para certificar la calidad de las máquinas.

A pesar del desarrollo alcanzado en tecnología eólica para plantas de potencia conectadas a la red, la situación técnica de los sistemas autónomos eólicos está lejos de la madurez tecnológica y competitividad económica, aunque se prevé que sea un negocio interesante en el futuro. El coste medio de una instalación aislada varía de los 3.000 a los 6.000 euros por kilovatio instalado, frente a los 1.100 euros para las conectadas a la red.

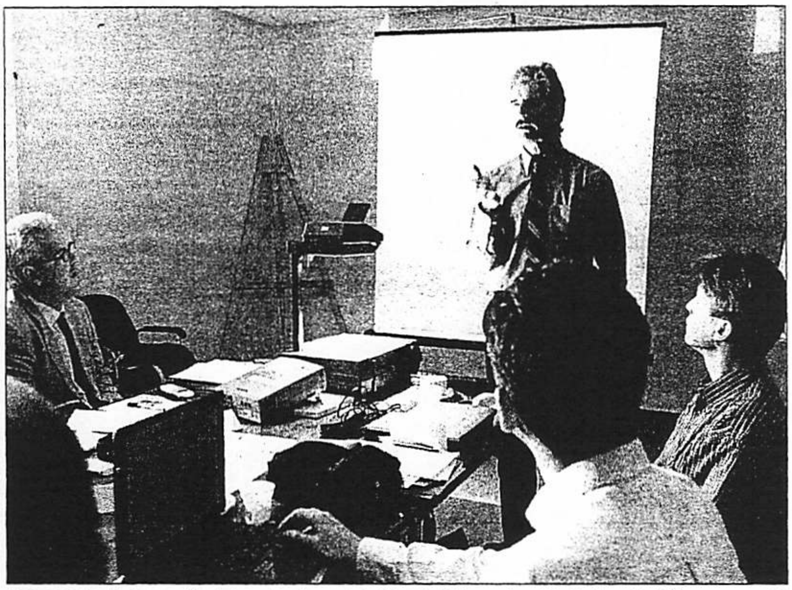
LUBIA

■ **ENERGÍA** REUNIÓN DE EXPERTOS QUE FORMAN PARTE DE LA AGENCIA INTERNACIONAL DE LA ENERGÍA EÓLICA

El Ceder será centro de calidad para pequeños aerogeneradores

Es uno de los pocos centros en el mundo que realiza ensayos con estas máquinas

N. F.
Soria



Un momento de la reunión de los miembros de la Agencia Internacional de la Energía Eólica F.S

El Centro de Desarrollo de Energías Renovables (Ceder) de Lubia se convertirá en un centro de certificación de calidad para pequeños aerogeneradores. Así lo confirmó el miembro del Departamento de Investigación de sistemas aislados de Energía Eólica del Ciemat, Félix Avia Aranda, que también es miembro del Comité Ejecutivo de la Agencia Internacional de la Energía en el grupo de viento. El Ceder acoge una reunión de los miembros de esta agencia que provienen de diversos países, como Holanda, Canadá, Estados Unidos, Holanda, Brasil e Italia.

Esta reunión de expertos va a abordar cuestiones relacionadas con los ensayos generales de aerogeneradores pequeños, así como se pretende elaborar un documento standar que recoja las actuaciones a llevar a cabo para la certificación de calidad de estas instalaciones. El objetivo es expedir estos certificados desde el Ceder para aquellos productores que estén interesados en contar con ellos. El centro de Lubia es el único de España y de buena parte de Europa que realiza ensayos experimentales para aerogeneradores pequeños. Existen centros similares en Estados Unidos y en Dinamarca. Entre los trabajos de investigación que desarrolla el Ceder se encuentra uno referido a la entrada a los sistemas eólicos autónomos, para lo que cuenta con dos pequeños molinos. Según explicó Félix Avia, se pretende colocar más aerogeneradores para continuar con los ensayos.

