

**EXPERT GROUP STUDY
ON
RECOMMENDED PRACTICES
FOR WIND TURBINE TESTING
AND EVALUATION**

8. GLOSSARY OF TERMS

*Submitted to the Executive Committee
of the International Energy Agency Programme
for
Research and Development
on Wind Energy Conversion Systems*

RECOMMENDED PRACTICES FOR WIND TURBINE TESTING

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Foreword

The evaluation of wind turbines must encompass all aspects of a Wind Energy Conversion Systems (WECS) ranging from: energy production, quality of power, reliability, durability and safety, through to cost effectiveness or economics, noise characteristics, impact on the environment and electromagnetic interference. The development of internationally agreed evaluation procedures for each of these areas is needed now to aid the development of the industry while strengthening confidence and preventing chaos in the market.

It is the purpose of the proposed recommendations for wind turbine testing to address the development of internationally agreed test procedures which deal with several aspects for characterizing wind turbines. The IEA expert committee will pursue this effort by periodically holding meetings of experts, to define and refine consensus evaluation procedures in each of these areas:

1. Power Performance
2. Cost of Energy from WECS
3. Fatigue Evaluation
4. Acoustics
5. Electromagnetic Interference
6. Safety and Reliability
7. Quality of Power

For items 1, 2, 3, 4, 5 and 7 documents have already been issued during the years 1982-1986. However due to the widening appeal of wind energy it was considered that a Glossary of Terms, expressed in simple language, would serve to introduce consistency into future publications of the IEA as well as be of use to those with an interest in wind energy such as planning authorities, manufacturers and users of wind turbines.

ANEMOMETER DISTANCE CONSTANT: Quantity related to the response time of an anemometer.

ANNUAL AVERAGE WIND SPEED: Wind speed averaged long enough to eliminate annual variations (ie many years).

ASPECT RATIO: In a HAWT, the rotor radius squared divided by the projected area of one blade.

AUGMENTOR: A device or structure which increases an air flow's speed by reducing the area through which it passes.

AUTONOMOMOUS SYSTEM: A wind turbine in combination with at least one other source of energy (eg diesel generator, solar collector, biogas system etc) commonly used to improve the continuity of supply.

AXIAL: Direction or motion perpendicular to the rotor plane.

AXIAL THRUST: Force in a wind turbine rotor parallel to its main axis.

AXIAL THRUST COEFFICIENT (C_T): For an HAWT; axial thrust (F) divided by the product of the dynamic pressure of the undisturbed wind flow and the rotor swept area:

$$C_T = \frac{F}{\frac{1}{2} \rho A V^2}$$

BATTERY STORAGE: Storage of energy by charging batteries.

BIN: An interval for test data grouping.

BIN WIDTH: Size of the interval used in the method of bins data reduction procedure (ie a wind speed bin having a span of 5-6 m/s has a width of 1 m/s).

BLADE: Component of a wind turbine with an aerodynamic shape which converts wind energy into rotational shaft motion.

BLADE CONE ANGLE: Angle between the rotor plane and the blade quarter chord line.

BLADE LOAD DISTRIBUTION: Description of the manner in which blade loads are distributed along the quarter chord line.

BLADE PITCH: (1) For HAWTs, angular setting of a blade measured at the tip as the angle between the chord line and the rotor plane, (2) for VAWTS, angular setting of a blade measured as the angle between the chord line and a line tangent to the arc swept by the blade.

BLADE-PITCH ADJUSTER: Trimming device to change the pitch angle of a blade.

BLADE PITCH CONTROL: A control system action which changes blade pitch to adjust rotor operation.

BLADE ROOT: For HAWTS; the part of the blade which is closest to the rotor axis.

BLADE SHAPE: For HAWTS; geometric description of a blade. (Usually includes twist, chord, and airfoil profile changes with respect to position along the quarter chord line.)

BLADE TIP: For HAWTS; portion of a blade farthest from the rotor axis.

BLADE TWIST: In a HAWT, the variation in angular setting along its length.

CHORD LINE: Straight line connecting an airfoil's leading and trailing edges.

CONE ANGLE: See Blade Cone Angle.

