Challenges in Performance and Safety Certification of Small-scale Vertical-axis Wind Turbines

Presented at the 4th World Summit for Small Wind (WSSW), March 21st - 22nd, 2013

Husum, Germany

Anant Jain[1]

Troy Hewitt[1]

Joseph Spossey[1]

Michael Hudon[1]

[1]Intertek Testing Services

USA

Outline

Intertek

Valued Quality. Delivered.

- Introduction - VAWT research history and current status
- VAWT designs and fundamentals
- VAWT certification standards
- Challenges and technical gaps in AWEA and BWEA
- Challenges and technical gaps in IEC Standards
- Recommended steps for initialization of loads measurement based certification
- Conclusion

Abbreviations

AWEA American Wind Energy Association
BWEA British Wind Energy Association
VAWT Vertical Axis Wind Turbine
HAWT Horizontal Axis Wind Turbine
DLC Design Load Cases
MLC Measurement Load Cases

Introduction - VAWT Research History and Current Status

Intertek
Valued Quality. Delivered.

- Aero-servo-elasto research on VAWTs began in 1970s in the US by Sandia National Laboratories (SNL).
- Multiple VAWT configurations 5m, 17m and 34m were designed and tested.
- National Research Council, Canada and Musgrove Turbines, UK.
- Criticism due to performance issues; research halted in 1990s.
- Sandia National Laboratories, funded by US-DOE reopened VAWT research for offshore applications.
- Small VAWT manufacturers (under 200 m^2 rotor area) consistently growing.
- Certification guidelines focus on HAWTs.

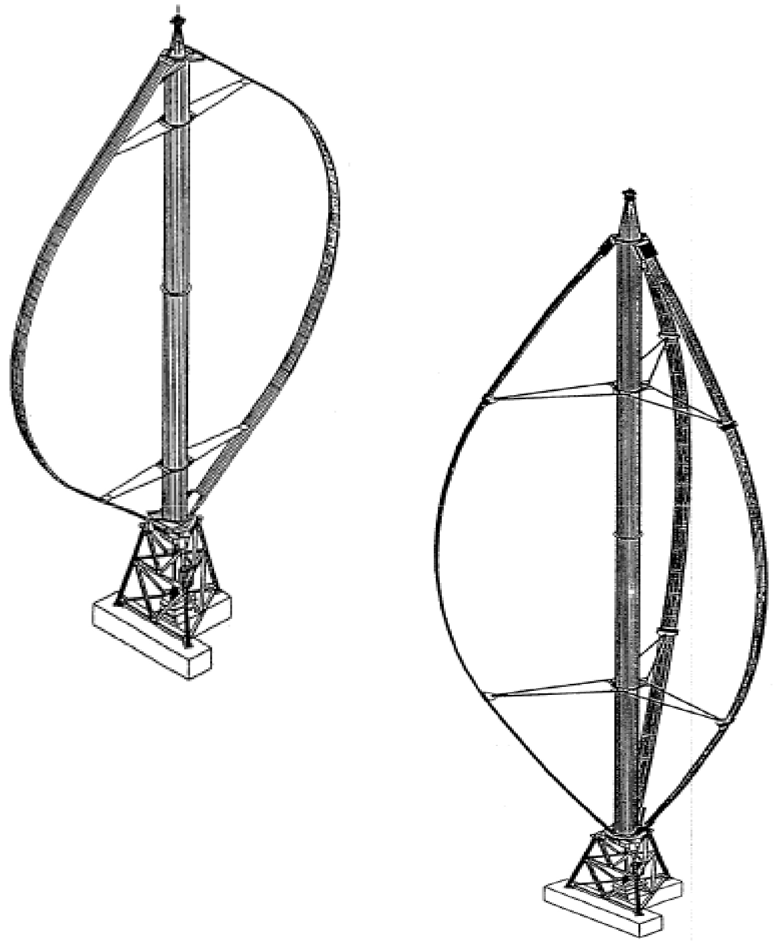

Figure 1: Two bladed and three bladed wind turbines designed and tested by SNL and Flowind [Flowind Corporation, 1996]

[Sutherland et. al., 2012]