Los miembros de la Agencia Internacional de la Energía Eólica elaborarán un documento técnico que reúna los preceptos para la certificación de calidad de los aerogeneradores. El encuentro de este organismo, a petición del representante español, tiene como objetivo dotar a estas instalaciones, que se emplean fundamentalmente para uso doméstico, de una marca de calidad, algo que han demando los usuarios de este tipo de máquinas.

Según Félix Avia, el mercado de los pequeños aerogeneradores cuenta con mayores dificultades que los grandes y, en este sentido, añadió que "una de las principales barreras que encuentra el usuario es que no cuenta con garantías para salir al mercado. Una solución a este problema es lo que se pretende buscar aquí".

VALDEAVELLANO

■ **OBRAS**

El Ayuntamiento invierte más de 90.000 euros en el nuevo depósito

REDACCIÓN
Soria

El Ayuntamiento de Valdeavellano de Tera iniciará en las próximas semanas las obras de un nuevo depósito de agua en el que se invertirá un presupuesto de 90.151 euros. Estas instalaciones se ubicarán a 900 metros del depósito viejo y al lado del vivero forestal. El nuevo depósito contará con una capacidad cinco veces superior a la que existe y el Ayuntamiento confía en que se va a ganar presión y que se solucionen los problemas de captación de agua que posee en la actualidad la población.

Por otra parte, en materia de saneamiento se ha concedido una ayuda de 10.030 euros, a través de la Reserva Regional de Caza de Urbión, que se destinará a acondicionar la red de captación de agua potable en manantiales y fuentes.

El Ayuntamiento de esta localidad también ha aprobado las Normas Urbanísticas de la localidad, expediente que se encuentra pendiente de que le dé el visto bueno la Junta de Castilla y León. El cambio de las Normas Urbanísticas tiene como objetivo ampliar la edificación en el casco urbano. Según explicó el alcalde, Jesús Gómez Tierno, "esta modificación se ha realizado de una manera razonada, con el fin de ampliar el casco un poco desde el núcleo actual que se encuentra ya muy consolidado".

ALMAZÁN

■ **ACTIVIDADES** LOS PARTICIPANTES DISFRUTARON DE UNA COMIDA DE HERMANDAD

Cien socios asisten a la Fiesta de la Primavera en el Hogar de Día

I. C.
Almazán

Un total de cien socios asistieron el pasado fin de semana a la Fiesta de la Primavera organizada por el Hogar de Día, en la que se celebró una comida de hermandad y también un baile amenizado por Ignacio Simón, el hombre orquesta, que acudió a la localidad desde Guadalajara con sus teclados. Los asistentes degustaron una comida poco después de las 14.30 horas, y participaron a continuación en la actividad musical.

Por otro lado, un nutrido grupo de personas participa cada semana en el taller de pintura que tiene lugar cada viernes por la tarde en las instalaciones del centro a partir de las 17 horas. Además, los socios pueden ya inscribirse, hasta el 16 de mayo como fecha límite, para solicitar plaza y asistir al segundo turno de los balnearios.

Otra de las actividades programadas desde el Hogar de Día adnamantino es un intercambio con la Comunidad de Galicia para los días 28 de mayo al cuatro de junio próximos. Los asistentes serán en total 14 y se alojarán en una residencia de tiempo libre de la Xunta. Finalmente, y hasta el día 30 de este mes se pueden rellenar las solicitudes para tomar parte en las actividades de turismo de naturaleza de cinco días previstos por el Imserso en la península, con posibilidad de viajar a Andalucía, Murcia, la Comunidad Valenciana, y la Comunidad Catalana. Otros circuitos culturales de seis días incluyen estancias en Portugal, Baleares y Canarias.

Imagen de la comida de hermandad del pasado verano I.C

List of participants

IEA R&D Wind Annex XI Topical Expert Meeting

POWER PERFORMANCE OF SMALL WIND TURBINES NOT CONNECTED TO THE GRID

April 25 -26 2002 Soria, Spain

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