CONTROL SYSTEM: Subsystem that adjusts WT's operation to protect it or its output.

CROSS WIND: Wind direction essentially perpendicular to the mean wind direction. (Usually horizontal variations but can also be vertical.)

CUP ANEMOMETER: A rotating device for measuring wind speed, characterized by cups mounted on radial arms which rotate about a vertical axis.

CUT-IN WIND SPEED: The wind speed at which the WT starts to produce useable power.

CUT-OUT WIND SPEED: The maximum wind speed at which the WT is designed to produce useable power.

CYCLIC PITCH: Change in the blade pitch of each rotor blade during one revolution of the rotor.

DOWN-WIND: In the direction of the flow of the wind.

EMERGENCY SHUTDOWN: An automatic shutdown of the WT triggered by a safety mechanism.

FAIL-SAFE: A design philosophy such that in the event of a failure of a component, the machine will remain in a nonhazardous condition.

FAN TAIL: Rotor used on some HAWTs for yaw orientation.

FEATHERING: To change the blade pitch angle of each blade of a rotor to a zero or near zero lift condition. (Normally used as a method of shutdown.)

FLAPPING: Blade motion in the out-of-plane of rotation direction.

FURLING: To adjust the rotor blades to reduce the driving force of the wind.

GOVERNOR: Control system, or part of such system, which controls rotor speed and/or torque to prescribed values.

GUST: A temporary change in the wind speed from the mean wind speed.

GUY: A cable or wire used as a tension support between the ground and a tower.

GUY ANCHOR: Means of fixing a guy wire to the ground.

GUYED TOWER: A tower that uses guys for support.

HORIZONTAL AXIS WIND TURBINE (HAWT): A wind turbine whose rotor axis is substantially parallel to the wind flow.

HUB: The fixture for attaching the blades to the rotor shaft.

HUB HEIGHT: Height of the centre of the rotor above the terrain surface.

IN-PLANE: Direction or motion parallel with the rotor plane.

KITE ANEMOMETER: A kite which has been calibrated to give quantitative wind speed data.

LEAD-LAG: Blade motion in the plane of rotation (HAWT).

LEADING EDGE: Part of a blade at the incidence of the air flow.

MAXIMUM DESIGN WIND SPEED: The maximum wind speed a wind turbine in automatic, unattended operation, but not necessarily generating, has been designed to sustain without damage to structural components or loss of ability to function normally.

MAXIMUM POWER: The largest amount of net power delivered by a wind turbine in normal operation.

MAXIMUM TESTED WIND SPEED: The maximum wind speed a wind turbine in automatic, unattended operation, but not necessarily generating, has sustained without damage to structural components or loss of ability to function normally.

MEAN WIND SPEED: Statistical mean of the instantaneous values of the windspeed during a given period. Note – This period can vary from a few seconds to a year.

METHOD OF BINS: A data reduction procedure by which test data are grouped into wind speed intervals (bins). For each bin, the number of samples and sum of parameter samples are recorded. The average parameter value within each wind speed bin can then be evaluated. (This is a general technique applicable to a variety of parameters.)

MONO TOWER: A wind turbine support tower comprising of a single column.

NACELLE: The housing which contains the drive train and other elements on top of a HAWT tower.

NET POWER (P): The power available from a wind turbine less any power needed for control, monitoring, display or maintaining operation, ie power available to the user. Unless otherwise specified, P will be 10 minute average values.

NET REACTIVE POWER (Q): The reactive power supplied by the power system or absorbed by the power system. Unless otherwise specified, Q will be 10 minute average values.

ONE-SEVENTH POWER LAW: Wind speed profile which uses the power law with an exponent of 1/7. (See also power law.)

OVERSPEED CONTROL: A system that limits rotor speed to a maximum value.

PEAK POWER RATIO OPERATION (PPR): Variable speed operation when maintaining the tip speed ratio for maximum power output.

PEAK WIND SPEED: Maximum wind speed that occurs during the time under consideration.

POTENTIAL ANNUAL ENERGY OUTPUT: The calculated total energy that would be produced by a wind turbine during a one-year period, assuming a certain distribution of wind-speed probability density and assuming 100 per cent availability.