VAWT Designs

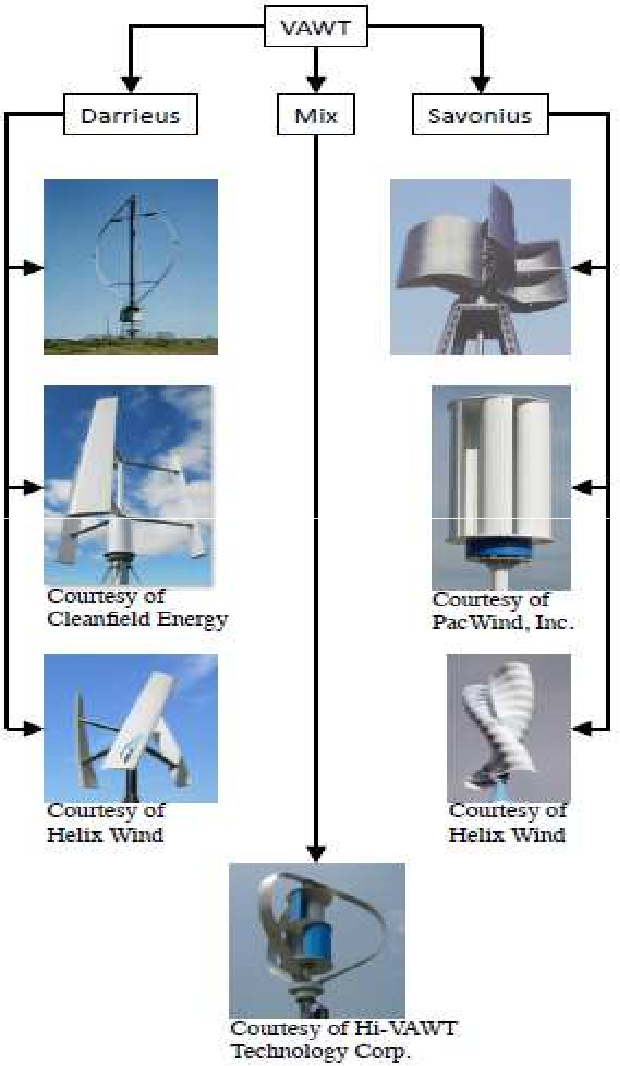

Figure 2: Current VAWT designs [Carrigan T. J., 2010]

- Basic categories: Darrieus, Savonius and Mix
- Critical component/systems in Darrieus VAWTs:
  - Lower and upper - rotor bearing system
  - Main shaft (inner and outer) and drivetrain components
  - Blade-arms and supporting connections
  - Blades (mechanically hinged to blade-arms)
  - Direct-drive generator assembly and couplings
  - Control system (not the pitch and yaw systems)
  - Braking system
  - Support structure (tower and foundation) and guy cables (including ground and tower-top anchors)
  - Condition monitoring sensors and control (prototype designs only)

VAWT Design Fundamentals

Intertek

Valued Quality. Delivered.

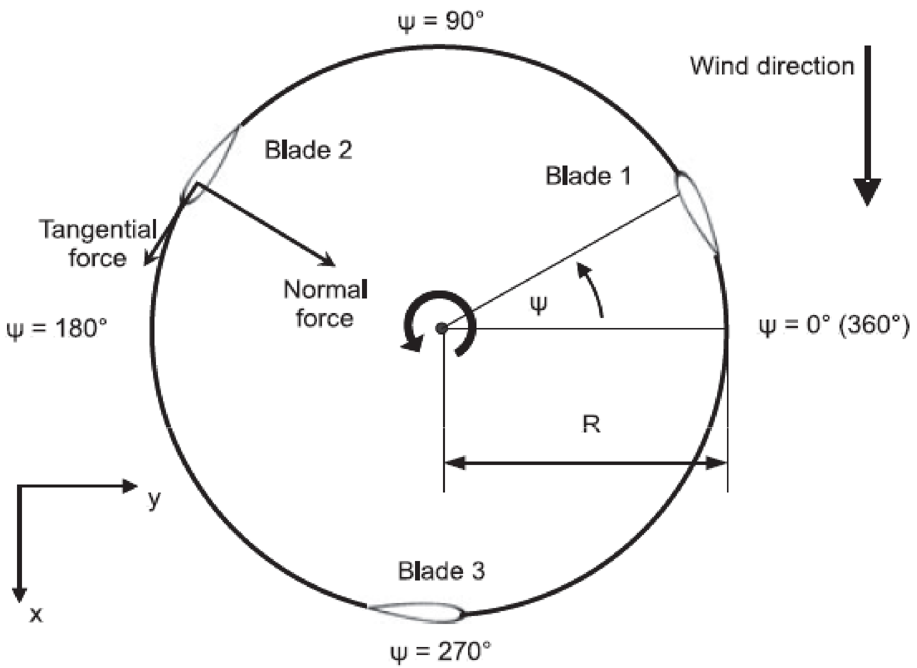

Figure 3: Sectional forces on the VAWT airfoil
[Scheurich et. al., 2013]

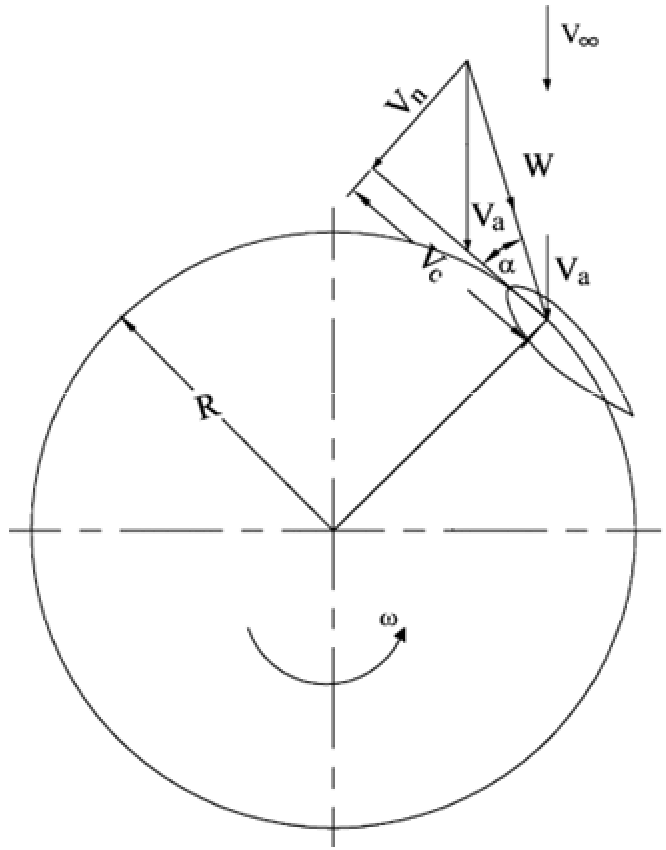

Figure 4: VAWT exposure to steady-wind condition
[Islam et. al., 2008]

VAWT Certification Standards

Intertek
Valued Quality. Delivered.