POWER COEFFICIENT (C_p): Power available from a wind turbine system (P) divided by the wind power of the undisturbed flow of the rotor swept area:

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

POWER CONDITIONING: To change or modify the characteristics of electrical power (ie d.c. to a.c. or 12 to 32 V).

POWER CURVE: A graph which depicts the net power of a WT as a function of wind speed.

POWER LAW: Mathematical idealization of a wind speed profile defined by

$$V_2 = V_1 \left[\frac{h_2}{h_1} \right]^N$$

where h_1 is the height above ground,
 h_2 is the height above ground,
 V_1 is the wind speed at height h_1 ,
 V_2 is the wind speed at height h_2 , and
 N is the constant exponent.

POWER OUTPUT: The power delivered by a WT.

PROJECTED AREA: Area covered at any instant by the rotor blades, as seen from the direction of wind velocity. (Area solidly covered by the blades as opposed to the swept area.)

QUARTER CHORD POINT: The point on an airfoil chord line one quarter chord length back from the leading edge.

QUARTER CHORD LINE: Line passing through the locus of quarter chord points of a rotor blade.

RATED POWER: Power output which the wind turbine is designed to achieve under normal operating conditions.

RATED WIND SPEED: The lowest wind speed at which rated power occurs.

RAYLEIGH DISTRIBUTION: A probability distribution function, commonly used to describe the variation in a wind speed over an extended period. Expressed as

$$p(u) = \frac{\pi}{2} \frac{u}{\bar{u}^2} \exp \left\{ -\frac{\pi}{4} \left[\frac{u}{\bar{u}} \right]^2 \right\}$$

where $p(u)$ is the Rayleigh probability function,
 u is the wind speed, and
 \bar{u} is the long term mean wind speed.

(When integrated and evaluated between specified limits, will indicate the fraction of time spent within these limits.)

RESONANCE: A dynamic condition in which the frequency of an applied force is close to a system's natural frequency.

ROTOR AXIS: Axis of the central shaft which, through bearings, supports the wind turbine rotor.

ROTOR DIAMETER: For a HAWT, diameter of the circular swept area of the rotor and blade assembly.

ROTOR PLANE: For a HAWT, the plane perpendicular to the rotor axis where the quarter chord lines intersect, or pass closest to, the rotor axis.

ROTOR POWER COEFFICIENT (C_K): Power delivered by a wind turbine rotor (P_K) divided by the wind power of the undisturbed flow through the rotor swept area

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

ROTOR SAFE LIFE: A design philosophy with a prescribed service life.

ROTOR SPEED: Angular velocity of a wind turbine rotor about its axis.

ROTOR SPEEDS: The rotational speed, or range of speeds, of the rotor of a WT operating between its cut-in wind speed and the wind speed corresponding to maximum power.

ROTOR TEETER: The angular variation from the perpendicular between the rotor plane and the rotor axis.

ROTOR THRUST: The axial force generated by the wind acting on the rotor.

ROTOR TILT: In a HAWT, the angle between the horizontal and the rotor axis.

ROTOR TORQUE: The moment (torque) produced by a rotor about its axis.

SHUTDOWN: A WT in a stopped condition.

SHUTDOWN WIND SPEED: Wind speed at which the control system will shut down the wind turbine.

SLIP RINGS: Assembly used to transfer electrical power or signals from a rotating shaft to a non-rotating member.

SOLIDITY: Rotor projected area divided by the rotor's swept area.

STALL REGULATION: The control of rotor power by utilizing aerodynamic stall of the rotor blade.

STAND-ALONE: Not part of a larger energy network.

START-UP WIND SPEED: The lowest wind speed at which a WT will begin rotation but not necessarily have a net energy output.

SURVIVAL WIND SPEED: The maximum wind speed a WT in automatic, unattended operation can sustain and remain operable.

SWEPT AREA: Area perpendicular to the rotor axis that a rotor will cover during one complete rotation.

TAILVANE: Vertical aerodynamic surface used for wind turbine control, (1) in some HAWTs for yaw orientation and control, (2) in some VAWTs to coordinate cyclic blade pitch.

TEETER: See Rotor Teeter.