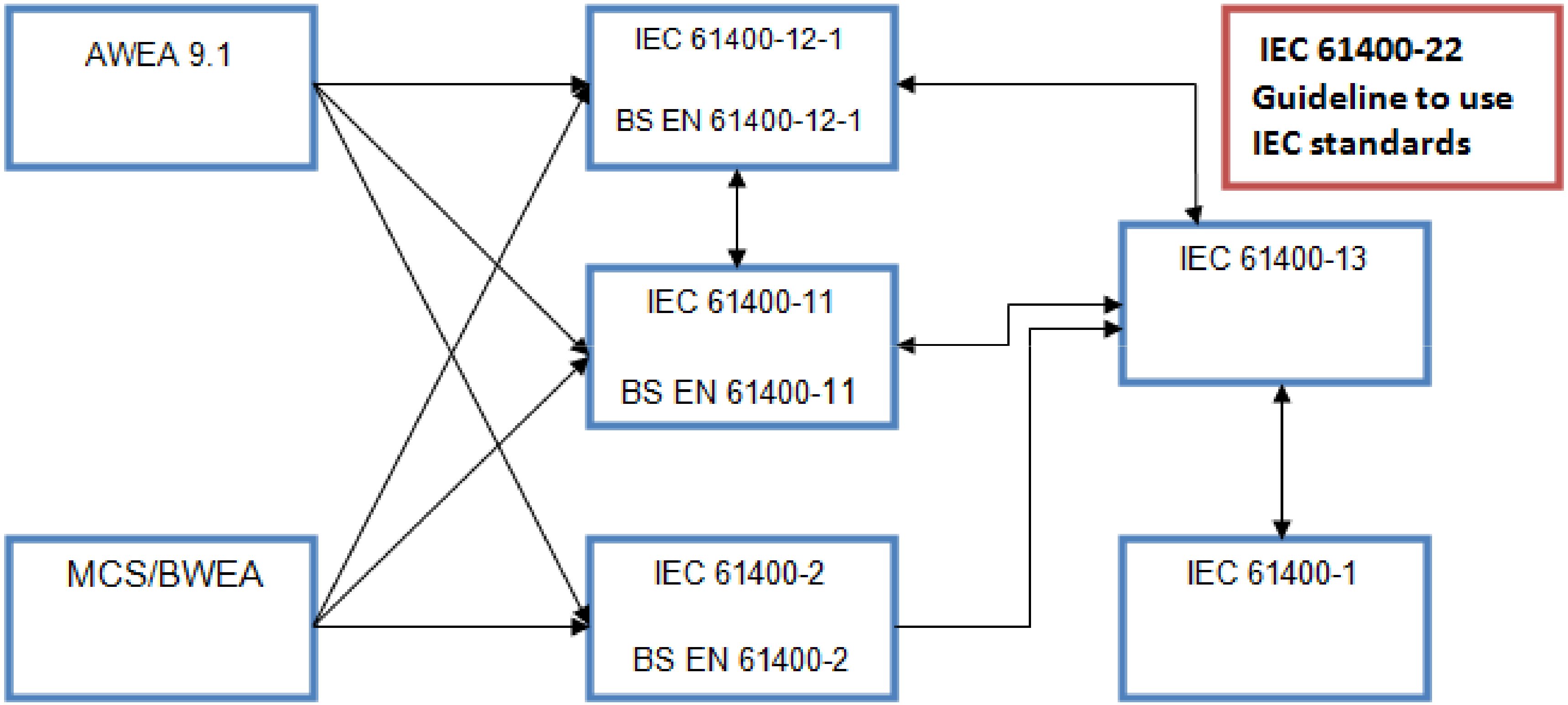

Figure 5: Interconnection web of VAWT certification standards

Gaps and Challenges in AWEA and BWEA Standards

Intertek

Valued Quality. Delivered.

- The strength and safety guidelines in the AWEA and BWEA standards refer to sections 7.4 (simplified load equations), 7.5 (aeroelastic modeling), 7.8 (partial safety factors) and 9.6 (safety and function testing) of IEC 61400-2.
- Simplified load equations and aeroelastic modeling: aero-servo-elasto tools undeveloped.
- Dynamic interactions of wind turbines with the tower: vortex shedding and wake modeling.
- Insufficient operational safety characterization test requirements:
  - Start-up drag tests
  - Coefficient of drag at zero angle of attack tests
  - Aerodynamic characterization testing
- Inapplicable control and protection testing.
- Insufficient and inapplicable support structure requirements.

[AWEA 9.1, 2009 and BWEA, 2008]

Gaps and Challenges in IEC 61400-2

- VAWT Certification: only option is to follow section 7.6 of IEC 61400-2 Ed. 2 (physical loads measurement).
- IEC 61400-2 and IEC 61400-13 standard is also written for HAWTs.
- Technical description of the wind turbine design is based on a generic HAWT design.
- The criteria to categorize between a small and large wind turbine.
- Guidelines on wake and vortex modeling requirements.

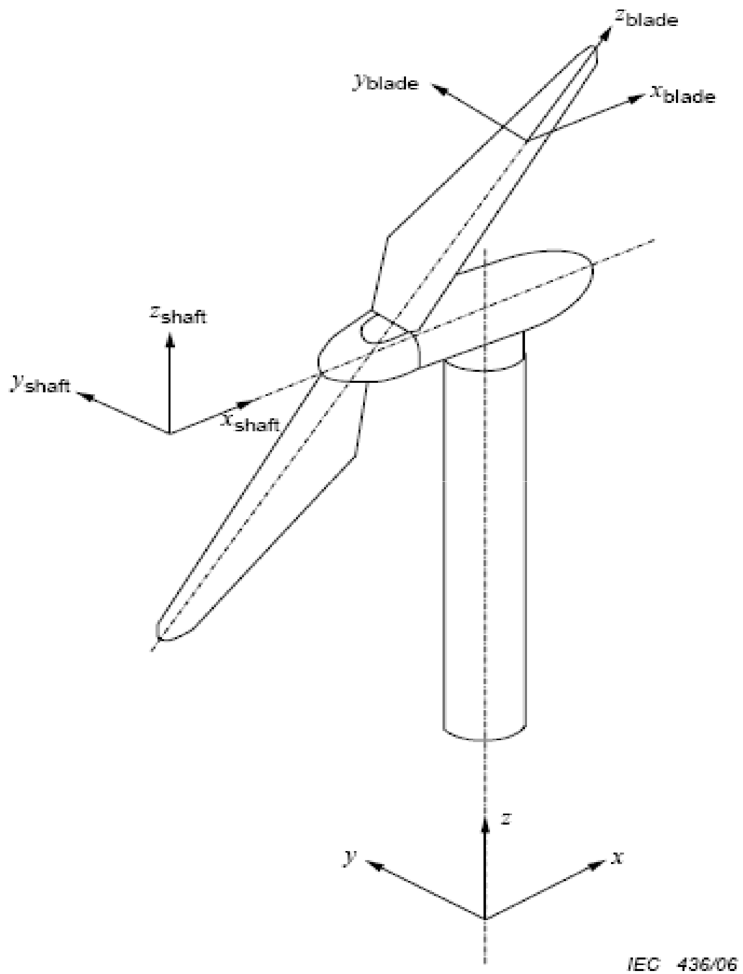

Figure 6: Wind turbine co-ordinate system [IEC 61400-2, 2006]

IEC 61400-2 (Continued..)

Intertek
Valued Quality. Delivered.

- Types of loads that are required for HAWTs as per the standards are applicable to VAWTs also.
- In addition, loads arising from whirl flutter, bending torsion flutter, stall flutter, etc., may also be needed for a complete analysis.
- New DLCs or modified DLCs shall be introduced.
- Partial safety factors for loads need to be updated for VAWTs due to difference between VAWT and HAWT loading characteristics.

Gaps and Challenges in IEC 61400-13

- Description of MLCs and supportive information, such as capture matrices.
- Correlation between the DLC wind distribution and MLC characteristic wind speed.
- Development of new MLCs and selecting the wind conditions.

MLC number	Measurement load case MLC	DLC number (IEC 61400-1)	Wind condition at DLC	Remarks
1.1	Power production	1.2	$v_{in} < v_{hub} < v_{out}$*	In this mode of operation, the wind turbine is running and connected to the grid
1.2	Power production plus occurrence of fault	2.3	$v_{in} < v_{hub} < v_{out}$*	Any fault in the control or protection system, which does not cause an immediate shut-down of the turbine
1.3	Parked, idling	6.2	$v_{in} < v_{hub} < 0{,}75\ v_{e1}$*	When the wind turbine is parked, the rotor may either be stopped or idling

Table 1: Normal operation measurement load conditions [IEC 61400-13, 2001]

IEC 61400-13 (continued..)

Intertek
Valued Quality. Delivered.

- The fundamental load quantities are not sufficient and/or applicable for characterization of VAWTs.
- Calibration methodology - sensors aligned perpendicular to each other orthogonally at 70% of the blade radius, not true for VAWTs.
- Data acquisition system: sequential vs. simultaneous acquisition.

Load quantities	Specification	Comments
Blade root loads	Flap bending Lead-lag bending	Blade 1: mandatory Other blades: recommended
Rotor loads	Tilt moment Yaw moment Rotor torque	The tilt and yaw moment can be measured in the rotating frame of reference or on the fixed system (for example, on the tower)
Tower loads	Bottom bending in two directions	

Table 2: Load quantities for measurement [IEC 61400-13, 2001]

Initializing loads measurement based certification

Intertek

Valued Quality. Delivered.