THRUST COEFFICIENT (C_T): For HAWT see axial thrust coefficient.

For VAWT: The net time averaged force experienced by a rotor in the direction of the wind (f) divided by the product of the dynamic pressure of the undisturbed wind flow and the frontal area of the rotor swept volume.

TILT: See Rotor Tilt.

TIP-SPEED: Linear speed of a blade tip.

TIP-SPEED RATIO: Linear speed of a blade tip divided by the corresponding wind speed.

TOWER: The structure of a WT that supports the rotor etc above the ground.

TOWER SHADOW: Wake created by air flow around a tower.

TRAILING EDGE: Area of a blade surface that is the last to contact an element of air flow during normal operation.

TURBULENCE INTENSITY: A measure of the variability of the wind speed from its mean value expressed as the ratio of the first standard deviation of wind speed to the mean wind speed, normally taken over a 10-minute period.

TURN OUT OF THE WIND: Act of adjusting yaw angle so a HAWT's rotor axis is not aligned to the wind direction.

UNITS: Numerical values are in metric Systems Internationale (SI) units. If desired they may be followed in parentheses by the local units.

UPWIND: The direction towards the wind.

UTILITY INTERCONNECTION: Electrical connection between a wind turbine and a utility grid in which energy can be transferred from the wind turbine to the utility grid and vice versa.

VERTICAL AXIS WIND TURBINE (VAWT): A WT whose rotor axis is vertical.

VERTICAL WIND-SPEED GRADIENT (WIND-SHEAR): The change in the windspeed with the height above ground level.

WEIBULL DISTRIBUTION: A commonly used probability distribution, more general in nature than the Rayleigh distribution. Often used in wind engineering, as it conforms well to the observed long-term distribution of mean wind speeds for a range of sites. Expressed as

$$p(\bar{u}) = \left[\frac{k}{c} \right] \left[\frac{\bar{u}}{c} \right]^{k-1} \exp \left\{ - \left[\frac{\bar{u}}{c} \right]^k \right\}$$

where $p(\bar{u})$ is the Weibull probability distribution of \bar{u} ,

\bar{u} is the mean wind speed of interest, and

c is the site parameter

k is the shape parameter both of which can be evaluated from real data.

c and k are related to the long term (ie annual) mean wind speed, V , via

$$V = c\Gamma(1+1/k)$$

where Γ is the gamma function.

When integrated and evaluated between specified limits, will indicate the fraction of time spent within these limits.

WIND-DIESEL SYSTEM: See Autonomous System.

WIND ENERGY CONVERSION SYSTEMS (WECS): A system for converting kinetic energy from the wind into a usable form.

WIND ENERGY CONVERTER (WEC) (pl WECS): A device for transforming the kinetic energy from the wind to another form of energy.

WIND SHEAR: A variation of wind velocity in a plane normal to the wind direction, usually in the vertical direction.

WIND SPEED: Speed of the air flow.

WIND SPEED DURATION CURVE: A characteristic depicting the cumulative hours the wind speed exceeds a specified wind speed in a year as a function of these specified speeds.

WIND SPEED PROFILE: Characteristic of wind speed as a function of height above ground.

WIND TURBINE (WT): A rotating machine including its support structure for converting the kinetic energy in the wind to another form of energy.

WIND TURBINE BLOCKED: Operating state in which the rotor and other external rotating parts are locked by means of a blocking device (for safety reasons such as during maintenance).

WIND TURBINE GENERATOR (WTG): A wind turbine where the output is electrical energy.

WIND TURBINE HEATING SYSTEM (WTHS): A wind turbine where the output energy is in the form of heat.

WIND TURBINE PUMP (WTP): A wind turbine directly coupled to a pump.

WIND TURBINE ROTOR: A systems of rotating aerodynamic elements attached to a single shaft that converts the kinetic energy in the wind into mechanical shaft energy.

WIND VANE: Device for indicating or recording wind direction.

WIND VELOCITY: Wind speed vector.

YAW ANGLE: Angle, in the horizontal plane, between the wind direction and the rotor axis of a HAWT.

YAW AXIS: A vertical axis about which a HAWT changes its directional orientation.

YAW RATE: Rate of change in yaw angle.

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