- Design basis evaluation based on IEC 61400-22.
- Site assessment.
- Power performance and power curve assessment based on IEC 61400-12-1.
- Ultimate and fatigue strength, and material properties.
- Modal analysis (zero and finite rpm).
- Aerodynamic load assessment (CFD).
- Measurement loads cases.
- Data acquisition system.
- Calibration: Static and dynamic.

Mode #	Mode type
1	1st Anti-symmetric Flatwise
2	1st Symmetric Flatwise
3	1st Rotor Out-of-plane
4	1st Rotor In-plane
5	2nd Anti-symmetric Flatwise
6	2nd Symmetric Flatwise
7	2nd Rotor Out-of-plane
8	2nd Rotor In-plane

Table 3: List of structural modes measured in VAWT modal analysis [Carne et. al. 1983]

Types of Sensors

Sensor type	*Application*	*Types*
Strain gauges	Strain and stress	Single-grid, rectangular-pattern, delta-pattern, quarter-bridge, half-bridge, full-bridge, etc.
Accelerometers	Vibration characteristics	Capacitive, heat-transfer, MEMS based, etc.
Load cells	Tensile and compressive loads	S-type, button-type, clamp-type, etc.
Pressure sensors	Sectional forces on blades and blades arms	Flush diaphragm, voltage output, Milliamp output, etc.
Velocity	Tangential velocity	Piezoelectric, piezoresistive, etc.
Rotation	Angular velocity	Magneto-resistive, hall-effect, etc.
Displacement	Component tip displacements	Capacitive, piezoelectric, etc.

Table 4: Recommended sensor types to be used in VAWT testing [IEC 61400-13, 2001]

Location of Sensors

Intertek
Valued Quality. Delivered.

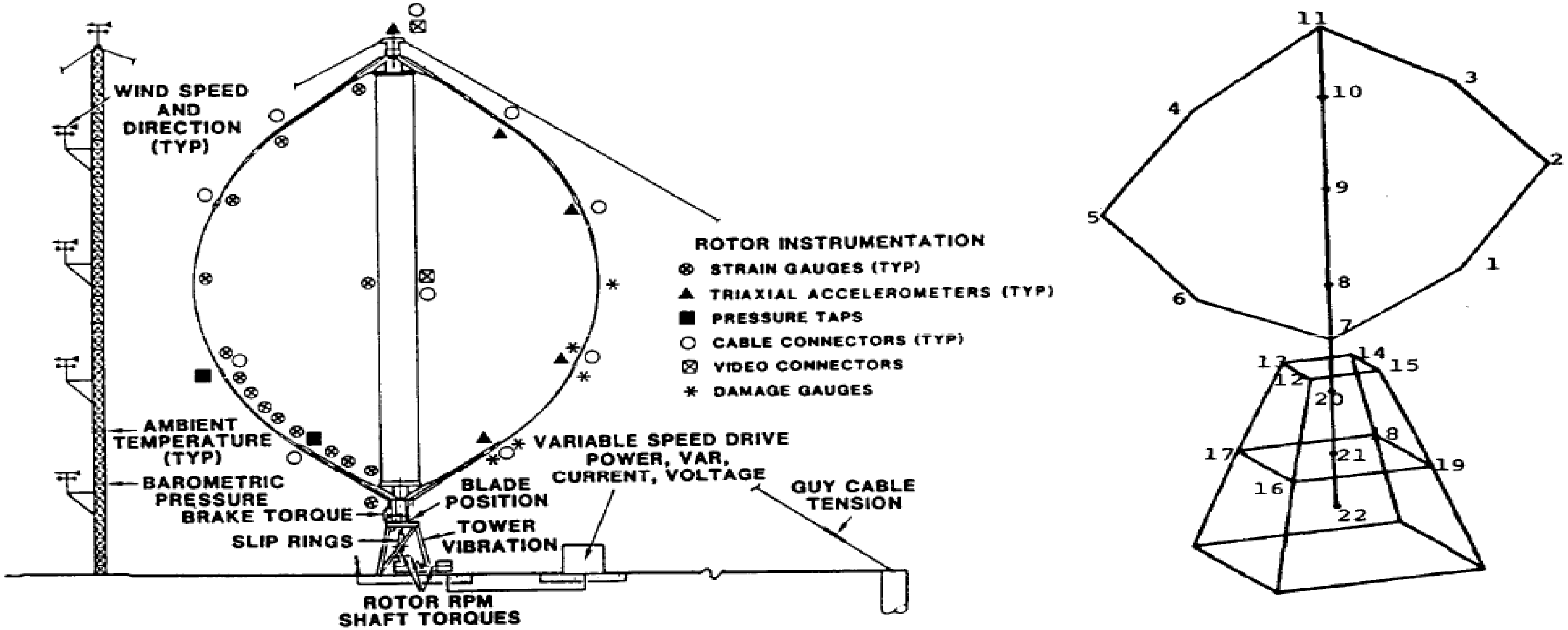

Figure 7 (a) and (b): Schemes to place sensors on VAWTs; [Ashwill, 1992] and [Carne et. al., 1983]

Conclusions

Intertek

Valued Quality. Delivered.

- Intertek develops its own testing requirements based on the applicable sections in the standards.
- Custom designing of test methodology increases time and project costs.
- Extension of the current AWEA and BWEA standards are recommended to address the issues discussed regarding VAWTs.
- VAWTs should be addressed more directly in IEC 61400-13.
- Wake and vortex modeling guidelines should be evaluated for their necessity to be used for VAWT certification.
- VAWT manufacturers may contribute towards development of standards.
- Harmonization of standards is needed.

References

Sutherland H. J., Berg, D. E., and Ashwill T. D. (2012) *'A Retrospective of VAWT Technology',* Sandia Report, SAND2012-0304, New Mexico, USA.

Flowind Corporation (1996) '*Final Project Report: High-Energy Rotor Development, Test and Evaluation*', Contractor Report, SAND96-2205, New Mexico, USA.

Carrigan T. J. (2010) '*Aerodynamic Shape Optimization of a Vertical Axis Wind Turbine*', M.S. Thesis, The University of Texas at Arlington, USA.

Scheurich, F. and Brown, R. E. (2013), *'Modeling the Aerodynamics of Vertical Axis Wind Turbines in Unsteady Wind Conditions'*, Wind Energ. 2013; 16:91-107, DOI: 10.1002/we.532, University of Glasgow, UK.

Islam, M., Ting, D. S. -K., and Fartaj, A. (2008) *'Aerodynamic Models for Darrieus-Type Straight-Bladed Vertical Axis Wind Turbines'*, Renewable and Sustainable Energy Reviews 12 (2008) 1087-1109, University of Windsor, Canada.

AWEA 9.1 (2009) *'AWEA Small Wind Turbine Performance and Safety Standard (AWEA Standard 9.1 – 2009) © The American Wind Energy Association'*, American Wind Energy Association, Washington DC, USA.

BWEA (2008), *'BWEA Small Wind Turbine Performance and Safety Standard (29 Feb 2008)'*, British Wind Energy Association, London, UK.

International Standard IEC 61400-2, Second Edition (2006), '*Wind Turbines – Part 2: Design Requirements of Small Wind Turbines',* International Electrotechnical Commission, Switzerland.

Technical Specification IEC TS 61400-13, First Edition (2001), *'Wind Turbine Generator Systems – Part 13: Measurement of Mechanical Loads',* International Electrotechnical Commission, Switzerland.

Carne, T. G., and Nord, A. R. (1983) *'Modal Testing of a Rotating Wind Turbine',* Sandia Report, SAND82-0631, New Mexico, USA.

Ashwill T.D. (1992) *'Measured Data for the Sandia 34-Meter Vertical Axis Wind Turbine',* Sandia National Laboratories, SAND91-2228, New Mexico, USA.


Salamat
Спасибо
谢谢
Eskerrik asko
Дзякуй
Gracias
Thank You
Merci
Asante
Kiitos
Dankie
obrigado
Grazie
dziękuje
ありがとう
תודה
Tak
köszönöm

QUESTIONS ??